CHAPTER IV.

MODES OF ESTIMATING THE POWER AND PERFORMANCE OF ENGINES AND BOILERS.

HORSES POWER.

209. *Q.*—What do you understand by a horse power?

A.—An amount of mechanical force that will raise 33,000 lbs. one foot high in a minute. This standard was adopted by Mr. Watt, as the average force exerted by the strongest London horses; the object of his investigation being to enable him to determine the relation between the power of a certain size of engine and the power of a horse, so that when it was desired to supersede the use of horses by the erection of an engine, he might, from the number of horses employed, determine the size of engine that would be suitable for the work.

210. *Q.*—Then when we talk of an engine of 200 horse power, it is meant that the impelling efficacy is equal to that of 200 horses, each lifting 33,000 lbs. one foot high in a minute?

A.—No, not now; such was the case in Watt's engines, but the capacity of cylinder answerable to a horse power has been increased by most engineers since his time, and the pressure on the piston has been increased also, so that what is now called a

200 horse power engine exerts, almost in every case, a greater power than was exerted in Watt's time, and a horse power, in the popular sense of the term, has become a mere conventional unit for expressing a certain size of engine, without reference to the power exerted.

211. *Q.*—Then each nominal horse power of a modern engine may raise much more than 33,000 lbs. one foot high in a minute?

A.—Yes; some raise 52,000 lbs., others 60,000 lbs., and others 66,000 lbs., one foot high in a minute by each nominal horse power. Some engines indeed work as high as five times above the nominal power, and therefore no comparison can be made between the performances of different engines, unless the power actually exerted be first discovered.

212. *Q.*—How is the power actually exerted by engines ascertained?

A.—By means of an instrument called the indicator, which is a miniature cylinder and piston attached to the cylinder cover of the main engine, and which indicates, by the pressure exerted on a spring, the amount of pressure or vacuum existing within the cylinder. From this pressure, expressed in pounds per square inch, deduct a pound and a half of pressure for friction, the loss of power in working the air pump, &c.; multiply the area of the piston in square inches by this residual pressure, and by the motion of the piston, in feet per minute, and divide by 33,000; the quotient is the actual number of horses power of the engine. The same result is attained by squaring the diameter of the cylinder, multiplying by the pressure per square inch, as shown by the indicator, less a pound and a half, and by the motion of the piston, in feet per minute, and dividing by 42,017.

213. *Q.*—How is the nominal power of an engine ascertained?

A.—Since the nominal power is a mere conventional expression, it is clear that it must be determined by a merely conventional process. The nominal power of ordinary condensing engines may be ascertained by the following rule: multiply the square of the diameter of the cylinder in inches, by the velocity of the piston in feet per minute, and divide the product by 6,000; the quotient is the number of nominal horses power. In using this rule, however, it is necessary to adopt the speed of piston prescribed by Mr. Watt, which varies with the length of the stroke. The speed of piston with a 2 feet stroke is, according to his system, 160 per minute; with a 2 ft. 6 in. stroke, 170; 3 ft., 180; 3 ft. 6 in., 189; 4 ft., 200; 5 ft., 215; 6 ft., 228; 7 ft., 245; 8 ft., 256 ft.

214. *Q.*—Does not the speed of the piston increase with the length of the stroke?

A.—It does: the speed of the piston varies nearly as the cube root of the length of the stroke.

215. *Q.*—And may not therefore some multiple of the cube root of the length of the stroke be substituted for the velocity of the piston in determining the nominal power?

A.—The substitution is quite practicable, and will accomplish some simplification, as the speed of piston proper for the different lengths of stroke cannot always be remembered. The rule for the nominal power of condensing engines when thus arranged, will be as follows: multiply the square of the diameter of the cylinder in inches by the cube root of the stroke in feet, and divide the product by 47; the quotient is the number of nominal horses power of the engine, supposing it to be of the ordinary condensing description. This rule assumes the existence of a uniform effective pressure upon the piston of 7 lbs. per square inch; Mr. Watt estimated the effective pressure upon the piston of his 4 horse power engines at 6·8 lbs. per square inch, and the pressure increased slightly with the power, and became 6·94 lbs. per square inch in engines of 100 horse power; but it appears to be more convenient to take a uniform pressure of 7 lbs. for all powers. Small engines, indeed, are somewhat less effective in proportion than large ones, but the difference can be made up by slightly increasing the pressure in the boiler; and small boilers will bear such an increase without inconvenience.

