An historical and descriptive account of the steam engine, comprising a general view of the various modes of employing elastic vapour as a prime mover in mechanics

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Chapter V. Cylinder and piston [...].

CHAPTER V.

Cylinder and Piston — Condenser — Air-Pump — Barometer and Steam-Gauge—Working Beam—Parallel Motion — Counter — Sun and Planet Wheel—Fly and other Modes of regulating Velocity—Boiler—Safety-Valves—Furnace.

HAVING taken a brief review of the early history and general principle of this stupendous machine, it may be advisable before we proceed to a description of the principal engines now employed, to examine more minutely the separate parts and the progressive improvements effected in each.

The cylinder and piston being those parts of the engine in which the effective force is more immediately produced, may first claim attention.

The piston of the atmospheric engine is generally made of cast iron nearly fitting the inside of the cylinder, a circular ledge or rim being formed round it to receive the packing, without which the steam would find a passage through the interstices in the cylinder. Mr. Smeaton, who greatly improved the atmospheric engine, coated the under side of the piston with elm or beech planks about two inches and a quarter thick; the wooden bottom being screwed to the iron with a double thickness of flannel and tar, to exclude the air between the iron and the wood. By the adoption of this improvement its property of conducting heat was reduced, and the wood having been previously jointed with the grain radiating in all directions from the centre, was not liable to expand by the heated steam. This piston was kept air-tight by a small stream of water continually falling on its upper surface; but in Mr. Watt's engine he was compelled to effect this by improving the fitting of the piston, the old mode being inadmissible. It is now cast with a projecting rim at bottom, which is fitted as accurately to the cylinder as it can be, to leave it at full liberty to rise and fall through the whole length. The part of the piston above the rim is about two inches less all round than the cylinder, to leave a circular groove for the hemp which forms the packing. To keep this in its place, a lid or cover is put over the top of the piston, with a ring or projecting part, which enters into the circular groove for the packing, and pressing upon it the plate is forced down by screws, which work into the body of the piston. By this means the packing is made to fill the diameter of the cylinder with tolerable accuracy, and to prevent for a time any steam passing between the piston and the cylinder. When, however, by continued working the piston became too easy, and so occasioned a waste of steam, it was found necessary to take off the top of the cylinder to get at the screws, even when fresh hemp or packing was not wanted, and this operation being attended with considerable labour, was seldom resorted to by the engine-man till a great waste of steam had taken place. By an improvement on this piston introduced by Mr. Woolf, this is now effected without taking off the cylinder cover, except, indeed, when new packing is required.

To accomplish this, Mr. Woolf fastens on the head of each of the screws a small cog-wheel or nut, and these are all connected together by means of a central wheel working loose upon the piston-rod in such a manner, that if any one of the screws be turned a similar motion is given to the remainder, a cap being provided in the upper end of the cylinder screwed down by bolts to make it steam tight. In a piston thus constructed, there is little difficulty in drawing down the packing, by applying a key to the square head of the projecting screw employed to communicate with the rest. Another method contrived by Mr. Woolf for the smaller pistons differs but little from the preceding in construction. Instead of having several screws all worked down by one motion, there is in this but one screw, and that one cut upon the piston-rod itself; on this is placed a wheel, the centre of which is furnished with a female screw, which is forced down by means of a pinion furnished with a square projecting head turned in a similar manner to the preceding.

For high-pressure engines, however, the metallic piston invented by Mr. Cartwright has the most decided preference. This not only saves the trouble and expense of packing, which must be frequently renewed in all other engines, but also a great deal of steam, on account of the more accurate manner in which it is made to fit the cylinder; this is effected in the following manner: Two metal rings are accurately ground into the cylinder, so that no steam can pass between their exterior surface and the inside of the cylinder, their upper and under sides are also ground perfectly flat, and applied one upon the other. On the upper ring is placed a plate of metal, rather smaller in diameter than the cylinder, while a similar flat plate is placed below the under ring, both of which, with the rings between, are attached firmly to each other by means of the piston-rod passing through them.

