RECENT IMPROVEMENTS

IN

THE STEAM ENGINE:

CONTAINING

DESCRIPTIONS OF THE MORE IMPORTANT MODERN ENGINES, AND AMONG THEM OF THE STEAM, AIR, AND GAS ENGINES SHOWN AT THE PARIS EXHIBITION IN 1867.

BEING

A SUPPLEMENT TO THE CATECHISM OF THE STEAM ENGINE.

BY

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PHILADELPHIA:

J. B. LIPPINCOTT & CO.

LONDON: LONGMANS & CO.

1868.

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INTRODUCTION

TO

CATECHISM OF THE STEAM ENGINE.

In this Introduction I propose to recapitulate the most useful information I have been able to collect respecting the improvements which have been made in the steam engine during the last decennium.

As this work addresses practical engineers, and not mere desultory or superficial enquirers, it is indispensable that the information it affords should not only be intrinsically sound and practical, but that it should be cleared of all tinge of antiquity. In an art so rapidly progressive as mechanical engineering, the knowledge of ten years ago is no longer adequate to satisfy the wants or direct the operations of present practice; and, under this conviction, it has appeared to me that the time has come when it would be proper to review the information which the present work contains, in order that it might be rendered more conformable to the accredited maxims of the time, and also that reliable information respecting altered modes and new improvements might be fully afforded. To this end I have carefully revised the text of the last edition; and I have introduced such alterations into it as appeared to me to be necessary to make the work consistent with the best indications of modern practice. But these alterations have not been numerous or extensive, as I found that although there was a good deal to add there was little to alter; and it seemed to me that the requisite additions could be much more conveniently made in a separate discourse, which would be introductory to the work, and which might be purchased separately by the possessors of the former editions, than by incorporating such new information in the body of the work itself, whereby it would be rendered inaccessible to all who did not feel disposed to purchase the entire volume. Under these convictions I have proceeded to prepare the present introduction; and I trust that it will be found to answer its intended purpose of giving an accurate and vigorous outline of contemporaneous engineering knowledge in its most select manifestations, and that it will set the reader face to faee with the works and opinions of those who are justly accounted the leaders of the art, so that he will be able to feel that he has been brought up to the highest point of information yet reached by the most eminent practitioners. It is this vitalizing species of knowledge which alone renders engineering works of much value; and the place of it can never be supplied by the resources of abstract speculation, or the pale reflections of the literary compiler.

THERMO-DYNAMICS.

One of the ablest series of researches which has been made of late years on subjects connected with steam, is that by which Mr. Joule has established the mutual relations of heat and power. It has long been known that heat may be made to produce power, and that power may be made to produce heat. But Mr. Joule has shown by elaborate experiments that the heat produced by friction is the mechanical equivalent of the power expended in maintaining the friction; and that the power represented by the descent of a pound weight through 772 feet, or 772 lbs. through one foot, would, if expended in friction, produce as much heat as would raise the temperature of a pound of water one degree Fahrenheit. If we had a perfect engine for extracting the power from heat, we ought to be able to recover from the heat generated by friction the exact amount of power expended in generating the heat. But in the best existing steam engines it is found that only about *one tenth* of the value of the heat is obtained as power, the residue being wholly wasted; so that if a steam engine were employed to generate heat by friction, only one tenth of the power would be obtained that would have to be consumed in the production and maintenance of the friction. The steam engine, indeed, has now been found to be a very wasteful machine; and the cause of the waste is traceable to the fact that it deals with extremes of temperature but little removed from one another, instead of with extremes of temperature as far removed from one another as possible. As in a waterfall the power generated with any given quantity of water is measureable by the difference of level between the highest and the lowest points, so in a steam engine the power generated with any given quantity of heat is measurable by the difference of temperature between the boiler and the condenser. The greater this difference is, the larger will be the proportion of heat utilized as power. But as in common furnaces the temperature may be taken at 3,000 degrees above the temperature of the atmosphere, while the temperature of the boiler is only about 200 degrees above the temperature of the condenser, the larger part of the fall in the temperature is lost, or not utilized, and the engine is consequently not nearly so effective as it would be if the steam could be received at the temperature of the furnace and expanded down to the temperature of the condenser. In practice there are impediments to the use of steam hotter than that which is at present employed. But it is, nevertheless, proper to understand that either a very much higher initial temperature must be dealt with, or else the combination of the fuel with oxygen must be conducted under such circumstances as to generate power rather than heat, before that measure of economy in the production of power can be attained which is known to be possible. In the animal economy a given quantity of carbon produces its equivalent of power with far less waste than in the best steam engine, although the temperature is not great: and the same result takes place in a Voltaic battery—the electricity generated by which may be made to work an engine with far less loss than its equivalent quantity of heat. It does not, however, appear to be in the least probable that electro-magnetic engines will be brought into use to supersede steam engines, unless some means should be discovered of obtaining the electricity from coal instead of zinc. Zinc, like coal, may be burned, and will produce heat. But a pound of coal consumed in an engine will produce more than twice the power produced in a Galvanic battery by a pound of zinc, and the cost of the coal will also be very much less.

SUPERHEATING.

The practice of superheating the steam before permitting it to enter the engine is now very generally pursued, especially in steam vessels; and the innovation has been productive of a material saving of fuel in many cases. The reasons which render superheating a source of economy may be inferred from the foregoing remarks on Thermo-dynamics; and in the first edition of my Treatise on the Steam Engine, published in 1844 — which was long before the benefits of superheating were recognized—an investigation was given of the economy to be derived from a certain assigned amount of superheating. This investigation was first made by me in 1834, and subsequent experience has shown that the estimate then arrived at was pretty nearly correct. It was, however, at the same time, pointed out by me in the Treatise on the Steam Engine, and also in the first edition of the Catechism of the Steam Engine, published in 1848, that the expedient of superheating would, no doubt, lead to the internal corrosion of the superheating vessel, and also of the internal parts or the engine; and this anticipation has also been verified by the result.* It is found in practice that if the steam is superheated to a temperature exceeding 315 degrees, the hemp packings of the stuffing boxes will be burned, the oil or tallow used in the engine will be carbonized, and the cylinders and valves will be liable to be grooved and injured by the heat and friction of the rubbing parts. In boilers already producing dry steam, and possessing an adequate amount of heating surface, the saving in coal accomplished by superheating common low pressure steam to this extent may be set down as about 10 per cent.; and although a larger economy than this has been obtained in some cases, the increased advantage is to be imputed to the acquisition of an increased heating surface, whereby the heat has been utilized in drying the steam that previously

* When the first edition of the present work appeared in 1848, the practice of transmitting the smoke through the steam chest in marine boilers was universal; and it will be seen at p. 257 that I reprehended that practice as certain to occasion internal corrosion of the steam chest, and I recommended that the smoke should be transmitted to the exterior of the boiler without being passed through the steam chest at all. This recommendation appears to have been adopted, as the smoke is rarely, if ever, now transmitted through the steam chest; and the internal corrosion of the steam chest has consequently ceased to be a source of injury. But where superheaters are employed the same internal corrosion which was formerly experienced in the steam chest reappears in the superheater—though, as this is a removable vessel, and one from which the steam can at any time be shut off, the evil of internal corrosion is not so serious when occurring there, as if it took place in the boiler itself.

I believe that the internal corrosion of superheaters might be prevented by placing pieces of charcoal within them, either in a wire cage or otherwise, for the carbon would satisfy the affinity of the oxygen which now produces oxidation, and would thus leave the iron free from attack.

ascended the chimney—rather than to the superior efficacy of a given quantity of heat when distributed in the assigned proportion between the water and the steam.* Upon the whole, superheating is now rather on the decline; at all events, it is not now carried much beyond that point which suffices to dry the steam, and to prevent the steam within the cylinder from suffering partial condensation, either by external radiation or by the generation of power.†

* In some cases where a large amount of advantage has been obtained from the application of superheaters, although the steam has not been heated to any inconvenient temperature, a part of the benefit is explicable on the supposition that the steam which was before mixed with spray has been dried in the superheater, whereby its volume has been much augmented although its temperature has not been very much raised. This benefit is manifestly a different one from that of superheating proper, and in a boiler already producing dry steam it would not be obtained.

† Steam in the production of power is itself condensed; and less heat will pass into the condenser than is generated in the boiler by the amount that is the equivalent of the power generated. If this were not so, a steam-engine would be a heat-producing engine; for the power of the engine is capable of producing heat by friction, and if we had in the condenser all the heat which the coal can generate, and if we also had the heat generated by the friction, we should have a total amount of heat greater than the coal could generate, which is an absurd supposition. There will consequently always be in the condenser less heat than the boiler produces; and the greater this disparity—supposing there is no loss by radiation—the more effective the engine will be. In a perfect engine the temperature of the condenser would not be raised at all; but the heat would wholly disappear by its transformation into power. In such an engine the steam would enter the cylinder at the temperature of the furnace; and as it expanded more and more, its temperature would fall more and more, until finally it entered the condenser at the same temperature as the condenser itself. Such an engine indeed would not require a condenser, since the steam would itself condense as the heat left it by its transformation into power.

But condensation is equally hindered by the application of a steam jacket; and high-pressure steam worked expansively in jacketed cylinders, combined with surface condensers in the case of steam vessels using salt water, is now regarded as the most promising expedient of economy.

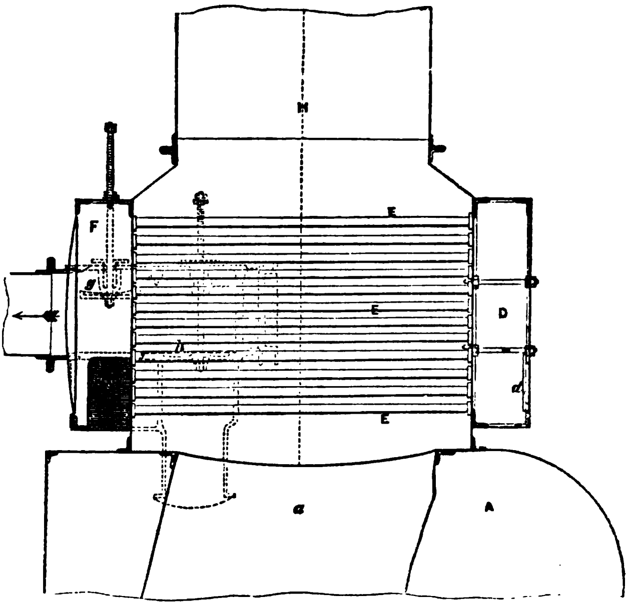
The construction of superheaters is very various. But in most cases the steam is sent through a faggot of small tubes set in the smoke at the root of the chimney.

An example of this arrangement is given in *fig.* 1, which is a representation of the superheater introduced by Messrs. R. Napier and Sons into the steamer 'Oleg,' belonging to the Russian Steam Navigation Company. A is the boiler, and *a* the uptake of the boiler; *d* position of inlet valve connecting boiler with superheater; D and F inlet and outlet chambers of superheater; E tubes through which the steam passes; *g* double outlet stop-valve chest, in which *g* connects superheater to steam pipe, and *h* connects boiler to steam-pipe direct. H is the chimney. The smoke in ascending the chimney impinges on the tubes transmitting the steam, whereby the steam is heated to the required extent.

In Lamb and Summers' superheating arrangement, a narrow rectangular pipe or chamber—which winds in a zigzag manner like the flue of a flue boiler—conducts the steam backwards and forwards amongst the smoke at the root of the chimney, until finally the steam debouches in the steam pipe.

This superheater is shown in *fig.* 2, where A is the winding rectangular chamber; B the stop valve for admitting steam into the superheater; C stop-valve for letting steam pass from the boiler to the

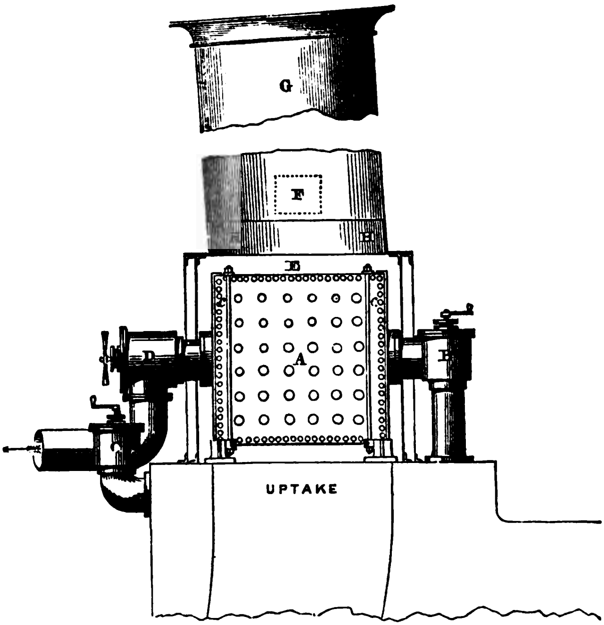
Fig. 1.



SUPERHEATING APPARATUS OF S. S. OLEG, BY R. NAPIER AND SONS. 1860.
Longitudinal Section.

engines without passing through superheater; D stop-valve for shutting off superheater; G is the chimney; F is a door for getting into it, and H H is a ring or cooming, over which the chimney passes, and the space between which and the chimney is filled with fire-clay to keep it tight.

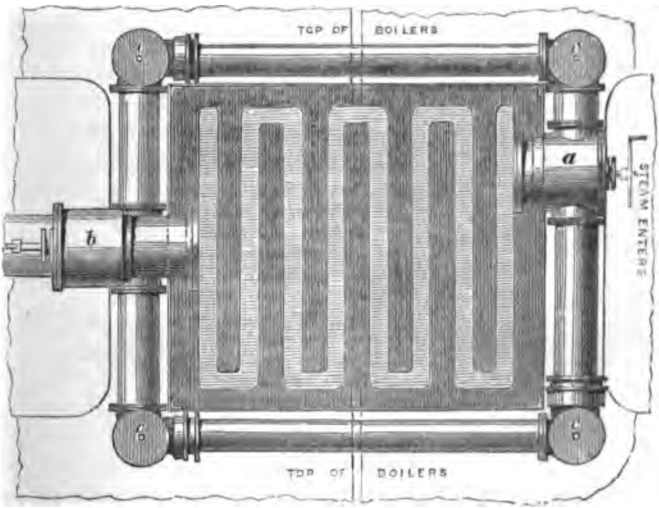
Fig. 2.



LAMB AND SUMMERS' SUPERHEATING APPARATUS, 1860. Vertical Section.

Another example of Lamb and Summers' superheater is given in *fig.* 3, which is a ground plan of the superheater as applied to four boilers, collectively of 400 horse power. The steam space is 4 inches wide, and the smoke spaces are each 6½ inches wide. The winding length through which the steam is conducted is 51 feet 9 inches, and the height of the

Fig. 3.

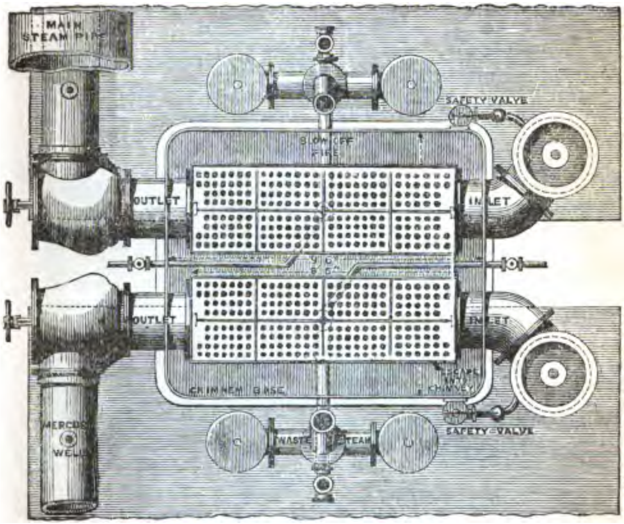


LAMB AND SUMMERS' SUPERHEATING APPARATUS, 1865. Ground Plan.

winding chamber is 5 feet 7 inches. The total area of heating surface in the superheater is 600 square feet, which is just 1½ square feet per nominal horse power. The steam issues from the boiler through the stop-valves *c c c c*, enters the superheater through the stop-valve *a*, and escapes through the stop-valve *b*.

Another form of superheater is shown in *fig.* 4, which is the superheater constructed by Messrs. Boulton and Watt for the steamer Great Eastern.

Fig. 4.



SUPERHEATING APPARATUS OF GREAT EASTERN, BY BOULTON, WATT, AND CO. Ground Plan.

This superheater consists of a square chest placed over the uptake at the foot of the chimney, and filled with vertical pipes through which the smoke passes. In this case the steam passes on the outside of the tubes, whereas in most cases it passes through the tubes as shown in *fig.* 1.

A common proportion of surface given to superheaters is 4 square feet per nominal horse power. But this is quite too much, and 1½ square feet per nominal horse power is sufficient. As, however, the nominal horse power is so indefinite a quantity as regards the boiler, it will be preferable to fix the surface of the superheater at ·3 square feet per cubic foot of water evaporated. It is of course necessary to be careful in introducing superheaters not to contract the area for the ascent of the smoke up the chimney, which should be left quite as large as before.

HIGH PRESSURE, EXPANSION, AND SURFACE CONDENSATION.

The use of a high-pressure of steam worked expansively is now beginning to acquire general acceptation in every class of engines; but, in steam vessels, the use of steam of any considerable pressure involves the necessity of employing surface condensers, so that the boilers may be fed with fresh water, as where salt water is used there is always the risk of salting; and if a boiler with a high-pressure of steam were to be salted up, so as to become red hot, it would probably burst. I have long discerned the importance of this combination for the purposes of steam navigation; and in 1838 I took out a patent for using high-pressure steam expansively in steam vessels, in which plan the feature of external condensation was introduced. The boiler proposed to be used, and which was practically constructed by me at that time, was a cylindrical one, and it was traversed by brass tubes 2½ inches in diameter, being the first example, so far as I am aware, of a tubular boiler like that of a locomotive applied to the purposes of steam navigation. The steam was proposed to be used expansively, and was cut off by a slide valve formed of two moveable plates worked on the back of the common slide valve; and the degree of expansion was regulated by a right and left-hand screw, which drew the plates nearer together, or separated them wider apart, according as much or little expansion was desired. The spindle on which the screws were cut passed through a stuffing-box, and was armed at the top with a small wheel, by turning which the amount of the expansion was determined. This was the first example, I believe, of a class of expansion valve much employed by Meyer of Vienna and many other Continental engineers, and which indeed has now come into extensive use both abroad and at home.

The steam under the arrangement recited was proposed to be condensed by being sent through a number of small copper tubes immerged in cold water. This method of condensation had been originally employed by Watt, but was dismissed by him on account of the cumbrous nature of the apparatus it involved, without conferring compensating benefit; and it was afterwards revived by Samuel Hall, about 1835, as an expedient for rendering marine boilers less subject to rapid decay than at that time they were found to be. But as Hall's condenser was not found to increase the durability of the boilers, it was discarded as an unserviceable innovation, which would hardly have been its fate if it had been combined with the use of high pressure steam, and if it had been shown that its employment was necessary to enable high pressure steam, with its concomitant benefits, to be applicable with safety. For many years, however, there was a marvellous apathy among the proprietors of steam engines regarding the consumption of fuel, except in Cornwall, where the system which prevailed of ascertaining and publishing the consumption of a great number of engines induced corresponding emulation and improvement. But the conviction has at length dawned upon us that in the case of all processes requiring a large expenditure of power, and especially in the case of steam navigation, the difference between a large and small consumption of fuel is so momentous that it may determine the success or failure of the speculation; and surface condensation is now very properly regarded not as a primary source of gain, but as an expedient for saving fuel by enabling steam of a high pressure to be used in steam vessels with safety. The surface condensers are nearly in all cases formed with small brass or copper tubes, and these tubes are sometimes drawn out of the solid, and sometimes formed out of brass or copper sheets brazed. The tubes with the brazed joints are, on the whole, the best, as in the drawn tubes the smallest speck in the metal is drawn out or elongated into a crack; and such tubes are consequently more liable to split. In some cases the water is sent through the tubes and in other cases the steam; but, on the whole, the best practice is to send the water through the tubes; and the steam should enter at the opposite side from the water, so that the hottest steam may meet the hottest water. The proportion of condensing surface commonly allowed for each nominal horse power varies from 12 to 18 square feet, and some engineers maintain that there should be as much cooling surface in the condenser as there is heating surface in the boiler—a conclusion from which I dissent altogether. I believe that 10 square feet per nominal horse power would be more than sufficient in all ordinary cases, if the surface were properly disposed, and a rapid circulation of the refrigerating water were maintained; and indeed in a really well-constructed condenser, employing a small jet, I feel persuaded that 1 square foot of condenser surface for each cubic foot evaporated from the boiler would be sufficient. The main condition of efficiency in condensers is the maintenance of a very rapid circulation of water through the tubes. The usual arrangement is to place the tubes horizontally in a square box, and to bring in the water at the bottom of the box, and the steam at the top. The water frequently passes through one-third of the tubes at first, and is then returned through another third lying immediately above, and finally through the third portion, so that the hottest water meets the entering steam. But in scarcely any condenser is the circulation rapid enough, and it is much better to have a little more area in the circulating pump, which will save surface in the condenser.

In Hall's condensers a good deal of trouble was at first experienced from the tallow supplied to the piston and stuffing boxes being distilled over with the steam and concreting in the tubes, so as to choke them up; and in consequence of this occurrence oil was finally used for the pistons and stuffing boxes instead of tallow. The same inconvenience has recurred in some of the recent surface condensers; and in engines furnished with such condensers it appears advisable to use oil instead of tallow, and also to use as little of it as possible. It is further advisable to feed the oil to the stuffing boxes and pistons continuously, by some such arrangement as it is fed to the bearings by, as the necessary amount of lubrication will be thus given with the least oil.

Where hot steam is employed in jacketed engines, and much tallow is introduced, it is found that the tallow is decomposed, and carbonises the piston; so that after a time the piston becomes like a piece of plumbago, or like cast iron which has been long immersed in sea water, and which finally becomes so soft that it may be cut by a knife. It is further found that instead of the surface condensers conducing to the durability of the boilers, they have the very reverse operation, and that it is necessary to introduce a certain proportion of salt water from the sea to prevent the boilers from being rapidly destroyed. Not only is the grease from the engine carried into the tubes of the condenser, but a certain proportion of it passes into the boiler; and the verdigris formed by the action of the grease upon the brass or copper tubes also distils over and attacks the surface of the iron within the boiler, so that in a short time it is eaten into pits and indentations, and becomes covered with an efflorescence of red rust. The presence of pieces of zinc within the boiler would probably hinder or retard this action; but the best antidote appears to be the introduction of a small jet of salt water into the condenser, which, if employed while the boiler is still new, will have the effect of covering the flues with a thin enamel of scale.* There should be no means of shutting off any of the surplus water thus introduced; but the surplus should escape spontaneously when the level becomes too high. The application of such a jet, moreover, will, if judiciously made, enable the refrigeratory surface of the tubes to be very much reduced, as the tubes will only be required to condense the hotter part of the steam, while the vapour may be condensed by the supplementary jet, if it is introduced at the proper place.

The introduction of surface condensers into ocean vessels performing long voyages has revealed many weaknesses of the system which are no doubt superable. But the conviction arises that the remedy may come too late; and it is exceedingly doubtful whether surface condensers will succeed in maintaining the ground they at present occupy. The experience of the corrosive action of such condensers on the boilers

* New boilers should be worked wholly with salt water at first, until a scale forms upon them. The sulphate of lime in sea water is deposited at the temperature due to the pressure of three atmospheres *without any concentration at all*; so that with high-pressure steam in boilers using salt water, the more blowing-off there is, the more deposit there will be.

is universal; and in some cases, where the boiler has been worked with salt water after the corrosive action had set in, the scale purposely produced from the salt water could not be got to adhere solidly to the iron, but when struck it fell off in flakes, revealing a thick coating of rust below. In such cases it has been found advisable to beat off all the rust and scale, and to cover the interior of the boiler with a thin coating of Scott's cement; after which it was found that the scale would permanently adhere. The water of boilers using surface condensers becomes in time of a bluish hue—a phenomenon due partly perhaps to the carbonisation of the oil or tallow which the water resulting from the condensation brings into the boiler with it, and partly to the distilled verdigris. I see no reason to doubt that practical objections such as I have here enumerated, which are the natural incidents of all innovation, will in time be surmounted. But I am not equally confident that the time for surface condensation has not gone by. Thirty, or even twenty years ago, the practical establishment of the system in connexion with high steam and expansive action, would have been a practical benefit. But the method I have since suggested for maintaining any desired amount of freshness in the water of the boiler without any material waste of heat in blowing off, constitutes an alternative method, which, by conferring most of the benefits of surface condensation without the evils, subverts the ground on which the system of external condensation rests, so that, like many other tardy realisations, it now comes too late. The sulphate of lime may be obstracted by filtration or deposition in a separate vessel heated to the temperature required, to ensure the separation of the lime.

When surface condensers are used, it is the best arrangement with reciprocating pumps, to *draw* the water through the tubes, rather than to *force* it through. The circulation should be very rapid, and all the arrangements should be such as to enable the condenser to be converted at once into an ordinary condenser, should any circumstance occur to render the transformation advisable. In America a form of condenser is sometimes used in which there is a vacuum both within and without the tubes, under which arrangement the tubes may be very thin, as there is no pressure upon them.

The tubes of surface condensers are usually half or five-eighths of an inch in diameter, and from five to seven feet long. But it is better to make them shorter and larger in diameter. They are sometimes fixed in with a brass screw—with a linen washer below, so as to form a gland at the end of each tube—the screw being screwed into the tube plate; and at other times the whole end of the barrel or case containing the tubes is covered with a sheet of india rubber, perforated to let the tubes through, and with a metal plate, similarly perforated but with somewhat smaller holes, screwed down on the india rubber. This last is the simplest arrangement, and it is now widely adopted.

The species of condenser proposed by me as a substitute for surface condensers, consists of a common condenser fitted with two jets, one of which is placed in the eduction pipe, or very high up in the condenser; and the other about the centre of the condenser. The water which enters by the highest jet, and which the steam first encounters, is not sufficient fully to condense the steam, but is itself heated to the boiling point—in which state it is withdrawn to feed the boiler; and this boiling feed, being in excess of the requirements of the boiler, and being purposely so arranged that it cannot be shut off, involves the necessity of a large amount of continuous blowing off. It is obvious that in this arrangement the ordinary jet will condense the residue of the steam not condensed by the first jet, and will maintain the vacuum at the proper point; and this will be done with less condensing water than usual, as if some of the water is withdrawn very hot, there will be less heat remaining to be abstracted by the rest. Even in surface condensers it would be advisable to heat the feed water by injecting it into the steam entering from the eduction pipe before sending it into the boiler, as there is a manifest loss by sending the feed water into the boiler very cold, and probably a very small surface condenser with supplementary jet is the best arrangement in engines using high steam.

In some engines the circulation of the refrigeratory water through the condenser is maintained by a common double-acting pump; and in other engines the circulation is maintained by a centrifugal pump, driven in some cases by a separate small engine, and in other cases by gearing. In some arrangements the ordinary air pump of one of the engines is used as a circulating pump for both of the engines, and the air pump of the other engine is used as an air pump for both the engines. When a centrifugal pump is used, it appears to be the best arrangement to drive it by a separate donkey engine, the speed of which may be varied as desired, and which engine may also be made to drive the supplementary feed and bilge pumps.

The question of the most eligible method of working steam expansively, especially in steam vessels, has now become of much interest; and various forms of double cylinder engines have been put forth, professing to satisfy the conditions of the problem. But it may safely be asserted, that for all pressures employed in the ordinary class of existing steam vessels, engines of the common single cylinder type are as efficient as any other; and in practice such engines are found to work quite as economically as engines with any greater number of cylinders, while they are manifestly simpler in construction. The first question that presses for solution in the case of steam vessels is, what kind of boilers shall be used that will be strong enough to withstand a high pressure of steam with safety; seeing that the ordinary marine boilers at present employed are quite too weak for higher pressures than those which they are at present constrained to bear. For pressures up to 30 or 40 lbs. per square inch, engines of the common type, with a length of stroke equal to the diameter of the cylinder, will answer very well. But if the pressure be raised to 60 or 70 lbs. per square inch, it will be advisable to double the length of the stroke and halve the area of the piston; so that the maximum pressure on the piston will only be the same as before, but the velocity of its motion will be doubled. In this increase of the velocity of the piston, there will be no disadvantage if the momentum be balanced by suitable counterweights attached to the cranks, and if the cylinder ports are made as large for the long and narrow cylinder as for the short and wide one. If such pressures be employed as 150 or 200 lbs. per square inch, it may be proper to introduce double cylinder engines. But the use of a long stroke is tantamount to the employment of double cylinders, in so far as it reduces the maximum pressure on the piston; and it is proper to exhaust the resources of single cylinder engines by suitably modifying the proportions to answer the intended amount of expansion, before entering on the ineligible complication of a multiplication of the number of cylinders. All engineers perfectly well know that the gain in power producible by a given amount of expansion is equally attained whether such expansion is accomplished in one cylinder or in fifty. But the more cylinders there are, the more equable will the pressure be made throughout the stroke—at the same time that there will be greater complication. The equalisation of the pressure, however, may be promoted by increasing the length of the stroke, which is a simpler expedient than increasing the number of cylinders; and in steam vessels great equality of the pressure is not important, while in land engines it may be attained to any desired extent by increasing the weight and swiftness of the fly-wheel. I no not by any means object to double cylinder engines *in toto*. I only say that they should not be introduced for nothing; and if they *are* introduced such an increased pressure of steam should be introduced simultaneously as will afford fair compensation and proper warrant for the increased complication which the innovation involves.

COMBINED SCREW AND PADDLE ENGINES.

In 1850, when it became important to accelerate the speed of a fleet of paddle vessels, I suggested a method of accomplishing the required acceleration, without disturbing the existing engines, by the application of an independent high-pressure engine in each vessel, which was to drive a screw placed at the stern; and the steam from this high-pressure engine was subsequently to pass to the paddle engines, and to drive them with the same pressure as that to which they had previously been subjected. This arrangement was virtually that of a double cylinder engine, for the steam was used twice over; and although the complication was greater than it might have been advisable to incur in new engines, it was excusable under the circumstances, as it afforded the means of accomplishing the desired acceleration with the least disturbance of the existing arrangements, and also at a trifling expense. I reckoned that each vessel, when laden for her intended voyage, after having been fitted with the auxiliary engine, would have been lighter than before; as, although the weight of the machinery would have been greater, the weight of the coals would have been less. By this expedient the power might have been nearly doubled without any increased consumption of coal per hour; and as by doubling the power, the speed would have been rendered one-fourth greater, almost one-fourth of the coal would have been saved on the voyage.

In 1852 the foregoing suggestion was published in my 'Treatise on the Screw Propeller,' and shortly afterwards it was announced that the Great Eastern was to be propelled by paddles and a screw. I do not recommend the plan for new vessels. But I consider the introduction of a duplicate high-pressure engine, with a separate propeller, to be the most eligible means of accelerating old vessels, whether paddles or screws. In paddle vessels a single direct-acting high-pressure engine driving a screw—which may be placed outside the rudder as in Beattie's plan—the steam from this engine passing subsequently to the paddle engines and driving them—is an arrangement that is cheap, easily applicable, and certain to be effective. In screw vessels a single high-pressure paddle engine may in like manner be set to drive a pair of paddles; and the steam from this engine would drive the ordinary screw engines as effectively as if they were supplied with steam direct from a low-pressure boiler. I believe that this form of the double cylinder engine is likely to be introduced in all cases in which it is considered desirable to obtain more speed in existing vessels with less coals.

MODERN FORMS OF SCREW ENGINES.

Geared engines for driving the screw have now practically gone out, as I have long foreseen would be the case; and the species of horizontal steeple engine of some such construction as that described at page 433 of my Catechism of the Steam Engine, and recommended in the early editions of that work, is now the species of screw engine employed by the most eminent constructors. The class of engines called 'Forge Hammer Engines,' in which two or more inverted cylinders are raised high upon framing, and the connecting rod engages the crank beneath, is still used by some makers; and in many cases—and especially if the engines are of no great dimensions—they have been found to work very satisfactorily. But on the whole, the horizontal steeple engine is preferred; and some class or other of horizontal direct acting engine is now used by Messrs. Penn, Maudslay, Ravenhill, Napier, Rennie, and indeed by all the most eminent engineers. A little further on I will give illustrations of some of the best existing examples of screw engines.

ON BALANCING THE MOMENTUM OF ENGINES.

The application of balance weights to the cranks of direct-acting screw engines, is now a very general practice; and it is found to conduce to the easy and steady working of the engines in a very marked manner. This application was first made by myself; and I took out a patent for the improvement in 1852, at which time I constructed some screw engines that were thus fitted. Mr. Penn shortly afterwards applied similar counterweights to the engines of the Himalaya, and since that time these counterweights have been very generally introduced. It was found in the Himalaya, that without the counterweights, the engines gave a most uneasy motion to the vessel, and also worked with great tremor and jolting; whereas when the counterweights had been applied, these injurious features of the rapid reciprocation of the engines were removed.

The principle on which the size of the counterweights should be adjusted to the wants of the engine, is of very easy apprehension. If the centre of gyration of the counterweights describes a circle of the same radius as that described by the crank pin, then the counterweights must just be as heavy as the piston, and all the parts which move with it. But if the centre of gyration of the counterweights has a greater radius than the crank pin, the counterweights must weigh less than the piston and its connections, and if it has a less radius, they must weigh more—the only material condition being that the momentum or amount of mechanical power resident in the counterweights when moving in one direction, shall balance the momentum of the piston and its connections when moving in the opposite direction, and which weight may be supposed to be collected in the crank pin.

MARINE GOVERNORS.

All marine engines, but especially screw engines, are liable to sudden fluctuations of velocity from the varying immersion of the propeller in a rough sea; and the necessity of employing some species of governor to redress these irregularities, has long been perceived. The common form of engine governor that is used in land engines is obviously inapplicable to such a purpose, as the balls would open and close by the heaving of the ship; and various kinds of marine governors have been proposed to satisfy the want, of which the first, so far as I am aware, was invented by myself in 1834, and applied to the Don Juan steamer in 1836. This governor was formed with balls similar to those of a common governor; and it stood on a cross stay extending between the engines, which were of the side lever construction, and was driven by a bevel wheel on the intermediate shaft, which wheel gave motion to a bevel pinion placed on the top of the governor spindle, which stood in a vertical position beneath the intermediate shaft. Upon the spindle, near its lower end, was fixed a strong transverse bar; and on this bar the balls were strung, one ball being on each side of the vertical spindle. The balls were capable of being moved in or out on the transverse bar, but when the engine was at rest, they were retained in contact with the spindle by a great plate spring, one side of which embraced a collar or neck formed on each ball. When, however, the spindle was put into revolution, the centrifugal force of the balls overcame the tension of the spring to an extent corresponding to their velocity; and the outward motion of the balls acted upon the throttle valve by a connection similar to that usual in land engines, and which was moreover of such a nature, that the rolling or pitching of the ship, if it affected one ball, would also affect the other in an equal and opposite manner, so as to afford mutual compensation and extinguish the effect of the ship altogether. There was in these engines a throttle valve in the injection pipe, as well as in the steam pipe, and the balls were made 14 inches in diameter, in order that they might have adequate power to overcome the friction of the parts, without requiring any great change of velocity to give the requisite centrifugal force.* Latterly, a marine governor called Silver's governor, and another called Porter's governor, both operating on the same principle as the foregoing, have been put forth. But the species of governor at present most employed in steam vessels, and which is known as Silver's fly-wheel governor, consists of a wheel like a small fly-wheel driven by a belt and with vanes like those of a fan fixed upon it, so that its revolution occasions a certain resistance. The driving pressure is transmitted through a spring, the tension of which measures the amount of the rotative resistance, and if the speed of the engine is constant, this tension is constant also. If, however, the speed of the engine is increased, the tension of the spring will be increased, and if the speed of the engine is diminished, the tension of the spring will be diminished; and these differences of tension are made to act on the throttle valve, and regulate the speed of the engine.

* I had models of several other kinds of governors constructed, in some of which there were four arms, and the balls compressed spiral springs. But only one example was practically introduced into a vessel by me, and as the vessel was lost shortly afterwards, this example was not much known.

In practice, Silver's fly-wheel governor is found to act in a perfectly satisfactory manner, and these governors have now been largely introduced.

BALANCED VALVES.

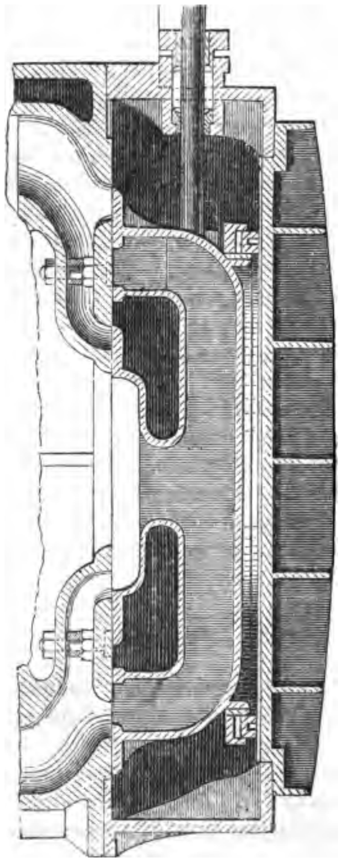
The three-ported valve, or that variety of it called the gridiron valve, is the kind of valve generally used in every species of engine: and in all marine engines of any considerable size, the pressure is taken off the face of the valve by some suitable equilibrium arrangement applied at the back. The arrangement most usually adopted consists in the application of a ring recessed in a groove at the back of the valve, which ring moves steam-tight upon the back of the valve casing; and within this ring a vacuum is maintained by opening a communication between the space encircled by the ring and the condenser. The practice of taking off the pressure by an arrangement of this kind originated with Messrs. Penn, who instead of a ring used at first a square frame. But this apparatus was difficult to construct; and it was consequently superseded by the ring, which was introduced by Mr. Edward Humphrys, to whom the steam engine is indebted for various improvements. In both Messrs. Penn's and Humphrys' arrangements, however, the ring is placed in a recess on the back of the valve, and moves with it. But in some engines drawn out under my direction in 1858 by Mr. Edward Cooper, the ring was recessed in the back of the valve casing, and the back of the moving valve worked steam-tight against this stationary ring.

This method of construction is now coming into general use; and it is preferable to the other method, as the ring, being stationary, is always accessible, so that it may be tightened up when the engine is going, whereas under Messrs. Penn's arrangement, the engine must be stopped, and the steam shut off, before the screws which tighten the ring can be approached at all. The ring which rubs upon the back of the valve may be of cast iron or brass; and above it is usually placed a ring of india rubber, and above that again a malleable iron ring, on which last ring the points of the tightening screws press. The whole of these rings are sunk in a recess cast in the door which covers the back of the valve casing; so that the cast iron or brass ring rises only a little way above the inner surface of the door. The back of the valve is planed true, and is sufficiently elongated for a portion of it to fall at all times within the ring, notwithstanding the travel of the valve. An example of the ordinary gridiron slide with ring at the back for taking off the pressure is shown in *fig.* 5, which is a representation of the section of one of the valves of the screw engines of the Great Eastern.

LINK MOTION.

This contrivance for giving motion to the valves is now employed in nearly every class of engines. It was brought out and applied to locomotives by Mr. Robert Stephenson in 1843, and was first applied to marine engines by Mr. Edward Humphrys. In a form of the link motion constructed by me in 1836, only one eccentric was employed, which gave motion to a double-ended lever in which a slot was made nearly

Fig. 5.



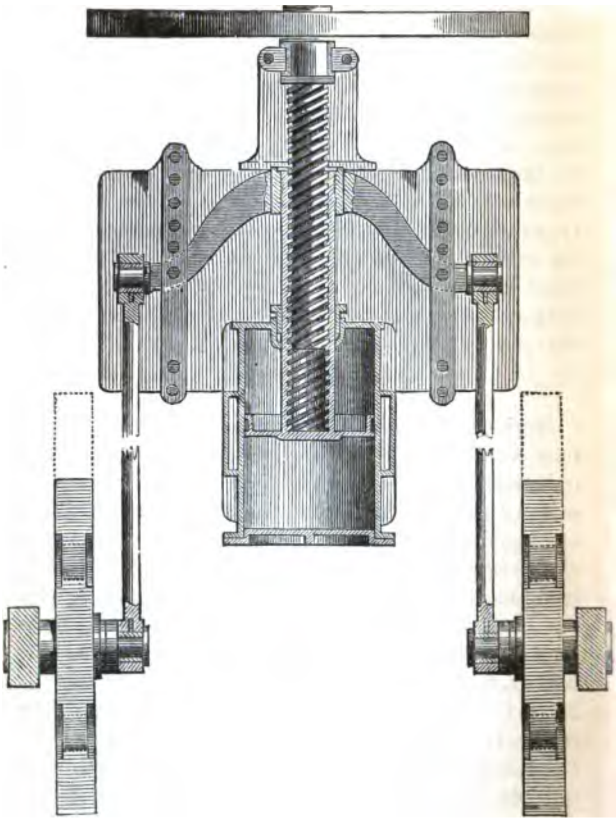
SECTION OF GRIDIRON SLIDE VALVE OF SCREW ENGINES OF THE STEAMER GREAT EASTERN, BY BOULTON AND WATT.

from end to end. In this slot the pin was placed which communicated with the valve rod; and by moving this pin along in the slot, which was done by appropriate mechanism, the engine was stopped or reversed, and any desired amount of expansion was accomplished. The defect of this arrangement was, that it did not reverse the lead in reversing the engine. But in most cases an imperfect action of the valve when the engine is moving backward is not very material, seeing that it is only in rare cases that the engine is required to work backward for any considerable length of time; and the arrangement is simpler than the species of link motion now in common use.

STARTING CYLINDERS.