216. *Q.*—How do you ascertain the power of high pressure engines?

A.—The actual power is readily ascertained by the indicator, by the same process by which the actual power of low pressure engines is ascertained. The friction of a locomotive engine when unloaded is found by experiment to be about 1 lb. per square inch on the surface of the pistons, and the additional friction caused by any additional resistance is estimated at about ·14 of that resistance; but it will be a sufficiently near approximation to the power consumed by friction in high pressure engines, if we make a deduction of a pound and a half from the pressure on that account, as in the case of low pressure engines. High pressure engines, it is true, have no air pump to work; but the deduction of a pound and a half of pressure is relatively a much smaller one where the pressure is high, than where it does not much exceed the pressure of the atmosphere. The rule, therefore, for the actual horse power of a high pressure engine will stand thus: square the diameter of the cylinder in inches, multiply by the pressure of the steam in the cylinder per square inch less 1½ lb., and by the speed of the piston in feet per minute, and divide by 42,017; the quotient is the actual horse power.

217. *Q.*—But how do you ascertain the nominal horse power of high pressure engines?

A.—The nominal horse power of a high pressure engine has never been defined; but it should obviously hold the same relation to the actual power as that which obtains in the case of condensing engines, so that an engine of a given nominal power may be capable of performing the same work, whether high pressure or condensing. This relation is maintained in the following rule, which expresses the nominal horse power of high pressure engines: multiply the square of the diameter of the cylinder in inches by the cube root of the length of stroke in feet, and divide the product by 15·6. This rule gives the nominal power of a high pressure engine three times greater than that of a low pressure engine of the same dimensions; the average effective pressure being taken at 21 lbs. per square inch instead of 7 lbs., and the speed of the piston in feet per minute being in both rules 128 times the cube root of the length of stroke.*

218. *Q.*—Is 128 times the cube root of the stroke in feet per minute the ordinary speed of all engines?

A.—Locomotive engines travel at a quicker speed—an innovation brought about not by any process of scientific deduction, but by the accidents and exigencies of railway transit. Most other engines, however, travel at about the speed of 128 times the cube root of the stroke in feet; but some marine condensing engines of recent construction travel at as high a rate as 700 feet per minute. To mitigate the shock of the air pump valves in cases in which a high speed has been desirable, as in the case of marine engines employed to drive the screw propeller without intermediate gearing, India rubber discs, resting on a perforated metal plate, are now generally adopted; but the India rubber should be very thick, and the guards employed to keep the discs down should be of the same diameter as the discs themselves.

219. *Q.*—Can you suggest any eligible method of enabling condensing engines to work satisfactorily at a high rate of speed?

A.—The most feasible way of enabling condensing engines to work satisfactorily at a high speed, appears to lie in the application of balance weights to the engine, so as to balance the momentum of its moving parts, and the engine must also be made very strong and rigid. It appears to be advisable to perform the condensation partly in the air pump, instead of altogether in the condenser, as a better vacuum and a superior action of the air pump valves will thus be obtained. Engines constructed upon this plan may be driven at four times the speed of common engines, whereby an engine of large power may be purchased for a very moderate price, and be capable of being put into a very small compass; while the motion, from being more equable, will be better adapted for most purposes for which a rotary motion is required. Even for pumping

* Tables of the horse power of both high and low pressure engines are given in the Key.

mines and blowing iron furnaces, engines of this kind appear likely to come into use, for they are more suitable than other engines for driving the centrifugal pump, which in many cases appears likely to supersede other kinds of pumps for lifting water; and they are also conveniently applicable to the driving of fans, which, when so arranged that the air condensed by one fan is employed to feed another, and so on through a series of 4 or 5, have succeeded in forcing air into a furnace with a pressure of 2½ lbs. on the square inch, and with a far steadier flow than can be obtained by a blast engine with any conceivable kind of compensating apparatus. They are equally applicable if blast cylinders be employed.