A shell being thus formed, the rings are each of them cut into three pieces, and in cutting them, such a portion of the metal is taken away as to leave room to introduce between two of the pieces, a spring in form of the letter V, the open end of which is placed outwards, almost close to the circumference; by which means the two pieces against which the two sides of the spring act, are pressed in the direction of the circumference, against the ends of the third piece, so that the three pieces are thus kept so uniformly in contact with the cylinder, that the longer the machine is worked, the better the rings must fit. To prevent steam passing through the cuts in the lower rings, the solid parts in those upon the upper side, are made to fall upon the divisions and springs of the under ones, thus interrupting the communication that would otherwise remain open, and forming a perfect break-joint. The interior surface of the cylinder in which the piston works, requires to be bored with the greatest exactness, though this was but little attended to in the early atmospheric engines, some of them being composed of timber hooped together in the same manner as barrels are constructed. Mr. Watt, in his first attempts at improving the steam engine, employed this material in the construction of his cylinders, though he afterwards abandoned it for those of bored metal; the operation of boring being performed with the greatest precision, by an apparatus invented by Mr. Wilkinson*.

Mr. Murray has also effected considerable improvements in this part of the engine, and the boring machines employed in his manufactory are of considerable value. They are worked by a separate steam engine, which is never stopped during the operation, as in that case a shoulder or ring would be formed, running completely round the cylinder.

In small engines, it is common to place the cylinder within the boiler, in which case no artificial

* For a description of Mr. Wilkinson's patent cylinder apparatus, see Appendix, A.

mode of retaining the heat is required; but to this arrangement in those of larger dimensions there are several objections, not the least of which is the frequent repairs that are necessary in the boiler; and a similar effect has been produced by the use of a double cylinder. This was first adopted by Messrs. Boulton and Watt, the outer cylinder or steam-jacket keeping the inner cylinder at the temperature of boiling water, by the action of a partition of steam made to pass between the jacket and the working cylinder.

We have already stated, that Mr. Watt's great improvement consisted in condensing the steam in a separate vessel where a vacuum was formed by the continued application of cold water. A metal box constructed for this purpose, and furnished with a pump for drawing off the water and air, is called a condenser. It is necessary that the parts appropriated to this purpose should be kept as cold as possible; and upon this account the air-pump and condenser are placed in a cistern of cold water, which is kept full by the continued action of a pump, also worked by the engine, and called the cold water pump, a little being allowed to pass off continually to preserve the water at an equable temperature.

The air-pump and condenser are usually of the same size; if of one-eighth, the capacity of the working cylinder, it will be found sufficient to keep the condenser empty in Mr. Watt's single engine. The best proportion for a double action engine is about two-thirds the diameter of the cylinder and half the length of stroke, the condenser, as in the single engine, being of similar capacity.

In Mr. Maudslay's portable engine the condenser is an hollow cylinder, and the air-pump is placed within it, so that there is no necessity for a pipe of communication from the air-pump to the condenser; and in this case a small cistern is fixed over the pump to contain the hot water, the discharge-valves being placed in the lid, which thus forms the bottom of the cistern or hot well.

In the early engines, on Messrs. Boulton and Watt's construction, the air-pump and condensing-cistern were placed at the outer end of the beam; in which case the pump-bucket being drawn up by the descent of the piston, the engine required less counter-weight than in the present form, in which the air-pump must be wholly worked by the counter-weight. It was necessary also, that the parts appropriated to the condensation of steam should be kept as cold as possible; on which account, the air-pump and condenser were placed in a cistern of cold water, which being continually on the overflow, carried off the excess of heat.

The mode of condensing by outward cold, was not however found sufficient; and Mr. Watt afterwards introduced a small jet of water, the dimensions of the air-pump being so far increased, as to extract the injection-water as well as the air.