In the larger class of marine engines the links are now very generally moved by means of a separate cylinder and piston devoted to the special purpose of moving the starting gear. The starting cylinder employed in the steamers Ulster and Munster is shown in *fig.* 6. The links of both engines are raised or lowered simultaneously by rods connecting them with the cross head of the small starting engine, which is formed without a crank; and the piston rod is made hollow, with a screw working in it, which screw may be turned by the hand wheel shown at the top of the figure, if necessary, to assist the ascent or descent of the piston. Such assistance, however, is seldom required; but on the contrary, the piston in its ascent and descent puts the wheel into revolution, like the fly of a roasting-jack, first in one direction and then

Fig. 6.



STARTING CYLINDER OF THE STEAMERS ULSTER AND MUNSTER, BY BOULTON AND WATT.

in the other; and any jerk, striking, or injurious rapidity in the motion of the piston is thus prevented. The hand-wheel is furnished with internal handles, to enable the attendants to obtain a firm hold of it without entailing the danger of striking them in its rotation; and in practice the apparatus is found to work in the most satisfactory manner.

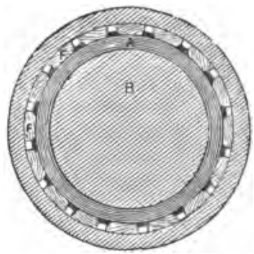
Starting cylinders of this or some analogous construction are now much employed in all classes of large engines. They were first introduced by myself in the steamer Don Juan in 1836; and a drawing of the engines of that vessel, in which the starting cylinders are shown, was published in the first number of the 'Artizan' in 1843. In 1852 I introduced starting valves, and they are now becoming general.

SHAFTS AND SHAFT BEARINGS.

The shafts of important engines, such as marine engines for driving the screw propeller, and also cranked and other axles of locomotives, are now frequently made of steel, which is peculiarly suitable for the formation of shafts, as its tensile and crushing strengths are both very much greater than those of any other known material. Piston rods are also sometimes made of steel. But the benefit of the practice is not so conspicuous in that instance; and in some cases steel piston rods have been found to break more frequently than iron ones. It is a good practice, however, to convert the iron piston rods into steel for a certain depth: as the benefit is thus retained of the toughness of the iron rod, with the additional gain of the exemption from ruts, and the high polish, of the steel surface. In the case of large double cranks set at right angles—like those proper for a direct-acting screw engine—being formed of steel, it is a useful practice to join the two portions together by stout flanges placed in the middle of the length; as the magnitude of the piece is thereby reduced, and the inconvenience is obviated of having to produce so awkward a piece as that of a very large shaft with two double cranks at right angles formed upon it. In the casting of these shafts, the steel is melted in crucibles, and a succession of persons carrying these crucibles from the furnace to the point where the casting is made is kept up, so that the whole of the mass of metal is collected into the casting in a short time. After the casting has been made, it is dug out of the pit, while still red-hot, and carried to the forge hammer, where it is beat and finished as a forging. Even in the best steel works, however, the method of forming such large masses of steel is still very imperfect; and a complete reorganisation of the system is necessary, before steel can be so largely introduced for industrial purposes as it is destined to be at no distant time, and to which the imperfections of the manufacture now constitute the only visible impediment. The same remark may be extended to the production of articles of wrought iron; and in both cases improved methods are not difficult of perception which will completely change the rude and expensive systems at present employed.

The length of the bearings of shafts running at so high a velocity as the crank shafts of direct-acting screw engines is now often made 3 or 3½ times the diameter. Sometimes the bushes are lined with soft metal; and the shaft where it penetrates the vessel at the stern is usually covered with brass, and the pipe it passes through is lined with strips of wood, usually *lignum vitæ.* This method, which was introduced by Mr. Penn, is represented in *fig.* 7, where A is a brass bush or covering which surrounds the shaft B, and which revolves with it. The cross section of the staves, or slips of wood surrounding A, with an intervening fillet of metal to steady the wood, is shown in the cut; and the lubrication is accomplished by the water which leaks through. For the eyes of feathering paddle wheels, wooden bushes are also sometimes employed; and generally each bush is formed by turning and boring out a solid piece of wood, but it is found that bushes put in in staves answer as well. Heretofore *lignum vitæ* was the wood generally used for these bushes. But it has now been found that African oak answers as well. The pins of the paddle wheels should always be covered with brass when wood is used: as the surface of iron becomes rough by corrosion, and then soon rasps the wood away. In sandy rivers wooden bushes do not last well, but are soon ground away;

Fig. 7.



SCREW SHAFT BEARINGS; TRANSVERSE SECTION OF SHAFT AND PIPE AT STERN.

and in such cases steel bushes welded into the eyes and hardened, and fitted with hardened steel pins, are found to be the best arrangement. In sea-going steamers brass bushes and brass-covered pins are found to work very satisfactorily, and to wear well when the rubbing surface is made large.

ACTUAL AND NOMINAL HORSES' POWER.

The actual and nominal power of engines—at first identical or nearly so—soon began to diverge; and in time, as the pressure of the steam was increased, the actual power of an engine became twice greater than it had been at first, while the nominal power, being an expression of the dimensions of the engine, remained the same. The divergence, however, did not stop here, but has gone on increasing, until in recent engines the actual power exerted has been in some cases *nine times* greater than is represented by the nominal power. In other words, an engine of 200 horse-power nominal has been proportioned to exert as much as 1800 actual horses' power. The uncertainty and varying character of the ratio subsisting between the actual and nominal power is a source of much perplexity; and proposals have been made in consequence to substitute some other unit for the horse-power. But the proper course would be to retain the nominal power as a unit, but to define this unit to be a square yard or a square metre of heating surface of the boiler, instead of a given capacity of cylinder. As the boiler is the measure of the power actually exerted by an engine, this method of reckoning the nominal power would preserve a more uniform ratio between the actual and nominal power than the present mode of reckoning.

The rule at present followed for determining the nominal power of an engine was first given by myself in my Treatise on the Steam Engine in 1844. The rule called the Admiralty rule is the rule of the late Mr. Barnes, who gave it to me in 1844, and was given by me to Mr. Lawrie, who made a slight change in it and subsequently communicated it to the Admiralty, by whom it was adopted. Mr. Barnes' rule was $\frac{(d-1)^2 v}{5640}$, where d was the diameter of the cylinder in inches, and v the velocity of the piston in feet per minute: and 1 inch was subtracted from the diameter of the cylinder, as a compensation for the friction. Mr. Lawrie discarded this allowance for the friction; and the rule then became $\frac{d^2 v}{6000}$, which is a simpler expression, but one which the Admiralty had no part in originating, as it was quite new to them when Mr. Lawrie communicated it. The rule given by me for the nominal power of land and paddle engines is $\frac{d^2 \sqrt[3]{s}}{47}$, where d is the diameter of the cylinder in inches, and s the stroke in feet; and the same rule is applicable to direct-acting screw engines by taking a different divisor. A proper divisor in the case of those engines would be 23·5, which will make the nominal power of a direct-acting screw engine exactly double that of a land or paddle engine of the same size; and this rule, while sufficiently exact for practical purposes, will occasion the least amount of disturbance in the existing rules and tables for ascertaining the nominal power, as the power will just be the double of that which the existing low-speed rules and tables give.

In the average class of modern engines the actual power may be taken at 4 to 4½ times the nominal power. But in some cases it is the double of this, and rises to 8 or 9 times the nominal power. The pressure of steam and actual and nominal power of some of the modern vessels in the navy is shown in the following table:—

POWER AND PERFORMANCE OF NAVY STEAMERS.

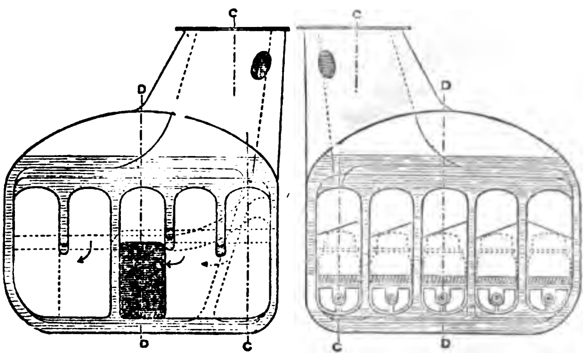
Name of Vessel.	Tonnage.	Displacement in tons when tried.	Speed in knots.	Date of trial.	Pressure in boiler per sq. in. in lbs.	Nominal power.	Actual power.	Name of Constructor of Engines.
Adventure	1793	2432	11·447	1862	12	400	1227	Ravenhill & Co.
Albion	3111	2912	10·986	1862	24	400	1835	Humphrys & Co.
Arethusa	3142	2801	12·695	1862	25	500	2871	Penn & Son.
Barossa	1702	2301	11·514	1862	20	400	1616	Boulton & Watt.
Black Prince	6039	9300	13·604	1861	25	1250	5772	Penn & Son.
Collingwood	2611	2573	10·460	1862	20	400	1424	Rennie & Sons.
Conqueror	1845	4300	9·934	1863	20	500	2018	Ravenhill & Co.
Constance	3212	2781	12·301	1863	32½	500	2020	Randolph & Co.
Defence	3720	5971	11·618	1862	20	600	2537	Penn & Son.
Defiance	3475	3958	11·884	1862	23½	800	3550	Maudslay & Sons.
Duncan	3716	4000	13·236	1861	20	800	3428	Penn & Son.
Emerald	2913	3503	12·003	1863	22	600	2323	Ravenhill & Co.
Euryalus	2371	3125	10·038	1861	20	400	1262	Penn & Son.
Galatea	3227	4270	13·004	1862	22½	800	3517	Penn & Son.
Gibraltar	3716	5545	11·538	1862	22	800	3494	Maudslay & Sons.
Glasgow	3037	2930	13·102	1862	20	600	2457	Ravenhill & Co.
Leander	2760	2547	11·737	1861	20	400	1728	Boulton & Watt.
Liffey	2654	3891	11·097	1862	20	600	1905	Penn & Son.
Liverpool	2656	2914	12·665	1861	20	600	2551	Humphrys & Co.
Meanee	2591	3551	9·701	1862	20	400	1456	Penn & Son.
Octavia	3161	2921	12·252	1861	20	500	2265	Maudslay & Sons.
Orontes	2823	3400	12·622	1863	25	500	2249	Boulton & Watt.
Prince Consort	4045	6430	13·119	1863	22	1000	4234	Maudslay & Sons.
Princess Royal	3129	4270	9·934	1863	20	400	1499	Maudslay & Sons.
Resistance	3710	4827	12·332	1862	20	600	2615	Penn & Son.
Revenge	3318	5531	11·176	1862	20	800	2890	Maudslay & Sons.
Royal Oak	4055	6416	12·529	1863	22	800	3704	Maudslay & Sons.
Shannon	2651	3612	11·550	1862	20	600	2023	Penn & Son.
Sutlej	3065	3826	11·087	1862	22	500	2270	Maudslay & Sons
Undaunted	3039	2694	12·925	1861	20	600	2503	Ravenhill & Co.
Warrior	6039	8852	14·356	1861	22	1250	5469	Penn & Son.

MODERN FORMS OF BOILERS.

Boilers are divisible into three main classes, land boilers, marine boilers, and locomotive boilers, and of each class there are many varieties. The old waggon boiler is now almost extinct, and there is no generally accredited species of land boiler which has taken its place. On the whole, land boilers are approximating in construction to marine boilers.

In the earlier times of steam navigation the boilers employed were invariably flue boilers. It is very

Fig. 8. *Fig.* 9.

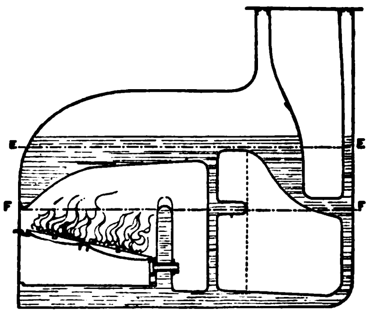


BOILERS OF STEAMERS ASIA AND AFRICA, BY R. NAPIER AND SON.

Transverse Section at A A, fig. 11. Transverse Section at B B, fig. 11.

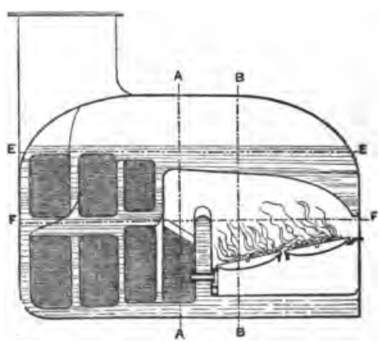
doubtful whether the efficacy of that class of boiler has yet been exceeded, and in some steam vessels of the highest efficiency flue boilers are still retained. *Figs.* 8 and 9 are transverse sections of the flue boilers of the mail steamers Asia and Africa, and *figs.* 10 and 11 are longitudinal sections of the same

Fig. 10.



Boilers of Steamers Asia and Africa.
Longitudinal Section through C C, fig. 8.

Fig. 11.



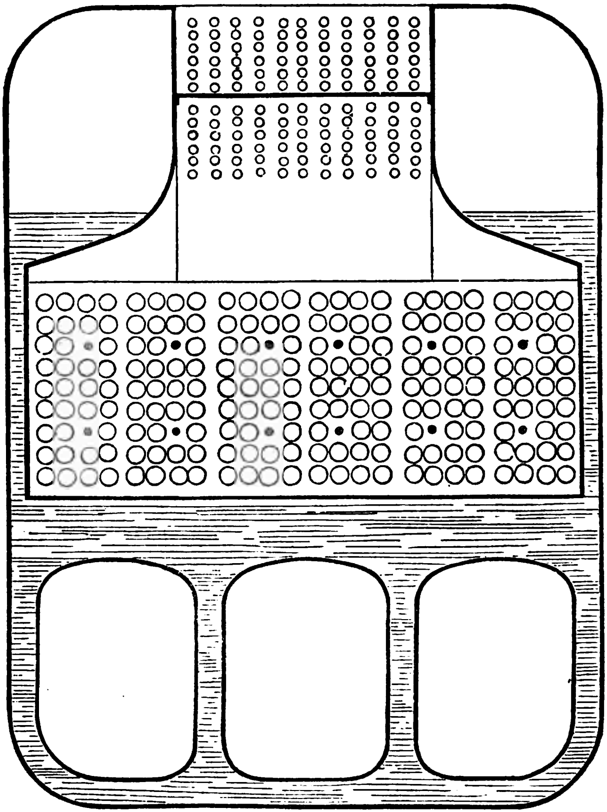
Boilers of Steamers Asia and Africa.
Longitudinal Section through D D, fig. 8.

boilers. Boilers of a similar construction to these have been in use in other vessels on the same line for the long period of 14 years.

The ordinary form of boiler now employed for marine purposes is the tubular boiler; and the features of the arrangement have not varied much since the first introduction of the tubular system in 1844. An example of this species of boiler is given in *fig.* 12, which is a representation of an ordinary marine tubular boiler with Beardmore's superheater introduced in the uptake. The flame and smoke after passing over a brick bridge at the end of the furnace returns through the tubes to the front of the boiler; and the smoke then passes up the chimney, but on its way thither encounters the horizontal tubes of the superheater. In this superheater there are two sets of tubes, separated by a diaphragm; and the steam passes back through one set of tubes, and forward through the other, so that it traverses a distance equal to twice the length of the superheater.

The best forms of tubular boiler do not differ materially from that constructed by me in 1838; and with the increasing pressures which are now used, it is inevitable that the rectangular shell at present employed should be discarded. The boilers introduced by Messrs. Penn in the Hydra are represented in *figs.* 13 and 14; and these boilers have the advantage of a cylindrical shell, and may be worked with safety to a pressure of 40 lbs. on the square inch. But the furnaces are too small; and cylindrical furnaces are very inconvenient for enabling a proper slope to be given to the fire-bars, as the width of the

Fig. 12.

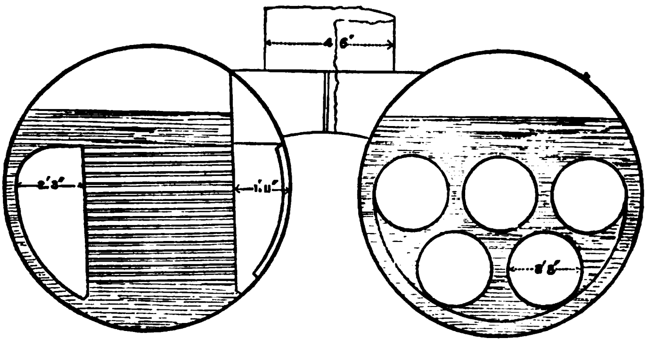


BEARDMORE'S SUPERHEATING APPARATUS.

Transverse Section.

bars at the back end is necessarily contracted; and the bars must either be made taper, or taper pieces must be cast to fill the vacuities at the front.

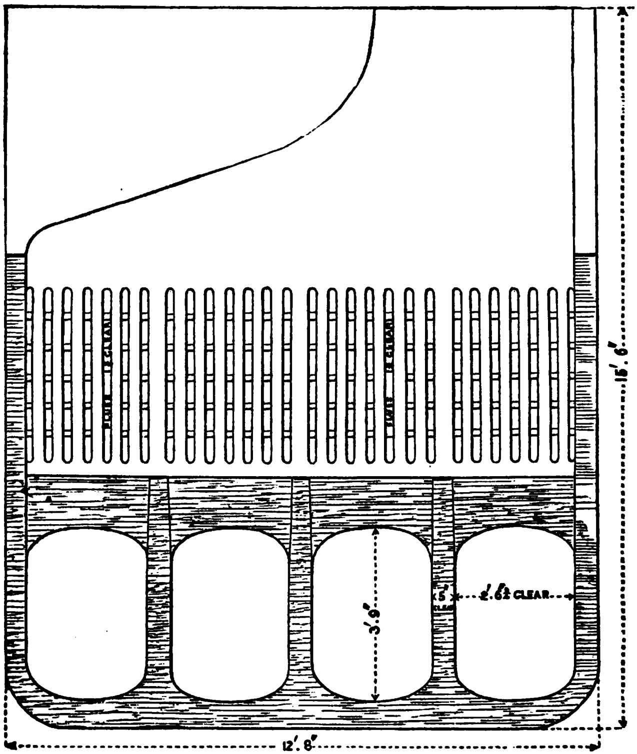
Fig. 13. *Fig.* 14.



BOILERS OF H.M.S. HYDRA, BY MESSRS. JOHN PENN AND SON.
Transverse Section, showing Tubes. Transverse Section through Furnaces.

The species of water-space boiler known as Lamb and Summers' boiler has now been widely introduced, and has this special feature of advantage, that it enables a rapid circulation of the water to take place. This boiler is shown in *fig.* 15, which is a transverse section of the boilers of the steamer Ripon. In this boiler the smoke, instead of being returned through small cylindrical tubes, is returned through a row of very narrow flat-sided flues; and in order to prevent these flat surfaces from being forced together by the pressure of the steam, they are strutted asunder by short struts, so that in the interior of the boiler, the whole heating surface of these flues is clear of stays or other obstructions.

Fig. 15.



BOILERS OF STEAMER RIPON ON LAMB AND SUMMERS' PLAN.
Transverse Section.

The same benefit of an effectual circulation that is obtainable in Lamb and Summers' boiler is also obtained in the boiler with upright tubes invented by

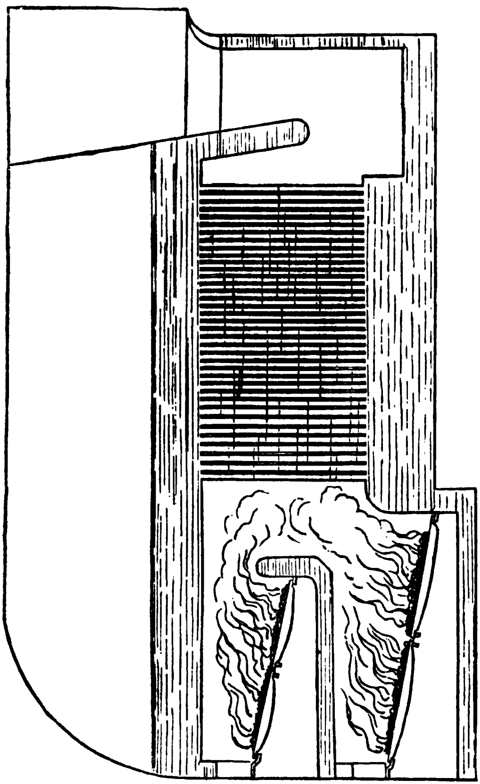


Fig. 16.

BOILERS OF COLLINS' LINE OF ATLANTIC STEAMERS, WITH DOUBLE-FURNACES AND UPRIGHT TUBES.
Longitudinal Section.

that remarkable genius the late Earl of Dundonald, and of which an example is given in *fig.* 16, which is a longitudinal section of one of the boilers of the steamer Atlantic. Boilers on this principle are not much used in this country, except in the case of the hay-stack boilers invented by Mr. David Napier, and which are very generally employed in the river steamers plying on the Clyde. In these boilers upright tubes, with the water within them, are also employed.

The importance of maintaining a rapid circulation in the water of the boiler is not yet sufficiently recognised. Not only will a rapid circulation add to the durability of the boiler by preventing the plates from being overheated, but it will materially increase the efficiency of the heating surface; and in the boilers of the Atlantic, it was found that by inserting a short piece of tube in the mouth of each upright pipe, whereby the length and consequently the velocity of the ascending column was increased, a sensible advantage was gained in the performance of the boiler. In many tubular boilers the tubes are set so closely together, that the circulation of the water amongst them is greatly impeded; and it has in consequence been found, that the evaporative power of such boilers has been increased by removing some of the tubes altogether—the loss of a part of the heating surface being more than compensated by the increased efficacy of the rest.

PROPORTIONS OF BOILERS.

The proportions of boilers per nominal horse-power are affected by two considerations—the first, what ratio it is intended shall subsist between the actual and nominal power; and the second, what amount of surface shall be allowed for the evaporation of a cubic foot of water in the hour. The greater the excess of the actual over the nominal power, and the less the expansion, the larger manifestly must be the surface per nominal horse power; and in proportioning boilers of every class the main thing to be had regard to is the number of cubic feet of water required to be evaporated in the hour. But in different classes of boilers very different quantities of surface are required to evaporate a cubic foot per hour. Thus in Smeaton's boilers a cubic foot was evaporated per hour with 5 square feet of heating surface, in Watt's land boilers with 9 or 10 square feet, in locomotive boilers a common proportion is 5 or 6 square feet, and in Cornish boilers 70 square feet; and those boilers which have the most heating surface per cubic foot evaporated are the most economical in coal. Thus in Smeaton's boilers, a hundredweight of coal evaporated 14·11 cubic feet of water; in Watt's boilers about the same; in locomotive boilers from 11 to 12 cubic feet, and in Cornish boilers about 19 cubic feet. The election therefore has to be made between a large amount of heating surface per nominal horse power, and a somewhat increased consumption of coal. A given amount of heating surface however will be made more effectual, if a high temperature be maintained in the furnace, and if the circulation of the water within the boiler is rapid and unimpeded; and at all times the evaporative efficacy of the boiler will be much increased by quickening the draught either by a blast pipe in the chimney or otherwise; but as somewhat more of the heat will in such case go up the chimney, there will be a somewhat increased consumption of coal.

The proportions of marine tubular boilers, as subsisting from 1844 to 1854, are exhibited in the following table:—

PROPORTIONS OF MARINE TUBULAR BOILERS.

By Boulton, Watt, & Co., 1844.

The actual power is here supposed to be 2½ times the nominal, and the steam to be of 10 lbs. pressure per square inch, and to be cut off at two-thirds of the stroke.

Areas and Contents.	Proportion per nominal Horse Power.	Proportion per actual Horse Power, 17½ lbs. on Piston.	Proportion per cubic foot of Water evaporated.
Heating surface of tubes in sq. ft.	10·25	4·10	7·25
Heating surface of plates in sq. ft.	2·75	1·10	1·75
Total heating surface in sq. ft.	13.00	5·20	9 00
Area of grate in sq. ft.	0·70	0·28	0·50
Sectional area of tubes in sq. in.	13·00	5·20	9·00
Sectional area of furnace uptake in sq. in.	16·00	6·50	12·00
Sectional area of chimney uptake in sq. in.	14·00	5·60	10·05
Sectional area of chimney in sq. in.	8·50	3·40	6·00
Area of base of boiler in sq. ft.	1·083	0·433	0.780
Capacity of boiler proper in cub. ft.	9·25	3·75	6·50
Capacity of steam-chest in cub. ft.	2·00	0·75	1·50
Total capacity of boiler and steam-chest in cub. ft.	11·25	4·50	8·00
Ratio of diameter to length of tubes	1-23 to 1-30		
Ratio of area to length of tubes	1-12 to 1-15		

In modern boilers, by the same makers, the proportion of grate of heating surface and of sectional area of tubes and chimney to evaporate a cubic foot of water per hour remain much the same; but as the proportion of actual to nominal power has been much increased, the dimensions of the boiler per nominal horse power have been much increased. Thus in the steamer Scud, the engines of which were made by Boulton and Watt, the heating surface per nominal horse power is 28 feet, but that vessel works up to 8 or 8½ times the nominal power. In more recent engines the same makers have given as much as 35 square feet of heating surface per nominal horse power. But these are exceptional cases: the usual proportion they give is 21 square feet per nominal horse power. Taking the evaporation as the measure of the power of the boiler, their present proportions for evaporating a cubic foot in the hour are as follows:—

PROPORTIONS OF BOILER TO EVAPORATE A CUBIC FOOT OF WATER IN THE HOUR. 1865.

Total heating surface of tubes and plates	10	square feet.
Grate surface	70	square inches.
Sectional area of tubes	10	„
Sectional area of back uptake	15	„
Sectional area of front uptake	12	„
Sectional area of chimney	6½ to 7	„

The quantity of water required to be evaporated to produce an actual horse power, depends of course upon the rate of expansion. Boulton and Watt usually put sufficient lap upon the valves to cut the steam off at half stroke, and then by the aid of the link, they are able to cut off at ⅓ of the stroke if required.

The particulars of the proportions and performance of the boilers of a number of modern steam vessels, as also the proportion of condensing surface per nominal horse power in the tubes of the condenser and other material facts, are recorded in the following table:—

PERFORMANCE OF VARIOUS SHIPS OF RECENT CONSTRUCTION BELONGING TO THE PENINSULAR AND ORIENTAL STEAM NAVIGATION COMPANY.

	Sultan.	Poonah.	Delhi.	Carnatic.	Baroda.	Moolton.	Ripon.	Syria.
Tonnage, gross	1124 tons	2152 tons	1898 tons	1775 tons	1874 tons	2257 tons	1908 tons	1932 tons
Horse power, nominal	210	500	400	400	400	400	450	450
Diameter of cylinders	44½ in.	102 & 48	90 & 43	96 & 43	96 & 43	96 & 43	76	76
Length of stroke in feet	4·0	3·3	3·0	3·0	3·0	3·0	7·0	7·0
Consumption of coal per voyage	515 tons	825 tons	988 tons	687 tons	758 tons	817 tons	930 tons	1089 tons
Consumption per I. H. P.	2 991 lbs.	2·39 lbs.	3·146 lbs.	2·340 lbs.	2·593 lbs.	2·52 lbs.	2 69 lbs.	3 121 lbs.
Indicated H. P. (mean at sea)	610	1335	1300	1250	1276	1200	1290	1300
Mean speed	9·5	10·38	11·09	11 4	11·7	9·92	10·0	10·0
Condensing surface per H. P., nominal	10·7	10·9	12·5	11·2	11·2	10·6	13·6	10·2
How expansion effected, whether by link or by separate valve	link	double cylinders	double cylinders	double cylinders	do uble cylinders	double cylinders	separate valves	separate valves
Whether any trouble experienced in lubricating pistons	none	the usual	none	the usual	the usual	none	none	none
Whether steam jackets or felting used	felting and wood	steam jackets	steam jackets	steam jackets	steam jackets	steam jackets	steam jackets	steam jackets
Whether much trouble is now experienced with valve faces	none	not much	none	none	not much	none	none	none
Heating surface per H. P., nominal	19·7 sq. ft	12·5 sq. ft	15·5 sq. ft.	12·0 sq. ft.	12·0 sq. ft.	12·0 sq. ft.	18·0 sq. ft.	18·0 sq. ft,
Grate surface per H. P., nominal	·62	·45	·56	·45	·45	·45	·54	·54
Area of flues per H. P., nominal	28 sq. in	17sq. in.	21 sq. in.	17 sq. in.	17 sq. in.	17 sq. in.	23 sq. in.	23 sq. in.
" " chimney " "	17	11	13	11	11	11	15	15
On trial trip—								
Ratio of, indicated to nominal H. P.	1 : 4·1	1 : 4·5	1 : 5·7	1 : 6·1	1 : 6·2	1 : 4·3	1 : 4·4	1 : 5·7
Pressure of steam	18 lbs.	25 lbs.	25 lbs.	26¼ lbs.	27½ lbs.	28 lbs.	24 lbs.	27½ lbs.
Temperature of ditto	290° in slide jackets	280° in slide jackets	300° in slide jackets	300° in slide jackets	360° in slide jackets	350° in slide jackets	300° in steam pipes	322° in steam pipes

SMOKE BURNING.

Notwithstanding the number of smoke-burning furnaces which have at different times been introduced, it cannot be said that any plan has yet been contrived which so far satisfies the conditions of the problem as to command general recognition of its eligibility, or to lead to its general adoption. These plans operate either on the principle of admitting air above the fuel to burn the smoke—which has the radical defect that the production of smoke in ordinary furnaces is variable, whereas the admission of air is constant, so that either too much or too little will generally enter—or on the principle of passing the smoke over the incandescent fuel, or through red-hot pipes or fire-brick passages—which though it will diminish the smoke, will rarely wholly prevent it; while the apparatus required is generally cumbrous. A proper smoke-burning furnace should obviate the smoke effectually; and it should be of simple construction, and be exempt from the objection of admitting too much or too little air to burn the smoke. In steam vessels it is most desirable that some proper species of firing apparatus should be employed; as the labour and difficulty of firing large furnaces at sea, especially in hot climates, is very great.

In 1838 I took out a patent for a smokeless furnace; and I then originated the doctrine—since so generally accepted—that instead of seeking to *burn* smoke, the proper course was to *hinder its formation.* In 1839 I introduced smokeless furnaces into different steamers, in which the arrangements had to vary to suit existing boilers; and in some cases I caused the smoke to pass over the incandescent fuel, in other cases to pass through heated fire-tile channels, and in other cases again two adjacent furnaces were fired alternately, and the smoke from the one passed through the glowing embers of the other. All these expedients, however, are imperfect; and no species of smokeless furnace has yet been contrived of such conspicuous eligibility, as to ensure its general adoption. I believe that a good smokeless furnace and a good self-feeding furnace will come together; and I also believe that the realisation of this desideratum is not very far off.

ON THE RESISTANCE OF SHIPS.

The doctrine first promulgated in my Catechism of the Steam Engine, that in well-formed steam vessels of the common type nearly the whole of the resistance is occasioned by the friction of the water upon the bottom of the vessel, instead of being mainly produced by the act of separating the water at the bow and closing it at the stern, as was the previous doctrine—is now receiving general recognition; and computations based on that supposition are found to accord very closely with the results obtained by experience. I was led to this conclusion from having to design some steamers in 1853, which I was desirous should possess the maximum speed with the minimum power, and I therefore constructed them on the pendulum lines recommended in the Catechism of the Steam Engine, as the most eligible for this purpose. I found the vessels when constructed and tried perfectly to fulfil my expectation of passing through the water with the minimum of disturbance, and there was no wave produced at the bow, or at any other part. Nevertheless, I did not find the speed to be sensibly superior to that of other vessels of ordinary good shape, and of similar size and power; and as in my vessels nearly the whole resistance was certainly that of friction, and as the total resistance was nearly the same as that of common vessels, there was no escape from the conclusion, that in ordinary sharp vessels nearly the whole resistance is also that of friction. This discovery points to the supreme importance of endeavouring to reduce the friction of the bottom; and it is found by recent experiments made in France, that the friction will be a good deal influenced by the nature of the coating* which the bottom receives. There is a great need for improvement here; whereas very little improvement is to be expected from altering the shape of the steamers we at present employ. We must of course draw them out to greater length, as we require higher speeds, and introduce more power; and contract them to shorter lengths as we are satisfied with the lower speeds proper to less power. But this elongation or contraction is merely a question of putting up the frames nearer together or further apart, and does not affect the shape, but only the proportion of length to breadth. The proper shape for a ship may be

* This topic is treated of more fully in my 'Hand-Book of the Steam Engine.'

expressed by an equation, only there will be a certain proportion of length to breadth, which will be suitable for each particular speed, or, in other words, the proper length will be a function of the intended speed; so that if we wish to double the speed, we ought also to double the length.

The friction of ships has been sought to be measured by the friction of water running in pipes and canals. But the friction per square foot of a ship is much less than the friction of a square foot of pipe or canal when the water and the ship are moving at equal velocities. The velocity of water in a pipe is usually measured by the discharge. But the discharge measures only the *mean* velocity, whereas it is the *maximum* velocity which is alone comparable with that of a ship. Moreover there is every reason to believe, that the friction of a ship per square foot is not the same at all parts, but will be more at the bow and less at the stern. The friction of the bottom and sides puts in motion a film of water of increasing thickness, and also of increasing velocity, which moves with the ship; and as the stern part is immersed in this moving water, the friction upon it is not so great as it would otherwise be. Screw propellers placed at the stern utilise a portion of this moving column by working in it; for the operation of this column is to diminish the visible slip, which is consequently less than would be the case if the screw were placed at the bow; and in some cases, indeed, there is not only no visible slip in the screw, but the visible slip is negative, or, in other words, the vessel travels faster than the screw

DOUBLE SCREWS.

A screw placed in each quarter is now often employed instead of a screw situated at the stern; and in my Treatise on the Screw Propeller, published in 1852, I strongly recommended that method of construction. Two screws have these advantages over one: they enable the necessary propelling area to be obtained at a greater depth in the water; and I long since explained—what Mr. Rennie's experiments have since demonstrated—that the resistance which the water would offer to the screw would depend mainly on the depth of its immersion, since the displacement will always be in the line of least resistance which is to the surface, and the resistance or grip will vary as the depth. Then two screws enable the ship to be easily manœuvred, if they are driven by separate engines; and finally the vessel is not wholly disabled, but will still have sufficient propelling efficacy to proceed on her voyage, even if one screw or screw-shaft should happen to break. These considerations render it probable, that two screws will obtain a preference over one; and each screw may be driven by a single horizontal balanced engine of the kind introduced by me in 1852, and which has been ever since at work in various vessels constructed by me about that time. This species of engine is described in the Catechism of the Steam Engine, p. 433.

VARIOUS FORMS OF SCREW.

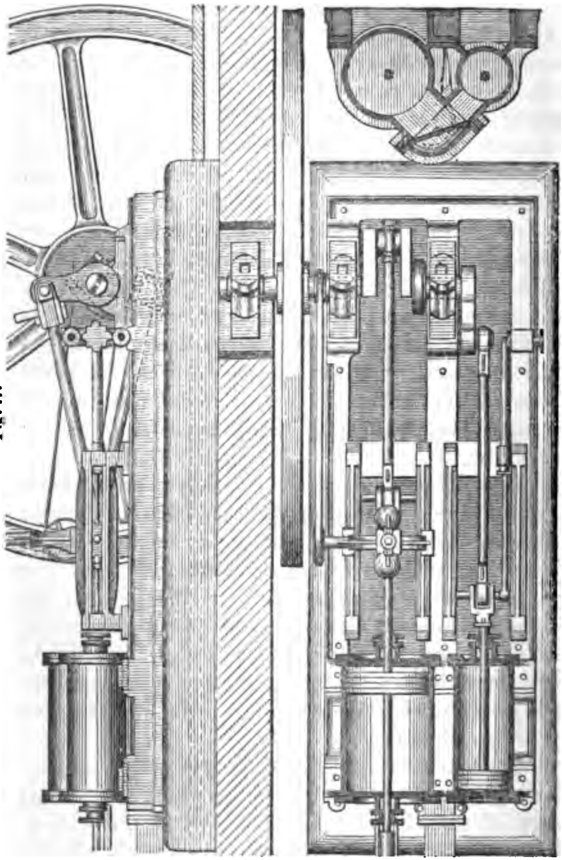
Notwithstanding the vast number of different kinds of screws which have been tried and proposed since the first introduction of screw vessels, there does not appear to be any better screw yet contrived than Smith's original screw with uniform pitch, as fitted in the Rattler. For merchant vessels three blades are preferable to two. But in the case of war vessels made with lifting screws, more than two blades cannot be employed. Lifting screws, however, appear likely to go out of use altogether. The gear they involve is a source of expense and complication, and is liable to shake loose in time and give trouble; while the benefit of the arrangement is very small. Steam vessels will almost always use steam; and for those rare occasions when it is wished to impel them by sails without steam, the resistance presented by the screw will not be great, if it be suffered to revolve like a great patent log, the function of which it may also be made to fulfil in measuring the speed of the vessel.

LAND ENGINES.

Single and Double Cylinder Engines compared. One of the most interesting illustrations of the comparative merits of the single and double cylinder engine, is afforded by the simultaneous erection of certain engines of each class and of the same power at the New River Waterworks in London. Both classes of engines are rotative engines, and they employ the same pressure of steam. The single cylinder engines which were constructed by Messrs. Boulton & Watt, have cylinders 60 inches diameter and 8 feet stroke. The double cylinder engines which were constructed by Messrs. Simpson & Co., have low-pressure cylinders of 46 inches diameter and 8 feet stroke, and high-pressure cylinders of 28 inches diameter and 5 feet 6⅜ths stroke. The pumps are the same in each case, being the combined piston and plunger pump invented by Mr. David Thomson, and first introduced by Messrs. Simpson in the Richmond Waterworks in 1848. The pressure of the steam in the boiler is 38 lbs. per square inch, and about 8 lbs. less than this in the cylinder at the commencement of the stroke. The pump lifts the water 127 feet, and the friction is about 33 feet. The performance of these two classes of engines is as nearly as possible the same, being about 87 millions of pounds raised one foot high by the consumption of a bushel or 94 lbs. of Welsh coals. This is equivalent to 1·9 or rather less than 2 lbs. per actual horse-power per hour.

Balanced Double Cylinder Engine. An example of this species of engine as made by Messrs. Carrett, Marshall & Co. of Leeds is exhibited in *fig.* 17. In this engine the cylinders are horizontal and the cranks are nearly opposite to one another, so that the pistons move in opposite directions, thereby balancing their own momentum while a very direct passage is at the same time afforded for the steam escaping from the high-pressure cylinder to enter the low-pressure one. The air pump is double acting, and for very high speeds is set vertically at the end of the engine, and is wrought by levers so proportioned, that the stroke of the air pump is half that of the piston. Messrs. Carrett & Co. consider that this engine

Fig. 17.



Carrett, Marshall and Co.'s Balanced Double Cylinder Engine.
Elevation Ground Plan and Transverse Section.

may be worked up to 600 feet per minute,* which may probably be done without inconvenience if the parts and passages are made sufficiently large, and if the bearings, piston-slides, and all the rubbing parts are made of sufficient area, and are well lubricated. In very fast moving engines it would be proper to have a small oil pump which would send an excess of oil to all the bearings, and this excess should on overflowing be returned into a small cistern or recess in the bed plate into which the oil pump would dip. A very effectual lubrication would thus be attained with certainty, without trouble, and without waste of oil; and the oil would not merely lubricate, but would *cool* the bearings, the heating of which at all speeds would thus be prevented.

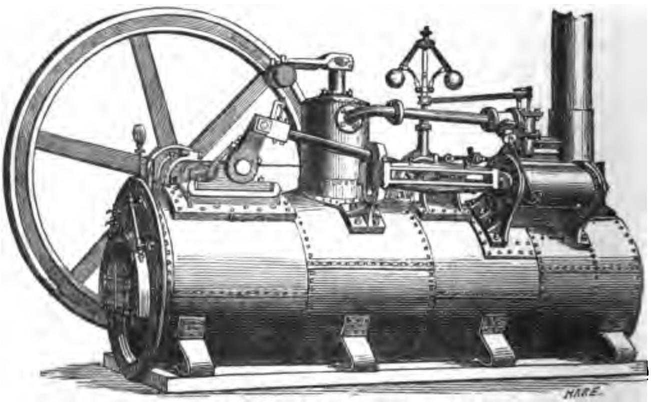
Engine and Boiler combined. A form of engine and boiler convenient for many purposes is shown in *fig.* 18, which is an elevation of a 20-horse engine set on the top of a tubular boiler constructed by Messrs. Carrett, Marshall & Co. of Leeds. This species of engine and boiler is easily removable, and may be set down anywhere without the necessity of foundations or any species of bricklayer's work. If it is thought desirable at any time to double the power, this may be done by setting another engine and boiler alongside the first, and connecting the two by a shaft; and one flywheel will suffice for both engines.

Another form of engine and boiler constructed by

* In 1854 I constructed a balanced marine with cylinder 42 inches diameter and 42 inches stroke, the piston of which worked at a speed of 700 feet per minute.

these makers is exhibited in *fig.* 19. Here it will be seen that both the engine and boiler are vertical, and as the engine is placed on top of the boiler, no foundations are required. The heating surface of this boiler is all formed of boiler plate, and consists of an internal fire box, water box, and uptake flue.