220. *Q.*—Then, if by this modification of the engine you enable it to work at four times the speed, you also enable it to exert four times the power?

A.—Yes; always supposing it to be fully supplied with steam. The nominal power of this new species of engine can readily be ascertained by taking into account the speed of the piston, and this is taken into account by the Admiralty rule for power.

221. *Q.*—What is the Admiralty rule for determining the power of an engine?

A.—Square the diameter of the cylinder in inches, which multiply by the speed of the piston in feet per minute, and divide by 6,000; the quotient is the power of the engine by the Admiralty rule.*

222. *Q.*—The high speed engine does not require so heavy a fly wheel as common engines?

A.—No; the fly wheel will be lighter, both by virtue of its greater velocity of rotation, and because the impulse communicated by the piston is less in amount and more frequently repeated, so as to approach more nearly to the condition of a uniform pressure.

* *Example.*—What is the power of an engine of 42 inches diameter, 3½ feet stroke, and making 85 strokes per minute? The speed of the piston will be 7 (the length of a double stroke) × 85 = 595 feet per minute. Now 42 × 42 = 1,764 × 595 = 1,049,580 ÷ 6,000 = 175 horses power.

223. *Q.*—Can nominal be transformed into actual horse power?

A.—No; that is not possible in the case of common condensing engines. The actual power exerted by an engine cannot be deduced from its nominal power, neither can the nominal power be deduced from the power actually exerted, or from anything else than the dimensions of the cylinder. The actual horse power being a dynamical unit, and the nominal horse power a measure of capacity of the cylinder, are obviously incomparable things.

224. *Q.*—That is, the *nominal* power is a commercial unit by which engines are bought and sold, and the *actual* power a scientific unit by which the quality of their performance is determined?

A.—Yes; the nominal power is as much a commercial measure as a yard or a bushel, and is not a thing to be ascertained by any process of science, but to be fixed by authority in the same manner as other measures. The actual power, on the contrary, is a mechanical force or dynamical effort capable of raising a given weight through a given distance in a given time, and of which the amount is ascertainable by scientific investigation.

225. *Q.*—Is there any other measure of an actual horse power than 33,000 lbs. raised one foot high in the minute?

A.—There cannot be any *different* measure, but there are several equivalent measures. Thus the evaporation of a cubic foot of water in the hour, or the expenditure of 33 cubic feet of low pressure steam per minute, is reckoned equivalent to an acual horse power, or 528 cubic feet of water raised one foot high in the minute involves the same result.

DUTY OF ENGINES AND BOILERS.

226. *Q.*—What is meant by the duty of a engine?

A.—The work done in relation to the fuel consumed.

227. *Q.*—And how is the duty ascertained?

A.—In ordinary mill or marine engines it can only be ascertained by the indicator, as the load upon such engines is variable, and cannot readily be determined; but in the case of engines pumping water, where the load is constant, the number of strokes performed by the engine will represent the work done, and the amount of work done by a given quantity of coal represents the duty. In Cornwall the duty of an engine is expressed by the number of millions of pounds raised one foot high by a bushel, or 94 lbs. of Welsh coal. A bushel of Newcastle coal will only weigh 84 lbs.; and in comparing the duty of a Cornish engine with the performance of an engine in some locality where a different kind of coal is used, it is necessary to pay regard to such variations.

228. *Q.*—Can you tell the duty of an engine when you know its consumption of coal per horse power per hour?