To shew the degree of vacuum in the condenser, and consequently the amount of pressure on the piston, a barometer-gauge has been employed. This is justly considered as a most important instrument, though unfortunately for the profit of steam engine proprietors but little attended to. This gauge is in fact a common barometer tube, of thirty inches in length, with a graduated scale, and connected with the condenser by a small tube furnished with a stop-cock. When the air is expelled from the cylinder this must be closed, otherwise the steam entering the tube would blow the mercury from the cup. On the cock being turned, and the communication opened with the condenser, the exact degree of vacuum will be shewn by the height of the mercurial column, which, if the condensation be not complete, or air be admitted, will descend, and on the contrary, if perfect, it will ascend, as in the Torricellian tube.

The steam-gauge employed by Mr. Watt, consists of an inverted syphon or bent tube of glass or iron, one leg of which is jointed to the steam-pipe, while the other is open to the atmosphere. A quantity of mercury being poured into the tube, it will occupy the lower or bent part, and the surface of the fluid metal in one leg being exposed to the pressure of the steam, while the external air acts upon the other, it is evident that the difference of level of the two surfaces will express the pressure of the steam in the height of the mercurial column passing up the graduated tube.

This gauge is just the reverse of the preceding; the barometer shewing the pressure of the atmosphere on a given space of the piston, while the steam-guage indicates the force of elastic vapour entering from the boiler. It is the duty of the fire-man frequently to look at this gauge, that he may know when to increase the fire in the furnace, and thus a sufficient supply of steam will always be secured to the engine.

In the early atmospheric engines, the working-beam was composed of a large and almost unhewn tree; but Mr. Smeaton employed a framing of wood for this purpose, which was afterwards much simplified and improved by Mr. Hornblower.

In double-acting engines it is usual to have the beam cast in one piece, the extremities being turned in a lathe to form cylindrical pins, upon which are fitted sockets or pieces, having other pins projecting from them to form the points of the parallel-motion and connecting-rod. Thus, there is one pin on each side of the socket, the two links of the parallel-motion being fitted to the two projecting pins at one end, while the double joint of the connecting-rod is fitted on the two pins at the other end of the beam. The advantage of this construction is, that the joints at the ends of the beam become universal joints, having liberty of motion in all directions; and in some of Mr. Murray's best engines, the same contrivance is applied to the crank-pin and connecting-rod.

The two great links of the parallel-motion, are each composed of a strap or loop of iron, bent so as to form a double link, in the upper bend of which are two sockets for the pivots at the end of the beam, and at the lower end are two others, for the pivots which project on each side of the piston-rod socket. The brasses of this joint are held in by wedges, put through the two links at the lower end, which, on being driven inwards, tighten the fittings at pleasure.

To ascertain the number of strokes made by the engine in a given time, a simple apparatus was contrived by Mr. Watt, called a counter. This is in some cases attached to the beam, each stroke moving one tooth, and the index hand shews how many strokes have been made in a given time; and by comparing this register with the diameter of the piston and the barometer-gauge, the exact power of the engine is accurately shewn.

The fly-wheel has justly been considered one of the most important and valuable parts of the steam-engine: when combined with the crank, it is employed to convert a reciprocating into a rotatory motion. If of moderate size, it should be cast in one piece of metal; this, however, cannot often be accomplished from its great weight, the fly-wheel of a large engine frequently exceeding ten tons. When of this size, the ring is usually cast in six pieces, of about a ton each, and connected by wrought-iron bolts; but a method has lately been introduced in large engines, of substituting the dove-tail for that mode of connecting the parts. In this case the arms are fastened into the ring, and the segments of the ring fastened together by a system of dove-tails, which admit of being put together only in one direction, which is contrary to that in which the centrifugal force acts. It is a great object in constructing fly-wheels, to choose that form which offers the least possible resistance to the medium through which it revolves, and on this account the ring should be smooth and truly circular; the radii being made with a thin edge to the air. It is also necessary that the various pieces connected with the fly, should be cast in the most solid manner, as the centrifugal force of so large a mass frequently moving at the rate of more than three hundred feet per second, would, in the event of any part flying off, be productive of the most fatal consequences.