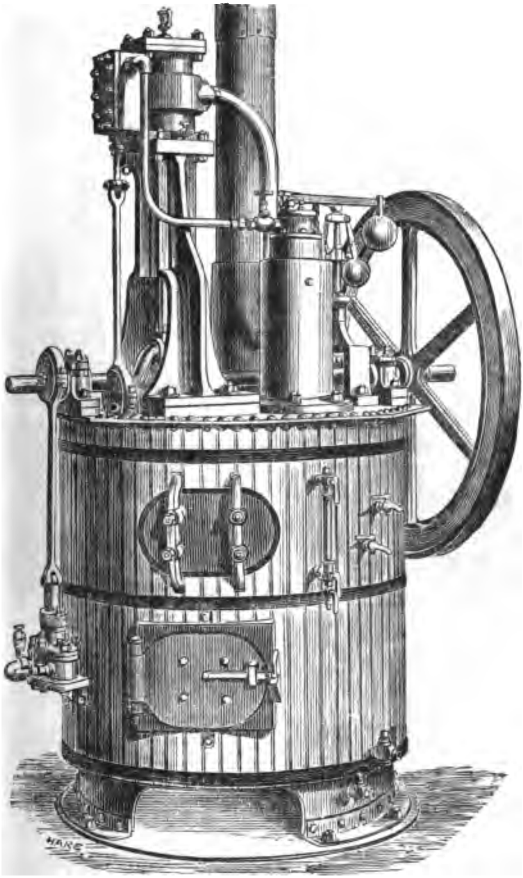
Fig. 18.



CARRETT, MARSHALL AND CO.'S COMBINED ENGINE AND BOILER.

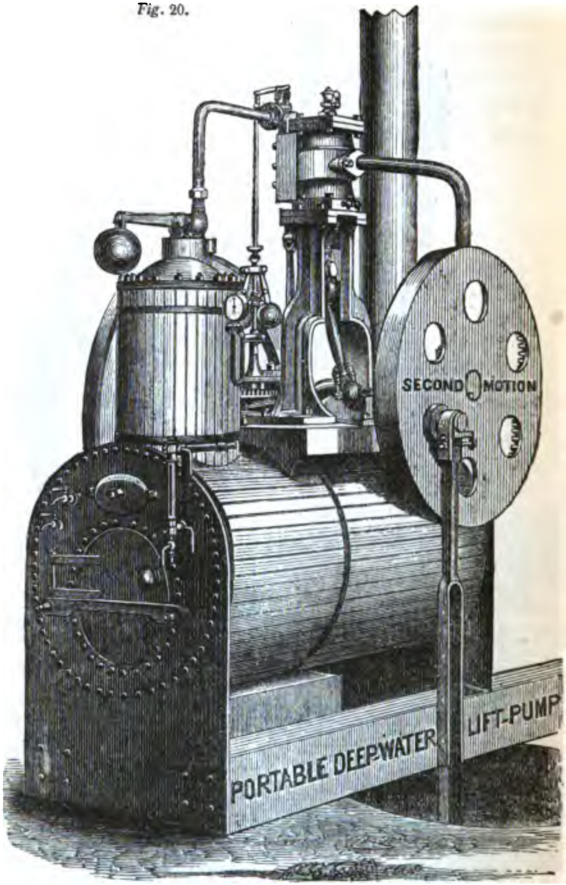
Another example of an engine set on a boiler and constructed by the same makers is shown in *fig.* 20, which is a form of engine applicable for pumping deep wells or mines. The boiler is set across the mouth of the well or shaft, and the pump is wrought off a pin in a plate or chuck fitted with internal gearing, to the end that the engine may move fast while the pump

Fig. 19.



VERTICAL ENGINE AND BOILER BY CARRETT, MARSHALL AND CO., LEEDS

Fig. 20.

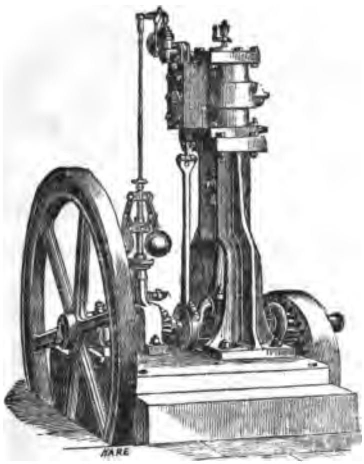


CARRETT, MARSHALL AND CO.'S PUMPING ENGINE AND BOILER.

moves slowly. This engine may also be used for irrigation.

Inverted Pumping Engine. An inverted pumping engine similar to the foregoing is shown in *fig.* 21; but here the boiler is removed, and the engine is set

Fig. 21.

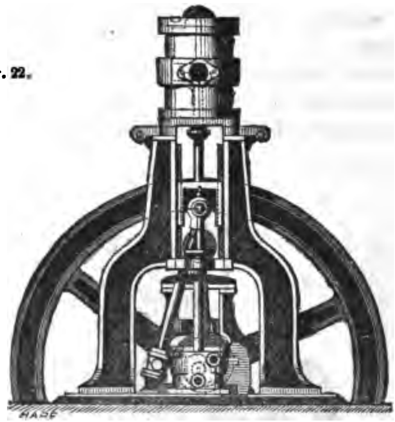


CARRETT, MARSHALL AND CO.'S FIXED PUMPING ENGINE FOR DEEP LIFTS.

on an appropriate foundation. The gearing whereby the fast engine drives the pump slowly is shown at the right in this drawing.

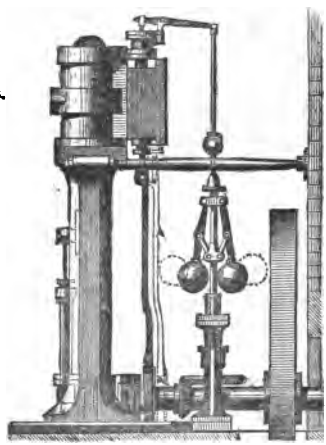
Inverted Factory Engines. *Figs.* 22 and 23 are representations of the inverted engine of the same makers suitable for general purposes. *fig.* 22 being a

Fig. 22.



CARRETT, MARSHALL AND CO.'S VERTICAL ENGINE. Front Elevation.

Fig. 23.



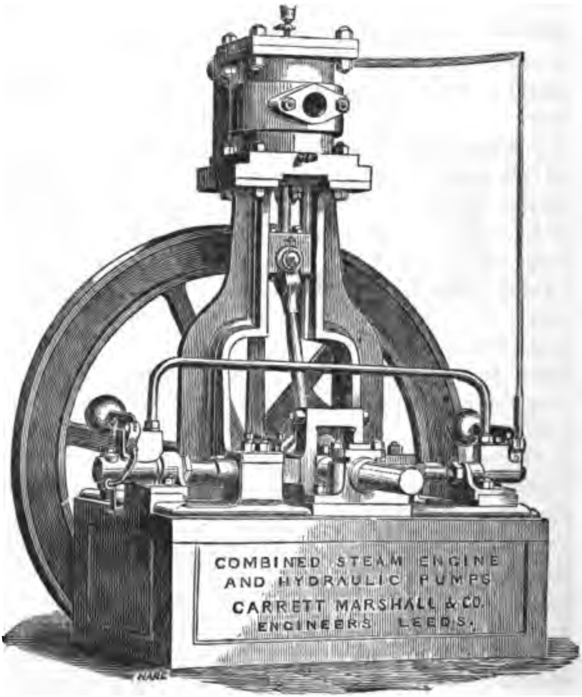
CARRETT, MARSHALL AND CO.'S VERTICAL ENGINE. Side Elevation.

front elevation, and *fig.* 23 a side elevation. In these engines the stuffing box in the bottom of the cylinder, through which the piston passes, is projected inwards above the cylinder bottom, so that there can be no dripping of water from the stuffing box, and if there is any leak it will be a leak of steam. The piston is suitably recessed to receive the projecting stuffing box.

Engine for working Hydraulic Pumps. A variety of this species of engine as applied to work hydraulic pumps for pressing bales, or for working any, other kind of hydraulic apparatus, is shown in *fig.* 24. There is a large and a small pump employed, and the large pump having created as much pressure as it can, feeds the small one. The arrangement is so contrived, that when the maximum pressure has been attained by the small pump, it stops the engine—thus obviating a waste of power by forcing the water through a loaded valve.

Ordinary direct acting Vertical Engine. In the vertical engine of Mr. Ferrabee of Stroud, the crank shaft lies across the top of an appropriate framing, with the cylinder beneath. This engine is represented in *fig.* 25, which is sufficiently illustrative to enable the material features of the engine to be readily apprehended. The engine is fitted with an expansion valve of the piston construction, and the amount of expansion is regulated by the governor which moves in or out, in an appropriate link motion, the point which moves the expansion valve; and the amount of its throw is correspondingly affected, and consequently the rate of the expansion. The feed water is heated by the waste steam, and the general design of the engine is very judicious.

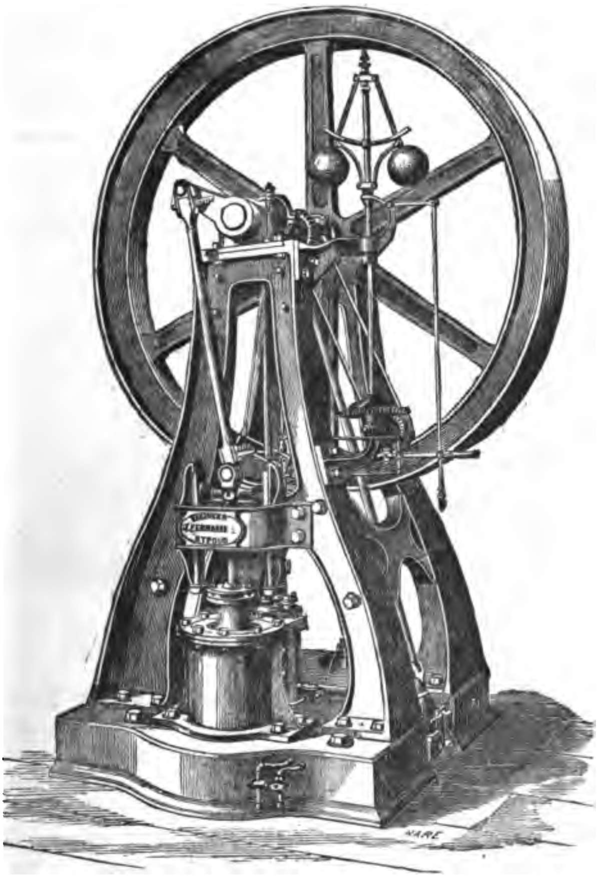
Fig. 24.



CARRETT, MARSHALL AND CO.'S COMBINED STEAM ENGINE AND HYDRAULIC PUMPS.

Fixed Horiz ntal Engine. The horizontal engine

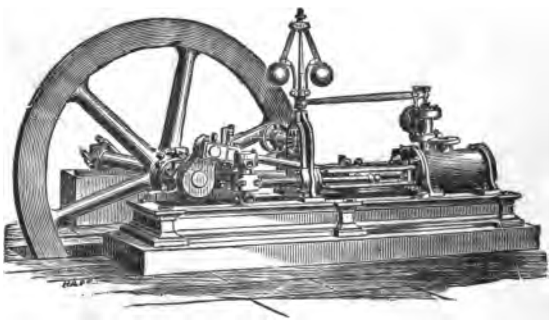
Fig. 25.



VERTICAL ENGINE BY FERRABEE OF STROUD.

of Messrs. Carrett, Marshall and Co. is shown in *fig.* 26, and this may be accepted as the common type of horizontal engine employed by most makers at the present time. The main features are a good strong bed-plate, to which the cylinder may be not merely bolted but also keyed against lugs, to obviate end play; and it is preferable to cast the shaft pillow-block upon the bed-plate rather than to bolt it on, for the sake of obtaining greater exemption from thrust or play.

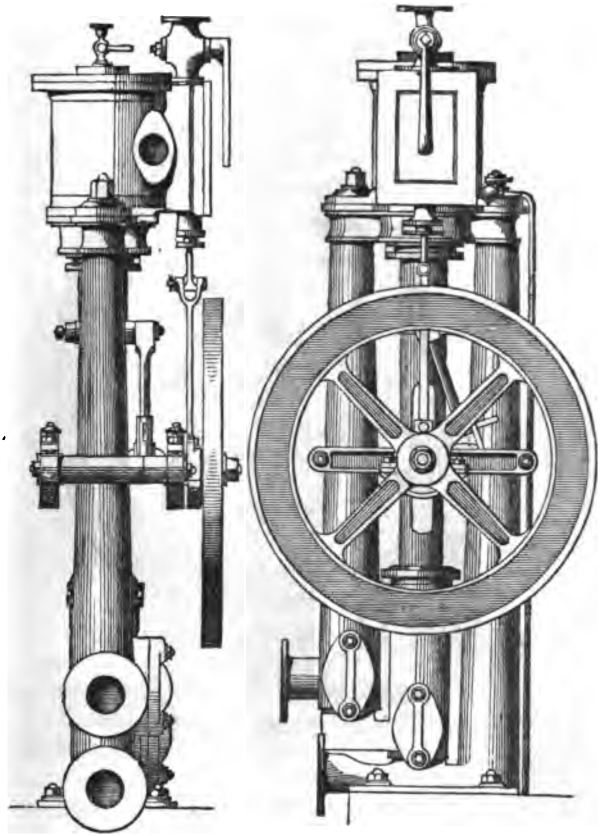
Fig. 26.



CARRETT, MARSHALL AND CO.'S HORIZONTAL ENGINE.

Donkey Engines. *Figs.* 27 and 28 represent Hawthorne's donkey engine for feeding boilers, and *figs.* 29 and 30 represent similar engines by Messrs. Carrett, Marshall & Co. They may be taken as common types of the Donkey engine; but Messrs. Hawthorne turn the fly-wheel by a connecting rod, whereas a frame with horizontal slot is more common.

Figs. 27 and 28.

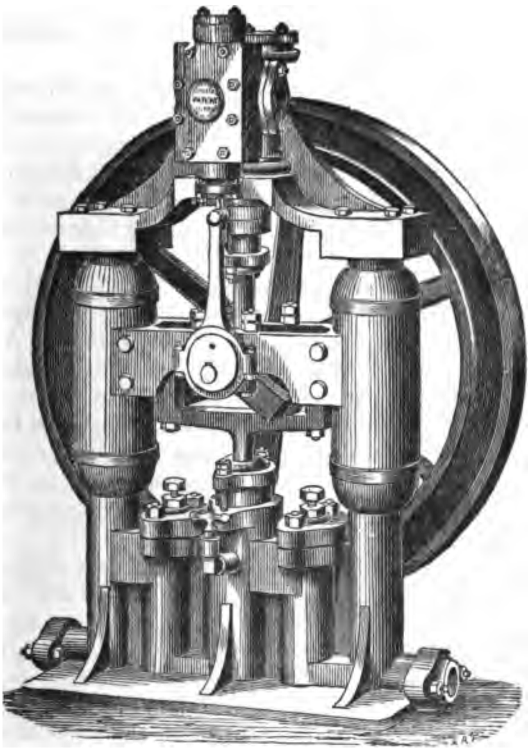


HAWTHORNE'S DONKEY ENGINE.
Front and Side Views.

Fig. 29.

Carrett, Marshall and Co.'s Steam Pump.

Fig. 30.



CARRETT, MARSHALL AND CO.'S DONKEY FEED ENGINE.

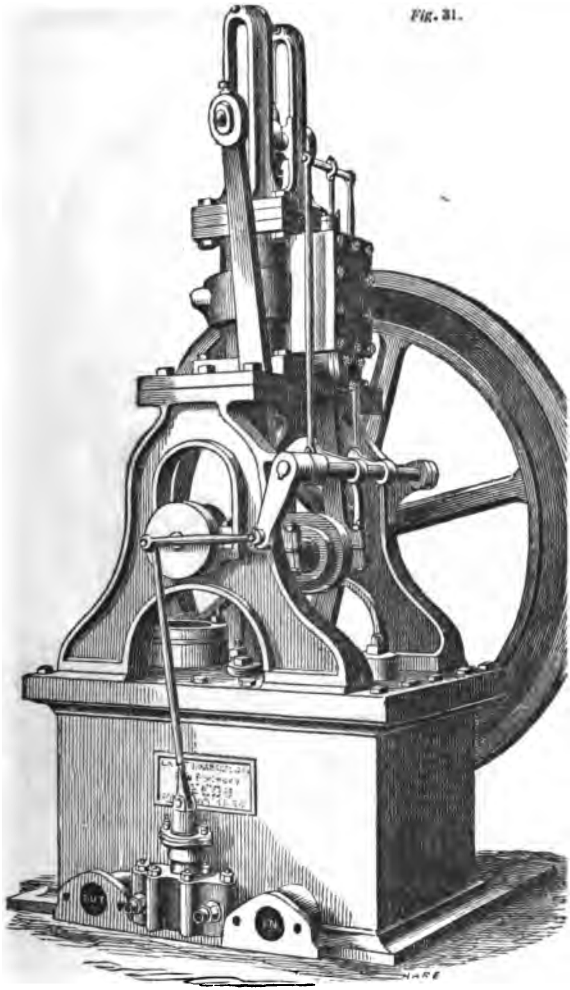
Fig. 31 represents a form of engine suitable for lifting water through moderate heights, and useful for feeding boilers, filling tanks, pumping water for irrigating, forcing liquid manure, and other similar purposes.

A useful form of water pressure engine which may be employed for blowing organs and for other domestic purposes is shown in *fig.* 32. These engines were first applied to such purposes by Mr. David Elder of Glasgow, who constructed a water pressure engine to blow the organ in Mr. Napier's house at Shandon on the Clyde.

Engines for high speed. Messrs. Carrett, Marshall & Co. employ engines to drive fans and centrifugal pumps direct without intermediate belting. An example of this combination is given in *fig.* 33, and it will be seen that the momentum of the piston is balanced by counterweights on the fly wheels, in the interior of the rims of which there are grooves into which fit corresponding projections on pulleys on the fan spindle, by the friction of which contact the fan is driven.

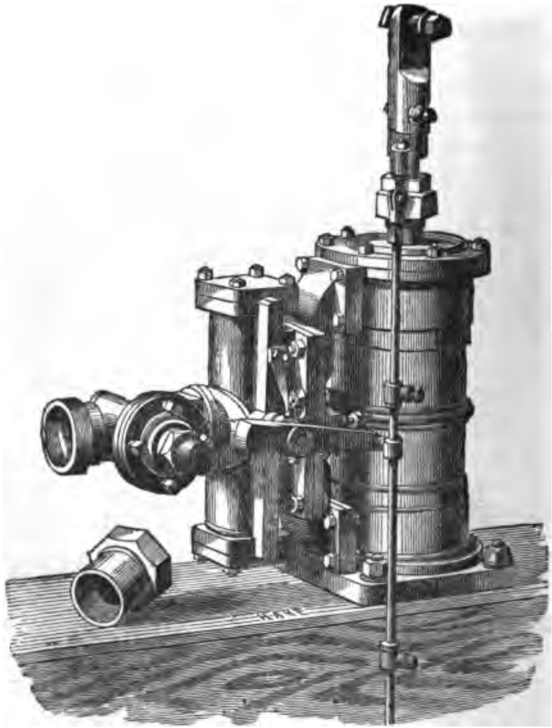
The best form of centrifugal pump is that of Appold with curved vanes, as represented in *fig.* 34. In 1851 pumps by Appold with straight vanes, with inclined vanes, and with curved vanes, were carefully tested, and it was found that the work done relatively to the power expended amounted with the pump with straight vanes to 24 per cent., with the pump with inclined vanes to 43 per cent., and with the pump with curved vanes—such as are shown in *fig.* 34, to 68 per cent. This pump has been much used in

Fig. 31.



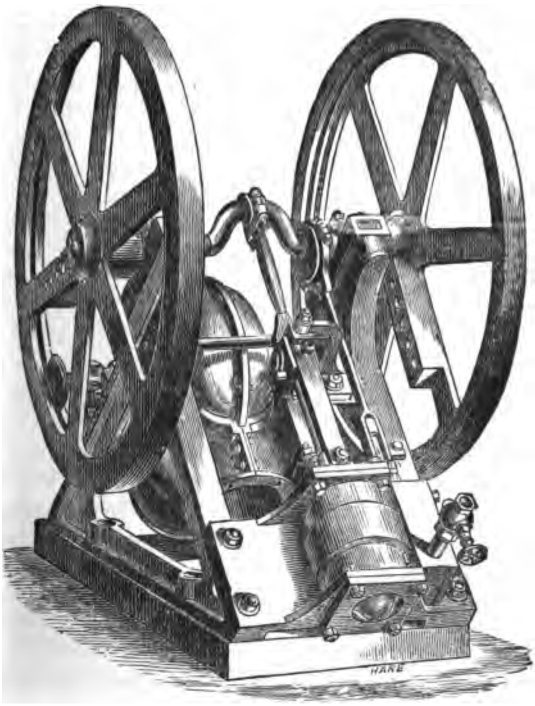
CARRETT, MARSHALL AND CO.'S WATER LIFTING ENGINE.

Fig. 22.



CARRETT, MARSHALL AND CO.'S WATER PRESSURE ENGINE.

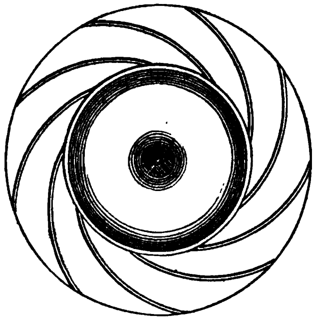
Fig. 33.



BALANCED VELOCIPEDE ENGINE BY CARRETT, MARSHALL AND CO.

raising water for irrigation, for draining land and foundations, for pumping out docks, and for various other purposes for which low lifts are required. But

Fig. 34.



APPOLD'S CENTRIFUGAL PUMP, BY EASTON, AMOS AND SON.

for some of these purposes the chain pump formed with square boards moving slowly in a wooden trunk appears to be fully as effective. The centrifugal pump is sometimes driven by toothed wheels, and sometimes by serrated surfaces of contact such as is shown in *fig.* 33, and which is known by the name of frictional gearing. But toothed wheels require to work so very fast when the lift is at all considerable, that they are soon cut away, and it appears advisable when gearing is used in such cases to make it spiral, or in steps, and with the teeth bottoming and very broad. If frictional gearing is used, it should be of much greater breadth and power than the authors of that scheme deem necessary, seeing that in certain cases the wheels which have been deemed by them of adequate size have been quite insufficient to transmit the strain.

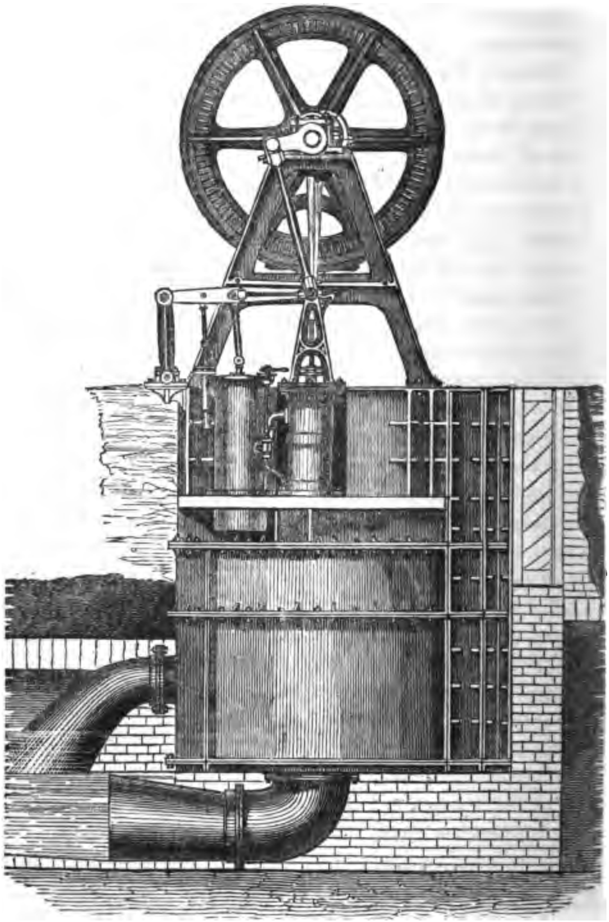
Messrs. Easton, Amos & Son combine the pump and the engine to drive it into one structure, and have found from a carefully conducted experiment with one of these machines, that with a mean lift of 6 ft. 6 in. nearly, the fan making 124 revolutions per minute, a quantity of water. = 6748 cubic feet or nearly 183¾ tons per minute was delivered. The engine power as per indicator diagrams, carefully taken, being 111·2 horse power, it follows that the useful work done was in this case 73¾ per cent. nearly of the power expended.

From several carefully conducted experiments made by the Court of Policy of Demerara upon one of the pumps in that country, it was found that the useful work done=66·55 per cent. of the power expended, while a well-constructed scoop, tried under precisely similar circumstances, gave no more than 22·3 per cent., and a centrifugal pump of another construction, 29·3 per cent. only.

By the combined system of construction any settlement of foundations which is more or less inevitable in all Fen districts is neutralised, as the whole of the machinery is self-contained, and its working unaffected by settlement, while the first cost of building foundations and masonry is materially less than by any other plan.

The arrangement of engines employed to drive Appold's centrifugal pump, by Messrs. Easton, Amos & Son of London — by whom large numbers of

Fig. 35.



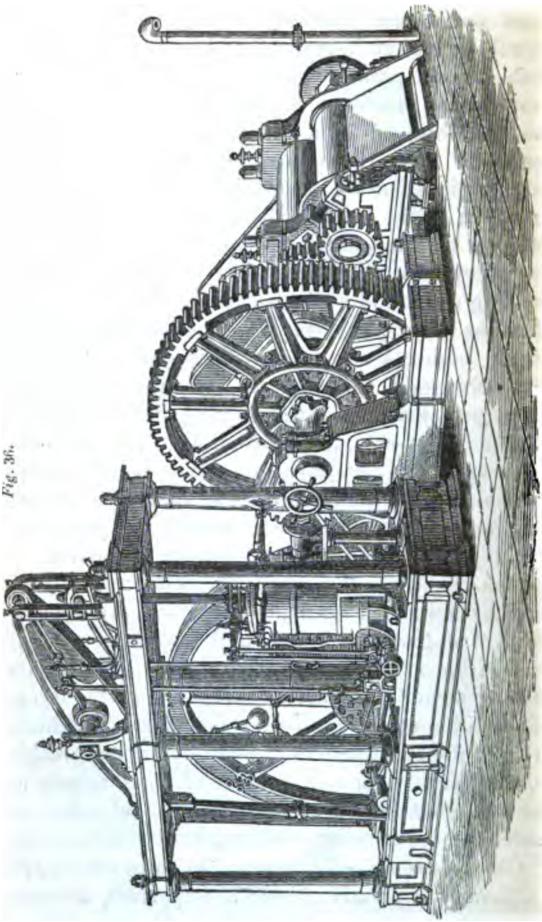
CENTRIFUGAL PUMP, BY EASTON, AMOS AND SON.

these pumps are made—is shown in *fig*. 35. The spindle of the fan is vertical, and is armed at the top with a bevel pinion, to which motion is given by a bevel wheel placed on the shaft of the engine. The fan is contained in a cast iron casing which also serves to support the engine, and there are two suction pipes, one for each side of the fan. The water drawn in at the centre of the fan is put into rapid rotation by the curved blades, and escapes at the periphery with such velocity as to support a corresponding column of water, and if the head is less than that—as it always is—the water necessarily overflows at the higher level. Centrifugal pumps have this great advantage, that they are without valves, and are consequently as efficient in forcing dirty water as in forcing clean—a quality which in many cases is of great value. They have sometimes been employed for maintaining the circulation in surface condensers. But the plan of using one of the air pumps as a circulating pump is simpler and is to be preferred.

Common Lever Engine. The old form of beam engine is still used for many purposes. An approved form of engine and sugar mill for expressing the juice from canes is shown in *fig*. 36. There is no novelty about this engine except the great strength of the different parts, which in this class of machinery is quite indispensable to obviate continual breaking down. The sugar mill consists of three rollers, and the canes pass down the inclined feeding table, and pass under the upper roller which squeezes out the juice.

Cowper's combined Engines. In cases where great uniformity of rotative power is important, combined

Fig. 36.



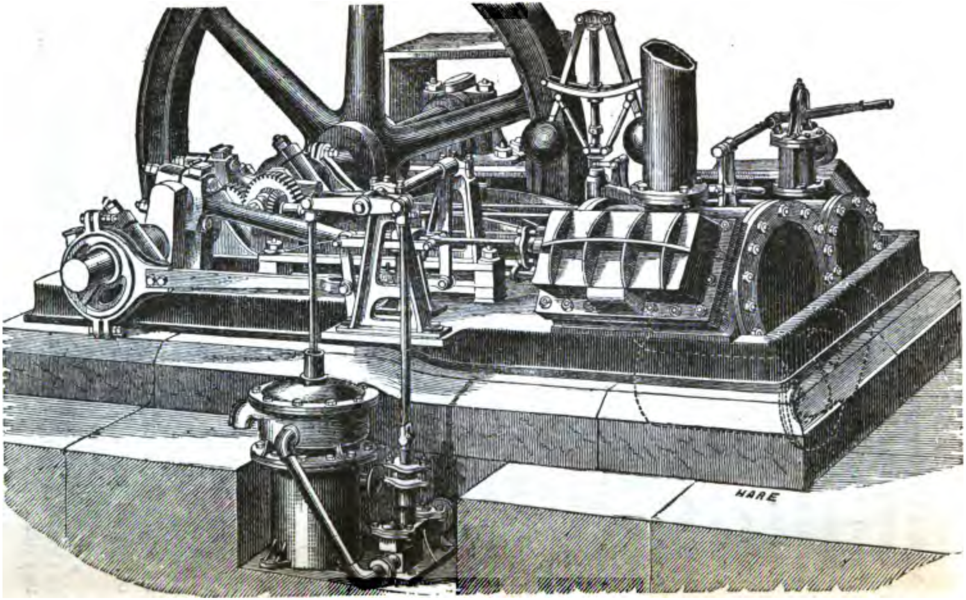
SUGAR MILL AND ENGINE.

with a large measure of expansion and a high pressure of steam a form of engine such as is represented in *fig.* 37 may be employed. This engine is a double cylinder engine; but instead of the pistons being made to operate on the same crank, as in ordinary double cylinder engines, or on opposite cranks, as in Messrs. Carrett, Marshall & Co.'s arrangement, the cranks are set at right angles with one another, so that when one piston is at its dead point the other is exerting its greatest power.* The small cylinder, instead of discharging directly into the large one, discharges into a reservoir beneath the engine, from which reservoir the large cylinder is fed; and the equability of motion proper to two engines working at right angles is thus obtained, with a large measure of expansion. This form of double cylinder engine appears to be an eligible form in cases in which two engines are necessary, as the benefits of large expansion are obtained without greater complication than that which appertains to two separate engines of the common kind.

The engines shown here were constructed by Messrs. Walter May & Co. of Birmingham, and set to work in the International Exhibition of 1862. The engines were made from the design of Mr. E. A. Cowper, by whom the plan was invented and patented. These engines were the only pair that was at work as condensing engines in the Exhibition, owing to there being no *large supply* of cold water

* This arrangement of the cranks and pistons was patented by Craddock in 1844, and was described in the 'Artizan' at that time.

Fig. 37.



COWPER'S COMBINED CYLINDER ENGINE.

available for condensing. The resource by which they were enabled so to work was by the application of Perkins' Surface Evaporator Condenser, which was adopted by Messrs. Walter May & Co. in this instance as a means of easily obtaining an excellent vacuum with a very small supply of water, viz. a supply equal only to the quantity of water used in the form of steam. Mr. Cowper's engine is fitted with a steam jacket, and the steam is expanded into nine times its original volume. But of course by earlier cutting off, this measure of expansion may be increased as much as may be desired.*

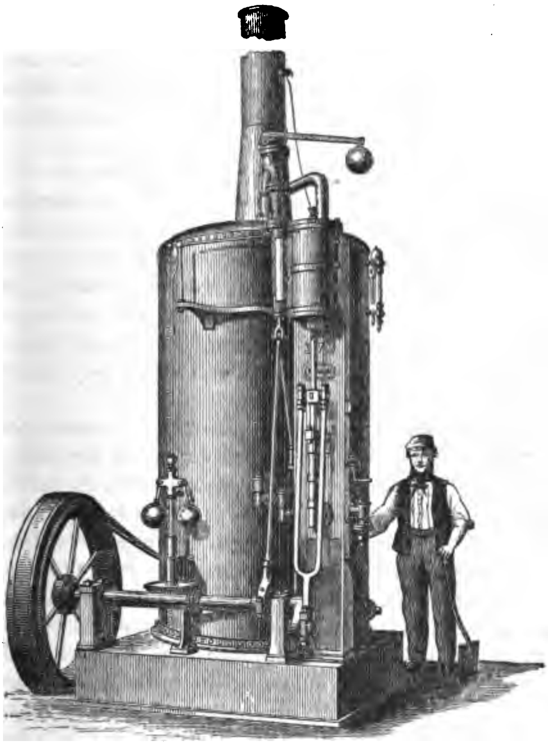
Continuous Expansion Engine. In Nicholson's continuous expansion engine the benefits of large expansion without increased complication, or the necessity of a receiver, are obtained by admitting the steam from the boiler into only one cylinder of a pair of engines; and when half the stroke has been performed, and the piston of the other engine is just beginning its stroke and therefore requires steam, some of the steam from the first cylinder is allowed to enter the second one, so that the second cylinder draws its steam direct from the first, instead of from a receiver; but it draws it at the middle of the stroke instead of at the end. This method may be applied easily to any existing

* A similar arrangement was introduced by me into a steamer in 1859, as a means of increasing the power by the addition of low pressure cylinders to the existing high pressure ones. The paddle-wheels were not connected; and one high and one low pressure cylinder placed nearly at right angles was set to turn each wheel. The steam passed from the high pressure cylinder not directly into the low pressure one, but into a reservoir which had pipes passing through it, which were heated by the escaping smoke in the manner steam is heated in a superheater.

engines. As a method of expansion it is only as efficacious as any other in the production of power. But its recommendation lies in the circumstance that the steam may be exhausted direct from one cylinder into the other, although the cranks are at right angles, and hence a large measure of expansion is producible in a pair of engines without increased complexity, without any risk of sticking on the centre, and with adequate equability of the rotative force.

Chaplin's Vertical Engine. Fig. 38 is a representation of the species of vertical engine and boiler constructed by Messrs. Chaplin & Co. of Glasgow. The waste steam maintains a strong draught in the furnace, and the steam is superheated somewhat before it enters the cylinder. The engine and boiler are erected upon a cast iron sole plate forming the ash pan, and into which water may be poured if desired. In some cases these engines are made with double cylinders; and besides being extensively employed for land purposes, they have been largely introduced into ships for pumping, hauling ropes, discharging cargo, &c. In many cases they are combined with a steam cooking apparatus, and a distilling apparatus for producing fresh from salt water; and the same fire which heats the cooking range also raises the steam in the boiler. The steam, in passing into the vessel in which it is condensed, sucks in sufficient air to aërate the water; and after being filtered by a filter attached to the condenser, it is then ready for use. In passenger ships the engine may be made to drive proper ventilating fans. I consider that every ship ought to be fitted with an engine, as it would

Fig. 38.



VERTICAL STEAM ENGINE BY CHAPLIN AND CO., GLASGOW.

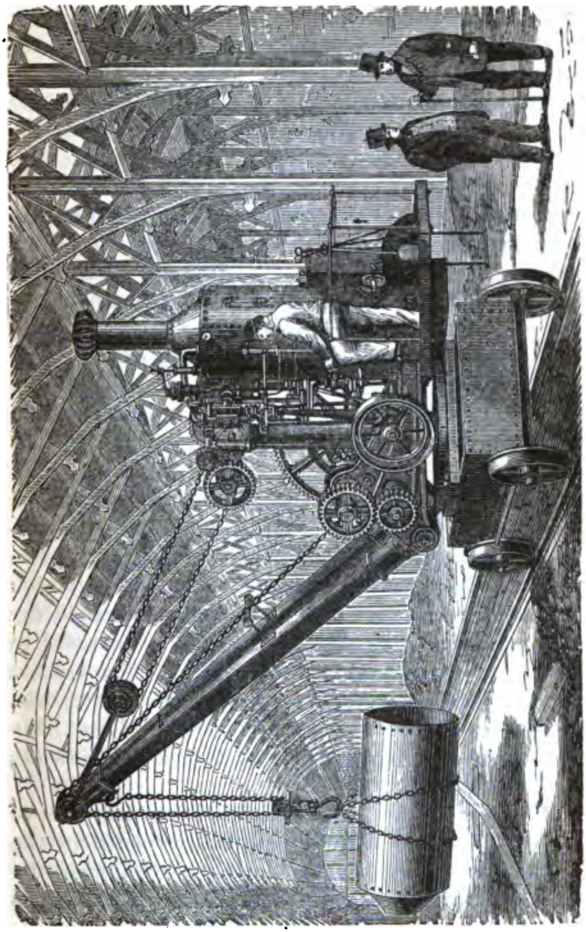
increase the safety of the ship, reduce the labour, and add to the comfort of all on board, while it also might be made available, with a simple apparatus, for the slow propulsion of the ship in calms.

Steam Winches and Cranes. Steam winches are now very commonly employed for hoisting the cargo out of ships; and steam cranes have also obtained a wide introduction.

Fig. 39 represents Chaplin's steam crane as employed at the Great Exhibition to move heavy weights. The engine and boiler help to counterbalance the load, and they swing completely round the central pillar. The jib is adjustable; and the operations of hoisting, lowering, and swinging, are all performed by the engine. The best form of steam winch that I have seen is that constructed by Messrs. Day & Co. at Southampton.

One of the most powerful and convenient machines for lifting heavy weights yet constructed is the shears contrived by Mr. Summers, and made by Messrs. Day & Co. for the docks in Southampton; and several similar shears have since been constructed by Messrs. Day for other places. The legs of these shears are formed of boiler plate, and there are two legs meeting at the top in the usual manner; but instead of the back chains and guys usually employed, there is a third or back leg, by moving which inwards, the top of the shears is bent forward; and by moving which outwards, the top of the shears is bent back. The inward or outward motion of the third leg on the ground is governed by suitable apparatus; but that to which the preference is given is a great screw working horizontally, and drawing in or out the leg in appropriate guides. The

Fig. 39.



CHAPLIN'S STEAM CRANE AT THE GREAT EXHIBITION 1862.

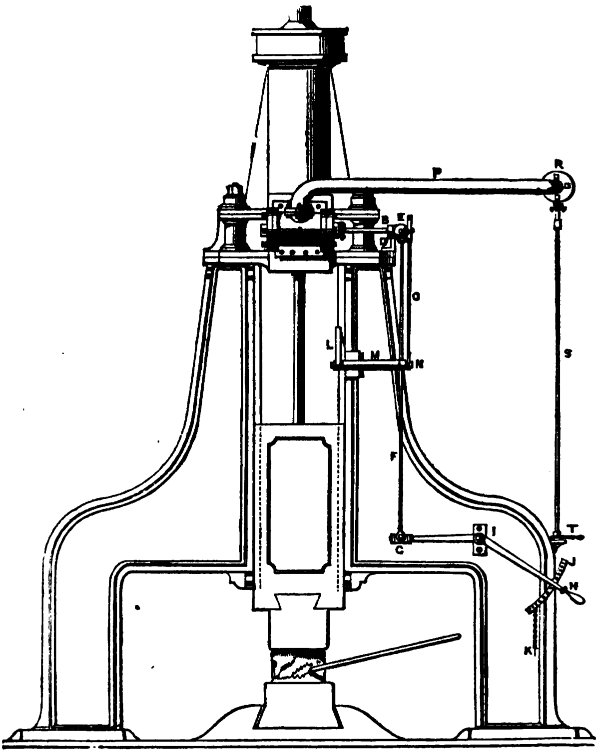
Southampton shears have lifted as much as 100 tons; and the hoisting and lowering, and also the movement of the back leg, is accomplished by a steam engine. The length of each front leg is 110 feet. The form is that of a parabolic spindle, 3 ft. 4 in. diameter in the middle, and 1 ft. 8 in. at the ends. The length of the back leg is 140 ft., and its form is rectangular, 40 in. by 46 in. at the middle, and 20 by 24 in. at the ends. The wrought iron screw which moves the back leg is 8½ in. diameter, and 48 ft. 3 in. long. This screw moves the shears at the rate of 12 ft. per minute, and its weight at the middle is carried by a pendulum prop, which the back leg moves aside as it passes. The back leg is held down by the flanges of the grooves in which its lower end works. The main purchase blocks consist of a pair of 4-sheave blocks, with 1⅛ chain-falls, and a leading-block above. These blocks are used for all weights over 20 tons, and hoist at the rate of about 4 ft. per minute. The light purchase-blocks have the same size of chain, but have only two sheaves above and one below. The engine which works this gear consumes about 6 cwt. of coal in the day; and the apparatus has been very successful in enabling a great deal of work to be done in a short time with superior accuracy, and at much less expense. Similar shears have been constructed by Messrs. Day & Co. for Hamburgh, Bremen, Bromley, Woolwich, and Holyhead.

Steam Riveting. Cylindrical boilers, and parts of other boilers, are now very generally riveted by the riveting machine, of which there are two forms—the one in which the die which forms the rivet head is forced forward by a cam, in the same manner as the punch of a punching machine, and the other in which it is forced forward by a piston moving in a cylinder, in the same manner as a steam hammer. The latter species of machine is now most generally used.

The first machine-riveting, so far as I am aware, was performed by myself in 1834, and the next was performed by Mr. Fairbairn, who employed a similar form of apparatus, resembling a common punching machine. Garforth's steam hammer apparatus has this advantage, that the die does not require adjustment for the thickness of the plate.

Steam Hammers. The steam hammer was suggested by Watt, but was brought into its present form by Nasmyth, whose hammer as improved by Wilson is represented in *fig.* 40. A is the cylindrical valve chest by moving the valve in which the steam is let in above or below the piston, and the hammer is forced up or down. The valve is worked by the short horizontal spindle B passing through a stuffing-box; D is a bracket supporting the outer end of the valve spindle; E is a balanced lever, jointed to the rod F passing down by the side of the frame to the level of the attendant's hand. This rod is jointed at G to the bent lever H, which is suspended on the stud I, and which terminates in a handle at H. By moving this handle up the hammer is raised up, and by moving it down the hammer is pressed down; and in order that the inexperienced workman may not move it too far down, if a light blow is wanted, a guard sector J is placed for the handle to move in; and by putting the pin K in one of the holes of the sector,

Fig. 40.