A.—Yes, if the power given be the actual, and not the nominal, power. Divide 166·32 by the number of pounds of coal consumed per actual horse power per hour; the quotient is the duty in millions of pounds. If you already have the duty in millions of pounds, and wish to know the equivalent consumption in pounds per actual horse power per hour, divide 166·32 by the duty in millions of pounds; the quotient is the consumption per actual horse power per hour. The duty of a locomotive engine is expressed by the weight of coke it consumes in transporting a ton through the distance of one mile upon a railway; but this is a very imperfect method of representing the duty, as the tractive efficacy of a pound of coke becomes less as the speed of the locomotive becomes greater; and the law of variation is not accurately known.

229. *Q.*—What amount of power is generated in good engines of the ordinary kind by a given weight of coal?

A.—The duty of different kinds of engines varies very much, and there are also great differences in the performance of different engines of the same class. In ordinary rotative condensing engines of good construction, 10 lbs. of coal per nominal horse power per hour is a common consumption; but such engines exert nearly twice their nominal power, so that the consumption per actual horse power per hour may be taken at from 5 to

6 lbs. Engines working very expansively, however, attain an economy much superior to this. The average duty of the pumping engines in Cornwall is about 60,000,000 lbs. raised 1 ft. high by a bushel of Welsh coals, which weighs 94 lbs. This is equivalent to a consumption of 3·1 lbs. of coal per actual horse power per hour; but some engines reach a duty of above 100,000,000, or 1·74 lbs. of coal per actual horse power per hour. Locomotives consume from 8 to 10 lbs. of coke in evaporating a cubic foot of water, and the evaporation of a cubic foot of water per hour may be set down as representing an actual horse power in locomotives as well as in condensing engines, if expansion be not employed. When the locomotive is worked expansively, however, there is of course a less consumption of water and fuel per horse power, or per ton per mile, than when the full pressure is used throughout the stroke; and most locomotives now operate with as much expansion as can be conveniently given by the slide valves.

230. *Q.*—But is not the evaporative power of locomotives affected materially by the proportions of the boiler?

A.—Yes, but this may be said of all boilers; but in locomotive boilers, perhaps, the effect of any misproportion becomes more speedily manifest. A high temperature of the fire box is found to be conducive to economy of fuel; and this condition, in its turn, involves a small area of grate bars. The heating surface of locomotive boilers should be about 80 square feet for each square foot of grate bars, and upon each foot of grate bars about 1 cwt. of coke should be burnt in the hour.

231. *Q.*—Probably the heat is more rapidly absorbed when the temperature of the furnace is high?

A.—That seems to be the explanation. The rapidity with which a hot body imparts heat to a colder, varies as the square of the difference of temperature; so that if the temperature of the furnace be very high, the larger part of the heat passes into the water at the furnace, thereby leaving little to be transmitted by the tubes. If, on the contrary, the temperature of the furnace be low, a large part of the heat will pass into the tubes, and more tube surface will be required to absorb it. About 16 cubic feet of water should be evaporated by a locomotive boiler for each square foot of fire grate, which, with the proportion of heating surface already mentioned, leaves 5 square feet of heating surface to evaporate a cubic foot of water in the hour. This is only about half the amount of surface usual in land and marine boilers per cubic foot evaporated, and its small amount is due altogether to the high temperature of the furnace, which, by the rapidity of transmission it causes, is tantamount to an additional amount of heating surface.

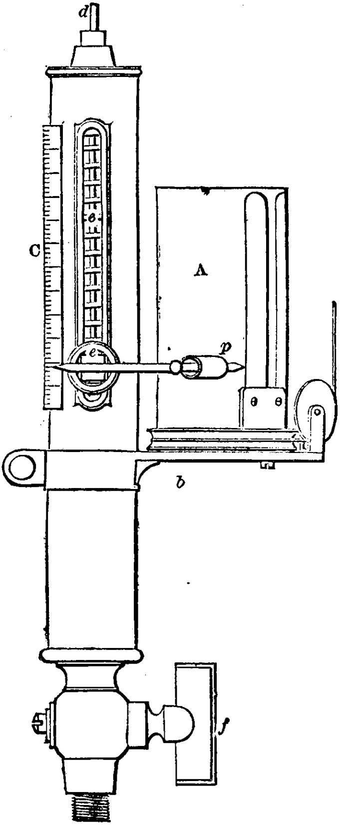
232. *Q.*—You have stated that the steam and vacuum gauges are generally glass tubes, up which mercury is forced by the steam or sucked by the vacuum?