Messrs. Murray and Wood form the radiating arms or cross bars of an elliptic figure, the narrowest edge meeting the air; and to these eminent engineers we are indebted for the following rule for proportioning the fly-wheel of the steam engine. Multiply the number of horse power of the engine by 2000, and divide it by the square of the intended velocity of the circumference of the fly-wheel in hundred-weights. Of this rule Mr. Buchanan furnishes an example: to find the weight of a fly-wheel proper for an engine of twenty horses' power, supposing the fly-wheel to be 18 feet in diameter, and to make 22 revolutions per second: wheel 18 feet diameter = 56 feet circumference; × 22 revolutions per minute = 1232 feet motion per minute ÷ 60 = $20\frac{1}{7}$ feet motion per second for the motion of the circumference of the fly-wheel. Then $20\frac{1}{7}$ feet per minute squared, = $420\frac{1}{7}$, and twenty horses' power × 2000 = 40000 ÷ $420\frac{1}{4}$ = 90·4 cwt. of the wheel required.

In addition however to this mode of regulating the velocity of the steam engine, a variety of plans have been suggested for equalizing the admission of steam; the most simple of which is by means of a handle connected with the throttle-valve. This is a thin circular vane placed in the steam pipe, turning on a pivot across its centre, which comes through the pipe, and has a small handle fixed on the end of it, by turning which, the passage is opened or shut. When the vane is set, so that its plane is perpendicular to the axis of the pipe, it nearly fills the circular passage, and allows very little steam, if any, to pass by it; but when the vane is turned edgeways, it presents a very small surface, and leaves the passage nearly open; so that by thus turning the handle, the attendant can at any time regulate the speed of the engine.

The governor or double pendulum, is also employed for this purpose. This consists of two balls, suspended by joints projecting from a vertical axis, which being caused to revolve by the machine to which it is connected, will increase the diameter of the path described by the balls with the increasing speed of the machine; or, in other words, their centrifugal force will cause them to fly off from the arbor in a degree proportionate to the velocity of the machine; and this motion is made to actuate the lever connected with the valve, which admits the steam from the boiler to the cylinder.

Another method, is to have the small pump worked by the engine, and raising up water into a cistern, from which it runs out again in a constant stream. By this means the water will accumulate, and rise in the cistern, if the engine work rapidly, so as to pump more water into the cistern than will flow out of it in the same time; and, on the contrary, the surface of the water will sink in the cistern, if the engine work slowly, and a float being in the cistern, and connected with a wire to the throttle-valve, a proportionate effect will be produced on the engine.*

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* The patent regulator invented by Mr. Job Rider, is described in Appendix, A.

The only materials that have hitherto been employed in the construction of steam-engine boilers, are iron, copper, wood, and stone. The latter of these was introduced by Mr. Brindley, who, in 1756, erected a steam engine near Newcastle-under-Lyne with a boiler of this description. It was composed of brick and stone firmly cemented together, and the water was heated by iron flues passing in various directions. An admirable cement for this species of boiler may be formed of boiled linseed oil, litharge, and red and white lead mixed together to a proper consistence, and then applied as a species of mortar to the stones. If the joints be properly filled, a cistern thus constructed will never leak, nor want any very considerable repair.

Savery's boilers were of copper, and contained about five or six gallons of water; and the Marquis of Worcester states, that he employed "a piece of a whole cannon" for that purpose.

The atmospheric-engine, constructed by Newcoman, was provided with a boiler of considerable dimensions, composed of wrought-iron plates, the upper part being of an hemispherical form to resist the elasticity of the steam; and it is of considerable importance that this part of the boiler be accurately proportioned to the power of the engine. If the boiler-top be too small, it requires the steam to be heated to a greater degree to increase its elastic force sufficiently to work the engine, and then the condensation on entering the cylinder will be greater. If the top contain eight or ten times the quantity of steam used at each stroke, it will require no more fire to preserve its elasticity than is sufficient to keep the water in a proper state of boiling; this, therefore, may be considered as the most eligible size.