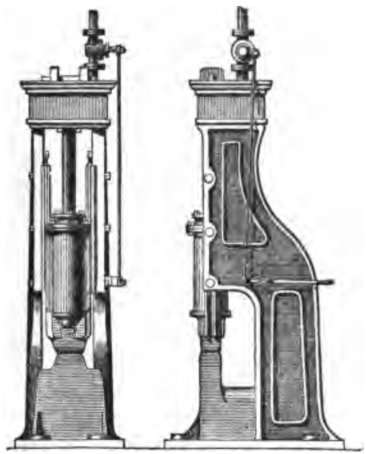
NASMYTH'S STEAM HAMMER.

and bringing the handle down to the pin, the proper blow answering to that position of the handle will be obtained.

The steam enters from the boiler through the pipe P, and there is a throttle valve at R, which is adjustable by the handle T.

In Condie's steam hammer the piston is stationary,

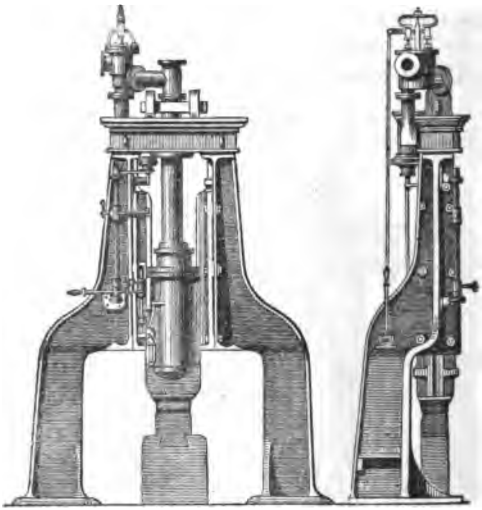
Figs. 41 and 42.



CONDIE'S 3½ CWT. STEAM HAMMER, BY A. C. WYLIE, LONDON.

and the cylinder moves; and the piston rod is hollow and serves as a steam pipe to let the steam into and out of the cylinder. *Figs.* 41, 42, 43, and 44, are representations of Condie's Hammer, *figs.* 41 and 42 being front and side views of a 3½ cwt. hammer intended for smith work for light forgings; and *figs.* 43 and 44 being a front and side view of a 6 cwt. hammer intended for heavier

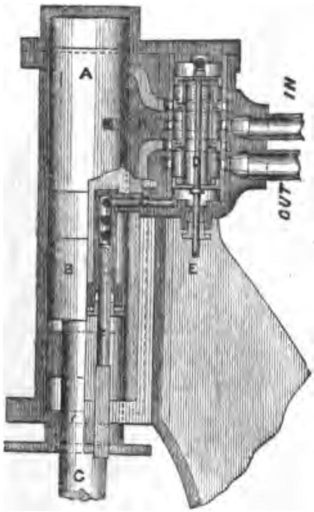
Figs. 43 and 44.



CONDIE'S 6 CWT. STEAM HAMMER, BY A. C. WYLIE, LONDON.

smith work or heavier forgings. In both of these hammers bars of any length may be welded, either along or across the anvil, and in the 3½ cwt. hammer the anvil block is in the same piece as the framing. These hammers are all made double acting, being pressed down as well as raised up by the steam; and in practice they have been found to act in a highly satisfactory manner. *Figs.* 45 and 46 are representations of the species of self-acting steam hammer constructed by Messrs. Carrett & Marshall of Leeds, *fig.* 45 being a section of the cylinder and slide of the

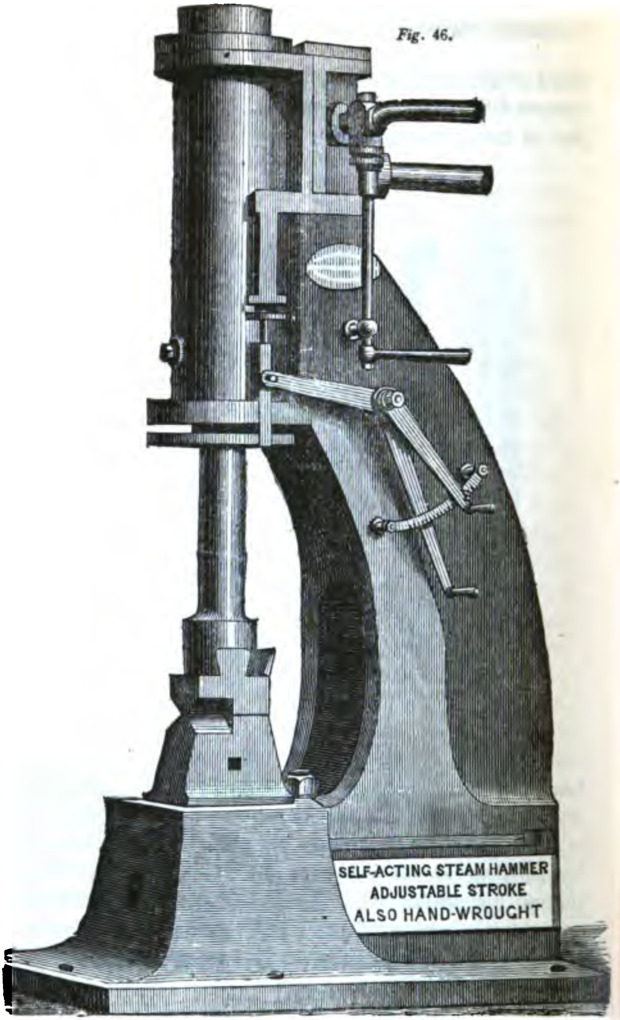
Fig. 45.



SECTION OF CYLINDER AND VALVE OF STEAM HAMMER.

hammer, and *fig.* 46 a perspective view. In *fig.* 45, A is the cylinder, B is the piston, and C its rod; G is the regulating stop-slide, which adjusts the stroke by passing steam early or late from beneath the piston to under the piston-slide-valve D, which reverses the action of the steam on the piston, thus effecting the down-stroke. A suitable contraction

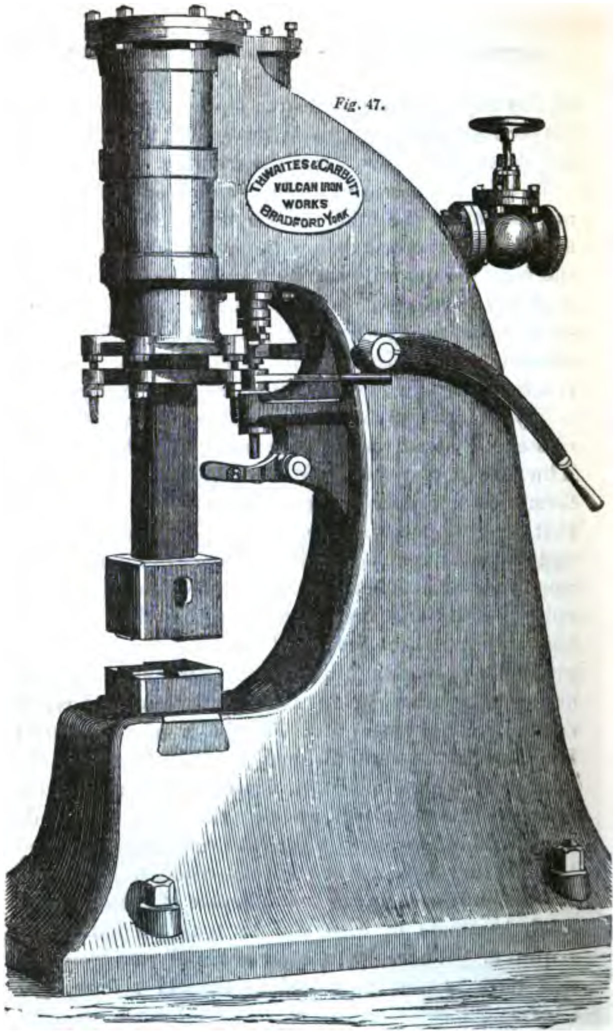
Fig. 46.



SELF-ACTING STEAM HAMMER BY CARRETT, MARSHALL AND CO., LEEDS, of the passage H regulates the strength of blow. The longer hand-lever regulates the stroke, and the other the strength of blow. E is the framing.

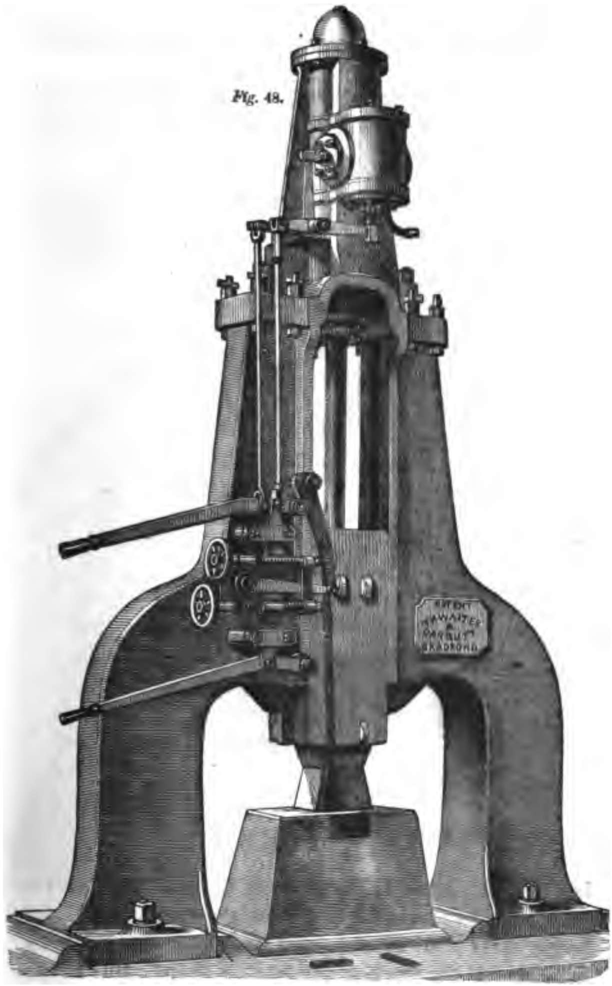
In this hammer the steam which works the hammer performs the office of moving the valve, being admitted above and below the piston-slide-valve, in the requisite quantity and for a suitable period of time, to give any required stroke, or a *light blow* with lead, or a *clear heavy blow* without lead, retaining the steam upon the piston until the blow is struck. There is a separate valve for working the hammer by hand.

Figs. 47 and 48 are representations of two different classes of steam hammer constructed by Messrs. Thwaites & Carbutt of Bradford, *fig.* 47 being the form most appropriate for small hammers, and *fig.* 48 that most appropriate for large. Messrs. Thwaites and Carbutt have had much experience in the construction of steam hammers, and for some time have made nothing else; and they state that they find that the hammers wrought by hand are preferred and are gradually taking the place of those wrought by self-acting mechanism, being under such easy and ready control. They state that they have made eighteen hammers for Messrs. Brown & Co. of Sheffield, the largest of which, a 15 ton. hammer, was made with wrought iron standards, and that they have now made several hammers with wrought iron standards, and believe that this method of construction will come into general use. In the manufacture of the Bessemer steel, hammers of 5, 8, and 12 tons are habitually required. When the standards are of cast iron, the box form is now preferred to the old T form, and



THWAITES AND CARBUTT'S HAMMER FOR SMALL FORGINGS.

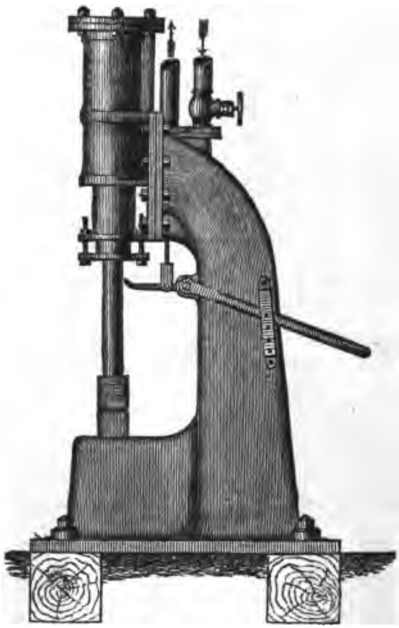
Fig. 48.



THWAITES AND CARBUTT'S HAMMER FOR HEAVY FORGINGS.

immense strength is necessary to enable the hammer permanently to endure the heavy shocks to which it

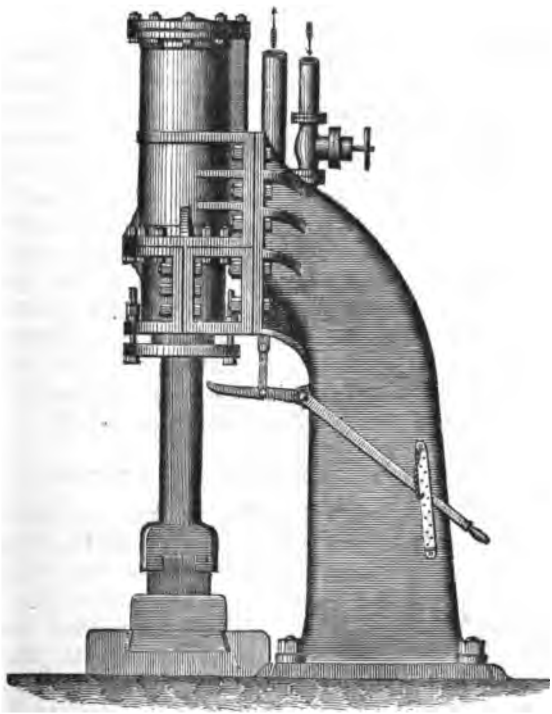
Fig. 49.



RIGBY'S STEAM HAMMER BY GLEN AND ROSS, GLASGOW.

is exposed. Messrs. Thwaites & Carbutt do not recommend hammers of the form shown in *fig.* 47 for larger sizes than 12 cwt., and such hammers are very suitable for the work of the smith's shop. But above that weight they recommend hammers with double standards, of the form shown in *fig.* 48, as being firmer and stiffer, and better suited for heavy work.

Fig. 50.



RIGBY'S STEAM HAMMER BY GLEN AND ROSS, GLASGOW.

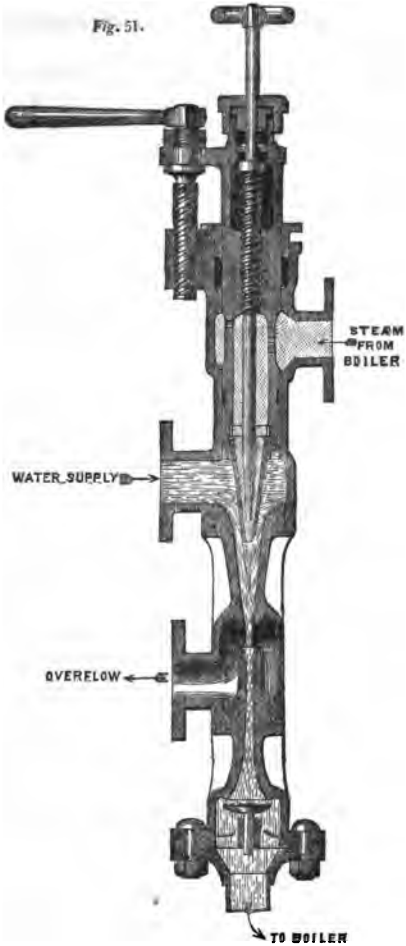
These hammers are controlled in their movements by two handles, one of which opens or shuts the stop valve, while the other gives motion to the working valve by which the steam is let into and out of the cylinder. This last valve is a balanced piston, so that it is quite easily moved, and the hammer is consequently under ready control.

Rigby's steam hammers, as constructed by Messrs. Glen & Ross of Glasgow, and represented in *figs.* 49 and 50, have obtained a very wide introduction, and have given much satisfaction to those employing them. *Fig.* 49 represents the form of hammer appropriate for light work, and which differs from the other form only in having the anvil-block, sole-plate, and standards cast in one piece. Hammers on this construction are made of 1, 2½, and 4 cwt. The form of hammer represented in *fig.* 50 is made of different weights, from 6 to 30 cwt. The hammer is urged by the steam in its descent as well as by gravity, and works with great rapidity at a pressure of from 25 to 30 lbs., which pressure should not be exceeded.

GIFFARD'S INJECTOR FOR FEEDING BOILERS.

This is an instrument for forcing water into boilers by means of a jet of steam proceeding from the boiler itself; and its action is somewhat paradoxical, as it is capable of sending water into a boiler which has a considerably greater pressure of steam than that which the steam comes from. The feed water must not be hotter than 120° Fahrenheit, to enable the injector to act; for one condition of its action is that the steam shall be condensed; and this circumstance appears likely to restrict the use of the instrument—

Fig. 51.



GIFFARD'S INJECTOR BY SHARP, STEWART AND CO., MANCHESTER.

unless suitably modified—as the feed water should certainly enter the boiler at the boiling point, to which it should be raised by heat otherwise going to waste. In this injector a stream of steam entering from the boiler at the highest nozzle, represented in *fig.* 51, is directed upon water entering the instrument through the nozzle next below; and as the whole power of the issuing steam has been expended in giving momentum to its own particles, that power, which cannot be destroyed, reappears as increased pressure, and forces the water into the boiler.* Should the water be shut off from the boiler as not being required, then it escapes, by the nozzle next beneath, through a loaded valve of the usual kind; and the valve at the bottom of the instrument prevents the return of the water when the instrument is not in use. The advantage of this apparatus is that it gets rid of the feed pump with its valves, which have been a source of constant trouble in engines working at a high speed. But unless it can be so modified as to send the feed water into the boiler at the boiling point to which it will be heated by the waste heat of the engine, I do not see how this injector can be retained as a main feeding instrument, though it will always be valuable as an auxiliary.

The sizes and prices of different injectors, proper for sending any desired number of gallons of water into a boiler in the hour, are given in the following table:—

* The injector is virtually a hydraulic ram reversed, in which the small quantity of water in the steam, moving at a high velocity, forces a larger quantity of water against a lower head.

DELIVERY OF WATER BY GIFFARD'S INJECTOR.

The following Table shows the Sizes and Prices of Giffard's Injectors, and the number of Gallons per hour they are capable of supplying to a Boiler, according to the pressure per square inch of steam employed, with a considerable margin for contingencies, especially in the smallest sizes :—

Diameter of Throat of Injector in Millimetres.	Pipes—Internal diameter in Inches.	Price at the Works—Brass.	Pressure of Steam in pounds per square inch.														Diameter of Throat of Injector in Millimetres.	Price at the Works—Cast Iron Casing.
			10 lbs.	20 lbs.	30 lbs.	40 lbs.	50 lbs.	60 lbs.	70 lbs.	80 lbs.	90 lbs.	100 lbs.	110 lbs.	120 lbs.	130 lbs.	140 lbs.		
		£	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.	gals.		£ s.
No. 2	9-16ths	9	20	28	35	40	47	49	53	57	60	64	67	70	73	75	No. 2	6 10
,, 3	9-16ths	12	45	64	78	90	101	111	120	128	136	143	150	157	163	169	,, 3	8 10
,, 4	1	15	80	114	139	161	180	197	213	228	241	254	267	279	290	301	,, 4	10 10
,, 5	1	19	126	178	218	251	281	308	333	356	377	397	418	436	453	470	,, 5	13 10
,, 6	1½	23	181	256	314	362	405	444	479	512	543	572	600	627	653	677	,, 6	16 10
,, 7	1½	27	246	348	427	493	551	604	652	697	739	779	817	854	888	922	,, 7	19 10
,, 8	1½	32	322	455	557	643	719	788	850	910	965	1018	1068	1115	1160	1204	,, 8	22 10
,, 9	1½	36	407	576	706	814	911	998	1078	1152	1222	1288	1351	1411	1468	1524	,, 9	25 10
,, 10	2	40	503	711	871	1005	1124	1232	1331	1422	1549	1590	1669	1742	1813	1882	,, 10	28 10
,, 11	2	45	608	860	1054	1216	1360	1491	1610	1720	1825	1924	2018	2107	2194	2277	,, 11	31 10
,, 12	2	50	724	1024	1254	1448	1619	1774	1916	2048	2172	2289	2402	2509	2611	2710	,, 12	34 10
,, 13	2½	55	849	1201	1472	1699	1982	2082	2248	2404	2550	2687	2819	2944	3064	3180	,, 13	37 10
,, 14	2½	60	985	1393	1707	1970	2203	2415	2609	2788	2957	3116	3270	3414	3553	3688	,, 14	41 10
,, 15	2½	65	1131	1599	1960	2262	2529	2772	2994	3200	3394	3577	3758	3920	4079	4234	,, 15	45 10
,, 16	2½	70	1287	1820	2230	2574	2878	3154	3406	3641	3862	4070	4270	4460	4641	4818	,, 16	49 10
,, 17	2½	75	1454	2054	2517	2905	3249	3560	3845	4111	4360	4595	4821	4865	5239	5439	,, 17	53 10
,, 18	2½	80	1629	2303	2822	3257	3642	3992	4311	4608	4888	5151	5405	5644	5874	6107	,, 18	56 10
,, 19	2½	85	1815	2566	3144	3629	4058	4448	4803	5135	5446	5740	6022	6289	5544	6794	,, 19	59 10
,, 20	3	90	2011	2843	3484	4021	4497	4928	5322	5688	6034	6360	6678	6968	7249	7528	,, 20	62 10
,, 21	3	95	2173	3135	3843	4433	4957	5433	5867	6248	6709	7008	7334	7633	7878	8149	,, 21	65 10
,, 22	3	100	2385	3440	4215	4865	5441	5962	6439	6857	7364	7692	8049	8377	8646	8944	,, 22	69 10
,, 23	3	105	2606	3747	4594	5311	5930	6517	7006	7494	7951	8407	8798	9189	9450	9775	,, 23	73 10
	3½		2836	4080	5002	5783	6457	7096	7628	8160	8657	9154	9580	10005	10289	10644	,, 24	77 10
	3½		3080	4427	5428	6275	7007	7700	8277	8855	9394	9932	10395	10857	11165	11550	,, 25	81 10
	3½		3373	4789	5871	6788	7579	8328	8953	9578	10161	10744	11243	11748	12243	12701	,, 26	85 10

To find the size of Injector for Stationary Boilers, multiply the nominal H.P. by 12·5; then, in the column headed by the working pressure, find the number of gallons so obtained, or not finding the exact number, take that which is next higher, and the Injector opposite this number is the one required. For Marine Boilers, instead of 12·5, multiply by 18·5 (giving thereby the requisite allowance for blowing off the brine, &c.), and proceed as above. A millimetre is ·03937 inches.

The construction of these injectors is a special branch of manufacture; and in applying to the manufacturer for any suitable size, it is necessary to state the number and description of the boilers for which the injectors are intended, and also to state whether they are to have a brass or cast iron casing, as this last condition will affect the price.*

Delabarre's Steam Jet. This is an arrangement for increasing the efficiency of a steam jet in chimneys. The jet orifice is surrounded by a short piece of pipe of larger diameter, and it by another short piece of still larger diameter, and it by another short piece still larger, and so on as far as is deemed desirable. These short pieces of pipe are all open at each end like ferrules, and the length of each is about equal to its diameter. The bottom of each is set on a level with the top of the preceding one, and the bottom of each is slightly belled out to intercept the smoke. A jet of this kind placed in a chimney is believed to be more effectual than a common jet, which will ascend the centre of the chimney without much affecting the surrounding smoke; whereas by this arrangement each succeeding pipe transforms the jet preceding it into a

* The following formula is given for determining the size or delivery of a Giffard's injector: If P be the pressure of the steam in atmospheres, D the diameter of the throat in inches, and G the number of gallons delivered per hour, then $G = (63{\cdot}4\ D)^2 \sqrt{P}$ and $D = {\cdot}0158 \sqrt{\frac{G}{\sqrt{P}}}$. Thus if the pressure of steam be 60 lbs. or 4 atmospheres, and the number of gallons to be delivered per hour be 308, then ${\cdot}0158 \sqrt{\frac{308}{\sqrt{4}}} = {\cdot}0158 \sqrt{154}$ $= {\cdot}0158 \times 12{\cdot}4 = {\cdot}19592$ = diameter in inches = 5 millimetres, as in the table.

new jet of less velocity and larger volume, until at length the whole column of smoke in the chimney is brought under the influence of the central jet.

On the benefit of Steam Jackets. The benefit of steam jackets round cylinders was ascertained by Watt, and such jackets were habitually used by him. But among succeeding engineers, jackets fell into disuse, as it was hastily and erroneously concluded that the waste by radiation was the only loss incident to the cooling of the cylinder, and that this loss would be as great in the jacket as in the cylinder. This error has now been for some years exploded. Nevertheless, although some few engineers have long urged the application of steam jackets to marine and locomotive engines, it is only very recently that jackets have been adopted by the best marine engine builders, and they are not even yet used in locomotives. One reason of this tardiness of amelioration is no doubt the fact, that steam jackets add something to the cost of the engine; and their full value, moreover, has not been sufficiently known or understood, since the whole question has been believed to be one of radiation, whereas the loss is by no means measurable by the loss from radiation, but is a much larger loss, and arises from the fact of the inner surface of the cylinder being cooled and heated by the steam at every stroke of the engine. This action is clearly demonstrated by a set of indicator figures taken in 1848, and kindly lent to me by Mr. E. A. Cowper. Four of these diagrams are represented in *figs.* 52, 53, 54, and 55, and they show the pressure really attained, together with the true expansion curve for the whole quantity of steam that entered the cylinder, dotted in, and which dotted curve would have been described

Fig. 52.

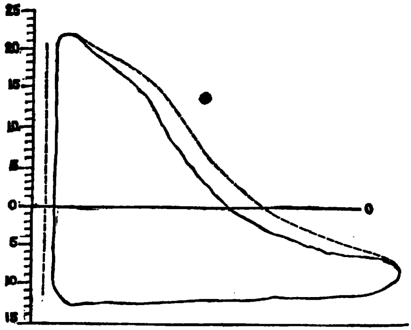


DIAGRAM SHOWING LOSS BY COOLING.

Fig. 53.

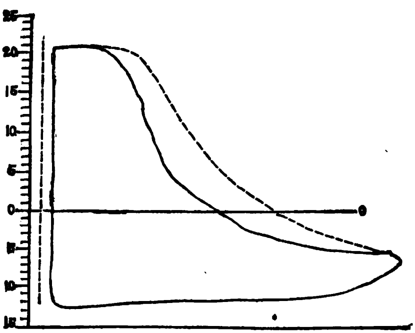


DIAGRAM SHOWING LOSS BY COOLING.

if the cylinder had been jacketed. The difference between these curves represents the amount of loss from the want of the steam jacket; and in *fig.* 52 this loss amounts to 11·7 per cent.; in *fig.* 53 to 19·66 per

Fig. 54.

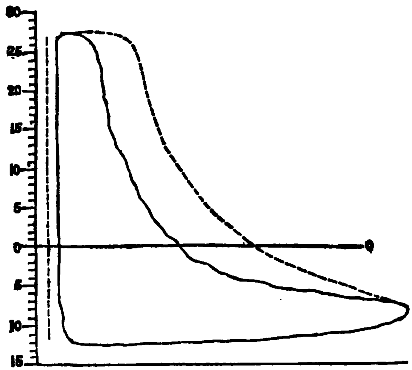


DIAGRAM SHOWING LOSS BY COOLING.

Fig. 55.

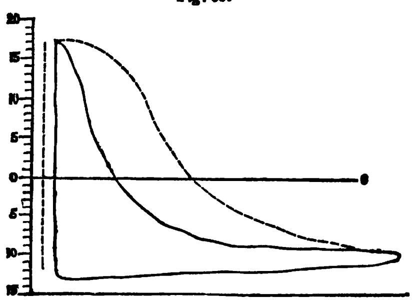


DIAGRAM SHOWING LOSS BY COOLING.

cent., there being rather more variation of temperature in this case, owing to there being more expansion; in *fig.* 54 the loss is 27·27 per cent.; whilst in *fig.* 55 the loss rises to the formidable proportions of 44·58 per cent. This loss is caused by the circumstance that the mass of the cylinder must remain at the average temperature intermediate between the highest and the lowest temperatures of the steam; so that when high pressure steam, which also has a high temperature, enters the cylinder, a considerable quantity of steam is at once condensed, owing to the abstraction of heat by the metal, and also to the transformation of a part of the heat into mechanical power. So soon as the steam is cut off and allowed to expand, it falls much more rapidly in pressure than answers to its augmented volume, owing to still more of it being condensed into water. The action of the steam is to heat the inner surface of the cylinder; and towards the end of the stroke, when the steam is much lower in pressure, and consequently in temperature, than it was at first, the temperature of the cylinder relatively with it is sufficiently high to boil off the water that was condensed from the steam as it entered the cylinder; and such water becoming steam causes the pressure to rise, and thus the curve approaches the true expansion curve at the end of the stroke. The cylinder is cooled by the loss of the heat used in boiling off the water shut within it, and the cooled cylinder condenses the next volume of steam that enters to perform the next stroke. Thus it follows, that without steam jackets a large quantity of steam passes through the cylinder in the form of water, without doing work;

whereas if the cylinder is steam jacketed, no condensation takes place, and the whole steam does its full duty according to the degree to which it is expanded. Indeed, without steam jackets, or hot air jackets, or other equivalent means of keeping up the temperature of the cylinder, it will follow that the cylinder will act to some extent as a condenser at the beginning of the stroke, and as a boiler at the end of the stroke.

MARINE ENGINES.

In illustrating the special features of the various forms of marine engines of modern construction, the most convenient course will be to take an example of an engine by each principal maker, and to describe its structure and peculiarities. A tolerably just conception will thus be arrived at of the present condition of marine engineering in this country in its most perfect form, care being taken that the examples selected are good and recent examples of their several kinds.

Boulton & Watt. The example of modern engines by these makers that I shall select is the oscillating paddle engines of the Holyhead steamers, Ulster and Munster; for although I might have selected a still more recent example, I could not have selected a more perfect one. These vessels have now been plying regularly across the channel at all seasons for a sufficient time thoroughly to test their qualities, and they have been found to maintain a very high speed and to work in a most satisfactory manner. The vessels are each 328 ft. long, with 35 ft. breadth of beam, 21 ft. depth of hold, and they each measure about 2,000 tons, builder's measurement. Each vessel is propelled by two oscillating engines of 96 in. diameter of cylinder, and 7 ft. stroke. The pressure of steam in the boiler is 26 lbs. per sq. in. The nominal power of each pair of engines by the Admiralty rule is 750 horses. They make 23 strokes per minute, and they work up to 4,100 actual or indicated horses power.

The boilers are tubular boilers with iron tubes; they are made in eight parts, and contain in all 48 furnaces. The total heating surface of the boiler is 18,400 sq. feet, and the total area of grate bars is 840 sq. ft. The area of the immersed midship section of the vessel is 350 sq. ft. and the coefficient of performance 860. The draught of water of each of the vessels when launched was: forward, 9 ft. 3 in.; and aft, 8 ft. 2 in. The draught of water with the engines, boilers, masts, and fittings, on board, but without water in the boilers, was, forward, 12 ft., and aft, 12 ft. 6 in. The draught of water when ready for sea, and complete with stores, and 75 tons of coals, was, forward, 13 ft., and aft, 13 ft. 4 in. The weight of the engines is 220 tons, of the boilers 230 tons, of the water in the boilers, 170 tons, and of the paddle wheels, 110 tons: making a total weight of 730 tons, or nearly 1 ton per nominal horse power. The pistons are each made with a metallic ring pressed out by springs. The average pressure on the piston is 28·77 lbs. per sq. in. The total number of tubes in the boilers 4,240, of $2\frac{1}{2}$ in. diameter, 5 ft. 3 in. long, and $\frac{1}{8}$th thick. The tube plates are of iron $\frac{3}{4}$ in. thick, and the tubes are $1\frac{1}{4}$ in. distant from each other. The length of each furnace is 7 ft., and its breadth $2\frac{1}{2}$ ft. There are two sets of boilers in each vessel, one before and the other behind the engines, and each set has a chimney 7½ ft. diameter and 44½ ft. high above the grates. The paddle wheels are, feathering, 33 ft. 9 in. diameter to the inner edge of the outer ring. There are 14 floats in each wheel, and each float is 4 ft. deep and 12 ft. long. The dip of the wheels is 5 ft. 9 in. at deep draught. The steam is superheated by passing up and down through annular steam chests surrounding the chimneys, divisions being introduced into the annular space to compel the steam to ascend and descend before escaping to the steam pipe. A similar arrangement had been introduced by me into the Don Juan steamer as far back as 1836. These vessels, and two similar vessels, the Leinster and Connaught, the engines of which were constructed by Messrs. Ravenhill, Salkeld & Co., have realised a speed of upwards of 20 miles an hour, and an average speed in all weathers, during the first six winter months, of 18 miles an hour. In the Leinster and Connaught the cylinders are 98 in. diameter, and 6 ft. 6 in. stroke, and the engines are rated at 720 nominal horses power, but are in reality 770 nominal horses power. There are eight boilers, containing 40 furnaces and 4176 tubes, and a total heating surface of 16,800 sq. ft. At the official trial the engines, with a pressure of steam of 20 lbs., made from 25 to 26 revolutions per minute, and exerted 4,751 actual horses power. The consumption of fuel is about 3 lbs. per indicated horse power per hour.

John Penn & Son. The engines of these makers which I shall select for illustration are the engines of the Warrior, Black Prince, and Achilles—all horizontal trunk engines of the construction represented at page 79 of my 'Catechism of the Steam Engine.'

These engines are each of 1,250 horse-power, and notwithstanding their immense size, they are distinguished by the same beauty and accuracy of workmanship for which Messrs. Penn's engines have long been famous. The cylinders are of 112 in. in diameter, and 4 ft. stroke. The trunks are of 41 in. diameter, which reduces the effective diameter of the cylinders to 104¼ in. The air pumps are double acting, 36 in. diameter, and 4 ft. stroke. The feed and bilge pumps are 7½ in. diameter; the crank shaft is of 19 in. diameter, and the screw shafting is of 17 in. diameter. The screw, which is on Griffith's plan, is 24½ ft. diameter, and 30 ft. pitch. There are two engines in each vessel, and they make about 45 revolutions per minute; there are 10 boilers in each vessel, and each of these boilers has 4 furnaces in it 7 ft. 3 in. long, and 3 ft. wide. The tubes are of brass, 2¾ outside diameter, and 6 ft. 8 in. long, and there are 440 tubes in each boiler, or 4,400 tubes in all. The smoke is carried off by two funnels on the telescopic principle, 7 ft. 6 in. diameter, and 54 ft. above the bars of the grate.

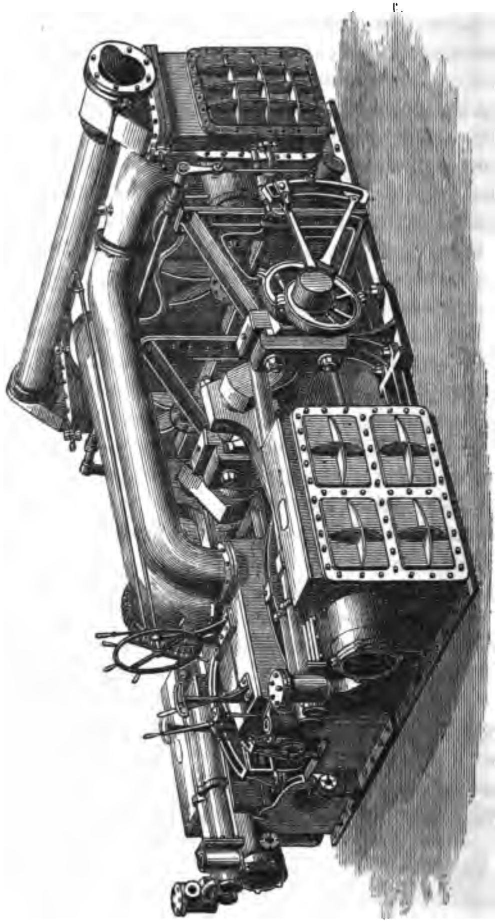
The Warrior and Black Prince are both iron vessels of 6,039 tons burden, built of iron, and covered with two thicknesses of teak, over which are bolted armour plates of iron 4 in. thick, and ploughed and tongued at the edges to enable each plate to give mutual support to those next it in the event of strain or shock. With an immersed midship section of 1,200 sq. ft., and a pressure of steam in the boilers of 22 lbs. per sq. in. these vessels exerted about 5,400 actual horse-power, and attained a speed of 14½ knots—the engines making 55 revolutions per minute.

Messrs. Ravenhill, Salkeld & Co. The form of screw engines employed by Messrs. Ravenhill, Salkeld & Co. is represented in *fig.* 56. This form of engine is a horizontal steeple engine of the same type as that of the Amphion, the engines of which, designed by the late Mr. Holm,* were constructed by Messrs. Miller, Ravenhill & Co. The Amphion was the first vessel built in this country with the engines below the water-line; and the species of engine with which she was fitted appears to me the best species of screw engine yet introduced, and one which perfectly satisfies the existing necessities of screw propulsion. There were faults of detail in the engines of the Amphion which have been subsequently corrected; and in the best examples of this form of engine a very perfect result is exhibited.

In the example shown in *fig.* 56 there are two cylinders placed side by side with their axes running athwart-ships in the vessel; and the cylinders are on one side of the vessel, and the condensers and air pumps on the other side. Two great pipes extending across the engine conduct the exhaust steam from the cylinders to the condensers. There are two long piston rods passing one above the shaft and the other below to the cross head which moves in guides on top of the

* The engines of the French frigate Pomone were also designed by Mr. Holm, who was a Swedish engineer of great ability.

Fig. 56.



Direct-acting Screw Engines by Ravenhill, Salkeld and Co.

condenser, and from which a return connecting rod proceeds to the crank to turn it round. The various subordinate features of the arrangement are made so plain by a reference to the drawing that it is needless to enlarge on them further.

Maudslay, Sons & Field. Messrs. Maudslay and Field have long employed a species of engine similar to the foregoing; but latterly they have made their screw engines with three cylinders instead of two, with the object of reconciling equability of motion with a high speed and a large measure of expansion. The aggregate capacity of these three cylinders is about half or three quarters larger than the two ordinarily used for the same power. This is for the purpose of using the steam more expansively. The steam is shut off much earlier in the stroke than heretofore. Six efforts are given in each revolution, which gives more uniform motion to the screw shaft, and the whole is so completely balanced that the unpleasant agitation felt in screw vessels at high speeds is entirely removed. The steam is superheated; the cylinders are cased all round and at both ends, and this case is filled with superheated steam, which keeps the cylinder up to the maximum temperature. The steam is condensed by surface condensers, having small perpendicular tubes —the cooling surface being about the same as the heating surface of the boiler. A still is provided to make up the waste. The cold water is forced amongst the outsides of the tubes by a pump, and is so directed that it all enters at the lower edge all round, and also in the centre of the cluster; then rising it is driven out at the upper edge of the tubes.

The superheating apparatus is composed of a number of horizontal tubes round at the end where they are fitted into a tube plate, but flattened throughout the greater part of their length. By these means the steam is greatly subdivided, and more effectually presented to the action of the heat, and more room is also afforded for the smoke to pass between them. To enable any of the tubes to be replaced when worn or leaky, the central tube of each group of nine is made oval at one end, to admit of any of the nine tubes of the group being introduced or withdrawn. One end of the tube intended to fit this hole has a flange and is fitted with four screws.

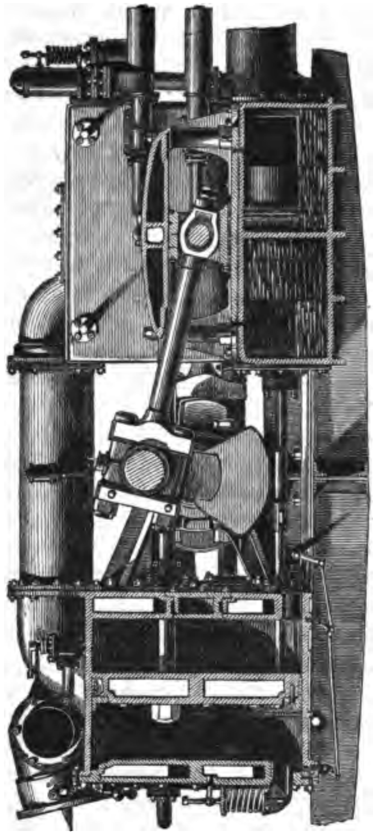
The boilers are of the usual tubular kind; they work at 20 to 25 lbs. pressure. The feed water is heated in its passage back into the boiler. Care has been taken that there should be as little waste of steam as possible in the passages between the slide and the cylinder; and the length of this passage is reduced by using two small slides instead of one large one to each cylinder. The expansion is effected by the slide alone. The slide valves, which are long and three-ported, are moved by a three-throw crank or eccentric; and the openings are large, while the travel is very small. The eccentrics are driven by a small spur wheel on the main shaft, and a similar wheel on the eccentric shaft. These wheels are connected by a pair of intermediate wheels fixed in a rising and falling frame. The elevation or depression of these wheels has the effect of altering the position of the eccentrics relatively with that of the main crank, and thus effects the forward and backward motion of the engine; and it also adjusts the degree of expansion within the limits of $\frac{1}{8}$th and $\frac{1}{4}$th of the stroke. This engine combines all the well-established sources of economy in the steam engine. The workmanship is of the very first quality; and the whole is of great strength and solidity. The thrust bearing is formed of collars on the shaft, but set wider apart than is usual; and each collar has a horse-shoe plate applied to it to take a proportion of the thrust. There are 5 or 6 of these collars and plates; each plate is adjustable by screws and admits of being separately taken out and replaced, and this can be done while the engine is working. A set of these engines of 500 horse-power has been fitted by Messrs. Maudslay in the steam frigate Octavia. Each of the three cylinders is 66 in. diameter, and the length of the stroke is 3 ft. 6 in. The valves are double-ported; each condenser is fitted with $5\frac{1}{2}$ miles of $\frac{1}{2}$ in. copper tubing (No. 18 wire gauge), and the circulating pumps, which are fitted with *lignum vitæ* packing, are worked by arms from the cross-heads. The Octavia is a vessel of 3,161 tons; and at the official trial in 1861 she realised a speed of $12\frac{1}{4}$ knots with a displacement of 2,921 tons, an immersed midship section of 552 sq. ft., a pressure of steam of 20 lbs., $69\frac{1}{2}$ revolutions, and an indicated power of 2,265 horses. The consumption of coal was only $2\frac{1}{4}$ lbs. per indicated horse power.