A.—Vacuum gauges are very often of this construction, but steam gauges more frequently consist of a small iron tube, bent like the letter U, and into which mercury is poured. The one end of this tube communicates with the boiler, and the other end with the atmosphere; and when the pressure of the steam rises in the boiler, the mercury is forced down in the leg communicating with the boiler and rises in the other leg, and the difference of level in the legs denotes the pressure of the steam. In this gauge a rise of the mercury one inch in the one leg involves a difference of the level between the two legs of two inches, and an inch of rise is, therefore, equivalent to two inches of mercury, or a pound of pressure. A small float of wood is placed in the open leg to show the rise or fall of the mercury, and this leg is surmounted by a brass scale, graduated in inches, to the marks of which the float points.

233. *Q.*—What other kinds of steam and vacuum gauges are there?

A.—There are many other kinds; but probably Bourdon's gauges are now in more extended use than any other, and their operation has been found to be satisfactory in practice. The principle of their action may be explained to be, that a thin elliptical metal tube, if bent into a ring, will seek to coil or uncoil itself if subjected to external or internal pressure, and to an extent proportional to the pressure applied. The end of the tube is sharpened into an index, and moves to an extent corresponding to the pressure applied to the tube; but in the more recent forms of this apparatus, a dial and a hand, like those of a clock, are employed, and the hand is moved round by a toothed sector connected to the tube, and which sector acts on a pinion attached to the hand. Mr. Shank, of Paisley, has lately introduced a form of steam gauge like a thermometer, with a flattened bulb; and the pressure of the steam, by compressing the bulb, causes the mercury to rise to a point proportional to the pressure applied.

Fig. 36.



THE INDICATOR.

234. *Q.*—You have already stated that the actual power of an engine is ascertained by an instrument called the indicator, which consists of a small cylinder with a piston moving against a spring, and compressing it to an extent answerable to the pressure of the steam. Will you explain further the structure and mode of using that instrument?

A.—The structure of the common form of indicator will be most readily apprehended by a reference to fig. 36, which is a M'Naught's indicator. Upon a movable barrel A, a piece of paper is wound, the ends of which are secured by the slight brass clamps shown in the drawing. The barrel is supported by the bracket *b*, proceeding from the body of the indicator, and at the bottom of the barrel a watch spring is coiled with one end attached to the barrel and the other end to the bracket, so that when the barrel is drawn round by a string wound upon its lower end like a roller blind, the spring returns the barrel to its original position, when the string is relaxed. The string is attached to some suitable part of the engine, and at every stroke the string is drawn out, turning round the barrel, and the barrel is returned again by the spring on the return stroke.

235. *Q.*—But in what way can these reciprocations of the barrel determine the power of the engine?

A.—They do not determine it of themselves, but are only part of the operation. In the inside of the cylinder C there is a small piston moving steam tight in a cylinder of which *d* is the piston rod, and *e* a spiral spring of steel, which the piston, when forced upwards by the steam or sucked downwards by the vacuum, either compresses or extends; *f* is a cock attached to the cylinder of the indicator, and which is screwed into the cylinder cover. It is obvious that, so soon as this cock is opened, the piston will be forced up when the space above the piston of the engine is opened to the boiler, and sucked down when that space is opened to the condenser—in each case to an extent proportionate to the pressure of the steam or the perfection of the vacuum, the top of the piston *c* being open to the atmosphere. A pencil, *p*, with a knife hinge, is inserted into the piston rod at *e*, and the point of the pencil bears upon the surface of the paper wound upon the drum A. If the drum A did not revolve, this pencil would merely trace on the paper a vertical line; but as the drum A moves round and back again every stroke of the engine, and as the pencil moves up and down again every stroke of the engine, the combined movements trace upon the paper a species of rectangle, which is called an indicator diagram; and the nature of this diagram determines the nature of the engine's performance.