Wooden boilers have as yet we believe been exclusively confined to America. They were introduced by Mr. Anderson and Chancellor Livingston. The merits of this boiler are, economy in construction, and a very material saving in fuel; the latter of which advantages will be readily seen from the circumstance, that wood is a bad conductor of heat, while metal is one of the best. That there is a great saving in the employment of this species of boiler where wood is cheap is sufficiently evident; that part, however, which is above the water, and consequently exposed to the action of the steam, speedily decays, and the elastic vapour passes through the joints. This, however, might be remedied, by coating the internal surface with thin metal, which might readily be connected with the furnace and flue, so as to make the whole boiler steam-tight.

The boiler of Messrs. Boulton and Watt's engine is so placed as to receive the greatest possible degree of heat, the flame passing through a long flue which twice encircles the lower part. This is kept constantly supplied with water, to repair the waste of evaporation by means of a pump communicating with the hot-well; and as it is necessary that this should always be preserved at the same level, the feed-pipe is closed by a valve in the bottom of the cistern, which prevents the water running down into the boiler until its level subside, and shews that it requires replenishing. To know the exact height of the water in the boiler, two cocks are mostly employed; one of which is carried below the requisite water-mark, and the other stands a little above the desired point. If water should issue from both cocks, the supply has not been sufficient, and more must be admitted; but if, on the contrary, water proceed from the one cock and steam from the other, it may then be considered about the proper level.

The patent boiler employed by Mr. Woolf, is different from that commonly used in engines which work with steam of a low pressure, the water being contained in several cylindrical tubes of cast iron which are exposed to the heat of the furnace nearly in an horizontal position. In the employment of this kind of boiler care should be taken that the flame and heated air be made to come completely in contact with the iron tubes of which it is composed, and so as to give out the least possible portion of heat previous to reaching the chimney.

This mode of raising steam of great elasticity, by exposing a large surface in a number of heated tubes, does not appear to have originated with Mr. Woolf, it having been proposed by Mr.

Blakey in a small tract which he published in Holland as far back as 1776. It appears, however, that Blakey's tubes were to be placed over each other upon the same principle as the olefient gas-retorts, and the water passing down the heated pipes, was thus readily converted into steam.

The high-pressure boiler, employed Mr. Trevithick, is supplied with water previously heated in a separate vessel, by a small force-pump worked by the engine. In some of the improved engines, however, another and more ingenious mode had been adopted, the water being driven in by the action of a volume of highly expansive steam.

Among the provisions made for the security of the high-pressure boiler, we may enumerate the soft metal plug and double safety-valve. The former of these contrivances is calculated to prevent the boiler being burst by the sudden introduction of water, when it has been allowed by carelessness to boil dry, and become red hot; and by the employment of two safety-valves placed in different parts of the boiler, the chance of accident is diminished at least one half, while the effect of the engine is in no shape impaired.

The greater part of the boilers employed in American steam-navigation are of wrought iron, and are usually more than a quarter of an inch in thickness, of a cylindrical form, and about thirty inches in diameter, with a cast-iron end about two inches thick; and the testimony of experienced engineers both in this country and America, has invariably shewn, that such a species of boiler, when old and thin by long wear, has generally given way by a small rent or fissure through which the steam escapes, gradually taking off the internal pressure, and thus securing the passengers adjacent from the dreadful consequences which have frequently resulted from the explosion of cast-iron boilers similarly constructed.*

The safety-valve being an object of considerable importance, both as regards the utility of the engine, and the preservation of those connected with its management, much attention has been given to its construction, and to this highly useful appendage we would particularly call the reader's attention.