Messrs. Robert Napier & Sons. The engines of the steamer Scotia for the Cunard line, by Messrs. Napier of Glasgow, are of the side lever description, and the cylinders are 100 in. in diameter, and 12 ft.

stroke. The parts of these engines are of enormous strength, and their general configuration is the same as that of the side-lever engines usually constructed by Messrs. Napier, except that the side levers are of wrought iron, and the slide valves, which are of the short D kind, connected with three rods, have metallic packing at the back, consisting of a cast iron segment cut obliquely at the centre, and accurately fitted to the back of the valve. There are two such segments opposite to each port with a space between them equal to the depth of the port, the purpose of which is to put the valve into equilibrium, whereby it is more easily worked. This improvement is due to Mr. Waddell; and it has been found to be useful and efficient in practice. The sole plate, condenser, and air pump of each engine are all cast in one piece; and the air pumps after being bored out are lined with brass chambers. The cylinders are formed with double bottoms, and the whole structure of the engine is of the most conscientious and substantial character.

One form of screw engine employed by Messrs. Napier is the horizontal steeple kind very similar to that employed by Messrs. Ravenhill and Messrs. Maudslay. But they also occasionally use, in the case of merchant steamers, inverted engines of the forge hammer type similar to those employed by Messrs. Caird, of which a description is given at page 126. An example of Messrs. Napier's horizontal engine is given in *fig.* 57, which is a representation of the engines of the armour-plated steamer Rolf Krake, constructed by Messrs. Napier & Sons for the Danish navy. In the first examples of this species of engine,

Fig. 57



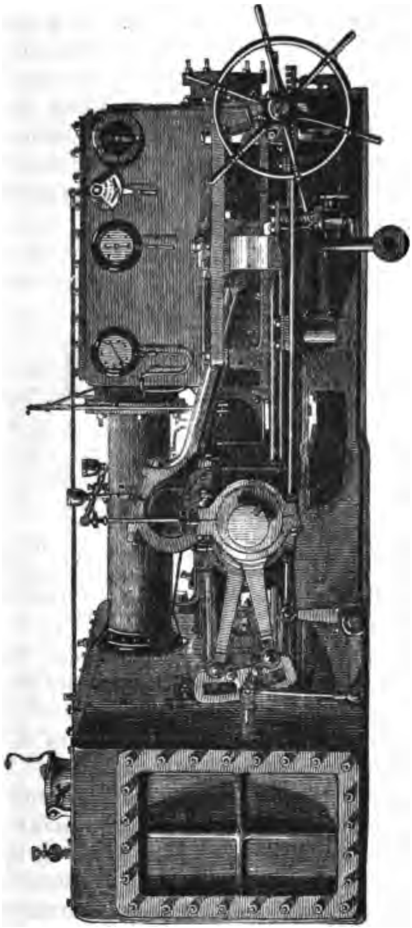
ENGINES OF THE DANISH ARMOUR-PLATED VESSEL ROLFE KRAKE, CONSTRUCTED BY NAPIER & SONS, GLASGOW.

constructed by Messrs. Napier, the piston rods, instead of being attached to a cross head moving in guides, were attached to a great plunger which constituted the bucket of the air pump; and from the bottom of this plunger, which was cast open at one end like a trunk, the connecting rod proceeded to turn the crank. But this plan is much inferior in simplicity and eligibility to that which Messrs. Napier have since adopted, as shown in *fig.* 57, and which, in the application of counter weights and otherwise, resembles the form of engine introduced by me in 1852.

Messrs. Day & Co. The screw engine of Messrs. Day & Co. of Southampton is also of the horizontal steeple variety, but in most of the details it is the most judiciously arranged engine I have met with. A representation of Messrs. Day's engine is given in *fig.* 58, which is engraved from a photograph of the engines of the steam screw yacht Brilliant, of 100 horse power, constructed by Messrs. Day. This vessel is 191 ft. long, 21 ft. broad, and of 419 tons builder's measurement. There are two engines, each with a cylinder 40 in. diameter, and 2 ft. stroke; and with a pressure of steam in the boiler of 20 lbs., and a vacuum in the condenser of 27 in. of mercury. The engines make 90 revolutions per minute, and exert 510 horse power. *Fig.* 59 contains two indicator diagrams taken from one of the engines, one diagram being taken from the cylinder on one side of the piston and the other diagram from the other side.

It will be seen by a reference to *fig.* 58 that the cylinders lie on the one side of the screw shaft, and the condensers on the other, as is the common arrange-

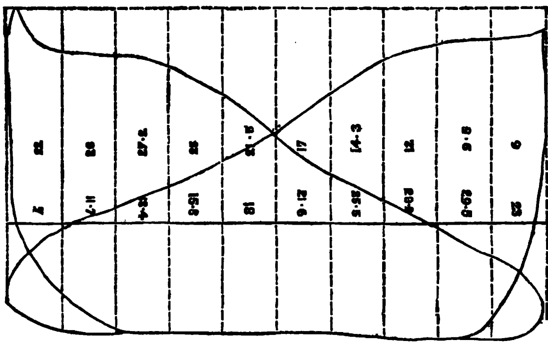
Fig. 58.



Horizontal Screw Engines of the Steam Yacht Brilliant, by Messrs. Day and Co., Southampton.

ment in this class of engine, and a single pipe conducts the exhaust steam from the cylinder to the condenser. The cylinders are cast with a square box around them, which is filled with steam from the boiler; but the upper part of the space between this box and the cylinders constitutes a passage for the exhaust steam, and is consequently separated from

Fig. 59.



INDICATOR DIAGRAMS FROM ENGINES OF SCREW STEAM YACHT BRILLIANT, BY MESSRS. DAY & CO., SOUTHAMPTON.

the rest of the box by a proper partition. The box itself is lagged to prevent the dispersion of the heat. The condenser stands between the guides of the two engines, in which situation it is quite out of the way, and leaves the guides perfectly accessible. Messrs. Day & Co. very generally employ surface condensers, but they are so compact that their presence is scarcely known by any external sign; and by merely opening a communication valve they may at any time be converted almost instantly into common condensers. The air pump of one engine acts as a circulating pump for the refrigerating water; and the water is sometimes drawn through the tubes and sometimes forced. The other air pump more than suffices to pump out the small quantity of water arising from the condensation of the steam; and the two air pumps are at any time available for their ordinary duties, should the condensation by jet be at any time resumed.

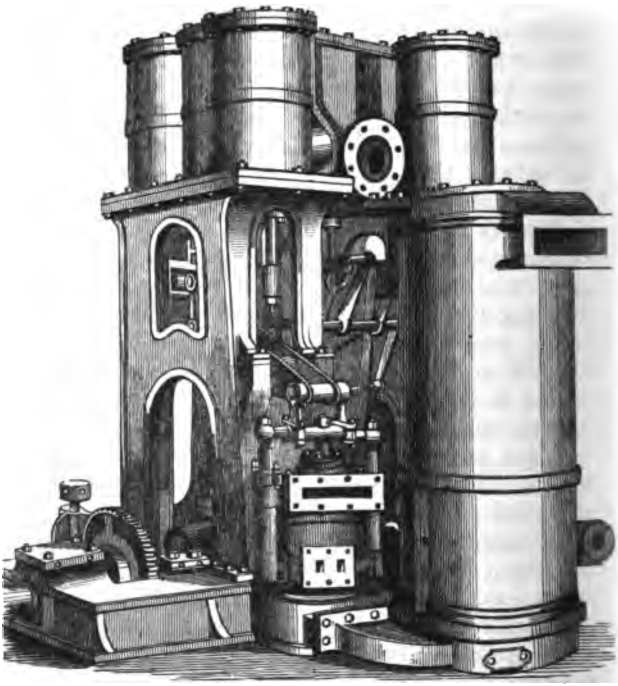
Messrs. Humphrys & Tennant. These makers generally employ double-cylinder engines, which in some cases, as in that of the Moultan, are vertical, and in other cases, like that of the Poonah, are horizontal. In the engines of the Moultan, the cylinders are inverted, and stand above the screw shaft; and the connecting rods, which are jointed to the ends of the piston rods as in locomotives, work down to the shaft. There are two large cylinders, and two small ones, the large cylinders being 96 in. diameter, and the small ones 43 in. The stroke of both is 3 ft. The two pistons are fixed on one rod, vertically over each other. The total heating surface in the boilers is about 12 sq. ft. per nominal horse power. The engines are fitted with Hall's surface condensers containing about the same surface as the boilers; and the cold water is caused to flow through them by a centrifugal pump on Appold's system, made by Easton & Amos. The boilers are also provided with Lamb's superheating apparatus, which contains about 3½ sq. ft. of surface per nominal horse power. The engines of the Poonah are similar to the foregoing, only horizontal. In Messrs. Humphry's recent horizontal engines, the air pump, which is also horizontal, and is placed beneath the condenser, is so constructed as to drain the condenser completely at every stroke; and the pump barrel is at all times filled with water, which being pressed by the air pump piston, displaces the water which last entered.

Messrs. Caird & Co. In their recent examples of screw engines, Messrs. Caird & Co. of Greenock have introduced surface condensers and other expedients to promote economy of fuel. The following are the principal particulars of the steamer Hansa, built to ply between Bremen and America :—The engines are direct acting, having inverted cylinders of 80 in. diameter, with a stroke of 3 ft. 6 in. The slide valves are double-ported, worked with a link motion, and having a variable grated expansion valve, placed immediately behind the main slide valve, worked by an eccentric and a shifting link, to vary the cut off from the cylinder as required. The crank shaft is 16 in. diameter at the bearings; the screw shafts are 14$\frac{3}{4}$ in. diameter; the propeller shaft bearings are covered with brass, and the stern pipe is bushed with brass. The surface condenser has 3,584 brass tubes, 1 in. external diameter, and 7 ft. long; the steam to be condensed surrounds the tubes, and cold water is passed through them at the rate of from 750 to 1,000 cubic ft. per minute, as may be necessary. The water is pumped from the sea by two horizontal double-acting pumps, worked from the forward end of the crank shaft. These pumps are 21 in. diameter, with a stroke of 24 in. The boilers are in four separate parts, having four furnaces in each part, with a total grate surface of 350 sq. ft., and a heating surface of

9,200 sq. ft. The superheating chest is placed immediately under the funnel, and has a total heating surface of 2,100 sq. ft. There are two safety valves to each boiler, loaded to 25 lbs. per sq. in. There is also an auxiliary boiler for keeping up the supply of fresh water that may be lost through blowing off steam, or from leaky joints. The grate surface of the auxiliary boiler is about 24 sq. ft., and the heating surface about 500 sq. ft. There is also a small boiler for working the deck winches; and a donkey engine for the steam of the boiler to work.

Rowan's Expansive Steam Engine. This species of engine combines the various improvements of a high pressure of steam with superheating and surface condensation; and is reported to have acted with a smaller consumption of fuel than has been heretofore attained in any engine whatever. In one case, an engine of this kind was reported by Professor Rankine as capable of working with a little over 1 lb. of coal per indicated horse power per hour; but this measure of economy does not appear to have been supported in practice. *Fig.* 60 is a representation of Rowan's engines as applied to drive the screw propeller. There are two inverted engines combined as usual at right angles, to turn round the screw shaft. But each engine has three cylinders—the middle one, which is the smallest, being a high pressure one, and the two side ones being low pressure. The three piston rods are connected to a cross head, and move up and down simultaneously. The steam, after having acted on the piston of the high pressure cylinder, passes into the low pressure cylinders, from whence

Fig. 60.



ROWAN'S TREBLE CYLINDER EXPANSIVE ENGINE.

it passes into a tall cylindrical vessel, traversed by small vertical tubes, and filled with cold water. The water surrounds the tubes; and through them the steam passes and is condensed and returned to the boiler as hot distilled water. An agitator is kept revolving within the cylindrical vessel to insure the cold water being equally distributed among all the tubes, and one of the air pumps is fitted up to maintain a circulation of water through the condenser, while the other is fitted to act as an air pump in the usual manner. About 10 or 11 sq. ft. of condenser surface per nominal horse-power is the proportion given in Rowan's engines.

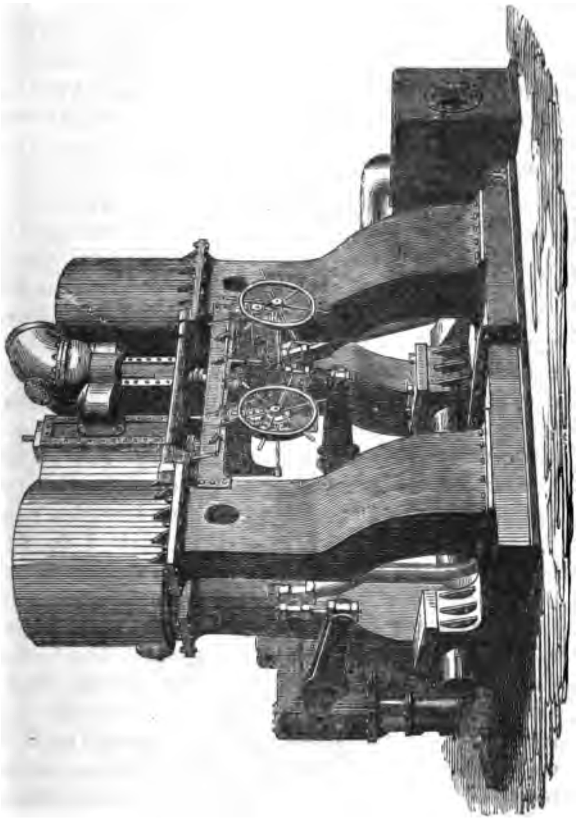
Messrs. Simpson & Co. Messrs. Simpson & Co. of London have lately introduced a species of double cylinder engine in which the high-pressure cylinder is placed within the low-pressure cylinder; the latter being in fact an annular cylinder, with a cylinder of smaller diameter within it. The steam is admitted and discharged from both cylinders by means of a single valve; and the arrangements appear on the whole to be such as will commend themselves to public approbation.

Millwall Iron Company. The direct acting engines constructed by the Millwall Iron Company for the West India Mail Company's screw steamer Rhone have two inverted cylinders working down to the screw shaft; and the engines are fitted with surface condensers, the pumps for maintaining a circulation through which are placed in a horizontal position at the end of the engines, and are worked off a crank on the end of the screw shaft. The intermediate shaft is formed of Krupp's steel; and the workmanship and materials of the engines are of the very first quality. A drawing of these engines is given in *fig.* 61.

In another set of engines by the same makers, there are three inverted cylinders working down to the screw shaft, and the cylinders have steam jackets and other economical arrangements which are expected to reduce the consumption to a little over 2 lbs. of coal per actual horse-power per hour.

Messrs. R. & W. Hawthorn. The marine engines of these makers have long enjoyed a very high reputation for efficiency and durability, and for a most remarkable exemption from accidental derangements or break-downs. Their screw engines are of the horizontal kind, with the condensers opposite to the cylinders; and long eduction pipes communicating from the one to the other as in Messrs. Penn's arrangement. But instead of the trunk, a short connecting rod joined to the piston rod is used after the fashion employed in locomotives. In the engines of H.M. screw gunboat Shearwater, constructed by Messrs. Hawthorn, the cylinders are 40 in. diameter, and the stroke 22 in. The nominal power is 150 horses, and the pressure of steam in the boiler is 20 lbs. per sq. in. There are two boilers of the ordinary gunboat construction, with three furnaces in each; and 297 brass tubes running at right angles to the furnaces, and containing a total heating surface of 2,892 sq. ft. or 19·2 sq. ft. per nominal horse-power. The Shearwater is a vessel of 669 tons; and with a displacement of 840 tons, and an area of midship section of 278 sq. ft., she realised a speed of

Fig. 61.



ENGINES OF THE STEAMER RHONE BY THE MILLWALL IRON COMPANY.

9 knots, the engines making 92 revolutions per minute, and exerting 632 actual horse-power. The screw propeller is one of Griffiths' of 10 ft. diameter.

Here, then, I close my remarks on marine engines of recent construction; and notwithstanding the innumerable and incessant efforts which have been made to introduce new improvements, I do not see that any considerable improvement has yet been introduced. Superheating, from which such exaggerated benefits were at one time expected, has collapsed to its proper dimensions; and it is now found that about the same amount of superheating as obtained in the old flue boilers is the most beneficial. The pressure has been gradually increasing, and that no doubt is a benefit if adequate measures be simultaneously adopted to increase the strength of the boiler. But the existing marine boiler is ill adapted to withstand any considerable pressure; and, as things now stand, to increase the pressure is to increase the risks of explosion. The method of surface condensation now so generally employed in steam vessels I do not believe will be permanently retained, at least in its present cumbrous form; and on the whole there is very little that is new in marine engines which can be characterised as a permanent amelioration. The introduction of the governor and the use of steel for shafts are valid steps of improvement, though not very momentous ones; and, indeed, the use of a steel shaft is only tantamount to the employment of an iron one so much larger than before. We now require marine boilers capable of enduring high pressures of steam with safety, and if salt water is used in the boilers, we require the introduction of some arrangement which will prevent the sulphate of lime from being precipitated on the heating surfaces, which takes place at a temperature answering to 40 lbs. pressure of steam without any concentration of the water at all. We also require the introduction of some simple and effectual mechanism for firing the furnaces, especially in the case of large vessels employed in warm climates. It would also be an advantage, especially in the case of vessels performing long voyages, if some really effectual and unobjectionable method could be introduced of burning the smoke.

LOCOMOTIVE ENGINES.

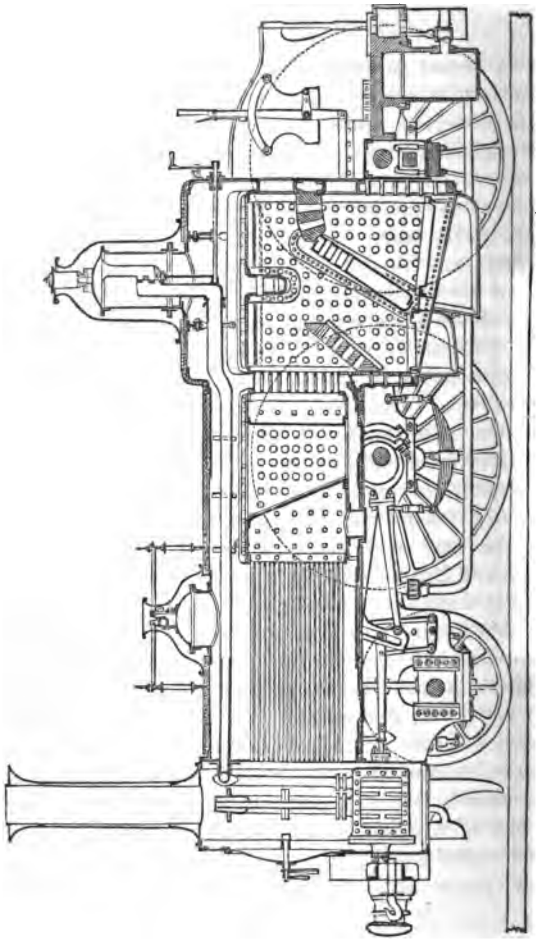
There are two main objects of aspiration which are set forth in the designs of many of the modern locomotives; the one to burn the smoke so as to enable coal instead of coke to be either wholly or partly used in the furnace; the other to realise great tractive power, so as to enable each goods engine to draw heavier trains than heretofore. Neither of these indications can be said to have been very perfectly fulfilled by any of the plans hitherto propounded for that purpose; and in seeking to increase the power, various forms of monstrosity have been produced, promising neither eminent success nor great longevity. In particular, the recent goods engines on some of the continental railways are remarkable examples of retrograde improvement; and it does not appear probable that the use of such cumbrous and gouty structures can long be retained after the stimulus of novelty attending their creation has passed away.

The various plans which have been propounded for burning smoke in locomotives are mostly reproductions of old plans long since tried in land and marine engines, and gradually abandoned. The principle on which these various arrangements are founded is either that of admitting air above the fuel, to burn the smoke, or that of using a sufficient area of fire bars, and a sufficiently thin fire, to enable the quantity of air required to burn the smoke to pass through the fire; and the smoke is conducted either among hot bricks and tiles, or over incandescent embers, to induce the more effectual union of the uncombined oxygen in the air with the unconsumed carbon in the smoke. All these methods, however, are only methods of approximation, which though they diminish the smoke by no means prevent it; and the consequence is, that locomotives pretending to burn the smoke, or unlawfully using coal even without this plea, are now spreading such large volumes of smoke over the face of the country as to constitute a new and serious nuisance. Heretofore coke only was used in locomotives, when of course no smoke was created. But, of late years, they have been gradually sliding into the use of coal; and the probability is, that the nuisance will go on increasing until it becomes intolerable, and is finally subverted by the strong hand of power. Some of the smoke-burning expedients employed are merely hollow pretexts for the evasion of the obvious duty of burning the smoke.

COAL-BURNING LOCOMOTIVES.

It would be impossible to enumerate within the limits to which these remarks have to be restricted, the numerous projects which have been propounded at different times for burning the smoke in steam boilers. Among those who have directed their attention to burning smoke in locomotives, the plans of Gray, Dewrance, Yarrow, M'Connell, Beattie, Cudworth, and Tembrinck, and especially the four last, have attracted most attention, and some of these expedients have obtained a pretty wide introduction. In M'Connell's arrangement the fire-box is divided longitudinally by a water space, so as in reality to form two furnaces like the furnaces of a marine boiler. Air is admitted at sundry openings at the front and sides of the fire-box, and the tubes are considerably shortened in the barrel of the boiler, so as to leave room for a combustion chamber in which the smoke may rest and be burned. In some of the forms of Beattie's boiler, a similar combustion chamber is employed, and an excellent and recent example of his engine is given in *fig.* 62, which is a representation of the express passenger engine Lacy, placed upon the London and South-Western Railway in 1864. In this engine the diameter of cylinder is 17 in.; stroke, 22 in.; working pressure, 135 lbs. per sq. in.; diameter of barrel of boiler, 4 ft.; length of barrel, 9 ft. 6 in.; length of fire-box, 4 ft. 6 in.; width of fire-box, 4 ft.; heating surface of fire-box and chamber, 178·36 sq. ft.; heating surface of hollow stays, 32·63 sq. ft.; heating surface of tubes,

Fig. 62.



BEATTIE'S COAL-BURNING EXPRESS ENGINE LACY.

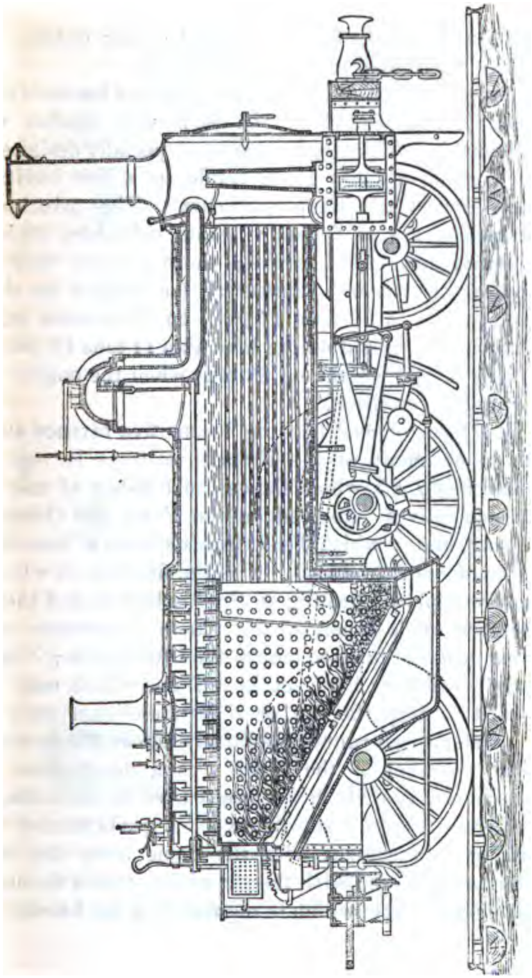
598·31 sq. ft.; total heating surface, 809·3 sq. ft. The driving and trailing wheels are coupled, and are 7 ft. in diameter; the leading wheels are 4 ft. in diameter. The distance between the driving and leading wheels is 6 ft. 2½ in., and between the driving and trailing wheels, 8 ft., making the total length of the wheel base 14 ft. 2½ in. The total weight of this engine is about 32 tons, distributed as follows: on the driving wheels 12 tons; on the leading wheels, 11 tons; and on the trailing wheels, 9 tons. There are 18 of these engines already made, and others in course of construction. The average consumption of fuel in these engines is 24 lbs. per mile, the average load being 15·5 carriages, and sometimes 30 carriages are taken. The average speed maintained with these engines is for express trains, 45 to 50 miles an hour, and for ordinary trains, 30 to 40 miles an hour. The piston rods, connecting rods, coupling rods, cross heads, wheel tires, and other main parts are of Bessemer's steel; and Allan's straight link is used for transmitting the motion to the valve.

The smoke is burned by dividing the furnace into two furnaces by the inclined water bridge running from side to side of the fire-box, which bridge is perforated; and the space between it and the furnace door is covered by a perforated fire block, thus forming an inclosed furnace, the smoke from which must escape through the perforations. This furnace is fitted with a door of its own below the ordinary fire door, which is placed higher than usual; and the furnace next the tubes may be fed with coke, while the other is fed with coal. The smoke escaping through the perforations is deflected by the hanging bridge down towards the incandescent coke, and is consequently in a great measure consumed; and the products of combustion pass through a number of short pipes into the combustion chamber, and from thence into the tubes. These engines are also fitted with Mr. Beattie's feed-water heater, which employs a portion of the exhaust steam to heat the feed-water boiling hot. In consequence of this arrangement, Mr. Beattie is precluded from using Giffard's injector; and the boiler is fed by pumps in the usual manner, which seems, all things considered, to be the preferable arrangement.

The peculiar feature of Cudworth's engine, represented in *fig.* 63, is the fire-box. This is made very long, and is carried back over the hind axle; the fire-grate is inclined towards the tube-plate, and at the lower end it is furnished with a trap-door through which the clinkers and ashes are discharged, and the fire is dropped. The fire-door is perforated; and air is admitted through it when necessary.

A thin fire is kept on the grate. The fresh fuel is supplied at the upper end only, and it gradually descends during combustion, so that there is only a bright clear fire at the lower end. The gases evolved from the fresh fuel mixed with air passing through the grate and door, are sufficiently heated in their way to the tubes to inflame, and hence less smoke is made. It is one of the advantages of this engine that owing to the fire-box projecting over the hind axle the weight on the coupled wheels is increased

Fig. 63.



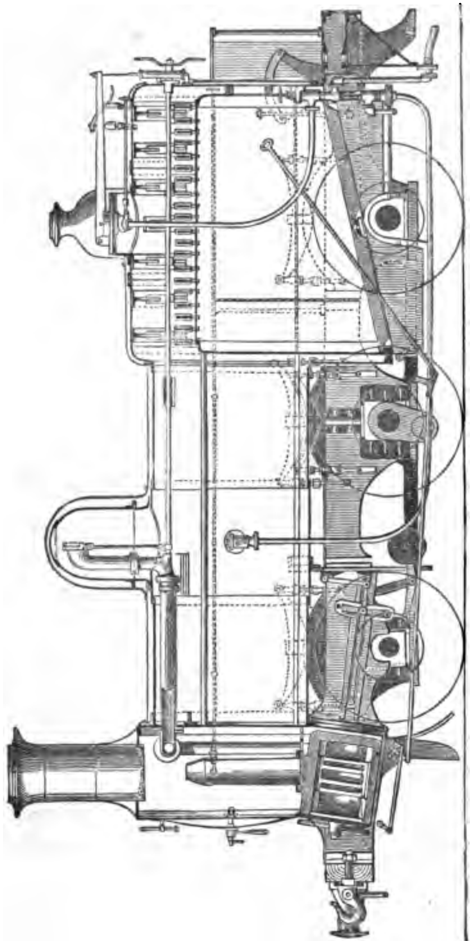
CUDWORTH'S COAL-BURNING LOCOMOTIVE. SOUTH EASTERN RAILWAY.

and equalised. In fact the weight of the engine is equally distributed over all the wheels.

Sharp, Stewart & Co.'s smoke-burning locomotive, which is represented in *fig.* 64, is very similar to Cudworth's. This engine has been specially designed for working a heavy goods traffic on a line having sharp curves and steep gradients. The principal dimensions are as follows: inside cylinders, 19 in. diameter, and 24 in. stroke; there are six wheels coupled, of 4 ft. 4 in. diameter: the weight on the leading axle is 12 tons 17 cwt., on the centre axle 13 tons 19 cwt., and on the hind axle 11 tons 13 cwt.; making a total weight of 38 tons when the engine is in running condition.

The form of coal-burning locomotive furnace employed on many of the French railways is represented in *fig.* 65, which shows the fire-box of one of the locomotives employed on the Paris and Orleans railway, and in which Tembrinck's system of burning the smoke is introduced. A is the fire-box in which the fire is placed, resting on the fire bars B, and these bars are made taper, so as to have a narrower air space near the furnace mouth than further in; C is a set of subsidiary bars set in a frame which may be opened to drop the fire, or to let the clinker out; D is a water space running obliquely across the furnace nearly parallel to the bars; E is a mouthpiece to receive the coal which is there roasted by the radiant heat from the fire; and the expelled gas is burned by coming into contact with the flame from the fire after being mixed with the air which enters through the air-valve at F, which is regulated by the handle G;

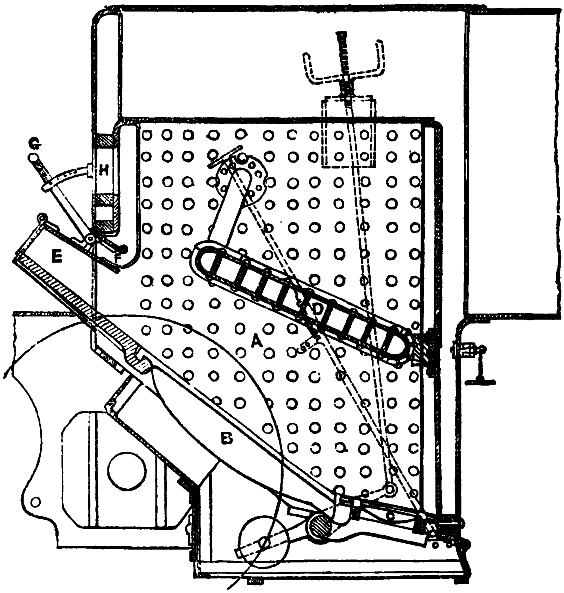
Fig. 64



SHARP, STEWART AND CO.'S COAL-BURNING LOCOMOTIVE.

H is one of the doors opening into the fire-box. It is stated that in these engines the evaporation with

Fig. 65.



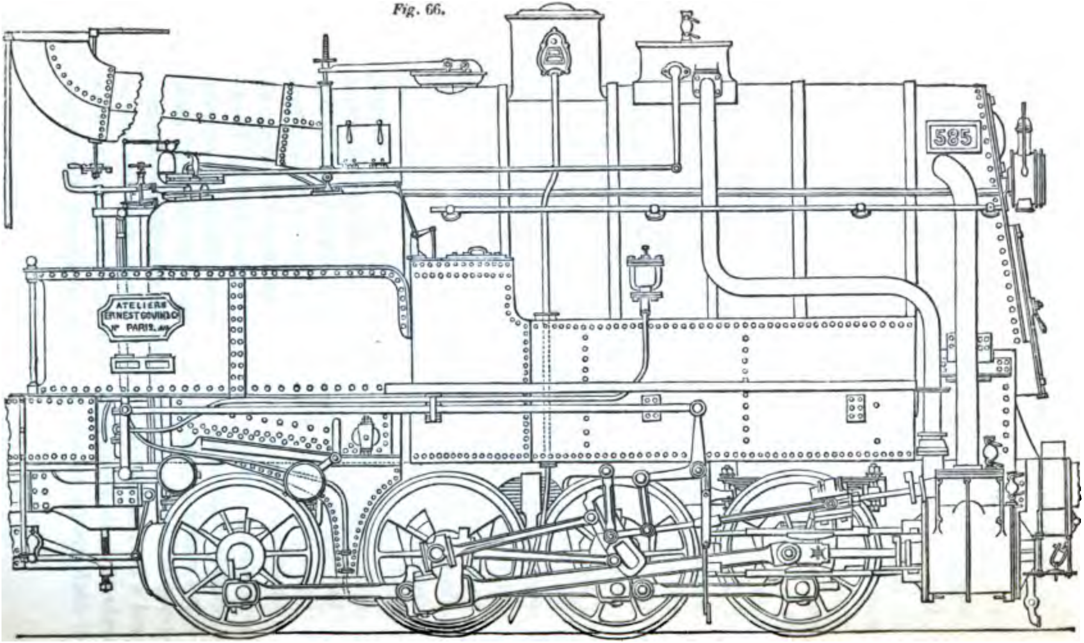
FIRE-BOX ON TEMBRINCK'S SYSTEM.

coal is about the same as with an equal weight of coke, and that the expense of the fuel is only half as great as when coke is employed.

FOREIGN GOODS LOCOMOTIVES.

Some idea will be formed of the kind of 'steam elephants' employed on some of the foreign railways in conveying goods, by a reference to *figs.* 66, 67, and 68, and which are a side elevation and two transverse sections of one of the 8-wheeled goods engines employed on the Northern Railway of France. It will be observed the fire-box is considerably wider than the width between the wheels; and the barrel of the boiler is crammed so full of tubes as to leave scarcely any room for steam, and little facility for the circulation of the water. Of course such a boiler will prime; but to meet this difficulty a superheater is carried along the top of the boiler: and as with all this gear the erection would be too high to go under the bridges with the addition of the chimney, a horizontal chimney a little turned up at the end is employed. Machines however even still more formidable than this are used in some cases; and on the same line engines with twelve coupled wheels and four cylinders are employed, two of the cylinders being placed at one end of the engine and driving six of the wheels, and the other two cylinders being placed at the other end of the engine and driving the other six wheels. So far as these parts are concerned, there are virtually two locomotives; but there is only one boiler resting on one framing, in which all the wheels are placed. To enable such a great length of coupled wheels, however, to get round curves the fore and after axles of each group of six wheels is susceptible of a little end play; and a horizontal lever with a fulcrum over the centre axle of each group extends to the fore and after axle of each group, to which it is so connected that when

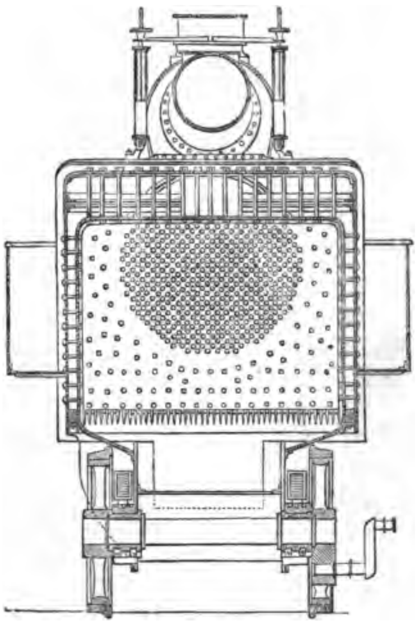
Fig. 66.



EIGHT-WHEELED GOODS ENGINE, NORTHERN RAILWAY OF FRANCE.

the fore axle moves a little on end in one direction, the after axle shall be constrained to move a little on end in the opposite direction. By this complex ar-

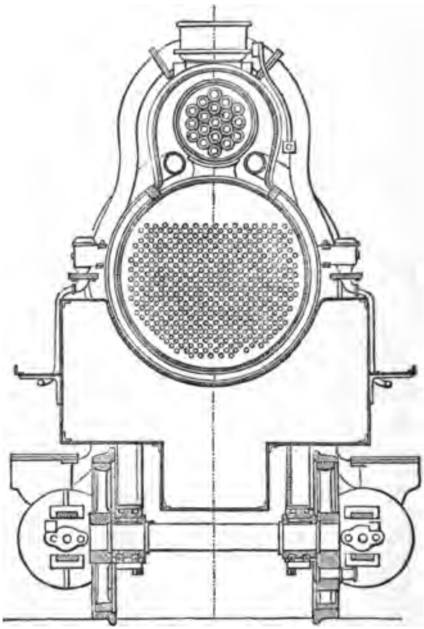
Fig. 67.



GOODS ENGINE NORTHERN RAILWAY OF FRANCE.
Cross Section through Fire-box.

rangement the one group of six wheels is enabled so to arrange itself relatively with the other group that an effect tantamount to that produced by a joint in the frame is obtained. The peculiar features of this engine will be better understood by a reference to *fig.*

Fig. 68.

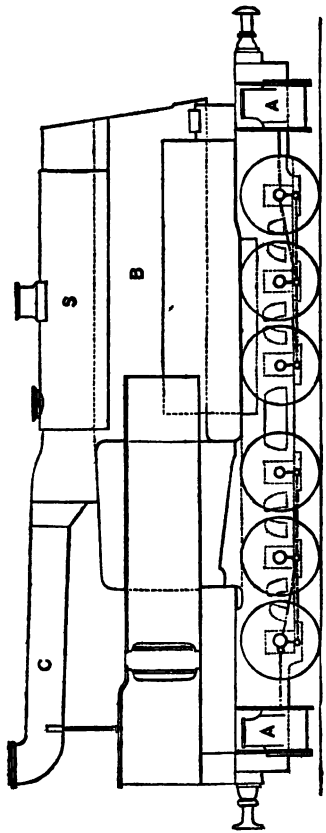


GOODS ENGINE, NORTHERN RAILWAY OF FRANCE.
Cross Section through Smoke-box.

69, where A A are the cylinders, B the boiler, S the superheater, and C the chimney.

One of the engines of the Orleans railway is represented in *fig.* 70, but as it resembles the construction

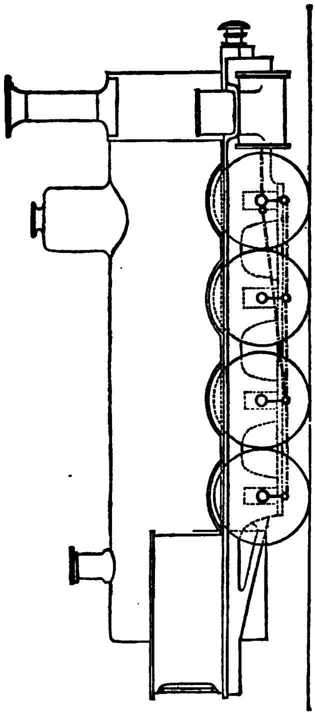
Fig. 69.



Four-Cylinder Locomotive with Six Driven Axles, Northern Railway of France.

of common locomotives, it is unnecessary to describe it.

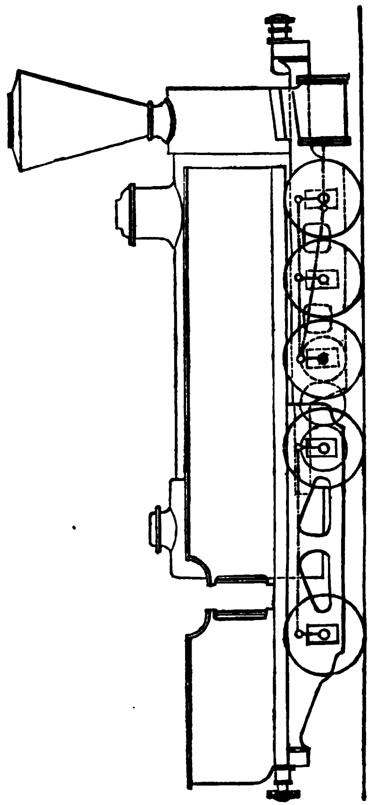
Fig. 70.



EIGHT-COUPLED WHEEL LOCOMOTIVE OF ORLEANS RAILWAY.

One of the steepest gradients which has to be surmounted by railways in any situation is that known as the Sœmmering incline, on the line from Vienna to Trieste, where it crosses the Styrian Alps. Various

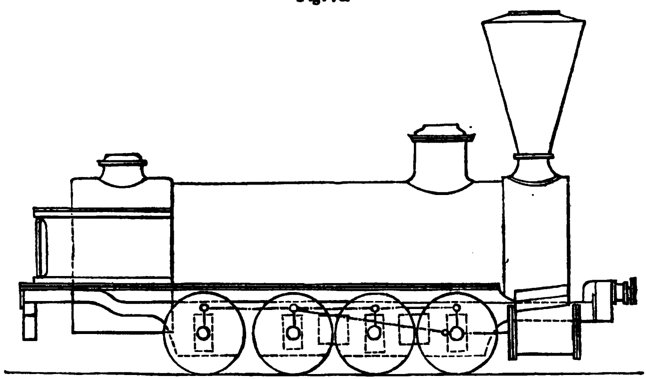
Fig. 71.



TEN-COUPLED WHEEL LOCOMOTIVE OF SŒMMERING INCLINE, 1856.

special forms of locomotives have been contrived to surmount this difficulty, in some of which the wheels of the tender were driven from the engine by pitched chains, and in other cases spur wheels between the axles are empolyed. *Fig.* 71 represents the form of engine employed on this service in 1856, and *fig.* 72 represents the form employed in 1861. In this last example the tender is attached to the engine in the

Fig. 72.



