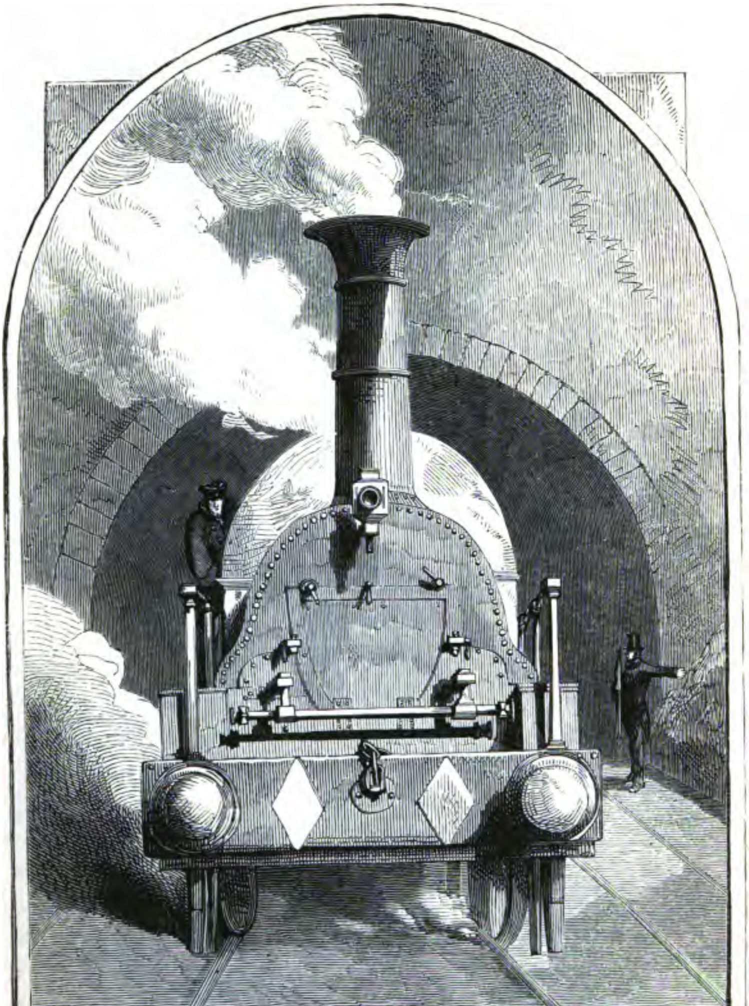

THE

STEAM-ENGINE,

ITS HISTORY AND MECHANISM:

BEING

Descriptions and Illustrations

OF THE

STATIONARY, LOCOMOTIVE, AND MARINE ENGINE.

For the Use of Schools and Students.

By ROBERT SCOTT BURN,

EDITOR OF THE "ILLUSTRATED LONDON DRAWING-BOOK;" "MECHANICS AND MECHANISM;"
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"ILLUSTRATED PRACTICAL GEOMETRY," ETC.

LONDON:
H. INGRAM AND CO.,
MILFORD HOUSE, MILFORD LANE, STRAND;
AND
W. S. ORR AND CO., AMEN CORNER, PATERNOSTER ROW.

LONDON:
PRINTED BY LEVEY, ROBSON, AND FRANKLYN,
Great New Street and Fetter Lane.

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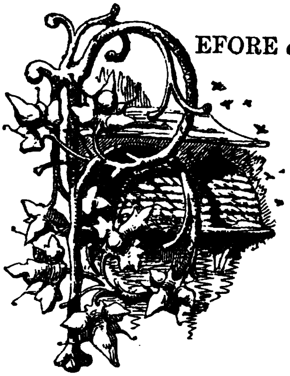
INTRODUCTORY CHAPTER.

THE PROPERTIES OF STEAM.



BEFORE entering upon the consideration of the historical and mechanical details of the steam-engine, it will be necessary to explain as briefly as possible the nature and properties of steam. It is but just, however, to state, that the new theory of *heat*, now being submitted to the test of experiment, will modify very much the theory of the steam-engine. Until the new views, however, have been conclusively affirmed, it would be premature here to specify them; we shall therefore confine ourselves to a statement of the theory of the steam-engine as generally received.

When a quantity of water is heated until it arrives at a certain fixed temperature, an elastic fluid or aqueous vapour is evolved; this is called steam, and resembles in many of its properties common air. Like air, it is elastic, capable of being reduced in bulk by compression; the pressure which it exerts in the vessel into which it is compressed being exactly in proportion to the amount of compression. (See volume on *Natural Philosophy* in this series.) Like air, steam is also capable of an increase of volume or bulk; this expansion reducing the pressure on the vessel in which it is allowed to expand just in proportion to the amount of expansion. The first property of steam now mentioned is termed its *elasticity*, the second its *expansibility;* although, having these properties in common with fluid gases, steam is distinguished by the term of aqueous vapour, inasmuch as it differs from a gas, which retains permanently its gaseous at a uniform temperature, otherwise it changes its condition, and returns to its original form of liquid. This property, by which steam is readily converted into water, is of immense importance; by virtue of this property the power of steam is made available in what are termed condensing engines, and offers the readiest means of forming a vacuum in the cylinder, into which comparatively little force is required to press the piston.

When a quantity of water is placed in a boiler, and heat applied to it, a circulation of the particles of water immediately commences; those nearest the bottom, receiving a certain quantity of heat, expand and rise upwards; the colder portion taking their place, and becoming heated in their turn, rise; small air-bubbles become formed at the bottom after the above process has gone on for a certain time; these bubbles contain aqueous vapour; these rise upwards, and on coming in contact with the colder portions above, are cooled or condensed, and give out their heat to the surrounding particles. This process continues until the whole mass becomes of a uniform heat, and a fixed temperature has been arrived at. After this, however long the heat might be applied to the boiler, the water would not increase in temperature; but the rising of the steam-bubbles would become so rapid that the whole mass would be in a state of agitation, and a vapour would be evolved in large quantities; this vapour, as before stated, is steam, and is invisible, like common air. The fixed temperature already alluded to is what is termed the *boiling-point*. Under the ordinary atmospheric pressure at the level of the sea, the boiling-point of fresh water is 212° Fahrenheit, that of salt water being somewhat higher, or about 213·2°: in the generation of steam of a high pressure the boiling-point varies, increasing in proportion to the pressure. With a pressure of 16 lbs. to the square inch, the temperature at which the water boils is 216·3°; at 18 lbs. to the inch, 222·7°; at 20 lbs., 228·4°; at 25 lbs., 240·9°; at 30 lbs., 251·4°; at 35 lbs., 260·6°; at 40 lbs. to the square inch, 268·8°; at 50 lbs., 282·7°; at 55 lbs., 288·8°. When steam is generated under a pressure of 15 lbs. to the square inch, it is termed "steam of one atmosphere;" when generated at 30 and 45 lbs. to the square inch, it is said to be of the pressure of steam of two and three atmospheres respectively.

One of the most striking peculiarities of steam is the enormous increase of its bulk, as compared with that of the water from which it is generated

The proportion of increase will be best remembered by the statement, that under the ordinary pressure of the atmosphere, or 15 lbs. to the square inch, a cubic inch of water will produce a cubic foot of steam; and as there are 1728 cubic inches in a foot, the increase of volume of steam is 1728 times. Under an increase of pressure the volume of steam is diminished: under a pressure of 30 lbs. the volume is only one-half; taking the "relative volume of steam" raised at a pressure of 15 lbs. at 1669, steam at 20 lbs. would have a volume of 1281; at 25 lbs., of 1047; of 30lbs., or double the ordinary pressure, of 882; at 35 lbs., 766; at 40 lbs, 678; at 45 lbs., 609; and at a pressure of 50 lbs. steam would have the relative volume 554. We have before stated, that steam is capable of being reduced from a state of vapour by being reduced in temperature; this temperature is always the same as that of the water from which it is raised. By gradually reducing the temperature of steam the vapour will be condensed, and be reconverted into water: a cubic foot of steam under the ordinary pressure occupying the space of about a cubic inch of water.

In raising steam, a large amount of caloric is absorbed which is not observable by the thermometer; this is termed "latent heat." By this is meant the amount of heat required to evaporate a given quantity of water compared with that necessary to bring the water to the boiling-point. Thus it is found that to evaporate a certain quantity of water into steam at 212°, it will take 5½ times as much heat as would raise the water from 32°, or the freezing-point, to 212°, the ordinary boiling-point; this excess of caloric, however, is not indicated by the thermometer,—hence the term *latent heat.* The latent heat of steam is generally reckoned at 1000°, the temperature of the steam being 212°; the sum therefore of the sensible heat, that is, the temperature indicated by the thermometer, 212°, and the latent heat 1000°, is equal to 1212°. The total amount of the indicated and latent heat at all temperatures is a "constant sum:" thus if the pressure is increased at which the steam is raised, so as to give a temperature of 300°, the latent heat is 912°; if 500°, 712°, and so on. It is from this property of steam that so much fuel is expended in raising it. The mechanical effect produced by the evaporation of a cubic inch of water is generally calculated as being sufficient "to raise a ton weight one foot high;" from this, however, is to be deducted loss from friction and other causes. In the body of the work will be found exemplifications of the properties of steam, and of the duty and the power of steam-engines ; we therefore hasten to the consideration of the general subject.

In arranging the materials and illustrations of our work, we have been guided by the same principles which dictated the method of elucidation in our volume, *Mechanics and Mechanism*, in the present series. We have aimed at presenting practical details rather than elaborate theories; not deeming these unnecessary, but conceiving that for the purposes of our treatise, and for the classes for which it is more particularly designed, correct illustrations and descriptions of the mechanical arrangements constituting the different varieties of steam-engines now in use will be more generally useful than expositions of strictly theoretical rules and mathematical formulæ, which serve in many cases to confuse rather than to enlighten the uninitiated reader, to deter rather than to induce the pupil to proceed in his investigations. The work necessarily assumes the form of a mere compilation ; but in addition to consulting the best authorities, and endeavouring to place the results of this in as attractive and regular a form as possible, we are indebted for some of our valuable illustrations to the editor of the *Practical Mechanic's Journal*, by whose courtesy we have been enabled to enrich our pages. From the number of the illustrations, and the method of arrangement, we venture to hope that our work will form in some measure a useful auxiliary in an Educational Series.

THE HISTORY
OF
THE STEAM-ENGINE.

CHAPTER I.

HISTORICAL NOTICES OF THE APPLICATION OF STEAM, FROM HERO, 130 B.C. TO SMEATON, 1772 A.D.

As before stated in our introductory remarks, the ancients are known to have had an acquaintance with the utility of the power of steam and heated air, and had devised certain contrivances in which this power was developed. These contrivances were, as may be supposed, applied to no purpose of utility, but served more as the means of exciting the wonder of the populace, as the miraculous production of their priesthood, and as forming part of the mysteries of their worship. Thus, one of the contrivances of the well-known Hero of Alexandria, who flourished 130 years before Christ,—the first personage who figures in the stereotyped history of the steam-engine,—was for the purpose of causing wine to flow from the hands of images placed beside the altar; and was effected as follows: "A steam-tight vessel or vase containing wine is placed within each image, the altar being made hollow, and partially filled with water; bent tubes reaching from the space in the altar above the water to the space in the vases above the wine; and other tubes are taken from the vases, below the level of the wine, to the hands of the images. Matters being thus prepared, when you are about to sacrifice," says Hero, "you must pour into the tubes a few drops lest they should be injured by heat, and attend to every joint lest it leak; and so the heat of the fire mingling with the water will pass in an aërial state through these tubes to the vases, and pressing on the wine, make it pass through the bent syphons until, as it flows from the hands of the living creatures, they will appear to sacrifice, as the altar continues to burn." In another contrivance, the force of the vapour of water was perhaps more obviously shown. In fig. 1, a caldron or vase *a* has a pipe *c* fitted to it, terminated by a small cup *d*. On the caldron being partially filled with water, and fire applied beneath it, the steam, issuing from the jet with considerable velocity, raises and supports for which Hero is famed, and one which in itself comprises nearly all the requisites of a complete prime-mover, is that known as the "Æloipile."

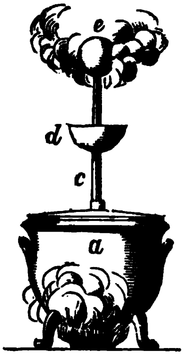


fig. 1.

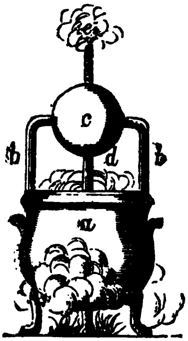


fig. 2.

This invention is, moreover, all the more remarkable and worthy of notice, from the fact that in recent times it has been introduced into practice as an efficient and economical steam-engine. Fig. 2 will explain the arrangement of its parts, and its operations. Let *a* be a caldron or vessel partially filled with water and placed on a fire; two pipes *b b* communicate with the interior of this, and are bent at the top at right angles; a hollow ball *c* revolves on the arms *b b*, and has two pipes *e d* placed at the opposite ends of its diameter; the ends of these pipes are made up, but apertures are made in the opposite sides of each. The steam rising through the tubes *b b*, passing into the hollow ball *c*, is ejected through the apertures in *e d;* the reaction of the opposite jets of steam on the surrounding air causes the globe *c* to rotate with rapidity on its axis, "as if it were animated from within by a living spirit." In fig. 3 the relative arrangements of the jets from the tubes *b c* is shown; the globe *a* revolving in the direction of the arrows. In these contrivances the properties of steam expansion and contraction are made known. It is somewhat remarkable—as taking the era of the introduction of steam and heated air as a motive-power much further back than is generally supposed—that Hero states that he made himself acquainted with the labours of his predecessors and contemporaries in connexion with pneumatical contrivances, and that many of those which he describes in his *Spiritalia seu Pneumatica* were not of his own invention; thus inducing the belief that this power was known for ages previously, although its operation, doubtless, was only known to the priests. All authorities agree in thinking that the knowledge of the power of steam was more widely disseminated than is generally believed. That this power was applied chiefly, if not exclusively, by the priesthood, for the purpose

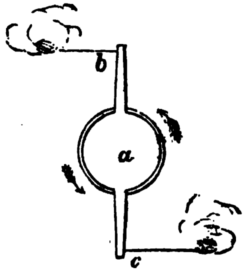


fig. 3.

which at times they could command, is also pretty conclusively ascertained. What schoolboy has not read of the mysterious Memnon, whose mystic utterance of sounds has even yet, in these utilitarian days, "a distinct and mysterious interest, for no myth of the most graceful mythology is so significant as its story." Yet the "seven mystic vowels, which are the very heart of mysteries to us," are said to have been produced by some of those pneumatic contrivances which Hero describes. "When the secrets of the waning faith," says an elegant writer, "were revealed by the votaries of a rival belief, the celestial harmony was then said to be produced by vapour, rising from water concealed in a cavity of the statue, being made to pass through a tube having a small orifice fashioned in a manner similar to that of an organ. As long as the fluid was heated by the rays of the sun, mysterious sounds were heard by the assembled worshippers, which died gradually away as the solar influence was withdrawn from the gigantic idol."

At this stage of our progress an inquiry will naturally arise—how is it, that with all the ingenuity of the ancients, so fertile and so suggestive a power should have been allowed to remain developed only in the devices of priestcraft, and not adapted to the purposes of a more varied and general utility? The cause of this apparent neglect may be traced to the same sources which influenced the obscurity which has hid from later times the arts of antiquity. Another cause may be in the following, so well put by an able writer: "The ancient philosophers esteemed it an essential part of learning, to be able to conceal their knowledge from the uninitiated. And a consequence of their opinion that its dignity was lessened by its being shared with common minds, was their considering the introduction of mechanical subjects into the regions of philosophy a degradation of its noble profession; insomuch that those very authors among them who were most eminent for their invention, and were willing by their own practice to manifest unto the world their artificial wonders, were notwithstanding so infected by this blind superstition, as not to leave any thing in writing concerning the grounds and manner of these operations; by which means it is that posterity hath unhappily lost, not only the benefit of those particular discoveries, but also the proficiency of those arts in general. For when once learned men did forbid the reducing of them to vulgar use and vulgar experiment, others did thereupon refuse these studies, as being but empty and idle speculations; and the divine Plato would rather choose to deprive mankind of these useful and excellent inventions, than expose the profession to the vulgar ignorant." For centuries no attention seems to have been paid to the development of the power of steam; at least, history is a blank as to any notices thereof. Nevertheless, there are sufficient indications of the fact that its power was not altogether unobserved by philosophers and men attached to science; many in their writings hinting at the power to be derived from "vapour," and alluding confidently as to the capability of huge "engines" being forced into motion by the power of this agent. About the year 1121, according to William of Malmesbury, "there were extant in a church at Rheims, as proofs of the knowledge of Gerbert, a public professor in the schools, a clock constructed on mechanical principles, and a hydraulic organ in which the air, escaping in a wonderful manner by the force of heated water, fills the cavity of the instrument, and

On the revival of learning throughout Europe, the dissemination of the writings of the ancient philosophers doubtless attracted attention to many of these contrivances. There is some probability attached to the supposition that the invention of Blasco de Garay, a sea-captain, introduced into notice in 1543, was founded upon or derived from one of these. His invention was designed for the propulsion of vessels, and appears to have been very efficient. Unfortunately no record is known to exist from which a knowledge of its parts can be ascertained. The following is the only account extant: "Commissioners were appointed by the Emperor Charles the Fifth to test the invention at Barcelona, on the 17th June, 1543; and the result was, that a ship of 200 tons burden was propelled by the machine at a rate of three miles an hour." The moving force was obtained from a boiler containing water,—liable, as was said, to explosion; and paddle-wheels were the propelling power. Strange as it may appear, no further result was obtained from this trial, and the invention was lost sight of. Towards the close of the sixteenth century numerous expedients and mechanical contrivances for raising water were described in published works; these being based in principle on the contrivances detailed by Hero. Baptista Porta, in 1606, the well-known inventor of the camera-obscura, published a commentary on Hero's *Pneumatica*, in which he describes the arrangement which is illustrated in fig. 4. Let *a* be a furnace, and *b* a small boiler or receptacle for the water to be heated; on the steam rising up the tube *c*, which is continued nearly up to the top of the air-tight box *d d* containing water, it presses on the surface of the water and forces it out through the tube *e*, which is continued down nearly to the bottom of the box *d d*. This contrivance, although the author made no application of it for the purpose of raising water, is worthy of notice, if only for containing within itself the first known germ of an important distinction in steam-mechanism, namely, the adaptation of a separate vessel for containing the water to be raised, from that in which the steam or vapour was generated. Baptista Porta gives this arrangement merely as carried out in an experiment on the relative bulks of water and steam.

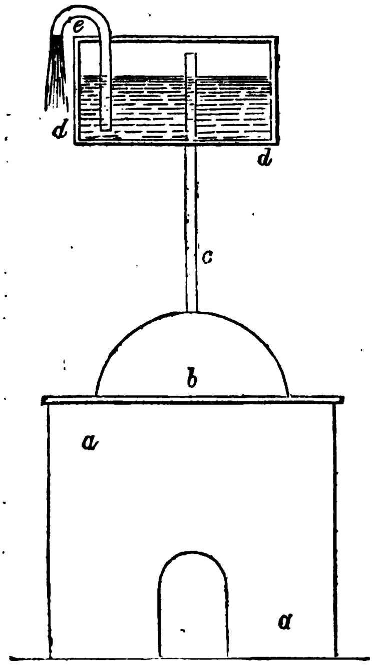


fig. 4.

Solomon de Caus, in a work dated Heidelberg, in 1615, entitled, *Les Raisons des Forces mouvantes avec diverses Machines tant utiles que plaisantes*, amongst a variety of insignificant and fanciful theories and de-

In fig. 5 we give an illustration of De Caus' theorem on this point. Let *a a* be a ball of copper, having a pipe *c* by which to partially fill *a a* with water; another pipe *b b* reaching nearly to the bottom of the globe is also provided. On placing the globe on a fire and carefully stopping up the vent *c*, the steam or vapour pressing on the water in *a a* presses it up the tube *b b*. He also details the following illustration of the force of steam. "Take a ball of copper of one or two feet diameter and one inch thick, which being filled with water by a small hole, subsequently stopped by a peg so that neither air nor water can escape, it is certain that if the said ball be put over a great fire so that it may become very hot, it will cause so violent a compression that the ball will be shattered in pieces. It, however, required no experiment of this stamp to prove the force of steam; the ancients were by no means ignorant of this; indeed they went so far as to attribute earthquakes to the force of pent-up vapours derived from subterranean heat. And Alberti, in 1412, notices the effects of pent-up vapour—dreaded by the lime-burners of that period—on the stones: "for when they come to be touched by the fire, and the stone grows hot, it turns to vapour, and bursting the prison in which it is confined with a tremendous noise, blows up the whole kiln with a force altogether irresistible."

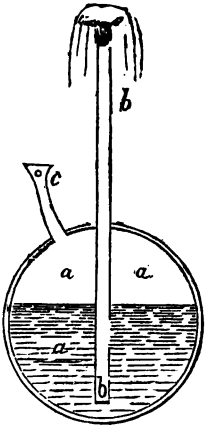


fig. 5.

M. Arago, in his anxiety, we presume, to claim the merit of the discovery of the invention of the steam-engine to a countryman of his own, attributes to De Caus a higher and more philosophical knowledge of the capabilities of steam than one would suppose he was in possession of, merely from his recital of the above experiment; and states that the ideas of the ancients respecting the force of steam had never reached any thing like the numerical appreciation realised by such experiments as those of De Caus. On this point we cannot do better than quote from the able treatise on the steam engine edited by John Bourne, Esq., C.E.: "We confess that we are at a loss to understand wherein this numerical appreciation can consist; for although De Caus or Rivault may have ascertained that steam will burst a cannon-ball or bomb, they never ascertained what sort of ball or bomb steam will *not* burst; so that they did not establish any limit to the power of steam, but only showed that it is capable of very powerful effects."

In 1629, in a work published by Giovanni Branca, a description is given of a contrivance in which the force of steam was used as the actuating power. The water is heated in a vessel the upper part of which is fashioned like a head; from the lips of this a pipe or tube issues, which directs the steam against the vanes or boards of a wheel, made somewhat like an undershot wheel; this is made, by the impinging of the steam on the floats or vanes, to rotate rapidly. The wheel is placed horizontally, as *b*, fig. 6; in the vertical axis of this a small trundle *c* is placed, which actuates the face-wheel *d*, and gives motion ultimately to stampers for compounding drugs in mortars. It is believed by some writers that this maidea is discarded. And it is doubtful whether Branca was the real inventor, as his book is avowedly "a collection of machines invented by others; and

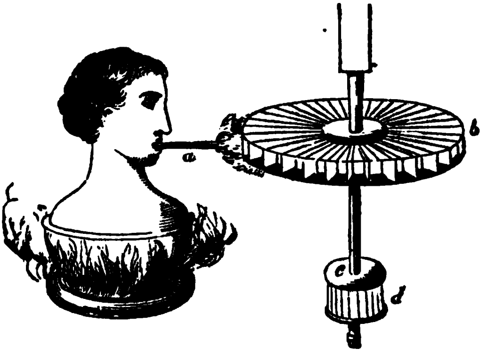


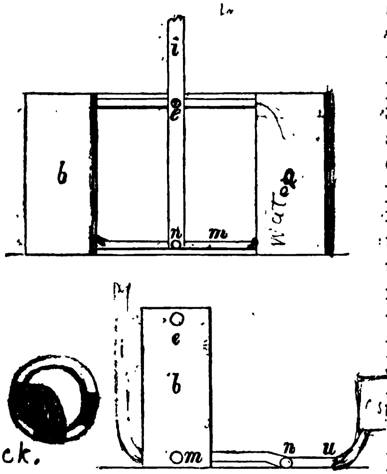
fig. 6.

this mode of moving a wheel by steam is probably, therefore, an idea of which he is the mere illustrator." He was, however, a "man of taste, as well as a person of ingenuity."

From the period now arrived at, up to the middle of the seventeenth century, history has no record as to the advances of the improvement of the steam-engine. All the contrivances hitherto published seem to have been more the result of closet study than every-day practice; more to be looked upon as the playthings of our philosophers than the purposed inventions of the practical mechanic. To this, however, De Garay's steam-boat propeller may perhaps be an exception; nevertheless it can be classed only as an experiment—questionless a successful one—and the barren results of which, in all probability, arose from some inherent defect in its principle or construction. At all events, up to the interesting period we now approach, no useful application of steam to the practical purposes of every-day life had yet been successfully introduced.

In 1663 the Marquis of Worcester, a nobleman who had undergone many changes of fortune in the civil wars of England, published a work entitled "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have, at the instance of a powerful friend, endeavoured now, in the year 1655, to set down in such a way as may sufficiently instruct me to put any of them in practice." Amongst the numerous devices which he enumerates, the following is the one which is closely connected with our present subject: "An admirable and most forcible way to drive up water by fire; not drawing or sucking it upward, for that must be, as one philosopher calls it, *infra sphærum activitatis*, which is not at such a distance: but this way hath no bounds if the vessel be strong enough; for I have taken a piece of a whole cannon whereof the end was burst, and filled it three-quarters full, stopping and screwing up the open end, as also the touch-hole, and making a constant fire under it. Within twenty-four hours it burst, and made a great crack; so that having a way to and one to fill after the other, I have seen the water run like a constant fountain-stream forty feet high. One vessel of water rarefied by fire driveth up forty of cold water; and a man that tends the work has but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the selfsame person may likewise abundantly perform in the interim between the necessity of turning the said cocks." The connection between this, the sixty-eighth proposition of the Marquis, and the two following, being the ninety-eighth and one hundredth, has been pretty conclusively established by a writer in the second volume of the *Glasgow Mechanic's Magazine:* "An engine so contrived," says the proposition, "that working the *primum mobile* forward or backward, upward or downward, circularly or cornerwise, to and fro, straight upward or downright, yet the pretended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping, the other; but unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore do I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me." The next proposition is as follows: "How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pounds descending doth what nothing less than one hundred pounds can effect."

"Upon so potent a help as these two last-mentioned inventions, a water-work is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up a hundred feet high an incredible quantity of water, even two feet diameter, so naturally, that the work will not be heard into the next room; and with so great care and geometrical symmetry, though it work day and night from one end of the year to the other, it will not require forty shillings' reparation to the whole engine, nor hinder one day's work; and I may call it the *most stupendous work* in the whole world: and not only with little charge to drain all sorts of mines, and furnish cities with water, though never so high-seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions,—but likewise supplying rivers with sufficient to maintain and make them portable from town to town, and for the bettering of lands all the way it runs. With many more advantages, and yet greater effects of profit, admiration, and consequence; so that deservedly I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions." "The *primum mobile*," says a writer of authority on the steam-engine, "is here evidently the force of steam, that, flow in whatever direction it may, is still capable of exerting the same mechanical power; and the movements, however numerous, can be made not to interfere with each other. The fall of a pound weight raising a hundred pounds weight clearly refers to a mechanism like a piston: one weighing a pound attached to a lever would raise one hundred pounds as high as one pound falleth; and were the weight of water to fall on a water-wheel, for instance, as is now often practised, it would raise a quantity very nearly equal to its own weight, and to the same height from which it fell. A child's force, too, would be sufficient to turn a cock even of a large engine; and the small noise made by this description pairing its power, are circumstances in the use of the machine now familiar to every person. It would be difficult to give a *clearer* description of the action of a steam-engine in general terms, without a special explanation of its minutiæ and principles. In this case, however, it obviously was the intention of Lord Worcester to conceal both." No drawing of this form of engine is extant, by which a notion of its arrangements can be obtained. Diagrams have, however, been given by various writers, detailing arrangements by which the effects as noticed by the marquis could be obtained. These, of course, are perfectly hypothetical; nevertheless, as a matter of some curiosity, we append a diagram illustrative of an arrangement proposed by Mr. Stuart, in his work *Historical and Descriptive Anecdotes of the Steam-engine*, a work abounding in interesting matter (in fig. 7). Steam is supplied to the receivers *a b* by a steam-pipe proceeding from a boiler; the steam is admitted alternately to the receivers *a b* by means of a cock placed at *e*. The receivers are connected with the deduction pipe *i* by a pipe *m*, containing valves opening outwards from each receiver; another pipe *n u* connects the cistern with the receivers; by means of the cock at *n* the communication between the cistern and each receiver may be interrupted at pleasure. The steam from the boiler passes into the receiver *a*, previously filled with water; pressing on its surface, it forces the water through the pipe *m* up the pipe *i*, which conveys it to its destination. After the water is expelled from the receiver *a*, the cock *e* is turned, which admits the steam into the receiver *b*; simultaneously the cock *n* is turned, which admits water from the cistern into *a*; the steam pressing on the surface of the water in *b*, forces it up the pipe *i*; on the whole of the water being expelled, the cock *e* is turned, shutting off the communication with the boiler from *b*, but opening it to *a*. Unless, however, the boiler from which steam is supplied is provided with means for filling it with water at intervals, to compensate for that evaporated during the process of working, it is evident that the continuity of action of the engine would be interrupted. An eminent authority therefore considers that there could not have been in this kind of engine "any feed-pump: in the absence of that instrument, two boilers must have been indispensable to make the action of the engine continuous." It will be interesting to trace briefly the evidence which has been collected in support of the opinion that the Marquis of Worcester had actually carried his engine into practical effect, this being with many a debatable point. In looking over the preposition of his celebrated work, it will be observed that he speaks of having "*seen* the water" raised; of "*having a way* to make his vessels." Again, although the marquis's veracity may be doubted in these incidental notices, it is worthy of note that a manuscript



I. way cock.

fig. 7.

found after his death bore this heading: "The Lord Marquis of Worcester's ejaculatory and extemporary thanksgiving prayer, when first with his *corporeal eye he did see* finished a perfect trial of his water-commanding engine, delightful and useful to whomsoever hath in recommendation either knowledge, profit, or pleasure." Other corroborative evidence might be given, but it is deemed sufficient to append a very conclusive statement of one who was neither influenced by prejudice or interest. The evidence to which we allude is that given by Cosmo de Medicis, Grand Duke of Tuscany, who visited England about the period of the invention, and whose movements during his travels were duly recorded by his secretary. Under date May 28th, 1699, is the following entry: "His Highness, that he might not lose the day uselessly, went again after dinner to the other side of the city, extending his excursion as far as Vauxhall, beyond the palace of the Archbishop of Canterbury, to see an hydraulic machine invented by my Lord Somerset, Marquis of Worcester. It raises water more than *forty geometrical feet* by the power of *one man only;* and in a very short space of time will draw up *four vessels* of water through a tube or channel not more than a span in width, on which account it is considered to be of greater service to the public than the *other* machine at Somerset House." "This, therefore, is superior in its operations to *another machine* by a *different machanic, and applied to the same purpose.*" The following is the entry in the Duke's journal of the other machine to which allusion was made in the first entry: "His Highness went to see an hydraulic machine raised upon a wooden tower in the neighbourhood of Somerset House, which is used for conveying the water of the river to the greatest part of the city. It is put in motion by *two* horses, which are continually going round; it not being possible that it should receive its movements from the current of the river, as in many other places where the rivers never vary in their course." "Nothing can be more satisfactory," says Mr. Stuart, "than this last notice. The water in the hydraulic machine at Vauxhall, by the most easy inference, was *not* elevated by a water-wheel, otherwise the Grand Duke would not have omitted so striking a deviation from that at Somerset House. The effect was equal to that of another worked by two horses; and a tyro in mechanics would at first sight say, that no combination of machinery could accomplish that work by one man which it required the power of twelve men to do in another. From all the circumstances, therefore, it appears to us clear, that this great effect was produced by some sort of a steam-engine: the very identical 'most stupendous water-commanding engine;' 'the semi-omnipotent engine;' the 'admirable and most forcible way to drive up water by fire.'"

The introduction of this, the first "feasible" scheme for producing useful effects by the power of steam, may be said to be the turning-point in the history of the steam-engine. From this time the march of progressive improvement was rapid and uninterrupted; invention followed invention, improvement succeeded improvement, until the steam-engine arrived at its present potent condition.* From this stage of our labours we shall cease

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* Sir Samuel Morland in 1683 submitted to Louis XIV. of France a plan for raising water by the aid of steam. The following notice is extracted from a Ms. in the British Museum. "The principles of the new power of fire invented by the Chevalier Morland in the year 1682, and presented to his most Christian Majesty 1683.—Water being evaporated by the power of fire, the vapour shortly acquires a greater space (near 2000 times)

to record the crude and visionary speculations of the philosopher or enthusiast; but have the more useful and pleasant task of describing the practical results of the application of the labours and ingenuity of our engineers and mechanics.

It is supposed by some engineers, that the method of raising water by steam, on the principle of atmospheric pressure (or the vacuum), was not unknown to the Marquis of Worcester; and that it is not improbable but that in the engine mentioned by the Grand Duke of Tuscany this agency was taken advantage of. This is, of course, mere conjecture; but in an invention next in chronological order, now to be noticed, atmospheric pressure, or the formation of a vacuum, was a distinguished feature. The engine to which we allude is that so well known as "Savery's." The period of the introduction of this engine may be looked upon as the commencement of the *practical* era; the very mode in which the inventor ushered it into the world, and presented its claims to consideration, proved this. In place of clothing his description in the studied mysticism of words, which up to this period had been the endeavour of all those who had preceded Savery in describing inventions in connexion with the subject, he, on the contrary, fully explained the principles of its action and the details of its arrangements; and instead of giving exaggerated statements of its power and economy, he practically detailed the reasons why he believed it to be a cheaper method of raising water from mines than any other plan then in operation; and earnestly invited parties interested to inspect the machine in operation, and form their own opinion as to its working value. Very little is unfortunately known of this ingenious man. From his title of Captain it has been conjectured that he was a seafaring man; probably this arose from his having been the inventor of an improved method of moving ships in a calm. It is doubtful whether he was or not; indeed, the latter is likely the case, as, in one of his papers describing an invention of his, he remarks: "I believe it may be made useful to ships; but I dare not meddle with that matter, and leave it to the judgment of those who are the best judges of maritime affairs." This does not read like the statement of one who was a practical seaman. Mr. Stuart conjectures, with greater probability, that he was the director or proprietor of a mine, and as such was known by the title which is even now appropriated to the same officer.

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than the water occupied before; and were it to be always confined, would burst a piece of cannon; but being well regulated according to the laws of gravity, and reduced by science to measure, to the weights and balance, then it carries its burden peaceably (like good horses), and thus becomes of great use to mankind; particularly for the elevation of water, according to the following table, which marks the number of pounds which may be raised 1800 times per hour, by cylinders half full of water, as well as the different diameters and depths of the said cylinders." Although no account is obtainable of the contrivance for raising water said to have been submitted by Morland to the King of France, the above extract is sufficient evidence of his being acquainted with the power of steam, and as to the value of its application to useful purposes. The table referred to in the above notice need not be given here; it bears with it the evidence of much care having been taken in the experiments necessary to obtain the given results, which may be said to possess considerable accuracy. It is but just, however, to notice that it is quite an open question whether Morland ever really submitted any plan for raising water by steam, as has been said. One historian of authority states that there is no distinct evidence as to his having done so; and in his book published in 1685, describing all sorts of machines for raising water, he makes not the slightest mention of

In 1698 he obtained a patent from William the Third "for raising water, and occasioning motion to all sorts of mill-work, by the impellant force of fire;" and in 1699 he exhibited a model of his engine before the Royal Society, a description and illustration of which is given in their *Transactions*, vol. xxi. p. 228. In 1702 he published a work entitled *The Miner's Friend*, written in a lively and interesting style, and containing a full and circumstantial account of the arrangements and operation of the engine. The following is the description, which is worthy of a place here, as an example of mechanical description, and as giving a notion of the merits of Savery as an inventor. In fig. 8, which is a perspective view of the whole apparatus, "*a a* are the furnaces which contain the boilers; *b*1, *b*2, the two fire-places; *c*, the funnel or chimney, which is common to both furnaces. In these two furnaces are placed two vessels of copper, which I call boilers; the one large, as *l*, the other small, as *d*. *d*, the small boiler contained in the furnace which is heated by the fire at *b*2; *e*, the pipe and cock to admit cold water into the small boiler to fill it; *f*, the screw that covers and confines the cock *e* to the top of the small boiler; *g*, a small gauge-cock at the top of a pipe going within eight inches of the bottom of the small boiler; *h*, a larger pipe, which goes the same depth into the small boiler; *i*, a clack or valve at the top of the pipe *h* (opening upwards); *k*, a pipe going from the box above the said clack or valve in the great boiler, and passing about an inch into it. *l*

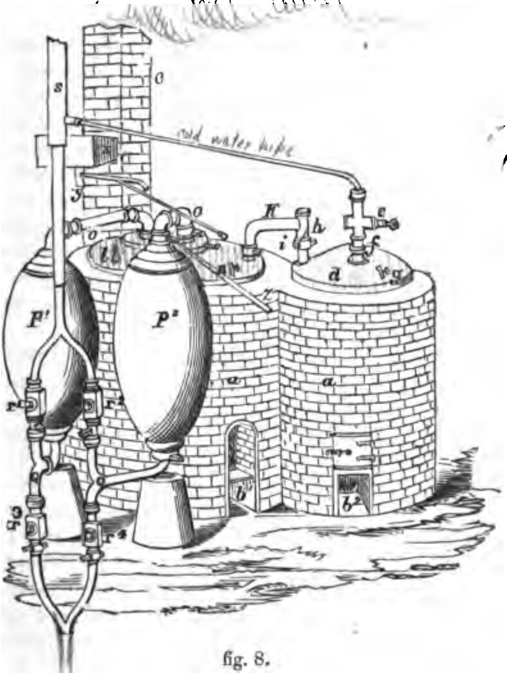

fig. 8.

at *b* 1; *m*, the screw with the regulator which is moved by the handle *z*, and opens or shuts the apertures at which the steam passes out of the great boiler into the steam pipes *o o*; *n*, a small gauge-cock at the top of a pipe which goes halfway down into the great boiler; *o*, *o*, steam-pipes, one end of each screwed to the regulator, the other ends to the receivers *p*1, *p*2, to convey the steam from the great boiler into these receivers; *p* 1, *p* 2, copper vessels called receivers, which are to receive the water which is to be raised; *q*, ~~screw~~ joints by which the branches of the water-pipes are connected with the lower parts of the receivers; *r* 1, *r* 2, *r* 3, *r* 4, valves or clacks of brass in the water-pipes, two above the branches *q*, and two below them; they allow the water to pass upwards through the pipes, but prevent its descent; there are screw-plugs to take out on occasion, to get at the valves *r*; *s*, the forcing pipe, which conveys the water upwards to its place of delivery, when it is forced out from the receivers by the impellant steam; *t*, the sucking pipe, which conveys the water up from the bottom of the pit, to fill the receivers by suction; a square frame of wood, or a box with holes round its bottom in the water, encloses the lower end of the sucking pipe, to keep away dirt and obstructions; *x*, a cistern with a buoy-cock coming from the force-pipe, so as it shall always be kept filled with cold water; *y*, a cock and pipe coming from the bottom of the said cistern, with a spout to let the cold water run down on the outside of either of the receivers, *p* 1, *p* 2; *z*, the handle of the regulator, to move it by, either open or shut, so as to let the steam out of the great boiler into either of the receivers."

In working the engine, "the first thing is to fix the two boilers of the engine in a good double furnace, so contrived that the flame of the fire may circulate round and encompass the boilers to the best advantage, as you do coppers for brewing. Before you make any fire, unscrew the two small gauge pipes and cocks, *g*, *n*, belonging to the two boilers, and at the holes fill the great boiler *l* two-thirds full of water, and the small boiler *d* quite full; then screw in the said pipes again, as fast and tight as possible, and light the fire under the large boiler at *b* 1, to make the water therein boil; and the steam of it, being quite confined, must become wonderfully compressed, and therefore will, on the opening of a way for it to issue out (which is done by pushing the handle *z* of the regulator as far as it will go from you), rush with a great force through the steam-pipe *o* into the receiver *p* 1, driving out all the air before it, and forcing it up through the clack *r* into the force-pipe, as you will perceive by the noise and rattling of that clack; and when all the air is driven out, the receiver *p* 1 will be very much heated by the steam. When you find it is thoroughly emptied, and is grown very hot, as you may both see and feel, then pull the handle *z* of the regulator towards you, by which means you will stop the steam-pipe *o*, so that no more steam can come into the receiver *p* 1, but you will open a way for it to pass through the other steam-pipe, *o*, and by that means fill the other receiver, *p* 2, with the hot steam, until that vessel has discharged its air, through the clack *r* 2, up the force-pipe, as the other vessel did before.

"While this is doing, let some cold water be poured on the first-mentioned receiver, *p* 1, from the spout *y*, by which means the steam in it being cooled and condensed, and contracted into a very little room, a vacuum or at all, on the clack *r* 3 at the bottom of the receiver *p* 1, there is nothing there to counterbalance the pressure of the atmosphere on the surface of the water at the lower part, *v*, of the sucking-pipe *t*; wherefore the water will be pressed up, and ascend into and fill the receiver *p* 1, by what is commonly called suction: the water as it rises lifts up the clack or valve *r* 3, which afterwards falling down again, and shutting close, hinders the descent of the water that way. The receiver *p* 2 being by this time emptied of its air, push the handle of the regulator from you again, and the force of the steam coming from the great boiler will be again admitted through *o*, and will act upon the surface of the water contained in the receiver *p* 1, which surface only being heated by the steam, it does not condense it, but the steam gravitates or presses with an elastic quality like air, and still increasing its elasticity or spring until it counterpoises, or rather exceeds, the weight of the column of water in the receiver and pipe *s*, which it will then necessarily drive up, through the passage *q r*, into the force-pipe *s*. The steam takes up some time to recover its power; but it will at last discharge the water out at the top of the force-pipe *s*, as it is represented in fig. 8. After the same manner, though alternately, the receiver *p* 2 is filled with water by means of the suction, and then emptied by the impellant force of the steam, whereby a regular stream is kept continually running out at top of the force-pipe *s*; and so the water is raised very easily from the bottom of the mine, &c., to the place where it is designed to be discharged. I should add, that after the engine begins to work, and the water is risen into and hath filled the force-pipe *s*, then also it fills the little cistern *x*, and by that means supplies the spout or pipe *y y*, which I call the condensing pipe, and which by its handle can be turned sideways over either of the receivers, *and is then open;* by this spout cold water is conveyed from the force-pipe, to fall upon the outside of either of the receivers when thoroughly heated by the steam, in order to cool and condense the steam within, and make it suck (as it is usually called) the water up out of the well into that receiver. It is easy for any one that never saw the engine, after half an hour's experience, to keep a constant stream; for on the outside of the receiver you may see how the water goes out as well as if the receiver were transparent; for as far as the steam continues within the receiver, so far is that vessel dry without, and so very hot as scarce to endure the least touch of the hand; but as far as the water is withinside of the said vessel, it will be cold and wet where any water has fallen on it, which cold and moisture vanish as fast as the steam in its descent takes place of the water. But if you force all the water out of the receiver, the steam, or a small part thereof, will go through the clack *r* 1 or *r* 2, and will rattle that clack so as to give notice to move the handle of the regulator, and then the steam begins to force the water out from the other receiver *p* 1, without the least alteration of the steam, only sometimes the stream will be rather stronger than before, if you pull the handle before any considerable quantity of steam be got up the clack *r*; but it is much better to let none of that steam go off, for that is but losing so much strength; and it is easily prevented by pulling the regulator some little time before that receiver which is forcing is quite emptied. This being done, turn the cock *o*, or condensing pipe *y*, of the cistern *x*, over the empty receiver, so that the cold water proceeding from *x* may run down through *y*, which is never opened but when turned over one of the receivers, but when it stands between them is tight and stanch. This cold water, falling on the outside of the receiver, by its coolness causes that steam which had such great force just before to condense and become an empty space, so that the receiver is immediately refilled by the external pressure of the atmosphere, or what is vulgarly called suction, whilst the other receiver is emptying by the impellant force of the steam; which being done, you push the handle of the regulator from you, and thus throw the force into the other receiver, pulling the condensing pipe over the receiver *p* 2, causing the steam in that vessel to condense, so that it fills while the other empties; the labour of turning these two parts of the engine, viz. the regulator and condensing water-cock, and tending the fire, being no more than what a boy's strength can perform for a day together, and is as easily learned as their driving of a horse in a tub-gin."

The method by which Savery managed to keep up the supply in the large boiler, for the purposes of evaporation, is highly ingenious, and is indicative of his inventive powers. Let *a*, fig. 9, represent the small boiler, which is supplied with water from the force-pipe *s* by the pipe *e*, supplied with a stop-cock (fig. 8); a pipe, *h*, descends within eight inches of the bottom of the boiler, and is provided with a valve, *i*, opening upwards; this pipe is connected with the large boiler *l*. The following is the operation, as described in the inventor's own words: "When it is thought fit by the person tending the engine to replenish the great boiler (which requires about an hour and a half or two hours to the sucking one foot of water), he turns the cock *e*, so that there can be no communication between the force-pipe *s* and the small boiler *d*, and putting in a little fire under the small boiler at *b* 2 (fig. 8), the water will then grow presently hot; and when it boils, its own steam, which hath no vent out, will gain more strength than the steam in the great boiler. . . . The water in the small boiler, being depressed by its own steam pressing on its surface, will force the water up the pipe *h*, through *k*, into the great boiler *l*; and so long will it run, till the surface of the small boiler *d* gets to be as low as the bottom of *h*; and then the steam and water will run together, and by its noise, and rattling of the clack *i*, will give sufficient assurance to him that works the engine that the small boiler hath emptied and discharged itself into the greater one *l*, and carried in as much water as is then necessary; after which, by turning the cock *e* again, you may let

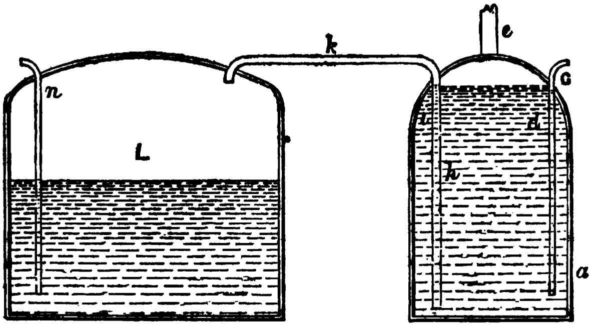

fig. 9.

Savery

fresh cold water out of the force-pipe *s* (see fig. 8) into the lesser boiler *d*, as before; and thus there will be a constant motion and continual supply of the engine, without fear or disorder. And inasmuch as from the top of the small boiler *d* to the bottom of the pipe *h* there is contained about as much water as will replenish the great boiler *l* one foot, so you may be certain it is replenished one foot of course." Captain Savery also introduced a contrivance by which the depth of the water in the boilers could be ascertained; this he termed a "gauge-cock," the principle of which is illustrated in fig. 9, at *c*, *n*, which are pipes continued down to within eight inches of the bottom of the boilers. When the attendant is desirous of knowing when the great boiler wants replenishing, he opens the stop-cock in connection with the pipe *n*: if water issues from it, the supply of water is sufficient; if steam issues from it, it is an evidence that the boiler requires a supply of water. By the cock *c* it is easily ascertained whether the small boiler requires a supply of cold water from the force-pipe *s*. This contrivance of the gauge-cock is still in use to the present day, the best evidence as to the practical value of Savery's ingenuity.

Such is a description of Savery's celebrated "fire-engine," an invention remarkable alike for the judiciousness of its arrangements, and the practical purposes for which, at the period, it was introduced. Considerable discussion has arisen as to whether Savery really invented the engine, or derived his ideas from other sources, as the invention of the Marquis of Worcester. Desaguliers details an evidently got-up story of Savery having bought up the copies of the pamphlet of the marquis, with a view to do away with all evidence of priority of invention on the part of the marquis. There is no evidence that this was done by Savery: on the contrary, all evidence goes to prove the fact that it was extremely unlikely for him to endeavour to detract from the fame of the marquis by way of gaining for himself a reputation. The buying up the pamphlets of the marquis would have been a useless labour, for it is altogether improbable that all recollection of an engine erected at Vauxhall, as reported by the Grand Duke of Tuscany, should have vanished from the minds of many who would have witnessed its action then alive; moreover many of the contemporaries of the marquis were then alive, at the period when Savery introduced his engine, some of them also members of the Royal Society, before which Savery, as we have seen, displayed a model of his engine. But the ingenuity of the arrangements of the engine itself conveys with it, we think, the undoubted stamp of originality. One honour—and that a high one—can at all events be ascribed to Savery without dispute, and that is of being the person who introduced into extended use an invention calculated to be of high practical value; and this labour, the work of which the world is not slow to estimate highly, he performed in the face of what he termed the "oddest and almost insuperable difficulties," with a perseverance and indomitable courage entitled to the highest commendation; and after all, he who, in spite of the opposition of prejudice and interest, succeeds in introducing into extended use inventions calculated to be of service in the promotion of the interests of humanity, is entitled to a higher reward, and to have the value of his labours judged of from a higher standard, than he whose services are confined to the mere discovery or elaboration of a mechanical or philosophical invention.

mospheric pressure" has been fully explained. Toricelli, after the death of Galileo, discovered that the flowing of water (open to the atmosphere) into any vacuous space is owing to the pressure of the atmosphere, which acts upon all bodies at the earth's surface with a definite pressure. In 1672 the celebrated Otto Guericke, in his *Experimenta Magdeburgica*, detailed an apparatus by which he could raise heavy weights. In fig. 10 we give a diagram illustrative of the arrangement. Let *a* be a cylinder in which a piston *b* works, air-tight; the piston-rod *b* has a rope attached to it passing over the pulleys *c c*, and continued to suspend a board *e* containing heavy weights. Suppose that by means of an air-pump the space below the piston (the piston being raised to the top of the cylinder by the weights on *e*) is deprived of its contained air, and a vacuum, more or less perfect, produced, the pressure of the external atmosphere would cause the piston to descend, raising the weights on *e*; now if a small stop-cock were opened to admit air at the lowest part of the cylinder below the piston, the weights would pull the piston up to the top of the cylinder, the pressure of the atmosphere being equal on both sides of the piston. By making a vacuum, as before, beneath the piston, it would descend; and thus, by repeating the process, the weights might be made to ascend and descend. The efficiency of a vacuum to raise heavy weights was thus established by means of this arrangement, and was no doubt pretty universally known at the period of the introduction of Savery's patent. It is clear, however, that the operation of withdrawing the air, so as to produce a vacuum by means of an air-pump, was too expensive and tedious an operation to be thought of as a working medium. Although there is no direct evidence of the fact, it is supposed that the Marquis of Worcester was acquainted with the method of forming a vacuum by condensing steam in close vessels; and, indeed, that the principle was carried out in the engine erected by him at Vauxhall. That Savery introduced the principle in his engine, we have already shown; indeed, in his patent, he claims "the method of making a speedy vacuum by condensing steam." Savery stated that he discovered the method by plunging a flask, which, with a little wine left in it, he had previously thrown in the fire, into a basin of cold water while the flask was filled with vapour. The sudden condensation of the steam in the interior of the flask created a vacuum, into which the water from the basin violently rushed. Desaguliers has thrown discredit on this statement, by saying that the experiment could not have been carried out in the way explained by Savery, inasmuch as the flask would be forced from the hand by the rushing of the water entering the flask: of this Savery makes no mention. A modern authority, however, states that this result, as indicated by Desaguliers, only happens under certain circumstances, so that the statement of Savery cannot be impeached on this ground. But another claimant has been put forward for the honour of the discovery of the principle of the formation of a vacuum

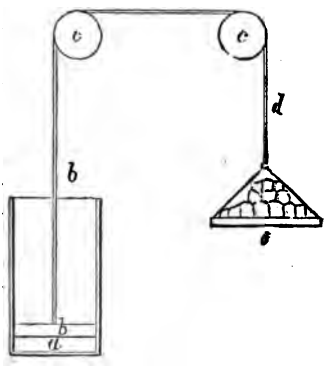

fig. 10.

by the condensation of steam. This claimant is the well-known Denis Papin. Denis Papin was born in France. Being a Protestant, he was forced to leave France on the revocation of the edict of Nantes, and coming to England, was employed by the celebrated Mr. Boyle to assist him in his experiments. In 1680 he was elected a member of the Royal Society. It was during his stay in England that he invented his celebrated "digester," in which, with the aid of high-pressure steam, he dissolved bones, &c., and to which apparatus he applied the important contrivance known as the "safety-valve:" this, under several modifications, is in use at the present time. In the form of a "riddle to stir up those that are ingenious in the same kind of learning, and make them find sometimes better things than what is propounded," he exhibited in 1685 a model of a machine for raising water; and in the solution which he himself gave of it, it appears "that the water was raised by rarefying the air in the vessel, into which it was impelled by the pressure of the atmosphere on the water in the cistern. The mode by which he rarefied the air was carefully concealed. In two of the solutions the same effect was produced by condensing it." On being appointed to the Professorship of Mathematics at Marburg, in Germany, he left England in 1687, in which country, although he ranked high as a man of science, he had gained little encouragement in the carrying out of his schemes. In Westphalia and at Auvergne he was employed to raise water by his machines; but he failed in doing so. This result was predicted by the celebrated Dr. Hooke. Having attempted a variety of methods of working machines, he, amongst others, tried the method of producing a vacuum by condensing the vapour produced by the combustion of gunpowder in a vessel. This, however, proved unsatisfactory. In 1690, in the *Acta Eruditorum* of Leipsic, he proposed a method of raising water by condensing steam in a cylinder. The following is a diagram illustrative of the arrangement proposed by Papin: let *a a*, fig. 11, be a cylinder supplied with a portion of water at *c*; *b* a tight-fitting piston, the stem or rod of which is passed through the cover of the cylinder; a lever *e* is pressed by a spring into a notch made in the piston-rod in such a way that the piston is kept suspended near the top of the cylinder, when the part in which the notch is made comes above the cover; a small pipe *f* is passed through the cover and the piston, and is capable of being kept closed at its upper extremity steam-tight. The piston being allowed to fall to the lower part of the cylinder, the stopper at the upper part of the pipe *f* is taken out, and water introduced beneath the piston to the space *c*. Fire is then applied to the cylinder *a*; the steam thus generated raises the piston. On the notched part rising above the cover, the lever *e* is pressed into it, which sustains the piston at the upper part of the cylinder. The fire is then withdrawn from the apparatus, and the cylinder being allowed to cool, the steam contained in it is condensed, and the lever *e* being withdrawn from the notch, the atmospheric pressure forces the piston to the lower part of the cylinder, carrying

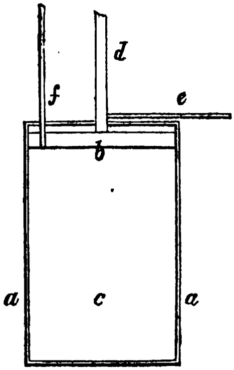

fig. 11.

with it such weights as may be attached to the rod applied, as in fig. [illegible] 10. A mere glance at the mode of operation of this engine—if engine it can be called—will suffice to show how incapable it is of being made a practically working apparatus. And yet it is really marvellous how, on the verge of a great discovery, Papin was content to pursue his investigations no further, and to "abandon his pursuit at the moment he had laid the foundation of the splendid mechanism of the lever engine, and had in his grasp a brilliant reward for a life of labour." With reference to the claim put forward by the advocates of Papin and Savery as to their discovery of the principle of the formation of a vacuum by steam, it is very evident that neither could substantiate his claim, the fact that a vacuum could thus be formed being known long before their time; long before, indeed, the principle of atmospheric pressure was established, Hero, Porter, and De Caus were aware of this fact. With reference to the charge which has been put forward against Savery, that he merely carried out the ideas of Papin, it is enough and perfectly satisfactory to know, that whatever might be the extent of the information Savery derived from the labours of others, he was the first to introduce a practically useful engine—distinct in many of its features from the schemes of others, and preserving those very qualities which took it out of the category of philosophers' toys or the "riddles" of men of science, and placed it in that of beneficial agents. And perhaps no better tribute can be paid to the value of Savery's engine, than the fact that Papin was so "thoroughly convinced of the superiority" of it that he abandoned his own contrivance, and adopted Savery's.*

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* The following is a diagram illustrative of what has been ascribed to Papin as a later invention; he, however, ascribes it to the ingenuity of the Elector of Hesse. under whose patronage he carried on his various experiments. Let *a* (fig. 12) be a boiler provided with a safety-valve (~~not shown in the diagram~~), through which it is supplied with water; the pipe *b*, with stop-cock, connects it with the receiver *d*. In this receiver a hollow floater, or piston, is placed, containing a cylinder; this cylinder is inserted in its place in the floater through the aperture, *f* in the top of the receiver, which aperture is closed with a lever valve, as in the diagram. *c* is a funnel through which water is introduced to the receiver, closed by a cock *m*; the forcing-vessel or receiver *d* is continued upwards to *g*, and is passed up near to the top of the air-vessel *h*. The water which is forced into the vessel *n* is led off to its destination through the pipe *i*. The steam from the boiler *a* is allowed to pass into the forcing-vessel *d*; pressing on the upper side of the

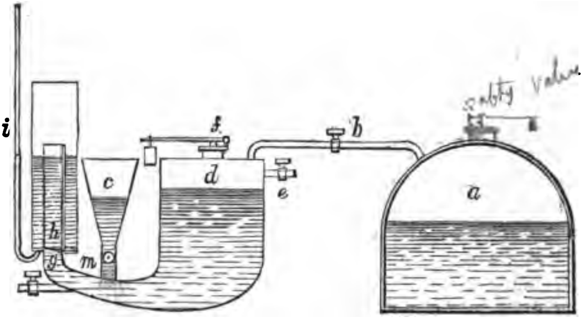

fig. 12.

We now approach the period of introduction of a steam-engine of a still higher range of practical value than Savery's. Before proceeding further, however, it will be necessary to point out a few of the defects of Savery's engine. In the first place, the danger of using the engine was considerable, from the high pressure at which the steam was used, and from there being no provision made for its escape on its reaching a given point. Comparing it with that now adopted in certain circumstances, the pressure was not in itself great; but the fact must be taken into consideration, that the state of the mechanical arts as then existing rendered it a matter of extreme difficulty, if not altogether an impossibility, to procure boilers and vessels so strongly and correctly made as to be considered, under the circumstances of usual working, safe. In the second place, the cost of working the engine was very great, from the large expenditure of fuel necessary to obtain the desired effect. That this expenditure was excessive may be gathered from this consideration: As the vessel each time had to be filled with cold water rushing in to supply the vacuum, a certain amount of steam on being admitted to force the water out of the vessel was condensed by coming in contact with the cold surface, and the water had to be heated for a small depth before the "steam was strong enough" to expel the water from the receiver. The cold surface of the interior of the receiver with which the steam came in contact produced condensation to such an amount as to form rather a considerable item in the cost of working the engine. When to reduce this loss the sides of the receivers were only moderately cooled, the vacuum in the interior was so much impaired, from a quantity of vapour of considerable pressure remaining, that the effective height to which the water could be raised was much lessened. This, in fact, operated at all times to such an extent as to limit the pressure of the atmospheric column to twenty or twenty-one feet. There was still another objection, and that a serious one, namely—the plan of working the engine by opening and shutting of cocks through the agency of the attendant, the efficiency of the engine being thus dependent on his carefulness and attention.

We have already explained the arrangement by which Papin proposed to use the vapour of water by making it act on the surface of a piston moving in a cylinder. This arrangement, although defective, contained, as we have noticed elsewhere, the germ of the steam-engine in its practically working condition; and this mechanism of a piston and cylinder was that which was destined, under the hands of succeeding inventors, to be an important feature in the modern steam-engine. The inventor who adopted this mechanism, and whose engine we are now about to notice, is well known in the history of the steam-engine as Thomas Newcomen, ironmonger, of Dartmouth. In conjunction with John Cawley, glazier, of the same place,—to whom, according to Desaguliers, he communicated his pro-

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reaching to the bottom of the vessel *d*, or the limits of its play, the stop-cock b is closed to prevent the further flow of steam into *d*, and the steam remaining in *d* is allowed to pass off by opening the cock *e*. Simultaneously with the opening of the cock *e*, the cock *m* is opened, which admits the water from the receiver *c* to pass into and fill the forcing-vessel *d*, raising at the same time the piston; the water in *h* is prevented from descending by a valve placed on the pipe *g*. The cylinder which is placed in the floating piston is inserted through the valve *f* in a red-hot state; this makes the steam hotter. The air-vessel *h* tends to keep up a continuous stream through the pipe *i*. This air-vessel was not, however, considered essential, for an engine framed without it raised ject,—he had been prosecuting a series of experiments on the power of steam. In the course of his labours he had written to the celebrated Dr. Hooke, a well-known *savant* and intimately acquainted with the contrivances of Papin, with reference to his project. Dr. Hooke, in a letter to Newcomen, dissuaded him from expending time and labour in endeavouring to produce motion on Papin's plan, *i. e.* by piston and cylinder; and made use of the remarkable expression, "could he (referring to Papin) make a speedy vacuum under your piston, your work is done." This expression shows that Dr. Hooke must have been ignorant of the great rapidity with which steam is condensed by contact with a cold body; or from being convinced that Papin had not been able to effect the arrangements which he claimed as his own. Nothing daunted, however, by this most discouraging opinion from one who ranked high as an authority, Newcomen and Cawley still prosecuted their experiments, which ultimately resulted in the bringing out of a machine, the component parts of which are still retained in one of the many forms of the steam-engine. In the patent granted to Newcomen and Cawley in 1705, the name of Savery was included. This arose from the fact that the latter was in possession of a patent for a "method of making a speedy vacuum by condensing steam." It does not appear, however, that Savery aided in carrying out the plan; and it is now conceded that, save receiving a portion of the profits, he had no further connexion with the scheme; to the other patentees, therefore, must the honour of the invention be paid. It is right, however, to state, that the assistance which Cawley rendered is unknown; and it appears probable that Newcomen was the principal party to whom the invention and its principal details were due.

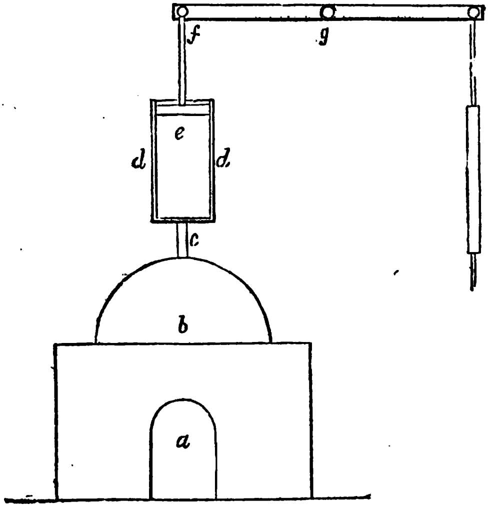

fig. 13.

The nature of the action and arrangements of the engine as first introduced by Newcomen may be gathered from the diagram in fig. 13. Let a be the furnace heating the boiler *b*; *c* a pipe conveying the steam to the interior of a cylinder *d*, the upper end of which is open to the air, in which a piston *e* works; this is attached to a lever *f* oscillating in the centre *g*, and having at its other extremity *h* a weight, as a pump-rod weighted, which, acting as a counterpoise, pulls the piston up to the top of the cylinder. Now supposing steam to be introduced to the interior of the cylinder, and thereafter to be condensed by throwing cold water over the exterior surface, a vacuum will be produced in the cylinder; and the atmosphere pressing on the upper side of the piston will force it downwards; and pulling down the end *f* of the great beam, will raise the end *h*, and along with it the counterpoise-weight or pump-rod there attached. The power of this engine will obviously depend on the surface of piston, the atmosphere exerting a pressure of about 14·75 lbs. on each square inch. Supposing the piston to be 50 inches in area, the weight which the engine would be able to lift would be nearly 800 lbs. This is the theoretical view of the case; the practical one widely differs. The effect obtained, as above noticed, depends on the absence of friction and the perfect formation of a vacuum. None of these desiderata, in the earlier stages of the engine, could be obtained. To reduce the friction of the piston moving in the cylinder, the piston was provided with "packing" placed round its edges, and made of hemp or leather well-lubricated. The friction, however, of the piston and working-beam was of so considerable an amount, that it detracted much from the working capabilities of the engine. The bad formation of a vacuum also reduced its working-power. When the void was imperfect, the vapour remaining in the cylinder resisted the atmospheric pressure in proportion to its temperature; this being tantamount to reducing the weight which could be lifted at the end of the beam. The fall of the cylinder was also prevented to a certain extent by air, which entered into the cylinder along with the steam from the boiler; this air not being condensed by the cold water, remained in the interior of the cylinder, and operated as an opposing power to the descent of the piston in proportion to the amount. This defect, which was termed *wind-logging*, continued to increase in power with the operation of the engine; and unless means had been afterwards adopted, the air would have so increased in volume as to stop the motion of the engine. The form of engine introduced at first by Newcomen resembled in some points that of Papin; an essential difference between them will, however, be obvious on consideration. In Papin's engine the piston was raised by the force of the steam; it required therefore, to be of a pressure considerably above that of the atmosphere. In Newcomen's engine, however, the steam was used at the ordinary pressure, or 212°, and only as a means of producing a vacuum beneath the piston, and thus aiding the atmospheric pressure by the improved mechanical means. The substitution, moreover, of the beam and connecting-rods opened the way to a great number of applications. Hence it will be observed that the name, "atmospheric engine," by which Newcomen's contrivance was known, was not so inappropriate.

We now proceed to detail the various improvements introduced from time to time, which resulted in bringing the atmospheric engine to comparative perfection. And first, as to the method of forming a vacuum in the cylinder. As in the engine already described, the cold water, to produce the vacuum, was originally thrown over the exterior of the cylinder. This plan was productive of much loss of working effect, from the circumstance that the boiler, being placed immediately beneath the cylinder, received the plashings of the cold water on its surface; this happening at every stroke of the engine, tended to condense the steam in the boiler. To obviate this, the cylinder was surrounded with an outer case, leaving a space between it and the interior cylinder. Into the space thus formed the cold water was introduced. A practical inconvenience was soon discovered to attend this plan, as the water soon became heated, and therefore comparatively useless in producing a vacuum in the interior of the cylinder. Again, it was necessary that, during the time when the cylinder was being filled with steam, the water in *the space* should be nearly of the same temperature as the steam. Means, therefore, were adopted by which this hot water was quickly withdrawn from the space as soon as the cylinder was filled with steam, and also for refilling the space as quickly with cold water, to produce the vacuum. These desiderata were effected by supplying the cold water from a cistern placed immediately above the cylinder, and by leading a pipe from the space between the cylinder and its casing to a small reservoir. The heated water thus obtained was conveyed to the boiler, compensating in some measure for the loss of power from causes already named. It is evident that if no means were taken to prevent it, the successive condensations of the steam in the interior of the cylinder would produce water, which in time would fill it. To remove this water, a pipe was inserted in the bottom of the cylinder, and conducted to a distance of at least thirty feet below it. It was necessary to take this so far down to counteract the force of the atmospheric pressure; as the pipe communicated with a vacuum, the water in the cistern, with which the eduction-pipe was connected, would be forced *into* the cylinder, unless the column of water in the tube or eduction-pipe was of sufficient length.

The air which found its way to the interior of the cylinder was ejected into the atmosphere through a pipe furnished with what was called a snifting-valve, opening upwards into a kind of cup containing water; the piston descending forced the air through this, the water surrounding it keeping it tight after the air escaped. The piston was rendered tight, and air prevented from finding its way to the interior of the cylinder, by a small quantity of water placed on its upper side, this supplied by a small pipe leading from the cistern above the cylinder. The pipe leading from the boiler to the cylinder was furnished with a cock, by which the supply of steam was regulated.

The operation of the engine, as thus constructed, is easily understood. On the steam being raised at a temperature of 212°, and the cock on the steam-pipe opened, the counterpoise—suppose this to be the weighted rod of a pump for withdrawing water from a mine—draws the piston to the top of the cylinder; the supply of steam is then shut off by turning the cock on the steam-pipe to its original position. The cold water is now admitted to the space between the cylinder and its casing, the steam under the piston being condensed; the atmospheric pressure on the upper side of the piston forces it downwards, drawing along with it the end of the beam, and raising the other, and also the water in the pump; the cold-water cock is then shut, and the steam opened. An equilibrium being thus restored on both sides of the piston, the counterpoise draws it up to the top of the cylinder; the cock of the pipe for withdrawing the hot water from the space around the cylinder is opened, and the water descends to the cistern; the cold-water cock is immediately opened, and the condensation being effected, the piston descends as before.

In the spring of 1712 Newcomen succeeded in obtaining a contract for drawing water from a mine at Wolverhampton. The account given by Desaguliers of the difficulties encountered in bringing this engine to work is very curious: "After a great many laborious attempts having been made, he at last made the engine work; but not being philosophers enough to understand the reasons, or mathematicians enough to calculate the powers and proportions of the parts, they very luckily found by accident what they sought for. They were at a loss for the pumps; but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the pumps, valves, clacks, and buckets, whereas they had but an imperfect notion of them before." The erection of this engine was the occasion of an improvement of great importance being accidentally discovered. The improvement consisted in a quicker means of obtaining a vacuum. As before described, the piston was kept tight by water playing on its upper surface; on the first trial of this engine, it made several strokes in quick succession. "After a search, they found a hole in the piston, which *let the cold water in to condense the steam in the inside of the cylinder*. The method of effecting the condensation was therefore changed; and effected henceforth by injecting cold water into the interior of the cylinder. The diagram in fig. 14 shows this arrangement: *a a* the cylinder, *b* the piston, *c* a pipe leading from the cold-water cistern, and provided with a cock to regulate the supply; the lower extremity of this pipe is inserted in the bottom of the cylinder, and the water is delivered in the form of a jet *d*, and, diffusing itself among the steam, the condensation is quickly effected; *e* the snifting-valve and pipe; *f* the pipe 30 feet long, for taking away the hot-water from the cylinder. This plan of obtaining a quick condensation suggested also a means of regulating the speed of the engine in cases where the weight to be lifted was variable, by throwing in a greater or less quantity of injection-water, thus producing a vacuum more or less perfect. Notwithstanding the very great improvements thus effected from time to time, the atmospheric engine at this stage of its progress was much restricted in its usefulness, and this from the unremitting attention which its operation demanded from the attendant. "When, for instance, the attendant opened the steam-cock, he was obliged to watch the descent of the piston, and at the instant when it was elevated to the proper height, it was to be again quickly shut, and at the same moment the injection-cock was to be opened. If the one did not follow the other, there resulted a great loss of vapour, or of effect; and this difficulty was further increased by the irregular production of the steam itself, from the varying intensity of the heat of the furnace

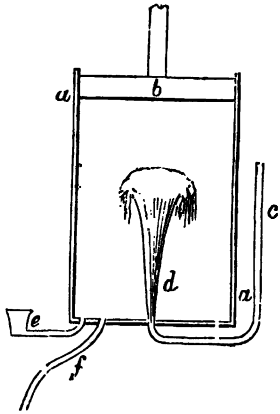

fig. 14.

newcomen [illegible]

After the injection had condensed the steam, and the piston was at liberty to descend, if the communication between the boiler and the cylinder was not opened at the precise instant when it had reached the limit of its downward movement, the immense weight on the piston, falling into the vacuum with a great velocity, would shake the apparatus to pieces. All this precision was required too from a mercenary attendant fourteen times every minute, at the hazard of the total destruction of the apparatus." It is obvious, then, that the further and more extended practical introduction of the engine depended on some method being discovered of making its movements self-acting. According to Desaguliers the honour of the invention of the self-acting movements is due to an idle boy of the name of Humphrey Potter, an attendant on the engine. The following is the statement: "It was usual to work with a buoy in the cylinder, enclosed in a pipe, which buoy rose when the steam was strong, and opened the injection-pipe, and made a stroke, whereby they were only able, from this imperfect mechanism, to make six or eight strokes in a minute, till a boy named Humphrey Potter, who attended the engine, added what is called a scoggan, a catch that the beam or lever always opened; and then it would go fifteen or sixteen strokes in a minute." "To scog," says a writer, in explanation of the term, "is a verb found in certain vocabularies throughout the north of England, implying to sculk; and this young gentleman, impelled by a love of idleness or play common to boyhood, and having his wits about him, after some meditation, devised this contrivance, by which so important an improvement was effected, and himself allowed the means of scogging for his own diversion." Whether this is the correct account of the origin of this improvement, it is difficult to ascertain; certainly the statement of Desaguliers has never been proved to be wrong. In the year 1718 an engine was erected having self-acting movements, termed "hand-gear," the invention of Mr. Henry Beighton, an engineer of Newcastle, and which consisted of a series of tappets operated on by the beam, and by which the various cocks were opened and shut as required. The following is a description of the means employed for this purpose: The entrance to the steam-pipe was covered with a sliding-valve placed inside the boiler; this valve was worked by a lever attached to the spindle of the valve which projected through the top of the boiler, as in fig. 15, where *a* is the steam-pipe, *b* the sliding-valve, the spindle of which passes through *c*, and is worked by the bent lever *d*. To this bent lever a horizontal one *e*, fig. 16, is connected; the other extremity is formed into a fork at *f*; a spindle joins the two extremities of the fork; and two stirrups, as at *g*, connected each side of the fork with an axle rotating on the centre *h*. This axle was made to move by the pins in the beam *n n* striking the ends of the spanners *k m*, which were firmly fixed in the axle *h*. On the axle, at a position between the two prongs, a lever called a *tumbling-bob* was fixed, having a Y-end, or two projecting arms *i i*, and a weight at the other. The injection-cock was opened and shut by the mechanism shown in fig. 17. Let *a a* be the beam corresponding to *n n*, in fig. 16, having projecting-pins which strike the end of the lever *d*, terminated with a toothed quadrant taking into a second quadrant, fixed on the spindle of the injection-cock. The following is the operation of the apparatus: on the beam *n n* falling, a tappet, or projecting-pin, strikes one of the spanners *k*; this turns the axle vibrating at *h*, and arms *i* striking the bar which joins the two prongs of the fork *ef*; this pulls forward the lever *e* towards the beam, and opens the steam-cock *b*, fig. 16. Simultaneously with the striking of the tappet on the spanner *k*, another tappet strikes the end of the lever *d*, fig. 17, and operating on the quadrants *fg*, shuts the injection-cock *h*. The piston is now drawn upwards by the counterpoise. On arriving within a short distance of the top of the cylinder, a tappet strikes the spanner *m*, fig. 16, and causes the tumbling-bob to fall over, moving, as before, the lever *e* from the beam; one steam-valve is thus shut, and by means of the tappets, lever, and quadrants, the injection-cock *h*, fig. 17, is opened. By means of this contrivance the atmospheric engine was rendered self-acting. Thus improved, the machine remained for a considerable period *in statu quo*. Minor improvements were from time to time introduced; but it was reserved for the celebrated engineer John Smeaton to bring it to as great a state of perfection as was possibly allowed by the nature of its principle. In fig. 18 we give a diagram illustrative of the general arrangements of an atmospheric engine, after the introduction of the self-acting movements of Beighton, and anterior to the improvements of Smeaton.

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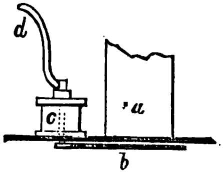


fig. 15.

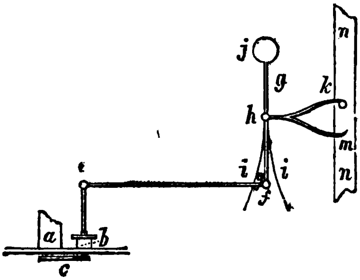


fig. 16.

Mr Henry Beighton

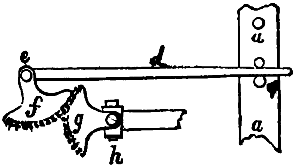


fig. 17.

In 1767, Smeaton was employed to construct an engine for the New River Company, and he availed himself of an opportunity of introducing several improvements. In calculating the proportions, on considering that the stoppage of water occurring at every stroke, and putting the piston, beam, and other appliances, from a state of rest to that of motion twice every stroke, resulted in a great loss of power, he determined to work the engine slower, putting on the piston all the load it would bear, working with larger pumps. In order still further to reduce the velocity of the column of water in the pump-barrel, he made the beam oscillate on a centre out of its true centre; the stroke of the piston being then nine feet, whilst that of the pump, which lifted thirty feet, was only six feet. This arrangement necessitated the employment of a long narrow cylinder, eighteen inches in diameter: with these arrangements he increased the load of the

the employment of a long cylinder Smeaton contemplated gaining other advantages, namely, "that every part of the steam being nearer the surface of the cylinder, would be more readily condensed; and, in consequence, that

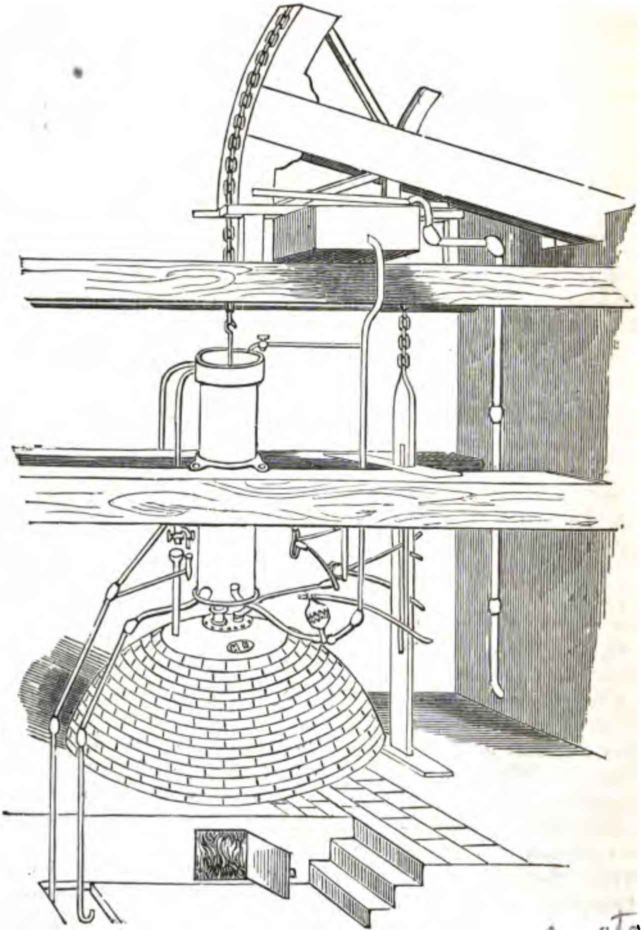


fig. 18.

Smeaton

a less quantity of injection-water would serve the cylinder, which would itself be more heated." Under these advantages Smeaton thought himself quite secure; "but how great," he writes, "was my surprise and mortification to find, that instead of requiring less injection-water than common, although the injection-pump was calculated to afford as much injection-water as usual, in proportion to the area of the cylinder, with a sufficient overplus to answer all imaginable wants, it was unable to support the engine with injection; and that two men were obliged to assist to raise the injection-water quicker by hand, to keep the engine in motion. At the same time the cylinder was so cold I could keep my hand upon any part of it, and bear it for a length of time in the hot well. By good fortune the engine performed the work it was appointed to do, as to the raising of water; but the coals by no means answered my calculation. The injection-pump being enlarged, the engine was in a state for doing business; and I tried many smaller experiments, but without any good effect, till I altered the fulcrum of the beam so much as reduced the load upon the piston from 10½ lbs. to 8¼ lbs. per inch. Under this load, though it shortened the stroke at the pump-end, the engine went so much quicker, as not only to raise more water, but to consume less coals; took less injection-water, the cylinder became hot, and the injection-water came out at 180° of Fahrenheit; and the engine, in every respect, not only did its work better, but went more pleasantly. This at once convinced me that a considerable degree of condensation of the steam took place in entering the cylinder, and that I had lost more this way by the coldness of the cylinder than I had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine. But in what degree this condensation took place under different circumstances of heat, and where to strike the medium, so as upon the whole to do the best, was still unknown to me. But resolving, if possible, to make myself master of the subject, I immediately began to build a small fire-engine at home, that I could easily convert into different shapes for experiments, and which engine was set to work in 1769." The result of the experiments conducted with this engine Smeaton carefully tabulated, and took as a guide to regulate his future practice. The engines of a large class which he afterwards erected fully verified by their performance the correctness of his assumptions, and evidenced the practical care with which he had, in this as in other matters, conducted his experiments. In 1772 he was employed to construct an engine at Long Benton Colliery, at Newcastle,—and in this he introduced the several improvements suggested by his experiments,—similar in construction to that introduced by Beighton; it was, however, "distinguished by juster proportions and greater nicety of detail than had yet been realised; and the innovations thus introduced were found to be highly beneficial in practice." The engine erected by Smeaton, and known as the "Chacewater Engine," was the most celebrated of his performances. We give, in fig. 19, a diagram showing the arrangements, derived from a plate in *Smeaton's Reports* (vol. ii. plate 11; published by Walton and Maberly, Paternoster Row). The diameter of cylinder was 72 inches, length of stroke 9 feet; making 9 strokes per minute with its full load of 51 fathoms of pump; capable of turning out per hour, from working barrels full 16¼ inches, 800 hogsheads of water, with a consumption of 13 bushels of coal, London measure, per hour. Calculated according to the modern formulæ, the power of this engine may be taken at 76 horses; but from Mr. Smeaton's statement, he estimated it at a higher rate. He says: "This engine, though not the largest that has been built, will be of considerably greater power than any I have seen; and, when worked at its full extent, will work with a power of 150 horses acting together; to keep which power throughout the twenty-four hours would require at least 450 horses to be maintained." Although there is nothing in connexion with the improvement of the atmospheric engine which can be said to be the invention of Smeaton, still the high praise is due to him of "giving the most perfect form and proportion to those materials supplied by his predecessors and contemporaries." "The improvements"—we quote from the *Artizan* treatise—"introduced by Smeaton chiefly resolve themselves into greater care in the construction of the

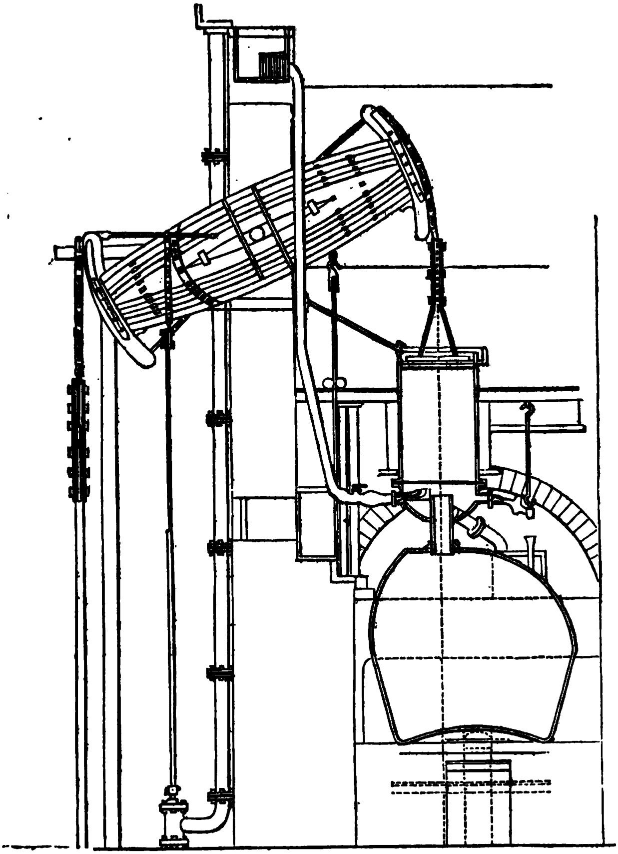


fig. 19.

Smeaton -

engines, and a better proportion and arrangement of the boiler; and involve neither the application of any new principle, nor any great expenditure of ingenuity. Before Smeaton's time, the manufacture of the engines was in the hands of very ignorant mechanics, who did not know the difference between power and force; and their perpetual aspiration was to make the piston exert a great force, without taking into account the velocity of the movement necessary to make it operate effectively. It was very rarely the case that the engine was adequately supplied with steam; and when an engine was found incompetent to its work, in consequence of this inadequacy, it was generally provided with a larger cylinder, which only aggravated the evil. Then the cylinders were very ill-bored; and the condensation from the water lying on the top of the piston, as well as from water escaping past it, was very considerable; while, at the same time, the piston rarely travelled a sufficient distance in the cylinder; and a great deal of steam was lost every stroke by filling a useless vacuity. The boilers, besides being too small, were generally badly set, the bottom being too far from the fire; and the firing was badly conducted, the coals being piled in a heap on the middle of the grate, instead of being spread evenly over it. The injection-cistern was generally set too low, by which means the water was not adequately dispersed within the cylinder; and the valve-gearing was for the most part so constructed that the regulator did not open fully, by which means the steam was throttled, and a heavy counter-weight was necessary to suck the steam into the cylinder, which of course had afterwards to be raised at an expenditure of power." The correction of these faults was left for Mr. Smeaton to effect.

Such as we now leave it, was the degree of perfection to which the steam-engine had arrived. The principles of its action apparently precluded the attainment of a higher degree of practical usefulness; and it remained for a brighter genius and a more original mind, than was possessed by any of those who had hitherto directed their attention to the subject, to thoroughly grapple with, and to understand, its defects; and by opening up a new path of discovery, to place the steam-engine, as a social power of rare value, in the high position to which its wonder-working powers has fairly entitled it.

* * *

CHAPTER II.

THE HISTORY OF THE INTRODUCTION OF THE MODERN STEAM-ENGINE.

In the year 1736, at the little town of Greenock on the banks of the Clyde, James Watt was born. Of a slender form, sickly appearance, retiring and bashful in his manners, and bearing with him no evidence of an intellectual capacity superior to his fellows, this youth, unaided by family wealth or station, or even by the adventitious aids of an early liberal education, was destined, during a long and active life, to be the means of introducing a power which aided this country materially during a time of difficulty and danger, and to leave behind him a name world-wide in its reputation.

When about sixteen years of age, he became acquainted with an obscure mechanic in Glasgow, who, "by turns a cutler and whitesmith, a repairer of fiddles and a tuner of 'spinnets,' was a useful man at almost every thing;" adding to this list of accomplishments "a knowledge of the construction of mathematical instruments and of 'spectacle-glasses,' he was dignified by the title of 'optician.'" To this individual Watt in his sixteenth year was apprenticed, chiefly, as is probable, more from the fact that it offered an easy calling suitable for his delicate health, than from any inducement it held out as that by which he could afterwards make a fair livelihood. After a short apprenticeship of less than two years, James Watt removed to London, where he succeeded in obtaining employment under a regular mathematical-instrument maker. Here he obtained that knowledge of business habits and processes which had been withheld from him in his earlier engagement. His stay in London was very limited; and probably from a severe cold which he caught while following his avocations, and the effects of which he felt for many years afterwards, he returned to his native town after an absence of little more than a year. He next endeavoured to raise a business of his own, and began to practise both in Greenock and Glasgow. In the latter place he met with an obstacle which threatened to put a sudden stop to his progress; this arose from the fact that he was not a "freeman," or "burgess," of the town. One spot, however, existed, within the boundaries of which all such absurd laws and regulations were inoperative and harmless for evil;—this was the "College of Glasgow." By the kind offices of some of the dignitaries, Watt was appointed mathematical-instrument maker to the university; and a room was allotted him within its precincts, in which he could carry on his avocations without molestation. Thus was the apparently untoward circumstance amply compensated for. And it is by no means idle to conjecture what would have been the results on the future prospects of the steam-engine had that absurd law not been in existence which drove Watt out of what might be looked upon as the open path of commerce, to take refuge in the place, of all others, the best fitted for, and offering the most eligible opportunities of, carrying on the series of experiments which by a fortuitous chain of circumstances were shortly presented to his notice; and by the successful prosecution of which he was destined to make himself so famous.

In the year 1759, in this situation, Watt had his attention directed to the subject of the steam-engine through the representation of Mr. Robinson, afterwards Professor of Natural Philosophy in the University of Edinburgh, and author of the well-known work entitled *Elements of Mechanical Philosophy*. The scheme proposed had reference to the moving of wheel-carriages by the aid of steam; but in consequence of Mr. Robinson leaving college, it was abandoned. Two years afterwards, however, Watt again returned to the subject, and instituted some experiments with a Papin's digester; and formed a sort of steam-engine "by fixing upon it a syringe one-third of an inch in diameter, and furnished," says Mr. Watt, whose own account we now quote, "also with a cock to admit the steam from the digester or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air, by which the steam contained in the syringe might escape. When the communication between the cylinder and digester was opened, the steam entered the syringe; and by its action upon the piston, raised a considerable weight (15 lbs.), with which it was loaded. When this was raised as high as was thought proper, the communication with the digester was shut off, and that with the atmosphere opened; the steam then made its escape, and the weight descended. The operations were repeated; and though in this experiment the cock was turned by hand, it was easy to see how it could be done by the machine itself, and make it work with perfect regularity. But I soon relinquished the idea of constructing an engine upon this principle, from being sensible it would be liable to some of the objections against Savery's engine, namely, from the danger of bursting the boiler, and the difficulty of making the joints tight; and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston."

Two years after relinquishing his experiment, as above stated, his attention was again directed to the subject, by a model of a steam-engine on Newcomen's plan, belonging to the Natural Philosophy class, being placed in his hands to be repaired (1763-4). At first directing his attention to the dry matter-of-fact details of the task he had intrusted to him, his active mind received a new impulse from the result of one or two trials of the engine, and he directed the full energy of his intellect to master the principle of the machine, and to ascertain the cause of its defects as an economical prime-mover. In conducting the experiments, two things attracted his attention; the first was the great loss of steam from the condensation caused by the cold surface of the cylinder; secondly, the great quantity of heat contained in a small quantity of water when converted into steam. If a quantity of water is heated in a close boiler some degrees above the boiling-point, and the steam suffered to escape suddenly, the temperature of the boiling-water remaining in the boiler will be reduced to the ordinary boiling-point. The steam, however, which escaped, although carrying off all the excess of heat, would, if condensed, form but a small quantity of water. The saving of this heat was therefore a matter of the highest importance. The loss of steam occasioned by the alternate heating and cooling of the cylinder was sufficient to fill the cylinder three or four times, and to work the engine. "By means of a glass tube inserted into the spout of a tea-kettle, he allowed the steam to flow into a glass of cold-water until it was boiling hot. The water was then found to have gained nearly a sixth part by the steam which had been condensed to heat it, and he drew the conclusion that a measure of water converted into steam can raise about six measures of water to its own heat, or eighteen hundred measures of steam can heat six measures of water." "Hence he saw that six times the difference of temperature, or fully 100 degrees of heat, had been employed in giving elasticity to steam, and which must all be subtracted before a complete vacuum could be obtained under the piston of a steam-engine." "Being struck," says Mr. Watt, "with this remarkable fact, and not understanding the reason of it, I mentioned it to my friend Dr. Black, who then explained to me his doctrine of latent heat, which he had taught some time before this period (summer of 1764); but having been occupied with the pursuits of business, if I had heard of it I had not attended to it, when I thus stumbled upon one of the material facts by which that beautiful theory is supported." In making his experiments, Watt found that the boiler of the model, although large enough according to the standard then in use, did not supply steam fast enough for the wants of the engine, which had a cylinder two inches diameter and six inches stroke. The vacuum too was very imperfect, yet required a large quantity of injection-water to effect it. These defects he attributed to the fact that a small cylinder consumed a greater quantity of steam than a larger one, in consequence of the condensation caused by the increased surface in proportion to its capacity. This defect he sought to remedy by substituting a cylinder made of materials which would conduct heat more slowly than brass, of which the model cylinder was made. For this purpose he constructed one of wood soaked in linseed-oil, and baked dry. This, however, was a failure, for in addition to its want of durability, an essential feature in practice, it was found to condense the steam as much as before. The principal loss sustained was, therefore, by the alternate heating and cooling of the cylinder; and the conviction was forced upon him that the grand secret lay in being able to effect the condensation of the steam without cooling the cylinder. To the attainment of this Watt directed his whole energies, and in the year 1765 the felicitous idea struck him, "that if a communication were opened between a cylinder containing steam, and another vessel were exhausted of air and other fluids, the steam, as an expansible fluid, would immediately rush into the empty vessel, and continue to do so until it had established an equilibrium; and if that vessel were kept very cool by an injection or otherwise, more steam would continue to enter until the whole was condensed." This brilliant idea was soon put to the test of experiment and found correct; and thus was solved the great problem which had for so many years perplexed and baffled his predecessors. It is said, that as soon as this happy thought had been realised, all the train of details necessary to carry it into efficient practice followed in rapid succession; and that not for a moment had he any hesitation in conceiving the rapid and immediate perfecting of the whole machine. In carrying out the idea into practice, the first difficulty that presented itself to the mind of Watt was, doubtless, a means of relieving the condenser from the accumulated water which would result from the successive condensation effected in it. This might, of course, be drawn away by the simple force of gravity, by using a pipe thirty feet long, as in Newcomen's engine. This plan, however, would not be effectual for removing the uncondensed steam, or the air that might find its way into the condenser. Some other plan was therefore desiderated. Watt proposed and adopted a pump which would draw off the contents of the condenser, this pump being worked by the engine itself. This constituted another step towards the perfecting of the mechanism: others rapidly followed. The next improvement was surrounding the cylinder with a casing, by which the heat would be retained. This of itself, however, would not effect the desired end: he therefore, to prevent the action of the cold atmosphere on the upper surface of the piston and on the interior surface of the cylinder, which would necessarily be exposed on its descent, closed the top of the cylinder with a close-fitting cover, in the centre of which the piston-rod worked through an aperture rendered tight by what is termed a "stuffing-box." The necessity of adopting the next expedient suggested to him was thus made obvious; and in place of the power of the atmosphere he employed the "*elasticity of the steam from the boiler to impel the piston down the cylinder.*" By this arrangement the method adopted of keeping the piston tight, by having water on its upper surface, was precluded from use; and instead, Watt adopted a hemp-packed piston lubricated with tallow. Thus, by successive improvements, the atmospheric engine was changed into a "steam-engine."

Before *illustrating* the improvements introduced by Watt, we propose to trace further the points connected with its history. Although the claim of Watt to the originality of the idea of separate condensation is now generally, if not universally, acknowledged, still it is but right to notice that of another party to this high honour. The claim is put forward by Mr. Hornblower, a rival and contemporary of Watt, in Gregory's *Mechanics* (vol. ii. first edition, p. 362), in the following statement: "About the time that Mr. Watt was engaged in bringing forward the improvement of the engine, it occurred to Mr. Gainsborough, the pastor of a dissenting congregation at Henley-upon-Thames, and brother to the painter of that name, that it would be a great improvement to condense the steam in a vessel distinct from the cylinder where the vacuum was formed; and he undertook a set of experiments to apply the principle he had established; which he did by placing a small vessel by the side of the cylinder, which was to receive just so much steam from the boiler as would discharge the air and condensing water, in the same manner as was the practice from the cylinder itself in the Newcomenian method, that is, by the snifting-valve and sinking-pipe. In this manner he used no more steam than was just necessary for that particular purpose, which, at the instant of discharging, was entirely uncommunicated with the main cylinder, so that the cylinder was kept constantly as hot as the steam could make it. Whether he closed the cylinder, as Mr. Watt does, is uncertain; but his model succeeded so well as to induce some of the Cornish adventurers to send their engineers to examine it; and their report was so favourable as to induce an intention of adopting it. This, however, was soon after Mr. Watt had his act of parliament passed for the extension of his term; and he had about the same time made proposals to the Cornish gentlemen to send his engine into that county. This necessarily brought on a competition, in which Mr. Watt succeeded; but it was asserted by Mr. Gainsborough, that the mode of condensing out of the cylinder was communicated to Mr. Watt by the officious folly of an acquaintance, who was fully informed of what Mr. Gainsborough had in hand. This circumstance, as here related, receives some confirmation by a declaration of Mr. Gainsborough, the painter, to Mr. More, late Secretary to the Society for the Encouragement of the Arts, who gave the writer of this article the information; and it is well known that Mr. Gainsborough opposed the petition to parliament through the interest of General Conway." Much doubt is, however, thrown upon the accuracy of this statement, from the fact, that Mr. More, the gentleman alluded to, in a trial, Bolton *v.* Bull, distinctly stated on oath, that he "never saw the principle laid down in Mr. Watt's specification either applied to the steam-engine previous to his taking it up, or ever read of any such thing whatever." It is not now an easy matter to reconcile this contradiction with the statement of Mr. Hornblower. Having given a brief statement regarding the claim made to the honour of the discovery of separate condensation, we now proceed to note the various steps in the history of the introduction of Watt's steam-engine.

Having satisfied himself as to the correctness of his principle, Watt proceeded to test it still further by the aid of a model on a large scale. The cylinder of this model was 9 inches diameter, and the piston-rod was attached to a balanced beam. An accident, however, occurred, which, along with his want of means, as well as of time to prosecute his experiments, brought his labours to a close. Having taken up the practice of a land-surveyor and engineer, and his time being pretty fully occupied, the invention lay dormant on his hands for three or four years. His silence on the matter doubtless proceeded from a variety of causes, the principal of which was, likely, the fact, that as a fair trial could only be given to his engine on a large scale, the risk of bringing it out would be too great, the apparatus required being exceedingly costly. From Watt's practice as an engineer, he became acquainted, however, with the celebrated Dr. Roebuck, an enterprising English gentleman resident in Scotland. An able practical chemist, he had succeeded in discovering a method of making sulphuric acid at a comparatively low cost; and being possessed of business habits and qualities of the first order, he succeeded in establishing at Prestonpans, near Edinburgh, a manufactory, in which the process was carried out on a large scale. The profits accruing from this establishment were such, that he gave up the practice of his profession, and confined his attention to carrying out commercial projects on a large scale. He founded the celebrated iron-works at Carron, which, as a project, were highly successful. Urged by his success in this undertaking, he leased the estate of Kinneil, a few miles from Carron, and which contained extensive beds of coal. While carrying on his operations there with the same energy which characterised his other proceedings, he became acquainted with Watt, who, no doubt, struck by his ability and business habits, looked upon him as one in every respect calculated to aid the undertaking of bringing the steam-engine into practice, and accordingly confided to him the secret of his discovery. Dr. Roebuck consented to bear the expense of conducting trials on a large scale; and Watt forthwith proceeded to construct ations and improvements succeeded each other, until at last the engine was brought to a state of comparative perfection—so far, at least, as could be attained, from the imperfect style of workmanship then available. The engine was tried at a coal-mine on Dr. Roebuck's estate; and such was the satisfactory nature of its operations, both as regarded the great saving of fuel and the water used for condensation, that Dr. Roebuck was satisfied as to its powers and capabilities, and closed with Watt, supplying the necessary funds to take out a patent, and to establish a manufactory for the production of the engines; the terms of partnership being, that the money for the above purposes was to be found by Roebuck, he obtaining two-thirds of the profits. On these terms Watt proceeded with his patent, which was taken out in 1769, and of which the following is the specification. It was not accompanied with drawings or sketches of any kind.

"My method of lessening the consumption of steam, and consequently fuel in fire-engines, consists of the following principles:

"First: That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it: first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and thirdly, by suffering neither water nor any other substance colder than the steam, to enter or touch it during that time.

"Secondly: In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them: these vessels I call condensers; and whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies.

"Thirdly, whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly, instead of using water to render the piston or other parts of the engines air and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver and other metals in their fluid state.

"And the said James Watt, by a memorandum added to the said specification, declared, that he did not intend that any thing in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

After Watt had obtained his patent, he proceeded to perfect the details of his engine. From the bad workmanship which he had to contend with, his difficulties were of a serious kind; that which harassed him most loss by friction. But another obstacle was about to be thrown in the path of progress, and which at one time bade fair to utterly ruin Watt's prospects of receiving a pecuniary reward for his great labours: this was the bankruptcy of Dr. Roebuck. The coal-fields of Kinneil, instead of throwing a golden shower of profits into his lap, were the means of bringing him to ruin. The quality of the coal was far beneath his expectations; and the difficulties of getting even an inferior produce daily increasing, he was necessitated, from the drain on his capital, to part with, from time to time, his share in other lucrative concerns with which he was connected: and thus, by degrees, the very perseverance which distinguished him in better times, tended, by its prompting him to preserve in this instance the wreck of his once great fortune, to sink him still further into difficulties, until at last irretrievable ruin overtook him; and he was obliged to enter into a negotiation to give up his connexion with Watt, from which he might have reaped a harvest greater than he had gathered from all his previous projects, lucrative as they were, put together. But this apparently untoward circumstance was the means of ultimately placing Watt in the eminent position which he afterwards occupied; so true, as we often find it, is the saying, that "man's extremity is God's opportunity."

The party with whom Roebuck negotiated for a transfer of his rights in the patent of Watt, was the celebrated Matthew Bolton, of Soho, near Birmingham; a man whose name will always be handed down to posterity in conjunction with his more celebrated compeer. The transfer was effected, and a partnership formed between Bolton and Watt. In character the very opposite in many respects of Watt, Bolton was possessed of rare business talents, an extensive acquaintance with business forms, and having that indomitable spirit of "perseverance which insures success" in an eminent degree; these, united with a degree of courage in prosecuting his engagements in the face of difficulties, rendered him a fitting coadjutor for the retiring and unambitious Watt. "To a man like Watt," says an able writer, "so unfitted, from feeling and habit, to stand alone, nothing could have been more auspicious than his gaining the protection of two such men in succession (as Roebuck and Bolton). Obstacles were seen by either only to be surmounted; and they both possessed, in an eminent degree, the master-art of infusing into all around them a portion of their own matchless energy. Projectors themselves, they were considerate of his feelings, and knew how much the flow of thought in irresolute or hesitating genius is quickened by the kindness and condescension of a patron. Assisted by their experience, and animated by their generous approbation of what he had already achieved, he was roused and carried onward to impart greater perfection to his mechanism."

At the period of the transfer of Roebuck's rights in the patent to Bolton, Watt was engaged in surveying in the north of Scotland. Shortly after the death of his wife happening, he was induced to accept of the invitation of his partner, and to take up his abode at Soho. This now celebrated locality, at the time of Bolton's purchase of it, is described as a "barren heath, on one black summit of which stood a naked hut, the habitation of a warrener." A little iron mill was subsequently erected, and round the hill there rippled a small stream. Bolton, with the quick perception which distinguished him as a man of business, saw at once the fabrication of those articles for which Birmingham has been so long famed. By collecting the water, he obtained sufficient quantity to move the water-wheel, which, in its turn, gave motion to an almost endless variety of manufacturing machines and tools.

Watt was now in a position for prosecuting his labours with vigour, and surrounded by those mechanical appliances, without which the attainment of perfection in the working details was hopeless. An engine was accordingly erected; and many Cornish adventurers, greatly interested in the success of the engine, on invitation, examined its operation. In their report they gave a favourable opinion as to the saving of fuel effected by it. Some years of the term for which the patent was valid had, however, expired; and fearful that its whole period would pass over before pecuniary results accrued, so as to afford a profit, or to reimburse the large expenses which had been gone to in perfecting the engine, Watt, at the suggestion of Bolton and his other friends, applied to parliament for an extension of his patent. This, after some opposition, was granted for the term of twenty-five years, dating from the time of the grant, namely 1775. This extension was no doubt deserved, no less a sum than 50,000*l.* having been expended in the manufacture of the engines by the firm before any return was realised. Having thus secured for a lengthened period the profits which might accrue from the sale of the engines, Watt was now in a position to introduce his machine with every advantage to the public. In this he was materially assisted by the admirable commercial arrangements of Bolton, who, after the grant of extension, became a partner with Watt in the manufacture of the machines; thus sharing the profits on this head, as well as those derived from a monopoly of the principle. "Had Watt," says Playfair, "searched all Europe, he could not have found another man so calculated to introduce the invention to the public in a manner worthy of its importance."

The most public and open inspection of the engines at work was invited, and every means taken to afford just opportunities of ascertaining their value. A congress of mechanics and scientific men was convened at Soho, and an elaborate series of trials made and comparisons instituted between its working capabilities and one on the principles of Newcomen of the best construction, in order to show the superior working capabilities of the new engine: these were manifest to all. But still further to place the merits of the machine on a basis which would satisfy all as to the character of its claims, the patentees issued the following: "All that we ask from those who choose to have our engines, is *the value of one-third part* of the coals which are *saved* by using our improved machines, instead of the old. With our engine, it will not, in fact, cost you but a trifle more than half the money you now pay to do the same work, even with one-third part included; besides an immense saving of room, water, and expense of repairs. The machine itself which we supply is rated at that price which would be charged by any *neutral manufacturer* of a similar article. And to save all misunderstanding, to engines of certain sizes certain prices are affixed." To aid in the introduction of the new machines, Bolton and Watt took old atmospheric engines off the hands of those who wished to lay down the improved form, and this frequently at a rate above their value.

Again, in estimating the power of their engines, or calculating the work which each could perform, Bolton and Watt, instead of placing the estimate of a horse's work at a low figure, and thus in the same proportion increasing the power of their engine, they actually increased the power of a horse's work to one-third. Smeaton had valued the work done by a strong horse as equal to lifting a weight of 22,000 pounds one foot high in a day; Bolton and Watt estimated at 33,000. But more than this, they stated that their engines were "calculated so, that they will raise 44,000 pounds one foot high with a bushel of coals; and when we say our engines have the force of five, ten, or more horses, we mean and guarantee that they will lift 44,000 pounds for each horse-power." On these terms, an engine which, according to Smeaton's estimate, was equal to twenty horses, was, according to Bolton and Watt, only equal to ten; thus giving the purchasers of the new engine an advantage of 100 per cent in value for no increase of cost.

Thus placed before the public on terms so highly liberal, the invention made rapid progress in public favour; and some idea of the profits accruing may be derived from the fact, that at Chacewater mine, Cornwall, the saving of fuel effected was equal to 6000*l.* annually; 2000*l.* of revenue from this one source being drawn by the firm.

The manufacture of the engines increased with such rapidity, that the original establishment at Soho was found too limited in its dimensions for the great quantity of work now flowing into the factory. Another was therefore constructed in the near neighbourhood, in which the operations could be carried on with a high degree of concentration, so essential to the turning out of work rapidly and efficiently. "We are," writes Bolton to the celebrated Smeaton, "systematising the business of engine-working; we are training workmen, and making tools and machines, to form the different parts with more accuracy and at a cheaper rate than can possibly be done by the ordinary methods of working. Our workshops will be of sufficient extent to execute all the engines which are likely to be soon wanted in this country; and it will not be worth the expense for any other engineer to erect similar works, for that will be like building a mill to grind a bushel of corn." The expenditure thus occasioned to the firm was not thrown away: a body of expert workmen was soon organised.

Having thus brought up our historical notes in connexion with Watt's engines to the contemplated point, we are prepared to proceed to the illustration of the successive steps of his invention, and of those beautiful contrivances which emanated from his mind.

The diagram in fig. 20 will illustrate the arrangements of parts of the early engines introduced by Watt for pumping the water from mines. Let *a* be the cylinder, in which the piston *b* works a rod passing through a steam-tight stuffing-box *c*; the cylinder is surrounded by an external casing *dd*, into the space formed by which the steam enters from the boiler through the pipe *e*. By opening the valve w, the steam is introduced to the pipe beneath the cylinder, and introduced into its interior through the aperture *f*. By opening the valve *g*, the steam is allowed to pass down to the interior of the condenser *h*. In this diagram the piston-rod is supposed to be attached to the end of the great beam which works the mine-pump, and the valves to be worked by mechanism, which we shall figure afterwards.

Before starting the engine, the air was extracted from the various parts. This was effected by opening the valves, and allowing the steam to flow into all the vessels and pipes; the air is thus forced down the pipe to the condenser *h*, and through the valve which connects this with the air-pump *i*.

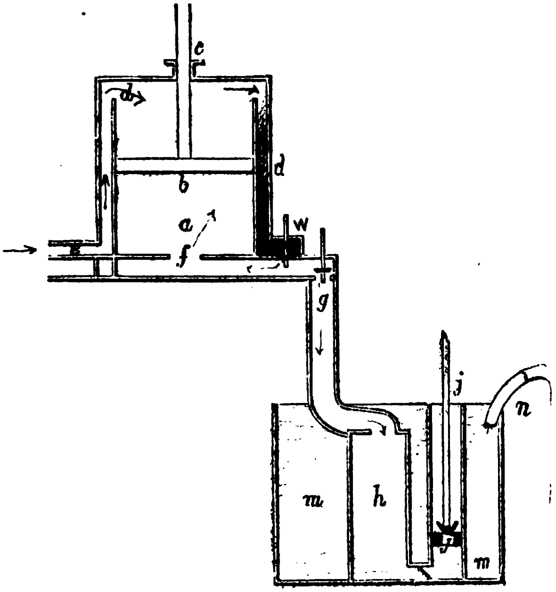


fig. 20.

The valve w is then shut, thus preventing more steam from entering the cylinder *a* through the aperture *f*; at the same time the steam in the condenser *h* is condensed by the cold water which surrounds it, and supplied to the cistern *m m*, in which it stands, by the spout *n*, supplied by a common force-pump worked by the great beam. The vacuum being thus formed beneath the piston *b*, the pressure of the steam, which has free access to the upper side of the piston, forces it downwards to the bottom of the cylinder. By the action of the beam, the air-pump piston is pulled upwards, and the water withdrawn from the condenser *h*. By the valve mechanism, the valve *g* is shut, and the valve w opened; steam is thus introduced beneath the piston, and an equilibrium being established between both sides, the counterpoise at the end of the great beam draws up the piston to the top of the cylinder; the air-pump is thus depressed, and the portion of condensed water lying in the lower part of the barrel passes through the clack or valve in the piston; the mechanism of the valve then shuts the valve w, and opens *g*; this taking place on the piston *a* reaching the top of the cylinder, the steam below the piston rushes through the valve *g* to the condenser, and a vacuum being formed as before, the piston is forced by the pressure of the steam on its upper side towards the bottom of the cylinder. The opening and shutting of the valves w and *g* was effected by simple mechanism, as follows.

Let *a*, fig. 21, be the spindle of the valve w admitting steam to the cylinder, and *b* that of the valve g admitting the steam to the condenser; these are connected by a joint to levers moving on the centres *c c*; *h h* is the plug-frame, having studs or projecting pins *o n*; these strike the handles or levers which are fixed on the rod *i i*, and to which the levers *r p* are fixed, actuating the levers *d e*, and lifting or depressing the valves *a b*; *s* is the counterbalance weight which acts the tumbling bob in Beighton's valve gearing already noticed. The condenser, in its original form as introduced by Watt, consisted of a series of thin copper pipes communicating with each other, and placed in a cistern filled with cold water: in some instances flat copper pipes were used; the object, in both cases, being to present as great a surface as possible to the action of the cold water, and to effect a rapid condensation. Notwithstanding many drawbacks attendant upon this plan, it was considered an economical one, inasmuch as a comparatively small power was required to work the pump for withdrawing the air and condensed water. To receive a quick condensation by this method, it was indispensable to have a large amount of surface exposed to the cold water; this necessitated condensers of such size, that Watt was at last obliged to return to a plan which he had adopted while in Scotland during his trials under Roebuck, of condensing the steam by introducing a jet of cold water into the condenser. The clumsy outer casing was, after repeated trials, found to be possessed of inconveniences; Watt therefore discarded it, and adopted a plan of intercasing composed of thin sheet-iron, the space being only one inch and a half between it and the cylinder; this space was supplied with steam by a pipe leading from the main steam-pipe. This arrangement involved a radical change in the method of distributing the steam to the cylinder. The details of the new construction may be gathered from the diagram in fig 22.

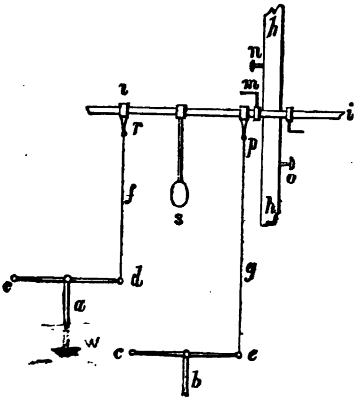


fig. 21.

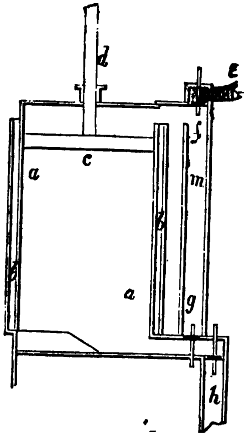


fig. 22.

Let *a a* be the cylinder, *b b* the outer casing, *c* the piston, *d* the piston-rod, *e* the steam-pipe leading from the boiler, *f* the "steam-valve," *g* the "equilibrium-valve," and *h* the "eduction-valve" in the pipe leading the steam to the equilibrium-valve. Supposing the piston at the top of the cylinder, the equilibrium-valve is closed, and the steam-valve *f* and eduction-valve *h* opened; the steam from below the piston rushes through *h* to the condenser, and a vacuum is formed; the steam pressing on the upper side of the piston, it is forced downwards. On reaching the bottom, the steam-valve *f* and eduction-valve *h* are closed, and the equilibrium-valve *g* opened; this allows the steam to gain access to the under side of the piston, as well as to its upper side; an equilibrium of pressure is therefore formed, and the counterpoise pulls the piston to the top, the steam above it flowing through the equilibrium-valve. In this form of engine there is alternately steam and a vacuum on the under side of the piston, the steam being always above the piston.

About the year 1780, Watt introduced another modification, having for its object the attainment of a more perfect condensation: this he proposed to effect by having a perpetual vacuum below the piston, while there was alternate vacuum and steam-pressure above it; thus, on the piston having accomplished its loaded stroke, that is, from top to bottom, the vacuum being made, the whole of the time in which the piston was ascending might be occupied in freeing the cylinder from the air and steam. This idea was carried out by aid of the following arrangements.

In fig. 23, *aa* is the cylinder, *b* the piston, *c* the "steam-valve," *d* the steam-pipe, *e* the "eduction-valve," *ff* the eduction pipe leading to the condenser, *g* the steam-port leading to the upper side of the piston. On the piston reaching the bottom of its stroke, the steam-valve *c* was shut, and the eduction-valve *e* was opened; the steam from the upper side of the piston rushed through *g* and *e*, and down the eduction-pipe *f* to the condenser; the vacuum was thus made on both sides of the piston, the counterpoise pulling the piston to the top; the eduction-valve remaining open during its ascent, a longer time was thus given to the formation of the vacuum above the piston. The advantages expected to flow from this ingenious arrangement did not, however, exist: it was found that in practice the condensation was so quickly performed, in fact almost instantaneously, that the longer time produced no better vacuum; and the cylinder approximating so much to the coolness of the condenser, a considerable quantity more of steam was required. Leakage to some extent also resulted from the arrangement. This arrangement of engine was therefore abandoned.

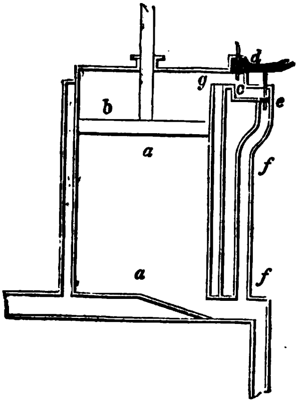


fig. 23.

We now come to notice an important improvement in the working of steam-engines, which the fertile genius of Watt added to the list of his brilliant inventions: this improvement was that of working the steam expansively. The patent for the expansive steam-engine was taken out in 1782; but the attention of Watt had been directed to the principle many years before; in 1769 he wrote to Dr. Small, as to a "method of still doubling the effect of steam, and that tolerably easy." Many matters, however, diverted his attention from this important point; and it was not until the above date that he took steps to introduce an engine in which the principle was carried out. The due understanding of its *rationale* is so important to the student of the steam-engine, that we propose entering into its consideration at some length.

Where steam is admitted to press on the top of a cylinder, during the whole of its descent the piston will move downwards with an accelerating velocity, which, if not checked, will be of such amount as materially to damage the mechanism. An able authority supposes that the value of the expansive principle was made known through the result of some trials which were instituted for the purpose of moderating the velocity of the piston, and consequently the shock as the piston reached the bottom of the cylinder. In Newcomen's engine he supposes this to have been effected by shutting the injection-cock earlier; and in Watt's condensing-engine, by shutting "the steam-valve at such a period of the stroke as would prevent the catch-pins from striking." This shutting off the steam-communication from the boiler, at a certain part of the stroke of the piston, allowing the steam to expand as the piston descends, constitutes the principle of the method of working expansively. By the action of the well-known law of pneumatics (see volume on *Natural Philosophy* in this series), the pressure of the steam on the piston decreases as the space increases into which the steam has liberty to expand itself; thus if the steam is cut off at one-fourth of its stroke, the pressure will, at the end of the stroke, exert only a force of one-fourth of its original pressure. By thus decreasing the power, a simple method of equalising the tendency to an accelerated motion was attainable. In addition, however, to this advantage, a still greater one resulted from the adoption of the principle in the economisation of steam, and the consequent saving of fuel. If steam of the temperature of 212° "flows into a cylinder six feet long, until the piston has moved eighteen inches downwards, when this quantity has expanded into double its former volume, and in doing so has pressed the piston to the middle of the cylinder, it will exert a pressure of not more than 7 pounds on each square-inch area of the piston. When the piston has been depressed another eighteen inches, the vapour will have expanded into three times its original bulk, and will then urge the piston downwards with a force of not more than 4⅔. [illegible]? pounds on each square inch; and when it has reached the bottom of the cylinder, and expanded into four times its original bulk, it will 3½. not exert a greater energy than about [illegible]? pounds on each square inch. If now we calculate the varying power of the steam from the commencement to the termination of its stroke, beginning with a force of 14 pounds, 3½ (and ending with [illegible] pounds, it will have exerted an average pressure of nearly 8¼ pounds on each square inch of the piston. But if the vapour had been permitted to flow freely into the cylinder as fast as the piston descended, it would have pressed it with a force of 14 pounds during the entire stroke of the piston. We thus see that one foot and a half of steam, acting expansively, has pressed 8¼ pounds through six feet; while six feet of steam, operating with its energy uniform and unimpaired, has only carried 14 pounds through six feet; thus showing that more than one-half of the whole steam has been saved by making it act expansively.

"Although the saving of steam is very considerable by making it work expansively, the power of the engine is reduced; thus, where the steam is cut off at one-fourth of the stroke, while the efficacy of the steam is increased four times,—that is, one-fourth the quantity of steam will complete the stroke,—the power is diminished nearly one-half. In engines worked expansively, therefore, the size of cylinder must be increased in proportion to the extent to which the expansive principle is carried. But although the engine is made larger to do the same quantity of work, this work will be done with a less consumption of fuel: this is obvious from the consideration, that at whatever point the steam is cut off, so much steam is saved; and that the steam, although it exerts a gradually decreasing force on the piston, still exerts a power of some extent, which power, whatever may be its amount, is gained without any expenditure of steam. To carry out the system of expansive working most conveniently, it is best to use steam of a pressure considerably higher than that of the atmosphere: unless this pressure is considerable, expansion cannot be carried out to any great extent with advantage; for if steam of a low pressure were used, the ultimate tension would be reduced to a point so nearly approaching that of the vapour in the condenser, that the difference would not suffice to overcome the friction of the piston, and a loss of power would be occasioned by carrying expansion to such an extent. It is clear that in the case of engines which carry expansion very far, a very perfect vacuum in the condenser is more important than it is in other cases." The advantage of applying steam expansively will be seen by an inspection of the following table: if the steam is cut off at one-half of its stroke, the performance of the engine will be multiplied 1·7 times; at

$\frac{1}{3}$	2·1	$\frac{1}{6}$	2·8
$\frac{1}{4}$	2·4	$\frac{1}{7}$	3·
$\frac{1}{5}$	2·6	$\frac{1}{8}$	3·2

Watt effected the cutting off of the steam at any desired point by merely altering the position of the tappets or projecting pins in the plug-frame, by which the valves were actuated upon at the proper time. As the motion of the piston was necessarily variable when the expansion principle was adopted, Watt contrived several ingenious mechanical combinations, by which the effect of the engine on the work it had to perform was uniform; he, however, did not apply these to any great extent, as he employed steam a little greater in pressure than that of the atmosphere, and cutting off only at one-third or one-fourth, according as circumstances dictated.

The reader desirous of becoming acquainted with these further evidences of Watt's inventive talent, will find several plans figured, by which this uniformity was obtained, in Stuart's *Descriptive and Historical Anecdotes of Steam-Engines*. We proceed to the consideration of more interesting and important matters in connection with the inventions of Watt.

Under the new arrangements it was a matter of importance to ascertain the state of the vacuum in the condenser and cylinder; for on the perfection of this obviously depended the efficiency of the engine. In order to ascertain this, Watt applied a mercurial barometer, having a connection with the inside of the pipe leading to the condenser; and another barometer was placed in connection with the boiler. The rise and fall of the mercury in the barometer attached to the condenser indicated the degree of exhaustion which had been made in it; and by the same operation in the barometer attached to the boiler, he had a measure of the pressure of steam acting in the piston: from the data thus obtained, he was able to calculate with considerable precision the amount of power given out by the engine. He afterwards, for this purpose, introduced a highly-ingenious invention which he termed the *indicator;* a diagram of which we now append, in order to show the nature of its operation. A small cylinder *b*, fig. 24, truly bored, is fixed on the cylinder-cover, having connection with its interior: a small piston *c* works in the cylinder *b*, the spindle or rod is continued upwards, its head terminated by a pointer, which is placed along a scale *d;* round the lower part of the spindle of the piston a spiral spring is coiled, one end of which is fixed to the piston, the other to a small bracket. The upper side of the piston is open to the air, the lower is open to the cylinder. The zero point of the scale is so adjusted, that the pointer will point to it when the cylinder is filled with air; and the pressure on both sides of the piston of the indicator is equal. On a vacuum being made in the steam-cylinder, the piston of the indicator is forced downwards; and the spring being thus put in a state of tension, the pointer will indicate the different points in the scale, corresponding to the degree of vacuum in the cylinder. When the cylinder becomes filled with steam, the piston of the indicator rises, and it falls again on the vacuum being made. Thus the power of the engine at any period of its stroke is faithfully transferred to the piston of the indicator, and by this means the power of the engine is estimated. In a future chapter we shall describe the modern indicator, and the means by which it is made to record on paper the working capabilities of the engine to which it is attached.

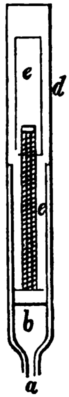


fig. 24.

We give a diagram, in fig. 25, illustrative of the arrangements of Watt's single-acting pumping-engine, as adopted at this period. At the present time the principle of this engine is still the same: the modifications in the details, arising from greater perfection in workmanship, although tending to give an appearance of greater elegance to its form, have not been extended to alteration of its principle of action. To such a high state of perfection did Watt bring it, that an eminent authority states that a pumping-engine "made after Watt's primitive type, would, with an equally effectual boiler, and an equal means of clothing and expansion, do about the same amount of duty as the best of the modern construction."* We have already detailed the method of action of this engine, so that we deem a further explanation unnecessary; a literal reference to its parts, and a few words as to the method of "working the engine," may, however, be useful. The cylinder is indicated by the letters *aa*, *b* the piston, *d* the piston-rod, attached to the end of the working beam *e e* by a chain passing round the quadrant (see p. 84, fig. 164, treatise on *Mechanics and Mechanism*, in this series, companion volume to the present); *ff* the plug-frame for working the valves by the tappets and levers as shown; *g* the equilibrium-pipe; *h* the condenser; *i* the air-pump; *j* the cold-water cistern; *k* the hot-water cistern. In commencing to work the engine, the first operation is expelling the air from the interior of the cylinder *a a:* this is effected by relieving the catches of the steam, equilibrium, and eduction valves; these being actuated by weights attached to them, are opened, and steam is thus admitted to all the internal parts, as cylinder and equilibrium-pipe. The first effect of this is to condense the steam by coming in contact with the cold surfaces of the engine; after the cylinder *a a* becomes hot, the steam finally issues through the "snifting-valve" placed at the foot either of the

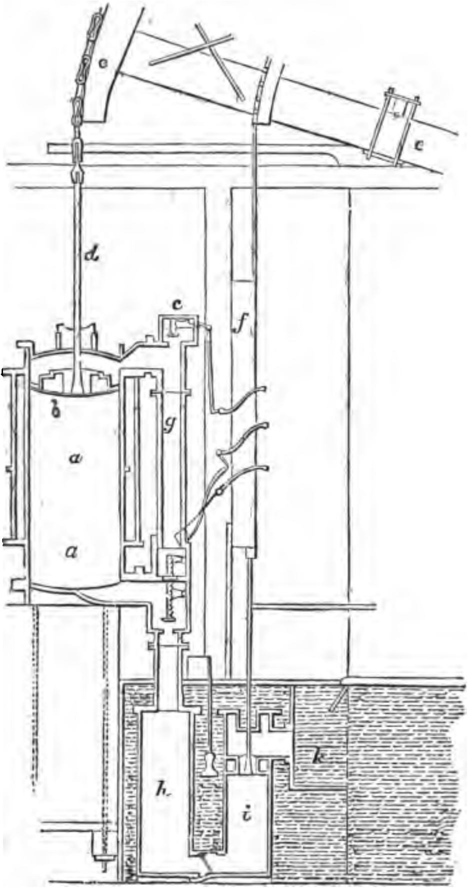


fig. 25.

condenser or of the air-pump. The valves are then to be shut, and a vacuum is thus formed in the engine. The first stroke of the engine is then made by opening the steam and eduction valves, and opening the injection-cock, so as to admit a jet of water to the condenser; the piston is then forced down into the vacuum by the steam above the piston. The plug-tree *ff* (fig. 25), in descending, strikes its tappets on the spanner or levers of the eduction and steam valves, shutting them, and opening the equilibrium-valve; the steam above the piston rushes through this to the under side of the piston; and an equilibrium being thus established on both sides of the piston, it is drawn up to the top of the cylinder by the action of the counterpoise at the pump end of the beam.

The single-acting engine as here described, although admirably adapted for the purposes for which it was introduced, namely, withdrawing water from coal and other mines, was obviously unfitted for extension to other purposes in which a continuous rotatory motion was desired. By a slight modification of the valves of his engine, Watt was enabled to overcome the difficulty; and in the "double-acting engine," for which we are indebted to his genius, the piston is both raised and depressed by the action of the steam, a vacuum being alternately made above and below the piston. In 1781 he took out a patent for this modification, but his attention had been drawn to it many years before; in fact, while prosecuting his petition for a prolongation of his original patent in 1774, he had exhibited a drawing of the plan to the House of Commons. In this drawing he explained how, after the piston had been pressed by the steam to the bottom of the cylinder, by shutting off the connexion beween the upper part and the boiler, and opening a communication between it and the under side of the cylinder, the steam by this means could be made to *raise* as well as *depress* the piston into a vacuous space, *which might be made above and below it alternately.* For the introduction of this form of engine, by which the dead-weight of the counterpoise was got rid of, and the efficacy of the engine as a general motive power so vastly increased, and the range of its powers so much extended, we are probably indebted to the rivalry which existed between the firm of Bolton and Watt and other engine-makers, and to the machinations which many of them condescended to employ for the purpose of obtaining a share of the public patronage. Holding such an extensive monopoly, a monopoly not only of legal power, but also, it may be said, of mechanical genius, and of a vast experience such as no others could lay claim to, it need not be wondered at that the firm encountered a vast amount of obloquy and reproach from various interested sources, and that angry feelings and bitter animosity on the part of their rival brethren in the trade existed to a large extent. Some notion of the state of matters thus existing may be derived from the statement of a late engineer (whose mind and talents should, we think, have prompted more generous feelings), who declared that, "when men of *better* judgment had constructed engines as good, or *better* than their own, they have (*i.e.* Bolton and Watt) just candour enough to admit the fact, and pride and avarice enough to claim them as their invention;" and who even went the length of trying much "to make it clear that Mr. Watt had no right to any patent whatever!" But this state of matters, however much to be deplored, was not the only thing Bolton and Watt had to contend against: their own feelings of rectitude and just principle, which undoubtedly characterised them in all their dealings, bore them up against all the attacks of slander and detraction; but an extensive and powerful combination to wrest from them the pecuniary advantages of their invention touched them in another way, and called forth another and more public reprisal. As already mentioned, the profits derived by Bolton and Watt from their engines was exactly in proportion to the saving which they effected to the proprietors who had them erected. Nothing in commerce could be fairer than this; yet to the discredit of a large number of them, they, forgetting the *two-thirds* which by the use of the engines were put into their pockets, they grudged the third which the patentees asked for the great benefits thus conferred. By a species of sophistry, which we see often acted upon by men who, in other matters, fulfil to the letter the their own use freely, and without consulting the rightful owners, the property which *mental* labour had created. They covertly, if not openly, therefore, supported a horde of "pirates," who endeavoured to wrest the invention of Watt from his grasp. Bolton and Watt for a length of time took no steps to stop this flood of wrong; but at last it reached to such a height, that a due regard to their own social rights, as well as to the claims of public morality, rendered it imperative upon them to take some public and decided steps to put, at once and for ever, a stop to these proceedings. An engine having been erected on Watt's plan at a mine at Cornwall, an action was begun against Mr. Bull, by whom several of the Cornish miners were represented. The principal plea put in, in defence, was the vagueness and want of precision in the specification, and through this the invalidity of the patent. The judges were divided on this point, and no judgment was given. Advantage, however, having been taken of this, and reckoning on it as a legal defect sustained by the patentees, the attempts to evade the patent rights again became numerous; and further steps, to put a stop to this, were again taken by the patentees. The trial before the Court of King's Bench this time resulted in their favour. The immediate effect of this "Cornish conspiracy," as it has been termed, was doubtless the introduction of the double-acting engine; for Watt, foreseeing the extent to which it could be applied in a vast range of manufacturing operations, was no doubt anxious to occupy this field also, and not to depend altogether on that of Cornish pumping-engines. It was in connection with the double-acting engine that Watt introduced those beautiful and philosophical inventions which we are now about to notice.

In the application of the steam-engine to the production of a *continuous* motion, the first step to be taken was the changing of the reciprocating motion of the piston-rod into a continuous rotatory one. If the reader will turn to pp. 47-49 of the companion treatise to the present volume, *Mechanics and Mechanism*, in this series, he will there find a description of the method of effecting this purpose by means of what is called a "crank." Although the works of philosophy and mechanics published at periods long anterior to the time of Watt and his contemporaries contained illustrations of this contrivance, and although, moreover, evidence of its use could be seen in almost every street in the knife-grinder's wheel (see p. 48, fig 72, *Mechanics and Mechanism*), or in many houses in the country in the "housewife's spinning-wheel," the animated rivalry which existed between several mechanics who claimed the honour of its discovery, as an important appliance of the steam-engine, is very remarkable; the great importance which was thus attached to its exclusive possession may be viewed, therefore, "as one of the many curious illustrations afforded, in the progress of this machine, of the great value of even an apparently trifling improvement." We may here trace the history of its application to the steam-engine.

In the year 1779, a Mr. Matthew Wasbrough, of Bristol, patented a contrivance by which the balanced beam of the atmospheric engine could produce a rotatory motion. This was effected by the employment of one or more pulleys, wheels, or segments of wheels, to which were fastened ratchets or checks. In another case he shifted a wheel and its axis from one set of teeth to another. A third method was, employing racks with teeth which tumbled or moved on their own axis or centre; and these racks he fastened to the working beam or great lever, or they were connected with it by means of chains. "For other purposes, instead of a working beam, he substituted a wheel or pulley, working by racks or chains from the steam piston; and to regulate the motion, he in some cases added a fly." Wasbrough fitted up one of his machines at Birmingham for a Mr. John Pickard. This party was instrumental, however, in introducing a much simpler method of producing rotatory motion; this was by substituting the crank. For this he took out a patent in 1780; and associated with him, in carrying its application into practice, the inventor of the previously mentioned mechanism, Wasbrough. They succeeded in introducing the method of working into several mills.

From Mr. Watt's own statement there appears every reason to conclude, that the idea of using the crank had been borrowed from his factory at Soho. The following is the statement alluded to:

"I had very early turned my mind to the producing continued motions round an axis; and it will be seen, by reference to my first specification in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury, or some other fluid metal, on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly; but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning-lathe (an invention of great merit, of which the humble inventor, and even its era, are unknown). But as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston (and even were a counterweight employed, to act during that ascent of a fly, heavy enough to equalise the motion), I proposed to employ two engines acting upon two cranks fixed on the same axis, at an angle of one hundred and twenty degrees to one another; and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly only would be requisite. This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 1779, when Mr. Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated, by a workman employed to make the model, to some of the people about Mr. Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed; and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time; which might be a fact, as the application of a single crank was sufficiently obvious. In these circumstances I thought it better to endeavour to accomplish the same end by other means than to enter into litigation; and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun-and-planet wheels.

"This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly; but is, perhaps, more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter-weight, and produced a more regular motion; so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse-mills; and, instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.

"I do not exactly recollect the date of the invention of the double engine; but a drawing of it is still in my possession, which was produced in the House of Commons when I was soliciting the act of parliament for the prolongation of my patent in 1774 and 1775. Having encountered much difficulty in teaching others the construction and use of the single engine, and in overcoming prejudices, I proceeded no further in it at that time; nor until, finding myself beset with a host of plagiaries and pirates in 1782, I thought it proper to insert it and some other things in the patent above mentioned."

The mechanism of the "sun-and-planet" wheels above alluded to, for the purpose of obtaining continuous rotatory motion from the reciprocating movements of the piston-rod, the reader will find explained in pp. 70-77, fig. 142, *Mechanics and Mechanism.* The method employed in the single-acting engine for connecting the piston-rod with the end of the working beam was obviously (see p. 84, fig. 164, *Mechanics and Mechanism*) incapable of being applied to the double-acting engine; where the piston was *pushed* up by the pressure of the steam, not *pulled* up by the counterpoise, as in the single-acting engine. The mechanism which Watt at first employed will be understood from an inspection of the diagram in fig. 26. Let *a* be the piston-rod, furnished with a rack at its upper end, working into teeth of a segment fixed on the rod of the working beam; as the piston-rod moved up and down, the teeth actuated those of the segment, and made the beam *c* reciprocate. In working expansively, a small fly-wheel, shown by the dotted lines *d*, was applied to the mechanism; on the centre of this was fixed a small toothed wheel, which was worked by the rack, of

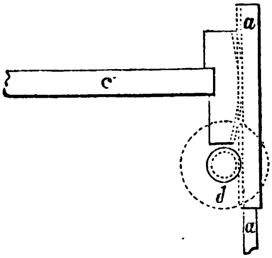


fig. 26.

the piston; the fly moved alternately from side to side as the piston ascended and descended. This contrivance was found possessed of many disadvantages on being carried into practice, especially in large engines, not the least of which was the great noise and jar occasioned by the teeth of the rack and segment engaging as the direction of motion of the piston-rod was changed. Some more elegant contrivance was therefore desiderated, and Watt's genius and mechanical ability no more failed him here than at other and more trying times; and the result of his cogitations was the production of that most beautiful and philosophical mechanism known as the "parallel motion." The principle of this contrivance the reader will find in p. 84, fig. 165, *Mechanics and Mechanism;* and an exemplification of its arrangement as carried out in practice in the diagram, fig. 63, p. 44 of the same work. The diagram here given, fig. 27, illustrates the arrangement of the parallel motion as first applied to the double-acting engine. Let *a a* be the working beam, *f* is the piston-rod, *g* the air-pump rod, *b c d* the links. Other exemplifications of this motion will be found in the diagrams in succeeding chapters of this volume.

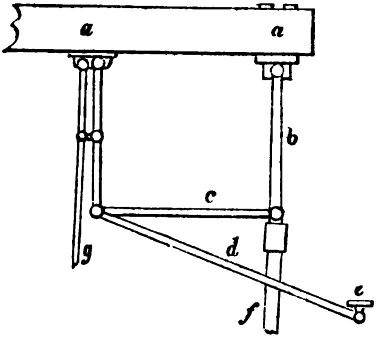


fig. 27.

In order to render the double-acting engine as perfect in its arrangements as possible, and independent of the attention of careless workmen, Watt introduced a method by which the engine itself regulated its own motion. This he effected by adopting what is now known as the "governor," a description of which will be found in pp. 87-89, *Mechanics and Mechanism*, and illustrations showing its application to the opening and closing of the valve by which the steam is admitted to the engine. In the single-acting engines the throttle-valve was opened and shut by hand, a

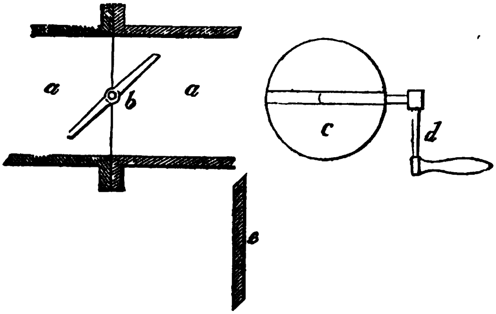


fig. 28.

sufficient uniformity of motion being thus obtained. A view of the valve is given in fig. 28: *aa* parts of the steam-pipe, joined together by a "flange-joint;" at the point of junction a thin disc or valve *b* is placed; the axis of this passes through a stuffing-box in the pipe, and is moved by a handle *d*. When the valve is parallel with the line of pipe, the steam-way is fully open; when brought up with its edges pressing on the interior of the pipe, the steam-way is closed; intermediate positions admit the steam in greater or less proportions. The manner in which the edges of the valve are "chamfered" off to go closely up to the pipe is shown at *e*. The "governor" was not the sole invention of Watt; in the application of it, however, to the steam-engine, it received the impress of his mechanical genius, and was, as it left his hands, in elegance and justness of proportion, and in original adaptation to his peculiar purposes, a very different affair than when used for regulating the sluice of water-mills, for which purpose, under the name of "lift-tenter," it was largely used. It is right, however, to state that, according to Stuart, a Mr. Clarke of Manchester suggested the adaptation of the "lift-tenter" to the regulation of the motion of the steam-engine.

The valves attached to the cylinder had to undergo some modification in their application to double-acting engines. The nature of these will be learned from an inspection of the diagram in fig. 29. The spindle of the valve *b* is continued upwards, and formed into a small rack; this works into the teeth of a quadrant *e*, which is moved by the spanner or lever *d*, worked by the plug-frame of the engine; the spindle or tail of the valve *c* works in a small aperture in a bracket below; additional steadiness was obtained by making the rack or slide in a projecting bracket.

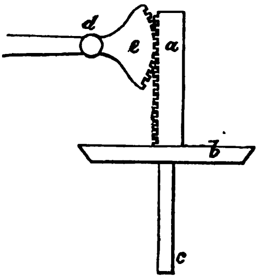


fig. 29.

In fig. 30 we give a diagram illustrative of the arrangements of the double-acting engine as it left his hands: *a* the cylinder, *b* the piston-rod, *d* the parallel motion, *mm* the beam, *o* the connecting-rod, *p* the sun-and-planet wheel giving motion to the fly-wheel, *e* the air-pump rod and plug-frame for moving the valves *f*, *g* the air-pump, *h* the condenser, *n* the hot-water pump for taking the hot water from the air-pump to the cistern, from which it is pumped by the pump *s*, and delivered to the boiler. Supposing the piston at the top of the cylinder, the action of the engine is as follows: as steam is being admitted by the upper valve to the upper side of the piston, it descends; and at a certain part of its stroke, the lappets in the plug-frame shut the steam-valve, and as the piston descends, the steam expands; on nearly reaching the bottom of its stroke, the upper exhaustion-valve is opened, and a communication made between the upper side of the piston and the condenser; the steam above the piston now rushes to the condenser, and a vacuum is formed. The lower steam-port is now opened, and the steam presses the piston upwards into the vacuum formed above the piston; at the proper period the lower steam-port is closed, and the lower exhaustion-valve opened; the steam now rushes from beneath the piston to the condenser, and a vacuum is formed beneath the piston. The movements thus proceed as long as required.

We have next to notice the arrangements which Watt introduced for

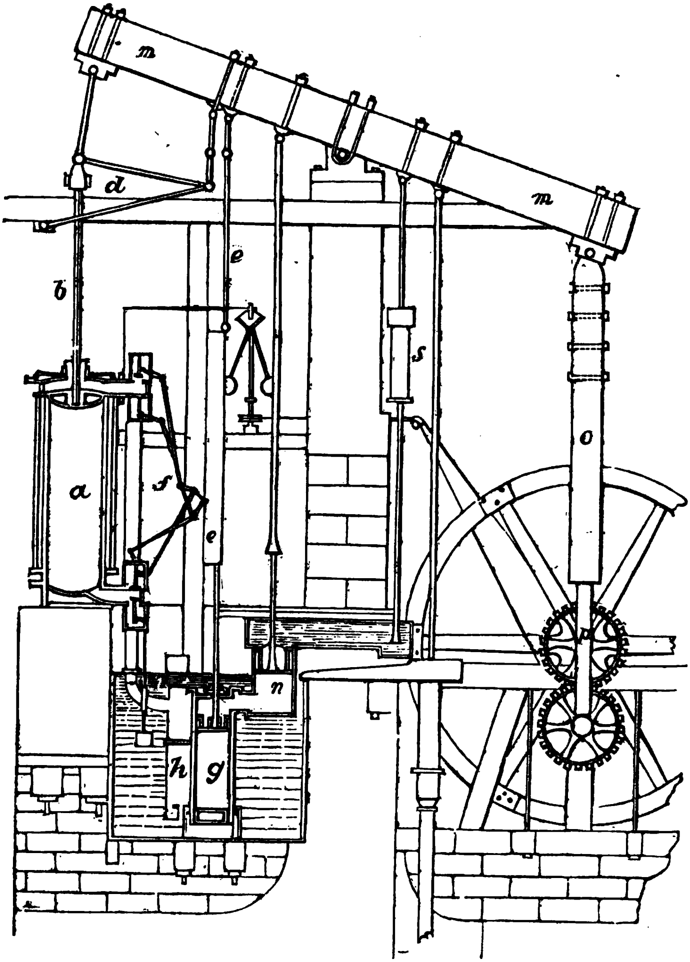


fig. 30.

means by which the steam-engine, in almost every respect, was made automatic. In fig. 31 we give a diagram illustrative of the general arrangements of the boiler. Previous to Watt's improved arrangements, the boilers of steam-engines were generally rude and clumsy affairs, ill adapted for raising steam either quickly or economically. This was owing, no doubt, partly to the low state of the mechanical arts, which precluded any attempt at nice adjustment of parts; and partly to no one studying the subject in all its bearings, in order to arrive at a knowledge of the just proportions necessary to attain the greatest amount of steam at the least expenditure of fuel. The shape, too, was chiefly dependent on caprice or preconceived with flat or concave bottoms. The waste of fuel from these boilers at length attracted the attention of practical men, with a view to remedy their defects. Boilers of an oblong form were therefore introduced; and the best of this kind, known as the "wagon" from its shape, owed its introduction to Watt. He also applied numerous valuable appendages, as already alluded to, and which we now propose to describe by the aid of the diagram here attached.

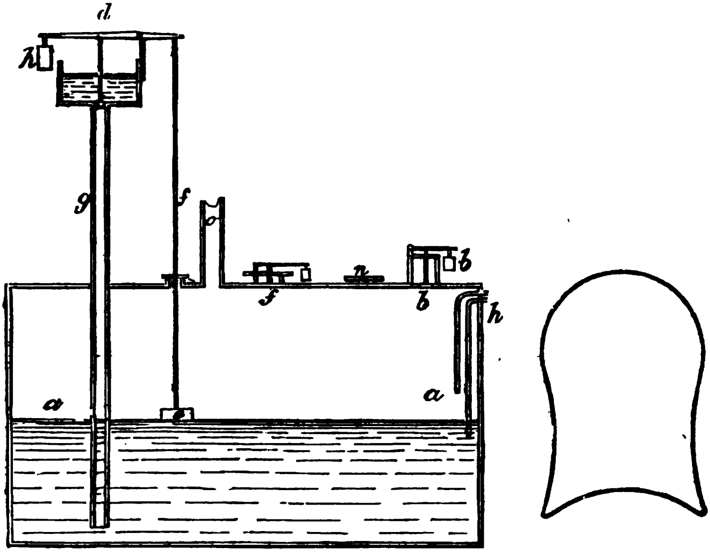


fig. 31.

And first, as to the important point of supply of water. A vertical pipe *g* was connected with the boiler, and reached to within a few inches of the bottom. This pipe varied in height according to the pressure of the steam employed in the boiler, allowing some 34 inches for each pound of pressure above that of the atmosphere. The top of this pipe was terminated by a small cistern, which was supplied with hot water from the hot-water cistern; this cistern was furnished with a valve opening upwards; the spindle was continued and connected by a jointed lever to the lever *d;* this lever vibrated on the centre attached to the side of the cistern; one end of this lever was weighted with a counterpoise, and the other had a rod attached to it, which descended into the interior of the boiler, passing through a stuffing-box, and having attached at its lower end a stone float *e*. The action of this apparatus was as follows. On the water getting too low, the float sunk, pulling with it the end of the lever, raising the counterpoise weight and the valve *d;* this allowed the water to descend the pipe to the boiler. On the level of the water thus rising, the float also rose, and actuating the lever, the valve was let into its seat, thus stopping the flow of water through the pipe. The safety-valve *b b*, instead of being open as in the old engines, was confined in a box, through the cover of which the spindle of the valve worked in a stuffing-box, and the steam which escaped was led by a pipe to the chimney-flue. Another safety-valve was also attached, as at *f*, and was termed "the internal safety-valve:" its office was to admit air to the interior of the boiler, when by any means a vacuum was formed in it by the condensation of the steam: to effect this, the valve opened inwards. The gauge-cocks *h h* were used to ascertain the state of the water in the boiler. When one was opened, water was forced through it alone, steam through the other: when this happened, the proportion of water in the boiler was accurately adjusted; if, on the other hand, steam rushed through that cock which should have emitted water, the water was deficient, and *vice versa*. Access was had to the interior of the boiler, for the purpose of cleaning it out, &c., through the "man-hole door" *n*: this was covered by a plate, and properly secured. The steam for the engine was conveyed by the pipe *o*. In a future chapter, while describing modern appliances of the steam-engine, we shall describe other arrangements and contrivances which the genius of Watt applied to the perfection of the steam-engine.

We have now brought the history of the steam-engine up to the period when Watt ceased making his improvements on it. Such was the perfection of his contrivances and the nicety of his details, that he left little to be done towards its improvement by other hands. On this point a recent writer, an engineer of note, has the following: "However far we may proceed in the path of steam-improvement, we shall find unequivocal traces of his having been there before; and the conceptions which start up in our minds, and which at first sight we believe to be original and important, we shall find, on inquiry, to have previously suggested themselves to his imagination. The fact appears to be, that the track of knowledge chosen by him has been so thoroughly explored, that he has left nothing for his successors to discover; and we do not at present see how any material improvement can now take place in steam-engines, except by the introduction of new powers of nature which the progress of discovery may reveal. The machine may perhaps be thrown into still more commodious forms, and greater niceties of workmanship may be lavished upon its construction; but every thing is to be got, by Watt's principle of action, that mere fire and water can give; and the next step of improvement must be the employment of cheaper agencies. And though the present steam-engine may pass away, as it no doubt will, and cease to have any existence except in the page of history, Watt's glory will suffer no obscuration, but in the lapse of years must rise to a wider and brighter effulgence. However excellent or extraordinary the new mechanism may be, it will, we believe we may predict, rather be compounded of the ideas of a multitude of minds than be the product of a single master-spirit; and ages must elapse before another such example of intellectual strength as Watt presented can be given to the world."

To this generous tribute paid to the memory and the genius of Watt, we must add another, emanating from the most practical and celebrated of our modern engineers, himself a bright example of what genius aided by perseverance can accomplish — William Fairbairn of Manchester. "The innumerable attempts that have been made to improve the principle of the condensing steam-engine since the days of its celebrated inventor Watt, have nearly all proved failures, and have added little, if any thing, to the claims next to perfection of that great man's ideas. It would be idle to speculate upon the various forms and constructions, from that time to the present, which have been brought forward in aid of the original discovery of condensation in a separate vessel. All that has been done is neither more nor less than a confirmation of the sound views and enlarged conceptions of the talented author of a machine which has effected more revolution and greater changes in the social system than probably all the victories and all the conquests that have been achieved since the first dawn of science upon civilised life. It would be useless to trace the history of the successful and the unsuccessful attempts at improvement which, for the last half-century, have presented themselves for public approval; suffice it to observe, that no improvement has been made upon the simple principle of the steam-engine as left by Watt, and but few upon its mechanism. In the construction of the parallel motion, the application of the crank, the governor, and the sun-and-planet motions, all of which have risen spontaneously from the mind of Watt, there is no improvement. The principles upon which all of them are founded have been repeatedly verified beyond the possibility of doubt; and their mechanism is at once so exceedingly simple and so ingeniously contrived, as to limit every attempt at improvement in these parts of the steam-engine. What appears to be the most extraordinary part of Mr. Watt's engine is, its perfect simplicity, and the little he has left to be accomplished by his suceessors."

We now hasten to conclude our notice of Watt. After the expiry of the period which parliament had granted him to monopolise the profits of the steam-engine, Watt retired from the firm; and leaving the management of the business to his son and the son of Bolton, retired from "that establishment which his genius had matured, and to which it had given a celebrity as wide as the boundaries of civilisation, to the enjoyment of the fortune which he had accumulated from the meritorious and well-directed exertions of a life distinguished for its activity and usefulness. The patent expired in 1800; and in the house which he occupied while at Soho, he resided till his death, which event occurred on the 23d of August, 1819. He had suffered some inconvenience through the summer, but was not seriously indisposed till within a few weeks of his death. He then became perfectly aware of the event which was approaching; and, with his usual tranquillity and benevolence of nature, seemed only anxious to point out to the friends around him the many sources of consolation which were afforded by the circumstances under which it was about to take place. He expressed his sincere gratitude to Providence for the length of days with which he had been blessed, and his exemption from most of the infirmities of age; as well as for the calm and cheerful evening of life that he had been permitted to enjoy, after the honourable labours of the day had been concluded. And thus, full of years and honour, in all calmness and tranquillity, he yielded up his soul without a pang or a struggle, and passed from the bosom of his family to that of his God." We conclude this portion of our treatise by giving the celebrated *éloge* pronounced on Watt as an inventor by M. Arago, the well-known French philosopher; also his character as a man by Lord Jeffrey.

"Gentlemen,—This creator of six or eight millions of workmen—of workmen indefatigable and industrious, among whom the arm of authority is never called upon to interpose for the suppression of revolt; this man, who, by his brilliant inventions, conferred upon England the means of sustaining itself during a political convulsion where its very existence as a nation was endangered; this modern Archimedes, this benefactor of the whole human race, whose memory future generations will eternally bless,—what was done to heap honour upon this man? The peerage is in England the first of dignities, the highest of national rewards. You will naturally suppose that Mr. Watt was at least elevated to the highest rank in the peerage. Such a thing was never even thought of. . . . Futurity will behold Watt appear before the grand jury of the inhabitants of the two hemispheres: they will see him penetrating, with the aid of his mighty machine, into the bowels of the earth, in the short period of a few weeks, to depths where, before his time, it would have required a century of painful labour to arrive; and there opening up spacious galleries and mines, clearing them in a few minutes of the immense volumes of water that encumber them, and snatching from virgin earth the boundless mineral wealth deposited there by bountiful nature. Uniting delicacy with power, he will be seen twisting with equal success the immense folds of the gigantic cable, by which the ship of the line embraces in safety her anchor in the midst of the tumultuous tossing waves; and the microscopic filaments of the delicate muslins and the aërial lace which float on the zephyrs of fashion. A few oscillations of the same machine will bring into culture extensive swamps; and fertile countries will be rescued from the periodic and deadly miasmata raised up by the burning heats of a summer sun. . . . Population, well fed, well clothed, well warmed, increasing with rapidity, is fast covering with elegant mansions the surface of countries formerly the deserts of the world, and which eternal barrenness appeared to condemn to the dominion of beasts of prey. In a few years, what are now but hamlets will become important cities; in a few years, towns such as Birmingham—where already one reckons three hundred streets—will take rank as the largest, most beautiful, and wealthiest cities of a powerful kingdom. Transferred to our ships, the steam-engine will replace a hundred-fold the power of triple and quadruple ranks of rowers, from whom our forefathers exacted a labour reckoned among the severest punishments of the most atrocious criminals. The steam-engine, in conclusion, drawing in its train thousands of travellers, will traverse the railway with far greater velocity than the best race-horse loaded only with his pigmy jockey.

"There, gentlemen, is a rapid sketch of the legacy of benefits conferred on the world by that machine which the ingenuity of Watt carried to such admirable perfection. We are accustomed to quote the 'Augustan age,' the time of Louis the Fourteenth. Noble spirits have already arisen, who have thought it just to speak of the age of Voltaire, of Rousseau, of Montesquieu. For my part, I pronounce without hesitation, that when to the immense services which the steam-engine has already achieved, there shall be added all the marvels it promises for the future, a grateful world will also cite the ages of Papin and of Watt."

The following is Lord Jeffrey's admirable sketch of the character of Watt. From this will be seen that the greatness of Watt as an engineer proceeded from the fact, that he was not merely an engineer, but did not disdain to take what would be called by a mere mechanic discursive flights into the regions of general science, gathering therefrom that strength of mind and that energy of imagination which enabled him to go so far beyond the beaten path of the mere mechanical improver. "Independently," says Lord Jeffrey, "of his great attainments in mechanics, Mr. Watt was an extraordinary, and in some respects a wonderful man. Perhaps no individual in his age possessed so much and so varied information, had read so much, or remembered what he read so accurately and well. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodising power of understanding, which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense, and yet less astonishing than the command he had at all times over them. It seemed as if every subject that was casually started in conversation with him, had been that which he had been last occupied in studying and exhausting; such was the copiousness, the precision, and the admirable clearness of the information which he poured out upon it, without effort or hesitation. Nor was this promptitude and compass of knowledge confined in any degree to the studies connected with his ordinary pursuits. That he should have been minutely and extensively skilled in chemistry and the arts, and in most branches of physical science, might, perhaps, have been conjectured; but it could not have been inferred from his usual occupations, and probably is not generally known, that he was curiously learned in many branches of antiquity, metaphysics, medicine, etymology, and perfectly at home in all the details of architecture, music, and law. He was well acquainted too with most of the modern languages, and familiar with their most recent literature. Nor was it at all extraordinary to hear the great mechanician and engineer detailing and expounding for hours together the metaphysical theories of the German logicians, or criticising the measures or the matter of German poetry.

"It is needless to say that, with those vast resources, his conversation was at all times rich and instructive in no ordinary degree; but was, if possible, still more pleasing than wise, and had all the charms of familiarity with all the substantial treasures of knowledge. No man could be more social in his spirit, less assuming or fastidious in his manner, or more kind and indulgent towards all who approached him. He rather liked to talk, at least in his latter years; but though he took a considerable share in the conversation, he rarely suggested the topics on which it was to turn, but readily and quietly took up whatever was presented by those around him, and astonished the idle and barren propounders of an ordinary theme by the treasures which he drew from the mine they had unconsciously opened. He generally seemed, indeed, to have no choice or predilection for one subject of discourse rather than another, but allowed his mind, like a great encyclopædia, to be opened at any letter his associates might choose to turn up, and only endeavoured to select from his inexhaustible stores what might be best adapted to the taste of his present hearers. As to their capacity, he gave himself no trouble; and, indeed, such was his singular talent for making all things plain, clear, and intelligible, that scarcely any one could be aware of such a deficiency in his presence. His talk too, though overflowing with information, had no resemblance to lecturing or solemn discoursing; but, on the contrary, was full of colloquial spirit and pleasantry. He had a certain quiet and grave manner, which ran through most of his conversation; and a vein of temperate jocularity, which gave infinite zest and effect to the condensed and inexhaustible information which formed its main staple and characteristic. There was a little air of affected testiness too, and a tone of pretended rebuke and contradiction with which he used to address his younger friends, that was always felt by them as an endearing mark of his kindness and familiarity, and prized accordingly beyond all the solemn compliments that ever proceeded from the lips of authority. His voice was deep and powerful, though he commonly spoke in a low and somewhat monotonous tone, which harmonised admirably with the weight and brevity of his observations, and set off to the greatest advantage the pleasant anecdote, which he delivered with the same grave brow, and the same calm smile playing soberly on his lips. There was nothing of effort indeed, or impatience, any more than of pride or levity, in his demeanour; and there was a finer expression of reposing strength and mild self-possession in his manner, than we ever recollect to have met with in any other person. He had in his character the utmost abhorrence for all sorts of forwardness, parade, and pretension; and, indeed, never failed to put all such impostures out of countenance, by the manly plainness and honest intrepidity of his language and deportment.

"In his temper and dispositions he was not only kind and affectionate, but generous and considerate of the feelings of all around him; and gave the most liberal assistance and encouragement to all young persons who showed any indications of talent, or applied to him for patronage or advice. His health, which was delicate from his youth upwards, seemed to become firmer as he advanced in years; and he preserved up almost to the last moment of his existence, not only the full command of his extraordinary intellect, but all the alacrity of spirit and the social gaiety which had illumined his happiest days. His friends in this part of the country never saw him more full of intellectual vigour and colloquial animation,—never more delightful or more instructive,—than in his last visit to Scotland in autumn 1817. Indeed, it was after that he applied himself, with all the ardour of early life, to the invention of a machine for mechanically copying all sorts of sculpture and statuary; and distributed among his friends some of his earliest performances, as the productions of 'a young artist just entering on his eighty-third year!'"

The discoveries of Watt, and the ingenious arrangements which he introduced, gave a great impulse to the inventive talent of others. The pecuniary advantages attendant upon the successful introduction of a steam-engine were too obvious not to act powerfully as an inducement for practical mechanics, as well as scientific men, to turn their attention to the subject. We propose, under the present division of our work, to describe a few of the more important of these inventions. The first we notice is that of Hornblower, the first who introduced into practice the "double-cylinder engines," modifications of which principle are now so largely adopted. The patent was taken out in 1781; but in 1779 Dr. Falck described a method by which he proposed to double the effect of steam by the use of two cylinders, taking advantage of its expansion. He employed two cylinders, the steam-communication from the boiler being common to both: in rushing into one cylinder, it was prevented from doing so into the other; and after depressing the piston of the first cylinder, it was admitted into the other, on the piston of which it operated in like manner.

Mr. Jonathan Hornblower, previous to the introduction of Watt's steam-engine to the Cornish districts, had been generally employed in the construction of engines on the old principle for the Cornish adventurers; it was therefore a matter of great importance to him, to be able to retain his business there. He therefore made strenuous efforts to oppose the introduction of Watt's engine to a field which he looked upon as exclusively his own; and with this view, he took out a patent for his double-cylinder expansive engine in 1781, which is said to have been invented so early as 1776. A description of this engine was given by Hornblower in the *Encyclopædia Britannica*, which pretty clearly explains its principle. The following diagram and explanation is derived from this.

In fig. 32, A B are two cylinders, of which A is the larger; the piston-rods are connected with the beam, as in Watt's single-acting engine; a square pipe G supplied the steam to the cylinder B; the eduction-pipe leading to the condenser is shown at K, which was formed of a conical shape; this was connected with rod-pumps for extracting the air and water; water was admitted to the condenser by a valve placed at the bottom, and a pipe was connected with it leading upwards, and furnished with a blow or snifting valve. The square pipe G branched off to both cylinders, and was furnished with two cocks *c d;* on the other side of the cylinders another square pipe is also placed, having in like manner two cocks *a b;* the vertical pipe *y* establishes a communication between the upper and lower parts of the cylinder B by opening the cock *b*. All these valves or cocks are actuated by the plug-frame attached to the great beam, in somewhat the same way as in Watt's engine; a pipe similar to *y* is placed on the other side of the cylinders, communicating with the valve *d*. "When the cocks *c* and *a* are open, and the cocks *b* and *d* are shut, the steam from the boiler has free admission into the upper part of the small cylinder B, and the steam from the lower part of B has free admission into the upper part of the great cylinder A; but the upper part of such cylinder has no communication with

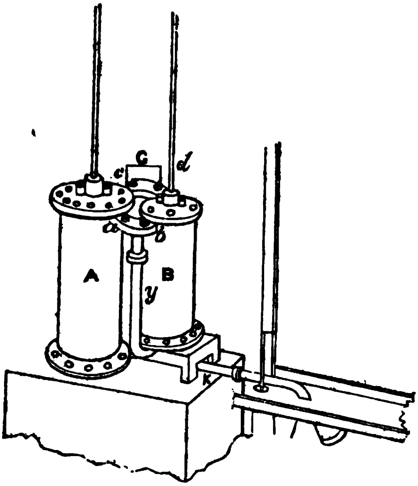


fig. 32.

its lower part. . . . . Suppose all the cocks open, and no condensation going on (in the condenser), the steam must drive out all the air, and at last follow it through the snifting-valve. Now shut the cocks *b* and *d*, and open the escape-valve of the condenser, the condensation will immediately commence, and draw off the steam from the lower part of the great cylinder. There is now no pressure on the under side of the piston of the great cylinder A, and it immediately descends. The communication *y* between the lower part of the cylinder B and the upper part of the great cylinder A being open, the steam will go from the lower part of B into the space left by the descent of the piston A. It must therefore expand, and its elasticity must diminish, and will no longer balance the pressure of the steam coming from the boiler and pressing above the piston of B. This piston, therefore, if not withheld by the beam, would descend till it came in equilibrio, from having steam of equal density above and below it. But it cannot descend so fast, for the cylinder A is larger than B, and the arch of the beams, at which the piston is suspended, is no longer than the arm which supports the piston of B; therefore, when the piston of B has descended as far as the beam will permit it, the steam between the two pistons occupies a larger space than it will when both pistons were at the top of their cylinders, and its density diminishes as its bulk increases. The steam beneath the small piston is therefore not a balance for the steam on the upper side of the same; and the piston B will act to depress the beam with all the difference of these pressures. The slightest view of the subject must show, that as the piston descends, the steam that is between them will grow continually rarer and less elastic, and that both pistons will draw the beam downwards. Suppose, now, that each one had reached the bottom of its cylinder, shut the cock *a* and the eduction-valve at the bottom of A, and open the cocks *b* and *d*. The communication being now established between the upper and lower part of each cylinder, their pistons will be pressed equally on the upper and lower surfaces; in this situation, therefore, nothing hinders the counterweight from raising the pistons to the top. Suppose them arrived at the top; the cylinder B is at this time filled with steam of the ordinary density, and the cylinder A with an equal absolute quantity of steam, but expanded into a larger space. Shut the cocks *b* and *d*, and open the cock *a* and the eduction-valve at the bottom of A; the condensation will again operate, and cause the pistons to descend; and then the operation may be repeated as long as the steam is supplied; and one measure-full of the cylinder B of ordinary steam is expended during each stroke." A glance at this invention will show the close similarity existing between it and the arrangements of Watt's engines: "the condenser and air-pump, the cylinder-covers with their stuffing-boxes, and indeed every thing good about the engine, is evidently borrowed from Mr. Watt, with the single exception of the two cylinders; and by them nothing was accomplished that had not been already attained by Mr. Watt quite as effectually with a single cylinder only." Although Hornblower claimed for his engine a superiority in an economical point of view, giving it a power equal to sixteen with the same quantity of coal which in Watt's only gave ten, still his practice did not bear out this assumption: Professor Robinson, by a series of elaborate calculations, made it evident that the same effect was produced in this as in Watt's expansion engine; which were borne out by the practice of Hornblower himself. From having adopted the principle of the separate condenser, this engine was an infringement of Watt's patent; proceedings were therefore taken, some years after the introduction of Hornblower's patent, against several parties who had used it. At the expiration of Hornblower's patent, he applied to parliament for a renewal of his privileges, without, however, being successful.

In fig. 33 we give a drawing of a very ingenious form of steam-engine, known as Dr. Cartwright's, in which there are several points worthy of notice. In fig. 33, *aa* is the cylinder, *bb* the piston; the piston-rod is continued downwards to work the piston of a small pump, which withdraws the water of condensation from the condenser *d*, forcing it up the pipe *e* to the hot-water well *gg*; a float-ball is placed within this cistern, which acts upon the lever closing and opening the valve on the top of the well to admit the atmosphere; this cistern, acting as an air-vessel, sends the water in a continuous stream up a pipe. A valve opening upwards is placed at the top of the pipe leading from the pump beneath the cylinder to the hot-water cistern, and another valve is placed at the bottom of the pump, opening upwards; a pipe communicates with the interior of the cylinder at bottom, and is led to the condenser *d*, into the space formed by the two concentric

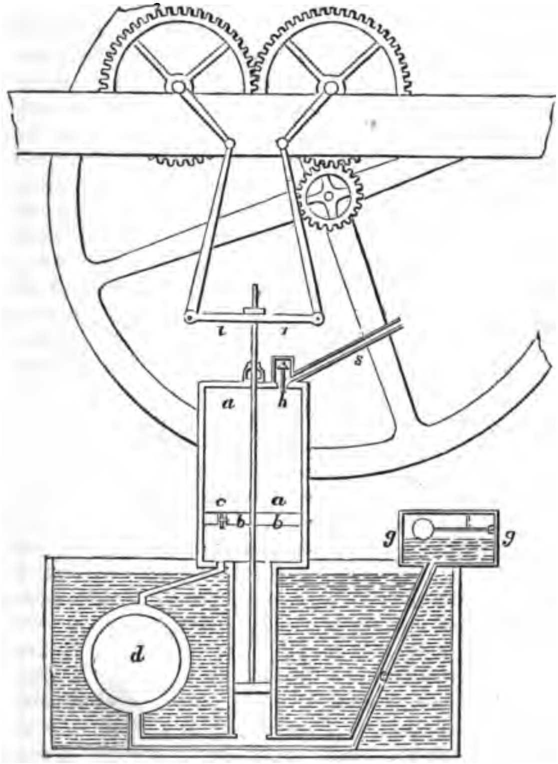


fig. 33.

circular vessels, the outsides of which are kept cold by being immersed in the cold water contained in the cistern. Steam is admitted to the upper side of the piston by the pipe *s* through the valve *h*; the spindle of this valve is continued for a short distance on both sides, the upper end passing through a stuffing-box in the valve-case; a valve *c* is placed in the piston, opening upwards; the piston-rod passes through a stuffing-box in the cylinder-cover; and by a cross-head, levers, and wheels, the reciprocating motion of the piston-rod is changed to the circular motion of the fly-wheel. For a description of this movement see *Mechanics and Mechanism*, p. 80, fig. 153.

The following is a description of the movement of this engine. On the piston being placed at the top of the cylinder, the piston strikes the tail or lower end of the spindle of the valve *h*, raising it out of its seat; this allows the steam to pass to the cylinder, pressing down the piston; the valve *c* in the piston is at the same time closed by its upper end striking against the cylinder-cover; on the piston reaching the bottom of the cylinder, the valve *h* is pressed into its seat by the cross-head *i i* striking its spindle, and the valve in the piston is opened by its lower end striking against the cylinder-bottom; the steam above the piston rushes through this valve, and pressing into the space between the vessels forming the condenser, the condensation is effected, and a vacuum formed above the piston; the momentum which the fly-wheel has derived from the downward stroke of the piston carries the piston upwards through the vacuum; the valve *h* is then opened, and *c* closed as before, and another down-stroke is made. Simultaneously with the descent of the piston in the cylinder, the piston of the pump is forced down; this closes the valve at bottom, and forces the water contained in the barrel of the pump beneath the piston up the pipe *e*, opening the valve and passing into the cistern; on the great piston rising, the pump-piston also rises, raising at the same time the valve, and drawing up the condensed water from the condenser. Several engines of this description were erected, and worked satisfactorily. In this engine, the whole of the parts of the piston were metallic. In a future chapter we propose to describe the construction of this form of piston. In this form of engine, the air which was pumped out of the condenser along with the condensed water was passed to the hot-water cistern; on its accumulating to a great degree, it depressed the surface of the water, the float sunk along with it, and the valve in the top of the box being opened, a portion of the air escaped.

In 1804 Arthur Woolfe, of Cambourne in Cornwall, obtained a patent for an improved steam-engine, in which advantage was taken of the expansive properties of steam. He employed steam of considerable pressure to work the piston of a small cylinder; and on its escaping from this, it was applied to the piston of a cylinder much larger in size, and which communicated with a condenser. The properties of steam on which this engine was founded, and the truth of which Woolfe thought he had established, were as follow:

Previous to his experiments being instituted, a fact had been asserted relative to the expansive property of steam, that with the expansive force of four pounds to the inch, steam was capable of expanding into a space four times its volume, and yet be equal thereafter to the pressure of the atmosphere. His experiments led him to infer, that steam of five pounds to the inch would expand into five times its volume; and that with steam of 6, 10, 20 lbs. to the inch, would expand into 6, 10, 20 times its bulk, and still have a pressure equal to the atmosphere, without any additional supply of heat. On this supposed discovery of the expansive property of steam, he proportioned his cylinders: if he adopted steam of six pounds to the inch, his large cylinder was six times the volume of the small one. Experience, however, soon showed the fallacy of this opinion; indeed, Woolfe himself was the first to become aware of it, and in his after-practice he adopted different proportions. The principle, however, of his engine is still in vogue with many of our engineers of high standing, and is being carried out in numerous instances, and with great success; it being beyond a doubt, that, by judicious arrangements, it is calculated to become an economical method of working.

We have now to notice the principle of "*the high-pressure steam-engine*," and a few historical points connected with it. The distinction between low-pressure and condensing engines, and high-pressure and non-condensing engines, is simple enough, and easily remembered. In the former, the steam, after working the engine, is passed into the condenser, and a vacuum being formed on one side of the piston, it is sucked down as it were, and by this means a considerable degree of power is obtained; in the latter, the steam, after working the piston, is passed at once to the atmosphere. An eminent authority thus distinguishes between the two, and draws a comparison between them: "All locomotive engines are of the high-pressure variety; and generally all engines are made on the high-pressure plan where the carriage of condensing water would be inconvenient, as the first cost of the machine becomes a point of more importance than an increased consumption of fuel. High-pressure engines are, *cæteris paribus*, necessarily more expensive in fuel than low-pressure engines, as they occasion the loss of the power derivable from a vacuum; and as the quantity of heat in the same *weight* of steam is nearly the same at all pressures, there is no counteracting source of economy to compensate for this deduction. The use of high-pressure engines in circumstances in which the low-pressure engine is applicable, is not to be commended; and the high-pressure engine is rarely employed for other purposes than locomotion on railways, except in the case of very small engines required for some temporary or trivial purposes. . . . . Where high-pressure steam is employed, it is expedient to make the pressure considerable, as the deduction to be made for the pressure of the atmosphere is less in proportion with a high than with a moderate pressure. Some locomotive engines are worked as high as 90 lbs. to the square inch." Notwithstanding the objections urged against the use of high-pressure engines, they are adopted in great numbers, and for an almost infinite variety of purposes in connexion with our arts and manufactures. Although with steam of high-pressure considerable danger exists in the liability to explosion of the boilers, still, from the general simplicity of detail, and the consequent cheapness in construction, and their extreme portability, we need not wonder at the extensive demand which is made for them.

The merit of the introduction of the first high-pressure steam-engine belongs to Leupold, a native of Plunitz, near Zwickau. He described it in his celebrated work entitled *Theatrum Machinarum Hydraulicârum*, published in 1727. With a modesty which formed not the least striking characteristic of this amiable man, he attributed the invention to Papin because this individual furnished the idea of using the expansive force of steam to raise water, and from his having taken the four-way cock which Papin used in his air-engine. The engine as constructed by Leupold is remarkable for the simplicity of its details; a diagram showing the method of its operation is given in fig. 34: where *aa* is part of the boiler, on which a four-way cock *b* is placed; *c* and *d* are two pipes communicating with the bottom of the two cylinders, in which the pistons *e* and *f* work; these are placed alternately,—that is, when the piston *f* is at the top, *e* is at the bottom; they are both loaded with lead, to act as counterpoises, and bring down the ends of the beams *g* and *h* to which they are attached; the other ends of these beams have pump-rods attached. Supposing the piston *f* at the top of the cylinder, the four-way cock is turned one quarter round; this opens a communication between the cylinder in which *f* works and the open air, and between the boiler and the cylinder in which *e* works; the steam in *f* passing into the air, the pressure on the piston is relieved, and it descends; the steam, however, acting on the piston of the cylinder *e*, presses it to the top: there have been thus two strokes of the pump-rods, one up by the cylinder piston *f*, the other down by *e*. On *f* reaching the bottom of its cylinder, and *e* the top, the four-way cock is turned back again a fourth; the communication between the interior of cylinder *e* and the atmosphere is thus opened, and between the boiler and cylinder *f*; a down stroke of *e* is thus made, and an up one of *f*; and so on alternately.

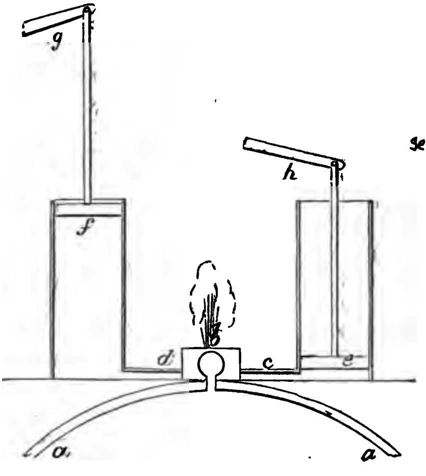
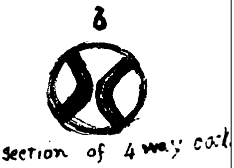


fig. 34.



Section of 4 way cock

By an inspection of the specification of Watt's steam-engine, already given, it will be seen that he contemplated the use of high-pressure steam; he, however, had a decided objection to its use, and consequently did not further prosecute his ideas. In 1802, Messrs. Trevethick and Vivian, of Cambourne in Cornwall, took out a patent for a high-pressure engine, which was used to propel a carriage or wagon; the arrangements of this engine are particularly ingenious, and some of the details modified, form features in many of the modern high-pressure engines. In fig. 35, the boiler *a a* is of a circular form, to resist the high pressure of the steam; to prevent the loss of heat by radiation, it is enclosed in a case filled with clay; the lower part of the case forms the fire-place, and the flame and heated air circulates round the boiler at its upper part, finally issuing into the chimney; *c* the cylinder, the lower part of which is within the boiler; *d* the piston; *g* the piston-rod, passing through a stuffing-box in the cylinder-cover, and having a connecting-rod *h* attached to the crank *i*; by this arrangement the fly-wheel revolves. The piston-rod works between guides, as shown in the diagram. A worm or snail wheel *j* in its revolution acts on the small wheel *k*, which is fastened on the end of the lever *l*, furnished with a counterpoise *n*; steam is admitted to the cylinder by the passage *e* through the valve *f*; by moving this cock or valve a quarter-turn, the steam is admitted either to the upper or under-side of the cylinder. By the falling of the wheel *k*, by the action of the cam or snail-wheel *j*, the lever is depressed and the weight *n* rises; this acts on a lever *m*, and by making its lower end move outwards, pulls the horizontal lever *o* through a part of its radius; and through the medium of the lever or spindle *h* the

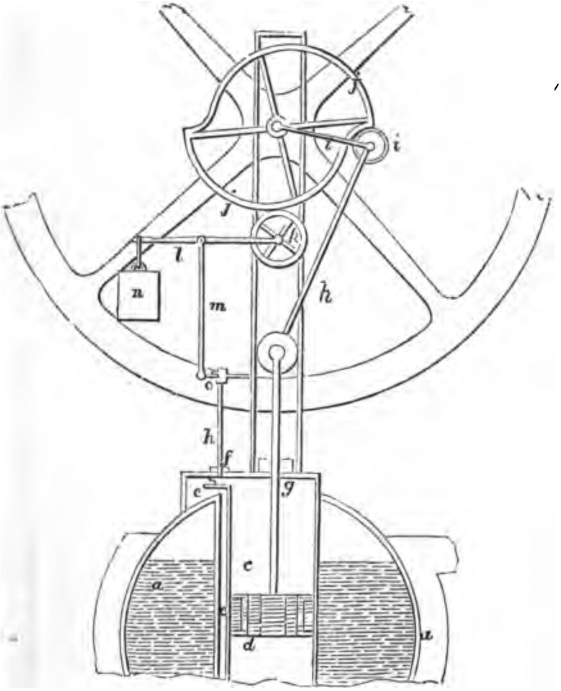


fig. 35.

valve is moved round one quarter. A click or ratchet is placed on the top of the spindle *h*, which, coiling up during the time that the lever *o* is moving outwards, does not move the cock *f;* but when the extremity of the worm-wheel *j* touches the wheel *k*, which will happen when the piston is near the top of its stroke, the wheel *k* goes into the cavity of the cam-wheel *j*; and the extremity of *m* returning, the lever *o* turns the cock *f* a quarter round; this admits the steam to the upper-side of the piston, and allows that beneath it to pass into the atmosphere.

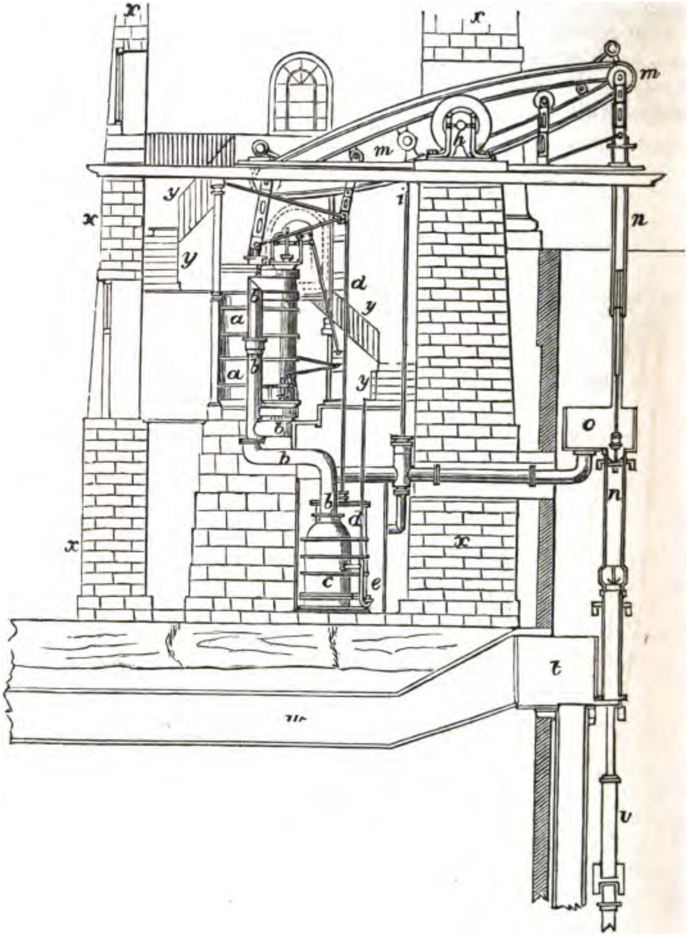


fig. 36.

We now proceed, as a conclusion to the present division of our work, to present examples of steam-engines in use at the present time; reserving for another division descriptions of the various details of modern engine-work; as boilers, safety-valves, feed-apparatus, cylinder-valves, valve gear-pistons—packed and metallic, &c. &c.

In fig. 36 we give a drawing of a large pumping engine erected at Walbottle Colliery, Northumberland, by the celebrated engineering firm of Messrs. Hawthorn of Newcastle. The principal feature in the arrangement is the economy and simplicity of working the forcing or plunger pump with two lifting-pumps direct from the beam; the engine, being a double-acting condensing one on the expansive principle, there is therefore no counterpoise on the left of the beam, the engine being equally loaded at the in-door and out-door stroke. The dimensions of the engine are as

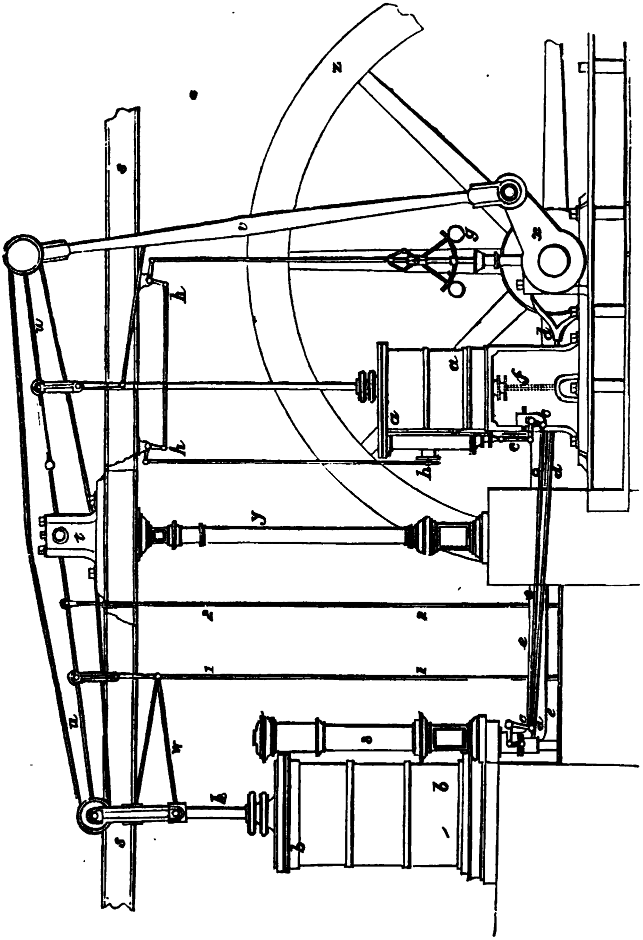


fig. 37.

follows: the cylinder *a a* is 77 inches in diameter, stroke 10 feet; the stroke of the beam *m m* 17½ feet and 14 feet—31½ total: length of stroke of pumps *n n* 8 feet, diameter of the plunger or ram 28¾ inches; diameter of lifting-pumps 16⅞ inches. The pumps deliver from 1100 to 1500 gallons of water per minute, according as the strokes are 5 or 7 per minute; *b b* the valves and steam-pipe leading to condenser *c*; *e* the injection-pipe and handle; *d d* the air-pump and lever; *n* the centre plummet-block, on which the great beam *m m* vibrates; *y y* the stairs for gaining access to the upper-story of the building *x x*. The water is led off to a neighbouring valley by the drift *t w*.

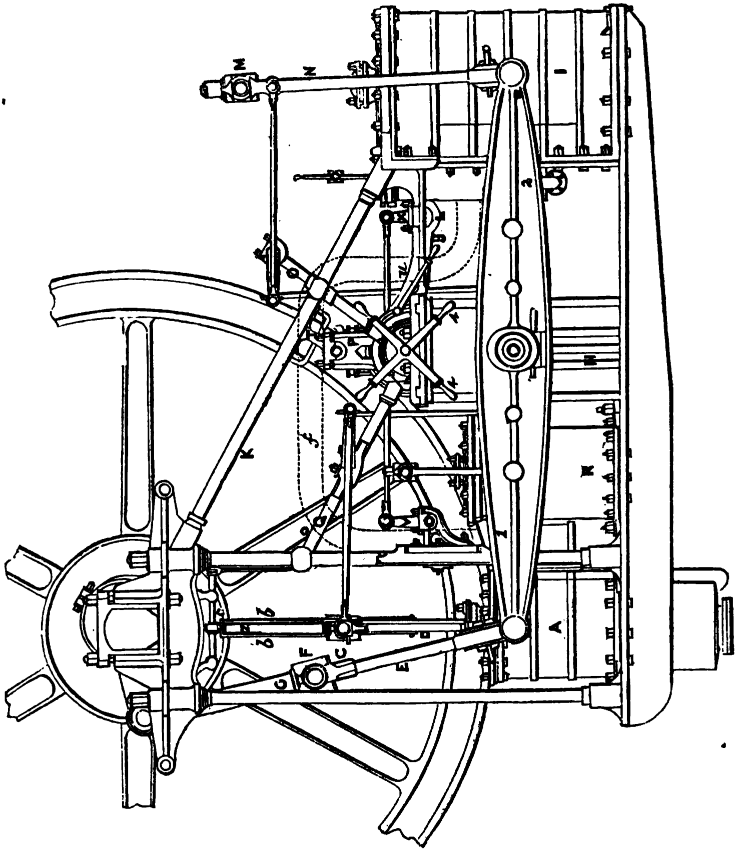


fig. 38.