The first engine that was made by Captain Savery had a steel-yard safety-valve, to let the steam fly off when it arrived at a dangerous degree of elasticity. The following figure will furnish a sufficiently accurate idea of this simple apparatus. A, the top of the boiler; B, the safety-valve or plug made to fit air tight in the tube or valve-seat beneath; C, the lever working on an axis at D, and furnished with a moveable weight, E, adjusted to balance the pressure of the steam.

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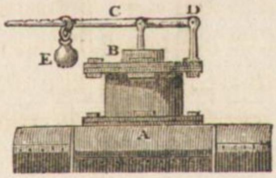
* In those boilers that are constantly employed with sea-water, a great accumulation of salt takes place; it is therefore necessary for ships which perform long voyages to be provided with two boilers, each of which should be capable of supplying the engine with the necessary quantity of steam.

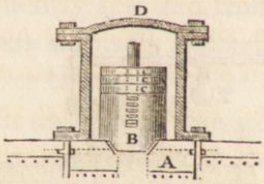
When steam of considerable elasticity is required, the weight is placed at the extremity of the lever, and as such acts with greater force on the safety-valve than when removed to a point nearer to the axis on which it revolves. So that should low-pressure steam be required, it will only be necessary to remove it nearer the axis or centre, and *vice versa.*



The lever and balance-ball which form this apparatus, would at all times be effectual were they not liable to be fastened by the corrosive nature of the materials of which the valve is composed, and, what is worse, their pressure altered by the addition of more weight. This, however, as too frequent experience has shewn, is continually the case, the engineer having more regard for the full performance of his machine than for his own safety or life; and to the overloading of this valve, these accidents may be principally attributed.

To prevent a recurrence of those accidents which first drew the attention of the legislature to this important part of the engine, and to which we have already referred, under the head of steam navigation, it appears advisable to inclose the safety-valve in an iron box, and so put it beyond the control of the engine-man.

The annexed figure represents an inaccessible safety-valve, calculated to answer all the purposes for which it is intended, namely, the preservation of those employed in the neighbourhood of the boiler, and economy in the use of steam.



In this, as in the preceding diagram, A represents the boiler, and B the safety-valve, furnished with a small upright staff, on which slide the additional weights CCC. The whole is inclosed in a box D, pierced with holes to allow the steam to escape after it has raised the valve B.

Should high-pressure steam be wanted, it is necessary only to increase the number of weights, and the desired effect is produced; or if, on the contrary, steam of the usual atmospheric pressure be wanted, the whole of the weights are taken off.

The safety-valve invented by the Chevalier Edelcrantz, has nearly the same properties as that employed by Mr. Woolf. It consists of a small brass cylinder which is fixed on the boiler, and fitted with a piston made to descend with its own weight when raised by the pressure of the steam.

The lower part of the cylinder being made to communicate with the boiler; the upper part is closed by a small cover screwed on to it, and perforated with a hole, through which the piston-rod passes freely, which serves the double purpose of keeping the piston perpendicular, and preventing it being blown out. The sides of the cylinder are pierced with a number of small holes, placed in succession at a short distance above each other, so that the open space for the steam to escape, increases with the height of the valve, and is ultimately enlarged so as to prevent any danger of explosion. The piston-rod is also furnished with a number of weights, fitting loosely on a small shoulder, similar to those employed in the common hydrometer; and these may be removed or increased at pleasure.

Another advantage likely to result from the adoption of this safety-valve is, the facility with which it may be employed to regulate the fire of the steam-engine furnace to the intensity of the elastic vapour required. This may readily be effected by a register pressing on the top of the safety-piston, and connected with the apertures for the admission of air, which, by increasing or decreasing the supply of oxygen, will have a proportionate result on the steam generated in the boiler, and consequently effect a considerable saving in the expenditure of fuel.

Another safety-valve, opening internally, has, we believe, also been added by Messrs. Boulton and

Watt. This is of great utility, more particularly in large engines, as it prevents the sides of the boiler being crushed in by the sudden introduction of water, or any artificial condensation that may take place from reducing the heat of the boiler-head.