EIGHT-COUPLED WHEEL ENGINE OF SEMMERING INCLINE, 1861.

manner usual upon other railways; but in *fig.* 71 the tender is stuck on to the end of the engine and is supported upon wheels which are put into revolution by means of rods proceeding from the nearest wheels of the engine, which wheels are themselves put into revolution by means of gearing. Upon the third axle of the engine a toothed wheel is fixed, which gears into another toothed wheel of the same size, and this last wheel gears into another toothed wheel on the next axle and turns it round. The positions of these toothed wheels are shown in the figure by dotted circles.

In some of the forms of engine with four cylinders, and six coupled axles, three of the axles and two of the cylinders are attached to a framing, on which the boiler rests on two points, one on each side of the fire box, while the other three axles and the other two cylinders are attached to a bogie or independent carriage travelling upon a centre on which the smoke box rests, and this bogie accommodates itself to the curves of the road. Such a device however is only a clumsy approximation to two independent engines, and the use of two engines with the footplates brought together as recommended by me in my 'Treatise on the Steam Engine' in 1845, so that one set of handles might govern the movements of both engines and one stoker fire both furnaces, would be greatly preferable to the use of those uncouth leviathans. The great height of these engines relatively with the width of base necessarily makes them top heavy; while the relative narrowness of the gauge —which limits the diameter of the barrel of the boiler and consequently the area for the introduction of the tubes—has led to such crowding and such contraction of the areas in this part, as to diminish the efficiency of the heating surface, besides leading to other inconveniences.

The principal dimensions of some of the more remarkable of the continental locomotives are given in the following table:—

PARTICULARS OF FOREIGN

Line on which the Engine runs	Northern of France		
Kind of Engine	Engerth 4 coupled axles.	4 coupled axles.	4 cylinders 6 driven axles.
Diameter of cylinder in inches	19·68	18·89	17·32
Length of stroke in inches	25·98	18·89	17·32
Diameter of driving wheel in inches	49·60	62·99	41·73
Pressure of steam in lbs. per square inch	120	135	135
Heating surface of fire box in square feet	115·71	107·64	107·64
Heating surface of tubes in square feet	2004·55	1687·76	2371·17
Total heating surface in square feet	3120·26	1795·40*	2378·81†
Weight of engine in tons when at work	88	99	131·34
Weight of tender in tons laden	50·16	—	—
Total weight in tons of engine and tender at work	138·16	99	131·34
Weight producing adhesion in tons	88	99	131·34
Greatest load drawn in tons	655	436	655
Speed regularly maintained in miles per hour in ascending incline	12·4	12·4	12·4

* To this has to be added heating surface of superheater 130 square feet.

AMERICAN LOCOMOTIVES.

The American locomotives differ in several of their features from those which are employed in this country, and there is nearly always some special feature in the traffic, the fuel or the climate to warrant the distinction, and to render it judicious; but the difference is not nearly so great as that which obtains in some of the continental locomotives. The fore part of the engine is usually supported upon a small four-wheeled truck or bogie; a large cone is placed around the chimney for catching the sparks, which are very

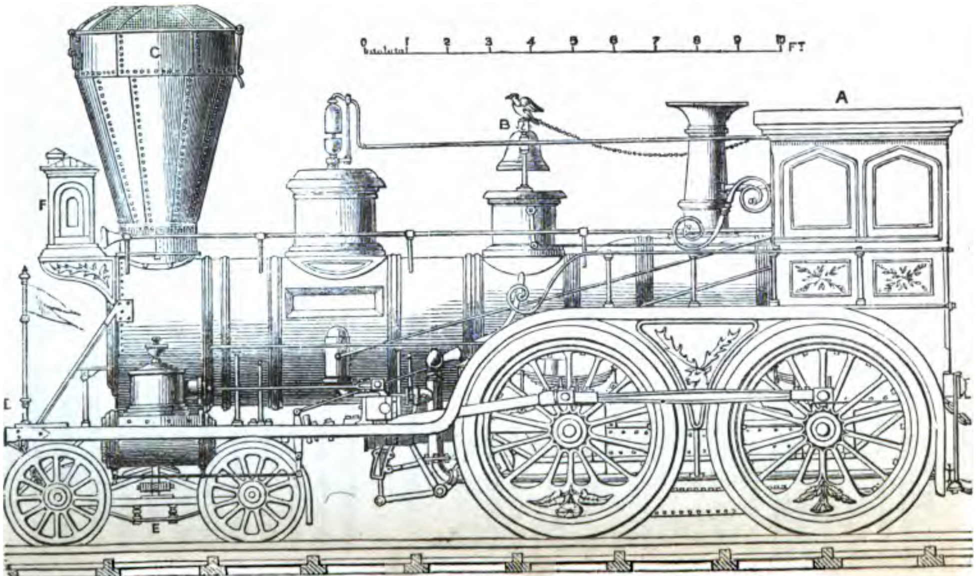
GOODS LOCOMOTIVES.

Orleans.	Lyons.	Eastern of France.	Western of France.	Sommering.	Turin.
4 coupled axles, separate tender.	3 coupled axles, separate tender.	Engerth 4 coupled axles, separate tender.	3 coupled axles, separate tender.	Engerth geared 5 coupled axles.	Double and 6 coupled axles.
19·68 25·69 45·66	17·71 25·59 51·18	19·68 25·98 49·60	17·32 23·62 55·11	18·70 24 01 41·92	15·98 21·96 48·03
120	120	120	120·135	146·25	117
114·50	89·34	104·49	86·11	75·35	157·15
2111·08	1245·08	2022·09	1442·35	1571·51	2006·23
2226·36	1334·42	2126·58	1528·46	1646·86	2163·52
9 ·24	81·4	99	72·6	91·52	145·2
40·04	44	52·8	44	57·2	
137·28	123·4	151·8	116·6	148·72	145·2
97·24 254	81·4 122	99 600	72·6 300	148·72 250	145·2 120
9·3	9·3	12·4	15·5	9·3	9·30

† To this has to be added heating surface of superheater 239 square feet.

inconvenient when wood is burned. A sort of inverted saucer over the mouth of the chimney deflects the sparks downwards into this cone, whence they are drawn off at intervals by a small door. The top of the cone is covered with wire gauze, to intercept any sparks which escape being driven out of the cone. In the front of the engine is an arrangement of bars of iron called a cowcatcher, for throwing any object off the line which may happen to be upon it; and this apparatus also acts like a snow plough, should snow have fallen on the line. *Fig.* 73 is a side elevation of a common form of American locomotive; A is a shed

Fig. 73.



Elevation of Locomotive Engine in general use on Railways in the United States.

or covering for protecting the engine driver from the weather; B is a bell which is rung when the engine approaches stations; C is an inverted cone round the chimney to catch sparks from the furnace; D, situation of cowcatcher; E is the truck or bogie by which the fore part of the engine is supported; and F is a lamp to give light by night. The driving wheels are generally four in number, coupled together; they are commonly from 5 ft. to 5 ft. 6 in. diameter, or when great speed is required, they are 6 ft., and sometimes 7 ft. in diameter; but it is almost the invariable custom to use four coupled wheels for all speeds. The coupled wheels are placed about 18 in. asunder; the hind pair is furnished with flanges, but the leading driving wheels are usually without flanges, and are commonly cylindrical, instead of being somewhat coned. The cylindrical wheels are said to wear much better than the coned, and to cause less oscillation. For working steep inclines, engines with eight wheels coupled, and from 2 ft. 6 in. to 2 ft. 9 in. diameter, are usually employed. These wheels are generally of chilled cast iron. It is usual to make the driving wheels of passenger engines with cast-iron centres and wrought-iron tires, but sometimes the tires are of chilled cast iron, which is said to be better fitted to endure the frost. In the heavy engines employed in transporting coal on the Reading Railway, and which burn anthracite coal, there are eight coupled wheels of 43 in. diameter, and the cylinders are 19 in. diameter, and 22 in. stroke; the boiler is 46 in. diameter, and contains 103 iron tubes, 2¼ in. external diameter and 14 ft. long; the furnace is 7 ft. long, and the bars are cast in pairs, and are made moveable by a lever, so that the clinker may be readily broken up. The ash pan is made to contain a few inches of water, to prevent the bars from being burnt out. A good deal of the coal is said to be wasted in these engines, from being carried up the chimney by the draught; and a good deal by falling through the bars of the grate. Upon the whole, anthracite coal cannot be said to have been very successfully introduced in locomotives. It is severe upon the furnace, and the evaporating efficacy reached does not appear to have been more than 7 lbs. of water per pound of coal, which is a good deal less than is obtained with coke.

There are generally no buffers between the engine and tender of American locomotives, but a wedge is interposed between the abutting surfaces to prevent shocks. In the various carriages of the train, central buffers alone are used. The whistle is larger than that used on the English lines. Glass gauges are not found to stand, and four or five gauge-cocks are employed instead. The feed pumps have air vessels both on the drawing and the forcing sides. The link motion is in universal use. The axle boxes are usually made close, and are supplied with oil, and provided with leather washers to keep the oil in. The boxes do not require to be packed or oiled more than once a month. The boxes are sometimes of bell-metal, sometimes of a composition of 92½ parts of zinc and 7½ parts of copper, and sometimes are lined with, or wholly composed of, soft metal.

To give toughness to the cast iron wheels, they require, after having been cast in a chill, to be annealed.

The wheels, therefore, as soon as they are set, and while yet red hot, are transferred to pits which have been made very hot by anthracite fires. The pits are hermetically sealed, to prevent the admission of air; and after three days the wheels are taken out, when the annealing process is found to be completed. The annealing does not affect the chilling of the tire, which is half an inch deep, as the operation of chilling takes place when the metal sets. It is necessary, however, with these chilled wheels to be careful not to apply the breaks too suddenly, so as to occasion slipping on the rails, as the friction takes out the chill at that spot and causes a flat soft place to form on the wheel, which destroys it altogether. Brake blocks of cast iron are used in some cases, and are found to be preferable to wood. The brakes are set by winding a chain in connection with them on an upright barrel having a handwheel at the top. In cases of emergency it has been proposed to work the brakes by a friction wheel which may be instantly pressed down on the driving wheel of the engine. A cord is carried along the top of every carriage of the train to a large gong bell placed on the engine. This cord is formed in lengths equal to the length of a carriage, and the pieces are connected together by metal snaps. A small shaft led along the top of each carriage with square or triangular ends and sockets and universal joints would be an equally simple arrangement. It is not found practically in America that there is any trouble in connecting the cord to the new carriages when a change in the carriages takes place.

The American railway carriages are of much larger dimensions than those employed in this country. The bodies are commonly made about 45 ft. long, 9½ ft. wide, and 7 ft. high. The carriages are open from end to end, and at the end doors are placed, opening upon platforms protected by railings, and establishing a passage between one carriage and the next adjoining. From the platform stairs descend, by means of which passengers enter or leave the carriages. The seats are ranged on each side of a central passage; and the backs of the seats are made to turn either way. On the roof of the carriages ventilators are placed; and there is a stove to warm the carriage in winter, and a supply of drinking water. To prevent the dust from arising, a canvas curtain has been introduced outside the wheels on some lines, extending from the carriage floor to the ground, whereby the dust is prevented from being sucked up by the motion of the train. In other cases jets of water propelled by a centrifugal pump, moved by a friction roller resting on one of the wheels, have been introduced in an air space on each side of the carriage, through which the air is admitted; and the air is thus cooled and freed from dust by the same operation.

The carriage rests at each end on a truck or bogie, the wheels of which are as far apart as the distance between the rails, so that the plan of such a truck forms a square. India rubber springs have been tried, but the result has not been satisfactory; and plate or volute springs are now usually employed.

In all the American locomotives, the internal fire box is considerably smaller at the top than at the bottom, so that the sides are much inclined, whereby the escape of the steam from the surface of the metal is facilitated, and the overheating of the plate prevented. The fire boxes are almost universally of iron. The tubes of the boiler are generally of copper—few iron or brass tubes being in use, except that in engines using anthracite coal, iron tubes are used to diminish the wear caused by the hard particles of coal carried up by the draught, and which copper cannot so well withstand. The general proportions of the American locomotives do not differ materially from those prevailing in England. On the whole, however, the blast pipes require to be smaller, and the draught more intense for engines burning wood, to maintain sufficient vividness of combustion; and the disposition now is to place the tubes farther apart than formerly, as has been long found in this country to be expedient. In some engines it has been found that an increased supply of steam was obtained by removing some of the central tubes; and the tubes are never placed closer than ¾ of an inch apart.

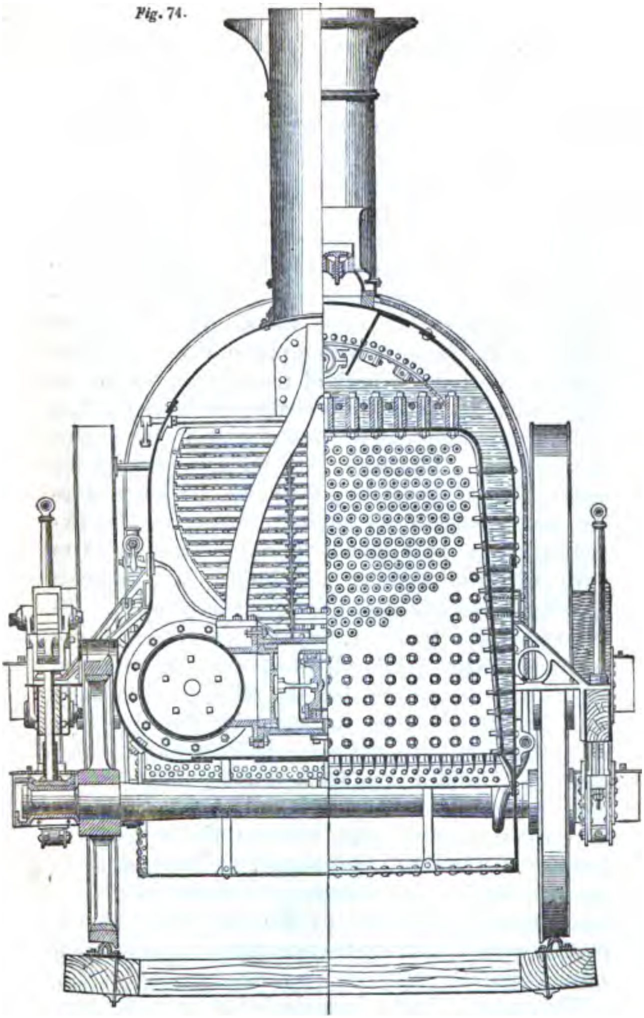
There is a separate blast pipe from each cylinder; and these pipes terminated at about the level of the lowest row of tubes. Suspended over these pipes, however, is a pipe entitled a 'petticoat pipe,' about 8 in. in diameter, which reaches nearly to the base of the chimney; and this pipe being generally made conical, has a petticoat configuration. The object of this arrangement is to equalise the draught through the different rows of tubes, as when the blast pipe is carried up to the level of the top row of tubes, the greatest draught will be through them.

STANDARD FORMS OF ENGLISH LOCOMOTIVES—BROAD GAUGE ENGINES.

The most powerful class of engines constructed for the broad gauge is that of the Great Britain and Iron Duke, of which the main particulars are given at page 84 of my 'Catechism of the Steam Engine,' and of which a cross section is given in *fig.* 74. In this engine, the cylinders are 18 in. diameter and 24 in. stroke. The grate contains 21 sq. ft. of area, and there are 305 tubes of 2 in. diameter in the boiler. The total heating surface is 1,952 sq. ft., and a cubic foot of water may be evaporated in the hour by every 5 sq. ft. of heating surface. An engine of this class will exert 750 actual horse-power. The pressure in the boiler is 100 lbs. per sq. in., and the initial pressure in the cylinder is about 10 lbs. less. But at high speeds the pressure in the valve box is greater than that in the boiler, which may be imputed to the momentum of the steam when its continuous flow is arrested by the shutting of the slide valve. At 60 miles an hour, when the handle which moves the link was in the first notch, and the steam cut off at $\frac{1}{4}$ of the stroke, the back pressure, when the area of the blast orifice was $\frac{1}{18}$ of the area of the piston, was 36 per cent. of the total pressure; and when the area of the blast orifice was enlarged to $\frac{1}{107}$ of the area of the cylinder, the back pressure fell to 10 per cent.

The pressure upon the slide valve of the Iron Duke

Fig. 74.



CROSS SECTION OF LOCOMOTIVE IRON DUKE, GREAT WESTERN RAILWAY.

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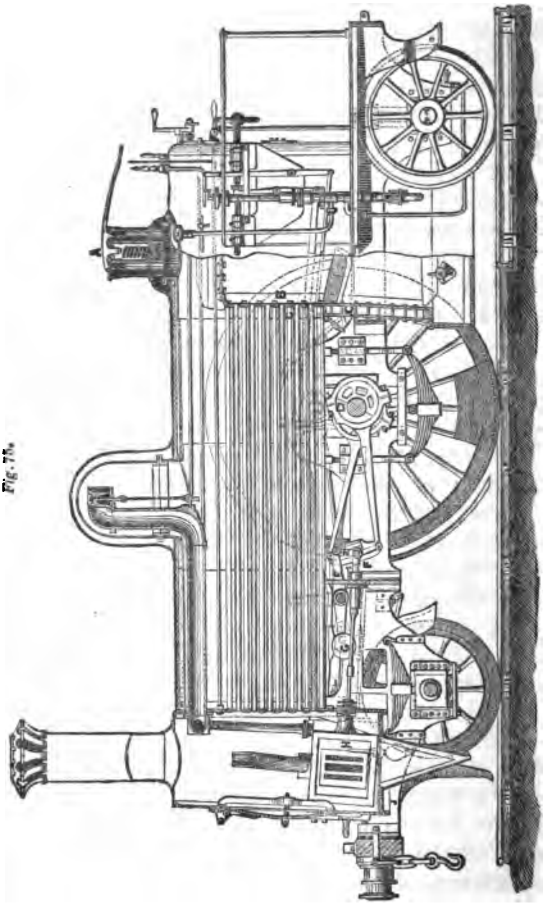
was relieved by means of a balance piston connected with the back of the valve by means of a link. But in locomotives this method of construction has not yet been carried out in a satisfactory manner. For moderately-sized engines it is perhaps hardly required, and a gridiron slide, which reduces the travel of the valve and correspondingly increases the leverage available for working it, is probably a preferable expedient in most cases. The benefit of taking off the pressure with a piston, instead of with a ring applied at the back of the valve as in marine engines, is that the valve is enabled to leave the face and let the water out of the cylinder if the engine should prime. But in the Iron Duke the pins at the ends of the link connecting the valve and piston were too small; and in all engines employing this expedient these pins should be very large so as to have adequate surface, and proper arrangements should also be introduced for their lubrication. To this end a close grease cup should be applied to the valve box with a side pipe to permit the steam to enter above the oil, so that the oil might gradually drip through the cock; and a suitable groove or shoot should be formed on the valve and piston to receive the drip of oil and conduct it to the joints in whatever position the valve may be when the drop falls. The communication pipe between the top of the piston and the blast pipe should be large, so as to equalise the pressure between the steam in the exhaust passage and that on the top of the piston else the valve will leave the face when the exhaustion takes place.

The steam is drawn from the boiler through a perforated steam pipe, and its admission to the cylinders is regulated by a gridiron slide set in the smoke box, and worked by a rod extending through the perforated steam pipe to the front of the boiler. The damper consists of an arrangement of iron venetians set against the ends of the tubes in the smoke box, each of which acts as a hanging-bridge in retaining the hottest smoke in contact with the tubes. These venetians are lifted or lowered by an appropriate handle, and the draught is thus regulated. The width between the rails on which the wheels of this engine run is 7 ft.

Narrow Gauge Engines—London and North-Western Railway. The type of express passenger engine employed on the London and North-Western Railway, and constructed at the Crewe Works, is represented in *fig.* 75, and the following are the principal dimensions of that engine:—Diameter of cylinder, 16 in.; stroke, 24 in.; driving wheels, 7 ft. 6 in. diameter; leading and trailing wheels, 3 ft. 6 in. diameter; weight on leading wheels, 9 tons 8 cwt.; weight on trailing wheels, 6 tons 2 cwt.; weight on driving wheels, 10 tons 10 cwt.—total weight, 27 tons; heating surface of fire box, 85 sq. ft.; heating surface of 192 tubes, $1\frac{7}{8}$ in. external diameter and 10 ft. 9 in. long, 915 sq. ft. (internal); total heating surface, 1000 sq. ft.

The distance of the leading from the driving wheels is 7 ft. 7 in., and the distance of the trailing from the driving wheels is 7 ft. 10 in.—making the length of the wheel base 15 ft. 5 in. The tender carries 2 tons of coal and 1,500 gallons of water, and

Fig. 75.



Express Passenger Engine, London and North Western Railway, 1865.

its weight laden is 17 tons 8½ cwt. It runs on six wheels of 3 ft. 6 in. diameter.

This form of express engine, designed by Mr. Ramsbottom, may be taken as representing the most approved form of construction in that class of locomotives in 1865. The arrangements are characterised by much simplicity and elegance; but their nature is made so clear by the drawing that it is unnecessary further to describe them.

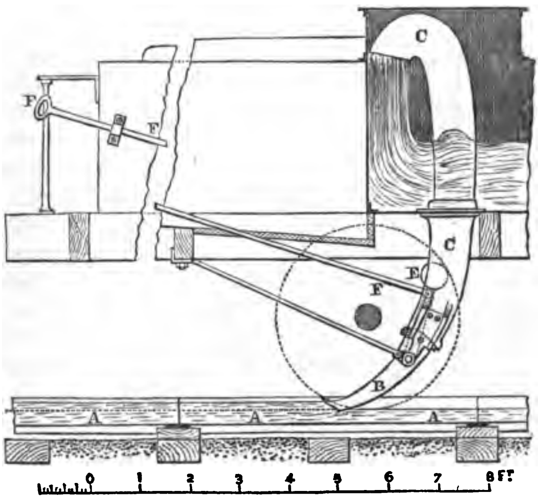
Supplying Water to Tenders while running. Mr. Ramsbottom has contrived an apparatus which, by enabling locomotive tenders to take in water while running, obviates the necessity of such numerous stoppages as were necessary heretofore. This apparatus, represented in *figs.* 76 and 77, consists of an open trough of water, lying longitudinally between the rails at about the rail level, and a dip-pipe or scoop attached to the bottom of the tender, with its lower end curved forwards and dipping into the water of the trough, so as to scoop up the water and deliver it into the tender tank whilst running along.

The water trough A of cast-iron, 18 in. wide at top by 6 in. deep, is laid upon the sleepers between the rails at such a level that when full of water the surface of the water is 2 inches above the level of the rails. The scoop B for raising the water from the trough, is of brass, with an orifice 10 in. wide by 2 in. high; when lowered for dipping into the trough, its bottom edge is just level with the rails and immersed 2 in. in the water. The water entering the scoop B is forced up the delivery pipe C, which discharges it into the tender tank, being turned over at the top so as to prevent the water from splashing over. The scoop is carried on a transverse centre bearing D, and when not in use is tilted up by the balance weight E clear of the ground. For dipping into the water trough it is depressed by means of the handle F from the footplate, which requires to be held by the engine-man as long as the scoop has to be kept down.

The upper end of the scoop B is shaped to the form of a circular arc, as is also the bottom of the delivery pipe C, so that the scoop forms a continuous prolongation to the pipe when in the position for raising water. The limit to which the scoop is depressed by the handle F is adjusted accurately by set screws, which act as a stop and prevent the bottom edge of the scoop being depressed below the fixed working level. The set screws also afford the means of adjusting the scoop to the same level when the brasses and tires of the tender have become reduced by wear, causing the level of the tender itself to be lowered. The orifice of the scoop is made with its edges bevilled off sharp, to diminish the splashing; and the top edge is carried forward 2 or 3 in. and turned up with the same object.

The water trough A is cast in lengths of about 6 ft., so as to rest upon each alternate sleeper, and is fixed to the sleepers, the height being adjusted by means of wood packing. The ends of each length are formed with a shallow groove, in which is inserted a strip of round vulcanised india-rubber, to make a flexible and watertight joint, the metal not being in contact; this meets all the disturbances arising from expansion, settlement of road, and vibration caused by the passage of trains. The length of trough now laid on the Chester and Holyhead Railway near Conway is 441 yds. on the level; and at each end the rails are laid at a gradient of 1 in 100 for a further length of 16 yds., the road being raised for that pur-

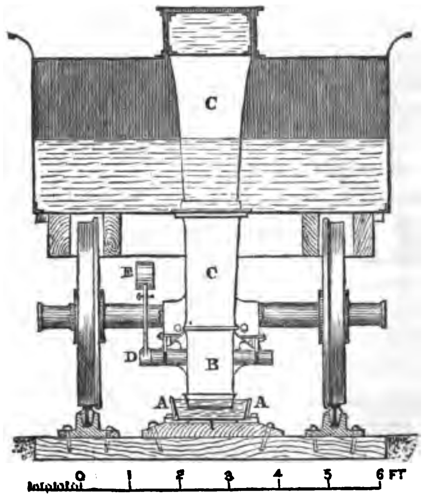
Fig. 76.



FEEDING SCOOP FOR RUNNING LOCOMOTIVES.

pose, so that the summit of the incline is 6 in. higher than the level portion: the trough is tapered off in depth to a bare plate, so that the same thickness of wood packing serves for fixing it throughout the entire length. The portion of the line where the trough is fixed is a curve of 1-mile radius, and the outer rail is canted 1 in. above the inner, the wood packing being made taper for fixing the trough horizontal; but the cant does not interfere with the efficient action of the scoop on the tender, since it amounts to only $\frac{1}{8}$ in. on the 10 in. width of scoop.

Fig. 77.



FEEDING SCOOP FOR RUNNING LOCOMOTIVES.

At each extremity of the water trough is an overflow pipe, limiting the height of water in the trough.

The trough contains 5 in. depth of water, and the scoop dips 2 in. into the water, leaving a clearance of 3 in. at the bottom of the trough for any deposit of ashes or stones. The trough is so constructed as to present no obstruction to be caught by any loose couplings or drag-chains that may be hanging from the trains passing over it; and experiments have been tried with a bunch of hook chains and screw couplings hanging down behind the tender and dragged along the trough without any damage occurring.

As to any difficulty from ice, a thorough trial has been afforded by severe winters; and by means of a small ice plough, which was run through the trough by hand each morning, the coating of ice was removed from the surface of the water, and no more was formed afterwards excepting a film so thin that it was removed by the scoop itself in passing through the trough, without being felt at all. It has indeed been shown, that the continuance of this action with the succession of trains in ordinary working would be sufficient in this climate to prevent the formation of any ice thicker than could be readily and safely removed by the passage of the scoop alone, even during the severest seasons.

The principle of action of this apparatus consists in taking advantage of the height to which water rises in a tube, when a given velocity is imparted to it on entering the bottom of the tube; the converse operation being carried out in this case, the water being stationary and the tube moving through it at the given velocity. The theoretical height, without allowing for friction, &c., is that from which a heavy body has to fall in order to acquire the same velocity as that with which the water enters the tube. Hence, since a velocity of 32 ft. per second is acquired by falling through 16 ft., a velocity of 32 ft. per second, or 22 miles per hour, would raise the water 16 ft.: and other velocities being proportionate to the square root of the height, a velocity of 30 miles per hour would raise the water 30 ft. very nearly (a convenient number for reference), and 15 miles per hour would raise the water 7½ ft—half the velocity giving one quarter the height. In the present apparatus the height that the water is lifted is 7½ ft. from the level in the trough to the top of the delivery pipe in the tender, which requires theoretically a velocity of 15 miles per hour; and this is confirmed by the results of experiments with the apparatus: for at a speed of 15 miles per hour the water is picked up from the trough by the scoop and raised to the top of the delivery pipe, and is maintained at that height whilst running through the trough, without being discharged into the tender.

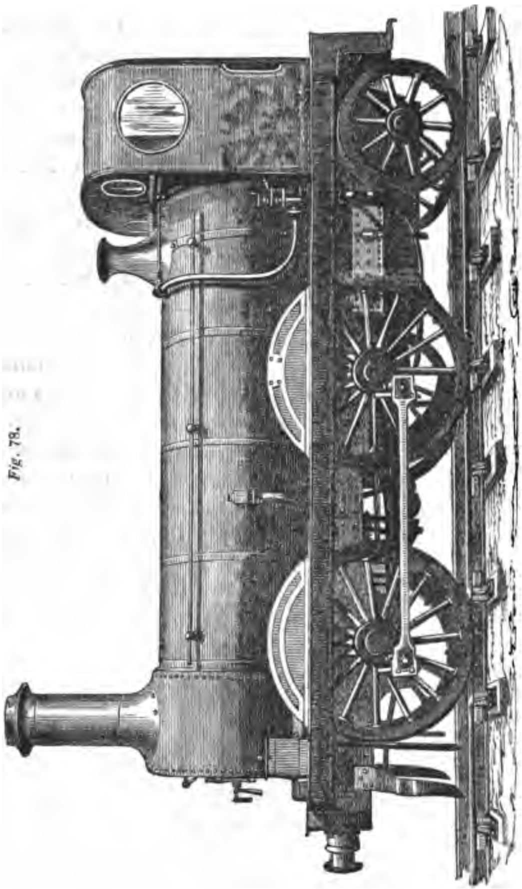
The theoretical maximum quantity of water that the apparatus is capable of lifting is the cubic content of the channel scooped out of the water by the mouth of the scoop in passing through the entire length of the trough; this measures 10 in. width by 2 in. depth below the surface of the water in the trough, and 441 yds. length—amounting to 1,148 gals. or 5 tons of water. The maximum result in raising water with the apparatus is found to be at a speed of about 35 miles per hour, when the quantity raised amounts to as much as the above theoretical total; so that, in order to allow for the percentage of loss that must unavoidably take place, it is requisite to measure the effective area of the scoop at nearly the outside of the metal, which is ¼ inch thick and feather-edged outwards, making the orifice slightly bell-mouthed and measuring at the outside 10½ in. by 2¼ in.; this gives 1,356 gallons for the extreme theoretical quantity. By experiment it appears that the variation in the quantity of water delivered is very slight at any speed above 22 miles per hour, at which nearly the full delivery is obtained; the greater velocity with which the water enters at the higher speeds being counterbalanced by the reduction in the total time of action whilst the scoop is traversing the fixed length of the trough. It also appears that at any speed above that which is sufficient to discharge the water freely from the top of the delivery pipe, all the water displaced by the scoop is practically picked up and delivered into the tender. In these experiments the water level was maintained the same in the trough each time by keeping it supplied up to the overflow orifice at each end; and the scoop was lowered to the same level each time by means of the set screws, the height of the tender itself being maintained practically the same in each case.

The construction of this apparatus was pressed upon Mr. Ramsbottom by the accelerated working of the Irish Mail, the arrangements connected with which made it necessary that the train should run from Chester to Holyhead (a distance of 84¾ miles) in two hours. A supply of 2,400 gallons of water is found to be required for this journey in stormy weather, and it became necessary, therefore, either very much to enlarge the tender tanks, or to introduce an arrangement under which the tender could take up water while running. The latter expedient was preferred, and it has now been matured and utilised with complete success.

Goods Engines — Glasgow and South-Western Railway. The most recent form of goods engine, constructed by Messrs. Hawthorn of Newcastle for the Glasgow and South-Western Railway, is represented in *fig.* 78. The following are the main particulars of that engine:—Diameter of cylinder, 16 in.; stroke, 22 in.; area of fire grate, 13·33 sq. ft.; heating surface of boiler, 930 sq. ft.; sectional area through tube ferrules, 1·986 sq. ft. The tubes are brass of 12-wire gauge at fire-box end, and 14-wire gauge at smoke-box end, fixed with steel ferrules at fire-box end only. Barrel of boiler 4 ft. diameter, and made of plates $\frac{7}{16}$ths thick. The leading and driving wheels are 5 ft. diameter coupled, and have tires of cast steel. The trailing wheels are 3 ft. 6 in. diameter, and have tires of the best Yorkshire iron. This class of engines has inside bearings only to all the axles, and the boiler is supplied with water by one of Giffard's No. 8. injectors.

Coupled Passenger Tank Engine—London, Chatham, and Dover Railway. This engine, also constructed by Messrs. Hawthorn, is represented in *fig.* 79, and its principal dimensions are as follows:—Diameter of cylinders, 15 in.; stroke, 22 in.; area of fire grate, 15·75 sq. ft.; heating surface of boiler, 906 sq. ft.; area through tube ferrules, 1·963 sq. ft. The tubes are brass, of 9-wire gauge at the fire-box end, and 13-wire gauge at the smoke-box end, and are fixed at each end with malleable cast-iron

Fig. 78.



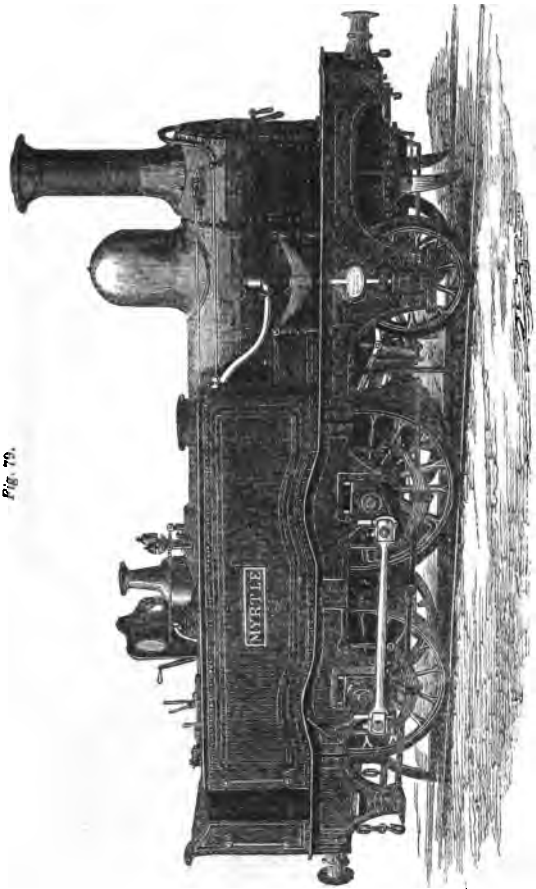
GOODS ENGINE GLASGOW AND SOUTH WESTERN RAILWAY.

ferrules. The barrel of the boiler is 3 ft. 9 in. diameter, and is made of $\frac{7}{16}$th plate. The leading wheels are 3 ft. 6 in. diameter, and the driving and trailing wheels are 5 ft. 6 in. diameter coupled. All the wheels have cast-steel tires. These engines have both outside and inside frames, and the boiler is supplied with water by two of Giffard's No. 8 injectors.

Coupled Express Passenger Engine—Great Northern Railway. This engine, also constructed by Messrs. Hawthorn, is represented in *fig.* 80. The chief dimensions are as follows:—Diameter of cylinders, 16½ in.; stroke, 22 in.; area of fire-grate, 14·92 sq. ft.; heating surface, 982 sq. ft.; sectional area through tube ferrules, 2·01 sq. ft. The tubes are of brass of 9-wire gauge at fire-box end, and 13-wire gauge at smoke-box end, fixed at each end by steel ferrules. The leading wheels are 4 ft. diameter, and the driving and trailing wheels of 6 ft. 6 in. diameter coupled. These engines have both inside and outside framing.

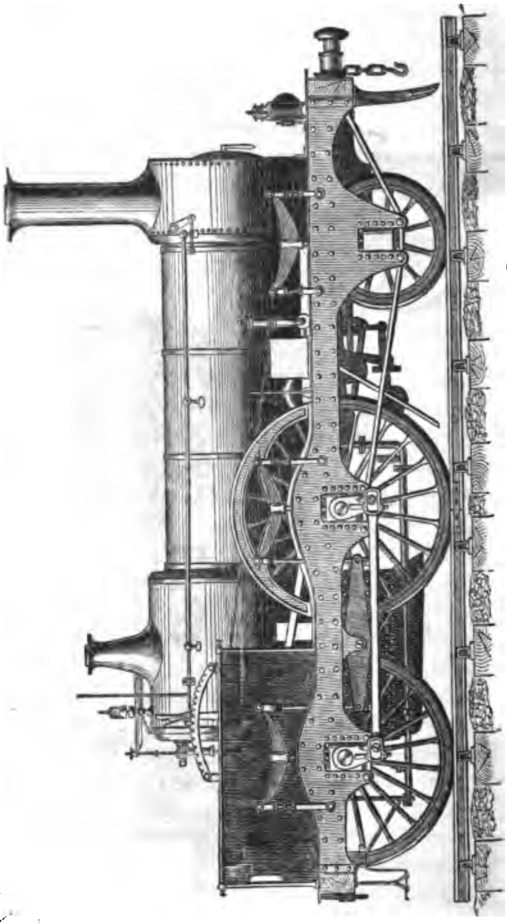
Goods Engine—Copiapo Extension Railway. This engine, represented in *fig.* 81, and also constructed by Messrs. Hawthorn, is somewhat on the American model, and it is intended to be capable of burning either wood or coal. The cylinders are outside cylinders of 16 in. diameter, and 24 in. stroke. The area of fire-grate is 15·77 sq. ft.; area of heating surface, 1,102 sq. ft.; and sectional area through tube ferrules, 2·147 sq. ft. The tubes are of brass of 11-wire gauge at fire-box end, and 14-wire gauge at smoke-box end; fixed in with steel ferrules to every

Fig. 79.



Coupled Passenger Tank Engine, London, Chatham and Dover Railway

Fig. 80.



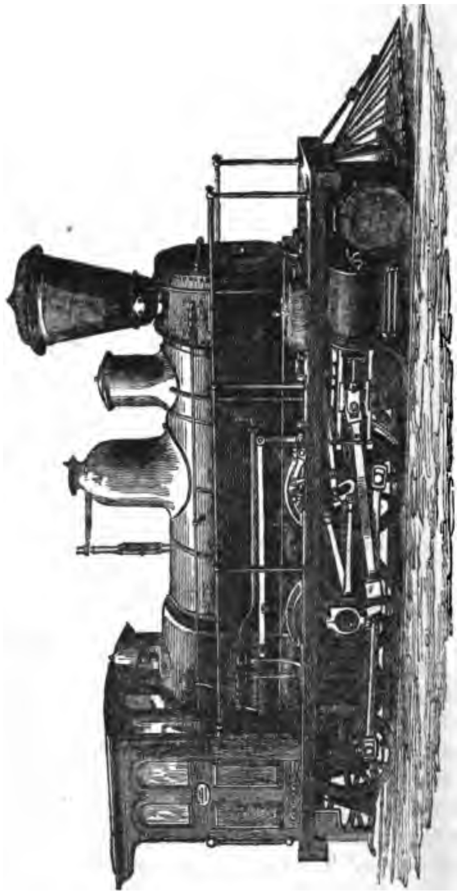
COUPLED EXPRESS PASSENGER ENGINE, GREAT NORTHERN RAILWAY.

tube at fire-box end, but with only every sixth tube ferruled at smoke-box end. The barrel of the boiler is 4 ft. 2 in. diameter, formed of plates $\frac{7}{16}$ths thick. The fire end of the engine is carried on a four-wheeled bogie or truck, with wheels of cast-steel 2 ft. 6 in. diameter; and there are three pairs of driving wheels all coupled, made of malleable iron and fitted with steel tires. There is also a spark-catcher on the chimney, of the kind usual in locomotives where wood is burned. These engines are all fitted to work with a pressure of steam in the boiler of 130 lbs. on the sq. in.; and, with the exception of the Great Northern engine, they all burn coal. Their symmetry, simplicity, and excellent proportions furnish a remarkable contrast to some of the continental engines, and do great credit to the persons concerned in their production. The ponderous class of engines called Crampton's engines, at one time employed in this country, has now gone out of use. Their great weight was found to be very injurious to the rails.

DETAILS OF MODERN LOCOMOTIVES.

Cylinders. It is very material that the cylinders and valves should be made of as hard metal as possible, as the hardness of the metal will mainly determine the durability. Sometimes valves will run only twelve months before requiring to be renewed, and they require to be refaced at the end of six months. But Stephenson's engines run four years, and have been known to run as long as seven years, without requiring material repair. The metal of the cylinders is so hard that a file will scarcely touch it.

Fig. 81.

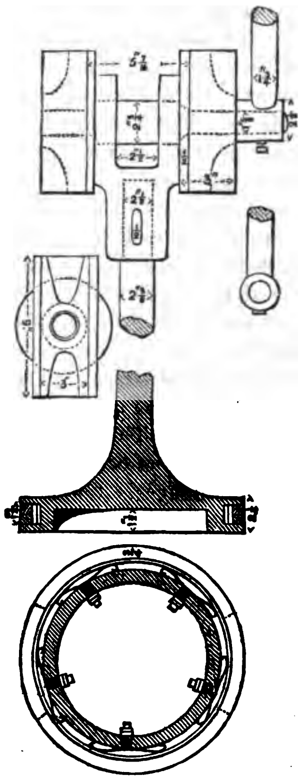


HAWTHORN'S GOODS ENGINE FOR COPIAPO EXTENSION RAILWAY.

The cylinders should always be directly connected with the frames of the locomotive, so as to discharge the whole strain upon them without communicating it to the boiler, as is the case when the cylinders are fixed to the boiler. Inside cylinders are cast in two parts, and are jointed by being scraped to an even surface. The joining surfaces should make a good joint by being greased with tallow and bolted together. The cylinders are formed with flanges for attaching them to the frames, and those flanges are planed parallel to each other: they are formed with a ledge on each side to rest on the edge of the frame, and are each bolted to the frame by twelve ¾-in. bolts. When outside cylinders are employed, they are bolted in the same manner to the outside and inside frames. The valve casing is cast on the cylinder. The area of the steam ports is in some cases one-ninth, and in other cases one-twelfth or one-thirteenth of the area of the cylinder, and the eduction port one-sixth to one-eighth of the area of the cylinder—proportions which allow, at mean speeds of 25 to 30 miles per hour, a pressure little different from that of the steam in the steam pipes to exist. For higher speeds the ports should be larger in proportion. The valve casing is covered with a door, which can be removed to inspect the valve or the cylinder face. Some valve casings have covers upon their front end as well as on their top, which admits of the valve and the valve bridle being more readily removed.