In fig. 37 we give an elevation of a double-acting condensing engine, to which M'Naught's patent has been applied; without the small cylinder *a a* the arrangement of a double-acting condensing engine, as applied to manufacturing purposes, will be easily understood from an inspection of the figure; *s s*, the spring beam, on which the plummet-block *t* is fixed; *u u*, the working beam (or *walking* beam, as it is termed by working engineers); *v*, the connecting-rod for turning the crank and fly-wheel ~~2 2~~; x x *y* the central pillar, *b b* the cylinder, *k* the piston-rod, *w* the parallel motion; 1 1 the air-pump rod, 2 2 the hot-water pump; the valves in valve-casing, [illegible], are worked by the eccentric-rod and levers, *d d e*. Where the power of the engine originally fitted-up becomes too small for the increased work to be done, it is increased by the very judicious arrangement as patented by Mr. M'Naught of Glasgow and Manchester, and the principle of which is also shown in the diagram in fig. 37. The steam is admitted at high-pressure to a small cylinder *a a*, fitted on the side of the beam next to the connecting-rod, and the parallel motion of which is attached to the spring beam, in the same way as in the large or original cylinder *b b;* after working the piston of the high-pressure cylinder *a a*, the steam passes by the pipe *e* to the low-pressure cylinder *b b*, from which it finally passes to the condenser. The valves of the high-pressure cylinder are worked by levers *c c*, which are attached to the lever which works the valves of the large cylinder; by this arrangement the valve-gear of both the cylinders is connected; and when that of the low-pressure cylinder is disconnected, by throwing the main eccentric out of gear, both sets of valves are disengaged, and can be worked with the same handle or lever simultaneously. The cold-water pump is proposed to be worked, either by a continuation of the piston-rod of the high-pressure cylinder below the cylinder, as at *f*, or by a cross-head to the piston-rod of *a a*, furnished with side-rods attached to the ends of a cross-bar beneath the cylinder. To

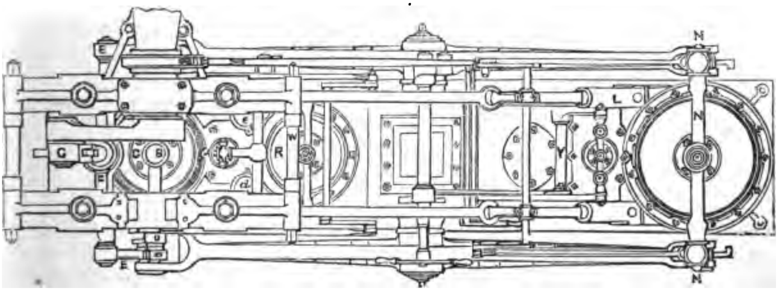


fig. 39.

this bar a pump or pumps may be attached. The steam acts upon the top of one piston and the bottom of another alternately; by this means much of the strain and shock is taken off the central journal of the beam *w w*; and by consequence, from the entablature-pillar and the walls. By this arrangement of double-cylinder engines much fuel is saved, extending in some instances to 40 per cent; increased steadiness of movement is also insured. The arrangement is also adapted to marine-engines, a class of engine which possesses many advantages, making it highly eligible for manufacturing purposes. The diagram in fig. 38 illustrates a form of marine-engine adapted for a factory, to which M'Naught's principle is applied. As this example presents many mechanical movements of interest to the student, we shall append a rather full description of its details. Fig. 38 is the side elevation, and fig. 39 the plan. The high-pressure cylinder A is 22 inches diameter, and 4 feet stroke; it is placed between the four wrought-iron columns supporting the crank-shaft. The system of connections for the crank is on the plan invented by Mr. David Napier.

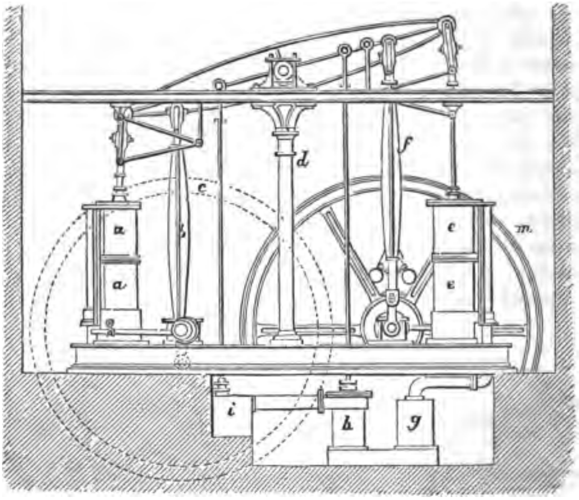


fig. 40.

The *low-pressure* cylinder I, which is worked by the exhaust steam from the cylinder A, is bolted to the sole-plate at the opposite end of the side-levers 1, 2. It is 33 inches diameter and 4 feet stroke. The crank-shaft bearing is stayed by two wrought-iron stays K, cottered into eyes cast on the inner ends of the crank-framing, and attached to the upper inner-edge of the cylinder by two eyes cast on the ends of frames L, attached at their extremities to the hot-well and the cylinder. The body of each of the pistons consists of a single hollow casting with four radiating strengthening feathers. The packing is composed of two cast-iron rings, each with two cuts, and actuated by a series of H springs placed between the body of the piston and the interior surface of the rings. The cross-head M is attached to the top of the piston-rod by a central eye in the usual manner, and is adjustable by a nut bearing on the upper-surface of the eye; from the ends of this cross-head the wrought-iron side-rods N N, pass down to the joint-studs in the double eyes of the side-levers, where they are attached in the usual manner (see *Mechanics and Mechanism*). The parallelism of the piston-rod is maintained by the arrangement of radius bars, detailed in the division of this work *Marine Engines*. The parallel motion-shaft of the low-pressure cylinder, I, is carried by a pair of short pillars O O, passing through round eyes forged in the diagonal stays circular portions of the valve rocking-shaft pedestals P. The parallel motion-shaft of the small cylinder is carried by bearings forged on the uppersides of the diagonal stays Q, which are fitted with round eyes at one end

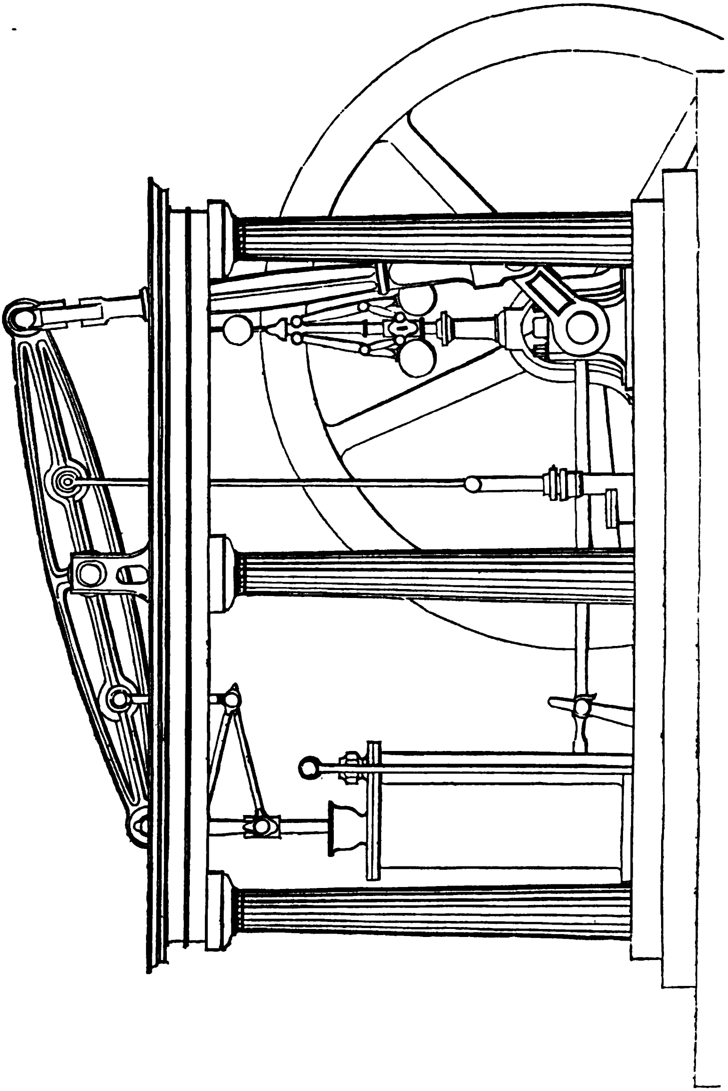


fig. 41.

for passing upon the wrought-iron pillars of the crank-framing, where they are supported by collars; the contrary ends are bolted to the pedestals P, upon which eyes are cast for the purpose. The air-pump R is worked by short side-rods attached to studs on the inner-sides of the side-levers, the cross-head being guided by light wrought-iron guide-rods bolted to the cover of the pump, and passing through eyes purposely formed in the cross-head; their upper-ends being fixed in the short diagonal stays Q. The condenser is of a rectangular section, and, together with the steam-passage leading from the low-pressure cylinder, is cast in one piece with the sole-plate. An air-vessel is fitted on its top, and on each side is bolted a pedestal P for the rocking-shaft of the valve-motion. The valves are of the usual single-cup species, similar to those used in locomotive engines; they are kept up to the valve-face by slight bent springs attached to the interior of the steam-chests. They are worked by an eccentric on the crank-shaft, the rod of which is fitted with a plain gab and guard at the extremity, for the pin of the rocking-lever T; the detaching apparatus for throwing it out of gear being worked by a hand lever on the end of a transverse shaft passing across the engine. The rocking-lever T is double ended, the eye at the lower end being jointed by a connecting link to a second lever V, placed on the rocking-shaft W, carrying a lever for working the valve of the high-pressure cylinder. The main rocking-shaft passes across the engine from front to back, and carries a short-toothed segment, placed just within the front pedestal. Near the end of this segment is placed a stud-pin, from which a lever-rod passes to the lever X, fast on the rocking-shaft Y; working on bearings in the frames L, and

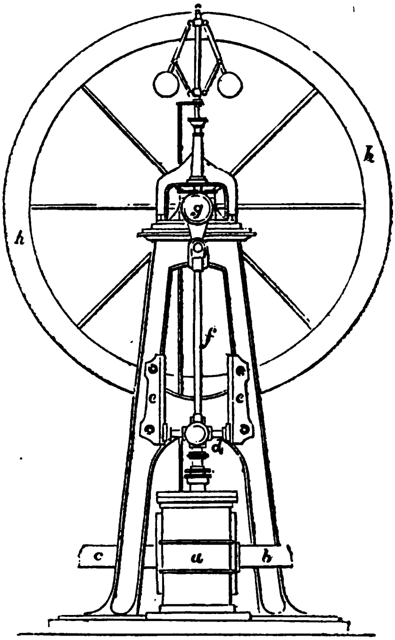


fig. 42.

carrying a lever at each end for giving motion to the cross-head of the low-pressure valve-spindle, which is guided by vertical rods, in the same manner as the air-pump bucket. By this arrangement the weight of one valve balances the other. The governor is situated behind the high-pressure cylinder, its spindle z being supported in a footstep on the engine-house floor, and steadied at its upper-end by two wrought-iron stays attached to the crank-shaft framing. The sliding-ring worked by the governor levers is jointed to two light links *b b*, passing up to a lever on the shafts *c*; whence, by a series of levers and connecting links, the motion

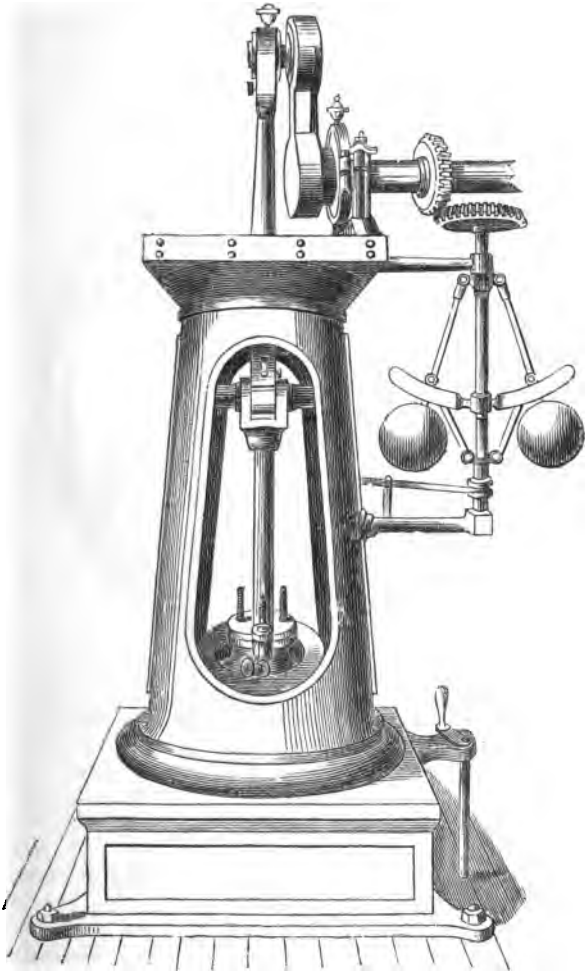


fig. 43.

is communicated to the throttle-valve, which is placed in the steam-pipe in front of the valve-chest of the cylinder A. The steam-pipe from the boiler, which is not shown in the drawings, conducts the steam by the thoroughfare *d*, seen in the ground-plan; a corresponding passage, *c*, conveys the exhaust steam by the dotted copper pipe *f*, to the front of the valve-chest of the low-pressure cylinder.

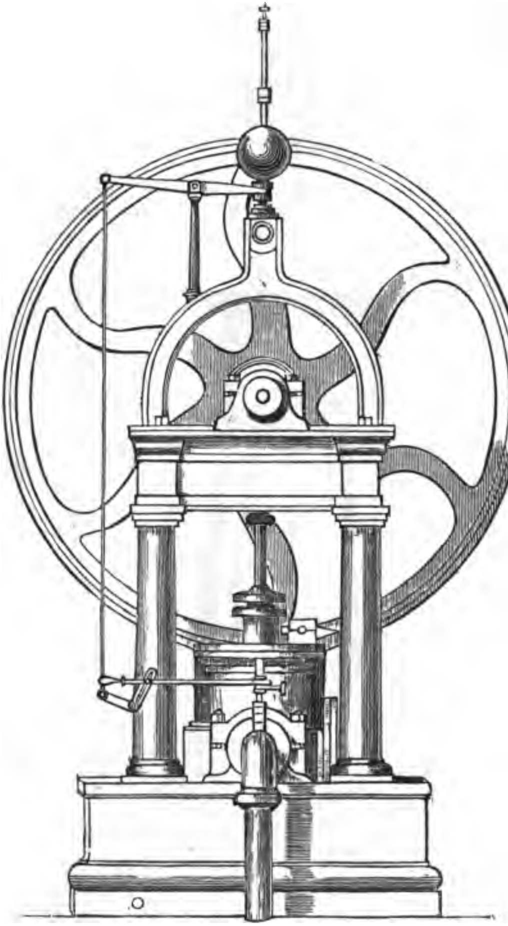


fig. 44.

The hand-gear for the valves consists of a quadruple lever, fast on a short spindle carried in bearings on the top of the condenser; on the inner end of this spindle is a small pinion, working into the toothed segment, previously mentioned as being fixed on the main valve rocking-shaft. By this means, when the eccentric-rod is thrown out of gear with the rocking-lever by handle w, the valves may be worked with great care by the quadruple-lever 4, 4. The engine is bolted down to a foundation of masonry by twelve bolts,—four at the high-pressure cylinder, four at the main centre, and four at the low-pressure cylinder. Two cast-iron beams of the double *z* section, 8 inches wide and 6 deep, are laid along the bottom

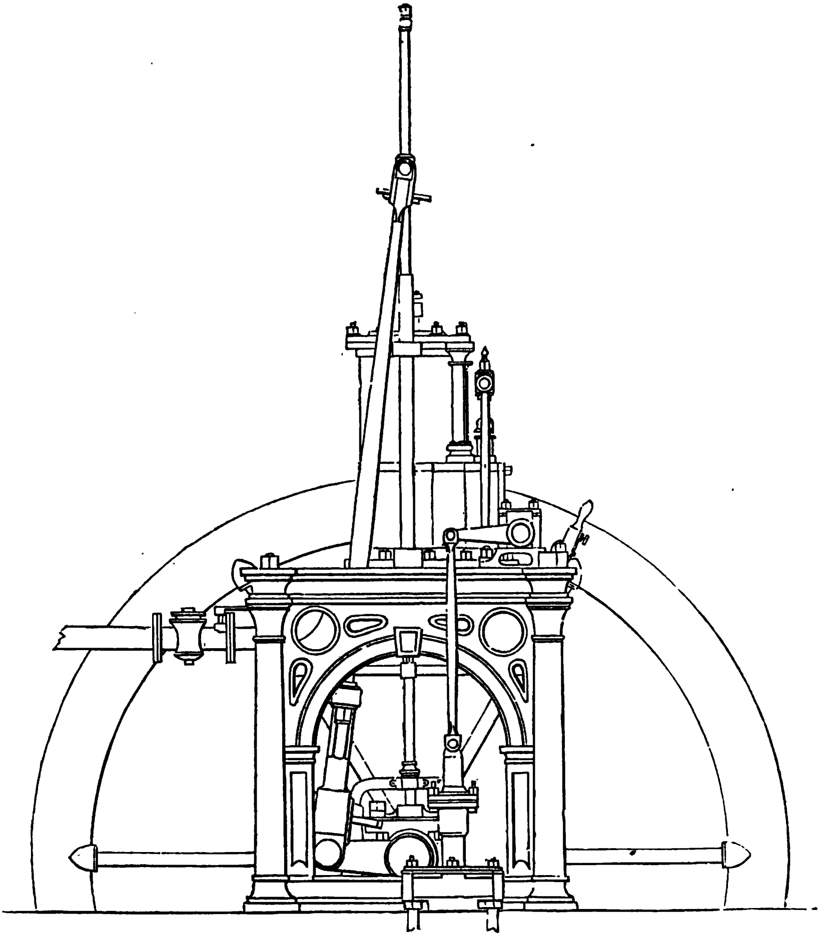


fig. 45.

of the masonry in a longitudinal direction, and through these the holding-down bolts pass; thus binding the whole foundation together, and giving the sole-plates a firm hold. Two transverse beams of similar section are laid in the masonry, above the longitudinal ones, their ends being laid in

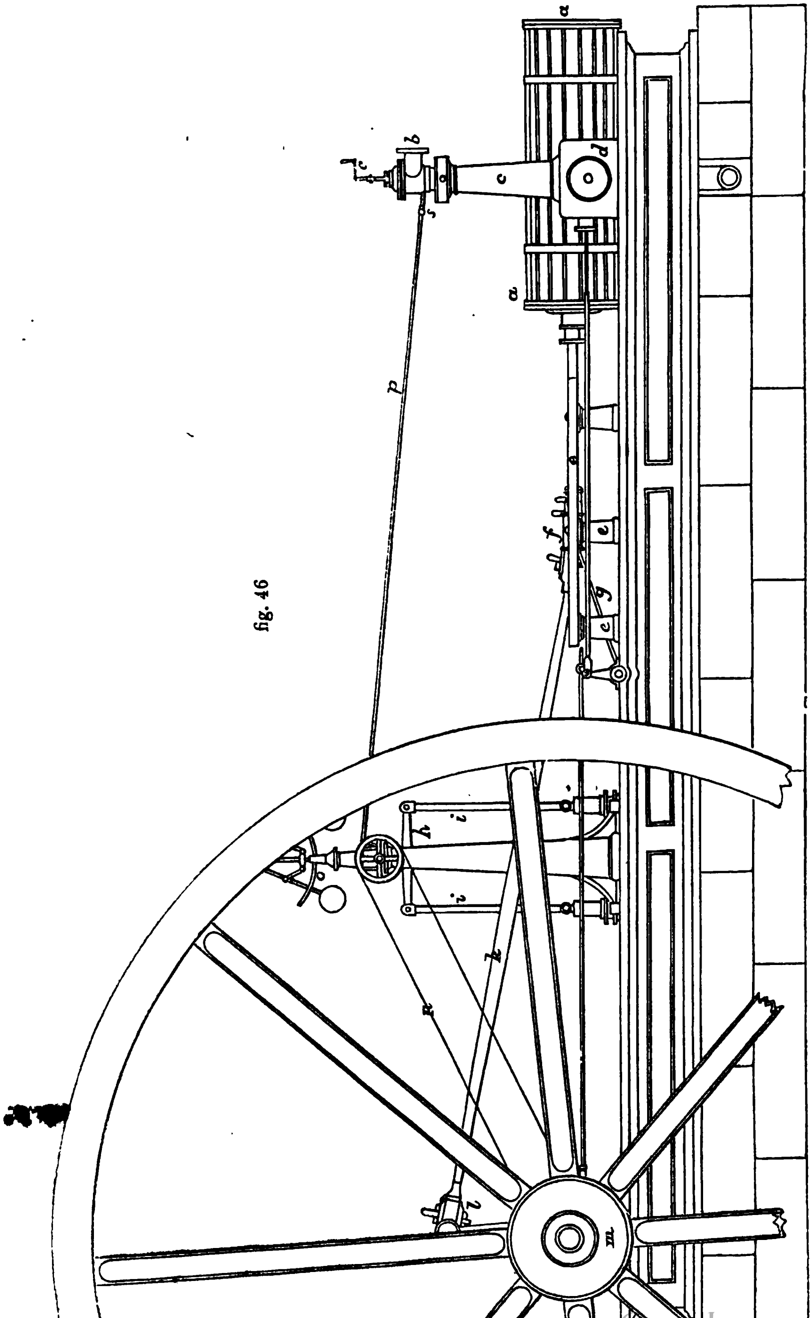


fig. 46

plan a considerable saving in the depth of masonry is effected, and a most substantial base is formed. The action of the engine is precisely similar to the ordinary Woolfe double-cylinder engine; but the relative position of the two cylinders, effects to a very great extent the economy and regularity of the expansive action of the steam, which may be here carried out to the utmost extent. The high-pressure steam, acting at one end of the side-levers, is always balanced by that of the low-pressure and the vacuum in the larger cylinder; so that the combined power of the two is conveyed to the crank-pin as if from a direct-acting cylinder. The example we have given is estimated at 60-horse power; but with the full pressure of 35 lbs. it can be worked up to 120. It was manufactured by Messrs. J. and G.

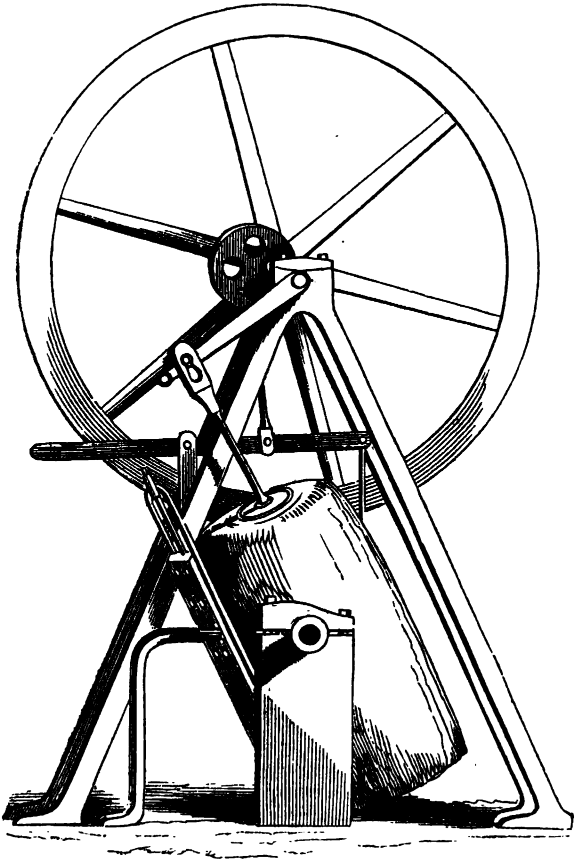


fig. 47.

Thompson, of the Clyde Bank Foundry, for the flax-mills at Prinlaws; for the drawings and description we are indebted to the courtesy of the editors of the *Practical Mechanic's Journal*, Messrs. Johnstone.

In fig. 40 we give an illustration of another form of double-cylinder expansive engine, lately introduced by Messrs. Varley: *aa* is the high-pressure cylinder; a connecting-rod *b*, placed between the cylinder and the central pillar *d*, gives motion to the fly-wheel *c*; the eccentric on the shaft moves the valves of the small cylinder; the steam, after working the small cylinder, passes to the low-pressure arc *ee*; a connecting-rod *f* moves the fly-wheel *m*; *g* is the condenser, *z* the air-pump, *i* the hot-water cistern. This engine possesses considerable novelty of arrangement, and is said to offer advantages in working economically. The balance of the moving parts is likely to insure steadiness of movement.

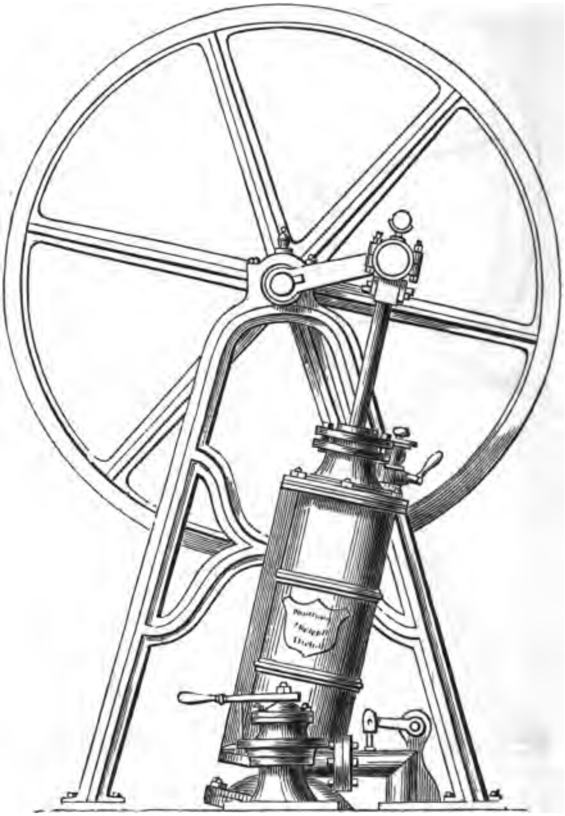


fig. 48.

In fig. 41 we give a side elevation of a high-pressure steam-engine of neat design.

In fig. 42 we give an elevation of a high-pressure engine of the kind known as "crank-over-head:" *a* is the cylinder, *c* the supply-pipe from the boiler, *b* the exhaust; the piston-rod is furnished with a cross-head *d*, which slides in the parallel slides *ee*; *f* the connecting-rod joined to the crank *g*, *hh* the fly-wheel; motion is communicated to the governor spindle from the fly-wheel shaft; the governor acts on a throttle-valve on the pipe *c*; the valves are worked by an eccentric placed in the fly-wheel shaft.

In fig. 43 we give an elevation of Fairbairn's high-pressure crank over-head engine. This is a first-class engine of its kind, the principal peculiarity being that the working parts are placed within a circular casing of great elegance of design.

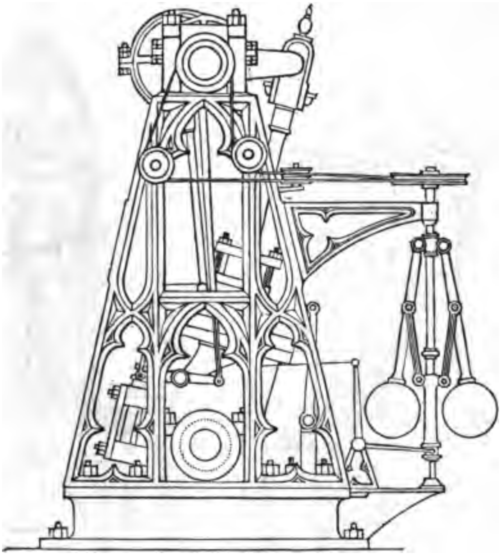


fig. 49.

In fig. 44, which is an elevation of Crosskill's fixed high-pressure steam-engine, we give another example of the crank over-head variety.

In fig. 45 we present an elevation of the form of high-pressure engine known as the "table engine;" in this form the fly-wheel shaft is beneath the table or platform on which the cylinder stands; the shaft is provided with two cranks, side-rods being connected with them, and attached at the upper-ends to the ends of a cross-head fixed on the piston-rod end; the ends of the cross-head move in parallel guides. (See *Mechanics and Mechanism.*)

In fig. 46 we give a side elevation of a horizontal engine, in which the cylinder *a* is placed horizontally; *b cc* the steam-pipe, *d* the valve casing, *ee* the piston-guide, *f* the piston-rod connected with the connecting-rod *k*; the crank is at *l*, fly-wheel at *m*; the governor *o* is moved by the cord *n*, with a small pair of bevil-wheels, *p* the rod for communicating with the throttle-valve at *s*; the pumps *ii* are worked by the oscillating lever *n*, the stud of the lever is lengthened, and a lever is connected with it, which extends downwards, and is moved backwards and forwards by the rod *g*, which is connected to it at its lower end, the rod *g* being connected with the piston-rod stud.

We now present examples of a form of engine in which the parts are much simplified; this variety is termed the "oscillating engine." The cylinder vibrates on an axis either at top or bottom; at top if vibrating in a vertical plane, but at bottom if horizontally; by this arrangement the rectilinear motion of the piston is made to accommodate itself to the circular motion of the crank, the piston-rod stuffing-box moving through the arc of a circle; this enables the piston-rod to be connected at once with the crank, without the intervention of a connecting-rod; thus securing the advantages of direct action. The valves are worked in the ordinary way by eccentrics and levers; but in some examples the action of the cylinder itself is made to open and shut them; thus simplifying the arrangements to a great degree. It is interesting to note that Watt constructed a model of this form of engine. This is shown in fig. 47.

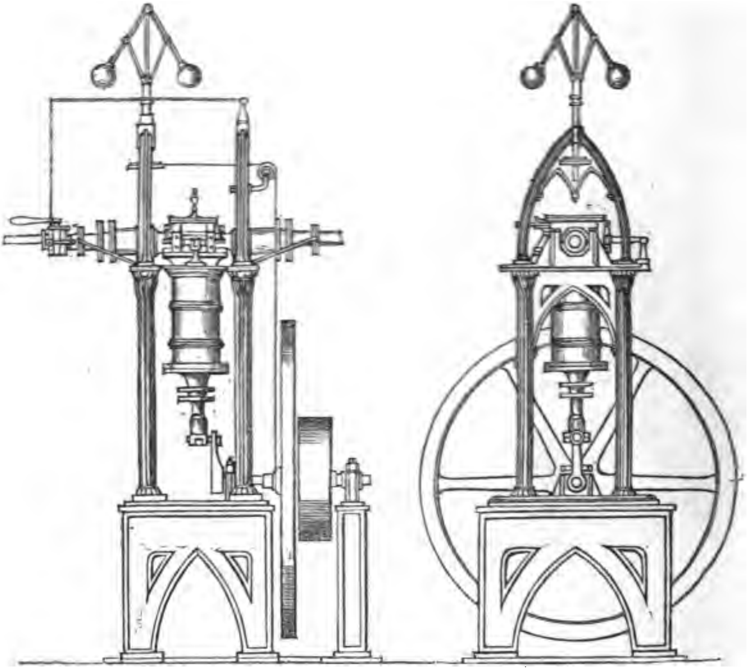


fig. 50.

The cylinder in this model, which was exhibited in the Great Exhibition, is cased with wood.

In fig. 48 we give an elevation of an oscillating engine by Evans exhibited in the Crystal Palace; and in fig. 49 another example also exhibited in the same place; it is of very elegant design, in the Gothic style, and is manufactured by Pope and Sons of Greenwich.

In fig. 50 we give two views of a modification of the oscillating engine, introduced by Mr. Joyce of Greenwich, and termed the "pendulous engine." The principle introduced by Woolfe is carried out in this form of engine; the cylinders are bedded side by side, and inverted; and suspended between the framing, the trunnion-pipes or steam-ways being placed at the ends, or what in the ordinary engine would be termed the bottoms of the cylinders. By this arrangement, a direct motion is given to the crank, without the introduction of the usual assemblage of appliances on the beam-engine. The cylinders vibrate from side to side, the movement of the cylinders working the slides by means of a bar; in the cuts, fig. 50, a front and side elevation is given.

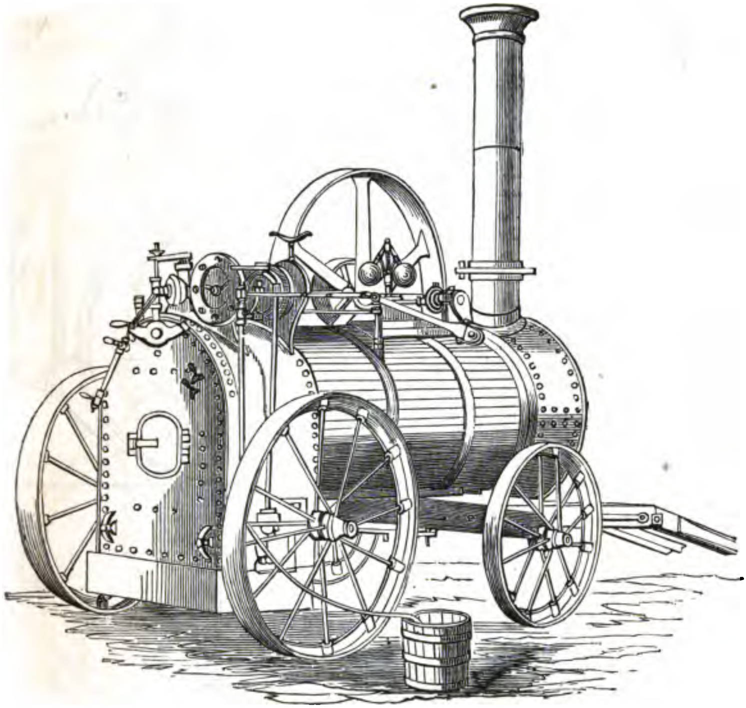


fig. 51.

Portable steam-engines are now much used for a variety of purposes, and in agricultural operations. In fig. 51 we give a view of Clayton and Shuttleworth's agricultural portable engine; and in fig. 52 Messrs. Barrett and Exhall's engine for the same purposes. In fig. 54 we give an elevation of Gough's portable engine, for pumping water from quarries and excavations; and in fig. 53 another adaptation for drawing up earth from railway cuttings, &c. &c.

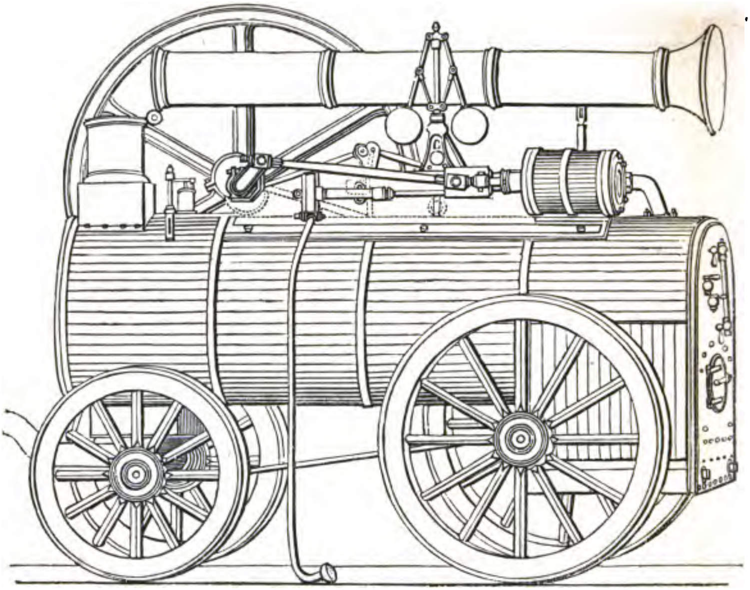


fig. 52.

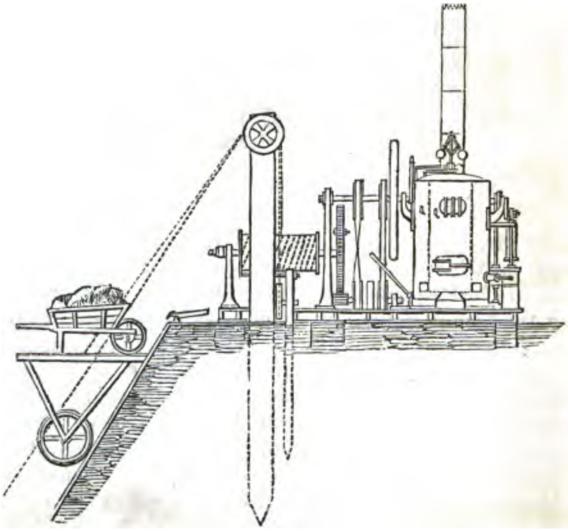


fig. 53.

In fig. 157, p. 81, *Mechanics and Mechanism*, we give the side elevation of a steam-pumping engine, applicable as a portable steam-engine for agricultural purposes by disconnecting the pump; we now give the front elevation, in fig. 55; *a* cylinder; *b* crank axle and horizontal slide; *d* the plunger; *ef* air-vessels; *g* inlet; *h* outlet.

In fig. 56 we give an illustration of the steam-engine for working a fan for withdrawing air from mines; and in fig. 57, Usher's steam-plough. In p. 113, fig. 206, *Mechanics and Mechanism*, we give an elevation of Nasmyth's steam-hammer.

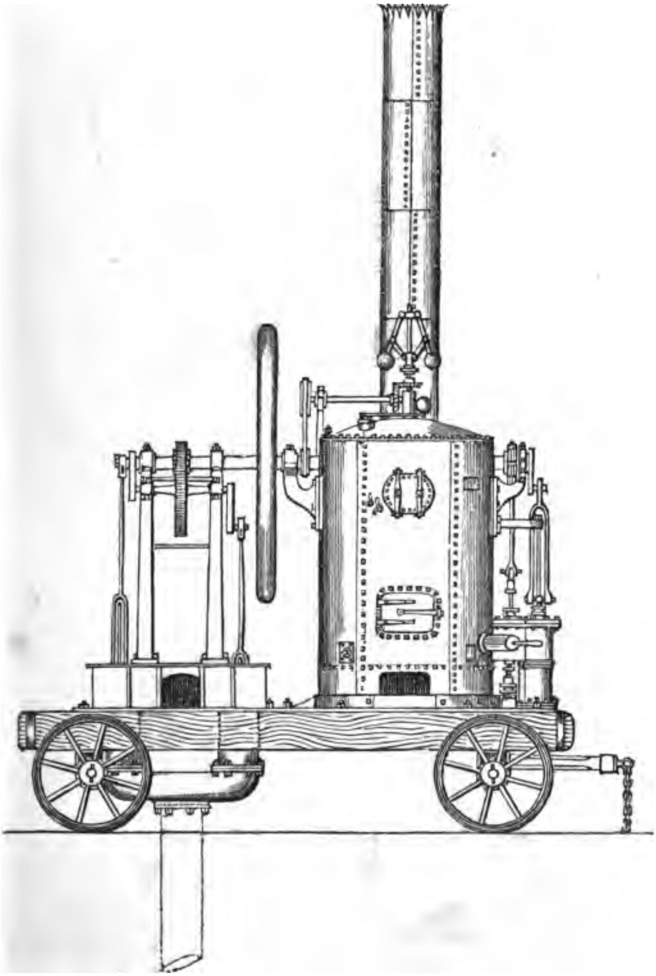


fig. 54.

In another chapter we propose to describe the rotatory engine, and

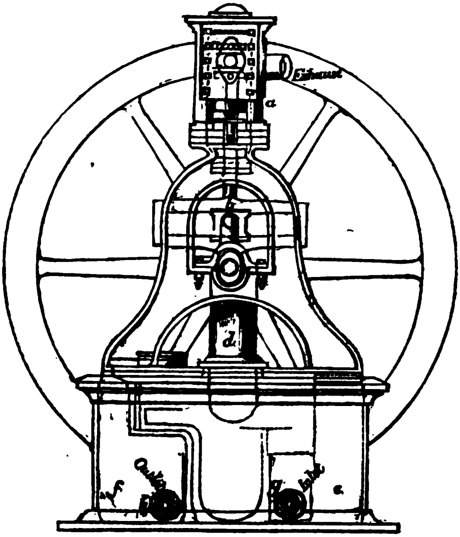
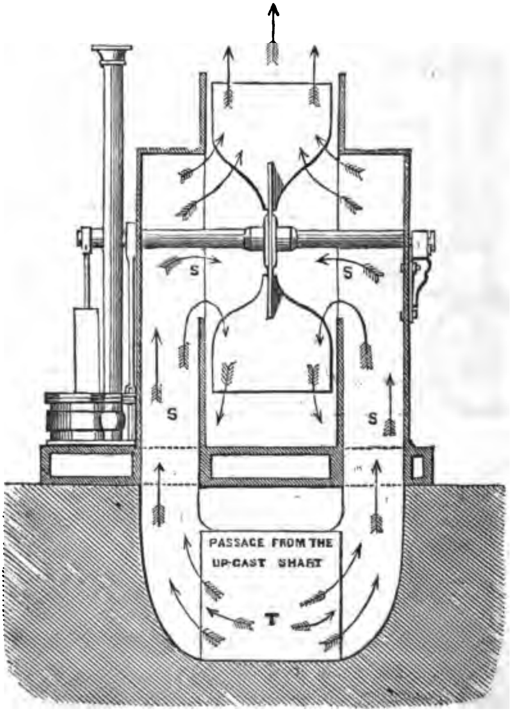

Exhaust
a
d
f
Outlet
Inlet
e

fig. 55.


S
S
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PASSAGE FROM THE UP-CAST SHAFT
T

other varieties, as the disc-engine, the arrangements of which present peculiarities different from those which we have already described. In the mean time we hasten to describe the various details of the cylinder engines.

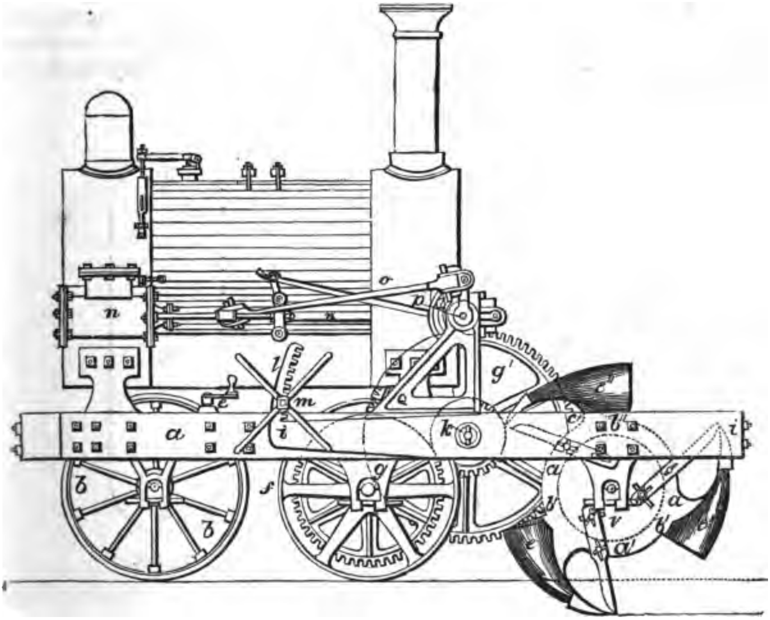

fig. 57.

CHAPTER III.

DETAILS OF BOILERS AND ENGINES.

Before describing the appliances of boilers as now adopted in modern practice, we propose giving a few sketches, illustrative of the varieties of boilers which have been introduced from time to time.

In the sketch given in fig. 19 of Smeaton's Chacewater engine, the form of boiler will be seen. Smeaton paid great attention to the construction of boilers; and a favourite form of his is known as the "hay-stack," or "hay-cock" boiler. A diagram, showing its form, is given in fig. 58; *a* is the fire-place, *cc* the upper flues, *bb* the lower ditto; the steam was taken from the upper-part *d* through the pipe *e*. This boiler was formed of plates of cast-iron, joined together with flanges and bolts. The cylindrical boiler, as in fig. 59, is constructed with two circular or semi-spherical ends, as at *aa:* the ends of this form of boiler are in America generally made flat. In some instances an internal circular flue, as *a*, fig. 60, is provided in this form of boiler; the flue extends from end to end, and the heated air and smoke, after passing from the fire-place, goes through this flue in its passage to the chimney. This form of cylindrical boiler, called the "Trevethick," from its introduction being attributed to that engineer, is generally used for high-pressure engines. When properly constructed it is very strong, and capable of resisting a very high degree of pressure.

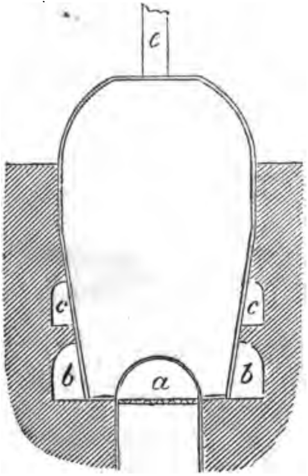

fig. 58.

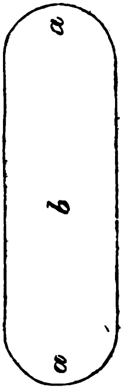

fig. 59.

We have already figured the form of boiler known as the "waggon" adopted by Watt. A boiler very generally used for condensing engines, and known as the "Cornish," consists of a cylindrical boiler, having a large internal circular flue, in which the fire-place is situated. The introduction of this form of boiler "has effected great improvements in the economy of fuel as well as the strength of the boiler." This form is shown in the sectional diagram in fig. 61, where *aa* is the boiler, *b* the internal flue, *c* the fire-bars. In order to obtain a larger fire-place in the Cornish boiler, one-half of the end in some instances has been cut away: this was first done by the Butterley Iron Company, and the boilers in which this arrangement is adopted are known as the "Butterley;" they are much used in Lancashire. The form is shown in the diagram fig. 62.

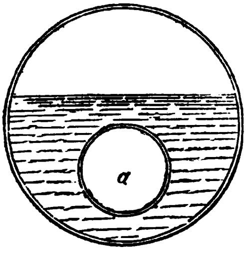

fig. 60.

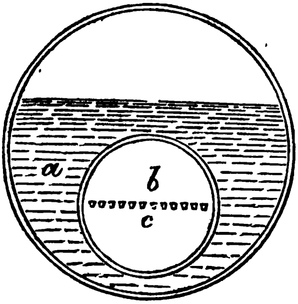

fig. 61.

The form of boiler which is considered by competent authorities as a very effective and economical kind, is that known as the double-flued and double-furnaced boiler, a sectional diagram of which is given in fig. 63; *a a* the flues, *b b* the furnaces, *c c* the boiler. This is now in general use, and is fast superseding all other constructions. "It consists," says Mr. Fairbairn of Manchester, "of the cylindrical form, varying from five to seven feet in diameter, with two flues, which extend the whole length of the boiler; they are perfectly cylindrical, and of sufficient magnitude to

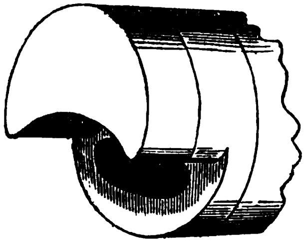

fig. 62.

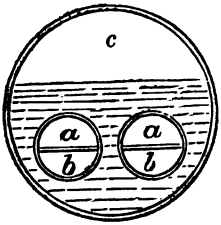

fig. 63.

admit a furnace in each. This boiler is the simplest, and probably the most effective, that has yet been constructed. It presents a large flue-surface as the recipient of heat; and the double flues, when riveted to the flat ends, add greatly to the security and strength of these parts. It moreover admits of the new process of alternate firing, so highly conducive to perfect combustion, and the prevention of the nuisance of smoke."

The boiler known as the "French," as having first been introduced into practice in France, and which is much used in Lancashire, is figured in fig. 64: *a* is the cylindrical boiler; *c c*, two tubes, stretch longitudinally below the boiler, and receive their supply of water by the vertical tubes *b b*, a brick arch *f* is thrown over, between the tubes *c c*; by this arrangement the flame and heated air from the furnace at *d*, fig. 65, pass along the under-side of arch *f* and tubes *c c;* returning to the chimney along the space between the bottom of tubular boiler *a a* and upper-side of arch *f*. This form of boiler is highly efficient; and the principle of making the flame and heated air impinge upon the outside of tubes containing water, instead of passing through the inside of tubes surrounded with water, is considered by some to be possessed of such superior advantages, as to be likely soon to supersede all other arrangements. This principle is carried out in a very effective manner by Messrs. Galloway in their patent boilers, which are taking a high place in the engineering world. Fig. 67 is a

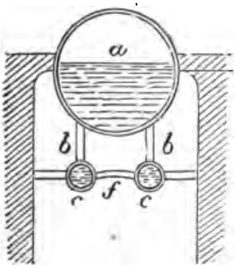

fig. 64.

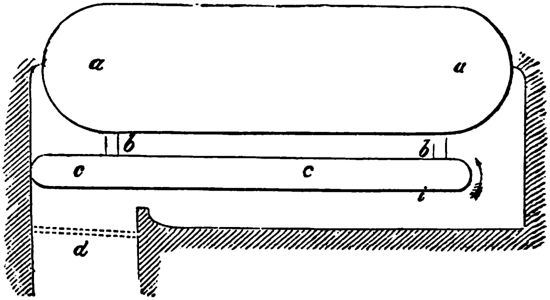

fig. 65.

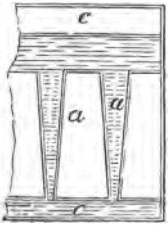

fig. 66.

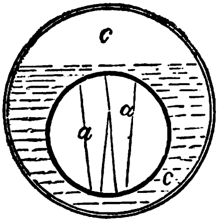

fig. 67.

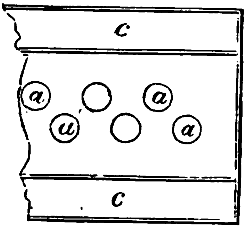

fig. 68.

sectional diagram across the boiler; fig. 66 part longitudinal section, and fig. 68 part plan. The peculiarity consists in arranging a series of vertical conical tubes, *aa*, within the central flue, in a zig-zag form, connecting the upper and lower part of the boiler *cc*. The boiler is of the double-furnace kind, firing each furnace alternately.

The great efficiency of the locomotive boiler, in which the heated air passes through the inside of tubes which are surrounded externally with water, has directed the attention of engineers to the construction of boilers for stationary engines on this principle. Fig. 69 is a longitudinal section

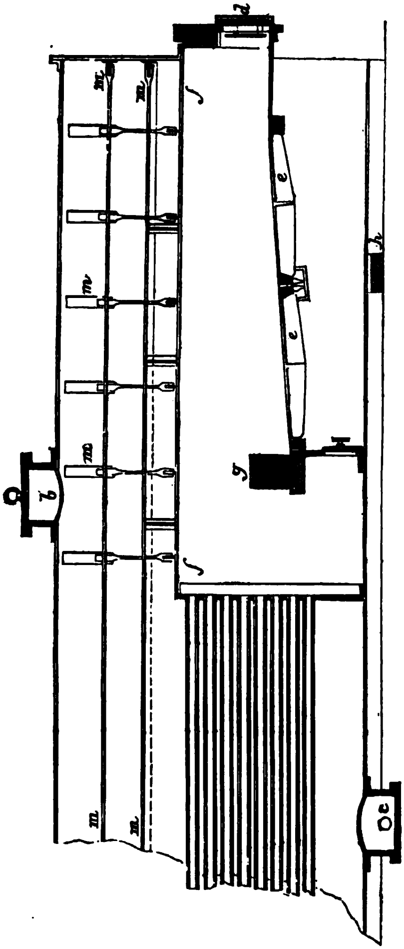

fig. 69.

of Messrs. Gordon's multitubular boiler, and fig. 70 a transverse section. This form of boiler requires no brick-setting; but after being attached to the engine and to the chimney-flue, can be set at work. They have double furnaces, which are fired alternately: *d* is the fire-door, *ff* the combustion-chamber, *ee* the fire-bars, *g* the fire-bridge, *aa* the tubes, *c* the pipe from which to withdraw the sediment, *b* the man-hole door, *m m* the stays to strengthen the boiler, *h h* the standard for supporting the boiler.

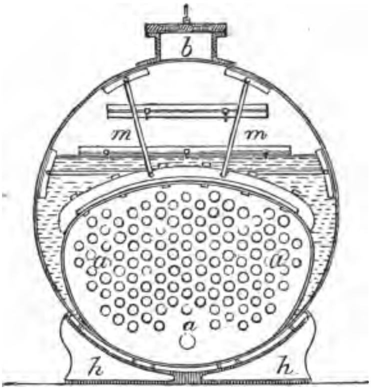

fig. 70.

The forms of boilers we have here given are such as are generally adopted for land or stationary engines; those for marine being arranged somewhat differently. It is impossible, under this division, to notice even a tithe of the arrangements introduced; we must content ourselves, therefore, with a few general notes.

The form of boiler originally introduced into steam-boats was merely

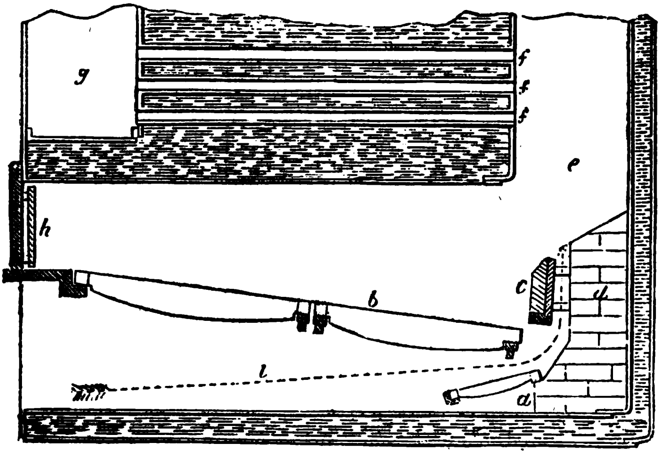

fig. 71.

a land-boiler, with large internal flues, like the Cornish boiler; the difference being, that in the latter the boiler was encased in brick-work, while in the former the external casing was of iron, leaving a space between, in which water was placed. The plan of the locomotive tubular boiler was next introduced, and with marked success. The next improvement was turning the tubes over the furnaces, as in fig. 71 : *h* the fire-door, *b* the fire-bars, *ff* the tubes passing through the boiler to the funnel-flue *g*. A form of boiler has been introduced, both for land and marine engines, which promises good results; it is known as the "vertical tubular," and is represented in the diagram, fig. 72, where *a* is the furnace door, *b* the lines representing the tubes; the heated air passes up through these, giving out the heat to the water with which they are surrounded. The tubes pass out at the top of the casing. As the water-level is below the top of the tubes, as at *b*, the steam is rendered thoroughly dry, or "anhydrous," as it is termed, and the inconveniences of priming are obviated.

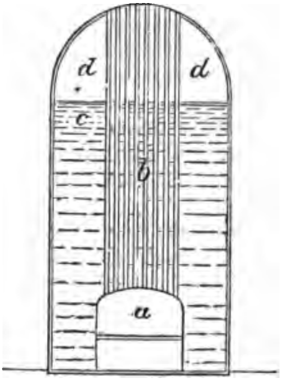

fig. 72.

The principle of boiler as patented by the Earl of Dundonald is considered good; it has been adopted with marked success in the line of Ocean American steamers of Collins. The diagram in fig. 73 shows the arrangement. The "boilers are provided with two rows of fire-places, and two tiers of tubes, one above the other, for the purpose of increasing the grate and boiler surface." The improved form of this boiler, as secured by the last patent of the Earl of Dundonald, is given in fig. 74 : *a a* the fire-bars (there are four furnaces abreast), the heated air passes over the inverted bridge named the "economical heat trap;" along *c* and *d*, and down among the tubes, and finally up the chimney-flue *e*; by this arrangement, "the heated products of combustion are retained in contact with the most efficient part of the heating surface of the boiler, until the complete ab-

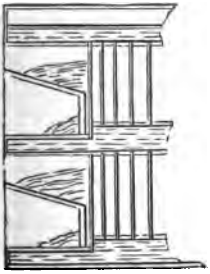

fig. 73.

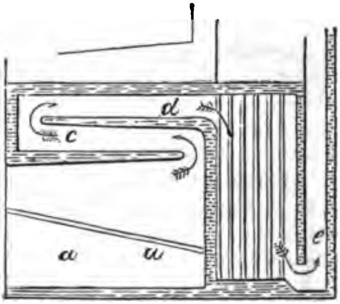

fig. 74.

sorption of all the useful caloric is effected." The natural tendency of heated air is to ascend; and only to descend when deprived of its caloric or principle of levity. In the ordinary boiler, the heated air has a free and uninterrupted ascent to the funnel; but in the patent boiler it is conveyed through the flues to the summit of the tube-chamber, and there constrained to maintain that elevated position by its levity, until the water has effectually absorbed all the useful caloric held in combination, and the products of combustion, deprived of their superabundant principle of levity, descend to the interior aperture leading to the funnel, where they escape into the atmosphere at a low temperature. It will be noticed, that in this form of boiler the French principle of filling the tubes with water, making the flame pass outside, is carried out.

Having now illustrated the forms of boiler introduced both for land and marine engines, to the extent we deem necessary for the purposes of our work, we now proceed to illustrate the appliances of modern boilers.

In condensing, or low-pressure engines, the water is supplied to the boiler through a stand-pipe; this is of altitude to contain a column of water sufficient to counterbalance the pressure of steam in the boiler. A small cistern is placed on the top of this stand-pipe, which is supplied with water from the hot-well by the power of the engine; a small valve is placed at the bottom of this cistern, which is opened by a lever; this lever is acted upon by the float in the inside of the boiler, the wire or rod connected with it passing through the top of the boiler, and fastened to the end of the lever: the arrangement has already been figured in Chapter II. In some instances, the wire or rod of the float passing through the boiler has stuck in its stuffing-box, and thus rendered the apparatus inoperative. A plan to obviate this has been recently introduced; this consists of a pipe, same height as the stand-pipe, containing a column of water; the rod of the float passing through this is moved without friction, and cannot stick. This apparatus of stand-pipe and float acts as a safety-valve in some measure, as before mentioned. The height of column of water in the stand-pipe is calculated so as to counterbalance the pressure of steam in the boiler; but should the pressure of steam increase beyond a certain point, the water will be forced out of the pipe through the valve in the cistern, and thus give timely warning. The stand-pipe has another apparatus connected with it, by which the degree of combustion in the furnace is regulated. At the throat of the chimney a valve, consisting of a flat plate sliding in a frame, is placed; when this is forced fully into its frame the aperture of the chimney is closed, thus preventing the smoke, &c. from the furnace gaining access to the chimney: by this means the intensity of combustion is lessened, and the fire finally goes out. In proportion, therefore, to the degree of opening of the mouth of the funnel, so will be the intensity of combustion in the grate. The sliding-valve has connected with it a chain, which, passing over two pulleys, is finally passed down the interior of the stand-pipe, and connected with a float which moves up and down in it. As the pressure of the steam increases in the boiler, the water is forced up the stand-pipe; this raises the float, and releasing the chain, the damper or valve at the mouth of the chimney is forced into its frame; the throat of the chimney is thus proportionally closed, the draught is diminished, the fuel in the furnace burns less fiercely, the pressure of steam is diminished, the water in the stand-pipe falls, and along with it the float; this tightens the chain, and the damper is pulled up.

In high-pressure engines, the chain of the damper passes over two pulleys, and is connected with a counter-balance weight, hung near the furnace door; the raising and depressing of the damper is done by hand.

In high-pressure boilers the water is supplied to the boiler by a force-pump, worked by the engine; the water being forced into the boiler against the pressure of the steam. A very ingenious apparatus for supplying high-pressure boilers with water, has been introduced by Mr. Turner of Ipswich. An elevation of this is given in fig. 75.

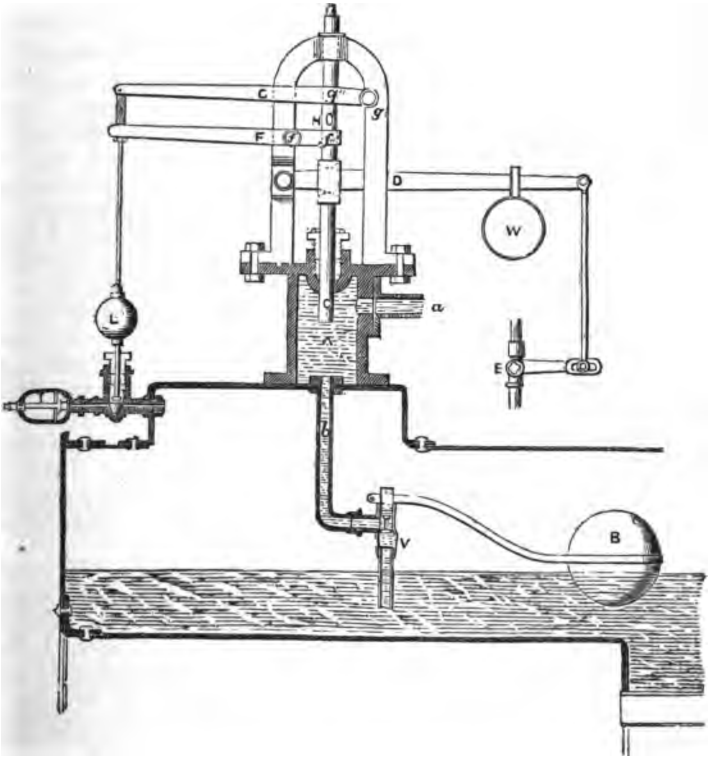

fig. 75.

This invention effects its object of rendering steam-boiler explosions arising from a deficiency of water next to impossible, by causing the boiler not only to regulate its own supply of water, but to sound an alarm almost instantly should the source of that supply fail; and to continue the alarm until its wants are supplied.

In fig. 75, A is a closed vessel, into which water is forced by the engine feed-pump through the pipe *a;* B is a portion of the boiler; V is a ball-valve for controlling the entrance of water from A; C is a ram of an area proportionate to the pressure and requirements of the boiler; D a lever carrying a weight W, which exerts a force upon the area of the ram considerably in excess of the force which the pressure of the steam would exert upon the same area; E is a small cock for admitting air to the pump; F and G are forked levers, having their fulcra respectively at *f* and *g*; H is a projection on the ram-guide, which acts upon the levers F and G; I is a steam-whistle; L a weight attached to the whistle-valve, exerting an upward pressure upon the lever F, and a downward upon the lever G. When the water in the boiler is at its proper level the valve is closed, and the water is forced into A; this raises the ram C and lever D, which turns the cock E, admitting air to the force-pump, and stopping its action. As the boiler takes its supply from A, the ram C descends, the air-cock E is closed, and the pump again brought into action.

In the event of the supply of water failing, the high-pressure maintained in A would rapidly fall to the same pressure as the steam in the boiler, owing to the communication through V remaining open. The excess of pressure from the weight W would thus be brought to bear upon the lever F; and counterbalancing the weight L, lift the whistle-valve, and sound an alarm. Should it happen that the air-pipe to the pump becomes choked, so that although the cock E be open the pump still continues to work, the pressure in A would rapidly increase, until sufficient to raise the lever G and the whistle-valve, thus sounding an alarm.

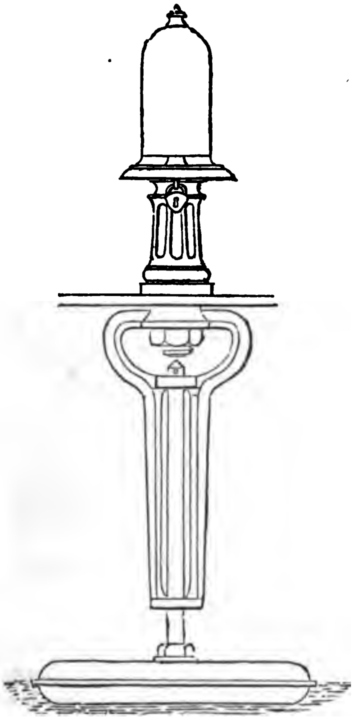
fig. 76.

A very ingenious apparatus for giving notice of the fall of the water in the boiler below its proper level, is that known as "Haley's safety signal for boilers."

The engraving, fig. 76, in which a part of the top of the boiler is shown in section, conveys a clear idea of this signal. The stand outside the boiler has a stem passing through a hole in the plate, screwed at the end, and provided with a nut. Inside the boiler it passes through the guide, and secures it and the stand at the same time; a copper float is screwed upon a brass spindle, working loosely through the guide, and which is hollow, except on the top, and is formed into a conical shape. A pin passes through this spindle near the top, to prevent its falling through the guide when the boiler is empty; and a little below, a small aperture admits steam through the hollow spindle into the interior of the float, by which means the inside and outside pressure are equalised; and being near the top of the spindle, water cannot enter the float. Immediately over the cone, through the stem of the stand, is a small aperture leading to a whistle locked up within the dome at the top. When the water is any distance above low-water mark, or the signal point, the float is lifted, and the cone presses against the aperture and closes it. When it falls below the warning-point, the float falls with it, and the aperture is opened, allowing steam to pass through it to the whistle.

The combined "safety-valve and water-indicator" of Messrs. Dangerfield and Bennet, is shown in figs. 77, 78; the former being an elevation, and the latter a section of the apparatus. Should the water in the boiler fall or rise beyond a given level, the buoy or float attached to the float-chain, which works round the wheel *a*, and is balanced at its other extremity by the weight *b*, rises or falls with the water. If falling, the end of the long link *c* presses on the lever *d*, opens the valve *e*, and permits the steam to escape; the steam in escaping comes in contact with a bell which is placed over the valve *e*, and continues to give a loud and shrill whistle, until the water in the boiler is again brought to its proper level; or being neglected, the whole of the steam escapes from the boiler, which causes the machinery to cease working, stops the water from being forced into the boiler upon the hot plates, and thereby prevents an explosion. The water in rising produces the same action upon the opposite lever. The column *g* opens as a door down its entire length, to admit the weights on the valve *e*; the weights being put in proportion to the area of the valve, and the pressure the boiler is intended to carry. The weights on the valve *e* are securely locked in the column *g*, and cannot be interfered with to cause any undue

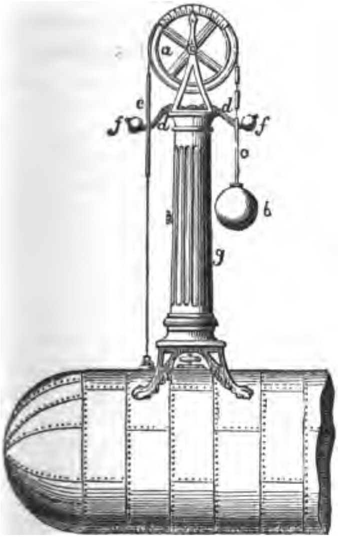

fig. 77.

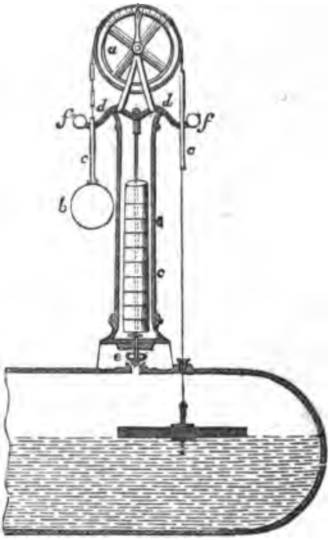

fig. 78.

pressure. The balls *f* balance the valve and levers when out of action. An index is fitted on the wheel *a*, which shows the height of the water in the boiler. This apparatus is very elegant in its general appearance, and has the merit of being self-acting.

In addition to these and other kindred contrivances, to notice all introduced for the last thirty years would take a goodly sized volume. The actual level of the water in the boiler is made visible by the contrivance known as the "water-guage;" this will be found described in the chapter on Locomotives. We pass on, therefore, to notice other appliances of the boiler. The pressure of the steam on the water in the boiler has been taken advantage of by Mr. Wilson, of Low Moor Iron Works, in his "safety apparatus for boilers," shown in fig. 79, which is part of a longitudinal section of a boiler with internal furnaces: *a* is a vertical pipe, like an ordinary feed water-pipe for low-pressure boilers. It is open at its lower end *b*, which is set about one inch above the top of the furnace-plates of the flue *c*, and passes up through the top of the boiler to a height sufficient to obtain a column of water rather more than equal to the greatest steam pressure at which the boiler is intended to be worked. Near the upper-end of this pipe, a branch *d* is formed upon it, forming a junction with the second vertical pipe *e*, which passes downwards outside the boiler-end; and its extremity is bent to terminate in the front of the furnace at *f*; or if two or more furnaces are fitted in each boiler, then a communication of the same kind must be formed with each of them. The height of the discharge-branch *d* is such, that at the ordinary working steam-pressure of the boiler, the water forced up the pump by this pressure shall stand at some point beneath the branch *d*. Should, however, the steam-pressure be increased by any means beyond the due working pressure, the water will rise higher up the pipe *a*, until, if the pressure increase, it reaches the branch *d*; when it will pass through the latter, descend the pipe *e*, and pour into the furnace.

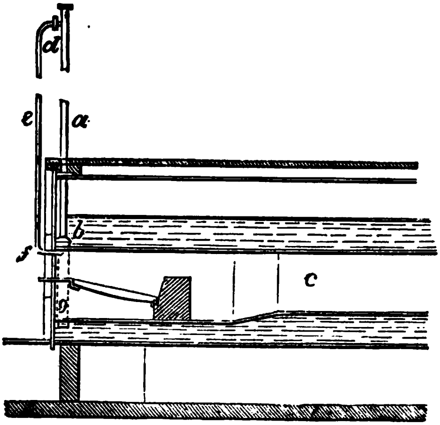

fig. 79.

This discharge of water will at once damp the fire, and therefore reduce the steam pressure; whilst, at the same time, it will draw the attention of the engine-attendant to the fact, that all is not right with the boiler. The open end *b* of the pipe *a* in the boiler is not exposed directly to the ebullition of the water, which would tend to derange the action of the apparatus; but is protected from this influence by insertion into a short length of wider pipe *g*, open at top and bottom, the water standing at the same level within it as in the boiler. In this way the water contained in the guard-pipe *g* is kept in a comparatively undisturbed state, the stilling effect of the pipe being further assisted by its expanded or funnel-shaped upper-end. In attaching this apparatus to a boiler, the branch *d* must be set at such a height as will allow of the obtainment of a column of water in the pipe *a*, of a head pressure a little more than the pressure to which the safety-valve *h* is loaded, so that the latter may have a short range to permit it to work freely when in good order, without the protector or water-discharging apparatus being brought into play. Thus, when the slight difference between the head-pressure in the water-pipe *a*, and that to which the safety-valve is loaded, is exceeded, owing to the sticking of the latter, or from any other cause, then the protector acts at once upon the fire. When the water-level in the boiler falls below the open end *b* of the water-pipe, which would endanger the overheating of the boiler-flues, a portion of the water contained in the pipe at the time will drop out of the end *b* into the boiler, whilst the remainder will be forced up the pipe by the steam pressure. As the upper-end of the pipe is closed, with only a small aperture to prevent its acting as a syphon when water passes down its branch *d*, the steam and water blown out will pass down the descending pipe *e*, and damp or extinguish the fire. This discharge of steam being so contrived that it shall take place before the parts of the boiler liable to overheating are quite bare, the damping of the fire will always remove all danger of explosion or injury to the boiler; which may be again set to work, after the supply to it of a proper quantity of water, which may be supplied at once without fear of any injurious effects. The advantages of this apparatus are, that it renders the dangerous accumulation of steam impossible, being entirely free from valves or connections, which are liable to derangement; whilst it can never fail to call the attention of the attendant to any objectionable increase of pressure, and it will remove the cause of the over-pressure unassisted."

Where the steam in boilers reaches a degree of pressure likely to be dangerous to its safety, what are termed "safety valves" are used. Mr. Fairbairn calls them the only "legitimate outlets" in circumstances such as the above. Two should always be provided to every boiler, of sufficient capacity to carry off the quantity of steam generated by the boiler. To prevent additions being made to the weight, Mr. Fairbairn, recommends a "lock-up valve," as represented in fig. 80. *a* is the valve; *b* is a shell of thin brass,

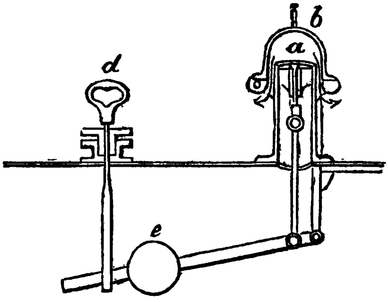

fig. 80.

opening on a hinge, and secured by a padlock; it is of such a diameter as to allow the waste steam to escape in the direction of the arrows. *c* is the weight, which may be fixed at any part of the lever to give the desired amount of pressure, but which cannot be fixed or altered unless the boiler is opened to allow a man to get inside. *d* is a handle, having a long slot, by which the valve may be relieved or tried at any time, to obviate the liability of its corroding or being jammed; but the engineer cannot put any additional weight upon the valve by this handle. The sticking of the valve in its seat is always a fruitful source of danger.

As a valuable aid towards obviating such disasters, we here illustrate and describe, in fig. 81, the very neat valve registered by Mr. James Nasmyth, of the Bridgewater Works, at Patricroft, which has met with very general and high approval, as uniting in a most simple combination all the qualities which can tend to the formation of a true and perfect safety-valve.

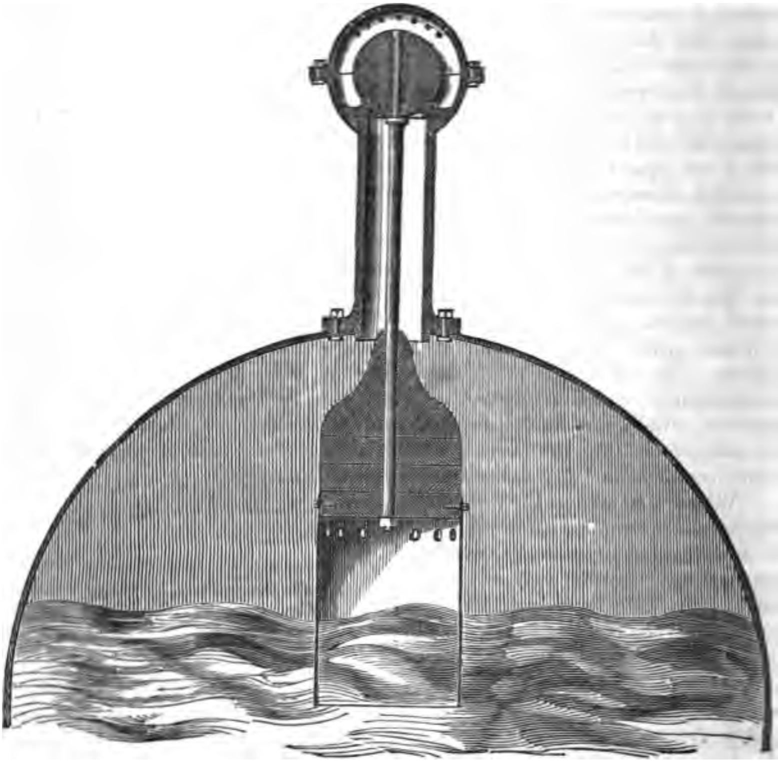

fig. 81.

The total absence of all spindles or other guiding agencies, which have hitherto proved so fertile a source of mischief and uncertainty in the action and permanent perfect condition of this vital part of a boiler apparatus, will be seen at a glance to characterise the design of this absolute safety-valve.

The chief feature of novelty, however, which distinguishes this improved safety-valve from all others hitherto proposed, consists in the peculiar and simple manner in which the motion of the water in the boiler is employed, as the agent by which the valve is prevented from ever getting set fast in its seat. The swaying to-and-fro sort of motion which at all times accompanies the ebullition of water in boilers, is made to act upon a sheet-iron appendage to the weight directly attached to the valve; and as the rod which connects this sheet-iron appendage and weight to the valve is inflexible, it will be easily seen how any slight pendulous motion given to the sheet-iron appendage is directly transferred to the valve; and as that portion of the valve which rests in the seat is spherical, the valve not only admits of, but receives, a continual slight motion in its seat in all directions, as the result of the universal pendulous motion of the appended weight, as acted upon by the incessant swaying motion of the water during ebullition. It will be seen that, as the spherical portions of the valve and seat are of equal width, the edges of their respective surfaces pass and repass each other continually, and so maintain and continually tend to improve the perfect spherical fit and agreement between the valve and its seat.

It may be proper to observe, that when the steam is nearly up to the desired pressure, the valve rests on its seat with a pressure next to no pressure at all, and is then, as it were, floating on steam. This action is common to all good valves; but the observation may tend to show how a slight movement of the water affects the valve in its seat. A pipe may lead the steam escaping from this valve to the manager's-office, and there give audible notice of its escape by acting in a steam-whistle there placed.

Still further to obviate the risk of boilers exploding from a dangerous pressure, "fusible plates" are introduced sometimes on the top of the boiler. These are made of a composition calculated to melt at a comparatively low temperature. Fusible plugs are also introduced into apertures on the boiler below water-line; these melting when the water gets too low, allow the steam to pass off. Little reliance, however, is to be placed on these contrivances.

All boilers are supplied with gauge-cocks, the nature of which has been already described; by these the level of the water in the boiler is ascertained.

Mercurial pressure-gauges are frequently used to indicate the exact degree of pressure in the boiler. A glass tube is placed in a small cistern filled with mercury; one end is closed, the other opens to the interior of boiler in the steam space: the steam passing down the tube presses on the surface of the mercury; by this means the air in the upper part of the tube is compressed, and in proportion to the compression so is the pressure in the boiler. In improved gauges, a scale is attached which shows the temperature of the steam as well as its pressure in the boiler. In fig. 82 an improved pressure-gauge is shown: *a a* is the pipe introducing steam from the boiler; *b* the pipe for leading off the water of condensation; *c c* the snugs for fixing the gauge in any convenient position. In mercurial gauges adapted for low-pressure boilers, the mercury is placed in a syphon tube, one end of which opens into the boiler, and the other is open to the atmo-

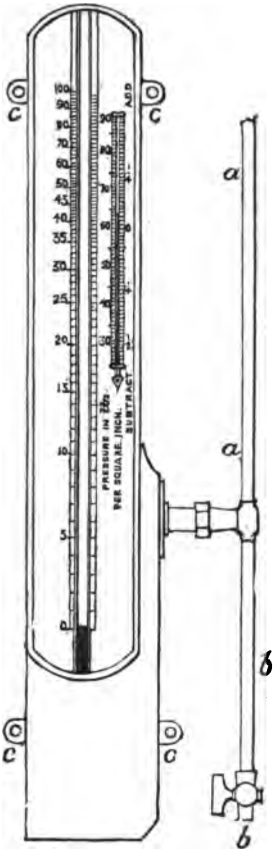

fig. 82.

syphon, and acts on a small plug floating on it; to this is attached a pointer, which shows on an index the degree of pressure. When the steam gets of very high pressure, the mercury is blown out of the tube; in this way acting as a safety-valve.

The consumption of smoke arising from the fuel used to raise the steam in the furnaces of boilers, has long been a favourite project among inventors; and the adoption of a good plan to effect this desideratum, always of importance, has more recently attracted earnest attention, from the fact of many Corporations making it imperative on those who employ steam-engines to consume their own smoke. We cannot pretend to notice all the plans introduced for this purpose, but must content ourselves with noticing only one; that, however, the most recently invented, and which has already taken a high place in the rank of effective plans. This, the invention of Mr. John Lee Stevens of London, is shown in the diagram in fig. 83. "The invention," says Mr. Lee, in his prospectus, from which our diagrams are taken, "consists in the combination of two sets of fixed fire-bars, the first of which is fed by the scoria and cinders voided from the second or upper set of fire-bars, with a calorific plate, as shown in the diagram; by which arrangement, the current of air entering at the lower part of the furnace passes through two strata of fire; and thence between the calorific plate and the bridge; and is thus so intensely heated, as continuously to produce the entire combustion of the gaseous products of the fuel, without the formation of smoke." In fig. 83, *b* the first and *a* the second set of bars; *c* the calorific plate, faced with fire-bricks; *d* the bridge, *e* the furnace-flue, *h* the furnace-door; *i* shows the direction of the current of air: this diagram shows the application of the principle to the Cornish boiler for land-engines. In fig. 71 the application is shown to marine boilers; the same letters of reference apply to this diagram as to fig. 83.

Still further to make the steam-engine automaton or self-acting in its arrangements, mechanism has been introduced by which the labour of the fireman or stoker is suspended, and the furnace supplied with fuel in proportion as required. Numerous contrivances have been introduced for this purpose; we shall only notice one, and that patented by Mr. Dean of Stockport, and in which neighbourhood it has been introduced with success. "It consists, first, of a double self-acting feed-apparatus, one side of which is caused to supply the furnace with fuel, whilst the other is at rest, and *vice versâ*, alternate; and, secondly, in placing a partition-wall in the furnace, between the fire doors and the bridge of the same, and employing two dampers, at or about the bridge, which are opened and closed alternately by certain levers and rods connected with the feeding apparatus." In addition, therefore, to acting as an automaton feed-apparatus to supply the furnace with fuel, it insures the combustion of the smoke and economisation of fuel. In fig. 84, we give an end view of a steam-boiler and furnace,

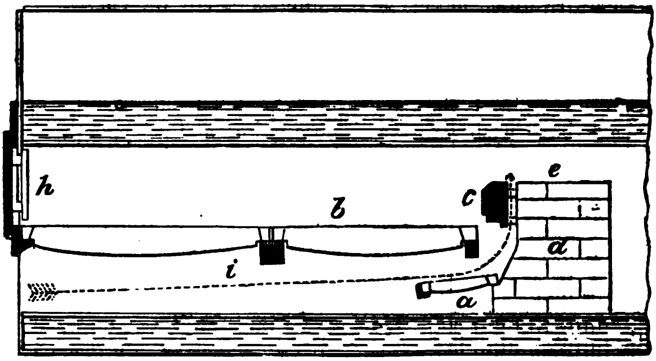

fig. 83.

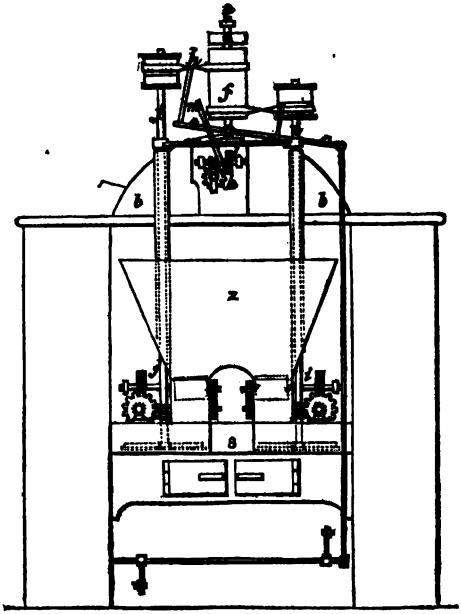

fig. 84.

with the feeding mechanism applied; in fig. 85, a plan or horizontal section below the boiler; and in fig. 86, a transverse section in front of the bridge of the furnace. "*a a* is the foundation brick-work supporting the boiler, *b b*, *c c* the 'dead plate' of the furnace, *d d* the fire-bars. *e* is the main driving-shaft, to which motion is communicated (by the engine) by a strap passing round the pulley *e′* at its upper-end, or by any other convenient means. Upon the main driving-shaft *e* is a pulley *f*, which, by means of the cross-belts *g* and *n*, drives alternately the shaft *i* of the right-hand feeding-apparatus, and the shaft *j* of the left-hand feeding apparatus. These shafts have each a fast and loose pulley at the upper-end; and the requisite shifting of the straps from the fast on to the loose pulley is effected in the following manner: A small crank *k* is caused to revolve by means of a worm on the driving-shaft *e*, actuating the worm gearing *l*; this crank *k* has a lever attached to it, furnished with two studs, *m* and *n*, which, as the crank revolves, causes the strap lever *o* to vibrate, and throw one strap on the loose pulley, and the other on the fast one, thus alternately setting in motion and stopping each feeding apparatus. It will be seen in figs. 85 and 86, that there is a partition-wall *p* in the furnace, reaching from the fire-bars to the bottom of the boiler; and extending from the bridge about half way to the fire-doors; and that there are two dampers *q* and *r* behind the bridge of the same, one of which is open and the other closed. The dampers are connected to the strap lever *o* by cranks and levers, so that when one side of the feeding-apparatus is supplying fuel to the fire, the damper upon that side is closed, and the damper on the other side open, and *vice versâ*. In the drawings the right-hand feeding-apparatus

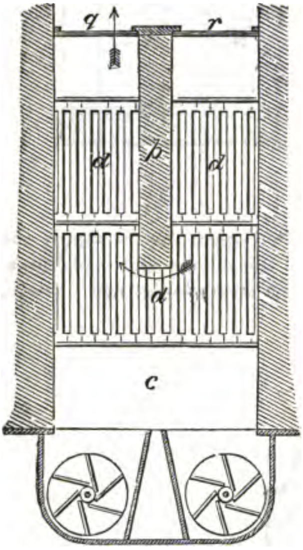

fig. 85.

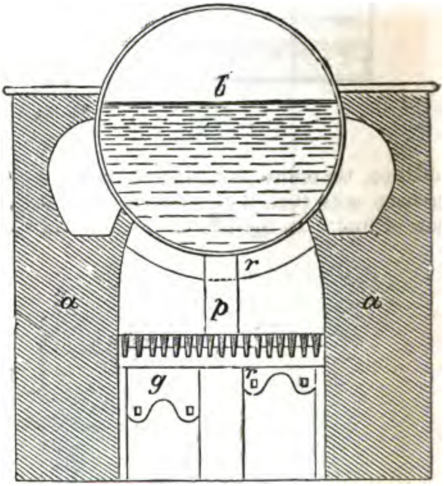

fig. 86.

is represented at work, and that upon the left hand as stationary. The right-hand damper being closed, the smoke, &c. from the fresh coal will have to pass round the partition-wall *p*, and over the fire at the left hand

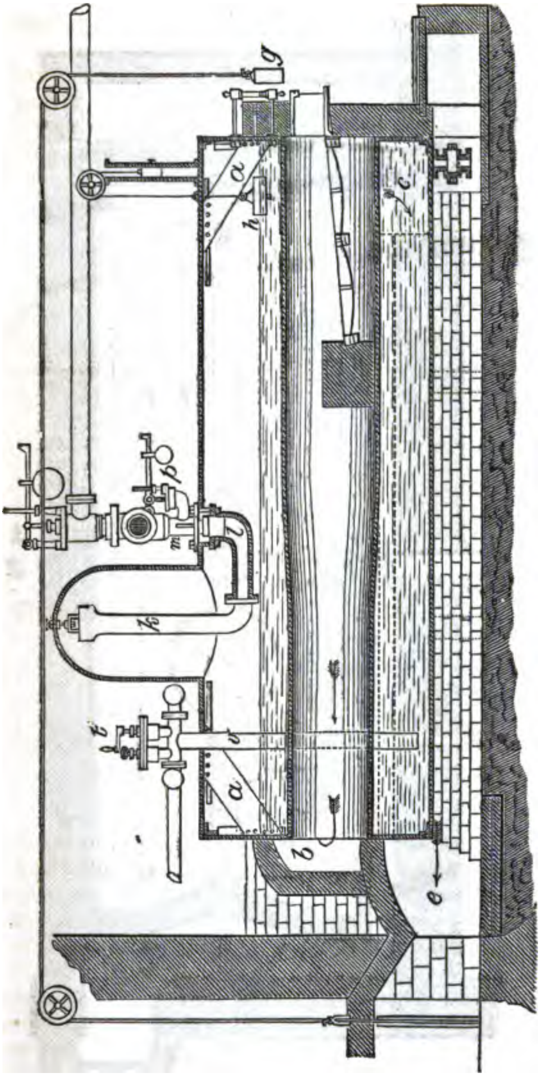

fig. 87.

of the furnace, and will thereby be consumed. It will be evident that, when by the revolution of the crank *k*, the feeding-apparatus and damper on the other side of the furnace are brought into action, the passage of the smoke will be reversed." The fuel is supplied to the hopper *z*, and is gradually spread over the furnace-bars from the centrifugal force generated by the revolving discs or plates.

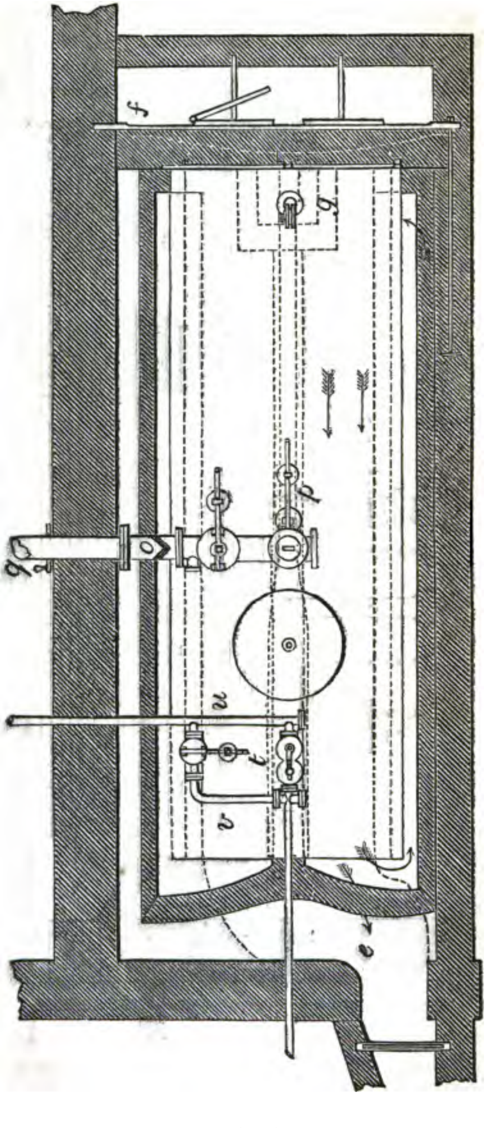

fig. 88.

As a conclusion to the present division of our work, we give drawings and description of a high-pressure boiler with improved fittings, for which we are indebted to the courtesy of Mr. William Johnson. Fig. 87 is a "longitudinal section" of boiler, fig. 88 a "plan," and fig. 89 an "end elevation." The boiler of which these are drawings, is that adapted to the engine on the double cylinder principle which we have illustrated in figs. 38, 39.

The class of boilers of which this is a good example, are considered by a competent authority to possess numerous features of economy and safety in working; and as affording an example of what a good high-pressure boiler should be, we give it here. The length of boiler is 22 feet by 7 feet 4 inches diameter; it has two internal cylindrical flues, in the entrances to which are placed the furnaces 6½ feet long by 3 feet wide. The flues are each three feet in diameter for a length of 12 feet from the front, after which they taper off to 2 feet 8 inches, as seen in the longitudinal section fig. 87, and by the dotted lines in the plan. The whole of the taper of the flues is given in the inside edges; this admits of a greater space between the two, for the entrance of a man to clean and repair. These flues act advantageously as longitudinal stays to the flat ends of the boiler; but as the points of connection are below the centre of the ends, the upper portions are stayed from the top of the shell by strips of boiler plate *a a*, 12 inches broad and ½ inch thick, and riveted at each end by angle irons. The arrows in the plan point out the direction of the current of flame, &c. The flame from the internal flues returns back by the side flues *b b*, thence passing by the side openings *c c* in the brick division into the separate bottom flues *d d*, running beneath the whole bottom of boiler, finally joining the main

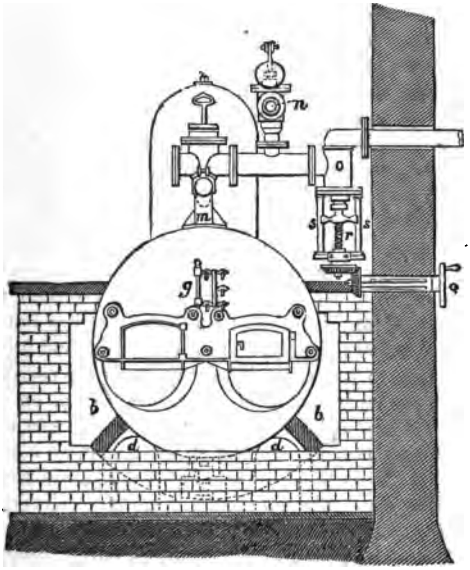

fig. 89.

flue at *e*. By this arrangement, the most intense heat is confined to the parts where sediment is most likely to be deposited, that is, on the top of the internal flues; and this part being nearest the surface of the water, the steam evolved is carried off in nearly a dry state. To retain the front brickwork above the fire doors, a stout cast-iron beam *f* is passed across the boiler-end, each extremity of the beam being embedded in the boiler and engine-house walls. The state of the water-level in boiler may be observed either by the glass gauge *g*, or the index of the stone float *h*; or it may be tested by the set of gauge-cocks attached to the glass gauge. The index of the stone float is attached to the counterweight *i*, which works freely inside a cast-iron pillar frame slotted down the front for the passage of the index, and graduated in inches. Immediately before this pillar is placed an alarm whistle, which is rendered self-acting in case of want of water by being connected with the stone float. The steam is taken from the boiler by an open ended T-headed pipe *k*, which is cottered to a bolt-stud passing through the receiving dome. The lower end of this pipe has an elbow for bolting to a short elbow pipe *l*, the end of which is bored to receive the foot of the stop-valve chest *m*. The flange of the latter rests on the top of the boiler, and bolts pass through it to the flange of the pipe *l*, the socket of which is thus held up against the conical foot of the stop-valve chest. *n* is the main safety-valve, fitted on a branch of the cross steam-pipe connecting the valve chest *l* with the main stop-valve elbow *o*. A second safety-valve *p* is also fitted to a branch at the stop-valve chest; this valve is loaded to 5 lbs. per square inch more than the main valve, and is intended to act only in case of the latter getting out of order. The bearing faces of this valve *p* are flat instead of conical, and it has consequently less tendency to stick to its seat. The stop-valve for regulating the steam supply of the engine is worked by a round wheel *q*, on a shaft passing through the wall of the engine-house. This shaft carries a small bevil wheel, whose box acts as a nut for the screwed spindle *r* of the stop-valve, which is guided in its vertical movement by a cross-piece working between the side-rods *s s*. The hand-wheel *o*, being placed in the engine-house, directly opposite the starting-gear of the engine, the engine-man has perfect control over it without moving from his post. Should any accident occur to the engine whilst he is in the boiler-house, he can easily shut off the steam, without going round to the engine-house for that purpose. A double valve chest is also fitted at *t*, for the two purposes of regulating the feed of water and the blow-off. The feed-water is supplied by a pump worked from the side lever of the engine, the water being conveyed by the pipe *w* to the valve chest *t*, whence it passes into the boiler; the surplus water, when the valve in this chest is closed, being discharged by a branch pipe *v* fitted with a lever valve, weighing a little above the steam pressure. The second valve in the chest *t* is for blowing off the dirty water collected in the bottom of the boiler.

Cylinder-Valves and Pistons.—The steam is admitted to the upper and under sides of the piston by means of slide-valves generally, although in some cases lifting or poppet-valves are used. Slide-valves are of three varieties—the "three-port valve," the "long D valve," and the "short D valve." Figs. 90 and 91 show the arrangement of the "three-port valve." In the valve-facing of the cylinder, as *d d* fig. 90, three apertures are cut, as *a b c*; that at *b* ends by a channel shown in fig. 91 to the upper side of the cylinder, that at *c* to the lower side, and that at *a* to the atmosphere. A valve-casing, as represented by *e e e*, is secured to the face of the cylinder; and into this the steam is admitted by the pipe *c c* proceeding from the boiler; a valve *h h* slides on the face of the cylinder, and is moved up and down by the rod *g* actuated by the engine; the valve *h h* is of sufficient size to cover two of the ports, one of which is always the exhaust port *a*. In the diagram the valve is so placed as to be admitting the steam from below the piston—this being at the top of cylinder—to pass up by the port *c* in the direction of the arrows, and out to the atmosphere by the exhaust port *a a*. As the steam which fills the casing cannot pass either by *a* or *c*, as the valve *h h* covers both of the apertures, it passes up the channel *b* by the port *b*, and presses on the top of the piston. The valve *h h* is therefore always so arranged, that when the piston is at the top of its stroke, the valve will cover the lower steam-port *c* and the exhaust *a;* while it is at the bottom of its stroke, the valve will then cover the upper steam-port *b b* and the exhaust. The valve-rod *g* is worked by an eccentric, as already explained in the work on *Mechanics and Mechanism.* The valve next to be described, and known as the "long D valve," is illustrated by the diagram in fig. 92. The ports for admitting steam to the upper and under sides of the piston are situated, one at top, as *a*, and the other at bottom, as *b:* the valve is semicircular, as at *m n*, and hollow at the back of the face *m*, which slides on the cylinder-facing. The valve is of length sufficient to cover the bottom and top ports *a d;* steam is admitted through the pipe *c* to the hollow space *p p*, situated between top and bottom faces of slide-valve. Supposing top and bottom faces, as *m*, to cover both ports *a d*, the steam from the boiler entering through the pipe *c* will not gain admittance either through *a* or *d;* but will remain only in the hollow part *p p*. But suppose the valve to be moved by the rod *s s*, so that the lower

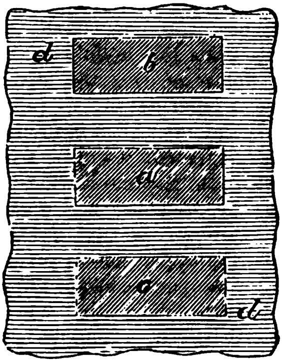

fig. 90.

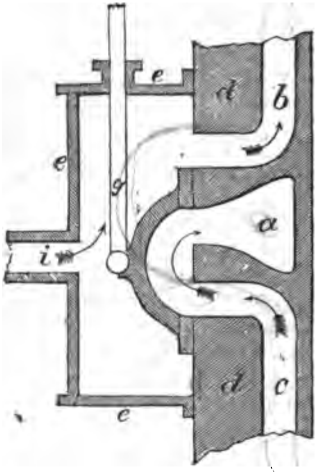

fig. 91.

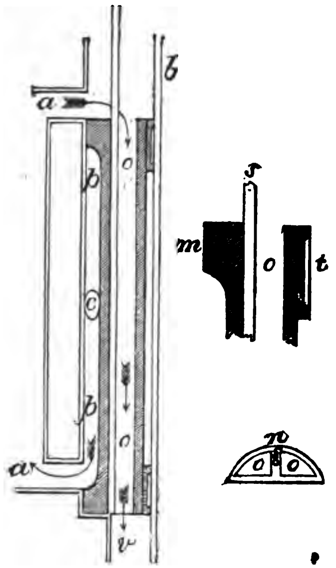

fig. 92.

port is opened, and a communication made between it and the condenser through the pipe *v*, at the same time the upper port is opened and a communication made between it and the hollow space *p p*; the steam then enters above the piston, depressing it. By means of the eccentric the slide-valve is moved in the contrary direction; the upper port *a* is opened, and a communication made between the upper side of the piston and the condenser, the steam passing down the hollow at the back of the valve as *o o*; the steam from the pipe *c* entering the cylinder by the port *d*, and the piston is turned up. By this arrangement it will be seen that an immediate communication is made between the condenser and under side of piston through the port *d*; but the steam from the upper side of piston passing through the port *a*, has to come down the channel along the whole length of valve before getting to the condenser by the pipe *v*. To prevent the steam from passing up or down as the ports are uncovered, the space between the back of valve, as *t*, and the inside of casing *b b*, is packed.

The "short D slide," which remains to be described, consists of two slide-pieces, *a b*, fig. 93, connected by two rods *c d*. In some cases only one rod is used, in others three; the section of this valve is similar to that of fig. 92, or the long D slide. In place of having one exhaust-passage, the short D valve "has two separate exhaust or eduction-passages fitted, to allow of the steam to pass to the condenser, one at the top of the slide-case, and the other at the bottom." Lifting or spindle-valves are similar in construction to those used by Watt in his engines. In working large engines, from the pressure of the steam forcing the valve against the working surfaces, considerable difficulty arises in starting the engine; in some instances a small engine is employed to work the slide on first starting, in others the steam is admitted to both sides of the valve. The "balance-valve" is sometimes used in marine engines. These are much easier to work than the slide-valve. The "equilibrium-valves," used in pumping engines, consist "substantially of a cylinder open at both ends, and capable of being moved on a fixed piston with an upright stem. The cylinder stands over the hole in the steam-

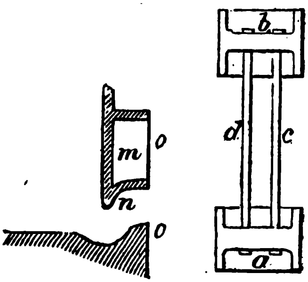

fig. 93.

box, and the piston prevents the steam from passing through it; but when the edge of the cylinder is raised from the bottom of the box, the steam then gains an exit, and it is clear that the cylinder can be raised without any considerable exertion of force, as it is pressed equally in all directions. Instead of the rubbing surface of a piston, however, two ground valve-faces are employed in practice; and the moving part of the valve is not a perfect cylinder."

In working expansively with the slide-valve, the steam is cut off by what is termed the "lap" of the valve. In engines not working expansively the steam is allowed to enter the cylinder during its whole stroke; in this case the length of the valve-face is just equal to the breadth of the steam-port. In working expansively the valve-face is lengthened, so that when the valve is at the middle of its stroke, there will be an excess of width of valve-face over the width of port. Thus in fig. 94, let *d* be the upper and *f* the lower port of a long D slide valve: in the method of allowing the steam to enter the cylinder during the whole stroke of the piston, the valve-face would just be equal to the breadth of port; but where the expansive system is adopted, the valve-face, as above stated, is lengthened at the parts *e e*, the dotted lines giving the portion *a a* where no lap is used. Generally the lap is given in what is called the "steam side" of the port, that is towards *t t;* sometimes, however, the lap is made on the eduction side, as well as towards *u u*, shown by the dotted lines. The effect of the "lap" on the valve is to cut off the steam at an earlier portion of the stroke than would otherwise be the case. An inspection of the diagram in fig. 94 will explain how this is effected: suppose the part *u* to be equal to the face of valve *a* without any "lap" to it,—that is, equal to breadth of port *d*,—when the lower edge of valve at *u* arrived at the upper edge of the port *d* the port would be fully open; but if the valve happened to be lengthened to an amount equal to the part *c* below the dotted line, the port would in this case be closed a space equal to width of port *c*, instead of being fully open if the valve-face had been equal to *a*.

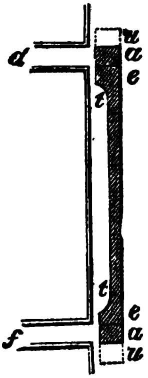

fig. 94.

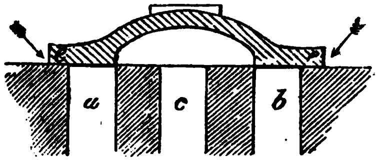

fig. 95.

In fig. 95 we give a diagram showing the lap of a locomotive or three-ported slide: *a b* the steam ports, *c* the exhaust; the lap is towards the steam side of the valves, as *e e*. In working engines, it is considered to promote their efficiency by giving what is called "lead" to the valve; this is done by making the port open a little before the termination of the foregoing stroke: thus, suppose the piston just about to terminate the upstroke, the upper port is opened a little, thus admitting steam before the other stroke is quite finished, and in consequence of the lap in the valve the exhaust port is opened sooner; so that by the time the piston begins its down-stroke, the steam from below the piston is escaping freely. If this arrangement was not adopted, we can easily conceive of the engine in its down-stroke having to press against the steam below the piston, which would get slowly out, inasmuch as the valve opens but slowly at the beginning of its stroke. To have the full perfection of working in the cylinder, the escape or release of the steam should be instantaneous if possible; the less steam the piston has to encounter in its motion either up or down the cylinder the better. By the arrangement of the valves now described, the "lap" and the "lead," the speed of locomotives has been much increased.

To obtain the full efficiency of the expansive method of working, it is considered best to have the cut-off instantaneously effected—this the slide-valve cannot do: at the beginning of the throw of the eccentric the motion is slow, and is gradually accelerated; the valve is therefore both opened and closed slowly. In some cases, therefore, expansion-valves and gearing are adopted. One species of expansion-valve is identical in principle and construction with the "throttle-valve;" another form is shown in fig. 96, it is a species of double beat valve; when this is raised, the steam from the boiler passing down *d* goes past the upper and lower valves *b c*, and through *e* to the cylinder. The supply of steam from the boiler to the pipe *d* is regulated by the ordinary throttle-valve; the upper valve *b* is made somewhat larger than the lower *c*; by this arrangement the pressure is greater on the upper valve, and tends to keep it in its seat; it will be observed that little opening of this valve will admit a large supply of steam, and that it is easily worked. The expansion-valve is worked by a series of levers and a *cam*. In p. 81., fig. 156, *Mechanics and Mechanism*, a diagram is given explaining how the revolution of a cam gives a reciprocating motion to the rod *g:* now suppose this rod to be connected with the expansion-valve, in such a way that it can lift it and depress it at intervals, and that these intervals are so timed as to close the expansion-valve at the exact period when the cut-off is to be effected, the system of expansive-working with an instantaneous cut-off will be carried out. It only remains for us to describe how the rod *g* is actuated on at the intervals required. Suppose the pulley *c*, attached to the end of the lever *a*, fig. 156, *Mechanics and Mechanism*, p. 81, to be in contact with the circular part *a* of the cam; it is obvious that no motion of a reciprocating kind would result. But supposing the circular part to be only continued for a certain distance of its circum-

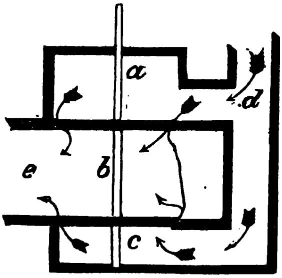

fig. 96.

ference, and that at one part the face of *a* swells abruptly out, when the pulley *c* came in contact with this portion it would be forced out, and the lever with which it is connected would have a reciprocating motion; this would act on the expansion-valve and raise it, admitting a certain portion of steam to work the piston. As soon, however, as the swelled portion of the cam, by its revolution, passed the line of the pulley *c*, the lever would be put into another position, and the valve would be instantly closed, thus effecting the cut-off. By having along the face or breadth of the cam a variety of swells or projections, and by mechanism by which the pulley can be brought in contact with one or other of these "steps" or "grades" as they are termed, any amount of expansion can be effected. The steps are so arranged as to cut off the steam at a certain period of the stroke; and thus the engineer can command any degree of expansion required, by making the desired step come in contact with the pulley: this is done by means of a screw. The pulley can also be disconnected from the cam.

In a form of expansion-valve adopted in locomotives, a supplementary valve to effect the cut-off is placed above the ordinary three-ported slide. This arrangement is shown in the diagram in fig. 97: *a a* is the ordinary slide-valve, *c b* the steam-ports, *d* the exhaust, and *a a* the valve; the valve-casing is at *e e*, *f f* the valve-casing of the supplementary valve. This valve consists of a solid plate with two apertures; these, when opposite the ports in the cover *e e*, admit steam to the ordinary valve-casing; the travel of the valve *m m* can be altered at pleasure, so as to cut off the steam at any desired point.

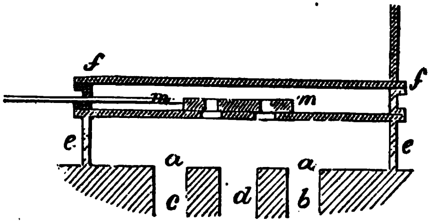

fig. 97.

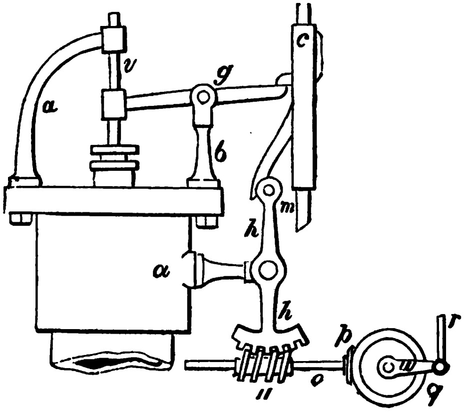

fig. 98.

In some cases the expansion-valve is worked by the governor acting on the cam, as in Maudsley's and Whitelaw's engines. We here give diagrams explanatory of a "self-regulating motion for expansion-valves," the invention of Mr. Howson of Manchester.

In referring to the drawings, fig. 98 is a general view of the apparatus. Figs. 99 and 100 are enlarged views of tappet-rod and levers, showing the different positions they assume: *a* is a case or nozzle containing a common equilibrium or double-beat valve, through which the steam is admitted through the pipe *i* in connection with the boiler to the cylinder; *v* is the valve-spindle, *u* its guide; *g* a lever for lifting the valve, having its fulcrum on the pillar *b* secured to the nozzle; *c* is a tappet-rod, having an upward and downward motion, and actuated by any suitable means from the motion of the crank-shaft, taking care that for one stroke of the piston there are two of the tappet-rod. A recess or slot *d* is cut in the tappet-rod *c* for the reception of the lever *e*, which has its upper end supplied with a notch *x* and a projection or stopping-piece *e*. The lower tail of the lever *e* forms an inclined plane *f*, which, when required, is allowed to come in contact with and slide against the adjustable stud *m*. This stud projects from the upper tail of the double lever *h*, which has its fulcrum on a pillar fixed to the nozzle, the lower tail being furnished with a series of teeth forming the segment of an ordinary worm-wheel; into this gears the worm *n*, keyed in the shaft or spindle *o*. On the same shaft is the bevil-pinion *p*, which gears into the bevil-wheel *q* fixed to a second shaft, to which a partially rotary motion is communicated by the governor-rod *r* and lever *w*. The operation of the machinery is as follows: The engine being in motion, and the tappet-rod *c* at the extent of its upward stroke, the valve will be down, and the levers *c* and *e* in the position shown at figs. 99 and 100; but on its descent, the notch *x* on the lever *e* will come in contact with the point of the lever *g*, thereby raising the valve. On the further descent of the tappet-rod, the lower end or inclined plane of the lever *e* slides against the stud *m*, and has a tendency to throw the former into the position shown

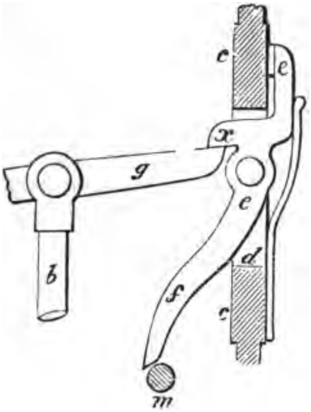

fig. 99.

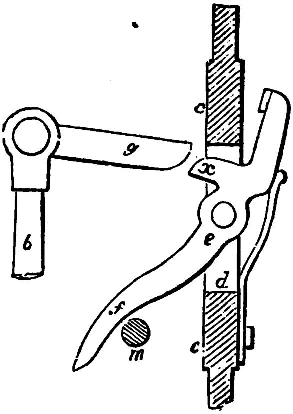

fig. 100.

at fig. 10. The lever *g* having its point then released from the notch *x*, the valve drops by its own weight, and, consequently, the supply of steam is cut off from the cylinder, the lever *g* assuming its former position as at figs. 8 and 9. On the return or upward stroke of the rod *c*, the upper part of the notch *x* sliding against and passing over the rounded or under part of the lever *g*, immediately assumes its proper position, preparatory to its making another descent. In order to prevent noise as much as possible, the projection *e*, which prevents the notch *x* from taking too great a hold on the lever *g*, is furnished with a small leather buffer. The variable motion obtained from the centrifugal force of the governor-balls through the action of the governor-rod *r*, lever *w*, wheel and pinion *q* and *p*, and worm *n*, communicates a like variable motion to the lever *h*, and, consequently, to its projecting stud *m*. It will now be easily perceived that the inclined plane *f* on the lever *e* will come in contact with and slide against the stud at different positions in the descent of the rod *c*, and the valve have varied lengths of time for remaining open; and consequently, varied quantities of steam will be admitted to the cylinder, according to the variations of the governor. The vibratory motion required for the stud *m* is so small, and the means for effecting it so powerful, that the most trifling alteration in the action of the governor will be communicated to the stud *m*; while the adoption of the worm and segment will form an infallible and solid bearing for the pressure of the inclined plane.

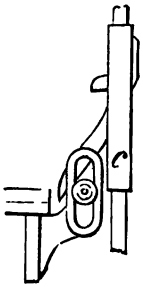

fig. 101.

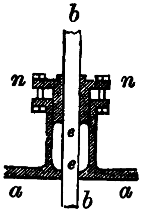

fig. 102.

Fig. 101 is a sketch in which the governor connection is dispensed with altogether; the stud *m* being adjusted by hand to a bracket fixed to the nozzle, the side of the slot in the bracket having a scale to which an index on the stud may be pointed, in order that the engineer may at once place it in a position that the steam may be cut off at the particular portion of the stroke required.

The piston-rod, in moving up and down through the cylinder-cover, is kept steam-tight by what is called a "stuffing-box." This is shown in fig. 102: *a a* is part of the cylinder-cover; a cylindrical hollow cup or box is cast on this of a much larger diameter than the piston-rod *b b*; this is curved inwards, as shown in the diagram; the aperture in the cylinder-cover is a little larger than the piston-rod, to admit of its easy working; packing, composed of plaited hemp, is wound tightly round the piston-rod *b b*, at the part *e e*; the stuffing-box "cover" *n n* is placed above this packing, and screwed tightly down by the screws.

The piston, as originally made by Watt, was kept tight by hempen packing; metallic pistons are now almost universally used. That known as Goodfellow's is extensively used in Lancashire. In fig. 103 we give a transverse section of this: *a a* is the body of the piston, with shoulder turned on it at *e*; an annular ring *o* is placed loosely round the piston; a plan of this ring is shown in fig. 104; this is turned eccentrically, and worked on its edge; this gives a uniformity of action to the whole circumference: its upper and lower edges are bevilled, as shown in fig. 106; these bevils bear or press against other rings *n n*, the interior of which are similarly bevilled, as shown in fig. 105. The outer springs *n n* are accurately ground to the upper and lower plates *m* and *c*, and the whole secured by the screw-bolts as shown. The outer rings *n n* are kept pressed against the cylinder by the action of the internal ring *o o* lying loosely on the plate *c*. These diagrams will sufficiently explain the peculiarity of a metallic piston; for notices and illustrations of other varieties we must refer the reader to other and larger works.

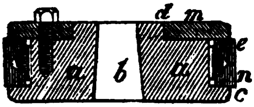

fig. 103.

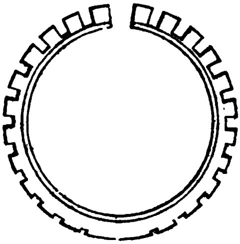

fig. 104.

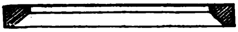

fig. 105.

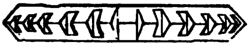

fig. 106.

We have already illustrated the mode of connection of condenser and cylinder, and the condensation by a jet of water admitted to the condenser; in fig. 107 we give a sectional diagram of an improved form of injection-valve for condensers introduced by Mr. Cowper, and described by him at the Institution of Mechanical Engineers. The object of this valve "was to maintain the full pressure of the water at the point of entrance into the condenser, and to obtain a more efficient distribution of the jet of water, without danger of getting it choked." In the diagram, fig. 107, *a* is the condenser, *b* the eduction-pipe leading from the cylinder, *c* the air-pump, *d* the cold water cistern in which they are immersed; the injection-valve is a conical one, rising a little above the bottom of the condenser, with a perforated cup below in the cistern. As shown in the drawing, the valve is lifted up by the screwed rod; and the injection-water can be regulated with the utmost nicety. The water enters the condenser in a fine sheet all round the valve, which sticks to the sides of the condenser, and fills the whole space with a fine spray. Mr. Cowper has also modified the air-pump; the bottom drops into a well, as in the drawing, in the bottom of the condenser, and the water rises up the space when the air-pump bucket dips into it, forming a water-valve instead of the ordinary foot-valve, and giving pressure enough to insure the bucket-valve opening if there was any obstruction.

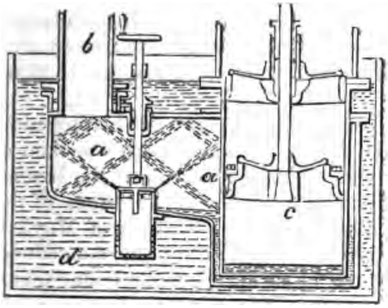

fig. 107.

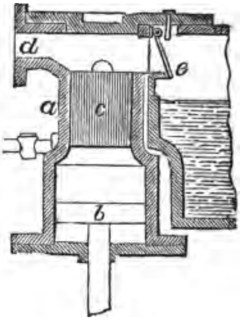

fig. 108.

In place of passing the steam into a receptacle, and being condensed by coming in contact with cold water, in other forms of condensers, as Hall's, the steam is passed down a series of copper-pipes externally surrounded with cold water; the condensed water falling into a box beneath, from which it is pumped away. By this arrangement the water used for raising steam can be again returned to the boiler. Mr. Pirson, of America, has recently introduced a condenser known as the "Fresh Water Condenser."

The peculiar feature of this condenser, which distinguishes it from all others previously known to the public, is the placing of the condensing tubes horizontally within the ordinary shower-condenser, which is made of enlarged dimensions for the purpose. By this arrangement, the water required for condensation is admitted through the ordinary injection-cock, and rises to the top of the external condenser; where it is discharged on a scattering-plate, from whence it passes directly on to the tubes of the internal condenser, which are below it, and arranged in three ranges or sets, one above the other. The steam from the cylinder is admitted into the upper range, and passes through the three before being discharged at the bottom. The fresh water produced by the condensation of the steam is pumped out by a small pump, and immediately returned to the boilers; while the water used to produce condensation is taken out by the air-pump of the engine. The internal condenser is not attached to the external one, but merely laid in it. The three ranges are separately made, and the outlet from the upper slips loosely into the one below it; so that when the whole internal condenser is together, it may be moved from one-eighth of an inch to one-fourth of an inch in any direction. This freedom prevents any liability to fracture from unequal expansion; and the tubes being in vacuum relieves them from all pressure. As the condensing water reaches the bottom of the tubes, it is immediately pumped out; so that there is not at any time any water around the tube other than the thin sheet passing over their surfaces. On the *Osprey*, the vacuum within the tube of the internal condenser is twenty-six inches, and the same in the external one; the internal vacuum is the result of condensation, while the external vacuum is produced by the air-pump. The *Osprey* has made three passages, or 2,750 miles in all, and has no trouble in keeping a full supply of fresh water in her boilers. This condenser has been used with considerable success on board the above-named vessel. Our account is extracted from a paper read by Mr. Bartol, at a late meeting of the Franklin Institute of Philadelphia.

Mr. Siemans, of Birmingham, an engineer well known for his ingenious inventions, has recently introduced a form of condenser highly spoken of, and known as the "Regenerative Condenser." At a meeting of the Institution of Mechanical Engineers, Mr. Siemans stated that the origin of this condenser was a suggestion to the author, by Mr. Graham of Mayfield Works, "to recover the heat from the condensing in the form of a reduced amount of boiling hot water." It consists of an upright rectangular trunk, *a*, of cast-iron, the lower end of which is cylindrical, and contains a working piston, *b*, which performs two strokes for each one of the engine. In the trunk is a set of copper plates, *c*, upright and parallel to each other; the intervening spaces being the same as the thickness of the plates, viz. between $\frac{1}{12}$th and $\frac{1}{16}$th of an inch.

The upper extremity of the condenser, fig. 108, communicates on the side, *d*, to the exhaust-port of the engine; and on the other, through a valve, *e*, to the hot well. The plates are fastened together by five or more thin bolts, with small distance washers between each plate. There is a lid at the top of the trunk, by removing which the set of plates can be lifted out. Immediately below the plates the injection-pipe enters.

The action of the condenser is as follows: Motion is given to the piston. At the moment that the exhaust-port of the engine opens, the plates are completely immersed in water; a little of which has entered the passage above the plates, and is, together with the air present, carried off by the rush of steam into the hot well, the excess of steam escaping into the atmosphere. The water then, in consequence of the downward motion of the piston, recedes between the plates, exposing them gradually to the steam, which condenses on them. Their upper edges, emerging first from the receding water, are surrounded by steam of atmospheric pressure, and become rapidly heated to about 210°. The immersion of the plates still continuing, the steam is constantly brought into contact with fresh cool surface, by which the greater portion of it is condensed; until, as the piston descends, the injection enters, and completes the vacuum. This is done by the time the working of the piston of the engine has accomplished one-seventh of its stroke. The upper extremities of the plates become heated to near 210°, and the lower to about 160°.

Taking the initial temperature of the condensing water at 60°, the final temperature at 210°, the latent heat of steam at 212° 960 units, the quantity of water required is 6·6 lbs. to condense 1 lb. of steam of atmospheric pressure. The common injection condenser (supposing the temperature of the condensed steam to be 110°) requires 21·2 lbs. in place of 6·6 lbs.

In fig. 109 we give a drawing of the ordinary vacuum gauge, used in connection with condensers in order to ascertain the degree of vacuum attained. The mercury is contained in a cast-iron cup open to the atmosphere; in this is placed a glass tube, open at the lower end and closed at its upper. A small iron tube is provided with a stop-cock, and connected with the condenser; this tube passes through the mercury in the cup, and up the interior of the tube near to its top. The air is exhausted from the glass tube through the iron tube connected with the condenser, as the mercury rises in the glass tube in proportion to the difference between the pressure of the uncondensed vapour in the condenser and the pressure of the atmosphere. To show the higher vacuums of 29 and 30, the height of this gauge must be nearly three feet. To obviate the inconvenience attending this form of gauge, the short vacuum gauge is used, as in fig. 110. A small glass tube contains the mercury, and is filled carefully as an ordinary barometer; it is bent upwards at the bottom, and ends in a bulb, which is provided with a small orifice at the upper side. The tube is attached to a scale, and entirely enclosed in a glass case, which is carefully cemented to a brass cup, terminating in a stop-cock and pipe connected with the condenser. The air in the interior of the glass case is always of the same density as in the condenser. In the long vacuum gauge, in fig. 109, the mercury is driven frequently out of the cup, if the stop-cock is left open while blowing through previous to starting. The short vacuum gauge, although possessed of many advantages, as shortness and compactness, has also disadvantages; these are, first, the vapour from the condenser deposits frequently a mist in the glass case so dense as to obscure the scale; and

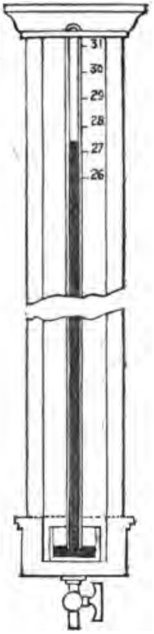

fig. 109.

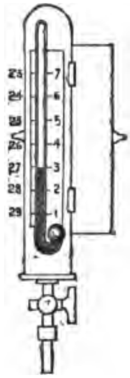

fig. 110.

secondly, if the stop-cock is not shut while blowing through, the case becomes filled with steam or with hot water; and its safety is thereby endangered. To obviate these inconveniences, Mr. Bramwell, of London, has designed an improved vacuum gauge, which he described before the Institution of Mechanical Engineers, and of which we give the diagram in fig. 111. "Instead of immersing the whole of the tube and scale in a glass chamber connected with the condenser, the bulb only is enclosed in a brass cup with a screw lid, on which the scale is cast; and the rest of the mercurial tube is passed through a stuffing-box in the middle of this lid, protecting it from injury by pushing it in a depression in the scale like a common thermometer. On the bottom of the brass cup is a stop-cock, with the pipe by which connection is made with the condenser; the same density is always preserved in it and the cup; and thus, the pressure being removed from the surface of the mercury in the bulb, it of course falls according to the rarefaction, a fall that can always be observed, as the tube containing the mercury is totally uncovered. By this means, the first and great objection to the short vacuum gauge is done away; and likewise the second, which is common to both long and short, viz. the risk of the stop-cock being left open while blowing through; as with this gauge it is a matter of perfect indifference whether it is open or not, as the only thing that can take place if it is open is, that the brass cup is filled with steam; but this can neither blow out the mercury nor damage the gauge."

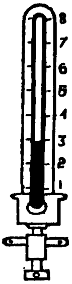

fig. 111.

In the companion volume to this treatise, *Mechanics and Mechanism*, we have described pretty fully the details of construction of the various parts of steam-engines, as connecting-rods, cranks, &c. and the method of putting the various parts together; we are, therefore, spared the necessity of here giving them, and proceed to the consideration of other matters worthy of notice.

Of contrivances for regulating the speed of steam-engines, the centrifugal-governor is the best known: the arrangements and method of attachment of this mechanism we have already, in *Mechanics and Mechanism*, fully described. In the pumping-engine the ordinary governor is not used, but a contrivance known as the "cataract" is adopted instead. This was in use prior to the period of the introduction of Watt's engines, and has since been much improved. The principle of the original cataract will be easily understood by an inspection of the diagram in fig. 112. Suppose *a* to be a vessel for containing water; on the end of the lever *m*, jointed at *c*, another lever, *f*, is attached to and forms part of the lever *m;* water is allowed to pass into the vessel *a* through the pipe *b*; as soon as the *a* fills, it tilts over in the direction of the arrow, and lifts up the end of lever *f*, as shown by the dotted lines: to the end of *f* a chain *e* is attached; this is connected with the end of the lever opening the injection-valve. The vessel *a* can only tilt over in the one direction, the stud *d* preventing it from falling the wrong way;

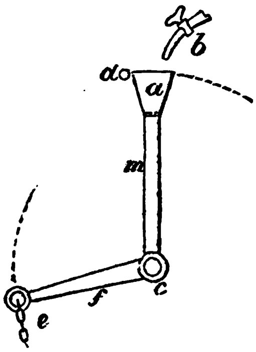

fig. 112.

when empty, the vessel *a* is brought up to its original position by the weight of the lever *f*, &c. The whole is contained in a box, from which the water is led away after working the cataract. The number of times the injection-valve is opened determines the number of strokes the engine makes in a given time; and the falling of the box or vessel *a*, which opens the injection-valve, is regulated by the quantity of water allowed to pass through the pipe *b*; this quantity of water is therefore proportioned to the quantity to be drawn from the mine, or the work to be done by the engine. The reader will find descriptions of forms of improved cataracts in the *Artisan Treatise on the Steam-Engine.*

In cotton-mills, and in cases where the engine is loaded to a certain extent, accidents frequently occur by parts of the machinery breaking down. The engine, thus relieved of a certain part of its load, "runs away," as it is termed, at a greatly increased speed, endangering the stability of the whole apparatus. The ordinary mechanism of the throttle-valve and governor is not found capable of making the engine recover its usual speed. An ingenious contrivance, highly esteemed, is given in the following diagram, fig. 113. The main object of this invention is to prevent damage by the accidental alteration of load, and to regulate the speed of steam-engines. It is intended to supersede the common throttle-valve, and prevent variation of speed and the many breakages arising from accidental alterations of weight. The valves can readily be connected with ordinary governors; and when attached, are so sensitive, that should a shaft break, or any weight be suddenly thrown on or off, the engine will recover its usual speed in less than two revolutions, without any interference by the engineer. This will be obvious, when it is considered that there are two valves fitted to the same spindle; and consequently, that each of them need be opened to only one half the extent, as if there were one valve. The result is, a throttle-valve of extreme sensibility, half an inch being the utmost amount of play allowed to the spindle between wide open and quite shut; therefore, a very slight change in the position of the governor-balls produces considerable change in the amount of opening afforded by the valves.

The governor is connected with the valve-spindle by a fork, in the usual manner, which, by means of a crank-lever, gives a slight motion on its axis to a bar, provided at the other end with another crank-lever connected with the valve-spindle. It may be attached to all ordinary governors. In the case of two fifty-horse engines coupled together in Sir C. Armitage's mill, at Pendleton, near Manchester, the result of a trial by throwing off the whole weight was the recovery of the usual speed in 1¾ revolutions. The load on these two engines consisted of 20,000 throstle-spindles, 13,000 mule-spindles, and 250 power-looms, with all the necessary apparatus for working the mill.

In fig. 113 we give a diagram illustrative of this apparatus, so capable of instantaneously regulating the performance of engines. *a* is the steam-pipe from boiler, *c c* the double-beat valve; when this is raised by the lever actuated on by the lever *d* of the connecting-rod, the steam passes from *a* in the direction of the arrows to the steam delivery-pipe *b*.

The "hydraulic motion regulator" is an American invention, recently introduced into this country, and which has already taken a high place as an effective governor for steam-engines; we give a diagram and description of this apparatus, taken from the inventor's circular (Mr. Pitcher).

The principle of the invention consists in working a small pump, the water delivered by which acts in the plunger of a second cylinder or barrel: the water from the pump escapes through an aperture of a certain area; this is calculated so as to maintain the plunger at a certain height in the cylinder. Should, however, the speed of the engine increase beyond its regular working speed, the pump is in consequence worked faster, and a greater quantity of water delivered to the plunger cylinder: but the aperture for its escape remaining unchanged, it cannot get away, it therefore fills the cylinder to a higher level; this raises the plunger, which, connected with the regulating-valve or throttle-valve, lessens the supply of steam to the cylinder and reduces the speed. The pump is worked by the engine by any of the ordinary methods of connection. In fig. 114, *e* is the pump worked by the engine; *c* the suction-valve, through which the supply of water is obtained, *b* the delivery-valve, supplying the cylinder *f*. To prevent the plunger from rising higher than necessary, a small hole, *g*, is made in the cylinder; when the plunger rises above this the water escapes by it, and the plunger rises no higher. The piston-rods pass through the bonnet or cover of the external casing *jj;* cups *i k* are used to return any water that may be drawn up through the stuffing-boxes; the piston-rods are thus lubricated, or made to work smoothly, with water surrounding them. The whole apparatus is enclosed in the casing *jj;* so that the same water is used over and over again. A spring is coiled round the piston-rod of plunger *f* at *z;* this prevents its falling further than necessary. The opening by which the water ordinarily escapes is made just above the delivery-valve *b;* and the amount of opening is regulated by a handle or lever which passes through the cover *h*, according to the speed at which the engine is desired to run. In place of the ordinary throttle-valve, the inventor prefers to use a regulating valve similar in principle to the disc-valve employed as the "regulator" in locomotive engines.

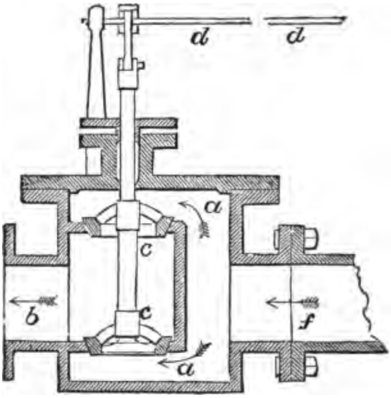

fig. 113.

In calculating the power of steam-engines, there are two terms used—the "nominal power" and the "actual, or effective power." By the term "nominal power," reference is made to an engine having a cylinder of given diameter, a given length of stroke, with a uniform pressure upon the piston of 7 lbs. per inch. Watt calculated the effective pressure on the piston in small engines at 6·8 lbs. per inch, and in large—as 100 horse-power—at 6·94; 7 lbs., however, is the effective pressure calculated. By the term "actual" power, is meant the number of times 33,000 lbs. the engine is capable of lifting 1 foot high per minute. By the term "duty" of an engine is meant the amount of work done in relation to the amount of fuel consumed.

In calculating the nominal horse-power of an engine, the following rule is adopted: "Square the diameter of the cylinder, and multiply the number of square inches thus found by the cube-root of the length of the stroke in feet, and divide the product by 47; the quotient is the number of nominal horse-power of the engine."

By the term "horse-power," as introduced by Watt, was meant the mechanical force necessary to lift 33,000 lbs. 1 foot high per minute. Prior to the extended introduction of steam-engines, the work at mines, &c. was frequently done with horse-power; it became, then, of importance to be able to state the amount of work done by a steam-engine, as compared with a given number of horses. The power of a horse, as calculated by Watt, was equal to the raising of 33,000 lbs. 1 foot high in a minute. Engines now, however, calculated at this rate, really exert a greater power than the nominal power; it is, therefore, of importance to be able to calculate the effective or actual power of an engine, without reference to its nominal power. This is ascertained by means of the "indicator," which gives the effective pressure on the cylinder of the engine: from this is deducted a pound and a half of pressure absorbed in friction, &c.; the velocity of the motion of the piston in feet per minute is thus ascertained: this is done by multiplying the number of revolutions of the engine per minute by the length of stroke. These data having been ascertained, the

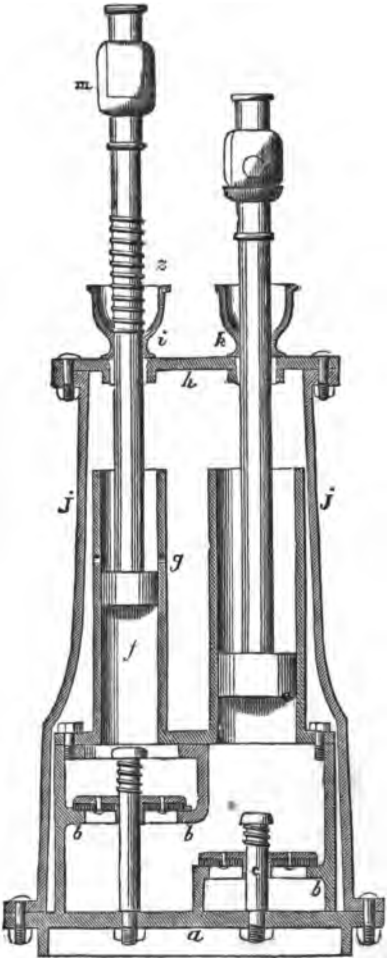

fig. 114.

following rule will give the effective power of the engine, calculated on Watt's data: "Multiply the area of the piston in square inches by the effective pressure (found as above) and by the motion of the piston in feet per minute, and divide this by 33,000; the quotient is the actual number of horse-power." For each horse-power of an engine it is calculated that 33 cubic feet of steam is expended per minute, or an evaporation of 1 cubic foot of water per hour. The combustion of 1 lb. of coal is calculated to raise 6 or 8 lbs. of water into steam; Watt reckoned 7½ lbs. of water to be evaporated by the combustion of 1 lb. of coal. In the modern Cornish engines, the same quantity of fuel evaporates 10 lbs. of water. Land engines are generally calculated to consume 10 lbs. of fuel per hour for every nominal horse-power, or 5 or 6 lbs. for each actual horse-power. In the Cornish engines the duty of an engine is "expressed by the number of millions of pounds raised one foot high by a bushel, or 94 lbs. of Welsh coal;" a bushel of Newcastle coal will only weigh 84 lbs; and, in comparing the duty of a Cornish engine with the performance of an engine in some locality where a different quality of coal is used, it is necessary to pay regard to such variations." In the engine at Long Benton Colliery, erected by Smeaton, the duty performed was equal to 9·45 millions of pounds, raised 1 foot high by the consumption of 1 bushel of Newcastle coal. In the present time, what with improved engines and boilers, and the extensive adoption of the principle of expansive working, the duty of Cornish engines is estimated at 60,000,000 lbs.; and in some instances the duty has increased to the large amount of 100,000,000 lbs. raised 1 foot by the consumption of 94 lbs. of fuel. For much valuable practical information on the power of engines, the heating surface for each horse-power, &c. &c. we refer the reader to Bourne's *Catechism of the Steam Engine.*

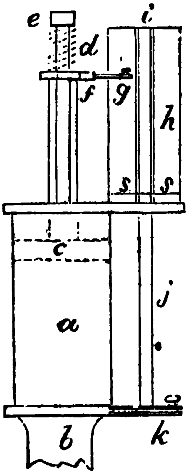

fig. 115.

We now, in concluding the present division, give a description and diagrams of the important instrument, the "indicator," so essentially necessary in computing the effective power of steam-engines. A small cylinder, as *a*, fig. 115, is placed in connection with the interior of the cylinder, either above or below the piston,—generally it is screwed into the aperture made in the cylinder-cover; a stop-cock is placed in the pipe *b*, by which the connection between the interior of steam-engine cylinder and that of the indicator can be closed or opened as required. Into the cylinder *a* a piston works; within the interior of the rod *c* of this, which is made hollow on purpose, a spiral spring is placed; the lower end of this is fixed to the piston, and the upper to a small cross-head, *e*, supported by side-rods, connected with the cylinder, *a a*. To the top of the piston-rod a pencil, *f g*, is attached; the point of the pencil works in contact with a slip of paper wrapped round the small cylinder, *h*, and kept in contact with it by the vertical strip of brass, *i i*, on which is marked a scale. The axis of this cylinder, *h*, is continued downwards, and provided with a pulley, *k*. This pulley is connected with the parallel motion, or other reciprocating part of the engine, by which motion is given to it, causing it to revolve only in one direction: the cylinder, *h*, makes its return motion to its original position by a spring coiled up in the bottom near *s s;* the direction of the cord, after leaving the pulley, is changed by a guide-pulley not shown in our diagram. The effect of the two motions, namely, the up and down motion of the piston, and the revolution of the cylinder, *h*, is to cause the pencil, *g*, to describe a curve, varying in its outline. Before the connection is made between the interior of cylinder *a a* and the steam-engine cylinder, what is called the atmospheric line is drawn on the paper; this is effected by pulling the cord, or allowing the engine to act on the pulley. The cock at the pipe *b* is then opened, when the piston is at the top of its stroke: the steam acting on the cylinder (steam-engine) piston acts also on that of the indicator; this will therefore rise, and with it the pencil, which is made to press slightly on the surface of the paper by a small spring; at the same time the roller, or cylinder, revolves. A line is thus traced on the paper, "which rises higher up on the cylinder as the pressure of the steam increases, and comes lower upon it as the steam-pressure subsides."

The method of ascertaining the pressure on the piston of the engine, from the diagram thus obtained, is very simple, and will be easily understood by reference to fig. 116. Suppose *a b c d* to be the slip of paper, on which the indicator diagram has been taken, and *e f* the atmospheric line, the divisions at the ends, as at *b c*, correspond to the divisions of the scale *i* on the indicator, fig. 115. Divide the length of the diagram into any number of equal divisions, and through these draw lines at right angles to the atmospheric line *e f;* measure the lengths of the spaces thus formed by the intersection of the diagram with the lines, as the length from *m* to *n*, and from *r* to *s*, and so on (the measurements must be taken from a scale corresponding to that in the indicator-scale), and all the lengths together; divide this by the number of spaces, and the quotient is the mean effective pressure on the piston in pounds per square inch. We have already described the rule for calculating the effective pressure of the engine. The indicator is not only useful to ascertain the amount of power exerted by the strokes of a steam-engine, but it serves also to point out particular defects in the working. Thus the nearer the diagram attains to the form of a parallelogram, the more perfect is the working of the engine. Where certain deviations from the square at the corners are indicated on the diagram, certain defects are made known.

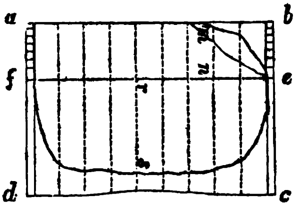

fig. 116.

For full information on the practical working of the indicator, and the method of ascertaining the defects as indicated by the diagram, we must refer the reader to other and more practical works—as the *Indicator and Dynamometer*, by Professor Main and D. Brown; published by Hebert, Cheapside.

CHAPTER IV.

ROTATORY ENGINES AND OTHER VARIETIES.

THE obtaining of a rotatory motion by the direct action of the steam, without involving the use of reciprocating motion as in the piston-rod of a cylinder engine, has long been a favourite problem with many mechanics, on the supposition that the various parts of an ordinary engine, as the piston, beam, connecting-rod, and crank, were not merely inconvenient, but that they acted as counteracting agencies to the full development of the power of the engine. Numerous attempts have been made to substitute an engine in which the main shaft received motion directly from the action of the steam; this acting on certain mechanical arrangements, placed within a case or exterior covering. The great objection which the advocates of the rotatory class of engines have raised, is the assumed loss of power sustained by the use of the crank. It is, however, an easy matter to prove the fallacy of this opinion; suffice it to state, that the opinion that there is a loss of power by the use of the crank, arises from a misconception of the principles of its action. There is no doubt that an efficient rotatory engine would be highly useful for certain applications, as the driving of a screw-propeller, where direct action is required; and a great saving of space and material would also be effected; but so far as the assumed gain of power which would result from their introduction is concerned, it may be taken as a general truth, supported by the best mechanical authority, that no advantage of this kind is possessed by them over the ordinary reciprocating kind. The great desideratum now hoped for, by the introduction of a rotatory engine among those mechanics who devote their time to its attainment, is not a gain of power, but only a simpler and more convenient mode of applying it. "Such a gain," says the reporter to the jury, section A. class v. Great Exhibition, "might indeed result from a freer access of the steam to the piston, from a diminution of the friction or the jar of the working parts, or from a more complete expansion; but, thanks to the more general diffusion of information in mechanics, practical men now know that there is no more possibility of increasing the work of an engine by merely altering the direction of any of its working parts, than there is of increasing the quantity of water which a reservoir will supply, by varying the pipes which serve to distribute it."

Although eminent authorities on engineering matters have expressed opinions inimical to the idea that a good rotatory engine will be introduced to the superseding of the reciprocating engine; still it is right to state that others, perhaps of equal standing, hold the contrary. The result, however, of the various discussions entered into on the point, seems to be that, if the engines can be kept tight, and the uniformity of wear in the packing effected, the great difficulty attendant on bringing them into practical operation will have been obviated. That this difficulty is one of no ordinary kind, may be gathered from the statement of one of our most practical engineers, that "he would as soon think of inventing perpetual motion, as of overcoming it."

We now proceed to illustrate the principle of a few of the most celebrated engines of this class yet introduced.

Rotatory engines are of several kinds; the Æloipile of Hero, already described, is an engine of the reaction species. A modern modification of this is exemplified in Avery's engine, introduced by Ruthven of Edinburgh, and to which at one time considerable attention was attracted.

This engine consists of two hollow arms *ab*, fig. 117, attached to a central pipe *c*, which revolves on its axis, and gives motion to the pulley *e*, from which the power is distributed as required by a belt; at opposite sides of the extremities of the pipes or arms *ab*, apertures are made, and the steam issuing from these in contrary directions, as in Hero's, cause the arms to revolve with great rapidity: steam is admitted to the arms through the pipe *d*. The arms are enclosed in a case *ff;* and the steam, after working, is let off to the atmosphere by a pipe communicating with the bottom of the case *ff.* The cold-water pump is worked by an eccentric on the horizontal shaft. Although several engines of this class have been introduced, and, according to the patentee, with marked success, as simple and economical, yet their number is by no means increasing. One great objection to it is the high pressure of the steam employed, and the limit to the power of the engine set by the difficulty of increasing the length of the arms *ab*, so as to obtain increase of power; the amazing velocity at which the arms revolve, 3000 and 4000 times per minute, makes it liable to speedy disarrangement of parts.

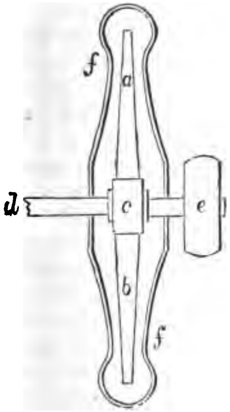

fig. 117.

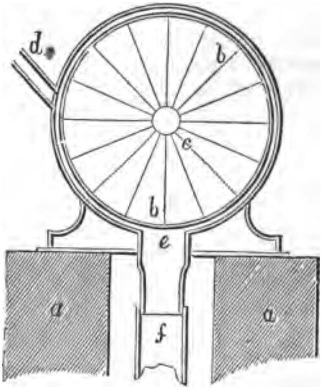

fig. 118.

Rotatory engines are sometimes made on the impulse principle, as exemplified in Branca's steam-wheel, already noticed. A modification of this principle is carried out in the rotatory engine patented in 1841 by Corde and Locke.

In fig. 118, *aa* is the foundation on which the steam-wheel is supported, *bb* the steam-wheel, provided with floats or buckets at the extremities of the radial arms; the shaft of this, as *c*, is carried through the outer-casing in which the wheel revolves through stuffing-boxes; the pulley or toothed wheel for communicating motion to the apparatus to be worked by the power of the engine is placed on this shaft outside the casing of the wheel. A vacuum is made in the interior of the casing by the medium of the condenser *f*, to which the steam is conducted by the pipe *e*. The exhausting is carried on by a small double-acting cylinder-engine working the air-pump. Attention has been much directed to this invention, principally through a very favourable report as to its working capabilities by Josiah Parker, the consulting engineer to the Royal Agricultural Society of England. A novel fact was elicited in the course of the experiments—namely, that when the steam, after working an ordinary reciprocating cylinder-engine, is admitted to the exhausted case, and made to impinge upon the floats of the wheel before finally passing to the condenser, an additional power is obtained equal to one-third, or 33 per cent; and this without any increase of fuel or increase of condensing apparatus.

The next class of rotatory engine to which we will direct the reader's attention, is that in which the piston is made to revolve round its axis. In the patent granted to Watt in 1769, he included a claim for a rotatory engine; and, from his own statement, it appears that "a steam-wheel moved by force of steam, acting in a circular channel against a valve on one side, and against a column of mercury or other fluid metal on the other side, was executed at Soho upon a scale of six feet, and tried repeatedly; but was given up, as several objections were urged against it." This failure did not, however, influence Watt to give up his trials; but in 1782 he took out a patent for two engines on a similar principle: one of these we here append an illustration of. In fig. 119, *a a* is a circular casing, *b* an axle passing through stuffing-boxes at the ends of the casing, *c* a piston revolving in the case, *d* a valve which, turning on a hinge like a door, passes into the recess *e*; *f* the pipe admitting the steam to the casing, *g* that leading to the condenser. The valve *e* extends the whole depth of the cylinder. On steam being admitted to the casing, it presses on the piston *c*, and causes it to revolve; on reaching that part of the casing near the eduction-pipe *g*, the piston strikes the valve *d*, and forces it into its seat *e*; the steam-entrance is thus closed, and the steam in the casing rushes to the condenser through *g*. On the piston passing *e*, the valve *d* falls open, as before, admitting steam to the casing to act on the piston. From the force with which the piston strikes the valve *d*, the machine rapidly falls into disrepair.

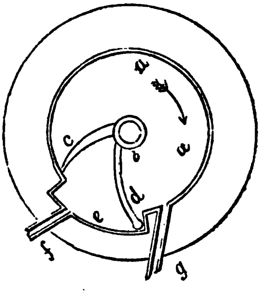

fig. 119.

Murdoch, an engineer, employed under Mr. Watt at Soho, introduced a rotatory engine, of which, in figs. 120, 121, we give drawings; the steam is admitted by the pipe *e*, and acts upon the projecting arms *b* of the rollers *a a*, placed within the casing *d d*. The steam, after working the rollers, passes into the condenser by the pipe *f*; the air-pump was worked by a crank fitted on the end of axis *a*. Packing is introduced into cavities at the end of each projection, as at *b*, to keep them steam-tight during the revolutions. There is much leakage in an engine of this kind, and the friction is great.

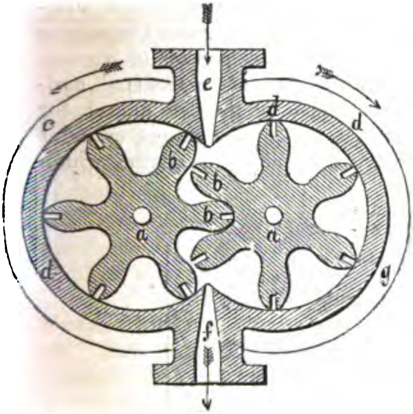

fig. 120.

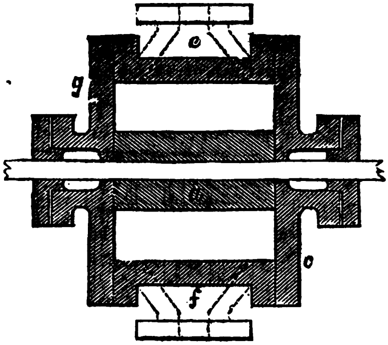

fig. 121.

From the great variety of rotatory engines of this class which have been introduced from the time of Watt till now, it is quite an impossibility for us to notice even a small proportion of their number; we must refer the reader to larger treatises, where several of the most ingenious are illustrated. We propose only giving illustrations of one or two of the most recently introduced, and which, from their admirable arrangement of

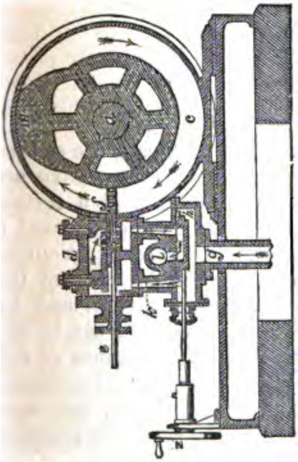

fig. 122.

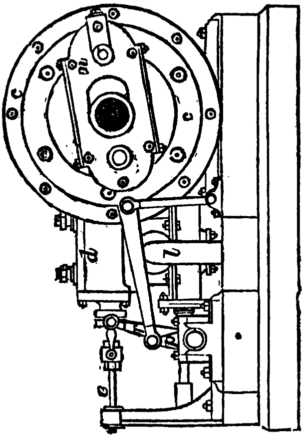

fig. 123.

parts, and their general efficiency, are likely to be introduced on a comparatively extensive scale.

A form of rotatory engine, which has been spoken highly of by competent authorities, is that invented by Mr. Isaiah Davies of Birmingham. Through the courtesy of William Johnson, Esq., editor of the *Practical Mechanic's Journal*, we are enabled to present our readers with a description and illustration of this (as well as of the one following this) ingenious rotatory steam-engine. In fig. 122 we give a transverse section of the engine, which is of the duplex construction. Fig. 123 is an external end-elevation corresponding, showing the arrangement of the cam motion for working the valves. Fig. 124 is a plan view, showing an engine or cylinder in elevation; the other in section. *a* is the main shaft of the engine, which both directly receives and transmits the power. Two pistons *b*, are carried loose on this shaft on three feathers; by this arrangement the pistons are carried round by the revolution of the shaft, but are allowed a certain amount of play laterally; that is, they can move backward and forward a slight extent on the shafts. It is in this point that the main objections to rotatory engines have been overcome; this side to side movement of the pistons preventing all wear and injurious binding of the piston: and by means of the end set-up plates the surest adjustment of parts can be obtained, thus obviating the excessive wear found in other engines of this class on the surface of the piston and the ends of the cylinder. The pistons, *b*, are cylindrical for the greater portion of their circumference, but have each projections cast as in fig. 123, these receiving the actuating pressure of the steam. The axes of the pistons coincide with the centres of the cylinders; and the diameter of the former being less than that of the latter, an annular space is left all round as at *c*. The pistons are placed on the shaft in such a manner that the projections are exactly opposite each other. The cylinders, *c c*, are bolted down on the same axial line upon a cast-iron

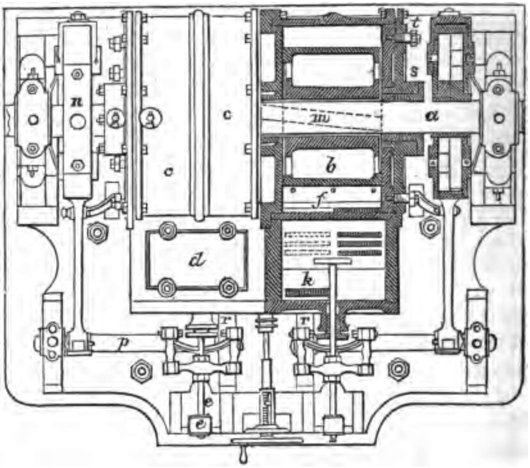

fig. 124.

foundation-plate, carried by a light stone foundation. Each cylinder is flanged at both ends, and the two are bolted together by bolts passing through a central partition plate placed between them to divide the spaces of each, the shaft being passed through a central hole in the plate. The transverse section in fig. 122 explains the valvular arrangement employed for the induction and eduction of the steam. The steam-chamber, *d*, is cast in one piece with the cylinder, and is provided with a movable cover and adjusting-screws, by which to adjust a metal plate placed at the back of the steam-valve to take off the pressure of the steam. The steam-valve is worked by a spindle, *e*, standing out in front of the engine, and which is actuated by a cam motion of a peculiar nature, presently described. The flat steam-stop, *f*, which acts as an abutment or movable partition, against which the steam re-acts in urging round the piston, is in one piece with the flat steam-valve. The supply steam is brought by the pipe *c*, which is bolted by flanges to the lower side of a receiving-chest containing an inverted *d* or single cup-valve, employed for stopping or reversing the motion of the engine. The valve is worked by a small hand-wheel, 2, on a screwed spindle, working into a socket on the spindle of the valve. By this means the valve may be adjusted to any desired position with the greatest nicety. As arranged in the diagram, the steam passes as shown by the arrows from the lower valve-chest up through the uncovered port *k*; and thence by the port at the front of the working valve-chest to the space above the top plate, which bears upon the upper face of the steam-valve. From this point it passes by the narrow gridiron slots in the plate to a similar series of slots in the upper side of the steam-valve; these slots extending across one half of the valve surface, and communicating with a narrow channel cored out of the centre of the valve's thickness; and finally terminating in a larger port, which in fig. 122 is represented as conducting the induction-steam into the cylinder above the end of the valve forming the stop-piece. The exhaust steam is meanwhile returning from that portion of the cylinder which is continued between the back of the projection and the lower side of the stop-piece *f*, by an exactly similar set of ports and slots, occupying the remaining half of the valve, as seen more clearly in fig. 124. The main exhaust channel, in the thickness of the valve, communicates, by means of three narrow slots in the lower surface of the valve, with a corresponding series in the bottom-supporting surface of the valve-chest, and the steam exhausts thence into a passage leading into a hollow of the reversing valve, and finally escapes by the exhaust port *l* into a waste pipe bolted to the side of the *stop* valve-chest. It is easy to understand how the passage of the steam may be entirely reversed, by setting the reversing valve to cover the front port and open the back one, when the steam will be immediately admitted, by what were before the exhaust valves, to that portion of the cylinder below the steam stop-piece *f*; the exhaust likewise taking the place of the former steam-ports on the upper side of the valve. The steam may also be entirely shut off from the cylinder, by placing the reversing-valve in the centre of its stroke, so as to cover both ports on its face. The action of this valve is essentially different from that of ordinary steam slide-valves, for it has to fulfil conditions of a very different character. It has to remain in one position for a long period during each revolution of the engine, to admit steam to urge round the piston; it must afterwards be quickly withdrawn, merely to allow of the passage of the projecting part of the piston; after which it is again passed inward. To produce these peculiar movements, Mr. Davies has applied an ingenious arrangement of cams, which work inside the frame *n* (see the elevation in fig. 123), in one piece, with an actuating rod partially supported by a link *o*, jointed to a stud on the foundation plate; the extremity of the actuating rod being jointed to the end of a short lever *p* keyed on the valve rocking-shaft. The rocking-shaft works in pedestals carried by the foundation-plate, and has keyed on it a lever with a forked upper end, connected by short links to a cross-head on the valve-spindle *e*. In an improved form of this engine, the inventor has substituted double-acting pistons for the single-acting ones, as in fig. 122, having two projections instead of one. The two projections are set opposite each other on the pistons, the latter being so placed on the shafts that the projections of each stand at right angles to one another; thus balancing both their own weight and the actuating pressure of the steam. Steam-stops, with the requisite valves, are provided for each projection on opposite sides of the engine; the two stops for one piston being simultaneously worked by one cam motion. In place, therefore, of describing the single motion of the engine in fig. 122, we shall explain that adapted for the engine with duplex projections. Fig. 125 exhibits a side elevation of this arrangement, in which the two dotted lines *a*, *b*, *c*, *d* are supposed to stand in planes coincident with the centre lines of the piston projections. The throw of the cams having been settled, the first thing to be done in setting out their curves is, to form the dotted square *e*, *o*, *p*, *h*, with diagonals drawn through it. To find the diameter of the anti-friction rollers *k l*, against which the cams work, the throw of the cams is added to the thickness of the roller studs, allowing about one-eighth of an inch clearance between the extremity of the cams and the roller studs. The true curve of the actuating cam surface is a matter of great nicety, as upon its exactitude depends the correct working of the valve-stops against the piston projections. The breadth of the end *m*, *n*, of the smaller cams, is determined by the piston projections themselves, as the two must correspond. On moving the rollers in the direction of the arrows, it is evident that no rectilineal motion will take place until the point *n* is gained; and the nature of the movement subsequent to this is thus determined. On the horizontal line *a b*, a semicircle with a radius equal to half the throw is delineated at *a*, and this is divided into any given number of equal parts; and from these points ordinates are drawn to the diametrical line. Thus, from the centre of the shaft the arc *a d* is described, being bisected by one of the diagonals before mentioned.

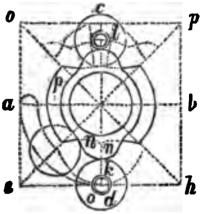

fig. 125.

That portion of the arc contained between the point *o* and the diagonal line is divided into the same number of parts as these micircle at *a*, drawing radial lines to each, and describing concentric arcs, commencing at the ordinates of the semicircle *a*. A line then traced through the points of intersection of these arcs with the radii will indicate the centre of motion of the traverse of the roller *d*, the periphery of which gives the required shape of the cam. The large cam *p* is of course formed so as to act in concert with the small one, which we have just described. In fig. 122, it will be seen that the actuating projections of the pistons which work up against the circumference of the cylinders are fitted with a packing-piece of metal *m*, placed obliquely across the face of the piston, so as to facilitate its passage across the slot in the cylinder. This stop-piece is kept up to its working face by the pressure of the steam behind it, a slight blade-spring being provided as an additional safeguard. The action of the cam motion is such, that at each revolution, when the projection *m* approaches the steam slide the latter is drawn back at such a rate as to keep its inner-faced end just clear of the approaching curved surface; and just at the instant of the passage of the face of the projection, the slide for an instant stops, and is then similarly pushed inwards, to fill up the space gradually left by the receding of the projection. The working-face end of the steam slide is fitted with a tongue-piece of brass, with a spring behind it, to work upon the cylindrical portion of the piston. The action of this tongue is clearly shown in the details of valve in fig. 126. To support the slide, fig. 122, against the pressure of the steam when stretched across the annular space of the cylinder, it is let into a groove in the centre partition and end set-up plates, thus providing it with a solid foundation. The adoption of the system of divided steam-ways in the slide removes all objectionable frictional wear at that part, as it is only for a quarter of an inch movement in each stroke that the steam-pressure in the valve is unbalanced. The instant the communication is opened on both sides of the stop, the pressure is equipoised, and the remainder of the valve's stroke is performed under a pressure not greater than that resulting from the mere weight of metal. At each revolution, a portion of the steam contained between the after curved side of the projection and the cylinder, which steam has before done its duty in carrying round the piston, is shut in by the steam-stop, to be again made use of in the succeeding stroke or revolution. Fig. 126 is an enlarged view of the steam-valve and partition-slide. In this view it is working in the same conditions as in fig. 122, the steam entering above the partition and escaping from below it, as before explained. Again referring to fig. 124, which, as a combined view of the whole engine, gives the clearest explanation of the arrangement, we shall now show how the difficulties attending the end wear of the piston have been effectually got rid of. A favourite argument of many writers, holding views adverse to rotatory engines, was that of supposing two plane circular discs of metal to be working together, revolving upon coincident centres. Experience had gone to show that the plates in these conditions would inevitably wear untrue, by reason of the much greater space passed through by the circumference of the discs, as compared with the space near the centre of motion. After working some time, the surfaces were no longer planes, but by the law of relative velocities became cones, the centres of which remained in contact, whilst the circumferential portions parted. Applying this result to the end wear of rotatory engines, it was held to be an invincible argument against their success; for the evil only increased by continued working. We shall now explain how this evil does not obtain in the engine under consideration. The end covers are double, the outer

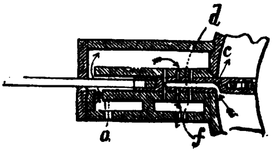

fig. 126.

one only being bolted to the cylinder flanges; the inner one is a plain disc, nicely fitted to the internal diameter of the cylinder, and faced for the circumferential portion of the piston to work against. This plate is capable of the most accurate adjustment by means of screws, which are of a peculiar arrangement; two screws, a hollow and a solid one, being employed. A hollow bolt screwed on the outside is first fitted into threads in the external cover, so as to project slightly through into the interior, and press against the exterior surface of the inner set-up plate. Through the centre of this hollow bolt a solid one is passed, and screwed into the disc by a thread cut for a short distance near the end of the bolt. By this contrivance the hollow bolt presses firmly against the back of the set-up disc, whilst the inner solid bolt, when turned, pulls the disc tight against the former, and enables the engine-attendant to set it accurately, so as to work with the least possible friction in the piston. The latter being used out, and only a narrow ring of metal being left near the circumference for frictional wear, the irregularity of wear found in the action of two plain discs of great area is not found here, as the difference in the distances passed through by the outer and inner portions of the bearing ring of the piston is quite inappreciable. Under a pressure of steam of 22½ lbs. the engine made 70 revolutions per minute, consuming 2 cwt. of slack coal in 2½ hours, having a power of 12 horses. We have been thus particular in describing this engine, as it may be taken as an excellent type of this peculiar class; one abounding in high ingenious mechanical contrivances, and one, moreover, which has passed the ordeal of practical working with a high degree of satisfaction.

The "elliptic rotatory engine" is one of the most successful examples of the modern attempts to apply steam-power directly to a revolving crank-lever, so as to economise steam, lessen the weight, simplify the constructive details, and convey the power directly to its work. Such an engine is, indeed, practically equivalent to the causing the steam to lay hold of and actuate the crank or revolving shaft, just as the hand turns round a winch, without the intervention of joints, levers, and connecting-rods. It is the invention of Mr. William Hyatt, the engineer to Champion's extensive Vinegar Works, of Old Street Road, St. Luke's, London, and is being carried out by him, in conjunction with Mr. Wright, the managing proprietor of the works. The essential peculiarity of the engine is to be found in the fact, that the steam-cylinder is bored elliptically, in order that the revolving piston within it, when set upon a shaft disposed eccentrically in relation to the minor axis of the ellipse, may fit accurately to the elliptic surface throughout the entire revolution. This is a peculiar and unlooked-for characteristic of the elliptical figure. The true action is only to be secured when the amount of ellipticity is exceedingly slight, the centre of motion of the revolving piston-shaft being in a line intersecting the minor axis, at about one-third the length of such axis. That such an engine does work in the most satisfactory manner, is now practically exemplified at the Old Street Vinegar Works, where the engine, from which our drawings, in figs. 127, 128, and 129, were made, is in daily operation. (1853.)

Fig. 127 is an external longitudinal elevation of the engine in working order. Fig. 128 is a corresponding end-elevation at right angles to fig. 127, the front end cover of the cylinder being removed to show the piston within. Fig. 129 is a plan of the engine.

The short steam-cylinder, *a*, open at each end, and fitted with two end-covers, is placed with its axis horizontal upon the base-plate *b*, being bolted down thereon by four projecting eyes *c*; the horizontal piston-rod, or main-engine shaft, *d*, is passed eccentrically through the cylinder, and in the vertical line of the minor or conjugate axis of the ellipse. The cast-iron rotatory piston *e* is suitably fitted with packing-pieces, and slotted trans-

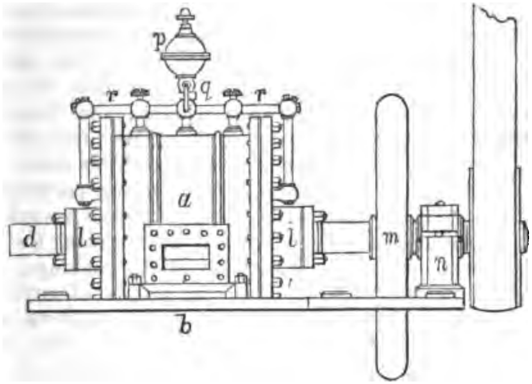

fig. 127.

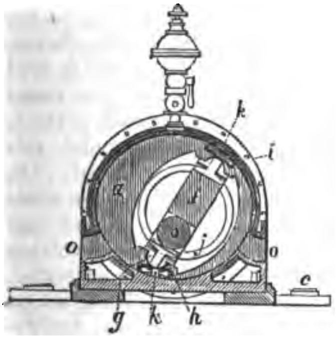

fig. 128.

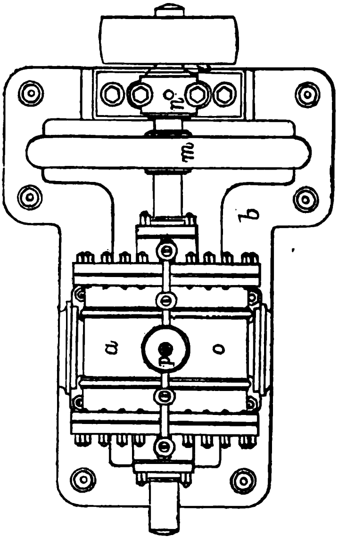

fig. 129.

versely at *f*, to fit the piston-rod, the transverse section of which at that part is rectangular. The slot *f* is for the purpose of allowing of the self-adjustment of the piston during its revolution in working, by sliding laterally over the squared shaft or rod *d*; or, instead of this more direct sliding action, a frame may be introduced to carry anti-friction-rollers, working upon the shaft-surface, and adjustable by the aid of screws and wedges. The packing of the piston—which packing is, at the same time, a portion of the working steam-pressure surface—consists of two metallic strips or ribs, *g*, of the length of the cylinder, the outer projecting surface of such ribs being rounded, whilst their inner flat sides are fitted into shallow groves *h*, formed diametrically opposite to each other along the piston, and in its axial line. The actual working packings are strips of metal, *i*, fitted on their inner sides to the external rounded surfaces of the pieces, *g*, whilst their outer surfaces bear against the interior of the cylinder. These outer-rubbing surfaces of the packings, *i*, are considerably rounded in transverse section, the radius of curvature being slightly less than that of the quickest curve of the cylinder's bore, so that the packing may work round the sharpest elliptic curves with facility; and helical springs are set in behind the packing-pieces, to admit of a free adjustment during working. The flat-end packing, for keeping the piston steam-tight at its two ends, is composed in each case of the brass-ring *j*, let into the end of the piston, and having two projections, *k*, upon it, passing through slots in the end of the strips *g*, thus forming a simple and effective end-packing. A small brass-plate, *k*, is let into the end of the strips, *i*, to complete the end-packing. The piston-rod is supported in a stuffing-box, *l*, on the outside of each cylinder end-cover; and the engine in the present case being a single one, the shaft has a fly-wheel, *m*, keyed upon it, the heavy rim of the wheel being cast hollow at certain parts to balance the overhang of the piston. That end of the shaft which passes away to the machinery to be driven is supported in a pedestal, *n*, bolted down on the base-plate; this bearing, in conjunction with the pair of stuffing-boxes, being the only bearings requisite. When one end only of the shaft is used for driving, no working valves are required in this engine, the steam being admitted in a constant stream by either of the two opposite ports *o*, the only variation of the current being when the slot *f* is horizontal, this being the dead centre of the engine; and both ports are then closed. Or, by another slight modification, the steam and exhaust ports may be made to extend a long way round the cylinder, in order that the engine may have no dead point, the steam being admitted to the back of the revolving piston-blade before it is entirely shut off from the front side. For reversing, an ordinary three-way cock answers every purpose, one cock being set on each side of the cylinder, and put in connection by means of two double-branched pipes; so that either side may be made the steam ingress side. The steam acts equally well in both directions of revolution, the effective pressure being that upon the overhang or eccentricity of the piston, which is constantly varying in effective area throughout the revolution; the piston being, indeed, a direct-acting crank-lever for turning the shaft. For lubrication, an oil-reservoir, *p*, is set on the top of the cylinder, a stop-cock, *q*, being fitted beneath it to command the flow through the pipes *r*, which have each two branches for lubricating the bored portion of the cylinder and the flat-end cover-surfaces. The length of the axial line of the cylinder of the engine is 24 inches, whilst its diameter or bore is to be defined by an ellipse with a major axis of 20⅛ inches, and a minor axis of 18⅝ inches. This engine is called a 30-horse, whilst with a pressure of 32lbs. of steam the indicator has shown a power of 50 horses. Our readers may judge of its compactness by comparing this power with the area actually occupied, as shown in our drawing.

"We think we may safely point to Mr. Hyatt's engine, as being the simplest and most compact of the really effective existing examples of the direct-pressure rotatory class. It is evidently applicable for all the purposes to which the ordinary engine can be applied, as well as to many which are beyond the reach of the old form. With an actuating power applied to its shaft, it at once becomes a forcing or exhausting pump; and, slightly modified, it becomes suitable for the purposes of locomotion. As a railway engine, it is proposed to use two cylinders—one on each driving axle—the axles being thus made the engine piston-rods; whilst the dead points are of course avoided by the usual expedient of setting the lines of greatest effect at right angles to each other, the axles being coupled in the common way. But the most obvious application of the engine is for screw propulsion. The screw-shaft becomes the piston-rod; and as there is no reciprocation about it, any reasonable speed is attainable, whilst the power is conveyed direct to the screw. Indeed, the practical valve of this motor is, in our opinion, as great, as its peculiar mechanical action is elegant."

A steam-engine, to which much attention has been directed of late, is that known as Simpson and Shipton's Reciprocating Steam-Engine. To an arrangement of parts of simplicity in detail, it adds the novelty of a movement remarkable for its originality. Although in many respects resembling at first sight an engine of the rotatory plan, it is nevertheless a reciprocating engine, only differing, in the words of the inventors, from the ordinary engine in the means adopted for obtaining the revolving motion direct out of the rectilinear, the principle through which power is obtained being the same as in the ordinary reciprocating engine; a piston acted upon by steam being propelled in a rectilinear direction in a cylinder or steam-chamber, which, in the present case, is square or rectangular instead of circular, the germ of the engine being "an eccentric revolving in its own diameter;" and which is, in fact, the piston and crank combined in one body; this having in itself two distinct motions, rectilinear and revolving. The following is derived from the inventors, descriptive of the principle and arrangement of the engine. In fig. 130 suppose *a* to be a crank filled up completely between the sides of the steam-chamber *e f*; when steam is admitted above the crank *a*, as shown by the arrows, it moves into the position shown by *b*; in that position, however, it will be observed that the crank will be too short to fill up the chamber, and the steam would consequently rush past it to the lower part of the chamber; it therefore becomes necessary to change the form of the crank, making it such that, at every position, the space between *e f* may be filled up; this form resolves itself into the circle *g g*, with the shaft or axle *c* passing through it out of the common centre; this is therefore an ordinary eccentric. When steam is brought

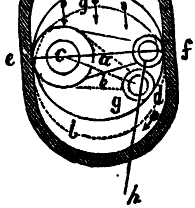

fig. 130.

to act on its surface, it is propelled into the dotted position *i i;* and from its being eccentric, a revolving motion is obtained during its propulsion.

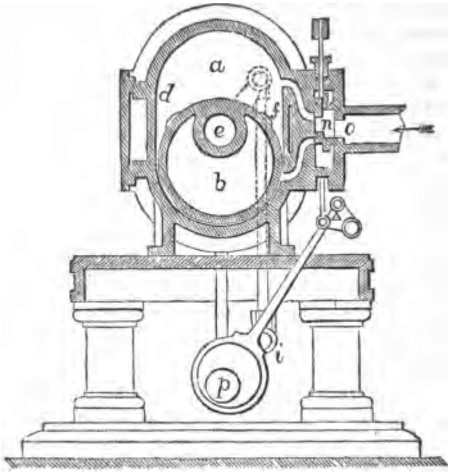

fig. 131.

In fig. 131 is a transverse section, and in fig. 132 a longitudinal section, showing the arrangements by which this principle is carried out.

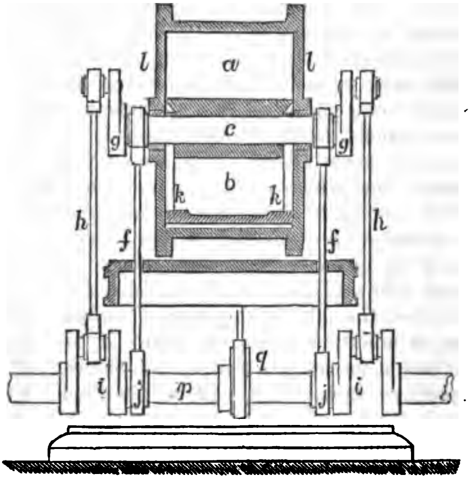

fig. 132.

a is the steam-chamber or cylinder; *b* the piston, keyed on eccentric to the shaft *c*, and carried on the rods *f f*, vibrating from the crank-shaft pedestals. This piston is turned true on the periphery; and in each end are turned conical seatings, in which are fitted rings of metal *k k*, cut open on one side, leaving a lap-joint to prevent escape of steam. These rings are capable of being adjusted by bolts passing through the side plates *l l*, and are thus easily adjusted. The cranks *g g* are keyed on the shaft at right angles to each other, equidistant from a line drawn through centre of shaft and centre of piston; these cranks convey the power to the lower cranks, *i i*, by rods or drag-links *h h*. The vibrating rods *f f* are carried on the pedestal *j j*. The ends of the cylinder *a* do not require to be bored, as the whole wear takes place on the plates *d* and *e*. The plate *e* is dovetailed in and fitted fast; *d*, being loose in its parallel recess, which allows it to follow up the piston as it wears; the plate *d* is kept up to the face of the piston by springs behind it, or by admitting steam into the recess at the back of it. This plate serves another useful purpose; this is the prevention of priming in the cylinder: as the water increases in the cylinder, it forces back the plate, and rushes from one side of the piston until it escapes. Steam is admitted to act on the piston by means of a valve *n* through the steam-ports *m m*, open to the top and bottom of the piston alternately; the valve is worked by an eccentric *o* keyed on the crank-shaft *p*. This valve is on the equilibrum principle, and exhausts through the back, and works between two parallel planed surfaces; the wear that takes place being accommodated by a ring of metal *o*, similar to that employed for packing the piston. This form of engine is being employed in numerous instances, and with marked economical effect.

As the concluding portion of the present division of our treatise, we propose briefly describing the principles of action of two varieties of engine which have been successfully introduced into practice; these are the "Cambrian" and the "Disc Engine."

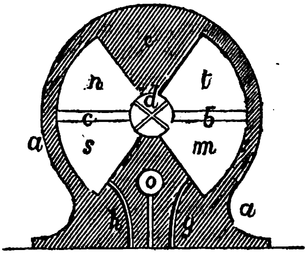

fig. 133.

In the Cambrian engine the piston has a semi-rotatory motion given to it by the following arrangement: Let *a a*, fig. 133, be the external casing or cylinder; *c b* the arms of a piston vibrating on the axle *d;* the steam space is divided into compartments by the triangular abutments *e f;* the pipe *g* admits steam to the compartment *m*, and *h* into *s;* the steam is exhausted through *o*. By passages cut in the piston-shaft, diagonally, as in *x;* steam is admitted from the space *s* into *t*, and from the space *m* into *n*. The steam, on being admitted to one of the spaces, as *m*, passes into the opposite space *n*, and thus presses on both ends of the piston *b* and *c*, but on opposite sides; the strain on the working parts is by this arrangement much reduced. By this pressure on the alternate sides of the piston a reciprocating motion is produced in the piston-shaft *d*, which is communicated to the crank-shaft in the usual manner. A large number of engines on this principle have been successfully introduced.

The movement of the "disc engine" is very peculiar; the most lucid exposition of its principle we have met with is that given by a "practical engineer," himself a well-known and able inventor, in the pages of the *Expositor*. We here append it: "The vessel in which the piston moves, the fixed recipient for the action of the steam, is the section of a hollow sphere, such as would remain after two equal opposite segments were cut off. In this is fitted the piston, called from its form and peculiar movement a disc. The centre of the disc coincides with that of the sphere; and as its diameter is equal to that of the inside of the sphere, it can have no direct movement like the common engine piston; but it may perform an oscillatory motion, such as a top or a teetotum describes when their spinning force is nearly exhausted; that is to say, each point in the periphery successively dips; and the lowest point seems to proceed round the periphery, though there need not necessarily be (nor is there in this engine) any absolute rotation. Like a wave each point in the disc in its turn rises and falls; and like the wave also, there is no onward motion. To understand the action more perfectly, we refer to the following diagram (fig. 134): *a a* is the spherical case we have described, *b* is the disc, and *c* a ball concentric with the axis *d; e f* are two conical covers, *g* is a crank, into which the end of the axis *d* is inserted. If the crank be now turned round, it will be seen that every part of the disc *b* will successively be brought into contact with the cones at two opposite radial lines; but the rotation of the axis of the crank need not necessarily cause the disc to perform any other than the oscillatory one we have described, and, as we have said, it cannot do so. There is a slot in the disc thus (fig. 135), and there is a partition in the engine extending from the outside to the ball and fitting the two cones. When we turn the two cranks, therefore, the oscillatory motion will be performed by the disc and axis, the side of the slot rubbing up and down on the surface of the partition." It is difficult to describe the way in which the disc receives the effort of the steam; but it may be sufficient to state, that the struggle or force of the steam to enter and escape, passing through an entrance made in one of the conical covers on one side of the partition to the exit-pipe placed on the other side of the partition, forces the disc partially round, and acting on the ball *c*, makes the lever *d* rise and fall in the direction of the arrows, and thus communicates motion to the crank *g*.

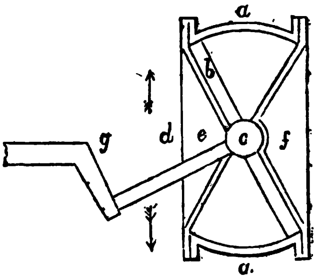

fig. 134.

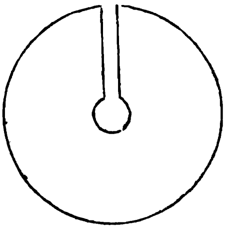

fig. 135.

The first patent for the disc-engine was taken out by a Mr. Dakeyne in 1830. His engine was not, however, put in practice. Henry Davies was the next inventor who turned his attention to this engine. He took out three patents, each combining successive improvements in its action, his last patent being taken out in 1844, in which his improvements had reference to working the engine expansively. He introduced a variety of improvements in the details of this engine; indeed he may with all truth be termed its inventor. In this form of engine, in order to insure the utmost efficiency of working, it is necessary that the contact between the surfaces of the conical ends and the sides of the disc should be as perfect as possible, to prevent the passage of the steam between the surfaces of the plate or disc and the cones. To make this more perfect, Davies formed a series of ribs or cogs on each side of the disc, radiating from the central ball to the outside of disc, and a similar series of cogs in the interior surfaces of the conical ends; these cogs on the disc and cones being so arranged that they work into one another like the teeth of pinions, the cogs being ground so as to insure as perfect contact as possible. He fitted up the sides of the slot in the disc with metallic packing, making them rub on the sides of the partition; by this arrangement he was enabled to work the engine expansively. The disc engine, as thus improved by Davies, was carried into practice pretty extensively, and a company was formed at Birmingham for introducing it on a large scale. From some cause this company ceased soon to exist, and the disc engine fell into comparative obscurity, until Mr. Bishopp, in 1844, introduced a variety of improvements, and, aided by the admirable mechanical resources of eminent engineering firms, he has succeeded in placing it in a comparatively high position among economical and compactly working engines. Mr. Bishopp has dispensed with the cogs or ribs on the disc and cones, and substituted a series of strips of metallic packing, forced outwards in contact with the face of the disc, which is quite plain in its surface, by a series of springs. To insure the perfect action of the sides of the slot in the disc against the partition, Mr. Bishopp adopts a semicircular bow which extends over the engine, its two extremities being attached to the opposite ends of the axis. A pin is carried by the bow, a rectangular truss being attached to this pin, and moving from side to side in a groove made in the outside of the engine, and which groove is concordant with the plane of the partition. By this arrangement, the centre line of the slot in the disc always moves in the same plane; the packing presses equally on the face of the partition, and any degree of expansion used as may be required. "Thus improved, these engines," remarks an authority, "are now no longer experimental. They have been adopted (1851) in about fifty cases, and are found to be both economical and durable." We have before us both the reports of Messrs. Terrey and Parkes, both of whom pronounce in their favour. Mr. Terrey, alluding to some comparative experiments made at Lewisham with a disc engine, and one erected by Messrs. Penn and Son, states that he is of opinion, from what he has seen of the improved disc engines, that their performance is equal to that of the best engines of the construction in common use, in the like conditions of pressure of steam and extent of expansive action. Mr. Parkes reports a considerable economy in fuel.

CHAPTER V.

RAILWAY LOCOMOTION AND LOCOMOTIVE ENGINES.

PREVIOUS to describing the modern mechanism of the locomotive engine, so called *par excellence*, in contradistinction to the "steam-carriage for common roads," which properly is also entitled to the distinctive appellation of locomotive, we propose giving a rapid sketch of the history of its introduction, and a notice here and there of the most striking of the machines from time to time introduced, ending in the comparatively perfect machine now in daily use on our railways. We must premise, however, that the nature of our treatise does not admit of our going into the history of the introduction of railways, or an explanation of their construction; it is with the engine, its history and construction, that we have alone to deal. The subject of railways belongs more exclusively to the treatise on "civil and mechanical engineering," and which may hereafter be added to the series of works of which the present forms a part.

It is difficult to decide to whom the honour is due of having suggested the use of the steam-engine for the purpose of propelling carriages. Savery hints at its use in this way, at least he considered that it was possible to apply it. Dr. Robison, the gentleman who was the means of directing the attention of Watt to the steam-engine, "threw out the idea of applying the power of the steam-engine to the moving of wheel-carriages;" but other occupations withdrew his attention from the subject, and nothing further was effected. In the patent taken out by Watt in 1784, he described the application of the steam-engine to the propulsion of carriages. "The boiler of this apparatus he proposed should be made of *wooden staves* joined together, and fastened with iron hoops like a cask. The furnace to be of iron, and placed in the midst of the boiler, so as to be surrounded on every side with water. The boiler was to be placed on a carriage, the wheels of which were to receive their motion from a piston working in a cylinder; the reciprocating motion being converted into a rotatory one by toothed wheels revolving with a sun and planet motion, and producing the required velocity by a common series of wheels and pinions. By means of two systems of wheel-work differing in their proportion, he proposed to adapt the power of the machine to the varied resistance it might have to overcome from the state of the road. A carriage for *two* persons *might*, he thought, be moved with a cylinder of seven inches in diameter, when the piston had a stroke of one foot, and made sixty strokes per minute. Watt, however, never built a steam-carriage." Such is the account given by one authority. Another, however, affirms that Watt did at least construct a model, of which we give a diagram in fig. 136, illustrative of its construction; and further states, that Messrs. Bolton and Watt constructed a steam-carriage, which was made to run on the roads of Cornwall in the years 1785-1786. We are, however, inclined to think that the model of the locomotive carriage, as here attributed to Watt, and which the writer states was made by Mr. Murdoch, Watt's assistant, was not only made by him, but owed its creation to the inventive genius of Murdoch himself. In a life or biographical sketch of Murdoch, read some two years ago at the Institution of Mechanical Engineers, it is there stated that Murdoch constructed the model of a steam-carriage while residing at Redruth in Cornwall, and the details and general arrangement of which resembles those in the diagram now given very closely. Leaving this matter to be decided by more competent authorities, we hasten to the other points of the present division.

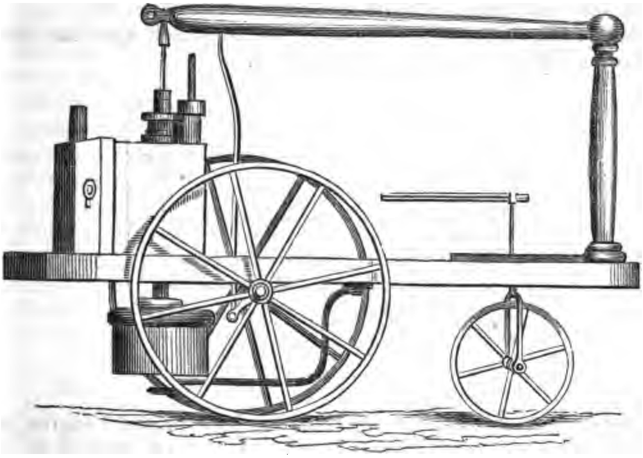

fig. 136.

Another claimant for the honour of having introduced the first steam-carriage is the celebrated William Symington, the engineer now acknowledged to be the first introducer of a practically-working steamboat. As early as 1784, it occurred to him that steam might be applied to the propulsion of carriages. He commenced experiments, with a view of perfecting the idea; and in 1786, submitted to the inspection of the professors, and other scientific gentlemen of Edinburgh, a working model of a steam-carriage. This gave such proofs of practicability, that he was urged to carry the machine into practice. Such, however, were the difficulties to be overcome in this, that he conscientiously stated his scruples to those anxious

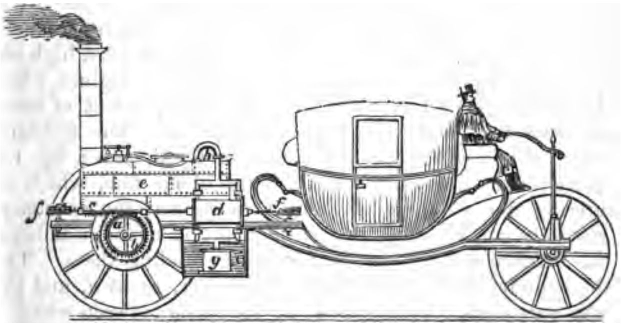

fig. 136*a*.

to aid him in the matter, advising them not to proceed with it. In fig. 136 *a* we give a lateral of the steam-carriage model as constructed by Symington; *d* the cylinder; *e*, boiler, supplied from the condenser; *ff*, direction pulleys; *g*, condenser; *h*, steam-pipe; *i*, water-tank; *a*, drum fixed on the hind axle; *b*, tooth and ratchet-wheels; *c*, rack-rods, one on each side of the drum, the alternate action of which upon the teeth and ratchet-wheels produces the rotatory motion.

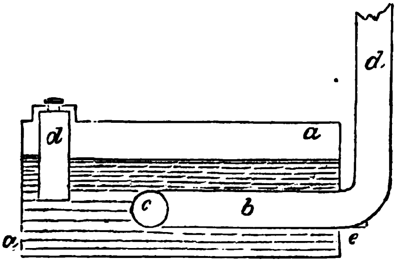

fig. 137.

In a previous chapter, we described the high-pressure engine patented by Messrs. Trevethick and Vivian; in the patent they claimed its employment in "propelling wheel-carriages of every description." In 1804, Mr. Trevethick set an engine to work on a very indifferent railroad at Merthyr Tydvil Colliery, in Wales; this worked very satisfactorily, and up to 1830 or 1831, it was the form which, more or less modified, was working the railroads on which steam was employed. "The advantages," says Trevethick in his evidence before the Committee of the House of Commons on carriages for common roads, "gained by this improvement, were a detached engine, independent of all fixtures, working with five times the power of Bolton and Watt's engine, without condensing water, and the fire enclosed in the boiler surrounded with water, and a force-draught created by the steam for the purpose of working on the roads without a high chimney; and from this was copied all the boilers for navigation-engines, which without could not have been available, this being independent of brick-work, light, safe from fire, and occupying little room." The following is a description of this engine: the boiler is cylindrical, as *a a*, fig. 137; *b* is the fire-place; *e* the fire-door; *c* the entrance of the flue, which is turned before entering the chimney. By this arrangement the economy of fuel effected was very considerable, the greater portion of the heat being given out by the furnace and flue to the water surrounding them. The lower part of the cylinder was placed within the boiler, as at *d*, and the upper portion was surrounded by a jacket, in the space between which and the cylinder the steam from the boiler was allowed to circulate freely; the loss of steam from condensation was by this means obviated. The steam was admitted above and below the piston by the four-way cock already described; and after working the piston, instead of passing it to the atmosphere, it was led by a pipe to the chimney. By this arrangement the draught of the furnace was greatly increased, and a convenient means established of getting rid of the waste steam. Had this plan been patented, the inventor would have probably reaped a golden harvest from this alone.

The piston-rod had a cross-head attached to it, as *e*, fig. 138, sliding in the parallel guides *f*, attached to the upper end of the cylinder, and steadied by a stay as at *g;* from both ends of this cross-head connecting-rods *d* proceeded, and were connected to the crank *e*, fixed on the centre *b* of the driving-wheel *a;* the axis of the driving-wheel passing with the carriage, and immediately beneath the cylinder. The principle of this arrangement is shown in fig. 151, p. 79, *Mechanics and Mechanism.* This engine, on its first trial, in which the propulsion was effected by the adhesion of the wheels on the rails, drew ten tons of bar-iron, besides the carriages, for nine miles, at the rate of five miles an hour, without stopping, and carrying its heavy load of fuel and water.

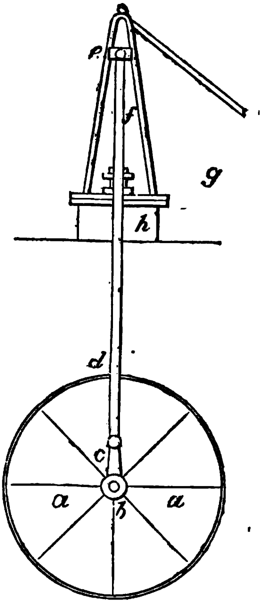

fig. 138.

We have now to notice the ingenious mechanism introduced to obviate an inconvenience in engine propulsion which only existed in imagination. With reference to this point, Dr. Lardner remarks: " It is a singular fact, that in the history of this invention, considerable time and great ingenuity were vainly expended in attempting to overcome a difficulty, which in the end turned out to be purely imaginary. To comprehend distinctly the manner in which a wheel-carriage is propelled by steam, suppose that a pin or handle is attached to the spoke of the wheel at some distance from its centre; and that a force is applied to this pin in such a manner, as to make the wheel revolve; if the face of the wheel and the surface of the road were absolutely smooth and free from friction, so that the face of the wheel would slide without resistance upon the road, then the effect of this force, thus applied, would be merely to cause the wheel to turn round; the carriage being stationary, the surface of the wheel would slide or slip upon the road as the wheel is made to revolve. But if, on the other hand, the pressure of the face of the wheel upon the road is such as to produce between them such a degree of adhesion as will render it impossible for the wheel to slide or slip upon the road by the force which is applied to it, the consequence will be, that the wheel will roll upon the road, and the carriage will be moved forward through a distance equal to the circumference of the wheel each time it performs a complete revolution. It is obvious that both of these effects may be partially produced; the adhesion of the wheel to the road may be insufficient to prevent stopping altogether, and yet it may be sufficient to prevent the wheel from slipping as fast as it revolves. Under such circumstances the carriage would advance, and the wheel would slip. The progressive motion of the carriage during one complete revolution of the wheel would be equal to the difference between the complete circumference of the wheel and the portion through which, in one revolution, it has slipped. When the construction of travelling steam-engines first engaged the attention of engineers, and for a considerable period afterwards, a notion was impressed upon their minds that the adhesion between the face of the wheel and the surface of the road must necessarily be of very small amount; and that, in every practical case, the wheels thus driven would either slip altogether, and produce no advance of the carriage, or that a considerable portion of the impelling power would be lost by the partial slipping or sliding of the wheels. It is singular that it should never have occurred to the many ingenious persons, who for several years were engaged in such experiments and speculations, to ascertain by experiment the actual amount of adhesion in any particular case between the wheels and the road. Had they done so, we should probably now have found locomotive engines in a more advanced state than that to which they have attained."

Space will not allow of our illustrating all the mechanisms introduced to obviate this imaginary difficulty,—indeed, this, for the purposes of our treatise, is not at all necessary;—we shall merely glance at the nature of a few of the most ingenious of these. Trevethick and Vivian, in their patent, claimed the plan of making, in *certain cases*, the external periphery of the driving-wheels "uneven, by projecting heads of nails, or bolts, or cross grooves, or *fittings to railroads* when required; and that *in cases of hard pull* we cause a lever bolt, or claw, to project through the rim of one or both of the said wheels, so as to take a hold of the ground." But, so far from adopting these contrivances at all times and under all circumstances, as a means of overcoming the imaginary difficulty before alluded to, they on the contrary expressly stated, that "in general the ordinary structure or figure of the external surface of these (the driving) wheels will be found to answer the intended purpose."

In 1811 Mr. Blenkinsop patented "certain mechanical means, by which the conveyance of coals, minerals, and other articles is facilitated, and the expense attending the same rendered less than heretofore." In this arrangement, a rack or toothed rail was laid down along one side of the railway; into the teeth of this rack a large toothed wheel worked, this receiving a circular motion from a steam-engine; the boiler and engine working this being supported by a frame on four wheels. By this means the engine was pulled along the rails, and was enabled to ascend gradients of considerable incline. The boiler was placed on a wooden or cast-iron frame; through the interior of the boiler a large tube was passed, containing the furnace; this tube was continued through the other end, and bent upwards to form the chimney. Two cylinders were placed at the top of the boiler, and the pistons were connected by cross-heads and connecting-rods, *f*, *e*, fig. 139, to the cranks, *c*, *d*, fastened in the centre of two toothed wheels represented by dotted circles. These worked into a large toothed wheel placed in the inside of the cogged wheel *a*; the cogs in this working into the teeth or cogs placed along one side of the railway *b b*. The engine was long used on the Middleton Colliery Railway, near Leeds. The following particulars were forwarded by the patentee to Sir John Sinclair:—With two eight-inch cylinders, the engine weighs five

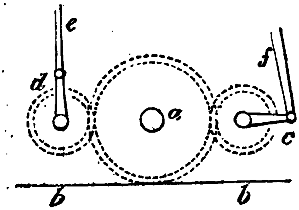

fig. 139.

tons, "consumes two-thirds of a hundredweight of coals, and fifty gallons of water per hour; draws twenty-seven wagons, weighing ninety-four tons, on a dead level, at three and a half miles per hour; or fifteen tons up an ascent of two inches in the yard; when 'lightly loaded' it travels ten miles an hour, does the work of sixteen horses in twelve hours, and costs 400*l.*"

We now approach the period at which two men appeared in the arena of invention; men who, up to the period of their death, were intimately connected with railway mechanism, and who were destined, during long and active lives, to be the means of introducing improvements in this branch of engineering, so effective as to cause quite a revolution in the art of travelling; these men are the well-known George Stephenson and Timothy Hackworth. To the former we are indebted for the system of railways as now established; to the latter nearly all the improvements in the locomotive which formed it the powerful and effective machine we now see it, owed their origin. And in thus paying to Hackworth part of the tribute of praise which has hitherto been nearly always allotted to Stephenson, we by no means detract from the high praise due by the world to the latter. Whatever may have been the improvements effected in the locomotive as a distinct mechanism, it never could have arrived at the height of its present efficiency as "a space and time annihilator," had not the improvements in the "iron way" been simultaneously effected. Without the improved system of rails introduced by Stephenson, the locomotive engine would have been comparatively useless; and without the speed attained by the improved locomotive, the improved system of rails would have been so commercially unremunerative as to have been altogether set aside. These were the elements of high velocity, "each of which formed the absolute condition of the existence of the other." "I am, I think, safe in saying," remarks Mr. Scott Russell, in his eulogium on George Stephenson, "that the wrought-iron railroad (Stephenson's) was essentially dependent on the locomotive engine. But that the modern locomotive engine could not subsist without the wrought-iron rail, and its multifarious appendages of chains, keys, locks, sleepers, switches, crossings, sidings, and turn-tables, is too evident to need proof. Without the smoothness of the rail, the engine would be jolted to pieces; and without the easy motion which it gives, the engine could not be made to draw a sufficiently profitable load to pay; and further, unless made of wrought-iron, it would be impossible to attain the high speed of the locomotive without imminent danger. It therefore appears, that the continuous wrought-iron railway and the locomotive engine were inventions intimately related to each other, and each a condition of each other's success. To Stephenson we are indebted for the chief features of improvement in both. It was the joint perfection of the road and the engine which created the Liverpool and Manchester line, and all the progeny of that wonderful and gigantic experiment, an experiment whose complete success now bears incontrovertible testimony to the genius of the man." Historical evidence, recently made public, proves most decidedly that to the inventive genius of Timothy Hackworth the locomotive engine owed nearly all the improvements which made it an efficient machine; improvements, too, effected at a time "when every thing had to be learned,—when, indeed, engineers were utterly thrown upon their own resources." Those who are desirous to enter into an investigation of the point, and to be made aware of the extent to which Stephenson was indebted to the ability and experience of Hackworth in locomotive mechanism, should read the article in the *Practical Mechanic's Journal*, p. 49, vol. iii. 1850-1, entitled "A Chapter in the History of Railway Locomotion," and the "Memoir," p. 225, same volume. We think that an unprejudiced perusal of these interesting papers will induce the reader to coincide with the opinions of the writer as therein expressed. "If George Stephenson deserved the title of the 'Father of Railways,' we think we may at least claim for Timothy Hackworth that of the 'Father of Locomotives.'"

In 1814 George Stephenson constructed a locomotive, Lord Ravensworth, of the Killingworth Colliery, having assisted Stephenson with money to conduct his experiments. This was tried on a tram-way at Killingworth. In 1815, in conjunction with another party, he took out a patent for "various improvements in locomotives." In this engine two cylinders were used, one at each end; the connecting-rods were attached to pins on a spoke of the wheels; they were placed at right angles to each other; by this means the motion was rendered continuous, one crank or pin receiving the full leverage of the connecting-rod while the other was at its dead point. A toothed wheel was placed on each axle inside the wheels, and round the two wheels a peculiar kind of endless chain was stretched (see p. 50, *Mechanics and Mechanism*); this chain was so constructed as to furnish a series of rectangular apertures, into which the cogs in the toothed wheels entered; by this arrangement, as the wheels revolved the chain was passed along, and one wheel could not revolve without the other; the relative positions of the cranks or pins (namely at right angles) was thus preserved. In the year 1816 he took a patent, in conjunction with Mr. Losh, which embodied many of his notable improvements in the construction of railways. In this patent one claim having reference to the construction of locomotives was included; this was a very ingenious method of "sustaining the weight, or part of the weight, of the engine upon pistons movable within cylinders, into which the steam or the water of the boiler is allowed to enter, in order to press upon such pistons, and which pistons are, by the intervention of levers and connecting-rods, made to bear upon the axles of the wheels of the carriage upon which the engine rests." In fig. 140 we give a transverse section, exhibiting the improvements here mentioned, and the arrangement of the parts of the engine at this period. The boiler is at *n n*; *b*, the internal furnace; *c*, the flue or chimney; *d*, the cylinder; *e*, the

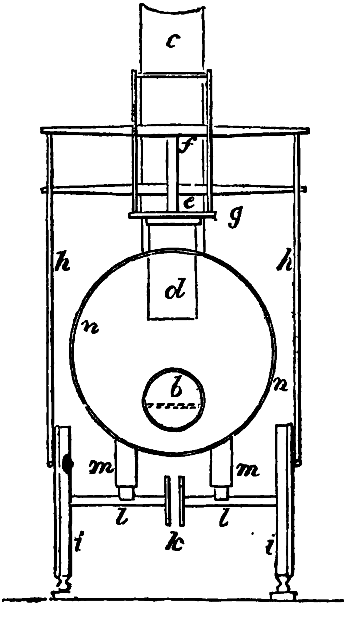

fig. 140.

cross-head of one piston, at the dead point of the turn of the crank; *f*, that at the full leverage; *g g*, the piston cross-head guides; *h h*, the connecting-rods; *i i*, the driving-wheels, running on the fish-bellied edge-rail, one of the improvements in railways included in the patent; *k*, the toothed wheel and endless chain; *m m*, the cylinders and pistons for acting on the axles as already described.

Engines on this plan were introduced by Stephenson on the Killingworth and on the Hetton Colliery Railway; and although every exertion was made by him to render them efficient and economical, and to get them into use on the different railways which began at that time to be formed, it is the opinion of competent authorities that they did not possess "those advantages which the inventor had anticipated."

On the 27th of September, 1825, the Stockton and Darlington line of railway, twenty-five miles long, was opened for public traffic. Twenty miles of this was worked by locomotives and horses, the powers of each being put thus in close competition. At this early period of the history of a line of railway, the first ever laid down on the improved principles as introduced by Stephenson, and which formed the nucleus of the railway system, the locomotives employed on it were five in number, four having been manufactured by Messrs. Stephenson at their factory at Newcastle, and one by Mr. Wilson of the same town. Such, however, was their inefficient working condition, that the power of steam was about to be abandoned, and the railway conducted by horses. Timothy Hackworth, to whom we have before alluded, and who, through the intervention of George Stephenson, had been appointed manager of the working department of the railway, stepped forward at this critical juncture, and proposed to construct an engine capable of working the line to the extent already mentioned. His offer was accepted, and he forthwith began his operations. The boiler of the engine made by Wilson, already alluded to, was taken as the boiler of the new machine. "This boiler was a plain cylinder," says the account from which we quote, in the *Practical Mechanic's Journal*, "thirteen feet in length, and four feet five inches diameter. The heating surface was obtained from a double tube of malleable iron in the form of the letter W, traversing the whole length of the boiler. One side of this tube was made available for the fire-grate, and the heated vapour being passed through it was returned by the opposite one to the chimney, which was actually a vertical continuation of this end. With this contrivance the engine had a heating surface double that of any other engine of its time. She was carried on six four-feet wheels, four of them being spring-mounted, and was the earliest of the six-wheel coupled class. The cylinders, eleven inches in diameter and twenty inches stroke, were placed vertically at what is now the smoke-box end of the engine, and worked directly upon the first pair of wheels. At the same end was attached a malleable iron cistern, into which the water passed from the tank previous to being introduced into the boiler, the driver having the power of regulating the supply; and a pipe from the steam-exhaust was led into the cistern for the purpose of admitting steam at pleasure to heat the water. Another pipe was provided for the purpose of leading off a steam-jet from the exhaust-pipe at the chimney end for discharge beneath the grate; the intention being to facilitate the combustion. In addition to its being the original of a class of engines now so universal, this engine was the first which had a blast-pipe fitted to it, the whole of the exhaust steam, excepting only such a portion as was required for the purposes before alluded to, being conveyed into the centre of the chimney, and then thrown out in a *jet* from a *conical pipe*." Trevethick led his waste steam to the chimney by a a pipe, no conical or blast-pipe being used to send it up the chimney in the form of a *jet*. Although Trevethick, before a committee of the House of Commons, claimed the use of the waste steam passing into the chimney as a means of quickening the draught, one writer on locomotive engineering states, that he had "no intention or expectation of improving the draught of the chimney thereby." How this holds with the fact it is now difficult to determine; but to return. The engine thus constructed by Hackworth was named the "Royal George," and commenced running in October 1827. The following statement affords an evidence of its power as compared with that of horses, with which it competed. The cost of the engine was 425*l.*; in one year (1828) she conveyed over twenty miles 22,442 tons, at a cost of, including all repairs, and maintenance, and interest on such capital at 10 per cent, one farthing per mile: "an economy in working which is rarely exceeded at the present day." The cost of the same work performed by the horses was 998*l.*; thus showing a difference of 532*l.* in favour of the engine over the animal power. "The points in the improvement," says the same writer, "in the 'Royal George' which conduced to this important result, evidencing not only her great superiority over her compeers, but the vast resources of the imperfectly developed locomotive system, were simply these: the increased evaporative surface of the boiler; the perfect command over heavy loads in all states of the weather, by reason of the superior tractive adhesion derived from the six-coupled wheels; and the introduction of the blast-pipe, an invention which alone will carry down the name of Hackworth to future ages in connexion with early locomotive history. Up to the period of which we write, no really efficient locomotive was in use, as the steam pressure invariably fell, in spite of the best efforts of the driver; and the superiority of the 'Royal George' in this respect alone at once elevated it far above its contemporaries, for it was capable of maintaining a speed of nine miles per hour throughout its run of twenty miles." Hackworth introduced other improvements in this engine, as the short-stroke force-pump, and the substitution of the adjustible springs to act on the safety-valves instead of weights.

We now approach that period in the history of steam locomotion at which the great impetus was given to the perfection of the engine. We allude to the opening of the Liverpool and Manchester Railway in 1830. In considering the means to be used for working the line, the choice of the directors lay between the employment of stationary steam-engines and locomotives. It is unnecessary here to enter into detail as to the investigations which the company deemed requisite to be instituted in order to ascertain the most efficient and economical method of working the line; suffice it to state that, in opposition to the Report of the engineers appointed to investigate the matter, Messrs. Rastrick and Walker, who recommended stationary engines, the directors ultimately resolved to adopt locomotive power; and offered for the best engine a prize of 550*l.*, to be decided by a public competition. It is generally understood that the opinion of Robert Stephenson in favour of locomotives induced the directors to adopt this power; and it is nothing derogatory to the great fame of Robert

Stephenson to state that it appears he was much indebted to Timothy Hackworth for a variety of sound practical information; indeed, Hackworth was the only person at this period who had any thing like a practical knowledge of the whole bearings of the case.

In offering the above reward for the best locomotive, the directors made the following stipulations: " the engine was to consume its own smoke; to be capable of drawing after it three times its own weight *at ten miles an hour*, and have not exceeding 50 lbs. pressure upon the square inch on the boiler ; two safety-valves, one locked up ; engine and boiler to be supported on springs, and rest on six wheels if it should exceed four and a half tons ; height to top of chimney not more than fifteen feet ; weight, including water in boiler, not to exceed six tons, but preferred if of less weight ; boiler, &c. proved to bear three times its working pressure, and pressure-gauge provided; cost of machine to be not more than 550*l*." The following is a description of the public trial of the competing engines: The " Rocket," constructed by George Stephenson, and of which we give a representation in fig. 141, weighed 4 tons 5 cwt., and the tender, with water and coke, 3 tons 4 cwt. 2 lbs. ; it had two loaded carriages attached, weighing 9 tons 10 cwt. 3 qrs. 20 lbs., thus making the whole weight to be moved equal to 17 tons. The velocity attained by this engine was 14 miles an hour, with an evaporation of 114 gallons per hour, and consumption of coke equal to 217 lbs. per hour. The greatest velocity attained was at the rate of 24⅙ miles per hour. The " Sanspareil," by Timothy Hackworth, and of which we give a representation in fig. 142, was the next engine tried, although from its not having been made in strict accordance with the specified rules, it was scarcely competent to enter the lists of competition. The weight of the engine was 4 tons 15 cwt. 2 qrs.; the tender and water and fuel being 3 tons 6 cwt. 3 qrs. ; the loaded carriages, three in number, attached to it being equal to 10 tons 19 cwt. 3 qrs. ; the whole weight to be moved being equal to 19 tons 2 cwt. The engine in her eighth trip became disabled through the feed-pump becoming disordered in its action, the level of the water in the boiler got low

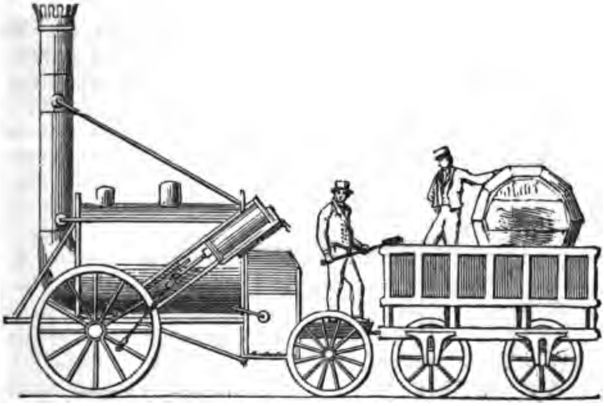

fig. 141.

therefore, and the leaden plug, which was used as a safety-valve, getting melted, an end was thus put to the experiment. Her rate of speed was however satisfactory, being equal to conveying 19½ tons at fifteen miles per hour. The greatest velocity attained was 22⅔ miles per hour. The consumption of fuel was very great in this engine, being equal to 692 lbs. per hour; this was in consequence of the great draught induced by the steam-blast in the chimney.

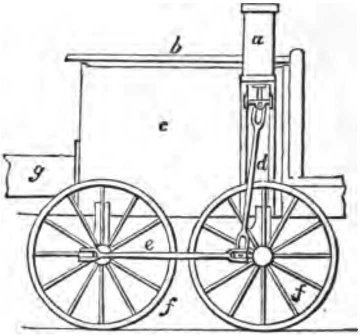

fig. 142.

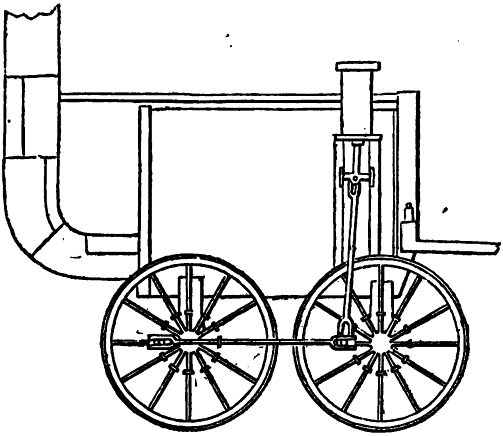

fig. 143.

The third engine, the "Novelty," by Messrs. Braithewaite and Erricson, and of which we gave a representation in fig. 143, carried its own water and fuel, and weighed 3 tons 1 cwt. The weight of the tank, water, and fuel, being 16 cwt. 14 lbs.; the two loaded carriages being 6 tons 17 cwt.; the total weight being 10 tons 14 cwt. 14 lbs. In consequence of successive accidents in the working arrangements of this engine, it was withdrawn from competition; its performances, however, were very satisfactory so far as they went.

Another engine, named the "Perseverance," constructed by Mr. Burstall, was also entered for competition; but being unsuited to the railway, was at once withdrawn. The judges on this interesting occasion were Mr. Nicholas Wood, Mr. Rastrick, and Mr. Kennedy. The prize was awarded to Mr. Stephenson for his engine the "Rocket."

The "Rocket" undoubtedly owed its efficiency, at least in an economical point of view, from the construction of the boiler, and the large amount of surface which was presented to the action of the heated air. This was obtained by introducing twenty-five copper tubes, three inches diameter, into the interior of the boiler, at its lowest diameter; these tubes opened at one end into the space below the chimney, and at the other into what is now termed the fire-box; by this arrangement, the flame and heated air passed through the tubes, which were surrounded by the water in the boiler. The furnace or fire-place was an external box, about three feet deep and two wide; the furnace was provided with an external casing; into the space thus formed the water from the boiler passed: a large additional amount of heating-surface was also thus obtained. The boiler or flue-tubes—"which has since proved to be the main-stay of the modern locomotive"—was the invention of Mr. Henry Booth, the secretary of the railway; a gentleman "to whom railways are indebted for much of their practical efficiency." From the invention not having been patented, Mr. Booth did not receive the great pecuniary advantages which might otherwise have resulted from this highly valuable improvement. We understand, however, that he received a pecuniary reward from the directors of the railway on account of it. As will be seen on inspection of the diagram, the cylinders were placed outside the boiler, near the fire-box, and inclined at an angle; and the piston-rod of which is connected with the driving-wheel by means of a connecting-rod.

In the "Sanspareil" of Hackworth, the cylinders were inverted and placed vertically; the piston-rod cross-head worked between parallel guides; and to the cross-head was attached the connecting-rod which communicated motion to the hind wheels; the fore and hind wheels were coupled by a connecting-rod. The boiler was cylindrical, with the flue returned to the front, where it entered the chimney; the flue was of course entirely surrounded with water.

The "Novelty" possessed some arrangements of considerable merit, the most distinguished feature being the construction of the boiler and fire-place. This will be seen by an inspection of the diagram in fig 144: *d* is the furnace placed inside the boiler, and surrounded with water; fuel is supplied to the fire-place *c* by the tube or funnel *e*, passing through the dome of the boiler, and covered with a lid or cap. Air is forced into the fire, to maintain combustion, by a small pair of fanners worked by the engine, through the pipe *b* communicating with the ash-pit *c*. The heated air is forced along the series of pipes *fg* to the chimney *h*, the steam space being at *i i*. By this arrangement a large amount of heated surface is obtained; the fireplace not only being surrounded with water, but the long range of pipes *fg*. The peculiar arrangements of the engine will be seen by the diagram in fig. 143. Mr. Stephenson not only obtained the prize, but the appointment of engine-manufacturer to the company. The attention of the firm was now devoted to the perfecting of the mechanism of the locomotive. "Each engine that issued month by month from the factory was an improvement on its predecessors, and the fourteen and twenty miles of the 'Rocket' were raised to sixty and seventy miles; and the Newcastle factory became the largest and most famous in the world." Other manufacturers entered the field of competition, and the vast amount of ingenuity and practical experience brought to bear on the mechanism of the locomotive by such eminent firms as those of Hawthorn and Company; Sharp, Roberts, and Company; Bury, Curtis, and Kennedy; and last, though not by any means least, of Timothy Hackworth, soon resulted in bringing the locomotive engine to its present high state of perfection.

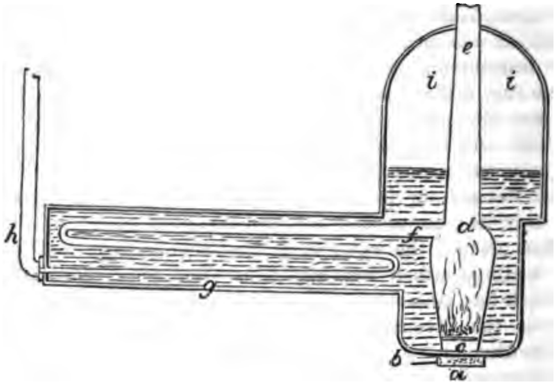

fig. 144.

We now proceed to give illustrations of locomotive engines, showing the majority of the improved arrangements as now introduced. It is impossible to notice the whole details so fully as we should wish in a short treatise like the present; we hope, however, that the illustrations we give will enable the reader pretty closely to understand the arrangements and operation of this beautiful machine.

For the purposes of description, we shall divide the locomotive into two parts:—the fire-box, smoke-box, and boiler; and the moving parts of the engine which give motion to the whole.

The fire-box, as may be seen by inspection of the longitudinal sections of engines hereafter given, at *c c c c*, fig. 147, is enclosed on all sides except the bottom; at this part the fire-bars are placed on which the fuel rests; and at the side next the funnel or chimney, this side is pierced with holes, into which are passed the smoke-tubes *d d*. To prevent the dispersion of the red-hot ashes from the fire, a plate-iron tray or receptacle is placed beneath the fire-bars. Fire-boxes are of two kinds, square and round, as in figs. 153, 155. The round top is recommended by some, as being best calculated to withstand the pressure of the steam. In both methods of construction, however, it is imperatively essential to strengthen the parts by numerous stays or bolts. The fire-box door (see longitudinal sections) is double, to prevent loss of heat; and the outer and inner boxes, between which the water of the boiler is allowed to flow, are here joined. The fire-bars are placed loosely in a frame, so as easily to be lifted out when required to be renewed. In some instances the fire-bar frame is suspended by catches; when these are withdrawn, the fire-bars and fuel above them are precipitated into the ash-tray.

The smoke-tubes are generally made of brass, but malleable iron ones are now becoming largely used. The number of tubes in each engine varies from 96 or thereabouts to 134. Great care is necessary to fit the tubes into the fire-box end, and also that of the smoke-box. They must be fitted water-tight. The diameter of the tubes is generally about one inch and a half. The communication between the fire-box at one end and the smoke-box *s s*, figs. 153, 155, is kept up entirely by means of the smoke-tubes *d d*. This is formed of plates of iron of the same shape externally as the fire-box. Access is had to the interior of the smoke-box by a door at the front of the engine; this is made in various ways: in some instances it is hinged at bottom and opens downwards; in others it is in two leaves, like ordinary folding-doors. The smoke-tubes pass through the side of the smoke-box nearest the fire-box. The cylinders are in many instances placed inside the smoke-box; by this arrangement, the loss by radiation and condensation of steam is avoided. The steam, after working the cylinder, is ejected up the chimney through the blast-pipe *h* fig. 153, and *e e* fig. 155. The diameter of chimney is about 13 inches, and the height is limited to about 7 feet above the boiler, to allow it to pass under the railway bridges.

The fire is moderated by a damper placed in the chimney; this is generally made of the "throttle-valve" species, being a plain disc, *a a* fig. 145, turning on an axis *d* somewhat out of the centre; it is provided with an aperture through which the end of the blast-pipe passes, when the damper is wholly shut, the end of the blast-pipe projecting above it; the damper is moved by the lever *e*, actuated on by a long lever under the control of the engine-man. This lever is furnished with three slots, which take into a rest; according as the lever rests on either of the slots, so is the opening of the damper regulated. The upper orifice of the chimney is sometimes covered with a wire-netting; this is in order to arrest the sparks. This contrivance is, however, fast falling into disuse, and a perforated iron plate is placed below the blast in the smoke-box. In American locomotives, where wood is extensively used for firing, a "spark-arrester" is adopted; this gives a degree of size to the chimney unusual in locomotives in this country. This will be described hereafter.

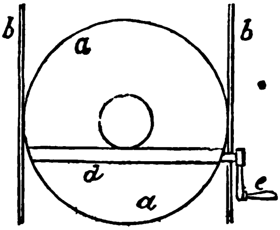

fig. 145.

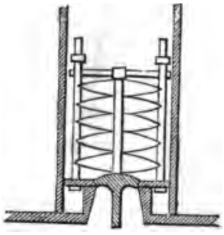

fig. 146.

The water is supplied to the boiler by means of a small force-pump, placed under the boiler and near the fire-box; this pump is worked by a lever from one of the engine eccentrics; in some instances the pump is worked from the piston cross-head. The water is drawn from the tank in the tender through a pipe properly coupled, by a ball-and-socket joint, at the part where the engine is attached to the tender; and the water is delivered to the boiler in some instances at the smoke-box end, a little below the water-level; at others near the fire-box, and in others again near the centre part of the boiler.

There are various appliances connected with the boiler. The safety-valve is generally placed above the fire-box, as in figs. 153-155, and is pressed down by a lever, the pressure being regulated by a spring balance. The nature of the arrangements of this kind of valve is explained at p. 45, fig. 66, *Mechanics and Mechanism.*

Lock-up safety-valves are falling into disuse, as, from not being easily got at, they are apt to stick in the seat and become inoperative. In some engines a valve, as shown in fig. 146, is used. This is loaded a little above the usual pressure; this being obtained by the bent springs forcing down the valve into its seat.

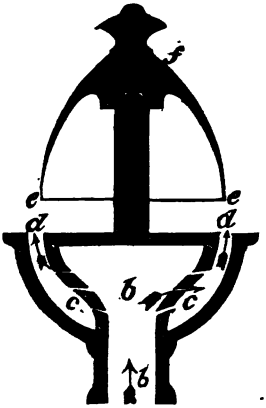

fig. 147.

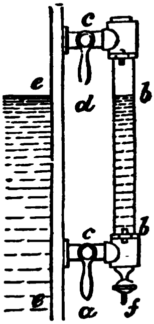

fig. 148.

The contrivance known as the steam-whistle is placed on the dome or top of the fire-box; this is shown at *b*, fig. 147. The peculiar noise elicited is caused by the steam rushing up the tube *b b* connected with the boiler; and the admission to which is regulated by a cock actuated upon by a handle or lever within reach of the engine man. The steam passes through the apertures *c c* and out at *d d*, and strikes the thin edge *e e* of the circular cup *f*, producing the sound so well known now-a-days in almost every district of the kingdom.

The level of the water in the boiler is ascertained by gauge-cocks, which are placed at different heights to indicate different levels at which the water stands. In addition, a glass water-gauge is attached to the front casing; the arrangement of this apparatus is shown in fig. 148. The tubes *c c* are in communication with the interior of the boiler; a strong glass tube *b b* connects the two tubes *c c;* the upper tube *c* communicates with the part of the boiler which should contain steam, the lower with that containing water. On opening the upper and lower handles *a a*, the water rises in the glass-tube to the same height as in the inside of the boiler. The oscillations of the water which would take place in the tube *b b*, from the rapid movement of the engine, is in some measure prevented by making the communication between the boiler and tube of a small size. A small cock, as *f*, is placed at the bottom tube, to clear the tube of its accumulated water. Entrance is obtained to the interior of the boiler by means of a man-hole door of similar construction to that described in another and preceding chapter.

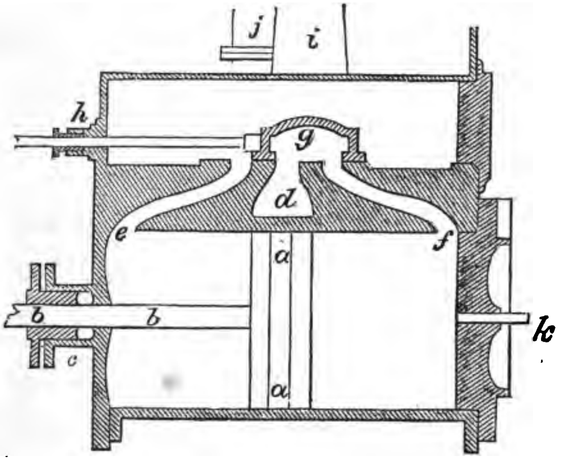

fig. 149.

The cylinders of locomotive engines are always of the three-ported species, as in the diagram, fig. 149. *a a* the piston; *b* the piston-rod; *c* the stuffing-box; *d* the exhaust-port, leading to the exhaust-pipe *i*; *g* the valve; *h* valve-rod; *e* port to upper side of piston; *f* port to under side; *k* cleansing and greasing-cock. Cocks are supplied to cylinders in some instances at top and bottom of cylinder: these are opened when required by levers within reach of the engine-man, to allow the water collected in the cylinders from priming and condensation. The steam is passed from the boiler to the cylinders by a pipe, the entrance to which is at the upper part of a cylindrical vessel O N, fig. 153, or within the dome; above the fire-box, as in fig. 155, the entrance to the pipe is placed thus far above the water to prevent priming as much as possible. The supply of steam to the cylinder is regulated by what is termed a "regulator." Various contrivances for this purpose are adopted. Fig. 150 explains a form much introduced. Two circular discs work in contact, one of which is fixed, and

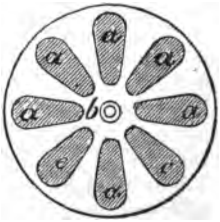

fig. 150.

the other is made to revolve by a lever connected with it, and actuated on by another lever or handle outside the casing. Apertures are made in both discs to correspond with each other in shape and position; when the apertures in both plates coincide, a free passage is given to the steam; but when the movable disc is turned round, so as to present the solid parts of its face opposite the apertures in the fixed disc, the entrance for the steam is lessened in proportion as the apertures in the fixed disc are closed. The discs are fixed on the entrance to the pipe which passes the steam to the cylinders.

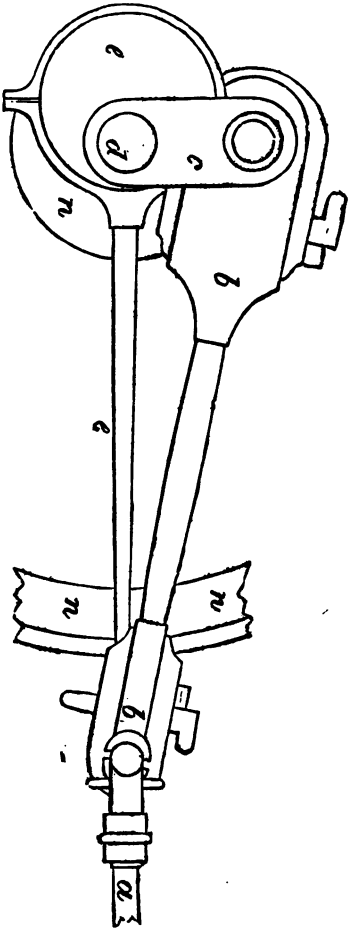

fig. 151.

The reciprocating motion of the piston-rod is changed into the circular one of the driving-wheel by means of a connecting-rod, as in fig. 151 : *a* is the piston-rod; *b* the connecting-rod, the brasses of which embrace the cranked axle of the driving-wheels *n n*, as explained in p. 87, fig. 169, *Mechanics and Mechanism;* the cranks are placed at right angles to each other, so that the motion is continuous. The slide-valves of the cylinder for admitting the steam to both sides of the piston are worked by eccentrics, as explained in p. 82, *Mechanics and Mechanism,* the position of which is shown in fig. 151.

In order to give the necessary facility for working the engine so as to make it move backwards or forwards as desired, various ingenious arrangements have been introduced: it will suffice for our purpose to describe one of these, and that the most generally adopted. It is known as the "link-motion," and owes its invention to Mr. Stephenson. The movements are effected by four eccentrics, two to give the backward, two the forward motion of the engine; two eccentrics to each cylinder. Let *b c*, fig. 152, be the two eccentric-rods, *b* the backing eccentric, and *c* the forward eccentric: these are connected to the curved link *a a*, the radius of which is equal to that of a circle described by each eccentric-rod revolving round the centre of its eccentric. The backward and forward eccentric-rods are attached to the extremities of the links. The valve-rod which works the slide-valve of the cylinder is provided with a piece of metal which slides between the grooves made in the interior faces of the links; the links are kept at a proper distance apart by bolts. The links are capable of being lifted up by means of the lever *g*, and connecting piece *f*. When the slide-valve is out of gear, the eccentric-rods are in the position shown in the diagram, the line of valve-rod bisecting the angle formed by the eccentric-rods. In this case, if the engine is in motion, as just in pulling up at a station, the eccentric-rods merely make the link oscillate or vibrate in the centre, of the valve-spindle, in and out alternately, as shown by the arrows *x y*. But if the valve is required to make the engine go ahead, or forward, the link is raised up by means of the handle *g*, until the forward eccentric-rod *b* is in a line with the valve-rod; and by this means the throw of the eccentric will be communicated to the valve-rod, and the engine will go forward. To reverse the engine, all that is necessary is to lower the links until the upper eccentric-rod *c* is placed in a line with the valve-rod, when the engine moves backward.

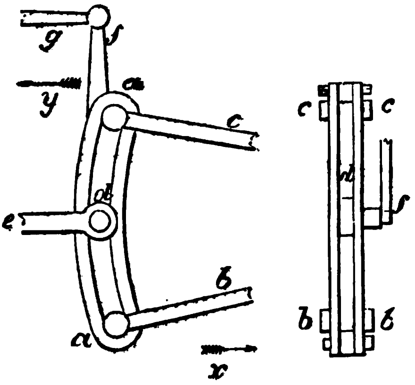

fig. 152.

Having sufficiently, for the elementary purposes of our treatise, given the details of the locomotive, we now proceed to give illustrations of engines, showing the connexion of the various parts. The first we give is the longitudinal section of a "fast passenger-engine," constructed by Mr. Hackworth; and for the drawing of which, and description, we are indebted to Mr. W. Johnson, fig. 153. She has been expressly designed for fast passenger trains, having driving-wheels 6 feet 6 inches diameter, with leading and hind wheels of 4 feet diameter. Her weight, in working order, is 23 tons 15 cwt., and this is distributed in the following manner: on leading wheels, 8 tons 6 cwt.; drivers, 11 tons 4 cwt.; and hind wheels, 4 tons 5 cwt. The crank axle, A, is carried in bearings in the inner frame, whilst those of the leading and hind wheels, B and C, are in the outer frame; the length from centre to centre of the latter pairs being 13 feet 6 inches; these proportions having been laid down with a strict reference to the stability of the leading wheels, without an undue detraction from the tractive adhesion of the drivers. The barrel, D, of the boiler presents the novelty of welded longitudinal seams: it is composed of five

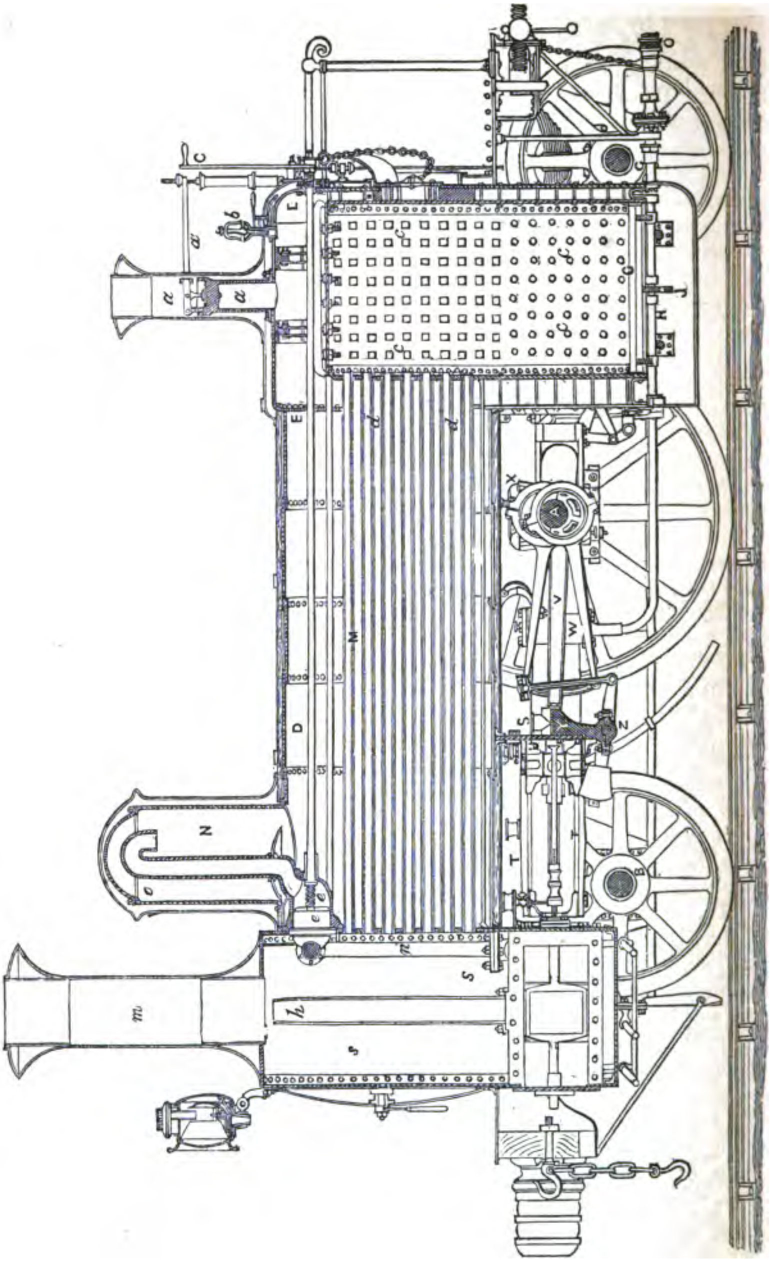

fig. 153.

plates, turned into rings, each being welded longitudinally, whilst their transverse junctions one with another are riveted in the ordinary way. The junctions, E E, of the two ends, with fire-box and smoke-box, are formed by angles or flanges welded on, instead of by separate angle irons riveted : these were turned and faced in the lathe to a true surface, for the bearing against the fire-box at one end, and the cylinder foundation-plate at the other, thus affording great accuracy in these details. The original idea of welding the boiler-plates is claimed by Mr. Hackworth, who, it appears, had actually made a boiler on this principle long prior to the date of the construction of the "farmer's engine" by Mr. Willis. The example of construction now before us is a very beautiful one ; indeed, it is unrivalled as a specimen of this class of workmanship. The lagging, or cleading, of the boiler is covered with sheet iron, giving the surface a smooth appearance.

The plate, F, forming the back corners of the fire-box, is 14 inches broad, and was originally made in three pieces for the convenience of setting; but, after the completion of the process, they were welded together, so as to form a single plate. The grate bars, G G, are arranged longitudinally, and are carried on two transverse bearers, supported on projections on a pair of longitudinal shafts, H H, at the bottom of the fire-box, and worked by a lever, I, standing up from the foot-plate, so that the driver may drop the whole set of bars instantaneously into the ash-box, J. The latter may also be dropped independently of the bars, by releasing the suspending bars, K K, on each side.

The fire-door, L, is provided with a regulator for the admission of air into the fire-box at pleasure, the baffle-plate being perforated with small apertures for its dissemination in the interior. The boiler tubes, M, are of brass, 2 inches in external diameter, and are 221 in number. At the smoke-box end of the tubes a baffle-plate is also fixed opposite the tube ends ; it is perforated with holes $1\frac{1}{8}$ inch diameter, the under sides of which correspond with the bottom line of the tubes, so that the hotter portion of the vapour is retained at the upper side, inducing a superior evaporative action. This addition does not interfere in any way with the cleaning of the tubes, as it may be removed with great facility. The dome, or steam chest, N, is formed out of a single plate, welded longitudinally, the flange for riveting it to the boiler being worked out of the same plate. The upper flange at O is welded on internally, being turned and faced to form a steam-tight joint with the convex cover, which is similarly formed, and is removable for obtaining access to the boiler.

The pistons also involve some novelties both in design and construction : they are made entirely of wrought-iron, with the rods forged on them; so that whilst there is thus a gain in lightness and strength, the dangers resulting from occasional looseness are completely removed. The inner framing, Q, consists of two wrought-iron slabs extending the whole length of the boiler's barrel, and attached at one end to the fire-box by $\frac{5}{8}$ inch angular plates riveted on. The peculiar advantage of this arrangement of frame is, that it yields to the expansion and contraction of the boiler, preserving a constantly uniform length between the cylinder and crank axle, and obviating the very common tendency to work loose, and cause leakage. The frame-plates extend from the centre of the crank axle, so as to counteract the effect of the strain of the engine at the most effective point; and a stiff connexion is formed with the barrel of the boiler by a strong central transverse plate, riveted on by means of stirrup angle-irons. At the smoke-box end, a foot, or flange, is formed on each frame-plate, for abutting against the tube-plate, to which it is riveted and bolted, the connexions being passed through the cylinder flanges.

The outer framing consists of a wrought-iron slab, 9 inches deep and 1 inch thick, extending the whole length between the buffer bars, the axle guards being forged with it in one piece. The transverse junction-plate, S, forms a very important feature of the engine; it is riveted to the boiler by double angle-irons, and extends across and between the inner and outer frame-plates, forming an effective fixed point for the pressure of the working gear.

The piston-rod motion consists of a pair of slide-bars, T T, attached at one end to protecting flanges cast on the cylinder cover, and at the other to the transverse junction-plate, S. The cross-heads, or motion-blocks, U, each consists of a malleable iron double eye-piece, with a box at the inner end, into which the piston-rod is keyed; and on the upper and lower sides of the double eye are bolted the brass slides, with protecting flanges to guide them on the motion-bars.

The connecting-rods, V, are of a plain rectangular section, and are attached to the cross-heads by a steel pin passing through them and through the double eyes, secured by a nut on the outside. The feed-pumps are placed in a line parallel to the piston-rods. The rams are of malleable iron, passed through and secured by a nut to the cross-head pin. The pumps are of brass; they are attached to the inner frame and transverse junction-plate.

It is an ascertained fact that, in too many cases, very little regard is paid to the obtainment of a sufficient area in the valve-cases for the admission of feed-water to the boiler. Owing to the contraction of this space, the valves are made of small size, and thus a great rise is absolutely necessary to admit a due supply of water; and this, coupled with their great rapidity of action, is frequently the occasion of great inconvenience in point of derangement and wear. Where the contraction exists in excess, the defect is heightened by the absorption of power in forcing the feed through the passages.

In the "Sanspareil," the valves and valve-boxes, W, are made very large, so as only to require $\frac{1}{8}$th inch lift of valve.

The eccentric sheaves are made with the smaller divisions of wrought-iron, having pins forged upon them, to connect them with the larger or prominent eccentric sides, which are of cast-iron. The eccentric rods and straps are of wrought-iron, and the rods are forged on the front halves of the straps, the latter being lined with brass. The back halves have an oil-vase, X, forged on each, with a syphon-pipe on each side the bolt, for lubricating the sheave. The slide-spindles are guided in brass bearings, in a bracket, Y, fixed to the transverse junction-plate; and the bottom of this bracket, at Z, forms a bearing for one end of the reversing weigh-bar.

The ordinary link motion is adopted for the slide and reversing gear, the lifting links for reversing being placed inside the motion links, and connected with the forward eccentric pins; and the levers on the reversing weigh-bar are forged on.

The fire-box is at *c c*, the smoke-tubes at *d d*, the balanced spring

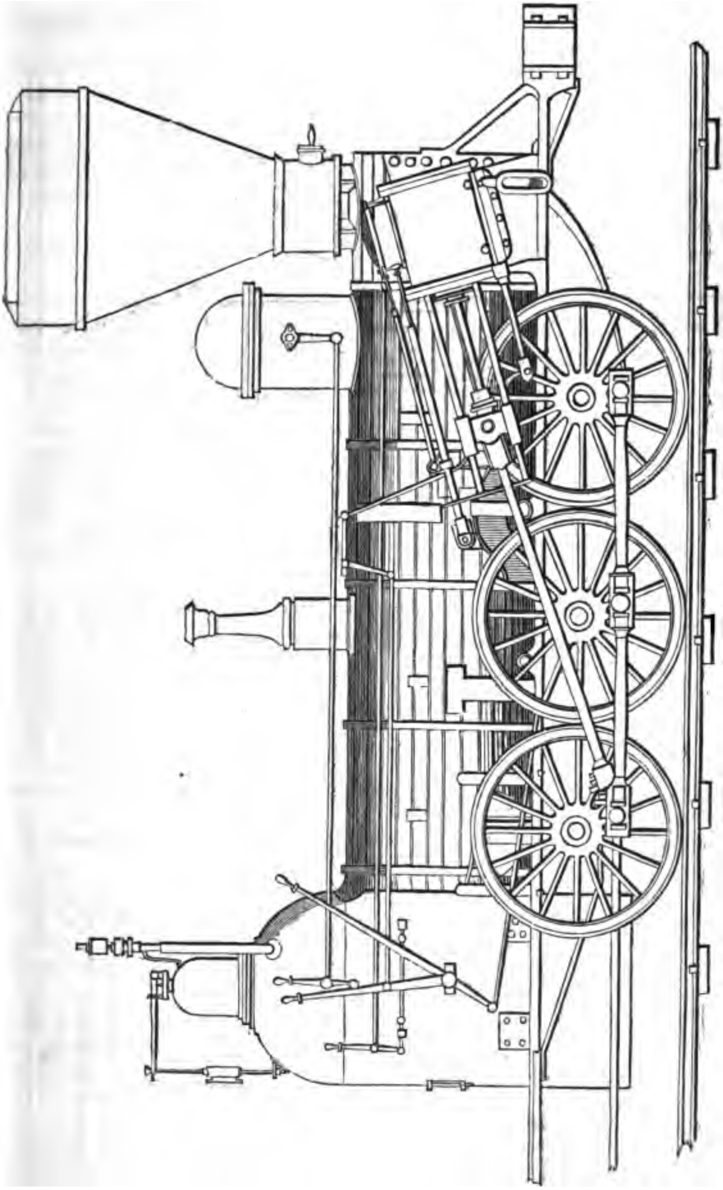

fig. 154.

safety-valve at *a a a'*; *b* the steam-whistle; *s s* the smoke-box; *h* the blast-pipe; *m* the chimney; *e e* the regulator; *c* the regulator-handle; *n* the pipe supplying steam to one cylinder; *o* the feed-pipe to supply boiler with water from tank in tender.

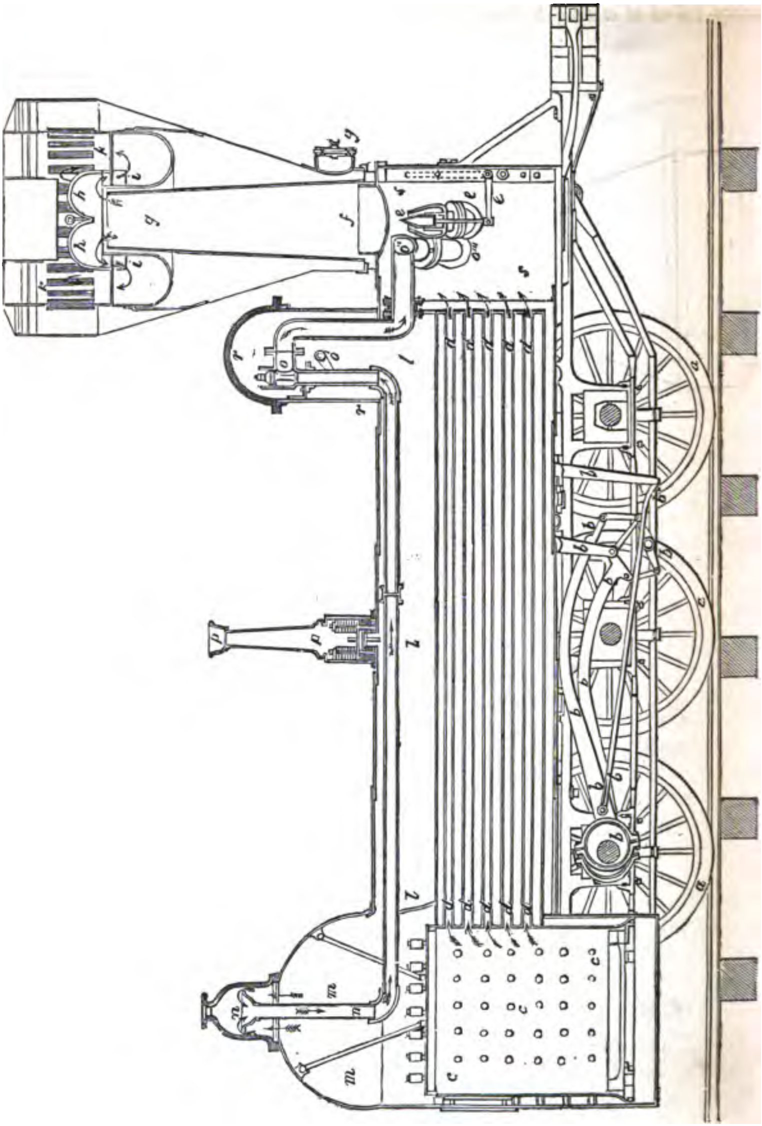

fig. 155.

In fig. 154 we give the elevation of an American locomotive, with outside cylinders; and in fig. 155 a longitudinal section of the same. *c c* the fire-box; *d d* the flue-tubes; *s s* the smoke-box; *e e* the conical blast-pipe, the opening of which is regulated by the levers as in the drawing; *m m* the steam-dome; *n n* the steam-pipe; *r r* the regulator dome; *o* the regulator, consisting of a spindle-valve, actuated on by the lever *o′*, admitting steam to the cylinder through the pipe *o″ o″*; *l l* the steam space above the tubes; *p p* the lock-up spring safety-valve; *f g* the funnel; *i i*, *h h*, *k k*, the "spark-arrester." The curved arrows show the direction of the heated air; the sparks being deposited in the curved vessels *i i*, the heated air and steam passing out at the vertical apertures *k k*. The eccentric-rods and gear for working the valves, &c. are shown at *b b*.

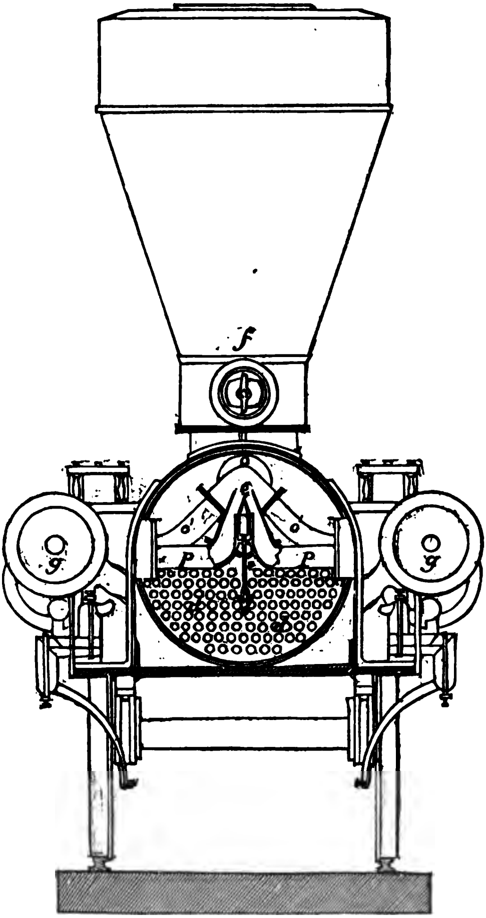

fig. 156.

In fig. 156 we give a transverse section of same engine at smoke-box end. *d d* the tubes; *c* the lever for working the conical blast-tube; *e e*; *o* the steam-pipe ; *o'* the pipe leading to the cylinders ; *p p* the pipes leading to the blast ; *g g* the cylinders ; *f* the funnel or chimney.

In fig. 157 we give the back or fire-box end elevation of the same engine. *c c* the fire-door ; *d d* the starting handles and levers for working the eccentric motions, &c. &c. ; *e e* the gauge-cocks ; *f f* the spring-balance safety-valve ; *h g* the steam-whistle, actuated by the lever *i*; *m m* the crank-pins, on the driving-wheels, to which the connecting-rods are attached ; *i i* the house or covering for sheltering the engine-men (this arrangement is adopted in all the engines working in the Northern States of America, the climate being too severe in winter to allow the men to be exposed to all weathers, as with us).

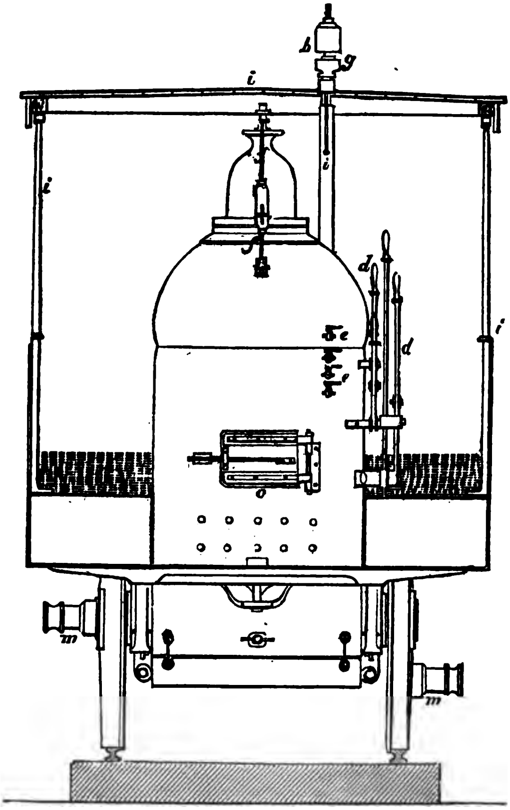

fig. 157.

In fig. 158 we give an elevation of another form of American locomotive : *a a* the cylinder and valve-casing ; *b* the piston cross-head ; *c* the connecting-rod ; *d d* the connecting-rod coupling the wheels together.

In fig. 159 we give a sketch of a first-class locomotive passenger engine on Crampton's patent principle, as used on the London and Northern and

Western Railway, showing the connection of engine and tender. In fig. 160 a form of engine as used for short journeys is shown; in this species

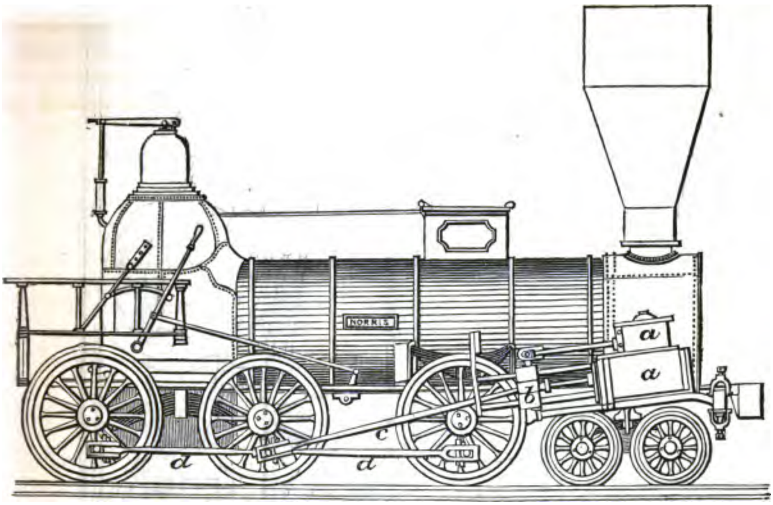

fig. 158.

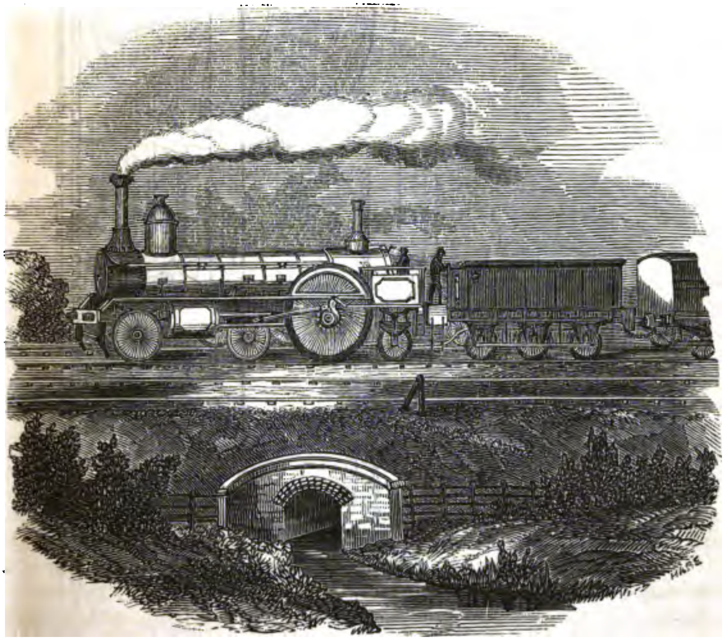

fig. 159.

of locomotive the tender forms part of the engine, and is called the "tank-locomotive."

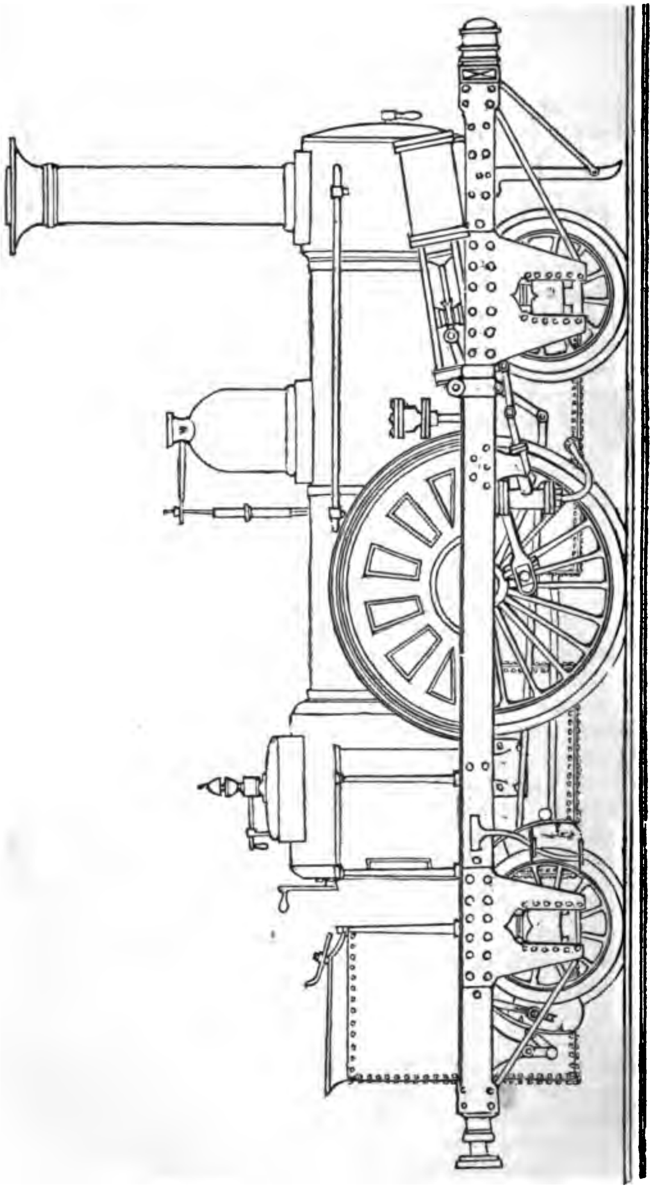

fig. 160.

CHAPTER VI.

STEAM-NAVIGATION AND THE MARINE ENGINE.

Under the present division of our treatise we purpose giving a few historical notes as to the introduction of the steam-engine for the purposes of navigation, preliminary to the illustrations and descriptions of the modern "marine engine." From the limited space now at our disposal, we shall be prevented from going so deeply into the historical details as might by some be considered necessary; but we shall nevertheless endeavour to notice the most important of these.

For many years previous to the application of the steam-engine to the propelling of boats, it had been a favourite object with mechanics, the substitution of sundry mechanical contrivances for sails. The most noticeable of these was the revolving wheel with float-boards on its periphery, which acted, on being immersed in the water, so as to move the boat forward: this, modified somewhat in its arrangements and construction, is identical in principle with the "paddle-wheel" of the modern steam-boat. The various contrivances introduced for boat-propulsion were actuated either by manual labour or that of horses, through the intervention of simple mechanical arrangements. The earliest notice we have of an attempt to substitute the power of steam for these methods of working is that of Blasco de Garay, to whose invention we have already alluded in the first chapter. Captain Savery, in the *Miner's Friend*, alluded to the capability of steam as a power for moving steam-boats; but it does not appear that he entered further into the matter than making a mere suggestion. Denis Papin, during his residence in England, is said to have constructed a model by which a steam-piston moving in a cylinder gave motion to the axle of the paddle-wheels; a rack was placed on the piston-rod, working into a pinion fastened on the axle of the revolving paddles. He employed two or three steam-cylinders; and when the piston of the one was ascending, that of the other was working downwards; and as they would give contrary motions, one was detached while the other was in action; and by this means the motion could be made continuous and tolerably regular.

In 1737 Jonathan Hall published "a description and draught of a new-invented machine for carrying vessels or ships out of or into any harbour, port, or river, against wind or tide, or in a calm." In this steam-boat the engine used was an atmospheric one, rotatory motion being obtained by a continuous arrangement of pulleys and cords or bands. We give in fig. 161 a diagram illustrative of the general appearance of this boat. From the imperfect mechanical arrangements, and the defects of the atmospheric as a rotative engine, this attempt at steam-boat propulsion was soon abandoned, if indeed it ever went beyond a mere speculation on paper.

Passing over various unsuccessful attempts made in America by Fitch and Ramsey, in 1785-1793; the Earl of Stanhope in England, in 1795; and of the Chancellor Livingstone and the celebrated Brunel on the Hudson in America, in 1797,—we proceed to notice the first successful steam-engine. We must, however, go back for a few years prior to the last-mentioned date. In 1787, Mr. Patrick Miller, of Dalswinton, a gentleman who devoted much of his time to experiments in the improvement of artillery and naval architecture, published a description, with drawings, of a "triple vessel moved with wheels." Convinced that, to give his invention every fair chance, it was necessary to employ some force greater than that of manual labour, he threw out the suggestion of employing the steam-engine for the purpose of moving the wheels; the force of steam, amidst other means proposed, presented itself, however, to his mind "as at once the most potent, the most certain, and the most manageable." "In Miller's family," says his son, in the narrative published in the *Edinburgh Philosophical Journal* in 1824, "there was at this time, as tutor to his youngest children, Mr. James Taylor, who had bestowed much attention on the steam-engine, and who was in the custom of assisting Miller in his experiments on naval architecture and the sailing of boats. One day, in the very heat of a keen and breathless contest in which they were engaged with a boat on the Leith establishment, this individual called out to his patron, 'that they only wanted the assistance of a steam-engine to beat their opponents;' for the power of the wheels did not move the boat faster than five miles an hour. This was not lost on Miller, and it led to many discussions on the subject; and it was under very confident belief in its success that the allusion was made to it in the book already mentioned. In making his first experiments, Miller deemed it advisable in every point of view to begin upon a small scale, yet a scale quite sufficient to deter-

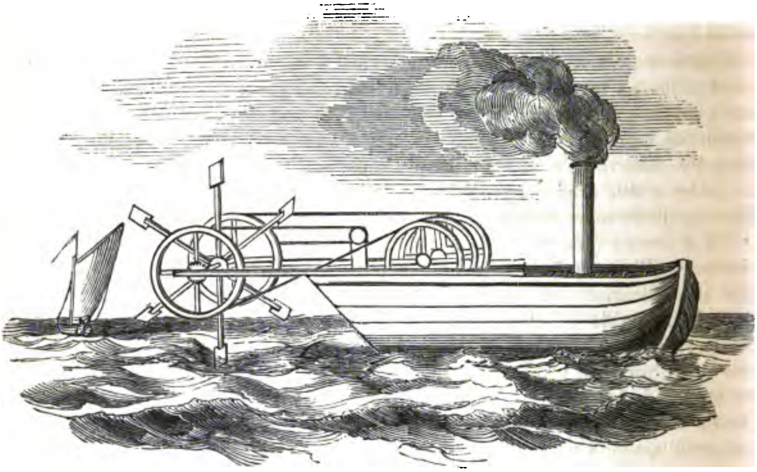

fig. 161.

mine the problem which it was his object to solve. He had constructed a very handsome double vessel with wheels, to be used as a pleasure-boat on his lake at Dalswinton; and in this little vessel he resolved to try the application of steam." To aid him in the fitting-up of the steam-engine, he secured the services of an engineer to whom he was introduced by Taylor, one whose name will be handed down to posterity as the engineer to whom practical steam-navigation is mainly indebted for its introduction,—William Symington. It was to this latter individual, an engineer of great practical attainments, that the task of fitting-up the steam-engine was intrusted. In the autumn of the same year in which he was employed, the steam-engine, having brass cylinders of four inches diameter, was placed on board the little pleasure-boat. "Nothing," says Mr. Miller in his narrative, "could be more gratifying or complete than the success of this first trial; and while for several weeks it continued to delight Miller and his numerous visitors, it afforded him the fullest assurance of the justness of his own anticipation of the possibility of applying to the propulsion of his vessels the unlimitable power of steam. On the approach of winter, the apparatus was removed from the boat, and placed as a sort of trophy in his library at Dalswinton, and is still preserved by his family, as a monument of the earliest instance of actual navigation by steam in Great Britain. In the succeeding year, a larger boat, sixty feet long, was tried on the Forth and Clyde Canal; the engines and machinery were constructed at the Carron Iron Works, near Falkirk; and in December 1789, "in the presence of a vast number of spectators, the machinery was put in motion." This second trial promised to be every way as prosperous as the first. It happened unluckily, however, that the revolving paddles had not been made of sufficient strength; and when they were brought into full action, several of the float-boards were carried away, and a very vexatious stop was for that day put to the voyage. The damage was repaired, and on the 25th December the steam-boat was again put in motion, and carried along the canal at the rate of seven miles an hour, without any untoward accident; although it appeared evident that the weight of the engine was an over-burden for the vessel (her planking being only three-quarters of an inch thick), and that under such a strain it would have been imprudent to venture to sea. The experiment, however, was again repeated on the two following days; and having thus satisfied himself (Miller) of the practicability of his scheme, he gave orders for unshipping the apparatus, and laying it up in the storehouses of the Carron Works." In consequence, as it appears from the statements in the narrative by his son, Miller was led to abandon further experiments with the view of introducing the steam-boat more extensively, partly from the large expenses which the first trial had cost him, and partly from his attention becoming much directed to agricultural pursuits. In 1801, Symington, patronised by Lord Dundas of Kerse, started a steam-boat on the Forth and Clyde Canal, for the purpose of towing boats. The following is Mr. Symington's own narrative: "Mr. Miller being very much engaged in improving his estate in Dumfriesshire, and I also employed in constructing large machinery for the lead-mines at Wanlockhead, the idea of carrying the experiments at that time any further was entirely given up, till meeting with the late Thomas Lord Dundas of Kerse, who wished that I should construct a steam-boat for dragging vessels on the Forth and Clyde Canal instead of horses.

Agreeably to his lordship's request, a series of experiments, which cost nearly three thousand pounds, were set on foot in 1801, and ending in 1802, upon a larger scale (than those on Dalswinton Lock) and more improved plan, having a steam-cylinder twenty-two inches diameter and four feet stroke, which proved itself very much adapted for the intended purposes. Having previously made various experiments, in March 1802, on the Forth and Clyde Canal, Lord Dundas and several other gentlemen being on board, the steam-packet took in tow two loaded vessels, each of seventy tons burden, and moved with great ease through the canal a distance of nineteen and a half miles in six hours, although the whole time it blew a strong breeze right a-head of us; so much so, that no other vessels could move to windward in the canal that day but those we had in tow, which put beyond the possibility of a doubt the utility of the scheme in canals and rivers, and ultimately in open seas. Though in this state of forwardness, it was opposed by some narrow-minded proprietors of the canal, under a very mistaken idea that the undulation of the water, occasioned by the motion of the wheel, would wash and injure its banks. In consequence, it was with great reluctance laid up in a creek of the canal, exposed for years to public view."

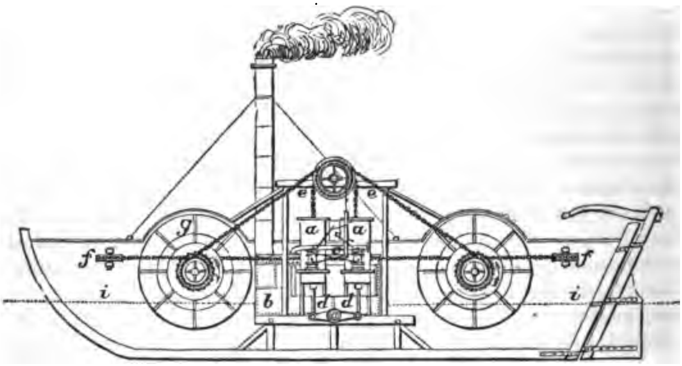

fig. 161^a.

In fig. 161^a we give a drawing of Symington's first engine, and in fig. 161^b a drawing of the second and improved design; for these we are indebted to the courtesy of Mr. Wm. Symington, of London, the son of the inventor. The following is the description of the various parts:

In fig. 161^a, *a a* are the cylinders, *b* the boiler, *c* steam-pipe, *d d* air-pump rods, *e e* connecting chains, *f f* direction pulleys, *g g* paddle-wheels, situated and wrought in a trough extending from stem to stern of the boat, and allowing free ingress and egress to the water; *h h* ratchet-wheels, for communicating motion to the paddles; *i i* the water-line.

In fig. 161^b, *a* the cylinder, *b* the boiler, *c* steam-pipe, *d* eduction-pipe, *e* condenser and air-pump, *g* hand-gear and pump-rod, *h* piston and connecting-rod, supported by the friction-wheels; *i* the rod which communicates motion to the air-pump lever; *j* crank; *k* paddle-wheel, situated in a cavity in the centre of the stern of the vessel; *l l* paddle-wheel cavity, open behind and below to the water; *m* steer-wheel; *nn* flotation line. This boat was steered by two rudders connected by iron rods, and wrought in the prow by the steer-wheel.

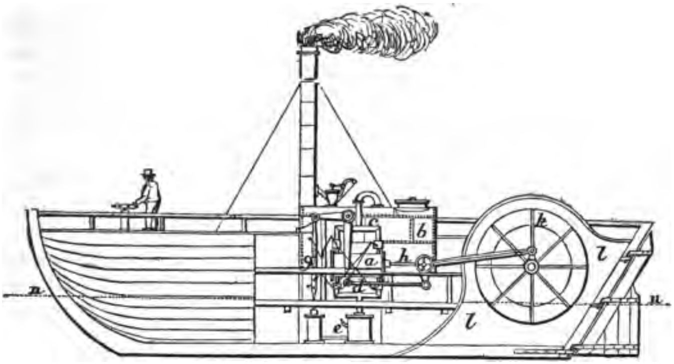

fig. 161^{b}.

We come now to notice the exertions of another individual who occupies an important place in the history of steam-navigation—Robert Fulton, an American. Passing over various matters connected with this individual, with reference to other inventions of his, we proceed at once to state that, on the occasion of his visit to Paris, he became acquainted with Chancellor Livingstone, then minister from the United States to the court of France; who, it may be recollected, has been mentioned as having been engaged in conducting steam-boat experiments at one period in America, but who had not succeeded. He explained to Fulton what had been done, informed him that on his return to America he intended to resume his experiments, and invited Fulton to turn his attention to the subject. This Fulton did, and instituted a variety of experiments with a view to ascertain the best expedients to be adopted. After many trials, he determined to use the paddle-wheel. In 1803, the first boat constructed by Livingstone and Fulton was completed ; " the wheels and other mechanism acted according to his (Fulton's) expectations, although her speed was not so great as he calculated upon her machinery producing." So satisfied, however, were they with this preliminary trial, that they wrote to Boulton and Watt, ordering them to make an engine, with modifications adapted for the peculiar purpose for which it was designed ; this engine to be sent to New York, to which place Fulton intended immediately to return. Livingstone, through the influence of his friends in America, obtained the privilege of navigating the waters of the State of New York by steam for twenty years, in which privilege Fulton was also included. Before leaving for New York, Fulton visited Scotland, and waited on Symington, who explained to him very fully the whole details of his plan. Symington, in his narrative, says, " Fulton politely made himself known, and candidly told me he was lately from North America, and intended to return thither in a few months; but having heard of our steam-boat operations, he could not think of leaving the country without first waiting upon me, in expectation of seeing the boat, and procuring such information regarding it as I might be pleased to communicate. He at the same time mentioned" (continues Symington) "however advantageous such an invention might be in Great Britain, it would certainly be more so to North America, on account of the many extensive navigable rivers in that country. And as timber of the first quality for building the vessels, and also for fuel to the engines, could be purchased there at a small expense, he was decidedly of opinion it could hardly fail in a few years to become very beneficial to trade in that part of the world; and that his carrying the plan to North America could not turn out otherwise than to my advantage; as, if I were inclined to do it, both the making and superintending of such vessels would naturally fall upon me, provided my engagements with steam-boats at home did not occupy so much of my time as to prevent me from paying any attention to those which might afterwards be constructed abroad. In compliance with his earnest request, I caused the engine-fire to be lighted up, and in a short time thereafter put the steam-boat in motion; and, carrying him four miles on the canal, returned to the place of starting, to the great astonishment of Fulton and several gentlemen who, at our request, came on board. During the above trip, Fulton asked me if I had any objections to his taking notes respecting the steam-boat; to which question I said, 'None.' And after putting several pointed questions respecting the general construction and effect of the machine, which I answered in a most explicit manner, he jotted down particularly every thing then described, with his own remarks upon the boat. But he seems," says Symington, "to have been altogether forgetful of this; as, notwithstanding his fair promises, I never heard any thing more of him till reading in a newspaper an account of his death." Thus provided with practical information from Symington, Fulton proceeded to America in 1806; and in 1807 Fulton had completed his steam-boat, and in the spring of that year it was launched on the Hudson. The steam-engine manufactured by Boulton and Watt had arrived; and, with the assistance of the engineers who had been sent out with it, it was fitted up in the boat; and in August of the same year the first trial was made. On this occasion, Livingstone and Fulton had invited many of their friends to witness the progress of the first steam-boat.

"Nothing," says the historian of the event, "could exceed the surprise and admiration of all who witnessed the experiment. The minds of the most incredulous were changed in a few minutes: before the boat had made the progress of a quarter of a mile, the greatest unbeliever must have been converted. The man who, while he looked on the expensive machine, thanked his stars that he had more wisdom than to waste his money on such idle schemes, changed the expression of his features as the boat moved from the wharf, and gained her speed; his complacent smile gradually stiffened into an expression of wonder. The jeers of the ignorant, who had neither sense nor feeling enough to repress their contemptuous ridicule and rude jokes, were silenced for the moment by a vulgar astonishment, which deprived them of the power of utterance, till the triumph of genius extorted from the incredulous multitude which crowded the shores, shouts and acclamations of congratulation and applause. . . . This famed vessel, which was named the *Clermont*, soon after sailed for Albany (150 miles from New York), and on her first voyage arrived at her destination without any accident."

The speed attained was about five miles an hour. She was ultimately placed as a passenger-boat between the above places, and succeeded so admirably as to place Fulton very speedily in a position of independence. The dimensions of the *Clermont* were, length 133 feet, depth 7 feet, breadth of beam 18 feet. The diameter of cylinder was 2 feet, stroke 4 feet; the diameter of paddle-wheels 15 feet; the float or ducket 4 feet long, and dropped 2 feet into the water. The burden was 160 tons; the boiler was 20 feet long, 7 deep, and 8 broad.

In the year 1808, a steam-boat called the *Comet* was tried on the river Clyde, in Scotland, by Mr. Henry Bell, a name deserving of honourable mention in the history of steam-navigation, as one who, by his persevering exertions, was a great instrument in bringing steam-vessels into use in this country. The attention of Bell, it appears, was directed to steam-boat propulsion by receiving a letter from Fulton. Whether this letter was written anterior to the starting of the *Clermont* is not known.

"Fulton," says Bell, "had occasion to write me about some plans of machinery in this country, and begged the favour of me to call on Mr. Miller of Dalswinton, and see how he had succeeded in his steam-boat scheme; and if it answered the end, I was to send him a drawing and full description of it, along with my machinery. This led me to have a conversation with Mr. Miller, and he gave me every information I could wish for at the time. I told him where, in my opinion, he had erred, or was misled by his engineer; and at the same time I told him that I intended to give Fulton my opinion on steam-boats. Two years after I had a letter from Fulton, letting me know that he had constructed a steam-boat from the different drawings of machinery that I had sent out, which was likely to answer the end, but required some improvement upon it."

Bell, as stated by Symington, frequently investigated the steam-boat constructed by the latter, while laid up in the creek of the canal formerly alluded to; and was led, after receipt of Fulton's letter, "to think of the absurdity of sending his opinion on these matters to other countries, and not putting them in practice himself in his own." From these considerations, he says, "I was roused to set on foot a steam-boat, for which I had made a number of different models before I was satisfied. When I was convinced they would answer the end, I contracted with a ship-builder in Greenock to build me a steam-vessel according to my plans, with a 40-feet keel and a 10½-feet beam, which I fitted up with a small portable engine having the power of three horses, and paddles, and called her the *Comet*, because she was built and finished the same year that a comet appeared in the north-west of Scotland." The *Comet* plied between Glasgow and Greenock, but was by no means a successful speculation for Bell. For the first six months very few, he says, "would venture their precious lives in her; but in the course of the winter of 1812, as she had plied all the year, she began to gain credit, as passengers were carried twenty-four miles as quick as by the coaches, and at a third of the expense, besides being warm and comfortable. But even after all, I was a great loser that year. In the second year I made her a jaunting-boat all over the coasts of England, Ireland, and Scotland, to show the public the advantage of steam-boat navigation over the other mode of sailing; having done what no king, prince, admiral, or general could do—make vessels go against both wind and tide, which had not before been accomplished in this country so as to make them of any use to this country."

A monument is erected on the banks of the Clyde in honour of Bell, as the father of public steam-navigation in this country. Bell having thus led the way, station after station throughout the kingdom was supplied with a steam-boat. At the end of 1823 there had been ninety steam-boats built in Scotland.

The opinion of nautical men during the first few years of the introduction of steam-boats was inimical to the idea that steamers were calculated to make progress against a heavy sea. This question was, however, set at rest, and decided triumphantly in their favour, by the deep-sea voyage undertaken by Dodd, who went to Glasgow for the express purpose of taking a steam-boat from that port up to London. The vessel he navigated was "90 feet long and 14½ feet broad, with a burden of about 75 tons; the engine was calculated to have a power of 14 horses, and the wheels were 9 feet in diameter. She was rigged with a square sail on the chimney mast, a bowsprit sail, and another on the mainmast. The crew consisted of a mate, four seamen of the first order, an engineer, a furnace-man, and a ship's boy. This was the first vessel of the kind that any one had ever dared to venture in on the tempestuous sea that terminates St. George's Channel on doubling Cape Lizard. . . . This interesting voyage, 758 nautical miles, was run in 122 hours."

The bold experiments of Napier, too, tended to hasten the application of steam-boats to deep-sea navigation.

On fairly considering the various claims put forward by different individuals for the honour of having introduced steam-navigation, we clearly think that the honour should be paid to William Symington, as being the first contriver of a *steam-boat* which was carried out into successful practice. The claims both of Henry Bell and Fulton are now, by the generality of authorities, set aside, and the high honour is left to be divided among Miller, Taylor, and Symington. What share Miller had in introducing the invention we have already shown; he played the part—and an important one, doubtless—of the capitalist who found the means to conduct the experiment; but he did nothing more. It is between Taylor and Symington that the matter rests; what claim Taylor had to be considered the inventor we must now endeavour to show. The documents from which our extracts are made have been furnished us by the son of William Symington, already alluded too.

The document chiefly relied upon in the Memoir of Taylor, as establishing his claims to the invention of steam-navigation, was a letter addressed to him by Mr. Symington, in the following terms:

Glasgow, Feb. 9, 1821.

"SIR,—In terms of my former agreement, when making experiments of sailing by the steam-engine, I hereby bind and oblige myself to convey to you by a regular assignation the one-half of the interest and proceeds of the patent taken by me upon that invention, when an opportunity occurs of executing the deed, and when required.

"I am, Sir, your obedient servant,
(Signed) "WILLIAM SYMINGTON."

"To Mr. James Taylor, Cumnock.

"We were not aware of the existence of this letter at the time we penned our former remarks. We think it right, therefore, to take the present opportunity of stating, that it does not alter our view of the case in the least, but, on the contrary, confirms it in the strongest possible manner. Why should Mr. Symington bind himself to assign a share in the patent for the invention to Taylor, if the whole right to it rested with Taylor, which is what Taylor's friends maintain? It could not have been because Symington acquired by any pecuniary means an interest in the invention that the patent for it was taken out in his name, for Symington was notoriously and confessedly a person without money. It must have been the invention of the thing, and that alone, which constituted Symington's title. The monied person in the business, or at least the person who procured from others the money to take out the patent, was Taylor; he also was the person who introduced Symington to the influential patronage of Mr. Miller of Dalswinton; and it seems to have been on these grounds—partly pecuniary considerations and partly gratitude—that Symington covenanted to assign to Taylor one-half of the fruits of his invention. If Taylor had been the principal in the affair, he would have been the assigning party, and Symington the party to receive the assignment. As it is, Symington appears as the principal, and Taylor as a mere auxiliary; which, no doubt, was the relation in which the parties actually stood towards each other.

"The improvement in the steam-engine devised by Mr. Symington was accomplished in 1785-1786; and it was in the spring of 1786 that Mr. Miller, as already mentioned, engaged him to carry on some experiments upon steam-navigation. These were made upon the lake at Dalswinton, Mr. Miller's property, in 1788. It is asserted that Mr. Taylor remained in Edinburgh after Mr. Miller had left, to superintend castings of the parts of the engine intended to be employed in moving the boat. But if this were necessary, why did not Taylor afterwards put the engine together? If he were capable of furnishing the drawings and models by which the various parts were to be constructed, surely there could be no necessity for sending for Mr. Symington from the Lead-hills to put the different pieces properly *in situ*. Mr. Miller would have been little less than mad to employ Symington in these experiments, when he had such a brilliant and inventive genius as Taylor residing under his own roof. If (as has been asserted) Taylor was the author of these experiments, where are the drawings and documents to substantiate his claim? Have they ever been seen by any person? Or, indeed, have they ever existed, except in the imagination of his partisans?

"There is an account of these experiments to be found in the *Scot's Magazine* for 1788, which it has been allowed was drawn up by Taylor himself. He acknowledges, in this statement, that the merit of the expense of trying the experiment was due to Mr. Miller, but that the engine used upon the occasion was the sole invention of Mr. Symington; and throughout the whole account he never introduces his own name, either directly or by implication. The notice alluded to was as follows:

"'On October 14 a boat was put in motion by a steam-engine, upon Mr. Miller's, of Dalswinton, piece of water at that place. That gentleman's improvements in naval affairs are well known to the public. For some time past his attention has been turned to the application of the steam-engine to the purpose of navigation. He has now accomplished, and evidently shown to the world, the practicability of this, by executing it upon a small scale. A vessel, twenty-five feet long and seven broad, was on the above date driven, with two wheels, by a small engine. It answered Mr. Miller's expectations fully, and afforded great pleasure to the spectators. The success of this experiment is no small accession to the public. Its utility in canals and all inland navigation points it out to be of the greatest advantage, not only to this island, but to many other nations of the world. The engine used is Mr. Symington's new patent engine.'—*Scot's Magazine*, Nov. 1788, p. 566.

"In 1789, Taylor is represented as being located at the Carron Iron Works, for the purpose of superintending the castings of an engine of increased size, the cylinders being 18 inches in diameter. But, in opposition to this, we have the affidavit of Mr. Stainton, one of the managers of these works, who states, that

"'He (Taylor) was never considered capable of superintending the work; that he never furnished a single drawing or model by which the work might be forwarded; but that, on the contrary, Mr. Symington was looked up to as being the person to whom all the necessary inquiries for the completion of the engine were to be addressed; and that, so far from considering Taylor a principal, he was rather looked upon as a spy appointed by Miller to watch Symington's conduct, that he did not waste too much of his time upon some experiments he was conducting at the same moment for the Wanlock Head Company.'

"The experiments with the new engine succeeded entirely; but when it had arrived at that point, that by a little more exertion it might have been perfected, Mr. Miller's excitement was over. He had been bitten by an agricultural mania, dismantled the steam-boat, and left steam-navigation to be promoted by other hands.

"In 1801 and 1802, Mr. Symington renewed his experiments, under the patronage of Lord Dundas, that nobleman having purposely gone down from London to engage him. He continued them until 1803, when he completed a steam-tug, which towed two merchant vessels 19½ miles upon the Forth and Clyde Canal, against the wind, in the presence of many spectators. Mr. Symington took out a patent in the usual way for the protection of his invention in 1801; and this fact must dispose of the charge of his having practised any concealment or secrecy with regard to the matter.

"A letter has been published from Mr. Symington to Taylor, in which the former promises to make over half the profits of the invention to the latter. This originated, I am told, in a representation made by Taylor, that he was possessed of considerable influence amongst noblemen and members of parliament, through whose intercession a parliamentary grant might be obtained. But even supposing Mr. Symington was not entitled to the honour of being the first applier of steam to the purposes of navigation, Taylor, from his own showing, and from that of his friends, must have still less claim; for he states that he (Taylor) called upon Mr. Miller, and endeavoured to persuade him to secure the right to the invention by a patent. If it was Miller's invention, Taylor's regretting his own incapability of securing the right by patent is an absurdity. * * * * That neither Mr. P. Miller (the son of the Mr. Miller of Dalswinton) nor Lord Dundas, who employed Symington to construct a boat on the Forth and

Clyde Canal, looked upon Taylor as the party by whom steam-navigation was introduced, the following letters will prove :

Letter from Mr. P. Miller to Mr. W. Symington.

Edinburgh, Feb. 3, 1824.

"Sir,—As I was not at home when you were employed by my father to erect a small steam-engine for him in a pleasure-boat of his, at Dalswinton, with which the first steam experiment now on record was made in the year 1788; nor had I an opportunity of being present at the second experiment, made the subsequent year on the Forth and Clyde Canal, likewise under your management,—may I request you to be so obliging as to inform me if you were acquainted with any practical system of steam-navigation that existed prior to that period, from which you could have derived any assistance in carrying my father's project into effect, or if you considered the speculations you were then engaged in as original in themselves at the time; for I never heard of any of the individuals who were engaged in the matter, that had either ever seen or ever heard of Mr. Jonathan Hull's pamphlet.

"Being credibly informed that a Mr. Henry Bell, of Helensburgh, near Glasgow, has publicly stated that my father's experiments failed, might I also request you to be so obliging as to mention what could have given him a handle for a groundless and unfounded mistake; for at least such did not happen at Dalswinton, as I can show by abundance of living testimony at this very day. I also know that there are many still alive who witnessed the experiment both days after the wheels were repaired, who are ready to bear evidence that every thing the reverse of failure took place on that occasion, and that these two days' experiments were as complete in success as any that have hitherto been made; and I would, at the same time, thank you to say if you know whether this Mr. Bell was ever amongst the spectators upon the occasion.

"I have learnt, however, that some years thereafter he applied to you to see the vessel you constructed for the Canal Company, and that you showed and explained every thing particularly to him, from whence he derived the skill he possesses in this matter; and likewise understand that Mr. Fulton, the American engineer, was also at Carron, and had the benefit of seeing the vessel and receiving instructions from you on the steam system which he so promptly and successfully carried into effect.

"I hope it will be convenient for you, on receipt of this, to give me the information of which I at present request the favour; and be so good as to address to me at the Albyn Club, Princes Street, where I shall be for a few days, previous to my return to Dalswinton.

"I am, sir, your most obedient servant,

(Signed) "PATRICK MILLER.

"To Mr. W. Symington."

From the Right Honourable Thomas Lord Dundas, to Mr. Symington, civil engineer.

"Dear Sir,—I was extremely sorry to hear that you had been at the house while I was from home. I beg to explain the cause of my absence, and the step I had taken to meet the chance of your arrival; and I must first state, that not having heard from you, I hardly thought you were able to accept the appointment I had made. Having accepted an invitation to sleep at Dunmore on Friday, I came over here during that day, and requested my son's tutor to receive you in the event of your coming to breakfast. Mr. Simpson, however, was not aware that you had been to Carsehall, or he would have done all in his power to make up for my absence, and, if possible, would have induced you to remain till my return.

"It was well known to me that you were the first person who propelled boats by steam, and I well recollect the trial boat lying near the drawbridge. The present model is a different one from that possessed by you; but I do not know if Mr. Bell used at first the 'eccentric' now in common use.

"The 'auletic wheel' I do not understand; but I will have the pleasure of calling upon you on Wednesday, when I shall be happy to receive your lecture, how much or how little of it may be within my sphere of comprehension.

"I am, dear sir, your very obedient servant,
(Signed) "THOMAS DUNDAS."

Documents have recently been discovered which substantiate still more fully the claims of Symington. These documents are in the handwriting of John Taylor, the brother of James, the claimant whose rights to the honour we have been examining, and whose name is not so much as once mentioned relative to the matter. We have been thus particular in giving the evidence on this important point. A pension of 50*l.* has, we believe, been granted to the widow of Taylor for his supposed services as introducer of steam-navigation; nothing was given to Symington during his life, and nothing yet to the relatives he has left behind him. We trust that little time will elapse ere the nation has, through the voice of its legislature, showed a nation's gratitude to the memory of the real introducer of steam-navigation—William Symington.

To afford a ready means of judging of the respective claims of the parties interested, the following summary is appended:

In 1786, Mr. Symington exhibited a working model of a steam-carriage in Edinburgh, and suggested steam-navigation.

In 1788, he superintended the construction of a steam-engine of his own invention, and the fitting of it into one of Mr. Miller's pleasure-boats; which boat was successfully propelled that year on Dalswinton Lake by the power of steam.

In 1789, a larger boat, with a more powerful engine of the same kind, was successfully propelled by steam on the Forth and Clyde Canal.

In 1800, he was engaged by Lord Dundas to construct steam-tugs for the Forth and Clyde Canal.

In 1801, the *Charlotte Dundas*, steam-tug, was repeatedly tried on the canal, towed vessels there and up the rivers Forth and Carron, into Grangemouth, and carried Mr. Fulton, the American engineer, eight miles on the canal in an hour and twenty minutes. In the same year he patented his direct-acting steam-engine for propelling vessels.

In 1802 and 1803, the second *Charlotte Dundas*, a larger and more powerful boat, towed vessels on the canal; and on one particular occasion dragged two laden sloops of seventy tons burden each, the *Active* and *Euphemia*, a distance of 19½ miles in six hours, against a strong adverse gale.

His experiments were here ended, through the fear of the managers of the canal that its banks might be injured by the undulation caused by the wheels.

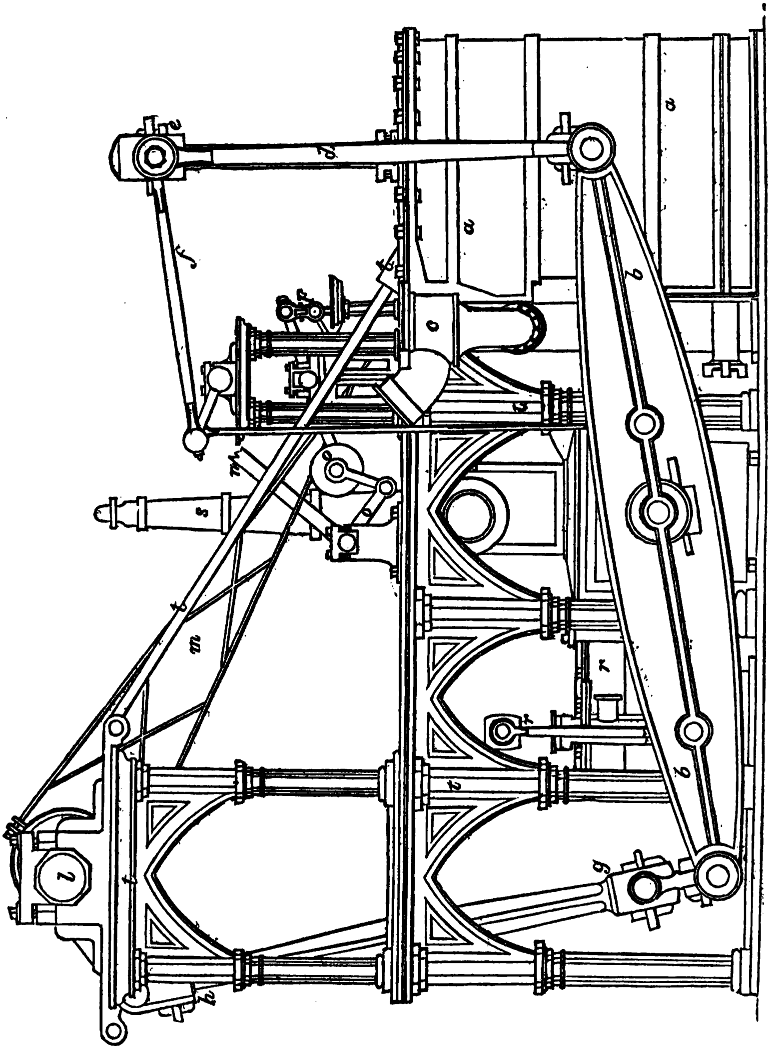

fig. 162.

In 1807, Mr. Fulton first succeeded in propelling a vessel by steam on the Hudson.

In 1811, Mr. Bell's first boat, the *Comet*, was tried, and set to work on the Clyde. Mr. Bell, as well as Mr. Fulton, had been on board of Mr. Symington's boats, and satisfied himself of their efficiency.

Having thus taken a rapid glance at the main points of interest in connection with the history of steam-boat navigation, we proceed to illustrate the various kinds of modern marine engines. These are of two kinds—engines as applicable to the driving of paddle-wheel steamers, and those applicable to "screw" steamers.

The engines adapted for paddle-wheel steamers are of two kinds, "side-lever" and "direct-action." The arrangements of the ordinary side-lever engine will be understood from an inspection of the drawing in fig. 162. As will be observed, this is a modification of the land beam-engine; but as the space overhead in all steam-boats is necessarily limited, the beams are arranged at the lower part of the engine. The cylinder is at *a a*, *b b* the working beam, *c* the steam-pipe, *d d* the side-rod connecting the end of the beam with the cross-head of the piston-rod *e*, *f* the parallel motion; *g* the connecting-rod connecting end of beam with crank *h*, *l* paddle-shaft, *m* eccentric-rod, *n o p* starting handle and valve gearing; *r r* condenser air-pump, worked by the side-lever connected with beam and cross-head of air-pump piston-rod, *s s* air-vessel, *t t* framing.

The drawing in fig. 38 shows the arrangement Mr. M'Naught adopts in his double-cylinder marine engines.

In fig. 163 we give a diagram illustrative of the connection of cylinder, condenser, and air-pump. *a* is the cylinder, *b* the piston-rod, *c* the lower, *d* the upper steam port, *e* the passage leading to the condenser *f*. A division is placed between the condenser and the eduction passage *e*, to prevent the injection-water passing to the lower part *c* of the cylinder. *g* the air-pump, *h i* the air-vessel. We now give descriptions of a few of the details of the engine worth notice. In the air-pump a valve is provided at the bottom plate opening upwards; this is to allow the water to pass from the condenser to the air-pump, but to prevent its return. Another valve is placed at the entrance to the hot-well *h* (fig. 163); this retaining the water in the cone, frees the air-pump bucket from an unnecessary weight of water. The air-cone is now frequently dispensed with. Two orifices

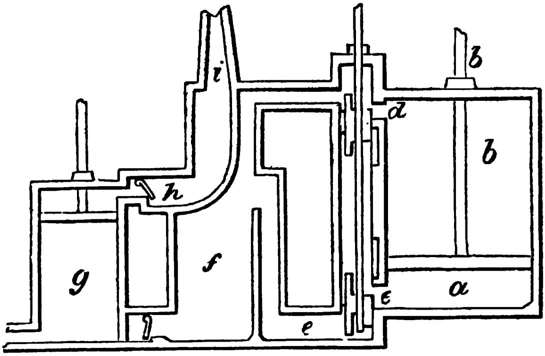

fig. 163.

are made in the hot-well *h*, fig. 163, one larger than the other; the small one communicates with the force-pump for supplying the boiler, the other with the sea, and is termed the waste-pipe.

Escape-valves are provided to the steam cylinder; the office of these is to allow a passage to the water which collects above and below the piston. The escape-valve at the bottom of cylinder is weighted with a pressure above that of the steam in the boiler; if this precaution were not taken, the steam *a* would blow through them on being admitted to the cylinder. The upper escape-valve is generally placed in the cylinder cover, and is retained by a spring in some instances. In some engines the escape-valves are applied to the ports of the cylinder and kept closed with springs.

The diagram in fig. 164 illustrates the method adopted in side-lever engines in working the slide-valves; *f* is the end of the cross-head of the valve-rod, *e e* side-lever, connected with the end *d* of the rocking-shaft *a* oscillating on the centre *b*, and which is moved alternately up and down by the eccentric lever *c*, to which the eccentric-rod is attached. *g* is the back balance-weight; the office of this weight is to balance the slide-valve in such a position that both of the steam-ports are closed when the engine is at rest. In starting the engine the rocking-shaft is moved by hand through the agency of a lever attached to it. In place of a lever, many engines have wheels placed vertically, like the steering wheels of ships. The best starting gear is that known as Stephenson's link motion, used in locomotives, and which, in Chapter V., we have illustrated and described. This also forms the best reversing gear, as by it the full speed a-head can be instantly changed for full speed a-stern without stopping the engines. In engines where this contrivance is not used, the eccentric has to be thrown out of gear before the engine can be reversed. On the crank-shaft, on which the eccentric is placed, a snug or projection is made, as at *b*, fig. 165; two snugs are also fitted, as at *c d*. Suppose the shaft revolves so as to bring the face *f* of the snug *b* against the snug *c*, the eccentric moves in the direction of the arrow; but if it is desired to change the motion, the shaft *a* revolves in the contrary direction, and the face *e* of the snug *b* comes in contact with the snug *d*.

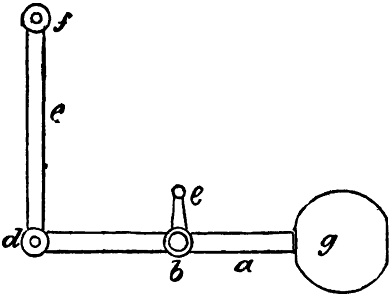

fig. 164.

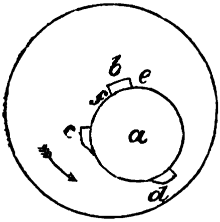

fig. 165.

The comparatively large space occupied by side-lever engines, has directed the attention of many of our engineers to devise arrangements by which space would be economised. This has been attempted, and in some instances with considerable success, by the introduction of the direct-action engine. The varieties of this class are very numerous. To the reader anxious to have a knowledge of these, we must refer to larger works; the *Artisan* treatise gives many illustrations under this head. Our space permits us only to give some simple diagrams illustrative of the most noted of these. The distinguishing feature in this form of engine is the absence of the side beams, rotatory motion being given at once to the paddle-shaft from the piston-rod. In fig. 166 we give a diagram illustrative of the

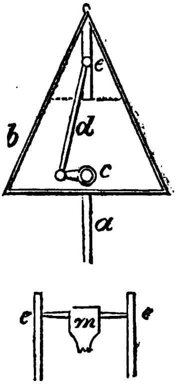

fig. 166.

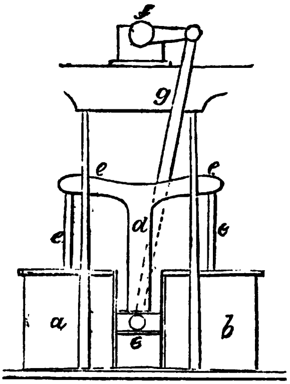

fig. 167.

"steeple-engine," much used in the Clyde. *a* is the piston-rod, carrying a triangular cross-head *b b*; *c* the paddle-shaft, *d* the connecting-rod, attached at one end to the upper extremity of the cross-head *b b*; and the parallelism of the piston-rod is maintained by the guide *e*, in which the cross-head *m* works.

In fig. 167 we illustrate the arrangement of the Siamese or double-cylinder engine introduced by Maudsley and Son. *a b* the two cylinders, *e e* the piston-rods connected with the cross-head *e e*, which is continued downwards to *d*, and which slides between the two parallel guides *e*; one

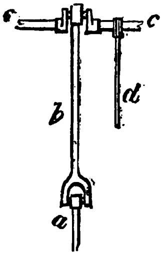

fig. 168.

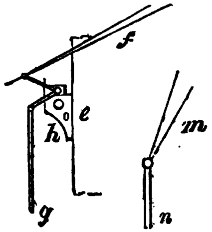

fig. 169.

end of the connecting-rod is attached to *e*, and the other to the crank *g*, on pedestal *f*. In fig. 168 we give a diagram illustrative of another form of direct-acting engine, which is considered as exceedingly compact; "indeed," says an authority, "no engine can occupy less room than this; for its length is little more than the diameter of the cylinder." Let *a* represent the piston-rod, *b* the connecting-rod, *c c* the paddle-shaft, *d* the air-pump rod worked by an eccentric on the shaft *c c*. The cylinder-valve is worked by the eccentric-rod *f*, fig. 169, from an eccentric on shaft *c c* fig. 168; the rod *f* works the levers *a* and valve-rod *g*; *h* the pedestal fixed to the pillar *e*; *m* is the eccentric-rod working the air-pump rod *n* corresponding to *d*, fig. 168. In direct-action engines, where the connecting-rod is between the piston and the crank, the engine is designated as belonging to the class known as the "Gorgon engine," introduced by Messrs. Seaward, where the connecting-rod is above the crank *a*; they come under the designation of steeple-engines.

A well known form of direct-action engine is that known as the "oscillating." We have already described the action of this; we now give a diagram showing its application to a paddle-wheel steamer (fig. 170).

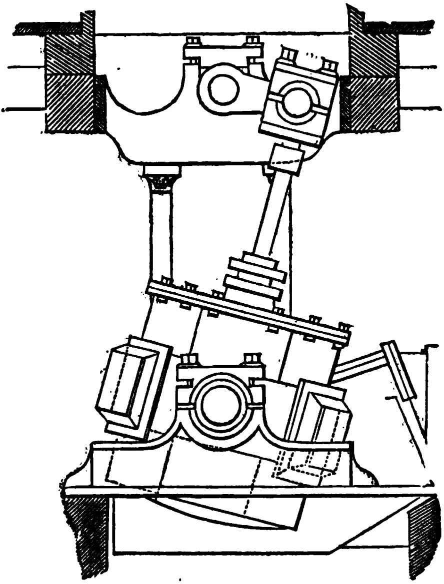

fig. 170.

Where vessels are propelled by the "screw," engines differing in arrangement from those we have already described are adopted. The screw having to make so many more revolutions than paddles in the same space of time, the speed of the screw-shaft is sometimes brought up by cog-wheels. In the engines of the *Great Britain*, this arrangement is adopted;

a pair of oscillating engines giving motion to a horizontal shaft; in this is fixed the driving wheel, taking into the toothed wheel on the screw-shaft. The inconveniences attendant on this form have, however, prompted in

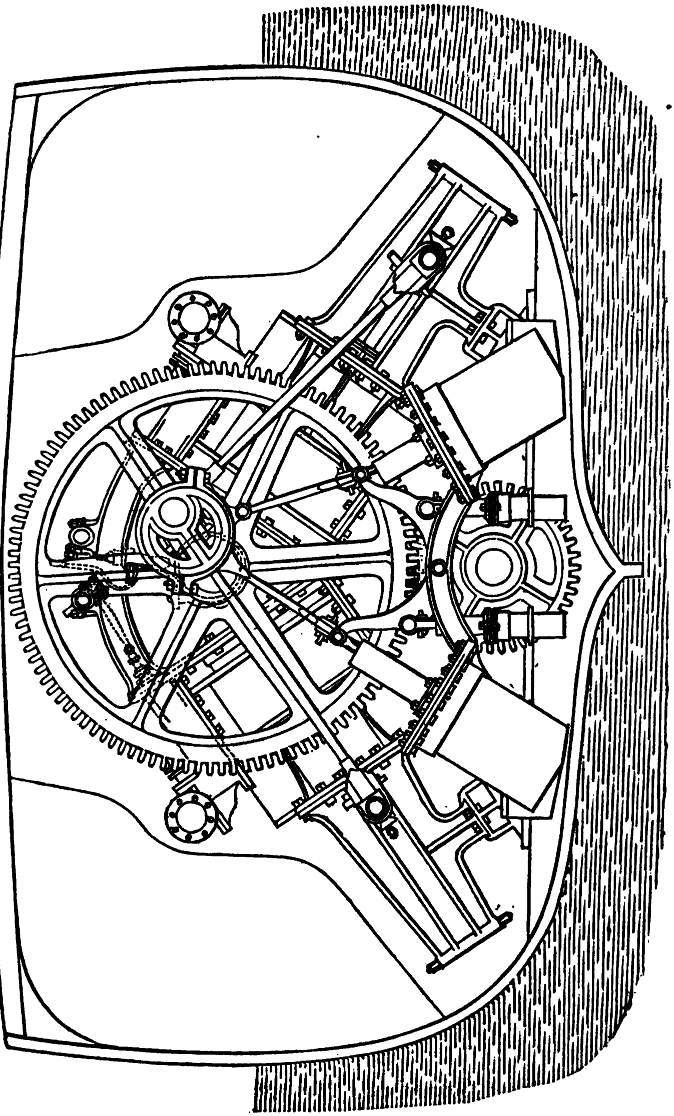

fig. 171.

other instances the use of engines connected directly to the screw-shaft; the difficulty in this case, however, is, that the valves of the air-pump are liable works. Mr. Bourne proposes to obviate this by replacing the air-pump valves by a species of ordinary slide-valve.

In fig. 171 we give a drawing of a double-geared engine, adapted for screw propulsion by Messrs. Scott and Co. of Greenock. The drawing shows a transverse section of the ship, showing the engines in complete external front elevation. The cylinders are fifty-two inches diameter, and three feet nine inches stroke, placed diagonally athwart the ship, and at right angles to each other; whilst the piston-rods project through the lower covers, to allow of long return connecting-rods. Each cylinder has two piston-rods, for greater steadiness, their outer ends in each case being keyed into a cross-head fitted at each end with slide-blocks, for working in a pair of inclined open guide-frames bolted to the bottom cylinder-cover, and supported beneath by projecting bracket-pieces, recessed and bolted down upon pedestal pieces on the engine sole-plate. From each end of this cross-head, immediately outside the guide-frame, a plain straight connecting-rod of round section passes up, to actuate the main first-motion shaft. The upper ends of these connecting-rods are jointed to side-studs, or crank-pins, fast in two opposite arms of a pair of large spur-wheels, which give motion to the screw-shaft by means of a pair of corresponding spur-pinions, fast on the shaft beneath a single pin in each wheel, answering for the two opposite connecting-rods on the same side of the engine. The main spur-wheels are eleven feet five and a half inches diameter, with one hundred and eight teeth of four-inch pitch, and fourteen inches in breadth on the face. They are keyed on the extremities of a common shaft, which is conveniently placed in the angular space formed by the two ends of the inverted steam-cylinders, being carried in a pair of pedestals cast with angular bracket-pieces to bolt down upon the cylinders.

The wheels are equally compactly placed, one on each side the cylinders and the general mass of machinery, and just filling up the space inside the connecting-rods. The pinions on the screw-shaft are four feet six inches diameter, so that the ratio between the screw and the engine's rate is two and a half to one. By this arrangement each piston is directly coupled to both of the large wheels, and the increased length of the cross-heads which the plan involves is counterbalanced by the effect of the double piston-rods; for by this division of the pressure the cross-strain leverage is proportionately diminished. The system of duplex gearing also insures a good, substantial, and well-balanced connection of the first-motion shaft with the screw-shaft. The air-pumps are both situated on one side of the engines, and are worked from the connecting-rod stud of the spur-wheel on that side, the pump cylinders being bolted at their lower ends by their foot-branches to the sole-plate, whilst their upper ends are connected together by a couple of arched cross-pieces. They are thus well bolted together, and to the main framing, their intermediate connecting brackets answering to carry their stud centres of a pair of bent levers for working the bilge and feed-pumps. The whole of the pumps are constructed on the trunk principle, of which class Mr. Humphries' engines, of the *Dartford,* are so well known as the earliest type. As the throw of the main driving-studs would be too great for the purposes of the air-pumps, it is very ingeniously reduced by means of an eccentric set upon the stud, so as to bring the real working centre nearer to the centre line of the first motion-shaft. One of the connecting-rods for working the pump is formed in one piece, with the eccentric ring, and the other is jointed to the ring on the opposite side; both rods descending to joint eyes on the upper ends of links which are again connected by bottom joints, in the recesses of the plunger-trunks of the pumps. The same intermediate joints of the lower ends of the connecting-rods also afford the means of connection with the upper ends of the bent levers of the bilge and feed-pumps, which levers serve the purpose of radius-bars for the air-pump rods. The links for working the plunger-trunks of the bilge and feed-pumps are jointed nearly at the middle of the bent levers, so as to give the required short stroke, the pumps themselves being set vertically, one on each side the screw-shaft, on the sole-plate. The cylinder-valves are combinations of the four-ported class, so successfully introduced on the Clyde by Mr. Thomas Wingate, and the equilibrium-valve. With this arrangement, the engines are handled with very great facility, and a very free exhaust is obtained. They are actuated by a pair of eccentrics on the main first-motion shaft, rods from which pass upwards to short levers on a pair of parallel rocking-shafts, working in end-bearings overhead. These bearings are carried upon a pair of parallel arched frame-pieces, stretching across between the two valve-chests, so that they thus bind the upper ends of the cylinders. The rocking-shafts are cranked at their centres, and have short connecting-rods jointed on to the crank-pins, and extending right and left to their respective valve-spindles. The steam enters the valve-chests on each side, through the elbow-branches, opening into stop or expansion valve-chests at the lower corners of the valve-casings, and the exhaust steam passes off to the condenser by passages round both sides of the cylinders. The condenser is entirely within the engine, beneath the cylinders; it answers, indeed, as the supporting pedestal for the cylinders, which are bolted down upon it.

Of engines adapted to drive the screw-propeller direct, without the intervention of gearing, recently introduced, the "trunk-engine," by Messrs. Penn, of Greenwich, is most remarkable; it is coming fast into general use. In this form of engine, the direct connection between the piston and crank obtainable by the oscillating engine is obtained without the inconveniences arising from the vibration of the cylinder. To the piston a hollow trunk or tube is attached; this passes through the cylinder-cover; between them a packing is interposed, to prevent any leakage between the trunk and the cover; the trunk is of such length as to project beyond the cylinder-cover when the piston is at the bottom of the cylinder. The trunk is of considerable dimensions; the connecting-rod is connected by a moveable joint to the piston, and its other end to the crank-pin; as the piston moves backwards and forwards, the connecting-rod vibrates within the trunk, and thus the direct action is obtained by very simple means. The trunk is on both sides of the piston, or, in other words, the piston is placed midway in the trunk, the connecting-rod being connected with that side of the piston nearest the crank. In this class of engines the cylinders are horizontal and placed side by side; the air-pumps are also horizontal; the great aim being to have all the machinery as low as possible beneath the water-line, a most important point in vessels of war. Both ends of the trunk pass through stuffing-boxes in the cylinder-cover; by this arrangement the pressure of the steam-side is prevented from preponderating over the other. In fig. 172 we give a diagram illustrative of the arrangement of the trunk-engine. Let *a a* be the piston, *b b* the trunk on the crank side, *c c* that on the opposite side; *d e* the connecting-rod, joined at one end *d* to the piston, and at the other *e* to the crank on the "propeller" shaft; *f* and *g* show the vibration of the connecting-rod in various points of the revolution of the crank. By this arrangement of piston and crank, it will be observed that the steam does not press on the whole surface of the piston, but only in the annular ring *a a*, between the outside of the trunk *b*, fig. 173, and the interior of the cylinder in which the piston moves.

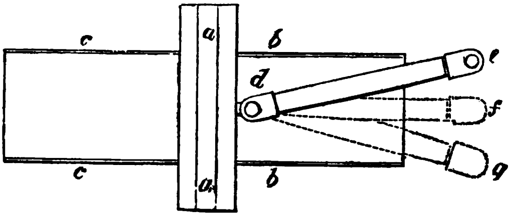

fig. 172.

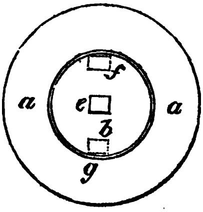

fig. 173.

Governors are usually applied to screw-engines in vessels of light draught, in order to regulate the speed. They are of the usual construction, although many new schemes have been recently introduced; for notices of these we refer the reader to the pages of the *Artisan*, more particularly the numbers for 1853. The necessity for a regulator of the speed of the screw-engine will be obvious, in considering that as the screw is placed at the extremity of the vessel, as it pitches in a heavy sea, the screw would revolve in the air; and as the load would thus be taken from the engine, it would revolve at too great a speed.

We must not omit the mention of an entirely new and very good form of engine adapted for working the screw-propeller, lately designed by Mr. John C. Bothams, engineer, of Salisbury, which differs from the ordinary marine engines in not being a pair of engines of the same description, with all the working parts in duplicate, but a combination of two engines of different form: the one A an ordinary oscillating engine, having an oscillating motion given to it by being attached to the piston P of the pendulous

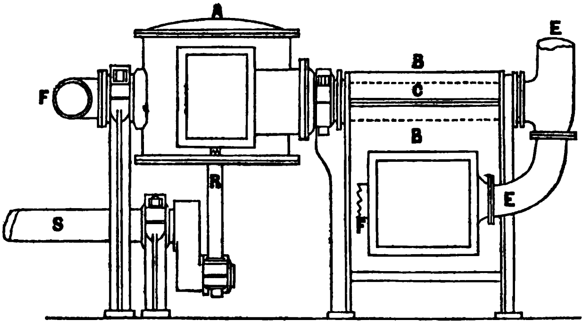

fig. 174.

engine B, by the hollow shaft C, which conveys steam to the oscillating cylinder A; the centre of gravity of the moving parts, the pendulous piston P, and the oscillating cylinder A being fixed as near as possible the required distance below the point of suspension C, according to the laws of pendulous motion.

The piston-rods R of the oscillating cylinder A have motion in two directions: a perpendicular motion derived from the cylinder A, and a horizontal motion from the pendulous piston P; the result being a circular motion to drive the screw-shaft S by means of a single crank.

Fig. 174 is a side view of the two engines, and fig. 175 a section through the pendulous engine B. The steam enters by the pipe E, and passes out by the pipes F F F to the condenser.

Fig. 176 represents an equilibrium surface condenser, and the pump to supply it with cold water: the former consists of a case B B sufficiently strong to resist the pressure of the atmosphere, and is divided into two separate spaces by the plates C D; through the upper plate C a number of thin metal tubes are passed, and are screwed by their lower ends into the plate D; the steam to be condensed is admitted at A into the steam-space S, and flows among or between the tubes, and is condensed by contact with the outer surface of the tubes, which are kept cold by a constant supply of water flowing over their inside surface. P is a pump to supply the condenser with cold water, which enters the pump at E above the piston, is lifted up into the upper part of the condenser W, flows down through the tubes into the lower space W, then is drawn into the lower part of the pump, and by the down-stroke of the piston is forced out at the opening F. No water being admitted to the condenser except when an equal quantity is pumped out at the same time, the tubes are relieved of the pressure of the atmosphere on their inside surface. The condensed steam flowing down the tubes on to the lower plates D, flows into the space H, and is pumped out by the feed-pump into the boiler.

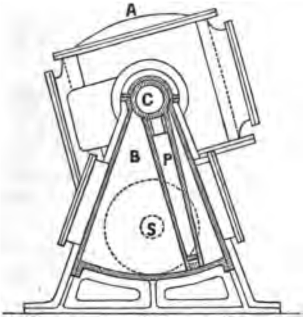

fig. 175.

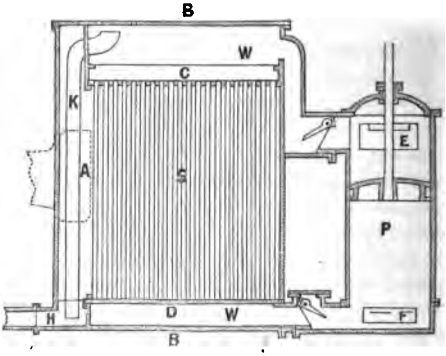

fig. 176.

In order to relieve the tubes from all inequality of pressure on their inner and outer surfaces, a pipe K, leading from the upper water-space W, down into the reservoir H, at the bottom of the steam-space S, acts as a trap; the water in H derived from the condensed steam being above the bottom of the pipe K, prevents a communication between the water-space WW and the steam-space S, as long as those spaces are in equilibrium, or nearly so.

The tubes, therefore, being relieved of the atmospheric pressure, are only employed to separate the steam from the salt water used for condensing, and need not be formed of metal of a greater thickness than 1lb. weight per square foot, and can also be of any form, corrugated as in fig. 177, to diminish the number of tubes and joints, the amount of surface being the same.

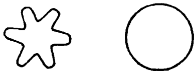

fig. 177.

The thinner the metal which can be used, the less the amount of surface required to condense a given quantity of steam. The pressures on the upper and under sides of the piston being always equal, the pump can be worked by a small amount of power, in the case of large marine engines, by the auxiliary engine used to fill the boilers.

The use of brine-pumps, refrigerator, salinometer, &c., is dispensed with, and also the waste of about one-fourth of the whole quantity of feed-water supplied to the boiler, after being raised to the boiling point, whereby a considerable saving of fuel is effected; and it must be borne in mind that for every ton of fuel saved a ton of freightage is gained.

This invention must ultimately prove of great value; and in bringing it to the notice of engineers, we are thereby rendering them good service.

THE END.

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