236. *Q.*—How does it do this?

A.—It is clear that if the pencil was moved up instantaneously to the top of its stroke, and was also moved down instantaneously to the bottom of its stroke, and if it remained without fluctuation while at the top and bottom, the figure described by the pencil would be a perfect rectangle, of which the vertical height would represent the total pressure of the steam and vacuum, and therefore the total pressure urging the piston of the engine. But in practice the pencil will neither rise nor fall instantaneously, nor will it remain at a uniform height throughout the stroke. If the steam be worked expansively the pressure will begin to fall so soon as the steam is cut off; and at the end of the stroke, when the steam comes to be discharged, the subsidence of pressure will not be instantaneous, but will occupy an appreciable time. It is clear, therefore, that in no engine can the diagram described by an indicator be a complete rectangle; but the more nearly it approaches to a rectangle, the larger will be the power produced at every stroke with any given pressure, and the area of the space included within the diagram will in every case accurately represent the power exerted by the engine during that stroke.

237. *Q.*—And how is this area ascertained?

A.—It may be ascertained in various ways; but the usual mode is to take the vertical height of the diagram at a number of equidistant points on a base line, and then to take the mean of these several heights as representative of the mean pressure actually urging the piston. Now if you have the pressure on the piston per square inch, and if you know the number of square inches in its area, and the velocity with which it moves in feet per minute, you have obviously the dynamical effort of the engine, or, in other words, its actual power.

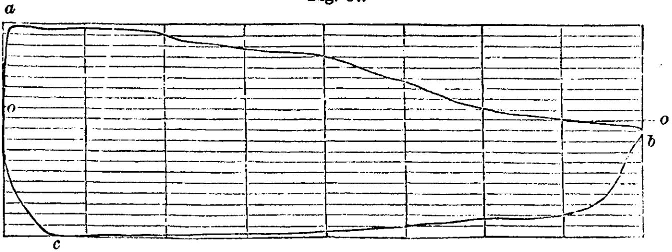
238. *Q.*—How is the base line you have referred to obtained?

A.—In proceeding to take an indicator diagram, the first thing to be done is to allow the barrel to make two or three reciprocations with the pencil resting against it, before opening the cock attached to the cylinder. There will thus be traced a horizontal line, which is called the *atmospheric line*, and in condensing engines, a part of the diagram will be above and a part of it below this line; whereas, in high pressure engines the whole of the diagram will be above this line. Upon this line the vertical ordinates may be set off at equal distances, or upon any base line parallel to it; but the usual course is to erect the ordinates on the atmospheric line.

239. *Q.*—Will you give an example of an indicator diagram?

A.—Fig. 37 is an indicator diagram taken from a low pres-

Fig. 37.



sure engine, and the waving line *a b c*, forming a sort of irregular parallelogram, is that which is described by the pencil. The atmospheric line is represented by the line o o. The scale at the side shows the pressure of the steam, which in this engine rose to about 9 lbs. per square inch, and the vacuum fell to 11 lbs. The steam begins to be cut off when about one-fourth of the stroke has been performed, and the pressure consequently falls.

240. *Q.*—Is this species of indicator which you have just described applicable to locomotive engines?

A.—It is no doubt applicable under suitable conditions; but another species of indicator has been applied by Mr. Gooch to locomotive engines, which presents several features of superiority for such a purpose.

This indicator has its cylinder placed horizontally; and its piston compresses two elliptical springs; a slide valve is substituted for a cock, to open or close the communication with the engine. The top of the piston rod of this indicator is connected to the short arm of a smaller lever, to the longer arm of which the pencil is attached, and the pencil has thus a considerably larger amount of motion than the piston; but it moves in the arc of a circle instead of in a straight line. The pencil marks on a web of paper, which is unwound from one drum and wound on to another, so that a succession of diagrams are taken without the necessity of any intermediate manipulation.

241. *Q.*—These diagrams being taken with a pencil moving in an arc, will be of a distorted form?

A.—They will not be of the usual form, but they may be easily translated into the usual form. It is undoubtedly preferable that the indicator should act immediately in the production of the final form of diagram.

DYNAMOMETER, GAUGES, AND CATARACT.

242. *Q.*—What other gauges or instruments are there for telling the state, or regulating the power of an engine?

A.—There is the counter for telling the number of strokes the engine makes, and the dynamometer for ascertaining the tractive power of steam vessels or locomotives; then there are the gauge cocks, and glass tubes, or floats, for telling the height of water in the boiler; and in pumping engines there is the cataract for regulating the speed of the engine.

243. *Q.*—Will you describe the mechanism of the counter?

A.—The counter consists of a train of wheel work, so contrived that by every stroke of the engine an index hand is moved forward a certain space, whereby the number of strokes made by the engine in any given time is accurately recorded. In most cases the motion is communicated by means of a detent,—attached to some reciprocating part of the engine,—to a ratchet wheel which gives motion to the other wheels in its slow revolution; but it is preferable to derive the motion from some revolving part of the engine by means of an endless screw, as where the ratchet is used the detent will sometimes fail to carry it round the proper distance. In the counter contrived by Mr. Adie, an endless screw works into the rim of two small wheels situated on the same axis, but one wheel having a tooth more than the other, whereby a differential motion is obtained; and the difference in the velocity of the two wheels, or their motion upon one another, expresses the number of strokes performed. The endless screw is attached to some revolving part of the engine, whereby a rotatory motion is imparted to it; and the wheels into which the screws work hang down from it like a pendulum, and are kept stationary by the action of gravity.

244. *Q.*—What is the nature of the dynamometer?

A.—The dynamometer employed for ascertaining the traction upon railways consists of two flat springs joined together at the ends by links, and the amount of separation of the springs at the centre indicates, by means of a suitable hand and dial, the force of traction. A cylinder of oil, with a small hole through its piston, is sometimes added to this instrument to prevent sudden fluctuations. In screw vessels the forward thrust of the screw is measured by a dynamometer constructed on the principle of a weighing machine, in which a small spring pressure at the index will balance a very great pressure where the thrust is employed; and in each case the variations of pressure are recorded by a pencil on a sheet of paper, carried forward by suitable mechanism, whereby the mean thrust is easily ascertained. The tractive force of paddle wheel steamers is ascertained by a dynamometer fixed on shore, to which the floating vessel is attached by a rope. Sometimes the power of an engine is ascertained by a friction break dynamometer applied to the shaft.

245. *Q.*—What will determine the amount of thrust shown by the dynamometer?

A.—In locomotives and in paddle steamers it will be determined by the force turning the wheels, and by the smallness of the diameter of the wheels; for with small wheels the thrust will be greater than with large wheels. In screw vessels the thrust will be determined by the force turning round the screw, and by the smallness of the screw's pitch; for with any given force of torsion a fine pitch of screw will give a greater thrust than a coarse pitch of screw, just as is the case when a screw works in a solid nut.

246. *Q.*—Will you explain the use of the glass gauges affixed to the boiler?

A.—The glass gauges are tubes affixed to the fronts of boilers, by the aid of which the height of the water within the boilers is readily ascertainable, for the water will stand at the same height in the tube as in the boiler, with which there is a communication maintained both at the top and bottom of the tube by suitable stopcocks. The cocks connecting the glass tube with the boiler should always be so constructed that the tube may be blown through with the steam, to clear it of any internal concretion that may impair its transparency; and the construction of the sockets in which the tube is inserted should be such, that, even when there is steam in the boiler, a broken tube may be replaced with facility.

247. *Q.*—What then are the gauge cocks?

A.—The gauge cocks are cocks penetrating the boiler at different heights, and which, when opened, tell whether it is water or steam that exists at the level at which they are respectively inserted. It is unsafe to trust to the glass gauges altogether as a means of ascertaining the water level, as sometimes they become choked, and it is necessary, therefore, to have gauge cocks in addition; but if the boiler be short of steam, and a partial vacuum be produced within it, the glass gauges become of essential service, as the gauge cocks will not operate in such a case, for though opened, instead of steam and water escaping from them, the air will rush into the boiler. It is expedient to carry a pipe from the lower end of the glass tube downward into the water of the boiler, and a pipe from the upper end upward into the steam in the boiler, so as to prevent the water from boiling down through the tube, as it might otherwise do, and prevent the level of the water from being ascertainable. The average level of water in the boiler should be above the centre of the tube; and the lowest of the gauge cocks should always run water, and the highest should always blow steam.

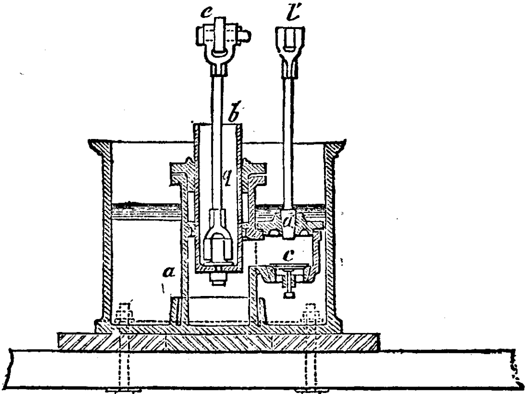
248. *Q.*—Is not a float sometimes employed to indicate the level of the water in the boiler?

A.—A float for telling the height of water in the boiler is employed only in the case of land boilers, and its action is like that of a buoy floating on the surface, which, by means of a light rod passing vertically through the boiler, shows at what height the water stands. The float is usually formed of stone or iron, and is so counterbalanced as to make its operation the same as if it were a buoy of timber; and it is generally put in connection with the feed valve, so that in proportion as the float rises, the supply of feed water is diminished. The feed water in land boilers is admitted from a small open cistern, situated at the top of an upright or stand pipe set upon the boiler, and in which there is a column of water sufficiently high to balance the pressure of the steam.

249. *Q.*—What is the cataract which is employed to regulate the speed of pumping engines?

A.—The cataract consists of a small pump-plunger *b* and barrel, set in a cistern of water, the barrel being furnished on

Fig. 38.



the one side with a valve, *c*, opening inwards, through which the water obtains admission to the pump chamber from the cistern, and on the other by a plug, *d*, through which, if the plunger be forced down, the water must pass out of the pump chamber. The engine in the upward stroke of the piston, which is accomplished by the preponderance of weight at the pump end of the beam, raises up the plunger of the cataract by means of a small rod,—the water entering readily through the valve already referred to; and when the engine reaches the top of the stroke, it liberates the rod by which the plunger has been drawn up, and the plunger then descends by gravity, forcing out the water through the cock, the orifice of which has previously been adjusted, and the plunger in its descent opens the injection valve, which causes the engine to make a stroke.

250. *Q.*—Suppose the cock of the cataract be shut?

A.—If the cock of the cataract be shut, it is clear that the plunger cannot descend at all, and as in that case the injection valve cannot be opened, the engine must stand still; but if the cock be slightly opened, the plunger will descend slowly, the injection valve will slowly open, and the engine will make a gradual stroke as it obtains the water necessary for condensation. The extent to which the cock is open, therefore, will regulate the speed with which the engine works; so that, by the use of the cataract, the speed of the engine may be varied to suit the variations in the quantity of water requiring to be lifted from the mine. In some cases an air cylinder, and in other cases an oil cylinder, is employed instead of the apparatus just described; but the principle on which the whole of these contrivances operate is identical, and the only difference is in the detail.

251. *Q.*—You have now shown that the performance of an engine is determinable by the indicator; but how do you determine the power of the boiler?

A.—By the quantity of water it evaporates. There is, however, no very convenient instrument for determining the quantity of water supplied to a boiler, and the consequence is that this element is seldom ascertained.