The valve stuffing box is commonly made to receive from 2 to 3 in. of hemp packing. The best form of valve casing to afford access to the faces is formed with a large cover underneath the cylinders, and with wrought iron end covers. The end covers can be easily taken off, and in case the cylinder faces have to be removed or filled up the large cover can be taken off, and the faces are then easy of access. With this form of chest the cylinders may be cast together in one piece. All the joints about the cylinders are made metal to metal. The cylinder barrel is $\frac{3}{4}$ to $\frac{13}{16}$ in. thick, and the flanges are $1\frac{1}{8}$ in. thick, finished size. The cylinder and valve chest covers, when of cast metal, are from $\frac{7}{8}$ to $1\frac{1}{8}$ in. thick, and the bolts are from $\frac{3}{4}$ to 1 in. diameter, pitched from $3\frac{1}{2}$ to 5 in. asunder. The thickness of the valve chest is $\frac{5}{8}$ to $\frac{3}{4}$ in. The cylinders are joined together by 1-in. bolts from 5 to 6 in. apart. Slide valves have been made of cast iron, and they wear longer than brass; but brass is to be preferred, as it does not wear the cylinder's face so much. The body of the valve should be $\frac{3}{8}$ to $\frac{1}{2}$ in. thick, and the face $1\frac{1}{4}$ in., although some valves are as little as $\frac{3}{4}$ in. thick in the face. The exhaust cavity should be about $2\frac{1}{2}$ in. deep, and well rounded off, so as to give a free exhaustion. The end of the valve rod should be forged in the form of a square ring or frame, into which a large square projection on the back of the valve fits. This ring should have a good broad bearing surface, so as to lessen the chance of wearing loose. A cock is still placed at each end of the cylinder, to allow the water to be discharged, which accumulates there; and the four cocks of the two cylinders are connected, as heretofore, so that by working a single handle the whole are opened or shut at the same time. A cock is also sometimes fitted to each of the covers of outside cylinders with the end formed into a swivel joint, so as to admit of being turned upwards to allow melted tallow and oil to be poured through it with the cylinder. But on the whole it is now judged preferable to use an apparatus which will feed the tallow to the cylinder continuously. A good deal of saving in tallow is accomplished by this apparatus, and the pistons are kept in better order. The valve faces are supplied with grease by oil cups, one on each side of the smoke box, provided with double cocks, so that a supply of oil may be admitted during the time the engine is at work. But here also it is desirable that the supply should be continuous.

Pistons and Piston Rods. Piston rods are sometimes made with a disc forged on one end about 3 in. thick and 6 in. diameter, a recess being bored out in the piston to receive the disc. The body of the piston is slipped down upon the rod until it encounters the disc, to which it is made fast with four $\frac{3}{4}$-in. or $\frac{7}{8}$-in. rivets. Sometimes the rod is only tapered into the piston and cuttered. The piston is made of cast iron or brass, but generally the latter, which is preferable to cast iron, as it does not so easily break under the action of priming and loose bolts, and it is also lighter. The thickness of the metal in the body for cast iron is $\frac{3}{4}$ to $\frac{7}{8}$ in., and for brass $\frac{5}{8}$ in. The thickness round the hole into which the rod is cuttered is $1\frac{1}{4}$ in. for brass, and for cast iron $1\frac{3}{8}$ in. The total breadth of the piston is from $2\frac{1}{2}$ to $4\frac{1}{2}$ in., and the cutters are $1\frac{5}{8}$ to $1\frac{7}{8}$ in. broad, and $\frac{5}{8}$ in. thick, tapering $\frac{3}{8}$ in. per foot. The rings are from $\frac{3}{4}$ to $1\frac{1}{4}$ in. broad, and $\frac{3}{4}$ in. thick. For soft cylinders brass piston rings are best, but for hard cylinders cast iron rings wear very smooth and require less looking at. On the London and North-Western Railway and on some other lines a wrought iron piston is used, the rod and piston being forged in one piece. The piston is recessed on the circumference to receive the packing rings, of which there are two for a 16-in. piston. These rings are formed of brass, and one is placed in each recess or groove. Under each ring there is a steel hoop $\frac{1}{8}$ in. thick, of the same breadth as the packing ring, which is $\frac{1}{2}$ in. broad and $\frac{1}{2}$ in. thick The depth of the recesses is $\frac{3}{4}$ in., and the thickness of the piston at that part is $\frac{3}{8}$ to $\frac{1}{2}$ in. The total breadth is $2\frac{1}{8}$ and $2\frac{1}{2}$ in., and the ends of the piston are recessed, so as to leave the body $1\frac{1}{2}$ in. thick. The brass rings are formed in two parts, and jointed with tongue pieces $\frac{1}{8}$ in. thick. The steam is admitted behind the ring through $\frac{3}{16}$-in. holes drilled in the back. The top of the piston rod is secured by a cutter into a socket with jaws, through the holes of which a crosshead passes, which is embraced between the jaws by the small end of the connecting rod, while the ends of the crosshead move in guides. The cross-head is made of wrought iron, and the piston rod is tapered where it joins the crosshead at the rate of about 1 in 30, and is secured by a cutter $\frac{3}{8}$ to $\frac{1}{2}$ in. thick, and 2 in. broad, tapering to $1\frac{3}{8}$ in. The crosshead is placed transversely to the guide bars, and is from $2\frac{1}{2}$ to $3\frac{1}{2}$ in. in diameter at the part where it enters the guide blocks. The feed-pump rod joins the crosshead outside the guide blocks. A good form of locomotive piston is shown in *figs.* 82, 83, *Figs.* 82, 83, and 84.

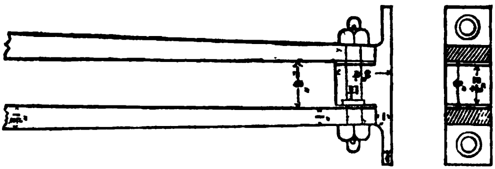


LOCOMOTIVE PISTON, CROSS HEAD, AND GUIDE BLOCK.

and 84, which also show the piston rod, crosshead, and guide blocks. The piston rod, it will be seen, is formed in the same piece with the piston. The packing rings are formed in two tiers, breaking joint with one another; and they are pressed out by springs, tightened by screws passing through the body of the piston. The cylinder bottom has a projection upon it to fit the recess in the piston, whereby waste of steam is prevented.

Guides. Most makers still attach their guides at one end to a cross stay, and at the other end to lugs upon the cylinder cover; and they are made stronger in the middle than at the ends. Some guide bars are grooved out to a depth ¾ to 1 in., being flat at the bottom, but wider at the top than at the bottom—the sides of the groove being sloped. The guide blocks are of brass; and in wearing down they maintain their position in the groove. This mode of construction prevents side play, such as occurs with flat bars and blocks with lateral flanges. Guides are best when made double, so as to admit a single-ended connecting rod. The guide blocks are commonly from 9 to 10 in. long and 3 in. broad, with ½-in. flanges in the case of flat bars. They are made of cast iron chilled, or wrought iron steeled. Sinclair uses cast iron for both blocks and bars, and it is said they wear well if properly attended to. I have also used the same in marine engines with the piston travelling 700 ft. per minute. Solid steel bars and brass blocks run well together. The bars are from 1½ to 2 in. thick at the middle, tapering to 1 or 1½ in. at both ends, and from 2½ to 3 in. broad. They are generally fixed at one end to the cylinder cover, and at the other end to brackets bolted or rivetted to the motion plate by two $\frac{7}{8}$-inch bolts or rivets. An example of the ordinary kind of guide bars is given in *figs.* 85 and 86:—

Figs. 85 and 86.



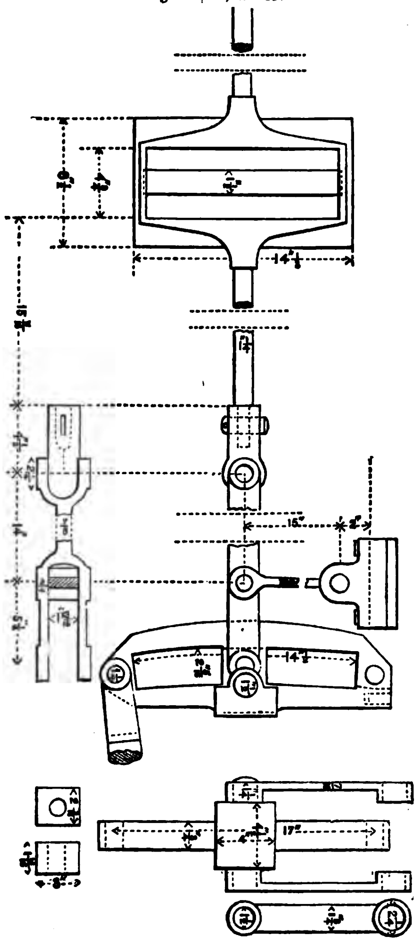
GUIDE-BARS OF LOCOMOTIVES.

Link Motion. The link motion proper for locomotives resembles the link motion as applicable to marine engines, of which I have already given examples. The valve spindle is from $1\frac{1}{4}$ to $1\frac{1}{2}$ in. diameter, and works through a stuffing box at each end of the valve chest. The end which is connected with the link motion is sometimes coupled to a square guide, which works in a socket fixed to the guide bars, and in outside cylinders to the side of the frame. On the end of the spindle is a socket secured by a cutter and jointed to a connecting rod $\frac{3}{4}$ to $1\frac{1}{8}$ in. thick, and 2 to 3 in. deep, which is, in most cases, suspended by a link from the boiler bottom and has a forked end, between which the motion or slotted link works. To each end of the slotted link an eccentric rod is coupled by a $1\frac{1}{8}$-in. pin. The other end of the eccentric rod is attached to the eccentric strap; and thus the valve derives its motion, in the manner explained elsewhere. An example of the slide valve and link motion, as usually applied in modern locomotives, is given in *figs.* 87, 88, and 89. In this view the valve is shown at the one end of the valve rod and the link at the other. To the ends of the link the eccentric rods are attached. The end of the valve rod nearest the link is sustained in its position by a short supporting link; but a guide would be better, as the versed sine of this link will distort the motion. The end of the valve rod joins the block which is placed within the link, and derives its motion from it.

Eccentrics and Eccentric Rods. In *fig.* 90 we have an example of the eccentric strap and rod of a modern locomotive. The eccentric is put on in two pieces secured together by cutter bolts; and it is secured on the axle by a key and also by two screw bolts penetrating a short distance into the axle. In Sinclair's Rouen Engines with straight axles the four eccentrics were cast in one piece.

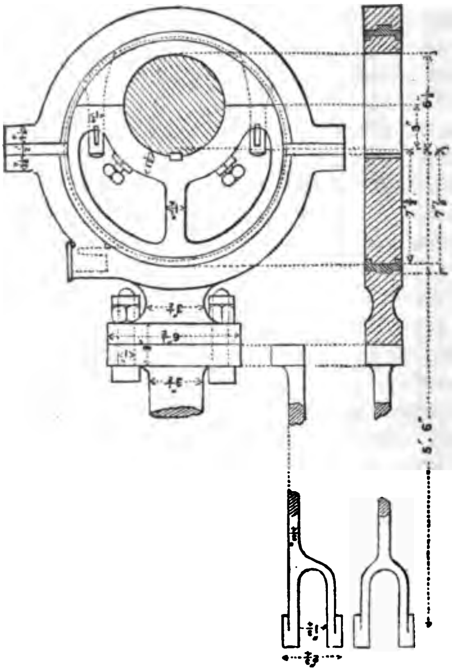
Sometimes eccentrics are made of wrought iron, and are steeled by case-hardening. Generally the smaller half of the eccentric is now made of malleable iron, though the larger half may be made of cast iron. When thus formed the weakest part is $\frac{3}{4}$ in. thick. If the eccentric be wholly of cast iron, it should be $1\frac{1}{2}$ in. thick in the weakest part. In addition to a pinching screw it should be secured by a key, let $\frac{1}{8}$ in. into the shaft, and $\frac{1}{4}$ in. into the eccentric. Most eccentrics have square grooves turned on the edges, into which fits a corresponding internal flange on the hoop or brass. The ordinary form of eccentric and hoop is shown in *fig.* 90.

Figs. 87, 88, and 89.



Locomotive Valve, Link-motion, and Connections.

Fig. 90.

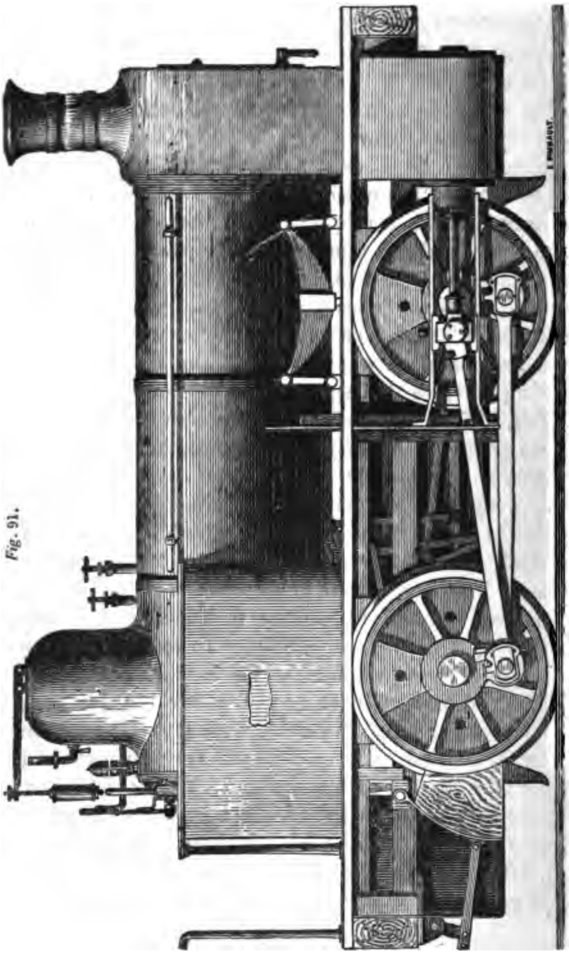


LOCOMOTIVE ECCENTRIC WITH ECCENTRIC STRAP AND ROD.

Mineral Locomotives. A class of locomotives is employed at collieries, and to carry iron ore and other minerals, of a cheaper construction and a smaller size than the common locomotives. At the Great Exhibition in 1862, Messrs. England & Co. exhibited an engine with 11-in. cylinders, six wheels—four of them coupled—of 4 ft. diameter, and with 153 tubes 1¾ in. diameter in the boiler. Messrs. Manning, Wardle & Co. of Leeds exhibited a colliery locomotive with 9-in. cylinders, four wheels coupled, of 2 ft. 9 in. diameter, and 55 tubes of 2 in. diameter in the boiler; the area of the grate being 4·9 sq. ft., and the pressure of steam 120 lbs. per sq. in. The Neath Abbey Iron Company exhibited a locomotive adapted for running on a gauge of 2 ft. 8 in. It had 8-in. cylinders, four coupled cast-iron wheels of 2 ft. 4 in. diameter, and 59 tubes in the boiler, 1½ in. diameter and 6 ft. long. The area of grate was 3·5 sq. ft., the total area of heating surface 181 sq. ft., and the weight 6 tons 17 cwt. With steam of 66 lbs. pressure it could draw 12 waggons, each weighing 4½ tons, at a speed of 8 miles an hour.

A very good example of a mineral locomotive engine is represented in *fig.* 91, which is a form of mineral tank locomotive engine, constructed by Messrs. Fletcher, Jennings & Co. of Whitehaven, who have devoted themselves to the special manufacture of this class of engine. In this engine the valve gear is worked from the fore axle so as to enable the hind axle to be got under the fire box, and thereby reduce the overhanging weight. The water is carried in tanks beneath the foot plate and under the barrel of the boiler. Messrs. Fletcher, Jennings & Co. have constructed numerous engines of this class for gauges of 2 ft. 3 in., 2 ft. 8 in., and 2 ft. 10 in., which are common gauges of the railways conveying minerals from the Welsh mines.

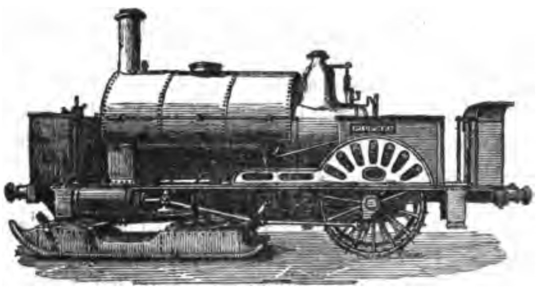
Fig. 91.



Mineral Tank Locomotive, by Fletcher, Jennings and Co., Whitehaven.

Locomotive for Running on Ice. *Fig.* 92 represents a locomotive for running upon ice, constructed by Messrs. Neilson of Glasgow, and reported to have been successfully employed in conveying goods and passengers on the Neva between St. Petersburg and Cronstadt during the winter months. The front part of the engine rests on a sledge, which is capable of being moved round a centre by a pinion gearing

Fig. 92



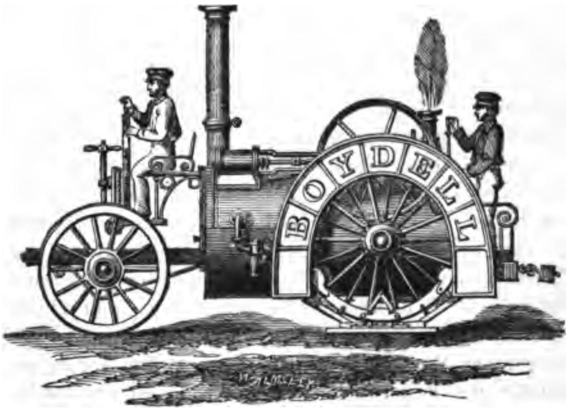
LOCOMOTIVE FOR RUNNING UPON ICE, BY MESSRS. NEILSON OF GLASGOW.

into a segment, and worked by the steering wheel shown at the front, which gives motion to an endless screw gearing with a suitable wheel, which turns the spindle of the pinion round with great force; and by swivelling the sledge—which, however, would be better done by a small engine—the machine is steered. The after part of the engine rests upon two driving wheels 5 ft. diameter, the peripheries of which are studded with steel spikes to grip the ice. The cylinders are of 10 in. diameter and 22 in. stroke. The weight of the engine is 12 tons, and it realises a speed of 18 miles an hour. It will be proper in such an engine to apply a shelving edge on each side of the sledge, so that its swivelling may not be prevented by sinking somewhat into the ice or beaten snow; and to the same end the swivelling gear should be powerful and under easy and rapid control under the worst circumstances likely to occur. In Russia and in Sweden extensive lakes and other tracts of water, being frozen in winter, are available for the application of such an apparatus. But in some of the lakes there are warm springs which create holes in the ice; and the desideratum to be aimed at is to render available the little vessels which ply in summer for plying also in winter by mounting them on a sledge, as was proposed by me to be done for some lakes in Sweden in 1847.

Locomotives for Common Roads. The rapid extension of railways in this country has nearly superseded the necessity of employing steam carriages on common roads, which at one time appeared likely to be extensively introduced. But in other countries not possessed of the same highly-developed system of locomotion the use of steam traction on common roads is still very important. In 1843 I described in the 'Artizan' an arrangement whereby the power of the engine of a common road locomotive might be communicated to the wheels without interfering with the free action of the springs; and ever since 1847, when I first went to India, I have continued to urge the employment of suitable locomotives upon the great roads of that country. In 1862, being then at Lahore, and finding that there was one of Boydell's traction engines at Bombay, which had been sent out for the government, but had never been used, I purchased it and had it conveyed to Moultan, and it went under steam from thence to Lahore, a distance of about 200 miles, over one of the worst roads in India. This journey, however, owing to exceptional circumstances, was not accomplished without considerable difficulty. From lying so long at Bombay, the woodwork of the shoes had become rotten, and the shoes had consequently to be taken off altogether on the road, when the engine sank in the soft ground; and it had in several instances to be extricated with considerable difficulty. I found, moreover, that special provision required to be made on many points to make the engine suited for such roads, which are not only filled with ruts and soft, but in summer are deep in dust, and during the inundations deep in mud. The dust, during the journey I referred to, rose over the surface of the shoes, and was lifted up by them and scattered in the air; and each spoke of the wheel acted as a scoop to lift up the dust and precipitate it over the engine. The evils presented by such difficulties, however, are not insuperable, but they indicate the necessity of covering over every working part of the engine so effectually that dust cannot enter, and also of not trusting to wood at all in such a climate in the construction of any of the parts. The shoes, or rather pattens, should be formed of wrought iron or steel boxes, 6 in. deep; and I think it would be preferable to have their movements governed by a central cam or eccentric, as in a feathering paddle-wheel, instead of leaving them to assume their respective positions from the action of gravity alone. The geared wheels and pinions should be formed of steel, as also most of the parts of the engine should be, to reconcile lightness with strength.

Boydell's engine is represented in *fig.* 93. It resembles a locomotive, the fore wheels of which are made to swivel by proper steering gear; and the main part of the weight is carried on the driving wheel, which is encircled by a series of boards called an 'endless railway,' which successively place themselves on the ground in advance of the wheel, and the wheel then passes over them without sinking in the ground. In fact they act on the principle of the snow shoe in giving area proportionate to the softness for sustaining the weight. No doubt improvements in the details of these engines may be suggested; but the principle is sound, and the modifications required to adapt them to conditions, such as obtain in an exotic country like India, cannot be anticipated by manufacturers at home, but must be indicated by persons on the spot who are determined to make the engines answer, instead of searching for some petty pretext to justify their condemnation. In connection with the movements of the army in India, such engines would be of signal value, to say nothing of the operations of agriculture; and the time has now come when the rise in the value of labour in India and the increasing demand for Indian produce—coupled with the improvements in steam cultivation at home—must open the doors of that great country, heretofore and even yet sealed up by the narrow policy of an exclusive oligarchy—now changed rather in name than in fact —and present a new field of effort and of emolument to the enterprise of the British engineer. No country

Fig. 93.



BOYDELL'S TRACTION ENGINE.

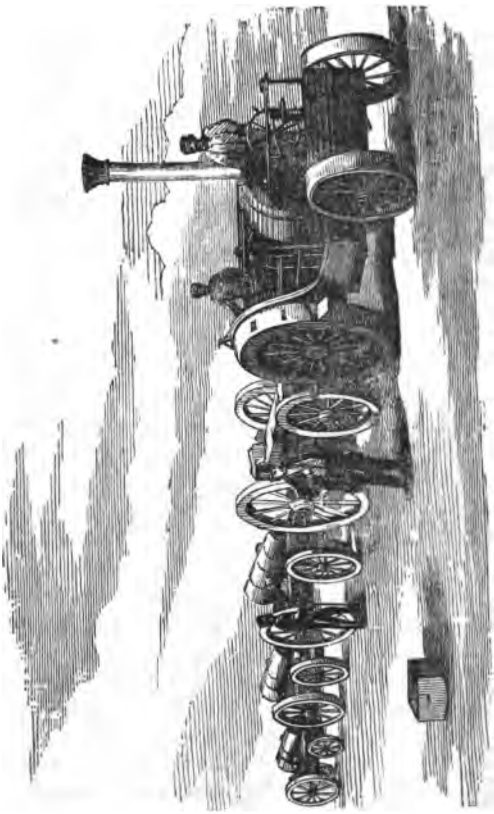
in the world is better suited than India for the application of steam cultivation. It consists in great part of vast alluvial plains, which may be mapped out into any shape judged suitable for steam culture; and as, with irrigation, three crops in the year may be calculated on, the apparatus may be kept in almost constant use for ploughing, or reaping, or threshing. Fuel is scarce in some parts, but may easily be cheapened by planting trees of rapid growth.

Bray's Traction Engine. This engine, which prevents sinking by using wide wheels, and prevents slipping by causing short spades to project at pleasure from the surface of the driving wheel by means of an eccentric on the driving axle, is represented in its original state in *fig.* 94; but the Company has since availed itself of the abilities of Mr. Clark in the production of a more perfect engine, which has now more of the locomotive type about it than before.

In Aveling's Patent Traction Engine, *fig.* 95, manufactured by Messrs. Aveling & Porter of Rochester, there is a single cylinder surrounded by a steam jacket, which is in direct communication with the boiler by means of steam ways or orifices made in the top of the boiler. There will be little tendency to prime in this engine, as the cylinder is brought to the forward part of the engine, and on ascending inclines the cylinder is necessarily fed with dry steam; while, in descending, little steam is required. By this arrangement the use of steam pipes either inside or outside the boiler is dispensed with. Engines with single cylinders and reversing gear, connected to the driving axle by chain gear, have proved themselves to be perfectly efficient. They are less complicated, and on the whole are better adapted for general traction purposes than engines with double cylinders.

The working parts are housed in from the influence of the weather. The toothed gearing is also covered with light iron splashers. The propelling gear consists of a pinion at each end of the crank shaft (either of which can be thrown in and out of gear with the spur wheel below by sliding it along a feather on the crank shaft) working into spur wheels

Fig. 94.

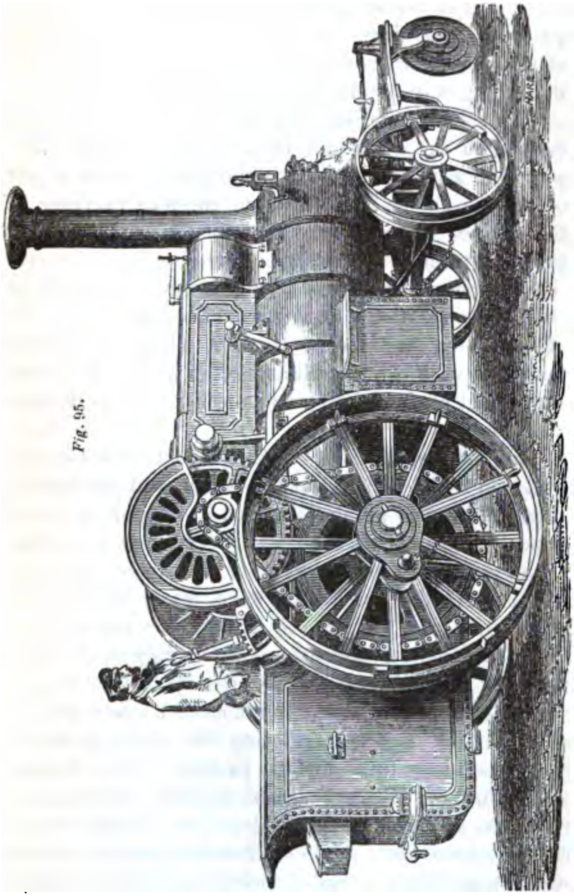


BRAY'S TRACTION ENGINE.

on a counter shaft below. On this shaft is a chain pinion with chilled teeth, to take in a pitch chain made of wrought iron links with steel pins. In the brackets carrying the shaft there are curved slots, struck from the centre of crank shaft above, for taking up the slack of the endless driving chain. These pinions are kept in the positions required by means of a simple clip of spring steel embracing the shaft, and lined with leather. The adjustment for taking up the slackness of the chain is effected by the brass bearings carrying the shaft being kept up in the slot by a block at the bottom of each. There is another cast iron block above, lying on the bearing, and kept down by a set screw. When the chain has to be shortened, the thinner block below is taken out, and the thicker one above is substituted in its stead. The brass step is thus fixed in a perfectly firm and solid adjustable bearing. The gearing is connected to the driving wheels by means of the endless chain, passing round the chain pinion on the counter shaft and a large chain wheel keyed on the axle. The driving wheels are 6 ft. 6 in. diameter; on the face of the wheels is an outer tire, parts of which may be removed and replaced by angle iron paddles or clips, for use in passing over soft and yielding ground.

The boiler is carried through from end to end, without any break in the configuration, whereby the use of angle iron is dispensed with. The stay bolts of the fire-box are pitched 4½ in. from centre to centre. The fire-box is adapted for burning wood or coal fuel. The water for feeding the boiler is carried in a tank made of wrought iron plates and bolted to the side

Fig. 95.



Aveling and Porter's Traction Engine.

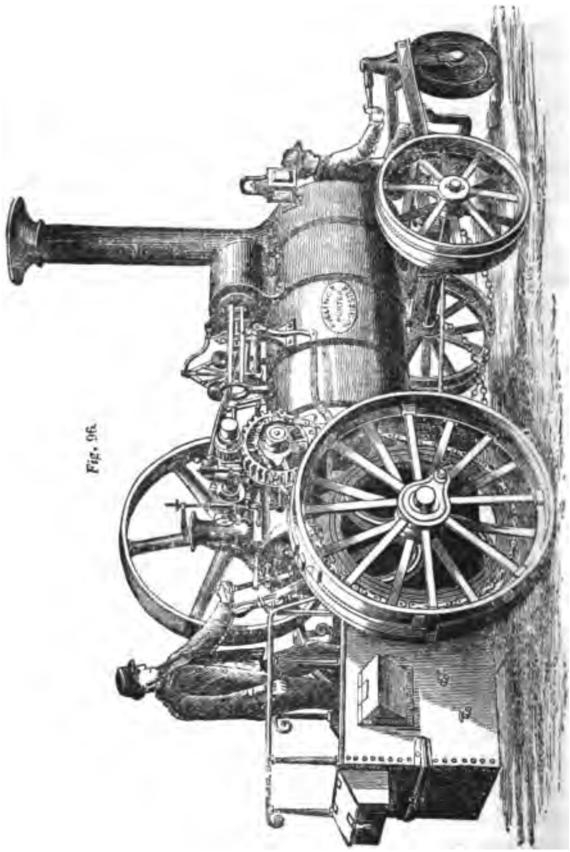
plates of the fire box, which are carried out for this purpose. The draw bar is formed of T iron, the ends of which are returned, or bent back, and bolted to the wrought iron side plates of the tank.

The steerage is effected by a single disc wheel carried on the lower end of a vertical spindle, supported in a collar-bearing on the front end of a pair of angle iron shafts secured to the fore carriage of the engine. The upper end of the vertical spindle is provided with a lever-handle extending back towards the steersman, who is seated between the shafts at the front end of the engine. This engine is capable of ascending inclines of 1 in 12, with a load of 20 tons, and with 8 tons will ascend an incline of 1 in 6. On a level road in fair condition it will haul 40 tons with ease.

One hundred and thirty of these engines are now in use in different parts of the world, and are used in sugar and coffee plantations, and in copper and lead mines, in dockyards, and wherever large quantities of materials and heavy weights have to be removed. Messrs. Aveling & Porter have manufactured and exported these engines to Russia for the government, to Jamaica, Queensland, Java, Egypt, Prussia, Buenos Ayres, &c., &c.; and the increased demand proves that steam power on common roads, and in new colonies, is now attracting the attention which its importance and utility justify. For feeding the traffic of railways steam traction on common roads is particularly valuable. In India, branch railways have been projected for this purpose, which were at one time intended to have a narrower gauge than the ordinary railways of that country. But the injudicious break of gauge has now been abandoned, and all railways, whether trunk or branch, established to carry on the communication of the country, are intended to have the same gauge. Prior to the formation of a railway, however, it is advisable to make a metalled common road on which traction engines may run; and when the traffic has thus been by degrees nursed up to a certain point of magnitude, it will become advantageous to lay down rails for the engines to run upon. This is the proper course of developement in a new or undeveloped country; and the construction of expensive lines of railway in districts covered with jungle, and destitute of population, cannot be justified by any principle of reason or any indication of common sense.

Aveling's Patent Agricultural Road Locomotive, designed for steam cultivation, threshing, sawing, and removing agricultural produce, is represented in *fig.* 96. The boiler, like that already described, is unusually large and is flush; it is clothed with hair felt, lagged and covered with sheet iron from end to end. The cylinder and working parts are, like those of the engine, intended exclusively for traction purposes. The gearing, however, is single, and for one speed only. There is a pinion on the end of the crank shaft, working into a spur wheel on a stud below; and on this wheel is cast a chain pinion to take in the endless pitch chain. This gearing works on the stud in a curved slot in the lower part of one of the crank shaft brackets, struck from the centre of the crank shaft. In the side of the bracket is an adjusting set screw,

Fig. 96.



AVELING AND PORTER'S AGRICULTURAL ROAD LOCOMOTIVE working through a tapped boss, and bearing at its inner end against the side of the stud shaft. By turning this screw the stud shaft may be caused to slide laterally in the curved slot, as this slot in the bracket is struck from the centre of the crank shaft, and by this arrangement the stud shaft may be adjusted to any desired amount, so as to tighten up the driving chain without interfering with the gearing together of the spur wheel on the stud and the pinion on the crank shaft.

The spur wheel receives motion from the pinion, which slides laterally by means of a groove and feather on the end of the crank shaft, but always revolves with the shaft. The object of this lateral adjustment of the pinion is to throw it in or out of gear with the spur wheel, so that, when the engine is not required to travel over the ground, the locomotive gear may be thrown out of action; and the engine can then be immediately employed to drive ploughing, threshing, sawing, or any other machinery, in the same manner as ordinary stationary or portable engines.

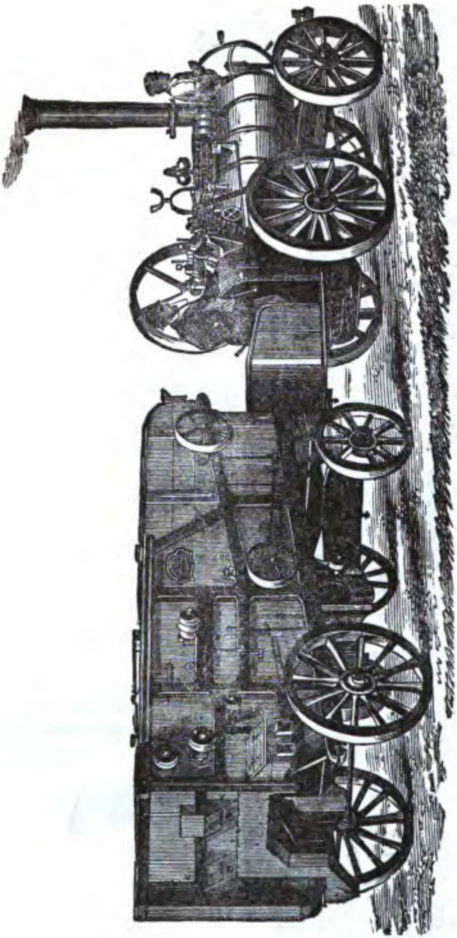
On the axle of the road wheels is a large chain wheel, round which and the chain pinion an endless chain passes, connecting it to the driving gear already described.

The road or driving wheels are loose on the axle, but are driven by a bolt passing through a boss on the nave and through the chain wheel on the one side, and on the other through a hole cast in the friction break, which, like the chain wheel, is keyed upon the axle. The object in connecting the wheels with the driving gear in this manner is to enable either wheel to be readily disconnected, which is a great advantage in turning very sharp curves. But a self-acting clutch may also be used for this purpose. The driving or road wheels are 5 ft. 6 in. in diameter, and 16 in. broad on the face; there is a 5 ft. fly-wheel for driving machinery when the engine is disconnected from the locomotive gearing. There are now many of these engines that have travelled from 4 to 6,000 miles, moving from farm to farm, with a threshing machine attached, over the worst roads in England at all seasons of the year. The saving of horse labour in this instance alone is far from being unimportant. The engine is none the less suitable for common farm purposes from being able to move itself about from place to place; and many years ago I suggested, in my 'Catechism of the Steam Engine,' the expediency of such a combination.

An engine very much resembling Messrs. Aveling & Porter's Farm Traction Engine is constructed by Messrs. Robey & Co. of Lincoln. This engine is represented in *fig.* 97; and an engine by the same makers, adapted to the general purposes of steam locomotion on common roads, is represented in *fig.* 98. Messrs. Robey & Co.'s portable engine is the same species of engine as that shown in *fig.* 96, but without the locomotive gear.

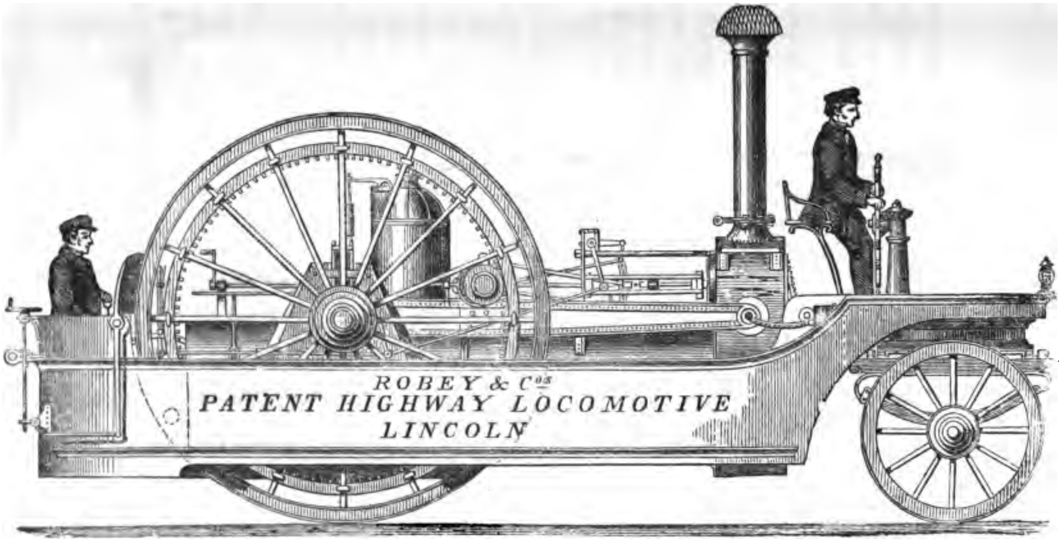
In traction engines for common roads the objects to be fulfilled are now different, so far as regards use in this country, from what they were in 1830 when Gurney, Hancock, Ogle & Summers, and various other engineers introduced steam carriages on the

Fig. 97.



ROBEY AND CO.'S FARM TRACTION ENGINE.

Fig. 98



ROBEY AND CO.'S HIGHWAY LOCOMOTIVE.

common road, some of which machines were characterised by much mechanical ability. At that time the design was to supersede stage coaches. But this end has been attained by railways more completely than could be done by any form of steam apparatus on the common roads. Although, however, steam coaches are no longer required in England, steam waggons may be made a valuable expedient of internal transport for domestic purposes, or as ancillary to railways; while in foreign countries less developed than England, and still without railways in many districts, steam coaches on the common road may be made a valuable intermediate improvement, and rails may finally be laid down when the traffic has risen to such a point as to warrant the expenditure.

The form of traction engine constructed by Messrs. Garrett & Son, represented in *fig.* 99, nearly resembles one of the forms employed by Messrs. Aveling & Porter; and most of these forms, it will be observed, are the natural developement of the common portable farm engine, which common sense indicates should be made capable of being put to as many useful purposes as possible.

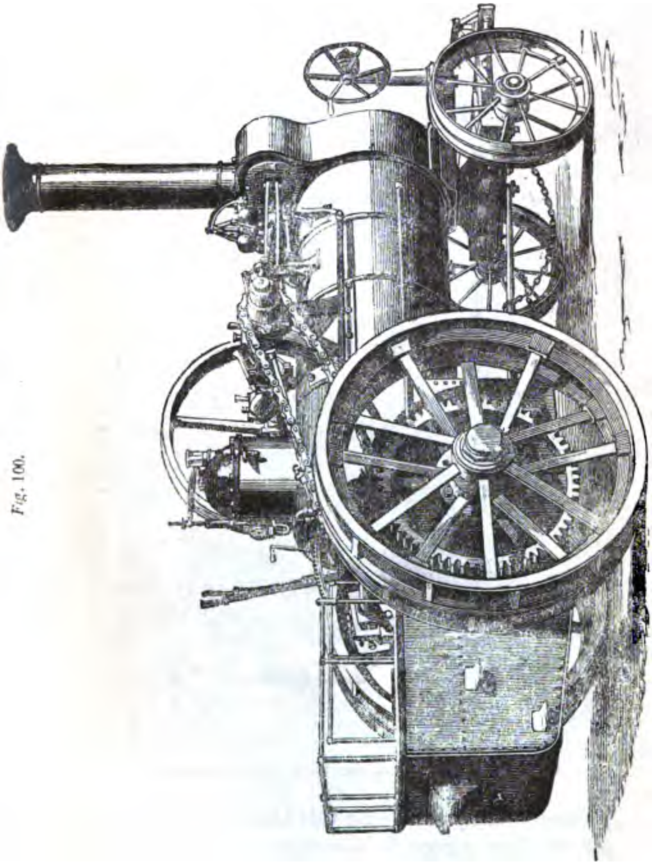
Messrs. Clayton, Shuttleworth & Co's Traction Engine is represented in *fig.* 100. This engine is substantially the portable engine of the same makers, with some additions; and in 101 there is another form of their portable engine adapted for pumping water.

One of the most important applications of the portable engine is to the work of steam ploughing, for

Fig 59.

GARRETT AND SON'S TRACTION ENGINE FOR COMMON ROADS.

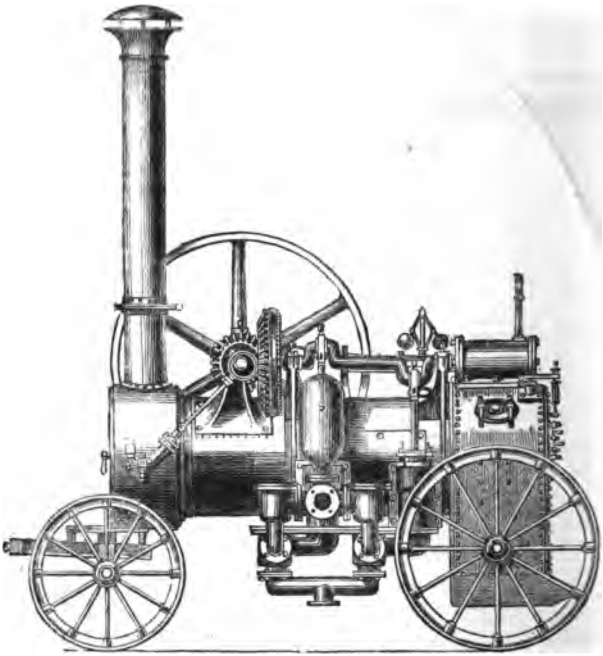
Fig. 100.



CLAYTON, SHUTTLEWORTH AND CO.'S TRACTION ENGINE.

which each principal manufacturer has some special arrangement. That known as Savory's system is re-

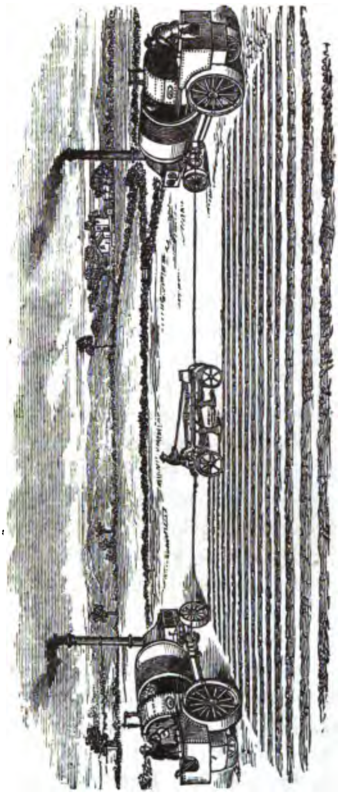
Fig. 101.



CLAYTON, SHUTTLEWORTH AND CO.'S PORTABLE STEAM PUMP.

presented in *fig.* 102. By this plan an engine suitable for winding a rope is placed on each side of a field, and the engine on the one side winds up a rope passing across the field which the other engine unwinds.

Fig. 102.

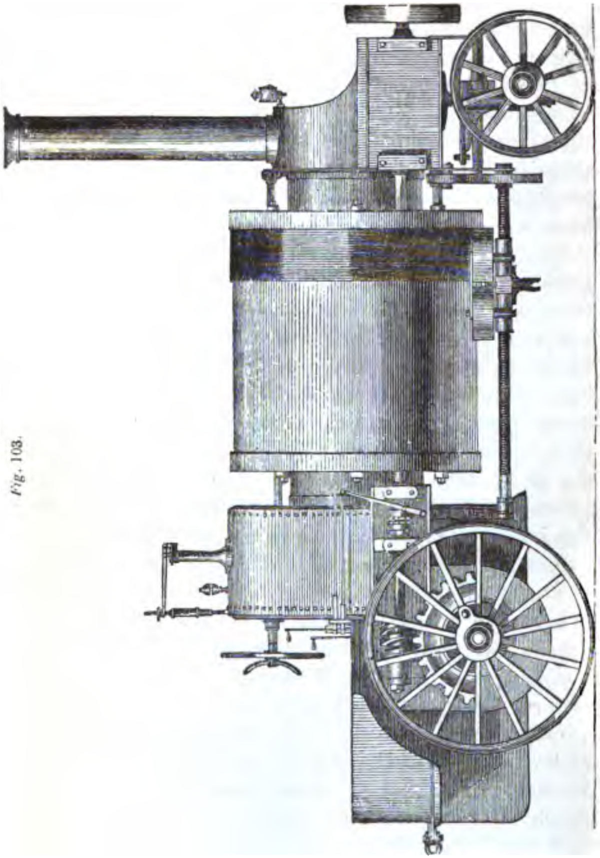


SAVORY'S SYSTEM OF STEAM PLOUGHING, BY R. GARRETT AND SON.

The plough is attached to this rope, and it is drawn to one side and to the other by each engine alternately, each advancing a short distance along the field for every cut that is made. The form of engine which winds up the rope is shown on a larger scale in *fig.* 103. The engine is a common portable engine, with a great drum encircling the horizontal part of the boiler, on which drum the rope—which is best made of steel wire—is wound. These engines are capable of travelling from place to place, carrying their own water and fuel.

The advantages of this system as compared with other methods proposing to accomplish the work with one engine, are, that only one rope passes across the field instead of two, and that the shifting of anchors intended to hold the pulley on which the return rope runs is obviated altogether, as also is the injury caused by the rope running over a comparatively small pulley, as this movable pulley generally is. The disadvantages are that the expense of two engines is incurred, and that one is standing idle half its time while the rope is being drawn across by the other. I have very great doubts, however, whether the method of ploughing by a rope at all is the proper one, or whether it is advisable to imitate the operation of ploughing, which is confessedly an imperfect one, since it does not sufficiently break up and pulverise the soil. It appears to me that some species of steam digger is the proper instrument to employ, which will pass over the field digging up a whole furrow at once. No doubt such an instrument would require a great deal of power to drive it. But the work done would be proportionate to the power expended, and one such machine hired out would suffice for many farms.

Fig. 103.



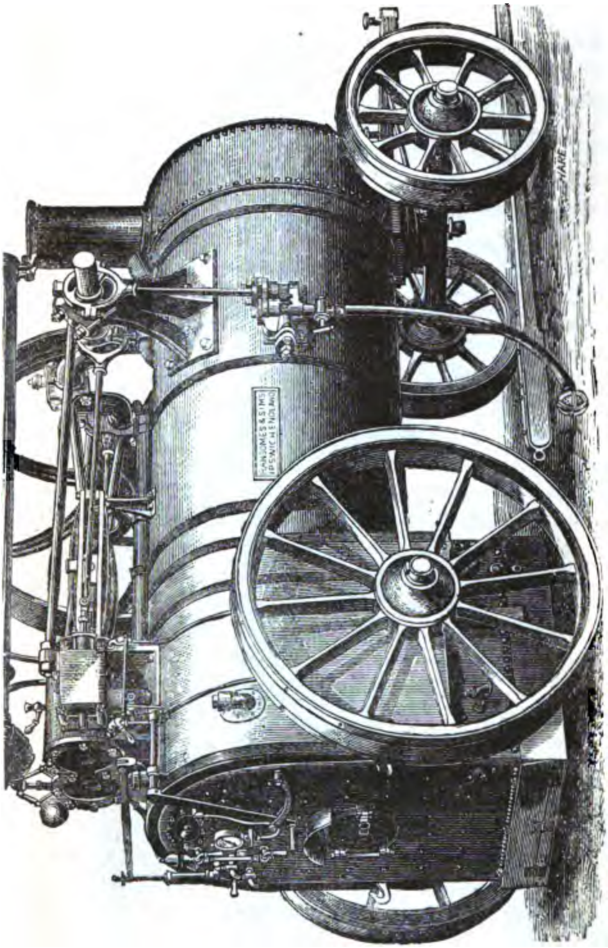
Portable Engine, by R. Garrett and Son, for Savory's System of Steam Ploughing.

The increasing power of agricultural engines has induced Messrs. Ransomes & Simms to employ for the larger powers a form of combined engine, consisting of two engines placed side by side, with the cranks at right angles, as in locomotives. An example of this form of engine is given in *fig.* 104; and it is distinguished by the faithful workmanship and good proportions by which Messrs. Ransomes & Simms have earned their high reputation.

In *fig.* 105 is shown a form of cylindrical boiler, patented by Messrs. Biddell & Balk, and manufactured by Messrs. Ransomes, which enables the fire box and tubes to be withdrawn from the shell or barrel, so as to give facility for removing and cleaning out the incrustation and dirt, which is so injurious in some cases, and which cannot easily be removed from boilers of the usual form. In this patent boiler the back tube plate, as well as the front outside plates, are bolted to flanges rivetted to the shell of the boiler. These flanges being truly placed, the steam-tight joints are made with as great a facility as the cylinder-cover joint of a large steam engine. Where the water is very dirty and leaves much deposit, this boiler is strongly recommended.

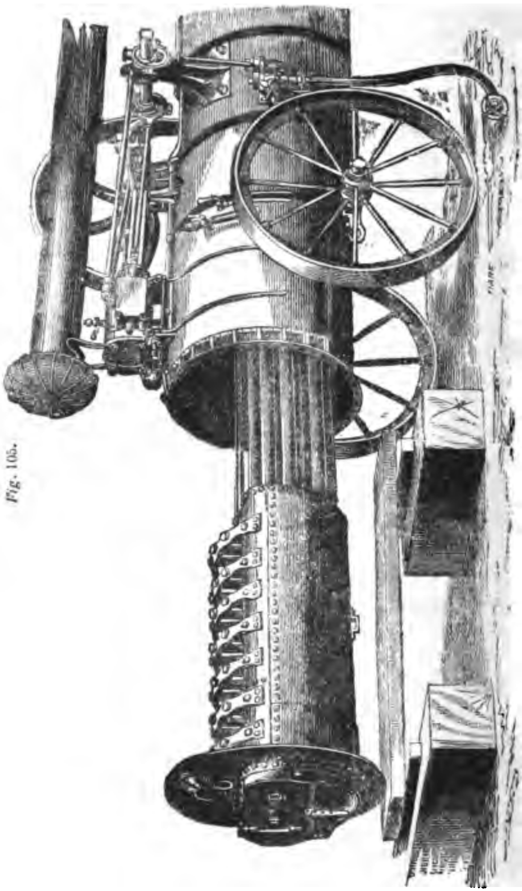
These boilers, as well as the ordinarily formed boilers, are constructed with especial reference to durability and strength. The bulk of the plates are of best Yorkshire quality, the remaining plates being Staffordshire. Ample water space is given round the fire box and between the tubes, so as to ensure free circulation of the water. Each boiler is tested to double its working maximum pressure.

Fig. 104.



Ransome and Simms' Combined Portable Engine, 20 horse-power.

Fig. 105.



BOILER WITH REMOVABLE FURNACE AND TUBES, BY RANSOMES AND SIMMS.

The boilers are mounted upon iron or wooden wheels, according to the wish of the purchaser, but iron ones are recommended as generally more durable and better adapted for change of climate.

Among the lightest forms of steam engine which have been hitherto produced, the steam fire-engines constructed to pump water for extinguishing fires must be accorded a prominent place. In the case of towns supplied with water maintained at a high pressure in the pipes, the simplest mode of extinguishing fires is to apply a proper hose and spout pipe direct to the distributing main. But in the case of towns where this high pressure in the water-pipes does not exist, and in cases also where there are no water-works, but, nevertheless, valuable property to be preserved, the use of steam fire-engines appears to be highly important. Such engines are much more effective than engines worked by hand, as the requisite power to work the pumps is always present, and as it acts with greater concert and less intermission than any number of men could do. For inflammable capitals like Constantinople, where the houses consist chiefly of wood, and there is no high pressure of water available for the extinction of fires, the use of steam fire-engines is peculiarly important, and is now beginning to attract much attention. In dockyards also, railway workshops, arsenals, and in fact in all isolated and important establishments, the value of such a powerful expedient for extinguishing fires is now beginning to be adequately apprehended. It has long been found that in all great fires the volume of water thrown on the burning mass by the jets of existing hand engines has been quite too small to extinguish the flames, and in fact the water has in many cases never reached the burning matter at all, but has been raised into steam before it could fall on the spot on which it has been directed. The use of steam appears to be indispensable to enable very large and powerful jets to be obtained, which would in all cases reach their intended destination, and would produce the extinguishing effect due to the refrigeration which a very large volume of water would necessarily cause.

The introduction of steam fire-engines has often been proposed, but, until lately, has been prevented by various practical impediments, of which one has been the great weight of steam engines of the ordinary description. In America, however, large numbers of steam fire-engines have been made, but many of them have been of a very complicated and precarious construction, and in this country none of them have been much adopted. In England, however, the makers of the ordinary hand fire-engines have begun to turn their attention to the subject; and both Messrs. Shand & Mason, and Messrs. Merryweather & Son, of London, have produced numerous steam fire-engines marked by special features of excellence and promising good results. Messrs. Shand, Mason & Co. manufacture two varieties of steam fire-engine, in one of which the cylinder is horizontal and works a horizontal double-acting pump affixed to the end of the piston rod; and the stroke is measured by a vertical slot in an enlarged part of the piston and pump rod, which permits the crank pin to move up or down in the manner usual in donkey engines for feeding boilers. The valve of the engine is worked by an eccentric in the usual manner, and the pump-valves are india-rubber discs, falling on a grating in the manner first introduced by Mr. Edward Humphrys, though few persons are now cognisant of the parentage of an improvement which has now become of almost universal application. The boiler consists of a fire box formed like the frustum of a cone, the better to disengage the steam from the inclined surface of the plate, on which is set a cylinder removable by bolts to contain the tubes. From the top of the frustum a number of very small and short copper tubes, set vertically very closely together, conduct the smoke into the chimney. The engine is provided with a small fly-wheel in the usual manner of donkey engines. In their vertical form of engine the boiler is the same as has been already described, but the engine is set with the cylinder inverted, and the pump is of the combined plunger and piston form invented by Mr. David Thomson, and first introduced by him in the Richmond Waterworks in 1845. In this form of pump the valves are like those of a common single acting pump, and the area of the plunger is half the area of the piston or bucket. As the piston ascends, the pump sucks itself full of water in the usual manner; but when the piston descends, the water being forced through the valves in the bucket into the space above the bucket, which is too small for it, inasmuch as half the area is occupied by the plunger, it follows that half the water will be forced through the delivery valve when the bucket is descending. The water left in the annular space between the side of the pump and the side of the plunger is forced out when the piston or bucket ascends; and we thus have the benefit of a double-acting pump with the gear of a single-acting one. The plunger is open at the top so as to constitute a trunk, and it is properly bolted to the bucket. The trunk and bucket are moved by means of two piston rods proceeding through the cylinder cover, one being placed on one side of the shaft, and the other diagonally on the other side of the shaft. The arrangement in fact very closely resembles that of Messrs. Napier & Sons' original form of direct-acting screw engine, except that in that case the engine was horizontal. The air pump answers to the water pump in this case; and from the bottom of the trunk a connecting rod proceeds to the crank to turn it round. On one end of the crank shaft is placed a small fly-wheel, and on the other end is an eccentric for working the slide valve, and also the pump employed to feed the boiler. A small piston, acted upon by the water which is being forced out, governs the speed of the engine by opening or shutting the throttle valve.

Messrs. Shand, Mason & Co.'s horizontal steam fire-engine is represented in *fig.* 106, and their vertical steam fire-engine is represented in *fig.* 107. The performance of each class of engine is very nearly the same, and in an experiment made with one of these engines at Messrs. Penn & Son's factory in 1864, with an engine having two cylinders of $6\frac{3}{32}$ in. diameter, and 7 in. stroke, the power generated with steam of 120 lbs. pressure in the boiler, and with 152 revolutions per minute, was about 15 horse-power. In the case of another engine of the same

Fig. 106

SHAND, MASON AND CO.'S HORIZONTAL STEAM FIRE-ENGINE.

dimensions, also tried in 1864, the power generated with a little increase in the pressure of the steam was 18-horse power, and the total weight of this engine with its appurtenances was 24 cwt. 2 qrs. In an engine which Messrs. Shand, Mason & Co. sent to the competitive exhibition at Middleburgh, in Holland, in July 1864, and for which they obtained the gold medal and 500 guilder prize, there was only one cylinder of 7 in. diameter and 8 in. stroke. In an experiment made with this engine, a jet of water $1\frac{1}{8}$ in. diameter was projected under a water pressure

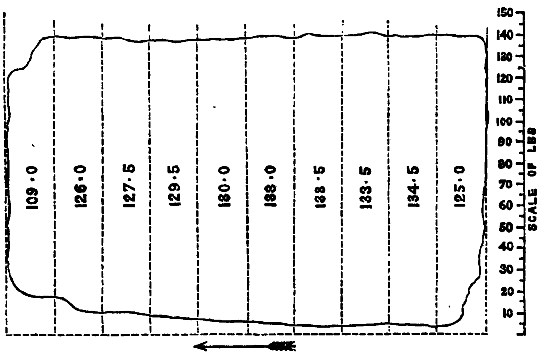
Fig. 107.

SHAND, MASON AND CO.'S VERTICAL STEAM FIRE-ENGINE.

of 125 lbs. per sq. in. With steam of 145 lbs. pressure in the boiler, an average pressure of 128·15 lbs. per sq. in. was maintained upon the piston at a speed of 165 revolutions per minute, and $5\frac{1}{2}$ lbs. per sq. in. of back pressure. In this case the engine exerted $32\frac{1}{4}$

actual horse-power; and as the total weight of the engine was only 32 cwt. the weight was about 1 cwt. per actual horse-power. As this is a very remarkable result, I here introduce a copy of the indicator diagram taken at the time.

Fig. 108.



INDICATOR DIAGRAM FROM SHAND, MASON AND CO.'S STEAM FIRE-ENGINE

Having personally examined Messrs. Shand, Mason & Co.'s engines when in course of construction, I can vouch for the faithfulness of the work; and I was also favourably impressed with the intelligence which presided over the general arrangements of these machines. But in the boiler the tubes are so thickly set, that it will be important to use pure water so that there may be no incrustation, which, if considerable, would prevent the access of the water and cement the tubes into a solid mass. It is a necessity of all fire-engine boilers, however, that they should have but little water in them, so that the steam may be quickly got up; and as such engines are never required to work for long periods at a time, there is abundant opportunity for cleaning the boilers out. By making the upright cylinder which encircles the tubes removable by unscrewing a few bolts, as these makers have done, they provide in a great measure against the only objection that can be made to any of their arrangements.

Prior to the introduction of steam fire-engines, Messrs. Merryweather & Son of Long Acre had obtained a high reputation in the construction of hand fire-engines, and also in the construction of other fire apparatus; and in turning their attention to the construction of steam fire-engines they brought to the problem the ripened experience that they already obtained in other analogous constructions. There are two main features in the mechanism Messrs. Merryweather employ in their steam fire-engines:—the one is in the boiler, which consists of a number of pendulous tubes hung in a furnace with a smaller internal tube within each, to enable the circulation of the water to be carried on; and the other is in the circumstance of the engine being without a crank, but the pump is worked by being attached to a reciprocating piston, as in Worthington's steam pump, or in the form of donkey engine introduced by Messrs. Penn, but subsequently abandoned; while the valve of one engine is moved by the other if there are two engines, and by a small independent cylinder and piston if there is only one engine, the valve of this small starting engine being itself moved by a tappet. The benefits which Messrs. Merryweather consider that they obtain by these peculiar features are, first, that in their form of boiler the steam is more rapidly got up than in any other, and certainly in this respect their engine seems to have the advantage over all its competitors; and second, that inasmuch as there is less waste of power in moving water slowly than in moving it rapidly, and as their pump and engine, with their long stroke and large capacities, move more slowly than is the case in other steam fire engines, there will be a gain from this source also, and the engine will consequently work with a maximum efficiency. Although, however, there is a loss of power in moving water quickly rather than in moving it slowly, the velocity of the water escaping from every species of pump must be the same to project a jet of the same diameter to the same height; and whether the plunger of the pump moves fast or slow the escaping water must have the velocity proper for the kind of jet that has to be employed. It consequently will matter little whether the water obtains its velocity directly from a fast moving plunger, or indirectly from the compression of the water which a larger plunger moving more slowly produces, seeing that in each case the water must leave the spout-pipe with the same velocity, and must carry away with it a corresponding amount of power. But whether the engine moves fast or slow a crank is equally applicable, and a crank will enable the engine to work with less waste of steam at the ends, as there will no longer be any necessity to leave the same clearance at the ends to obviate the risk of striking. Every species of reciprocating engine which is without a crank, is more or less of a rattle-trap; and although the example of the Cornish engines shows us that such engines are capable of pumping water with great efficiency and without intermission for long periods of time when moving slowly, yet it is now found that rotative pumping engines are quite as efficient, while they certainly work in a smoother and less precarious manner, and are capable of maintaining higher speeds without inconvenience. On the large scale, the pumping engine without a crank has been practically given up: and the same considerations which make that abandonment advisable on the large scale make it equally advisable on the small.

The consideration of the properties and performance of the steam fire engines exhibited at the International Exhibition of 1862 was delegated to a special committee. But two engines of Messrs. Shand, Mason & Co., and one of Messrs. Merryweather and Son, were the only engines which presented themselves to be experimentally tested. All the boilers were filled with cold water, and Messrs. Merryweather & Son's engine got steam up to 100 lbs. pressure in 12 minutes and 10 seconds, and Messrs. Shand, Mason & Co.'s first engine in 18 minutes and 30 seconds, whilst in their second engine, owing to some mismanagement which compelled them to draw the fire, 30 minutes were consumed. Messrs. Merryweather & Son's engine was 2 minutes and 50 seconds at work before it began to draw water. Nevertheless it projected 500 gallons of water into a tank 60 ft. distant in 17 minutes and 15 seconds from the time at which the fire was lighted, but the steam fell 15 lbs. during the first trial, and after three trials the engine became disabled. It resumed work, however, in an hour and a half, at the ninth trial, having been repaired on the ground in that time; but on the thirteenth trial it was again disabled. Messrs. Shand Mason & Co.'s engine, though longer in getting up the steam, drew water immediately it was put on, and during the first trial the pressure in the boiler fell only 5 lbs. per sq. in. This engine worked without accident, and almost without intermission, throughout the day. The seventeenth trial lasted 63 minutes, and the pressure in the boiler was kept up at 90 lbs. per sq. in. throughout. This experiment only confirms the anticipations which might have been reasonably formed from the distinctive features of the two engines placed in competition; and there can be no doubt that, on the whole, engines without a crank will be found more liable to derangement than those which are provided with that valuable appendage.

In July 1863 the experiments with these engines and several others were resumed at the Crystal Palace, and much interest was excited by the event. The engines presented for experiment were those of Messrs. Merryweather & Son, Shand & Mason, Easton & Amos, Butt & Co., Roberts, Nichols (Manhattan) and Gray & Son. The principal particulars of the several engines are exhibited in the following table:—

Name of Maker.	Weight of Fire Engine. t.	cwt.	qr.	lb.	No. of Cylinders.	Diameter of Cylinders. in.	Length of Stroke of Piston.	No. of Pumps.	Diameter of Pumps.	Gallons of Water in Boiler.	Cubic Content of Steam Space in feet.	Area of Fire Box Surface in square feet.	Area of Tube Surface in square feet.	Total Area of Heating Surface in square feet.
Merryweather & Son . .	2	18	0	8	2	8	24 in.	2	6½ in.	30to90	19 to 9	14·5	192·5	207
Shand, Mason, & Co. . .	2	17	1	0	2	8¼	9 in.	2	7 in.	28¼	7 cu. ft. 800c. in.	19¾	108	127¾
Easton & Amos	2	18	3	12	2	9½	8½ to 9 in.	4	2 of 5¾ 2 of 6¼	41	11·05	37	173	210
Butt & Co. . .	2	14	0	4	1	10½	12 in.	1	6	62	8·5	16½	183½	200
Roberts . . .	1	19	1	4	1	7	13 in.	1	9½	12½	6597 in.	23	118	141
Nichols (Manhattan) . .	2	10	1	4	1	9	8½ in.	1	rotatory	38	7·25	48·5	133·5	182
Gray & Son . .	1	18	1	4	1	9½	8 in.	1	7	17½	3·855	21·74	53·45	75·19

The boilers of these different engines were very various. In Merryweather and Son's boiler the shell was formed of homogeneous iron, $\frac{5}{16}$ of an inch thick double rivetted, and the tube and top plates of Lowmoor iron, $\frac{11}{16}$ thick; stays of Bowling iron, 1 in. thick, and the tubes of copper. The height of the boiler was 60 in., and the diameter 45 in. Shand, Mason & Co.'s boiler was an upright cylindrical iron boiler of 45 in. diameter at the fire-box, 45 in. at the barrel, and 60 in. high. The smoke passed through vertical brass tubes on its way to the chimney.

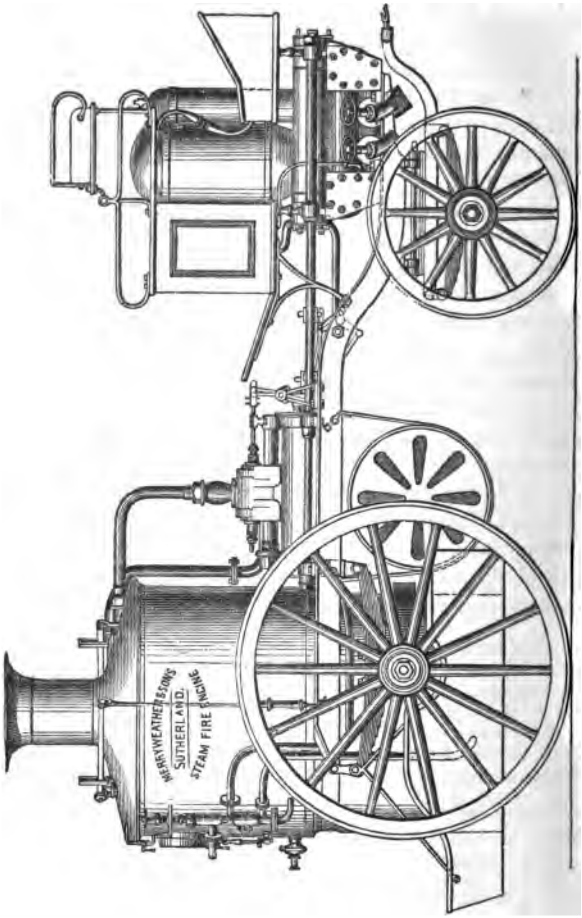
In Easton & Amos's boiler there was a central furnace surrounded by a shell of vertical tubes 2 in. diameter. Butt & Co.'s boiler was an upright tubular boiler 36⅝ in. diameter, and 65 in. high. The fire-box was 20 in. high, and there were 313 tubes of 1¼ external diameter. In Roberts' boiler the body was 30 in. diameter, and 24 in. deep, and there were 248 tubes ¾ in. diameter inside. Nichol's Manhattan engine was fitted with Lee and Larned's annular boiler; and

Gray & Son's boiler consisted of a cylinder fitted with tubes revolving slowly on trunnions within an iron casing lined with fire clay.

On the first trial the task set to all the engines was to deliver 1,000 gallons of water into a tank 67 ft. distant, the water in all the boilers being cold when starting, and the order in which this was done by the different exhibitors was: 1, Easton & Amos; 2, Merryweather & Son; 3, Shand, Mason & Co.; 4, Butt & Co., and 5, Roberts. In the second trial, which consisted in doing the same work with the steam already up, the order of rapidity with which the work was done by the different exhibitors was as follows: Shand, Mason & Co., Butt & Co., Merryweather & Son, Roberts, and Easton & Amos. In subsequent trials the engine of Messrs. Merryweather & Son worked with great efficiency, and took the first prize of 250*l.*, the second prize of 100*l.* being awarded to Messrs. Shand, Mason & Co. The steam fire engine Sutherland, which achieved these successes, is represented in *fig.* 109, and Messrs. Merryweather & Son's description of this engine is as follows:—

This engine has two steam cylinders, each $8\frac{5}{8}$ in. in diameter, with pistons of 24 in. stroke. The two pump cylinders are $6\frac{1}{8}$ in. in diameter, and the pistons of the pumps being on the same rods as the steam pistons, make the same extent of stroke. Both steam cylinders and pumps are fixed horizontally on the wrought iron side frames of the engine, and rigidly connected together by strong tie-rods running throughout the entire length of cylinder and pumps. The valve motion is of a simple character, and is so arranged that when one piston is changing stroke the other is in the middle of its stroke, thus imparting a very uniform and steady motion. On the middle of each piston rod is keyed a boss carrying a short arm projecting horizontally. Parallel to and at a short distance from each piston-rod, are fixed in suit-

Fig. 109.



STEAM FIRE ENGINE SUTHERLAND, BY MESSRS. MERRYWEATHER AND SON.

able bearings, so as to be able to revolve freely on their axes, two twisted bars or quick screws, having a pitch of 1 turn in 16 in. At the ends of these twisted bars or screws next the steam cylinders are cut two strong square-threaded screws, having 1 turn in 1½ in., on to which are fitted 2 gun-metal nuts, which nuts are received by the forked ends of the weigh-shaft levers for moving the slide-valves. To the short arms on the piston-rods above mentioned are attached 2 gun-metal sliding pieces, which clasp, and move freely on the twisted bars or screws, and having the same motion as the piston-rods, impart a slow, easy, reciprocating rotating motion to the twisted bars or screws, causing the gun-metal nuts and weigh-shaft levers to be brought backward and forward with a slow, easy action, thus moving the slide-valves into the required position—viz., that of closing steam and exhaust ports shortly before the end of the stroke, thus preventing the possibility of striking the ends of the cylinders. By this arrangement, each cylinder cuts off its own steam and exhaust, and is entirely independent of the other for forming the cushion required to stop the momentum of the pistons. Thus, *each piston brings itself to rest;* but when at half-stroke, by means of a connection between the weigh-shaft levers, it gives steam to No. 2 cylinder, the piston of which brings itself to rest and liberates No. 1 piston, and so on alternately.

The slide-valves are of the equilibrium piston form, and with full steam (150 lb. per sq. in.) can readily be moved by the hand with a force of 5 lb., thus saving power which is more usefully employed in forcing water.

The engine is started merely by opening the steam valve, which can be so regulated as to allow it to run as slow as half-a-stroke per minute, and has no dead points or centres.

The pump has all its valves below the pump cylinders, and so arranged that no water remains in the pump when at rest, so that it cannot freeze. The suction valves, 4 in number, are each 10 in. long and 1·375 in. wide, with a lift of 1 in., which presents an area of 13·75 sq. in.; the delivery valves, also 4 in number, are each 10 in. long, and 1·25 in. wide, with a lift of 1 in., and an area of 12·5 sq. in.; the whole are made of gun-metal, india-rubber faced, but gun-metal valves can be fitted if preferred. The engine is fitted with 4 deliveries, each 2½ in. in diameter, for attaching hoses, and the suction hose is 5½ in. diameter.

The side cover of the pump can be readily removed and the valves and seats re-adjusted if necessary.

The side frames are of Bowling angle iron, firmly secured together by wrought iron cross-stays, and pivoted over the fore-carriage, so that the engine may travel on the roughest road. Beneath the front part of the frame, and below the pivot, are the wrought iron fore-carriage and front wheels, which lock completely round and under the frame of the engine.

Above the pump, and fore and aft of the copper-suction and delivery air vessels, are the tool-boxes and seats for the driver and ten men. The delivery hose is carried in a cylindrical drum (capable of containing from 500 to 600 ft. of leather hose), attached beneath the frame near the boiler.

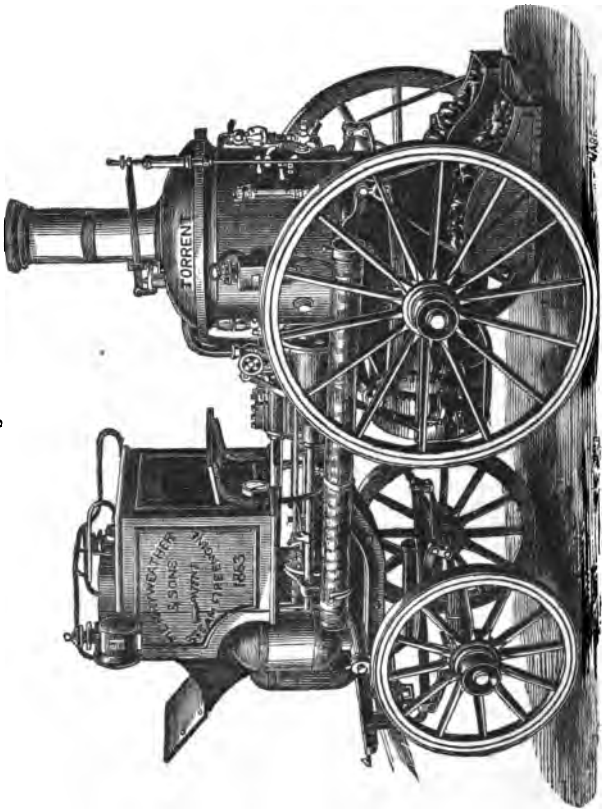
The vertical boiler has very large steam and water spaces, with a tubular circulating shell of homogeneous metal $\frac{5}{16}$ in. thick, and double rivetted. The tube and top plates are of Lowmoor iron $\frac{11}{16}$ in. thick; the stays are of Bowling iron of 1 in. in diameter, and the tubes are of solid drawn copper. The height of the boiler is 5 ft., and the diameter 3 ft. 6 in. When the engine is at work, the boiler contains on an average 60 gals. of water; the steam space varies from 9 to 19 cubic ft.; the fire-box surface is 14·5 sq. ft., and the tube surface 192·5 sq. ft., making a total heating surface of 207 sq. ft.

The top plate is provided with four hand-holes, so that the interior of the boiler can be got at most readily. The top and bottom tube plates are connected together by strong wrought iron stays. The boiler is fitted with two large safety valves, two pressure gauges, back and front, No. 5 Giffard's injector, water-glass, gauge cocks, &c. There is also a steam jet in the chimney for assisting the draught. A portion of the outer shell of the boiler is kept down below where it is rivetted to the lower tube-plate to which the side frames are attached, so that the bolts do not go into the water or steam space of the boiler. At the lower part of the boiler is attached a large bunker for carrying coals or other fuel.

The engine is mounted on four springs and high wheels, so that it is suited for the most rapid travelling.

The steam fire-engine Torrent, which has obtained some celebrity in connection with Captain Hodges' fire-brigade, in consequence of its efficient action at various fires, is represented in *fig.* 110. Messrs. Merryweather & Son's description of this engine is as follows:—

Fig. 110.



STEAM FIRE ENGINE TORRENT, BY MESSRS. MERRYWEATHER AND SON.

This engine has undergone some very severe tests, and proved to be efficient in every respect, its arrangements being of so simple a character, that ordinary persons have managed it with but very little previous knowledge of the mechanism of a steam fire-engine. It has a steam cylinder of 6½ in. diameter, with a piston stroke of 12 in. The steam and water pistons are continuous. The pump is 4⅝ in. in diameter, with a stroke of 12 in., the cubic contents of which are 1·45 gals. The arrangement for moving the slide valve, which is of the piston equilibrium form, is of the simplest kind. In the centre of the piston-rod a light cross-head is keyed, having a slight bearing upon each of the tie-rods which connect the steam cylinder and pump together; to this cross-head are attached two light rods, which are again connected to two small weigh-shaft-levers, which give a slight motion as the piston advances and recedes, to an ordinary flat valve, that admits steam to a small piston which is on the same rod as the piston slide valve. This engine can be started at any point by merely opening the steam valve, and can be driven at any speed (so as to adapt itself to any quantity of water) even as slow as one stroke per minute, as there are no dead points or centres.

The suction valves, of which there are two, are 9·5 in. long and 1·3625 in. wide, with a lift of 1 in., and an area of 10 sq. in., and the two delivery valves are 9·5 in. long, and 1 in. wide, with a lift of barely 1 in. and an area of 9·5 sq. in. The whole of the valves are of gun metal, leather faced (india-rubber can be used if preferred), and are placed below the pump cylinder, readily accessible, and so arranged that no water can possibly remain in the pump when at rest (to prevent freezing). It has two delivery outlets of 2½ in. each, and a suction of 3½ in., all inside diameter. The frame is of Bowling angle iron, pivoted over the fore-carriage and front wheels, which lock and turn completely under the main part of the engine.

The boiler is of steel, with Lowmoor iron tube and top plates, and vertical water tubes; the tube-plate is flanged to form a mud pocket, which receives all the deposit and from which it is easily blown out. The top plate has four hand holes, so that the interior of the boiler is easily accessible. The boiler is 48 in. high, the diameter being 28 in. The shell is of homogeneous metal, full ¼ in. thick. The tube and top plates are $\frac{9}{16}$ in. thick, and the tubes are of solid drawn homogeneous copper. The quantity of water contained in the boiler, when at work, is from 15 to 30 gals. The steam space is about 4 cubic ft., the fire-box surface 7·5 sq. ft., including flue surface, and the tube surface 57 sq. ft., making a total of 64·5 sq. ft. of heating surface. The boiler is fed by a Giffard's injector, by the main pump, and by a feed pump. It is fitted with a safety valve, a double steam pressure gauge, a water pressure gauge, water gauge, gauge cocks, &c., and has a small steam jet for assisting the draught.

The wrought iron frame of the engine is attached to a portion of the outer shell of the boiler, left for the purpose below the water and steam spaces. At the bottom of the boiler are attached the coal-bunkers, and below the frame, in front of the boiler, is an iron frame for carrying the hose.

The frames of the engine are made of steel $\frac{3}{8}$ in. thick, and attached to the back and front plate of the boiler. Transverse to the frames, and over the cylinders, is a steel and wood frame combined, and at the back and front, a central longitudinal frame terminating at the smoke-box. The cross leading frame is also of steel, to which the steering spindle fork is attached. The slides of the main axle are inclined to divert the percussions on the main springs, and to keep the centres of the spur-gear in their most fitting relative positions. The whole weight of the boiler and the principal part of the machinery is borne by the driving wheels, which sustain each $2\frac{3}{4}$ tons weight to promote their adhesion, while the power of the engine is such as to make them skid round in 'reverse' when it is found necessary to stop *instantly*; the engine is also fitted with a break. The motion consists of spur-gear in duplicate 5 to 1, which allows the steam pistons to make 650 ft. per minute, or about half the speed of the carriage. There is also a universal differential motion applied to the main axle. Provision for causing the driving wheels to move at different degrees of speed, when it is necessary to do so, and to pass readily over any obstacles on the road, is made by the line of the steel cranked shaft, or first motion which moves in bearings fixed to the boiler and frames, and that of the second motion, or main driving axle, being often in different planes. The first motion and boiler all take the average undulation of the road, and the second motion has, on uneven roads, a continued elevation and depression at either end.

The main shaft is a bar fitted with a centre cross pin and two bevel wheels or couplings free to move in any way. On this centre bar are two more bevel wheels, and the two driving wheels are respectively connected firmly together by wrought iron pipe shafts, which move freely upon the centre shaft. Upon these external shafts the spur wheels are fitted free, and driven by the two pinions fast on the first motion crank axle. The two spur wheels actuate the two bevels first mentioned, and also the central shaft by two driving bars, each of which moves freely on the three points of contact, allowing the two spur wheels to keep unremitting connection with their respective pinions, at all the various positions in the planes of the two axles, transmitting to the central bevel wheels their united power, through the two universal driving bars. When the carriage moves along a straight road, these bevel wheels merely act as circular clutch couplings; but in passing round curves, they revolve in part, allowing either driving wheel to take the inner curve, or, if necessary, to become stationary, while the other wheels make a circuit round it. The driving wheels are each 4 ft. in diameter and 7 in. wide, and are made of cast bosses and steel spokes and rim, with outer segments and exterior felloes of wood. Upon these are bolted segments which admit of elongation and substitution, without interfering with the rest of the wheel. The cylinders are each 6 in. in diameter, with a stroke of 8 in., and the link-motion is the same as in railway locomotives, with an extra expansion link-motion for forward gear, which allows a constantly free exhaust, and a cut off at any part of the stroke up to $\frac{2}{10}$. This, with Gray's variable blast pipe, and short tubes of ample size, enables the exhaust to be freed at a minimum pressure, keeping up a constant working pressure of 150 lbs. The steering apparatus is simple and can be managed with great ease, as there is but one leading wheel, the obstructions of the road being yielded to by the vertical axis and its appliances. To assist this forked steering shaft, and allow it to rise and fall, as well as turn freely, a parallel motion is arranged, so as to transmit the longitudinal strain received by the wheel to a fixed pin level with its axle, and made fast to the frame between the cylinders, the parallel rods having a universal hold of a beam lever, and also the ends of the axle of the leading wheel.

A soft metal plug is inserted in the boiler, in the event of no water being found along the roads, that will immediately put out the furnace fire. The engine is fitted with two steam whistles, gauge glass, water cocks, and two steam pressure gauges, one for the stoker, and the other for the driver and steerer.

Messrs. Merryweather, in common with Messrs. Shand, Mason & Co., have been able to produce steam fire-engines weighing not more than a cwt. per actual horse-power, and they find that the engines most in demand are those with single cylinders weighing from 26 to 27 cwt., and those with double cylinders weighing from 35 to 40 cwt. The pumps have their valves so arranged, that they deliver their water at the lowest part, so as to prevent the accumulation of grit or other obstructions in the valves by causing the valve seats to be swept at each stroke by the effluent water. The only want I see in Messrs. Merryweather and Son's engines is a crank, and the sooner they introduce it the better.

At the International Exhibition of fire-engines held at Middleburgh, in Holland, in July 1864, Messrs. Merryweather and Son's engine obtained the silver medal, and 200 guilder prize; and the makers allege that their engine would have done still better than it did, only that before the trial their boiler had been working with salt water and that some of the salt still remained. Medals and inferior prizes were awarded to Messrs. A. Bikkers & Son, Rotterdam; F. Requilé and Beduwê, Liege; Peek Brothers, Middleburgh; and W. C. Pasteur & Co., Rotterdam.

Ice-making Machines. One of the most remarkable applications of the steam-engine is to the manufacture of ice; which is accomplished by forcing the heat out of air by mechanical compression, and then by again allowing the compressed air to expand. Such demand is thus created for the restoration of the heat before forced out as to produce a great reduction in the temperature of surrounding objects. On the occasion of my first visit to India in 1847, the inconveniences caused by the heat drew my attention to the subject of artificial refrigeration, which I proposed to accomplish by compressing air until its temperature became so high that its surplus heat would be readily extracted by the application of cold water; and then by allowing this air subsequently to expand under such circumstances as to generate power, a very low temperature it was plain would be produced which might be regulated to suit the requirements of a practical system of refrigeration. Subsequently the same idea was propounded by various other parties; and an ice-making machine has been constructed in which the refrigeration is produced by power aided by the agency of ether. But in Kirk's machine for producing cold the ether is discarded and air alone is used, which air is passed through a regenerator as in Stirling's air engine. This machine is now in successful use in Young's Paraffine Works in Scotland.

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LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET