CHAPTER VIII.

CONSTRUCTIVE DETAILS OF ENGINES.

PUMPING ENGINES.

422. *Q.*—Will you explain the course of procedure in the erection of a pumping engine, such as Boulton and Watt introduced into Cornwall?

A.—The best instructions on this subject are those of Mr. Watt himself, which are as follows:—Having fixed on the proper situation of the pump in the pit, from its centre measure out the distance to the centre of the cylinder, from which set off all the other dimensions of the house, including the thickness of the walls, and dig out the whole of the included ground to the depth of the bottom of the cellar, so that the bottom of the cylinder may stand on a level with the natural ground of the place, or lower, if convenient, for the less the height of the house above the ground, the firmer it will be. The foundations of the walls must be laid at least two feet lower than the bottom of the cellar, unless the foundation be firm rock; and care must be taken to leave a small drain into the pit quite through the lowest part of the foundation of the lever wall, to let off any water that may be spilt in the engine house, or may naturally come into the cellar. If the foundation at that depth does not prove good, you must either go down to a better if in your reach, or make it good by a platform of wood or piles, or both.

423. *Q.*—These directions refer to the foundations?

A.—Yes; but I will now proceed to the other parts. Within the house, low walls must be built to carry the cylinder beams, so as to leave sufficient room to come at the holding down bolts, and the ends of these beams must also be lodged in the wall. The lever wall must be built in the firmest manner, and run solid, course by course, with thin lime mortar, care being taken that the lime has not been long slaked. If the house be built of stone, let the stones be large and long, and let many headers be laid through the wall: it should also be a rule, that every stone be laid on the broadest bed it has, and never set on its edge. A course or two above the lintel of the door that leads to the condenser, build into the wall two parallel flat thin bars of iron equally distant from each other, and from the outside and inside of the wall, and reaching the whole breadth of the lever wall. About a foot higher in the wall, lay at every four feet of the breadth of the front, other bars of the same kind at right angles to the former course, and reaching quite through the thickness of the wall; and at each front corner lay a long bar in the middle of the side walls, and reaching quite through the front wall; if these bars are 10 feet or 12 feet long it will be sufficient. When the house is built up nearly to the bottom of the opening under the great beam another double course of bars is to be built in, as has been directed. At the level of the upper cylinder beams, holes must be left in the walls for their ends, with room to move them laterally, so that the cylinder may be got in; and smaller holes must be left quite through the walls for the introduction of iron bars, which being firmly fastened to the cylinder beams at one end, and screwed at the other or outer end, will serve, by their going through both the front and back walls, to bind the house more firmly together. The spring beams or iron bars fastened to them must reach quite through the back wall, and be keyed or screwed up tight; and they must be firmly fastened to the lever wall on each side, either by iron bars, firm pieces of wood, or long strong stones, reaching far back into the wall. They must also be bedded solidly, and the residue of the opening must be built up in the firmest manner.

424. *Q.*—If there be a deficiency of water for the purpose of condensation, what course should be pursued?

A.—If there be no water in the neighborhood that can be employed for the purpose of condensation, it will be necessary to make a pond, dug in the earth, for the reception of the water delivered by the air pump, to the end that it may be cooled and used again for the engine. The pond may be three or four feet deep, and lined with turf, puddled, or otherwise made water tight. Throwing up the water into the air in the form of a jet to cool it, has been found detrimental; as the water is then charged with air which vitiates the vacuum.

425. *Q.*—How is the piston of a pumping engine packed?

A.—To pack the piston, take sixty common-sized white or untarred rope-yarns, and with them plait a gasket or flat rope as close and firm as possible, tapering for eighteen inches at each end, and long enough to go round the piston, and overlapped for that length; coil this rope the thin way as hard as possible, and beat it with a sledge hammer until its breadth answers the place; put it in and beat it down with a wooden drift and a hand mallet, pour some melted tallow all around, then pack in a layer of white oakum half an inch thick, so that the whole packing may have the depth of five to six inches, depending on the size of the engine; finally, screw down the junk ring. The packing should be beat solid, but not too hard, otherwise it will create so great a friction as to prevent the easy going of the engine. Abundance of tallow should be allowed, especially at first; the quantity required will be less as the cylinder grows smooth. In some of the more modern pumping engines, the piston is provided with metallic packing, consisting for the most part of a single ring with a tongue piece to break the joint, and packed behind with hemp. The upper edge of the metallic ring is sharpened away from the inside so as to permit more conveniently the application of hemp packing behind it; and the junk ring is made much the same as if no metallic packing were employed.

426. *Q.*—Will you explain the mode of putting the engine into operation?

A.—To set the engine going, the steam must be raised until the pressure in the steam pipe is at least equal to three pounds on the square inch; and when the cylinder jacket is fully warmed, and steam issues freely from the jacket cock, open all the valves or regulators; the steam will then forcibly blow out the air or water contained in the eduction pipe, and to get rid of the air in the cylinder, shut the steam valve after having blown through the engine for a few minutes. The cold water round the condenser will condense some of the steam contained in the eduction pipe, and its place will be supplied by some of the air from the cylinder. The steam valve must again be opened to blow out that air, and the operation is to be repeated until the air is all drawn out of the cylinder. When that is the case shut all the valves, and observe if the vacuum gauge shows a vacuum in the condenser; when there is a vacuum equivalent to three inches of mercury, open the injection a very little, and shut it again immediately; and if this produces any considerable vacuum, open the exhausting valve a very little way, and the injection at the same time. If the engine does not now commence its motion, it must be blown through again until it moves. If the engine be lightly loaded, or if there be no water in the pumps, the throttle valve must be kept nearly closed, and the top and exhaustion regulators must be opened only a very little way, else the engine will make its stroke with violence, and perhaps do mischief. If there is much unbalanced weight on the pump end, the plug which opens the steam valve must be so regulated, that the valve will only be opened very slightly; and if after a few strokes it is found that the engine goes out too slowly, the valve may be then so adjusted as to open wider. The engine should always be made to work full stroke, that is, until the catch pins be made to come within half an inch of the springs at each end, and the piston should stand high enough in the cylinder when the engine is at rest, to spill over into the perpendicular steam pipe any water which may be condensed above it; for if water remain upon the piston, it will increase the consumption of steam. When the engine is to be stopped, shut the injection valve and secure it, and adjust the tappets so as to prevent the exhausting valve from opening and to allow the steam valve to open and remain open, otherwise a partial vacuum may arise in the cylinder, and it may be filled with water from the injection or from leaks. A single acting engine, when it is in good order, ought to be capable of going as slow as one stroke in ten minutes, and as fast as ten strokes in one minute; and if it does not fulfil these conditions, there is some fault which should be ascertained and remedied.

427. *Q.*—Your explanation has reference to the pumping engine as introduced into Cornwall by Watt: have any modifications been since made upon it?

A.—In the modern Cornish engines the steam is used very expansively, and a high pressure of steam is employed. In some cases a double cylinder engine is used, in which the steam, after having given motion to a small piston on the principle of a high pressure engine, passes into a larger cylinder, where it operates on the principle of a condensing engine; but there is no superior effect gained by the use of two cylinders, and there is greater complexity in the apparatus. Instead of the lever walls, cast iron columns are now frequently used for supporting the main beam in pumping engines, and the cylinder end of the main beam is generally made longer than the pump end in engines made in Cornwall, so as to enable the cylinder to have a long stroke, and the piston to move quickly, without communicating such a velocity to the pump buckets as will make them work with such a shock as to wear themselves out quickly. A high pressure of steam, too, can be employed where the stroke is long, without involving the necessity of making the working parts of such large dimensions as would otherwise be necessary; for the strength of the parts of a single acting engine will require to be much the same, whatever the length of the stroke may be.

428. *Q.*—What kind of pump is mostly used in draining deep mines?

A.—The pump now universally preferred is the plunger pump, which admits of being packed or tightened while the engine is at work; but the lowest lift of a mine is generally supplied with a pump on the suction principle, both with the view of enabling the lowest pipe to follow the water with facility as the shaft is sunk deeper, and to obviate the inconvenience of the valves of the pump being rendered inaccessible by any flooding in the mine. The pump valves of deep mines are a perpetual source of expense and trouble, as from the pressure of water upon them it is difficult to prevent them from closing with violence; and many expedients have been contrived to mitigate the evil, of which the valve known as Harvey and West's valve has perhaps gained the widest acceptation.

429. *Q.*—Will you describe Harvey and West's pump valve?

A.—This valve is a compromise between the equilibrium valve, of the kind employed for admitting the steam to and from the cylinder in single acting engines, and the common spindle valve formerly used for that purpose; and to comprehend its action, it is necessary that the action of the equilibrium valve, which has been already represented in *fig.* 34, should first be understood. This valve consists substantially of a cylinder open at both ends, and capable of sliding upon a stationary piston fixed upon a rod the length of the cylinder, which proceeds from the centre of the orifice the valve is intended to close. It is clear, that when the cylinder is pressed down until its edge rests upon the bottom of the box containing it, the orifice of the pipe must be closed, as the steam can neither escape past the edge of the cylinder nor between the cylinder and the piston; and it is equally clear, that as the pressure upon the cylinder is equal all around it, and the whole of the downward pressure is maintained by the stationary piston, the cylinder can be raised or lowered without any further exertion of force than is necessary to overcome the friction of the piston and of the rod by which the cylinder is raised. Instead of the rubbing surface of a piston, however, a conical valve face between the cylinder and piston is employed, which is tight only when the cylinder is in its lowest position; and there is a similar face between the edge of the cylinder and the bottom of the box in which it is placed. The moving part of the valve, too, instead of being a perfect cylinder, is bulged outward in the middle, so as to permit the steam to escape past the stationary piston when the cylindrical part of the valve is raised. It is clear, that if such a valve were applied to a pump, no pressure of water within the pump would suffice to open it, neither would any pressure of water above the valve cause it to shut with violence; and if an equilibrium valve, therefore, be used as a pump valve at all, it must be opened and shut by mechanical means. In Harvey and West's valves, however, the equilibrium principle is only partially adopted; the lower face is considerably larger in diameter than the upper face, and the difference constitutes an annulus of pressure, which will cause the valve to open or shut with the same force as a spindle valve of the area of the annulus. To deaden the shock still more effectually, the lower face of the valve is made to strike upon end wood driven into an annular recess in the pump bucket; and valves thus constructed work with very little noise or tremor; but it is found in practice, that the use of Harvey and West's valve, or any contrivance of a similar kind, adds materially to the load upon the pump, especially in low lifts where the addition of a load to the valve makes a material addition to the total resistance which the engine has to overcome. Instead of end wood driven into a recess for the valve to strike upon, a mixture of tin and lead cast in a recess is now frequently used, and is found to be preferable to the wood.

430. *Q.*—Is there any other kind of pump valve which is free from the shocks incidental to the working of common valves?

A.—In some cases canvass valves are used for pumps, with the effect of materially mitigating the shock; but they require frequent renewal, and are of inferior eligibility in their action to the slide valve, which might in many cases be applied to pumps without inconvenience.

431. *Q.*—Could not a form of pump be devised capable of working without valves at all?

A.—It appears probable, that by working a common reciprocating pump at a high speed, a continuous flow of water might be maintained through the pipes in such a way as to render the existence of any valves superfluous after once the action was begun, the momentum of the moving water acting in fact as valves. The centrifugal pump, however, threatens to supersede pumps of every other kind; and if the centrifugal pump be employed there will be no necessity for pump valves at all. There is less loss of effect by the centrifugal pump than by the common pump.

432. *Q.*—What is the best form of the centrifugal pump?

A.—There are two forms in which the centrifugal pump may be applied to mines;—that in which the arms diverge from the bottom, like the letter V; and that in which revolving arms are set in a tight case near the bottom of the mine, and are turned by a shaft from the surface. Such pumps both draw and force; and either by arranging them in a succession of lifts in the shaft of the mine, or otherwise, the water may be drawn without inconvenience from any depth. The introduction of the centrifugal pump would obviously extinguish the single acting engine, as rotative engines working at a high speed would be the most appropriate form of engine where the centrifugal pump was employed.

433. *Q.*—This would not be a heavy deprivation?

A.—The single acting engine is a remnant of engineering barbarism which must now be superseded by more compendious contrivances. The Cornish engines, though rudely manufactured, are very expensive in production, as a large engine does but little work; whereas by employing a smaller engine, moving with a high speed, the dimensions may be so far diminished that the most refined machinery may be obtained at less than the present cost.

434. *Q.*—Are not the Cornish engines more economical in fuel than other engines?

A.—It is a mistake to suppose that there is any peculiar virtue in the existing form of Cornish engine to make it economical in fuel, or that a less lethargic engine would necessarily be less efficient. The large duty of the engines in Cornwall is traceable to the large employment of the principle of expansion, and to a few other causes which may be made of quite as decisive efficacy in smaller engines working with a quicker speed; and there is therefore no argument in the performance of the present engines against the proposed substitution.

VARIOUS FORMS OF MARINE ENGINES.

435. *Q.*—What species of paddle engine do you consider to be the best?

A.—The oscillating engine.

436. *Q.*—Will you explain the grounds of that preference?

A.—The engine occupies little space, consists of few parts, is easily accessible for repairs, and may be both light and strong at the same time. In the case of large engines the crank in the intermediate shaft is a disadvantage, as it is difficult to obtain such a forging quite sound. But by forging it in three cranked flat bars, which are then laid together and welded into a square shaft, a sound forging will be more probable, and the bars should be rounded a little on the sides which are welded to allow the scoriæ to escape during that operation. It is important in so large a forging not to let the fire be too fierce, else the surface of the iron will be burnt before the heart is brought to a welding heat. In some cases in oscillating engines the air pump has been wrought by an eccentric, and that may at any time be done where doubt of obtaining a sound intermediate shaft is entertained; but the precaution must be taken to make the eccentric very wide so as to distribute the pressure over a large surface, else the eccentric will be apt to heat.

437. *Q.*—Have not objections been brought against the oscillating engine?

A.—In common with every other improvement, the oscillating engine, at the time of its introduction, encountered much opposition. The cylinder, it was said, would become oval, the trunnion bearings would be liable to heat and the trunnion joints to leak, the strain upon the trunnions would be apt to bend in or bend out the sides of the cylinder; and the circumstance of the cylinder being fixed across its centre, while the shaft requires to accommodate itself to the working of the ship, might, it was thought, be the occasion of such a strain upon the trunnions as would either break them or bend the piston rod. It is a sufficient reply to these objections to say that they are all hypothetical, and that none of them in practice have been found to exist—to such an extent at least as to occasion any inconvenience; but it is not difficult to show that they are altogether unsubstantial, even without a recourse to the disproofs afforded by experience.

438. *Q.*—Is there not a liability in the cylinder to become oval from the strain thrown on it by the piston?

A.—There is, no doubt, a tendency in oscillating engines for the cylinder and the stuffing box to become oval, but after a number of years' wear it is found that the amount of ellipticity is less than that which is found to exist in the cylinders of side lever engines after a similar trial. The resistance opposed by friction to the oscillation of the cylinder is so small, that a man is capable of moving a large cylinder with one hand; whereas in the side lever engine, if the parallel motion be in the least untrue, which is, at some time or other, an almost inevitable condition, the piston is pushed with great force against the side of the cylinder, whereby a large amount of wear and friction is occasioned. The trunnion bearings, instead of being liable to heat like other journals, are kept down to the temperature of the steam by the flow of steam passing through them; and the trunnion packings are not liable to leak when the packings, before being introduced, are squeezed in a cylindrical mould.

439. *Q.*—Might not the eduction trunnions be immersed in water?

A.—In some cases a hollow, or lantern brass, about one third or one fourth the length of the packing space, and supplied with steam or water by a pipe, is introduced in the middle of the packing, so that if there be any leakage through the trunnion, it will be a leakage of steam or water, which will not vitiate the vacuum; but in ordinary cases this device will not be necessary, and it is not commonly employed. It is clear that there can be no buckling of the sides of the cylinder by the strain upon the trunnions, if the cylinder be made strong enough, and in cylinders of the ordinary thickness such an action has never been experienced; nor is it the fact, that the intermediate shaft of steam vessels, to which part alone the motion is communicated by the engine, requires to adapt itself to the altering forms of the vessel, as the engine and intermediate shaft are rigidly connected, although the paddle shaft requires to be capable of such an adaptation. Even if this objection existed, however, it could easily be met by making the crank pin of the ball and socket fashion, which would permit the position of the intermediate shaft, relatively with that of the cylinder, to be slightly changed, without throwing an undue strain upon any of the working parts.

440. *Q.*—Is the trunk engine inferior to the oscillating?

A.—A very elegant and efficient arrangement of trunk engine suitable for paddle vessels has latterly been employed by Messrs. Rennie, of which all the parts resemble those of Penn's oscillating engine except that the cylinders are stationary instead of being movable; and a round trunk or pipe set upon the piston, and moving steam tight through the cylinder cover, enables the connecting rod which is fixed to the piston to vibrate within it to the requisite extent. But the vice of all trunk engines is that they are necessarily more wasteful of steam, as the large mass of metal entering into the composition of the trunk, moving as it does alternately into the atmosphere and the steam, must cool and condense a part of the steam. The radiation of heat from the interior of the trunk will have the same operation, though in vertical trunk engines the loss from this cause might probably be reduced by filling the trunk with oil, so far as this could be done without the oil being spilt over the edge.

441. *Q.*—What species of screw engine do you consider the best?

A.—I am inclined to give the preference to a variety of the horizontal steeple engine, such as was first used in H. M. S. Amphion. In this engine the cylinders lie on their sides, and they are placed near the side of the vessel with their mouths pointing to the keel. From each cylinder two long piston rods proceed across the vessel to a cross head working in guides; and from this cross head a connecting rod returns back to the centre of the vessel and gives motion to the crank. The piston rods are so placed in the piston that one of them passes above the crank shaft, and the other below the crank shaft. The cross head lies in the same horizontal plane as the centre of the cylinder, and a lug projects upwards from the cross head to engage one piston rod, and downwards from the cross head to engage the other piston rod. The air pump is double acting, and its piston or bucket has the same stroke as the piston of the engine. The air pump bucket derives its motion from an arm on the cross head, and a similar arm is usually employed in engines of this class to work the feed and bilge pumps.

442. *Q.*—Is not inconvenience experienced in direct acting screw engines from the great velocity of their motion?

A.—Not if they are properly constructed; but they require to be much stronger, to be fitted with more care, and to have the bearing surfaces much larger than is necessary in engines moving slowly. The momentum of the reciprocating parts should also be balanced by a weight applied to the crank or crank shaft, as is done in locomotives. A very convenient arrangement for obtaining surface is to form the crank of each engine of two cast iron discs cast with heavy sides, the excess of weight upon the heavy sides being nearly equal to that of the piston and its connections. When the piston is travelling in one direction the weights are travelling in the opposite; and the momentum of the piston and its attachments, which is arrested at each reciprocation, is just balanced by the equal and opposite momentum of the weights. One advantage of the horizontal engine is, that a single engine may be employed, whereby greater simplicity of the machinery and greater economy of fuel will be obtained, since there will be less radiating surface in one cylinder than in two.

CYLINDERS, PISTONS, AND VALVES.

443. *Q.*—Is it a beneficial practice to make cylinders with steam jackets?

A.—In Cornwall, where great attention is paid to economy of fuel, all the engines are made with steam jackets, and in some cases a flue winds spirally round the cylinder, for keeping the steam hot. Mr. Watt, in his early practice, discarded the steam jacket for a time, but resumed it again, as he found its discontinuance occasioned a perceptible waste of fuel; and in modern engines it has been found that where a jacket is used less coal is consumed than where the use of a jacket is rejected. The cause of this diminished effect is not of very easy perception, for the jacket exposes a larger radiating surface for the escape of the heat than the cylinder; nevertheless, the fact has been established beyond doubt by repeated trials, that engines provided with a jacket are more economical than engines without one. The exterior of the cylinder, or jacket, should be covered with several plies of felt, and then be cased in timber, which must be very narrow, the boards being first dried in a stove, and then bound round the cylinder with hoops, like the staves of a cask. In many of the Cornish engines the steam is let into casings formed in the cylinder cover and cylinder bottom, for the further economisation of the heat, and the cylinder stuffing box is made very deep, and a lantern or hollow brass is introduced into the centre of the packing, into which brass the steam gains admission by a pipe provided for the purpose; so that in the event of the packing becoming leaky, it will be steam that will be leaked into the cylinder instead of air, which, being incondensable, would impair the efficiency of the engine. A lantern brass, of a similar kind, is sometimes introduced into the stuffing boxes of oscillating engines, but its use there is to receive the lateral pressure of the piston rod, and thus take any strain off the packing.

444. *Q.*—Will you explain the proper course to pursue in the production of cylinders?

A.—In all engines the valve casing, if made in a separate piece from the cylinder, should be attached by means of a metallic joint, as such a barbarism as a rust joint in such situations is no longer permissible. In the case of large engines with valve casings suitable for long slides, an expansion joint in the valve casing should invariably be inserted, otherwise the steam, by gaining admission to the valve casing before it can enter the cylinder, expands the casing while the cylinder remains unaltered in its dimensions, and the joints are damaged, and in some cases the cylinder is cracked by the great strain thus introduced. The chest of the blow-through valve is very commonly cast upon the valve casing; and in engines where the cylinders are stationary this is the most convenient practice. All engines, where the valve is not of such a construction as to leave the face when a pressure exceeding that of the steam is created in the cylinder by priming or otherwise, should be provided with an escape valve to let out the water, and such valve should be so constructed that the water cannot fly out with violence over the attendants; but it should be conducted away by a suitable pipe, to a place where its discharge can occasion no inconvenience. The stuffing boxes of all engines which cannot be stopped frequently to be repacked, should be made very deep; metallic packing in the stuffing box has been used in some engines, consisting in most instances of one or more rings, cut, sprung, and slipped upon the piston rod before the cross head is put on, and packed with hemp behind. This species of packing answers very well when the parallel motion is true, and the piston rod free from scratches, and it accomplishes a material saving of tallow. In some cases a piece of sheet brass, packed behind with hemp, has been introduced with good effect, a flange being turned over on the under edge of the brass to prevent it from slipping up or down with the motion of the rod. The sheet brass speedily puts an excellent polish upon the rod, and such a packing is more easily kept, and requires less tallow than where hemp alone is employed. In side lever marine engines the attachments of the cylinder to the diagonal stay are generally made of too small an area, and the flanges are made too thick. A very thick flange cast on any part of a cylinder endangers the soundness of the cylinder, by inducing an unequal contraction of the metal; and it is a preferable course to make the flange for the attachment or the framing thin, and the surface large—the bolts being turned bolts and nicely fitted. If from malformation in this part the framing works to an inconvenient extent, the best expedient appears to be the introduction of a number of steel tapered bolts, the holes having been previously bored out; and if the flanges be thick enough, square keys may also be introduced, half into one flange and half into the other, so as to receive the strain. If the jaw cracks or breaks away, however, it will be best to apply a malleable iron hoop around the cylinder to take the strain, and this will in all cases be the preferable expedient, where from any peculiarities of structure there is a difficulty in introducing bolts and keys of sufficient strength.

445. *Q.*—Which is the most eligible species of piston?

A.—For large engines, pistons with a metallic packing, consisting of a single ring, with the ends morticed into one another, and a piece of metal let in flush over the joint and riveted to one end of the ring, appears to be the best species of piston; and if the cylinder be oscillating, it will be expedient to chamfer off the upper edge of the ring on the inner side, and to pack it at the back with hemp. If the cylinder be a stationary one, springs may be substituted for the hemp packing, but in any case it will be expedient to make the vertical joints of the ends of the ring run a little obliquely, so as to prevent the joint forming a ridge in the cylinder. For small pistons two rings may be employed, made somewhat eccentric internally to give a greater thickness of metal in the centre of the ring; these rings must be set one above the other in the cylinder, and the joints, which are oblique, must be set at right angles with one another, so as to obviate any disposition of the rings, in their expansion, to wear the cylinder oval. The rings must first be turned a little larger than the diameter of the cylinder, and a piece is then to be cut out, so that when the ends are brought together the ring will just enter within the cylinder. The ring, while retained in a state of compression, is then to be put in the lathe and turned very truly, and finally it is to be hammered on the inside with the small end of the hammer, to expand the metal, and thus increase the elasticity.

446. *Q.*—The rings should be carefully fitted to one another laterally?

A.—The rings are to be fitted laterally to the piston, and to one another, by scraping—a steady pin being fixed upon the flange of the piston, and fitting into a corresponding hole in the lower ring, to keep the lower ring from turning round; and a similar pin being fixed into the top edge of the lower ring to prevent the upper ring from turning round; but the holes into which these pins fit must be made oblong, to enable the rings to press outward as the rubbing surfaces wear. In most cases it will be expedient to press the packing rings out with springs where they are not packed behind with hemp, and the springs should be made very strong, as the prevailing fault of springs is their weakness. Sometimes short bent springs, set round at regular intervals between the packing rings and body of the piston, are employed, the centre of each spring being secured by a steady pin or bolt screwed into the side of the piston; but it will not signify much what kind of springs is used, provided they have sufficient tension. When pistons are made of a single ring, or of a succession of single rings, the strength of each ring should be tested previously to its introduction into the piston, by means of a lever loaded by a heavy weight.

447. *Q.*—What kind of piston is employed by Messrs. Penn?

A.—Messrs. Penn's piston for oscillating engines has a single packing ring, with a tongue piece, or mortice end, made in the manner already described. The ring is packed behind with hemp packing, and the piece of metal which covers the joint is a piece of thick sheet copper or brass, and is indented into the iron of the ring, so as to offer no obstruction to the application of the hemp. The ring is fitted to the piston only on the under edge; the top edge is rounded to a point from the inside, and the junk ring does not bear upon it, but the junk ring squeezes down the hemp packing between the packing ring and the body of the piston.

448. *Q.*—How should the piston rod be secured to the piston?

A.—The piston rod, where it fits into the piston, should have a good deal of taper; for if the taper be too small the rod will be drawn through the hole, and the piston will be split asunder. Small grooves are sometimes turned out of the piston rod above and below the cutter hole, and hemp is introduced in order to make the piston eye tight. Most piston rods are fixed to the piston by means of a gib and cutter, but in some cases the upper portion of the rod within the eye is screwed, and it is fixed into the piston by means of an indented nut. This nut is in some cases hexagonal, and in other cases the exterior forms a portion of a cone which completely fills a corresponding recess in the piston; but nuts made in this way become rusted into their seat after some time, and cannot be started again without much difficulty. Messrs. Miller, Ravenhill & Co. fix in their piston rods by means of an indented hexagonal nut, which may be started by means of an open box key. The thread of the screw is made flat upon the one side and much slanted on the other, whereby a greater strength is secured, without creating any disposition to split the nut. In side lever engines it is a judicious practice to add a nut to the top of the piston rod, in addition to the cutter for securing the piston rod to the cross head. In a good example of an engine thus provided, the piston rod is 7 in. in diameter, and the screw 5 in.; the part of the rod which fits into the cross head eye is 1 ft. $5\frac{1}{2}$ in. long, and tapers from $6\frac{1}{2}$ in. to $6\frac{13}{16}$ in. diameter. This proportion of taper is a good one; if the taper be less, or if a portion of the piston rod within the cross head eye be left untapered, as is sometimes the case, it is very difficult to detach the parts from one another.

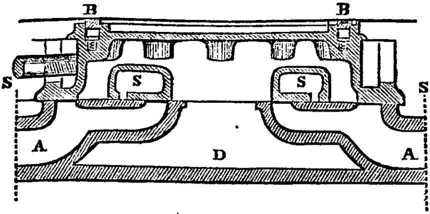
449. *Q.*—Which is the most beneficial construction of slide valve?

A.—The best construction of slide valve appears to be that adopted by Messrs. Penn for their larger engines, and which consists of a three ported valve, to the back of which a ring is applied of an area equal to that of exhaustion port, and which, by bearing steam tight against the back of the casing, so that a vacuum may be maintained within the ring, puts the valve in equilibrium, so that it may be moved with an inconsiderable exercise of force. The back of the valve casing is put on like a door, and its internal surface is made very true by scraping. There is a hole through the valve so as to conduct away any steam which may enter within the ring by leakage, and the ring is kept tight against the back of the casing by means of a ring situated beneath the bearing ring, provided with four lugs, through which bolts pass tapped into bosses on the back of the valve; and, by unscrewing these bolts,—which may be done by means of a box key which passes through holes in the casing closed with screwed plugs,—the lower ring is raised upwards, carrying the bearing ring before it. The rings must obviously be fitted over a boss upon the back of the valve; and between the rings, which are of brass, a gasket ring is interposed to compensate by its compressibility for any irregularity of pressure, and each of the bolts is provided with a ratchet collar to prevent it from turning back, so that the engineer, in tightening these bolts, will have no difficulty in tightening them equally, if he counts the number of clicks made by the ratchet. Where this species of valve is used, it is indispensable that large escape valves be applied to the cylinder, as a valve on this construction is unable to leave the face. In locomotive engines, the valve universally employed is the common three ported valve.

450. *Q.*—Might not an equilibrium valve be so constructed by the interposition of springs, as to enable it to leave the cylinder face when an internal force is applied?

A.—That can no doubt be done, and in some engines has been done. In the screw steamer Azof, the valve is of the equilibrium construction, but the plate which carries the packing on which the top ring rests, is an octagon, and fits into an octagonal recess on the back of the valve. Below each side of the octagon there is a bent flat spring, which lifts up the octagonal plate, and with it the packing ring against the back of the valve casing; and should water get into the cylinder, it escapes by lifting the valve, which is rendered possible by the compressibility of the springs. An equivalent arrangement is shown in figs. 39 and 40, where the ring is lifted by spiral springs.

Fig. 39.

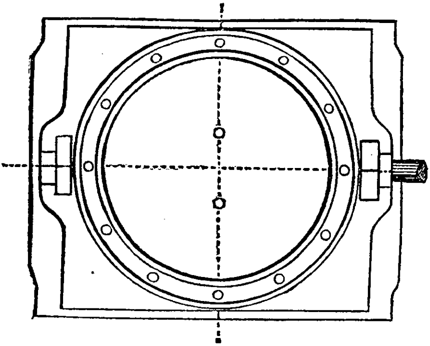


EQUILIBRIUM GRIDIRON SLIDE VALVE.
Longitudinal Section. Scale ¾ inch = 1 foot.

451. *Q.*—What species of valve is that shown in figs. 39 and 40?

A.—It is an equilibrium gridiron valve; so called because it lets the steam in and out by more than one port. A A are

Fig. 40.



EQUILIBRIUM GRIDIRON SLIDE VALVE.
Back View with Ring removed. Scale ¾ inch = 1 foot.

the ordinary steam passages to the top and bottom of the cylinder; B B is the ring which rubs against the back of the valve casing, and D is the eduction passage. S S S S shows the limits of the steam space, for the steam penetrates to the central chamber S S by the sides of the valve. When the valve is opened upon the steam side, the cylinder receives steam through both ports at that end of the cylinder, and both ports at the other end of the cylinder are at the same time open to the eduction. The benefit of this species of valve is, that it gives the same opening of the valve that is given in ordinary engines, with half the amount of travel; or if three ports were made instead of two, then it would give the same area of opening that is given in common engines with one third the amount of travel. For direct acting screw engines this species of valve is now extensively used.

452. *Q.*—Will you describe the configuration and mode of attachment of the eccentric by which the valve is moved?

A.—In marine engines, whether paddle or screw, if moving at a slow rate of speed, the eccentric is generally loose upon the shaft, for the purpose of backing, and is furnished with a back balance and catches, so that it may stand either in the position for going ahead, or in that for going astern. The body of the eccentric is of cast iron, and it is put on the shaft in two pieces. The halves are put together with rebated joints to keep them from separating laterally, and they are prevented from sliding out by round steel pins, each ground into both halves; square keys would probably be preferable to round pins in this arrangement, as the pins tend to wedge the jaws of the eccentric asunder. In some cases the halves of the eccentric are bolted together by means of flanges, which is, perhaps, the preferable practice. The eccentric hoop in marine and land engines is generally of brass; it is expedient to cast an oil cup on the eccentric hoop, and, where practicable, a pan should be placed beneath the eccentric for the reception of the oil droppings. The notch of the eccentric rod for the reception of the pin of the valve shaft is usually steeled, to prevent inconvenient wear; for when the sides of the notch wear, the valve movement is not only disturbed, but it is very difficult to throw the eccentric rod out of gear. It is found to be preferable, however, to fit this notch with a brass bush, for the wear is then less rapid, and it is an easy thing to replace this bush with another when it becomes worn. The eccentric catches of the kind usually employed in marine engines, sometimes break off at the first bolt hole, and it is preferable to have a bolt in advance of the catch face, or to have a hoop encircling the shaft with the catches welded on it, the hoop itself being fixed by bolts or a key. This hoop may either be put on before the cranks in one piece or afterwards in two pieces.

453. *Q.*—Are such eccentrics used in direct acting screw engines?

A.—No; direct acting screw engines are usually fitted with the link motion and two fixed eccentrics.

AIR PUMP AND CONDENSER.

454. *Q.*—What are the details of the air pump?

A.—The air pump bucket and valves are all of brass in modern marine engines, and the chamber of the pump is lined with copper, or made wholly of brass, whereby a single boring suffices. When a copper lining is used, the pump is first bored out, and a bent sheet of copper is introduced, which is made accurately to fill the place, by hammering the copper on the inside. Air pump rods of Muntz's metal or copper are much used. Iron rods covered with brass are generally wasted away where the bottom cone fits into the bucket eye, and if the casing be at all porous, the water will insinuate itself between the casing and the rod and eat away the iron. If iron rods covered with brass be used, the brass casing should come some distance into the bucket eye; the cutter should be of brass, and a brass washer should cover the under side of the eye, so as to defend the end of the rod from the salt water. Rods of Muntz's metal are probably on the whole to be preferred. It is a good practice to put a nut on the top of the rod, to secure it more firmly in the cross head eye, where that plan can be conveniently adopted. The part of the rod which fits into the cross head eye should have more taper when made of copper or brass, than when made of iron; as, if the taper be small, the rod may get staved into the eye, whereby its detachment will be difficult.

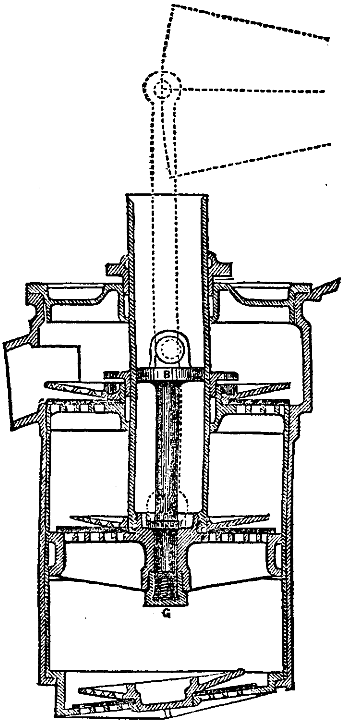
455. *Q.*—What species of packing is used in air pumps?

A.—Metallic packing has in some instances been employed in air pump buckets, but its success has not been such as to lead to its further adoption. The packing commonly employed is hemp. A deep solid block of metal, however, without any packing, is often employed with a satisfactory result; but this block should have circular grooves cut round its edge to hold water. Where ordinary packing is employed, the bucket should always be made with a junk ring, whereby the packing may be easily screwed down at any time with facility. In slow moving engines the bucket valve is generally of the spindle or pot-lid kind, but butterfly valves are sometimes used. The foot and delivery valves are for the most part of the flap or hanging kind. These valves all make a considerable noise in working, and are objectionable in many ways. Valves on Belidor's construction, which is in effect that of a throttle valve hung off the centre, were some years ago proposed for the delivery and foot valves; and it appears probable that their operation would be more satisfactory than that of the valves usually employed.

456. *Q.*—Where is the delivery valve usually situated?

A.—Some delivery valve seats are bolted into the mouth of the air pump, whereby access to the pump bucket is rendered difficult: but more commonly the delivery valve is a flap valve exterior to the pump. If delivery valve seats be put in the mouth of the air pump at all, the best mode of fixing them appears to be that adopted by Messrs. Maudslay. The top of the pump barrel is made quite fair across, and upon this flat surface a plate containing the delivery valve is set, there being a small ledge all round to keep it steady. Between the bottom of the stuffing box of the pump cover and the eye of the valve seat a short pipe extends encircling the pump rod, its lower end checked into the eye of the valve seat, and its upper end widening out to form the bottom of the stuffing box of the pump cover. Upon the top of this pipe some screws press, which are accessible from the top of the stuffing box gland, and the packing also aids in keeping down the pipe, the function of which is to retain the valve seat in its place. When the pump bucket has to be examined the valve seat may be slung with the cover, so as to come up with the same purchase. For the bucket valves of such pumps Messrs. Maudslay employ two or more concentric ring valves with a small lift. These valves have given a good deal of trouble in some cases, in consequence of the frequent fracture of the bolts which guide and confine the rings; but this is only a fault of detail which is easily remedied, and the principle appears to be superior to that of any of the other metallic air pump valves at present in common use.

Fig. 41.



Trunk Air Pump. Scale ½ inch to 1 foot.

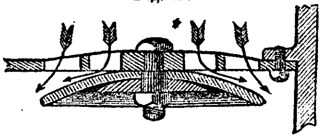
457. *Q.*—Are not air pump valves now very generally made of india rubber?

A.—They are almost invariably so made if the engines are travelling fast, as in the case of direct acting screw engines, and they are very often made of large discs or rings of india rubber, even when the engines travel slowly. A very usual and eligible arrangement for many purposes is that shown in fig. 41, where both foot and delivery valves are situated in the ends of the pump, and they, as well as the valve in the bucket are made of india rubber rings closing on a grating. The trunk in the air pump enables guide rods to be dispensed with.

458. *Q.*—The air pump, when double acting, has of course inlet and outlet valves at each end?

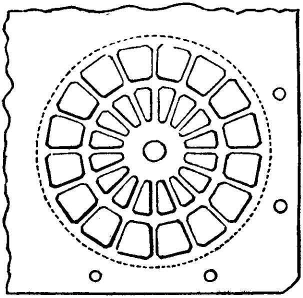
A.—Yes; and the general arrangement of the valves of double acting air pumps, such as are usual in direct acting screw engines, is that represented in the figure of Penn's trunk engine already described in Chapter I. Each inlet and outlet valve consists of a number of india rubber discs set over a perforated brass plate, and each disc is bound down by a bolt in the middle, which bolt also secures a brass guard set above the disc to prevent it from rising too high. The usual configuration of those valves is that represented in figs. 42, 43, and 44; figs. 42 and 43 being a section and ground plan of the species of valve used by Messrs. Penn, and fig. 44 being a section of that used by Messrs. Maudslay. It is important in these valves to have the india rubber thick,—say about an inch thick for valves eight inches in diameter. It is also advisable to make the central bolts with a nut above and a nut below, and to form the bolt with a counter sunk neck, so that it will not fall down when the top nut is removed. The lower point of the

Fig. 42.



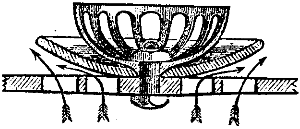
PENN'S DISC VALVE FOR AIR PUMP.
Section.

Fig. 43.



PENN'S DISC VALVE FOR AIR PUMP.
Ground Plan.

Fig. 44.



MAUDSLAY'S DISC VALVE FOR AIR PUMP.
Section.

bolt should be riveted over on the nut to prevent it from unscrewing, and the top end should have a split pin through the point for the same purpose. The hole through which the bolt passes should be tapped, though the bolt is not screwed into it, so that if a bolt breaks, a temporary stud may be screwed into the hole without the necessity of taking out the whole plate. The guard should be large, else the disc may stretch in the central hole until it comes over it; but the guard should not permit too much lift of the valve, else a good deal of the water and air will return into the pump at the return stroke before the valve shuts. Penn's guard is rather small, and Maudslay's permits too much lift.

459. *Q.*—What is the proper area through the valve gratings?

A.—The collective area should be at least equal to the area of the pump piston, and the lower edges of the perforations should be rounded off to afford more free ingress or egress to the water.

460. *Q.*—Is there much strain thrown on the plates in which the valves are set?

A.—A good deal of strain; and in the earlier direct acting screw engines these plates were nearly in every case made too light. They should be made thick, have strong feathers upon them, and be very securely bolted down with split pins at the points of the bolts, to prevent them from unscrewing. The plate will be very apt to be broken should some of the bolts become loose. Of course all the bolts and split pins, as well as the plates and guards, must be of brass.

461. *Q.*—How are the plates to be taken out should that become necessary?

A.—They are usually taken out through a door in the top of the hot well provided for that purpose, which door should be as large as the plates themselves; and it is a good precaution to cast upon this door—which will be of cast iron—six or eight stout projecting feet which will press upon the top of the outlet or delivery valve plate when the door is screwed down. The upper or delivery valve plate and the lower or foot valve plate should have similar feet. A large part of the strain will thus be transferred from the plates to the door, which can easily be made strong enough to sustain it. It is advisable that the plates should lie at an angle so that the shock of the water may not come upon the whole surface at once.

462. *Q.*—Does the double acting air pump usual in direct acting screw engines, produce as good a vacuum as the single acting air pump usual in paddle engines?

A.—It will do so if properly constructed; but I do not know of any case of a double acting air pump, with india rubber valves, which has been properly constructed.

463. *Q.*—What is the fault of such pumps?

A.—The pump frequently works by starts, as if at times it did not draw at all, and then again on a sudden gorged itself with water, so as to throw a great strain upon the working parts. The vacuum, moreover, is by no means so good as it should be, and it is a universal vice of direct acting screw engines that the vacuum is defective. I have been at some pains to investigate the causes of this imperfection; and in a sugar house engine fitted with pumps like those of a direct acting screw engine to maintain a vacuum in the pans, I found that a better vacuum was produced when the engine was going slowly than when it was going fast; which is quite the reverse of what was to have been expected, as the hot water which had to be removed by the condensation of the steam proceeding from the pan, was a constant quantity. In this engine, too, which was a high pressure one, the irregularities of the engine consequent upon the fitful catching of the water by the pump, was more conspicuous, as the working of this vacuum pump was the only work that the engine had to perform.

464. *Q.*—And were you able to discover the cause of these irregularities?

A.—The main cause of them I found to be the largeness of the space left between the valve plates in this class of pumps, and out of which there is nothing to press the air or water which may be lying there. It consequently happens, that if there be the slightest leakage of air into the pump, this air is merely compressed, and not expelled, by the advance of the air pump piston. It expands again to its former bulk on the return of the pump piston, and prevents the water from entering until there is such an accumulation of pressure in the condenser as forces the water into the pump, when the air being expelled by the water, causes a good vacuum to be momentarily formed in the pump when it gorges itself by taking a sudden gulp of water. So soon, however, as the pressure falls in the condenser and some more air leaks into the pump, the former imperfect action recurs and is again redressed in the same violent manner.

465. *Q.*—Is this irregular action of the pump the cause of the imperfect vacuum?

A.—It is one cause. Sometimes one end of the pump will alone draw and the other end will be inoperative, although it is equally open to the condenser, and this will chiefly take place at the stuffing box end, where a leakage of air is more likely to occur. I find, however, that even when both ends of the pump are acting equally and there is no leakage of air at all, the vacuum maintained by a double acting horizontal pump with india rubber valves, is not so good as that maintained by a single acting pump of the kind usual in old engines.

466. *Q.*—Will you specify more precisely what were the results you obtained?

A.—When the vacuum pan was exhausted by the pumps without any boiling being carried on in the pan, but only a little cold water being let into it, and also into the pumps to enable them to act in their best manner, it was found that whereas with the old pump a vacuum of 114 on the sugar boiler's gauge could be readily obtained, equal to about 29½ inches of mercury, the lowest that could possibly be got with the new horizontal pump was 122 degrees of the sugar boiler's gauge, or 29 inches of mercury, and to get that the engine must not go faster than 10 or 12 strokes per minute. The proper speed of the engine was 75 strokes per minute, but if allowed to go at that speed the vacuum fell to 130 of the sugar maker's gauge, or 28½ inches of mercury. When the steam was let into the worms of the pan so as to boil the water in it, the vacuum was 134 at 75 revolutions of the engine, and went down to 132 at 40 revolutions, but rose again to 135, equal to about 28¼ inches of mercury, at 20 revolutions.

467. *Q.*—To what do you attribute the circumstance of a better vacuum being got at low speeds than at high speeds?

A.—It is difficult to assign the precise reason, but it appears to be a consequence of the largeness of the vacant space between the valve plates. When the piston of the air pump is drawn back, the air contained in this large collection of water will cause it to boil up like soda water; and when the piston of the pump is forced forward, this air, instead of being expelled, will be again driven into the water. There will consequently be a quantity of air in the pump which cannot be got rid of at all, and which will impair the vacuum as a matter of course.

468. *Q.*—What expedient did you adopt to improve the vacuum in the engine to which you have referred?

A.—I put blocks of wood on the air pump piston, which at the end of its stroke projected between the valve plates and forced the water out. I also introduced a cock of water at each end of the pump between the valve plates, to insure the presence of water at each end of the pump to force the air out. With these ameliorations the pump worked steadily, and the vacuum obtained became as good as in the old pump. I had previously introduced an injection cock into each end of the air pump in steam vessels, from which I had obtained advantageous results; and in all horizontal air pumps I would recommend the piston and valve plates to be so constructed that the whole of the water will be expressed by the piston. I would also recommend an injection cock to be introduced at each end of the pump.

PUMPS, COCKS, AND PIPES.

469. *Q.*—Will you explain the arrangement of the feed pump?

A.—In steam vessels, the feed pump plunger is generally of brass, and the barrel of the pump is sometimes of brass, but generally of cast iron. There should be a considerable clearance between the bottom of the plunger and the bottom of the barrel, as otherwise the bottom of the barrel may be knocked out, should coal dust or any other foreign substance gain admission, as it probably would do if the injection water were drawn at any time from the bilge of the vessel, as is usually done if the vessel springs a leak. The valves of the feed pump in marine engines are generally of the spindle kind, and are most conveniently arranged in a chest, which may be attached in any accessible position to the side of the hot well. There are two nozzles upon this chest, of which the lower one leads to the pump, and the upper one to the boiler. The pipe leading to the pump is a suction pipe when the plunger ascends, and a forcing pipe when the plunger descends. The plunger in ascending draws the water out of the hot well through the lowest of the valves, and in descending forces it through the centre valve into the space above it, which communicates with the feed pipe. Should the feed cock be shut so as to prevent any feed water from passing through it, the water will raise the topmost valve, which is loaded to a pressure considerably above the pressure of the steam, and escape into the hot well. This arrangement is neater and less expensive than that of having a separate loaded valve on the feed pipe with an overflow through the ship's side, as is the more usual practice.

470. *Q.*—Will you describe what precautions are to be observed in the construction of the cocks used in engines?

A.—All the cocks about an engine should be provided with bottoms and stuffing boxes, and reliance should never be placed upon a single bolt passing through a bottom washer for keeping the plug in its place, in the case of any cock communicating with the boiler; for a great strain is thrown upon that bolt if the pressure of the steam be high, and if the plug be made with much taper; and should the bolt break, or the threads strip, the plug will fly out, and persons standing near may be scalded to death. In large cocks, it appears the preferable plan to cast the bottoms in; and the metal of which all the cocks about a marine engine are made, should be of the same quality as that used in the composition of the brasses, and should be without lead, or other deteriorating material. In some cases the bottoms of cocks are burnt in with hard solder, but this method cannot be depended upon, as the solder is softened and wasted away by the hot salt water, and in time the bottom leaks, or is forced out. The stuffing box of cocks should be made of adequate depth, and the gland should be secured by means of four strong copper bolts. The taper of blow-off cocks is an important element in their construction; as, if the taper be too great, the plugs will have a continual tendency to rise, which, if the packing be slack, will enable grit to get between the faces, while, if the taper be too little, the plug will be liable to jam, and a few times grinding will sink it so far through the shell that the waterways will no longer correspond. One eighth of an inch deviation from the perpendicular for every inch in height, is a common angle for the side of the cock, which corresponds with one quarter of an inch difference of diameter in an inch of height; but perhaps a somewhat greater taper than this, or one third of an inch difference in diameter for every inch of height, is a preferable proportion. The bottom of the plug must be always kept a small distance above the bottom of the shell, and an adequate surface must be left above and below the waterway to prevent leakage. Cocks formed according to these directions will be found to operate satisfactorily in practice, while they will occasion perpetual trouble if there be any malformation.

471. *Q.*—What is the best arrangement and configuration of the blow-off cocks?

A.—The blow-off cocks of a boiler are generally placed some distance from the boiler; but it appears preferable that they should be placed quite close to it, as there are no means of shutting off the water from the pipe between the blow-off cock and the boiler, should fracture or leakage there arise. Every boiler must be furnished with a blow-off cock of its own, independently of the main blow-off cocks on the ship's sides, so that the boilers may be blown off separately, and may be shut off from one another. The preferable arrangement appears to be, to cast upon each blow-off cock a bend for attaching the cock to the bottom of the boiler, and the plug should stand about an inch in advance of the front of the boiler, so that it may be removed, or re-ground, with facility. The general arrangement of the blow-off pipes is to run a main blow-off pipe beneath the floor plates, across the ship, at the end of the engines, and into this pipe to lead a separate pipe, furnished with a cock, from each boiler. The main blow-off pipe, where it penetrates the ship's side, is furnished with a cock: and in modern steam vessels Kingston's valves are also used, which consist of a spindle or plate valve, fitted to the exterior of the ship, so that if the internal pipe or cock breaks, the external valve will still be operative. Some expedient of this kind is almost necessary, as the blow-off cocks require occasional re-grinding, and the sea cocks cannot be re-ground without putting the vessel into dock, except by the use of Kingston's valves, or some equivalent expedient.

472. *Q.*—What is the proper construction and situation of the injection cocks, and waste water valves?

A.—The sea injection cocks are usually made in the same fashion as the sea blow-off cocks, and of about the same size, or rather larger. The injection water is generally admitted to the condenser by means of a slide valve, but a cock appears to be preferable, as it is more easily opened, and has not any disposition to shut of its own accord. In paddle vessels the sea injection pipes should be put through the ship's sides in advance of the paddles, so that the water drawn in may not be injuriously charged with air. The waste water pipe passing from the hot well through the vessel's side is provided with a stop valve, called the discharge valve, which is usually made of the spindle kind, so as to open when the water coming from the air pump presses against it. In some cases this valve is a sluice valve, but the hot well is then almost sure to be split, if the engine be set on without the valve having been opened. The opening of the waste water pipe should always be above the load water line, as it will otherwise be difficult to prevent leakage through the engine into the ship when the vessel is lying in harbor.

473. *Q.*—What is the best arrangement of gauge cocks and glass gauges?

A.—Gauge cocks are generally very inartificially made, and occasion needless annoyance. They are rarely made with bottoms, or with stuffing boxes, and are consequently, for the most part, adorned with stalactites of salt after a short period of service. The water discharged from them, too, from the want of a proper conduit, disfigures the front of the boiler, and adds to the corrosion in the ash pits. It would be preferable to combine the gauge cocks appertaining to each boiler into a single upright tube, connected suitably with the boiler, and the water flowing from them could be directed downward into a funnel tube communicating with the bilge. The cocks of the glass tubes, as well as of the gauge cocks, should be furnished with stuffing boxes and with bottoms, unless the water enters through the bottom of the plug, which in gauge cocks is sometimes the case. The glass gauge tubes should always be fitted with a cock at each neck communicating with the boiler, so that the water and steam may be shut off if the tube breaks; and the cocks should be so made as to admit of the tubes being blown through with steam to clear them, as in muddy water they will become so soiled that the water cannot be seen. The gauge cocks frequently have pipes running up within the boiler, to the end that a high water level may be made consistent with an easily accessible position of the gauge cocks themselves. With the glass tubes, however, this species of arrangement is not possible, and the glass tubes must always be placed in the position of the water level.

474. *Q.*—What is the proper material of the pipes in steam vessels?

A.—Most of the pipes of marine engines should be made of copper. The steam pipes may be of cast iron, if made very strong, but the waste water pipes should be of copper. Cast iron blow-off pipes have in some cases been employed, but they are liable to fracture, and are dangerous. The blow-off and feed pipes should be of copper, but the waste steam pipe may be of galvanized iron. Every pipe passing through the ship's side, and every pipe fixed at both ends, and liable to be heated and cooled, should be furnished with a faucet or expansive joint; and in the case of the cast iron pipes, the part of the pipe fitting into the faucet should be turned. In the distribution of the faucets of the pipes exposed to pressure, care must be taken that they be so placed that the parts of the pipe cannot be forced asunder, or turned round by the strain, as serious accidents have occurred from the neglect of this precaution.

475. *Q.*—What is the best mode of making pipes tight where they penetrate the ship's side?

A.—In wooden vessels the pipes where they pierce the ship's side, should be made tight, as follows:—the hole being cut, a short piece of lead pipe, with a broad flange at one end, should be fitted into it, the place having been previously smeared with white lead, and the pipe should then be beaten on the inside, until it comes into close contact all around with the wood. A loose flange should next be slipped over the projecting end of the lead pipe, to which it should be soldered, and the flanges should both be nailed to the timber with scupper nails, white lead having been previously spread underneath. This method of procedure, it is clear, prevents the possibility of leakage down through the timbers; and all, therefore, that has to be guarded against after this precaution, is to prevent leakage into the ship. To accomplish this object, let the pipe which it is desired to attach be put through the leaden hause, and let the space between the pipe and the lead be packed with gasket and white lead, to which a little olive oil has been added. The pipe must have a flange upon it to close the hole in the ship's side; the packing must then be driven in from the outside, and be kept in by means of a gland secured with bolts passing through the ship's side. If the pipe is below the water line the gland must be of brass, but for the waste water pipe a cast iron gland will answer. This method of securing pipes penetrating the side, however, though the best for wooden vessels, will, it is clear, fail to apply to iron ones. In the case of iron vessels, it appears to be the best practice to attach a short iron nozzle, projecting inward from the skin, for the attachment of every pipe below the water line, as the copper or brass would waste the iron of the skin if the attachment were made in the usual way.

DETAILS OF THE SCREW AND SCREW SHAFT.

476. *Q.*—What is the best method of fixing the screw upon the shaft?

A.—The best way is to cut two large grooves in the shaft coming up to a square end, and two corresponding grooves or key seats in the screw boss opposite the arms. Fit into the grooves on the shaft keys with heads, the length of which is equal to half the depth of the boss, and with the ends of the keys bearing against the ends of the grooves in the shaft. Then ship on the propeller, and drive other keys of an equal length from the other side of the boss, so that the points of the keys will nearly meet in the middle; next burr up the edge of the grooves upon the heads of the keys, to prevent them from working back; and finally tap a bolt into the side of the boss to penetrate the shaft. Propellers so fitted will never get slack.

477. *Q.*—What is the best way of fitting in the screw pipe at the stern?

A.—It should have projecting rings, which should be turned; and cast iron pieces with holes in them, bored out to the sizes of these rings, should be secured to the stern frames, and the pipe be then shipped through all. Before this is done, however, the stern post must be bored out by a template to fit the pipe, and the pipe is to be secured at the end to the stern post either by a great external nut of cast iron, or by bolts passing through the stern post and through lugs on the pipe. The pipe should be bored throughout its entire length, and the shaft should be turned so as to afford a very long bearing which will prevent rapid wear.

478. *Q.*—How is the hole formed in the deadwood of the ship in which the screw works?

A.—A great frame of malleable iron, the size of the hole, is first set up, and the plating of the ship is brought to the edge of this hole, and is riveted through the frame. It is important to secure this frame very firmly to the rest of the ship, with which view it is advisable to form a great palm, like the palm of a vice, on its inner superior corner, which, projecting into the ship, may be secured by breast-hook plates to the sides, whereby the strain which the screw causes will be distributed over the stern, instead of being concentrated on the rivets of the frame.

479. *Q.*—Are there several lengths of screw shaft ?

A.—There are.

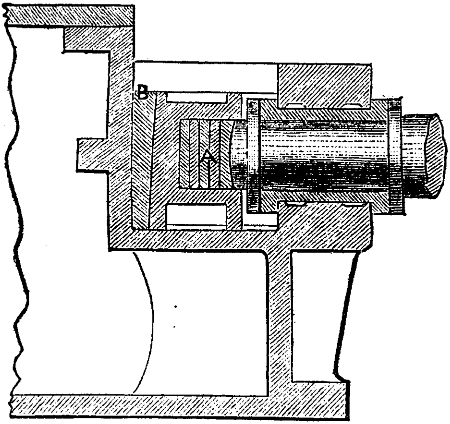
480. *Q.*—How then are these secured to one another ?

A.—The best mode of securing the several lengths of shaft together is by forging the shafts with flanges at the ends, which are connected together by bolts, say six strong bolts in each, accurately fitted to the holes.

481. *Q.*—How is the thrust of the shaft usually received ?

A.—In some cases it is received on a number of metal discs set in a box containing oil; and should one of these discs stick

Fig. 44.



End of the SCREW SHAFT of CORREO, showing the mode of receiving the Thrust. A, discs; B, tightening wedge.

fast from friction, the others will be free to revolve. This arrangement, which is represented in *fig.* 44, is used pretty extensively, and answers the purpose perfectly. It is of course necessary that the box in which the discs A are set, shall be strong enough to withstand the thrust which the screw occasions. Another arrangement still more generally used, is that represented in *figs.* 55 and 56, p. 331. It is a good practice to make the thrust plummer block with a very long sole in the direction of the shaft, so as to obviate any risk of canting or springing forward when the strain is applied, as such a circumstance, if occurring even to a slight extent, would be very likely to cause the bearing to heat.

482. *Q.*—Are there not arrangements existing in some vessels for enabling the screw to be lifted out of the water while the vessel is at sea?

A.—There are; but such arrangements are not usual in merchant vessels. In one form of apparatus the screw is set on a short shaft in the middle of a sliding frame, which can be raised or lowered in grooves like a window and the screw shaft within the ship can be protruded or withdrawn by appropriate mechanism, so as to engage or leave free this short shaft as may be required. When the screw has to be lifted, the screw shaft is drawn into the vessel, leaving the short shaft free to be raised up by the sliding frame, and the frame is raised by long screws turned round by a winch purchase on deck. A chain or rope, however, is better for the purpose of raising this frame, than long screws; but the frame should in such case be provided with pall catches like those of a windlass, which, if the rope should break, will prevent the screw from falling.

DETAILS OF THE PADDLES AND PADDLE SHAFT.

483. *Q.*—What are the most important details of the construction of paddle wheels?

A.—The structure of the feathering wheel will be hereafter described in connection with an account of the oscillating engine; and it will be expedient now to restrict any account of the details to the common radial paddle, as applied to ocean steamers. The best plan of making the paddle centres is with square eyes, and each centre should be secured in its place by means of eight thick keys. The shaft should be burred up against the head of these keys with a chisel, so as to prevent the keys from coming back of their own accord. If the keys are wanted to be driven back, this burr must be cut off, and if made thick, and of the right taper, they may then be started without difficulty. The shaft must of course be forged with square projections on it, so as to be suitable for the application of centres with square eyes. Messrs. Maudslay & Co. bore out their paddle centres, and turn a seat for them on the shaft, afterward fixing them on the shaft with a single key. This plan is objectionable for the two reasons, that it is insecure when new, and when old is irremovable. The general practice among the London engineers is to fix the paddle arms at the centre to a plate by means of bolts, a projection being placed upon the plates on each side of the arm, to prevent lateral motion; but this method is inferior in durability to that adopted in the Clyde, in which each arm is fitted into a socket by means of a cutter—a small hole being left opposite to the end of each arm, whereby the arm may be forced back by a drift.

484. *Q.*—How are the arms attached to the outside rings?

A.—Some engineers join the paddle arms to the outer ring by means of bolts; but unless very carefully fitted, those bolts after a time become slack sideways, and a constant working of the parts of the wheel goes on in consequence. Sometimes the part of the other ring opposite the arm is formed into a mortise, and the arms are wedged tight in these holes by wedges driven in on each side; but the plan is an expensive one, and not satisfactory, as the wedges work loose even though riveted over at the point. The best mode of making a secure attachment of the arms to the ring, consists in making the arms with long T heads, and riveting the cross piece to the outer ring with a number of rivets, not of the largest size, which would weaken the outer ring too much. The best way of securing the inner rings to the arms is by means of lugs welded on the arms, and to which the rings are riveted.

485. *Q.*—What are the scantlings of the paddle floats?

A.—The paddle floats are usually made either of elm or pine; if of the former, the common thickness for large sea-going vessels is about $2\frac{1}{2}$ inches; if of the latter, 3 inches. The floats should have plates on both sides, else the paddle arms will be very liable to cut into the wood, and the iron of the arms will be very rapidly wasted. When the floats have been fresh put on they must be screwed up several times before they come to a bearing. If this be not done, the bolts will be sure to get slack at sea, and all the floats on the weather side may be washed off. The bolts for holding on the paddle floats are made extra strong, on account of the corrosion to which they are subject; and the nuts should be made large, and should be square, so that they may be effectually tightened up, even though their corners be worn away by corrosion. It is a good plan to give the thread of the paddle bolts a nick with a chisel, after the nut has been screwed up, which will prevent the nut from turning back. Paddle floats, when consisting of more than one board, should be bolted together edgeways, by means of bolts running through their whole breadth. The floats should not be notched to allow of their projection beyond the outer ring, as, if the sides of the notch be in contact with the outer ring, the ring is soon eaten away in that part, and the projecting part of the float, being unsupported, is liable to be broken off.

486. *Q.*—Do not the wheels jolt sideways when the vessel rolls?

A.—It is usual to put a steel plate at each end of the paddle shafts tightened with a key, to prevent end play when the vessel rolls, but the arrangement is precarious and insufficient. Messrs. Maudslay make their paddle shaft bearings with very large fillets in the corner, with the view of diminishing the evil; but it would be preferable to make the bearings of the crank shafts spheroidal; and, indeed, it would probably be an improvement if most of the bearings about the engine were to be made in the same fashion. The loose end of the crank pin should be made not spheroidal, but consisting of a portion of a sphere; and a brass bush might then be fitted into the crank eye, that would completely encase the ball of the pin, and yet permit the outer end of the paddle shaft to fall without straining the pin, the bush being at the same time susceptible of a slight end motion. The paddle shaft, where it passes through the vessel's side, is usually surrounded by a lead stuffing box, which will yield if the end of the shaft falls; this stuffing box prevents leakage into the ship from the paddle wheels: but it is expedient, as a further precaution, to have a small tank on the ship's side immediately beneath the stuffing box, with a pipe leading down to the bilge to catch and conduct away any water that may enter around the shaft.

487. *Q.*—How is the outer bearing of the paddle wheels supplied with tallow?

A.—The bearing at the outer end of the paddle shaft is sometimes supplied with tallow, forced into a hole in the plummer block cover, as in the case of water wheels; but for vessels intended to perform long voyages, it is preferable to have a pipe leading down to the oil cup above the journal from the top of the paddle box, through which pipe oil may at any time be supplied.

488. *Q.*—Will you explain the method of putting engines into a steam vessel?

A.—As an illustration of this operation it may be advisable to take the case of a side lever engine, and the method of proceeding is as follows:—First measure across from the inside of paddle bearers to the centre of the ship, to make sure that the central line, running in a fore and aft direction on the deck or beams, usually drawn by the carpenter, is really in the centre. Stretch a line across between the paddle bearers in the direction of the shaft; to this line, in the centre of the ship where the fore and aft mark has been made, apply a square with arms six or eight feet long, and bring a line stretched perpendicularly from the deck to the keelson, accurately to the edge of the square: the lower point of the line where it touches the keelson will be immediately beneath the marks made upon the deck. If this point does not come in the centre of the keelson, it will be better to shift it a little, so as to bring it to the centre, altering the mark upon the deck correspondingly, provided either paddle shaft will admit of this being done—one of the paddle brackets being packed behind with wood, to give it an additional projection from the side of the paddle bearer. Continue the line fore and aft upon the keelson as nearly as can be judged in the centre of the ship; stretch another line fore and aft through the mark upon the deck, and look it out of winding with the line upon the keelson. Fix upon any two points equally distant from the centre, in the line stretched transversely in the direction of the shaft; and from those points, as centres, and with any convenient radius, sweep across the fore and aft line to see that the two are at right angles; and, if not, shift the transverse line a little to make them so. From the transverse line next let fall a line upon each outside keelson, bringing the edge of the square to the line, the other edge resting on the keelson. A point will thus be got on each outside keelson perpendicularly beneath the transverse line running in the direction of the shaft, and a line drawn between those two points will be directly below the shaft. To this line the line of the shaft marked on the sole plate has to be brought, care being taken, at the same time, that the right distance is preserved between the fore and aft line upon the sole plate, and the fore and aft line upon the central keelson.

489. *Q.*—Of course the keelsons have first to be properly prepared?

A.—In a wooden vessel, before any part of the machinery is put in, the keelsons should be dubbed fair and straight, and be looked out of winding by means of two straight edges. The art of placing engines in a ship is more a piece of plain common sense than any other feat in engineering, and every man of intelligence may easily settle a method of procedure for himself. Plumb lines and spirit levels, it is obvious, cannot be employed on board a vessel, and the problem consists in so placing the sole plates, without these aids, that the paddle shaft will not stand awry across the vessel, nor be carried forward beyond its place by the framing shouldering up more than was expected. As a plumb line cannot be used, recourse must be had to a square; and it will signify nothing at what angle with the deck the keelsons run, so long as the line of the shaft across the keelsons is square down from the shaft centre. The sole plates being fixed, there is no difficulty in setting the other parts of the engine in their proper places upon them. The paddle wheels must be hung from the top of the paddle box to enable the shaft to be rove through them, and the cross stays between the engines should be fixed in when the vessel is afloat. To try whether the shafts are in a line, turn the paddle wheels, and try if the distance between the cranks is the same at the upper and under, and the two horizontal centres; if not, move the end of the paddle shaft up or down, backward or forward, until the distance between the cranks at all the four centres is the same.

490. *Q.*—In what manner are the engines of a steam vessel secured to the hull?

A.—The engines of a steamer are secured to the hull by means of bolts called holding down bolts, and in wooden vessels a good deal of trouble is caused by these bolts, which are generally made of iron. Sometimes they go through the bottom of the ship, and at other times they merely go through the keelson,—a recess being made in the floor or timbers to admit of the introduction of a nut. The iron, however, wears rapidly away in both cases, even though the bolts are tinned; and it has been found the preferable method to make such of the bolts as pass through the bottom, or enter the bilge, of Muntz's metal, or of copper. In a side lever engine, four Muntz's metal bolts may be put through the bottom at the crank end of the framing of each engine, four more at the main centre, and four more at the cylinder, making twelve through bolts to each engine; and it is more convenient to make these bolts with a nut at each end, as in that case the bolts may be dropped down from the inside, and the necessity is obviated of putting the vessel on very high blocks in the dock, in order to give room to put the bolts up from the bottom. The remainder of the holding down bolts may be of iron, and may, by means of a square neck, be screwed into the timber of the keelsons as wood screws—the upper part being furnished with a nut which may be screwed down upon the sole plate, so soon as the wood screw portion is in its place. If the cylinder be a fixed one it should be bolted down to the sole plate by as many bolts as are employed to attach the cylinder cover, and they should be of copper or brass, in any situation that is not easily accessible.

491. *Q.*—If the engines become loose, how do you refix them?

A.—It is difficult to fix engines effectually which have once begun to work in the ship, for in time the surface of the keelsons on which the engines bear becomes worn uneven, and the engines necessarily rock upon it. As a general rule, the bolts attaching the engines to the keelsons are too few and of too large a diameter: it would be preferable to have smaller bolts, and a greater number of them. In addition to the bolts going through the keelsons or the vessel's bottom, there should be a large number of wood screws securing the sole plate to the keelson, and a large number of bolts securing the various parts of the engine to the sole plate. In iron vessels, holding down bolts passing through the bottom are not expedient; and there the engine has merely to be secured to the iron plate of the keelsons, which are made hollow to admit of a more effectual attachment.

492. *Q.*—What are the proper proportions of bolts?

A.—In well formed bolts, the spiral groove penetrates about one twelfth of the diameter of the cylinder round which it winds, so that the diameter of the solid cylinder which remains is five sixths of the diameter over the thread. If the strain to which iron may be safely subjected in machinery is one fifteenth of its utmost strength, or 4,000 lbs. on the square inch, then 2,180 lbs. may be sustained by a screw an inch in diameter, at the outside of the threads. The strength of the holding down bolts may easily be computed, when the elevating force of the piston or main centre is known; but it is expedient very much to exceed this strength in practice, on account of the elasticity of the keelsons, the liability to corrosion, and other causes.

THE LOCOMOTIVE ENGINE.

493. *Q.*—What is the amount of tractive force requisite to draw carriages on railways?

A.—Upon well formed railways with carriages of good construction, the average tractive force required for low speeds is about 7½ lbs. per ton, or $\frac{1}{300}$th of the load, though in some experimental cases, where particular care was taken to obtain a favorable result, the tractive force has been reduced as low as $\frac{1}{500}$th of the load. At low speeds the whole of the tractive force is expended in overcoming the friction, which is made up partly of the friction of attrition in the axles, and partly of the rolling friction, or the obstruction to the rolling of the wheels upon the rail. The rolling friction is very small when the surfaces are smooth, and in the case of railway carriages does not exceed $\frac{1}{1000}$th of the load; whereas the draught on common roads of good construction, which is chiefly made up of the rolling friction, is as much as $\frac{1}{30}$th of the load.

494. *Q.*—In reference to friction you have already stated that the friction of iron sliding upon brass, which has been oiled and then wiped dry, so that no film of oil is interposed, is about $\frac{1}{11}$th of the pressure, but that in machines in actual operation, where there is a film of oil between the rubbing surfaces, the friction is only about one third of this amount, or $\frac{1}{33}$d of the weight. How then can the tractive resistance of locomotives at low speeds, which you say is entirely made up of friction, be so little as $\frac{1}{500}$th of the weight?

A.—I did not state that the resistance to traction was $\frac{1}{500}$th of the weight upon an average—to which condition the answer given to a previous question must be understood to apply—but I stated that the average traction was about $\frac{1}{300}$th of the load, which nearly agrees with my former statement. If the total friction be $\frac{1}{300}$th of the load, and the rolling friction be $\frac{1}{1000}$th of the load, then the friction of attrition must be $\frac{1}{420}$th of the load; and if the diameter of the wheels be 36 in., and the diameter of the axles be 3 in., which are common proportions, the friction of attrition must be increased in the proportion of 36 to

3, or 12 times, to represent the friction of the rubbing surface when moving with the velocity of the carriage. $\frac{12}{429}$ths are about $\frac{1}{35}$th of the load, which does not differ much from the proportion of $\frac{1}{33}$d as previously determined.

495. *Q.*—What is the amount of adhesion of the wheels upon the rails?

A.—The adhesion of the wheels upon the rails is about $\frac{1}{5}$th of the weight when the rails are clean, or either perfectly wet or perfectly dry; but when the rails are half wet or greasy, the adhesion is not more than $\frac{1}{10}$th or $\frac{1}{12}$th of the weight or pressure upon the wheels. The weight of a locomotive of modern construction varies from 20 to 25 tons.

496. *Q.*—And what is its cost and average performance?

A.—The cost of a common narrow gauge locomotive, of average power, varies from 1,900*l.* to 2,200*l.*; it will run on an average 130 miles per day, at a cost for repairs of 2½*d.* per mile; and the cost of locomotive power, including repairs, wages, oil, and coke, does not much exceed 6*d.* per mile run, on economically managed railways. This does not include a sinking fund for the renewal of the engines when worn out, which may be taken as equivalent to 10 per cent. on their original cost.

497. *Q.*—Does the expense of traction increase much with an increased speed?

A.—Yes; it increases very rapidly, partly from the undulation of the earth when a heavy train passes over it at a high velocity, but chiefly from the resistance of the atmosphere and blast pipe, which constitute the greatest of the impediments to motion at high speeds. At a speed of 30 miles an hour, the atmospheric resistance has been found in some cases to amount to about 12 lbs. a ton; and in side winds the resistance even exceeds this amount, partly in consequence of the additional friction caused from the flanges of the wheels being forced against the rails, and partly because the wind catches to a certain extent the front of every carriage, whereby the efficient breadth of each carriage, in giving motion to the air in the direction of the train, is very much increased. At a speed of 30 miles an hour, an engine evaporating 200 cubic feet of water in the hour, and therefore exerting about 200 horses power, will draw a load of 110 tons. Taking the friction of the train at 7½ lbs. per ton, or 825 lbs. operating at the circumference of the driving wheel—which, with 5 ft. 6 in. wheels, and 18 in. stroke, is equivalent to 4,757 lbs. upon the piston—and taking the resistance of the blast pipe at 6 lbs. per square inch of the pistons, and the friction of the engine unloaded at 1 lb. per square inch, which, with pistons 12 in. in diameter, amount together to 1,582 lbs., and reckoning the increased friction of the engine due to the load at $\frac{1}{7}$th of the load, as in some cases it has been found experimentally to be, though a much less proportion than this would probably be a nearer average, we have 7018·4 lbs. for the total load upon the pistons. At 30 miles an hour the speed of the pistons will be 457·8 feet per minute, and 7018·4 lbs. multiplied by 457·8 ft. per minute, are equal to 3213023·5 lbs. raised one foot high in the minute, which, divided by 33,000, gives 97·3 horses power as the power which would draw 110 tons upon a railway at a speed of 30 miles an hour, if there were no atmospheric resistance. The atmospheric resistance is at the rate of 12 lbs. a ton, with a load of 110 tons, equal to 1,320 lbs., moving at a speed of 30 miles an hour, which, when reduced, becomes 105·8 horses power, and this, added to 97·3, makes 203·1, instead of 200 horses power, as ascertained by a reference to the evaporative power of the boiler. This amount of atmospheric resistance, however, exceeds the average, and in some of the experiments for ascertaining the atmospheric resistance, a part of the resistance due to the curves and irregularities of the line has been counted as part of the atmospheric resistance.

498. *Q.*—Is the resistance per ton of the engine the same as the resistance per ton of the train?

A.—No; it is more, since the engine has not merely the resistance of the atmosphere and of the wheels to encounter, but the resistance of the machinery besides. According to Mr. Gooch's experiments upon a train weighing 100 tons, the resistance of the engine and tender at 13·1 miles per hour was found by the indicator to be 12·38 lbs.; the resistance per ton of the train, as ascertained by the dynamometer, was at the same speed 7·56 lbs., and the average resistance of locomotive and train was 9·04 lbs. At 20·2 miles per hour these resistances respectively became 19·0, 8·19, and 12·2 lbs. At 44·1 miles per hour the resistances became 34·0, 21·10, and 25·5 lbs., and at 57·4 miles an hour they became 35·5, 17·81, and 23·8 lbs.

499. *Q.*—Is it not maintained that the resistance of the atmosphere to the progress of railway trains increases as the square of the velocity?

A.—The atmospheric resistance, no doubt, increases as the square of the velocity, and the power, therefore, necessary to overcome it will increase as the cube of the velocity, since in doubling the speed four times, the power must be expended in overcoming the atmospheric resistance in half the time. At low speeds, the resistance does not increase very rapidly; but at high speeds, as the rapid increase in the atmospheric resistance causes the main resistance to be that arising from the atmosphere, the total resistance will vary nearly as the square of the velocity. Thus the resistance of a train, including locomotive and tender, will, at 15 miles an hour, be about 9·3 lbs. per ton; at 30 miles an hour it will be 13·2 lbs. per ton; and at 60 miles an hour, 29 lbs. per ton. If we suppose the same law of progression to continue up to 120 miles an hour, the resistance at that speed will be 92·2 lbs. per ton, and at 240 miles an hour the resistance will be 344·8 lbs. per ton. Thus, in doubling the speed from 60 to 120 miles per hour, the resistance does not fall much short of being increased fourfold, and the same remark applies to the increase of the speed from 120 to 240 miles an hour. These deductions and other deductions from Mr. Gooch's experiments on the resistance of railway trains, are fully discussed by Mr. Clark, in his Treatise on railway machinery, who gives the following rule for ascertaining the resistance of a train, supposing the line to be in good order, and free from curves:—To find the total resistance of the engine, tender, and train in pounds per ton, at any given speed. Square the speed in miles per hour; divide it by 171, and add

8 to the quotient. The result is the total resistance at the rails in lbs. per ton.

500. *Q.*—How comes it, that the resistance of fluids increases as the square of the velocity, instead of the velocity simply?

A.—Because the height necessary to generate the velocity with which the moving object strikes the fluid, or the fluid strikes the object, increases as the *square* of the velocity, and the resistance or the weight of a column of any fluid varies as the height. A falling body, as has been already explained, to have acquired twice the velocity, must have fallen through four times the height; the velocity generated by a column of any fluid is equal to that acquired by a body falling through the height of the column; and it is therefore clear, that the pressure due to any given velocity must be as the square of that velocity, the pressure being in every case as twice the altitude of the column. The work done, however, by a stream of air or other fluid in a given time, will vary as the cube of the velocity; for if the velocity of a stream of air be doubled, there will not only be four times the pressure exerted per square foot, but twice the quantity of air will be employed; and in windmills, accordingly, it is found, that the work done varies nearly as the cube of the velocity of the wind. If, however, the work done by *a given quantity* of air moving at different speeds be considered, it will vary as the squares of the speeds.

501. *Q.*—But in a case where there is no work done, and the resistance varies as the square of the speed, should not the power requisite to overcome that resistance vary as the square of the speed?

A.—It should if you consider the resistance over a given distance, and not the resistance during a given time. Supposing the resistance of a railway train to increase as the square of the speed, it would take four times the power, so far as atmospheric resistance is concerned, to accomplish a mile at the rate of 60 miles an hour, that it would take to accomplish a mile at 30 miles an hour; but in the former case there would be twice the number of miles accomplished in the same time, so that when the velocity of the train was doubled, we should require an engine that was capable of overcoming four times the resistance at twice the speed, or in other words, that was capable of exerting eight times the power, so far as regards the element of atmospheric resistance. We know by experience, however, that it is easier to attain high speeds on railways than in steam vessels, where the resistance does increase nearly as the square of the speed.

502. *Q.*—Will you describe generally the arrangement of a locomotive engine?

A.—The boiler and engine are hung upon a framework set on wheels, and, together with this frame or carriage, constitute what is commonly called the locomotive. Behind the locomotive runs another carriage, called the tender, for holding coke and water. A common mode of connecting the engine and tender is by means of a rigid bar, with an eye at each end through which pins are passed. Between the engine and tender, however, buffers should always be interposed, as their pressure contributes greatly to prevent oscillation and other irregular motions of the engine.

503. *Q.*—How is the framing of a locomotive usually constructed?

A.—All locomotives are now made with the framing which supports the machinery situated within the wheels; but for some years a vehement controversy was maintained respecting the relative merits of outside and inside framing, which has terminated, however, in the universal adoption of the inside framing. It is difficult, in engines intended for the narrow gauge, to get cylinders within the framing of sufficient diameter to meet the exigencies of railway locomotion; by casting both cylinders in a piece, however, a considerable amount of room may be made available to increase their diameters. It is very desirable that the cylinders of locomotives should be as large as possible, so that expansion may be adopted to a large extent; and with any given speed of piston, the power of an engine either to draw heavy loads, or achieve high velocities, will be increased with every increase of the dimensions of the cylinder. The framing of locomotives, to which the boiler and machinery are attached, and which rests upon the springs situated above the axles, is formed generally of malleable iron, but in some engines the side frames consist of oak with iron plates riveted on each side. The guard plates are in these cases generally of equal length, the frames being curvêd upward to pass over the driving axle. Hard cast iron blocks are riveted between the guard plates to serve as guides for the axle bushes. The side frames are connected across the ends, and cross stays are introduced beneath the boiler to stiffen the frame sideways, and prevent the ends of the connecting or eccentric rods from falling down if they should be broken.

504. *Q.*—What is the nature and arrangement of the springs of locomotives?

A.—The springs are of the ordinary carriage kind, with plates connected at the centre, and allowed to slide on each other at their ends. The upper plate terminates in two eyes, through each of which passes a pin, which also passes through the jaws of the bridle, connected by a double threaded screw to another bridle, which is jointed to the framing; the centre of the spring rests upon the axle box. Sometimes the springs are placed between the guard plates, and below the framing which rests upon their extremities. One species of springs which has gained a considerable introduction, consists of a number of flat steel plates with a piece of metal or other substance interposed between them at the centre, leaving the ends standing apart. It would be preferable, perhaps, to make the plates of a common spring with different curves, so that the leaves, though in contact at the centre, would not be in contact with the ends with light loads, but would be brought into contact gradually, as the strain comes on: a spring would thus be obtained that was suitable for all loads.

505. *Q.*—What is the difference between inside and outside cylinder engines?

A.—Outside cylinders are so designated when placed upon the outside of the framing, with their connecting rods operating upon pins in the driving wheels; while the inside cylinders are situated within the framing, and the connecting rods attach themselves to cranks in the driving axle.

506. *Q.*—Whether are inside or outside cylinder engines to be preferred?

A.—A diversity of opinion obtains as to the relative merits of outside and inside cylinders. The chief objection to outside cylinders is, that they occasion a sinuous motion in the engine which is apt to send the train off the rails; but this action may be made less perceptible or be remedied altogether, by placing a weight upon one side of the wheels, the momentum of which will just balance the momentum of the piston and its connections. The sinuous or rocking motion of locomotives is traceable to the arrested momentum of the piston and its attachments at every stroke of the engine, and the effect of the pressure thus created will be more operative in inducing oscillation the farther it is exerted from the central line of the engine. If both cylinders were set at right angles in the centre of the carriage, and the pistons were both attached to a central crank, there would be no oscillation produced; or the same effect would be realized by placing one cylinder in the centre of the carriage, and two at the sides—the pistons of the side cylinders moving simultaneously: but it is impossible to couple the piston of an upright cylinder direct to the axle of a locomotive, without causing the springs to work up and down with every stroke of the engine: and the use of three cylinders, though adopted in some of Stephenson's engines, involves too much complication to be a beneficial innovation.

507. *Q.*—Whether are four-wheeled or six-wheeled engines preferable?

A.—Much controversial ingenuity has been expended upon the question of the relative merits of the four and six-wheeled engines; one party maintaining that four-wheeled engines are most unsafe, and the other that six-wheeled engines are unmechanical, and are more likely to occasion accidents. The four-wheeled engines, however, appear to have been charged with faults that do not really attach to them when properly constructed; for it by no means follows that if the axle of a four-wheeled engine breaks, or even altogether comes away, that the engine must fall down or run off the line; inasmuch as, if the engine be properly coupled with the tender, it has the tender to sustain it. It is obvious enough, that such a connection may be made between the tender and the engine, that either the fore or hind axle of the engine may be taken away, and yet the engine will not fall down, but will be kept up by the support which the tender affords; and the arguments hitherto paraded against the four-wheeled engines are, so far as regards the question of safety, nothing more than arguments against the existence of the suggested connection. It is no doubt the fact, that locomotive engines are now becoming too heavy to be capable of being borne on four wheels at high speeds without injury to the rails; but the objection of damage to the rails applies with at least equal force to most of the six-wheeled engines hitherto constructed, as in those engines the engineer has the power of putting nearly all the weight upon the driving wheels; and if the rail be wet or greasy, there is a great temptation to increase the bite of those wheels by screwing them down more firmly upon the rails. A greater strain is thus thrown upon the rail than can exist in the case of any equally heavy four-wheeled engine; and the engine is made very unsafe, as a pitching motion will inevitably be induced at high speeds, when an engine is thus poised upon the central driving wheels, and there will also be more of the rocking or sinuous motion. Locomotives, however, intended to achieve high speeds or to draw heavy loads, are now generally made with eight wheels, and in some cases the driving wheels are placed at the end of the engine instead of in the middle.

508. *Q.*—As the question of the locomotive boiler has been already disposed of in discussing the question of boilers in general, it now only remains to inquire into the subject of the engine, and we may commence with the cylinders. Will you state the arrangement and construction of the cylinders of a locomotive and their connections?

A.—The cylinders are placed in the same horizontal plane as the axle of the driving wheels, and the connecting rod which is attached to the piston rod engages either a crank in the driving axle or a pin in the driving wheel, according as the cylinders are inside or outside of the framework. The cylinders are generally made an inch longer than the stroke, or there is half an inch of clearance at each end of the cylinder, to permit the springs of the vehicle to act without causing the piston to strike the top or bottom of the cylinder. The thickness of metal of the cylinder ends is usually about a third more than the thickness of the cylinder itself, and both ends are generally made removable. The priming of the boiler, when it occurs, is very injurious to the cylinders and valves of locomotives, especially if the water be sandy, as the grit carried over by the steam wears the rubbing surfaces rapidly away. The face of the cylinder on which the valve works is raised a little above the metal around it, both to facilitate the operation of forming the face and with the view of enabling any foreign substance deposited on the face to be pushed aside by the valve into the less elevated part, where it may lie without occasioning any further disturbance. The valve casing is sometimes cast upon the cylinder, and it is generally covered with a door which may be removed to permit the inspection of the faces. In some valve casings the top as well as the back is removable, which admits of the valve and valve bridle being removed with greater facility. A cock is placed at each end of locomotive cylinders, to allow the water to be discharged which accumulates in the cylinder from priming or condensation; and the four cocks of the two cylinders are usually connected together, so that by turning a handle the whole are opened at once. In Stephenson's engines, however, with variable expansion, there is but one cock provided for this purpose, which is on the bottom of the valve chest.

509. *Q.*—What kind of piston is used in locomotives?

A.—The variety of pistons employed in locomotives is very great, and sometimes even the more complicated kinds are found to work very satisfactorily; but, in general, those pistons which consist of a single ring and tongue piece, or of two single rings set one above the other, so as to break joint, are preferable to those which consist of many pieces. In Stephenson's pistons the screws were at one time liable to work slack, and the springs to break.

510. *Q.*—Will you explain the connection of the piston rod with the connecting rod?

A.—The piston rods of all engines are now generally either case hardened very deeply, or are made of steel; and in locomotive engines the diameter of the piston rod is about one seventh of the diameter of the cylinder, and it is formed of tilted steel. The cone of the piston rod, by which it is attached to the piston, is turned the reverse way to that which is adopted in common engines, with the view of making the cutter more accessible from the bottom of the cylinder, which is made to come off like a door. The top of the piston rod is secured with a cutter into a socket with jaws, through the holes of which a cross head passes, which is embraced between the jaws by the small end of the connecting rod, while the ends of the cross head move in guides. Between the piston rod clutch and the guide blocks, the feed pump rod joins the cross head in some engines.

511. *Q.*—What kind of guides is employed for the end of the piston rod?

A.—The guides are formed of steel plates attached to the framing, between which work the guide blocks, fixed on the ends of the cross head, which have flanges bearing against the inner edges of the guides. Steel or brass guides are better than iron ones: Stephenson and Hawthorn attach their guides at one end to a cross stay, at the other to lugs on the cylinder cover; and they are made stronger in the middle than at the ends. Stout guide rods of steel, encircled by stuffing boxes on the ends of the cross head, would probably be found superior to any other arrangement. The stuffing boxes might contain conical bushes, cut spirally, in addition to the packing, and a ring, cut spirally, might be sprung upon the rod and fixed in advance of the stuffing box, with lateral play to wipe the rod before entering the stuffing box, to prevent it from being scratched by the adhesion of dust.

512. *Q.*—Is any provision made for keeping the connecting rod always of the same length?

A.—In every kind of locomotive it is very desirable that the length of the connecting rod should remain invariable, in spite of the wear of the brasses, for there is a danger of the piston striking against the cover of the cylinder if it be shortened, as the clearance is left as small as possible in order to economize steam. In some engines the strap encircling the crank pin is fixed immovably to the connecting rod by dovetailed keys, and a bolt passes through the keys, rod, and strap, to prevent the dovetailed keys from working out. The brass is tightened by a gib and cutter, which is kept from working loose by three pinching screws and a cross pin or cutter through the point. The effect of this arrangement is to lengthen the rod, but at the cross head end of the rod the elongation is neutralized by making the strap loose, so that in tightening the brass the rod is shortened by an amount equal to its elongation at the crank pin end. The tightening here is also effected by a gib and cutter, which is kept from working loose by two pinching screws pressing on the side of the cutter. Both journals of the connecting rod are furnished with oil cups, having a small tube in the centre with siphon wicks. The connecting rod is a thick flat bar, with its edges rounded.

513. *Q.*—How is the cranked axle of locomotives constructed?

A.—The cranked axle of locomotives is always made of wrought iron, with two cranks forged upon it toward the middle of its length, at a distance from each other answerable to the distance between the cylinders. Bosses are made on the axle for the wheels to be keyed upon, and bearings for the support of the framing. The axle is usually forged in two pieces, which are afterward welded together. Sometimes the pieces for the cranks are put on separately, but the cranks so made are liable to give way. In engines with outside cylinders the axles are made straight—the crank pins being inserted in the naves of the wheels. The bearings to which the connecting rods are attached are made with very large fillets in the corners, so as to strengthen the axle in that part, and to obviate side play in the connecting rod. In engines which have been in use for some time, however, there is generally a good deal of end play in the bearings of the axles themselves, and this slackness contributes to make the oscillation of the engine more violent; but this evil may be remedied by making the bearings spheroidal, whereby end play becomes impossible.

514. *Q.*—How are the bearings of the axles arranged?

A.—The axles bear only against the top of the axle boxes, which are generally of brass; but a plate extends underneath the bearing, to prevent sand from being thrown upon it. The upper part of the box in most engines has a reservoir of oil, which is supplied to the journal by tubes with siphon wicks. Stephenson uses cast iron axle boxes with brasses, and grease instead of oil; and the grease is fed upon the journal by the heat of the bearing melting it, whereby it is made to flow down through a hole in the brass. Any engines constructed with outside bearings have inside bearings also, which are supported by longitudinal bars, which serve also in some cases to support the piston guides; these bearings are sometimes made so as not to touch the shafts unless they break.

515. *Q.*—How are the eccentrics of a locomotive constructed?

A.—In locomotives the body of the eccentric is of cast iron, in inside cylinder engines the eccentrics are set on the axle between the cranks, and they are put on in two pieces held together by bolts; but in straight axle engines the eccentrics are cast in a piece, and are secured on the shaft by means of a key. The eccentric, when in two pieces, is retained at its proper angle on the shaft by a pinching screw, which is provided with a jam nut to prevent it from working loose. A piece is left out of the eccentric in casting it to allow of the screw being inserted, and the void is afterward filled by inserting a dovetailed piece of metal. Stephenson and Hawthorn leave holes in their eccentrics on each side of the central arm, and they apply pinching screws in each of these holes. The method of fixing the eccentric to the shaft by a pinching screw is scarcely sufficiently substantial; and cases are perpetually occurring, when this method of attachment is adopted, of eccentrics shifting from their place. In the modern engines the eccentrics are forged on the axles.

516. *Q.*—How are the eccentric straps constructed?

A.—The eccentric hoops are generally of wrought iron, as brass hoops are found liable to break. When formed of malleable iron, one half of the strap is forged with the rod, the other half being secured to it by bolts, nuts, and jam nuts. Pieces of brass are, in some cases, pinned within the malleable iron hoop; but it appears to be preferable to put brasses within the hoop to encircle the eccentric, as in the case of any other bearing. When the brass straps are used, the lugs have generally nuts on both sides, so that the length of the eccentric rod may be adjusted by their means to the proper length; but it is better for the lugs of the hoops to abut against the necks of the screws, and, if any adjustment be necessary from the wear of the straps, washers can be interposed. In some engines the adjustment is effected by screwing the valve rod, and the cross head through which it passes has a nut on either side of it, by which its position upon the valve rod is determined.

517. *Q.*—Will you describe the eccentric rod and valve levers?

A.—In the engines in use before the introduction of the link motion, the forks of the eccentric rod were of steel, and the length of the eccentric rod was the distance between the centre of the crank axle and the centre of the valve shaft; but in modern engines the use of the link motion is universal. The valve lever in locomotives is usually longer than the eccentric lever, to increase the travel of the valve, if levers are employed; but it is better to connect the valve rod to the link of the link motion without the intervention of levers. The pins of the eccentric lever in the old engines used to wear quickly; Stephenson used to put a ferule of brass on these pins, which being loose, and acting like a roller, facilitated the throwing in and out of gear, and when worn could easily be replaced, so that there was no material derangement of the motion of the valve from play in this situation.

518. *Q.*—What is the arrangement of a starting lever?

A.—The starting lever travels between two iron segments, and can be fixed in any desired position. This is done by a small catch or bell crank, jointed to the bottom of the handle at the end of the lever, and coming up by the side of the handle, but pressed out from it by a spring. The smaller arm of this bell crank is jointed to a bolt, which shoots into notches, made in one of the segments between which the lever moves. By pressing the bell crank against the handle of the lever the bolt is withdrawn, and the lever may be shifted to any other point, when, the spring being released, the bolt flies into the nearest notch.

519. *Q.*—In what way does the starting handle act on the machinery of the engine to set it in motion?

A.—Its whole action lies in raising or depressing the link of the link motion relatively with the valve rod. If the valve rod be attached to the middle of the link, the valve will derive no motion from it at all, and the engine will stop. If the attachment be slipped to one end of the link the engine will go ahead, and if slipped to the other end it will go astern. The starting handle merely achieves this change of position.

520. *Q.*—Will you explain the operation of setting the valve of a locomotive?

A.—In setting the valves of locomotives, place the crank in the position answerable to the end of the stroke of the piston, and draw a straight line, representing the centre line of the cylinder, through the centres of the crank shaft and crank pin. From the centre of the shaft describe a circle with the diameter equal to the throw of the valve; another circle to represent the crank shaft; and a third circle to represent the path of the crank pin. From the centre of the crank shaft, draw a line perpendicular to the centre line of the cylinder and crank shaft, and draw another perpendicular at a distance from the first equal to the amount of the lap and the lead of the valve: the points in which this line intersects the circle of the eccentric are the points in which the centre of the eccentric should be placed for the forward and reverse motions. When the eccentric rod is attached directly to the valve, the radius of the eccentric, which precedes the crank in its revolution, forms with the crank an obtuse angle; but when, by the intervention of levers, the valve has a motion opposed to that of the eccentric rod, the angle contained by the crank and the radius of the eccentric must be acute, and the eccentric must follow the crank: in other words, with a direct attachment to the valve the eccentric is set *more* than one fourth of a revolution in advance of the crank, and with an indirect attachment the eccentric is set *less* than one fourth of a circle behind the crank. If the valve were without lead or lap the eccentric would be exactly one fourth of a circle in advance of the crank or behind the crank, according to the nature of the valve connection; but as the valve would thus cover the port by the amount of the lap and lead, the eccentric must be set forward so as to open the port to the extent of the lap and lead, and this is effected by the plan just described.

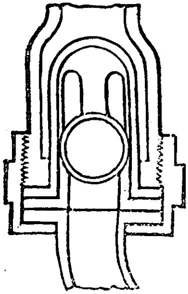
521. *Q.*—In the event of the eccentrics slipping round upon the shaft, which you stated sometimes happens, is it necessary to perform the operation of setting the valve as you have just described it?

A.—If the eccentrics shift upon the shaft, they may be easily refixed by setting the valve open the amount of the lead, setting the crank at the end of the stroke, and bringing round the eccentric upon the shaft till the eccentric rod gears with the valve. It would often be troublesome in practice to get access to the valve for the purpose of setting it, and this may be dispensed with if the amount of lap on the valve and the length of the eccentric rod be known. To this end draw upon a board two straight lines at right angles to one another, and from their point of intersection as a centre describe two circles, one representing the circle of the eccentric, the other the crank shaft; draw a straight line parallel to one of the diameters, and distant from it the amount of the lap and the lead: the points in which his parallel intersects the circle of the eccentric are the positions of the forward and backward eccentrics. Through these points draw straight lines from the centre of the circle, and mark the intersection of these lines with the circle of the crank shaft; measure with a pair of compasses the chord of the arc intercepted between either of these points, and the diameter which is at right angles with the crank, and the diameters being first marked on the shaft itself, then by transferring with the compasses the distance found in the diagram, and marking the point, the eccentric may at any time be adjusted without difficulty.

522. *Q.*—Will you describe the structure and arrangement of the feed pumps of locomotive engines?

A.—The feed pumps of locomotives are generally made of brass, but the plungers are sometimes made of iron, and are generally attached to the piston cross head, though in Stephenson's engines they are worked by rods attached to eyes on the eccentric hoops. There is a ball valve, *fig.* 45, between the pump and the tender, and two usually in the pipe leading from the pump to the boiler, besides a cock close to the boiler, by which the pump may be shut off from the boiler in case of any accident to the valves. The ball valves are guided by four branches, which rise vertically, and join together at the top in a hemispherical form. The shocks of the ball against this cap have in some cases broken it after one week's work, from the top of the cage having been flat, and the branches not having had their junction at the top properly filleted. These valve guards are attached in different ways to the pipes; when one occurs at the junction of two pieces of pipe it has a flange, which along with the flanges of the pipes and that of the valve seat are held together by a union joint. It is sometimes formed with a thread at the under end, and screwed into the pipe. The balls are cast hollow to lessen the shock, as well as to save the metal. In some cases where the feed pump plunger has been attached to the cross head, the piston rod has been bent by the strain; and that must in all cases occur, if the communication between the pump and boiler be closed when the engine is started, and there be no escape valve for the water.

Fig. 45.



523. *Q.*—Are none but ball valves used in the feed pump?

A.—Spindle valves have in some cases been used instead of ball valves, but they are more subject to derangement; but piston valves, so contrived as to shut a portion of water in the cage when about to close, might be adopted with a great diminution of the shock. Slide valves might be applied, and would probably be found preferable to any of the expedients at present in use. In all spindle valves opened and shut rapidly, it is advisable to have the lower surface conical, to take off the shock of the water; and a large lift of the valve should be prevented, else much of the water during the return stroke of the pump will flow out before the valve shuts.

524. *Q.*—At what part of the boiler is the feed water admitted?

A.—The feed pipe of most locomotive engines enters the boiler near the bottom and about the middle of its length. In Stephenson's engine the water is let in at the smoke box end of the boiler, a little below the water level; by this means the heat is more fully extracted from the escaping smoke, but the arrangement is of questionable applicability to engines of which the steam dome and steam pipe are at the smoke box end, as in that case the entering cold water would condense the steam.

525. *Q.*—How are the pipes connecting the tender and locomotive constructed, so as to allow of play between the engine and tender without leakage?

A.—The pipes connecting the tender with the pumps should allow access to the valves and free motion to the engine and tender. This end is attained by the use of ball and socket joints; and, to allow some end play, one piece of the pipe slides into the other like a telescope, and is kept tight by means of a stuffing box. Any pipe joint between the engine and tender must be made in this fashion.

526. *Q.*—Have you any suggestion to make respecting the arrangement of the feed pump?

A.—It would be a material improvement if a feed pump was to be set in the tender and worked by means of a small engine, such as that now used in steam vessels for feeding the boilers.

The present action of the feed pumps of locomotives is precarious, as, if the valves leak in the slightest degree, the steam or boiling water from the boiler will prevent the pumps from drawing. It appears expedient, therefore, that at least one pump should be far from the boiler and should be set among the feed water, so that it will only have to force. If a pump was arranged in the manner suggested, the boiler could still be fed regularly, though the locomotive was standing still; but it would be prudent to have the existing pumps still wrought in the usual way by the engine, in case of derangement of the other, or in case the pump in the tender might freeze.

527. *Q.*—Will you explain the construction of locomotive wheels?

A.—The wheels of a locomotive are always made of malleable iron. The driving wheels are made larger to increase the speed; the bearing wheels also are easier on the road when large. In the goods engines the driving wheels are smaller than in the passenger engines, and are generally coupled together. Wheels are made with much variety in their constructive details: sometimes they are made with cast iron naves, with the spokes and rim of wrought iron; but in the best modern wheels the nave is formed of the ends of the spokes welded together at the centre. When cast iron naves are adopted, the spokes are forged out of flat bars with T-formed heads, and are arranged radially in the founder's mould, the cast iron, when fluid, being poured among them. The ends of the T heads are then welded together to constitute the periphery of the wheel or inner tire; and little wedge-form pieces are inserted where there is any deficiency of iron. In some cases the arms are hollow, though of wrought iron; the tire of wrought iron, and the nave of cast iron; and the spokes are turned where they are fitted into the nave, and are secured in their sockets by means of cutters. Hawthorn makes his wheels with cast iron naves and wrought iron rims and arms; but instead of welding the arms together, he makes palms on their outer end, which are attached by rivets to the rim. These rivets, however, unless very carefully formed, are apt to work loose; and it would probably be found an improvement if the palms were to be slightly indented into the rim, in cases in which the palms do not meet each other at the ends. When the rim is turned it is ready for the tire, which is now made of steel.

528. *Q.*—How do you find the length of bar necessary for forming a tire?

A.—To find the proper length of bar requisite for the formation of a hoop of any given diameter, add the thickness of the bar to the required diameter, and the corresponding circumference in the table of circumferences of circles is the length of the bar. If the iron be bent edgewise the breadth of the bar must be added to the diameter, for it is the thickness of the bar measured radially that is to be taken into consideration. In the tires of railway wheels, which have a flange on one edge, it is necessary to add not only the thickness of the tire, but also two thirds of the depth of the flange; generally, however, the tire bars are sent from the forge so curved that the plain edge of the tire is concave, and the flange edge convex, while the side which is afterward to be bent into contact with the cylindrical surface of the wheel is a plane. In this case the addition of the diameter of two thirds of the depth of the flange is unnecessary, for the curving of the flange edge has the effect of increasing the real length of the bar. When the tire is thus curved, it is only necessary to add the thickness of the hoop to the diameter, and then to find the circumference from a table; or the same result will be obtained by multiplying the diameter thus increased by the thickness of the hoop by 3·1416.

529. *Q.*—How are the tires attached to the wheels?

A.—The materials for wheel tires are first swaged separately, and then welded together under the heavy hammer at the steel works; after which they are bent to the circle, welded, and turned to certain gauges. The tire is now heated to redness in a circular furnace; during the time it is getting hot, the iron wheel, turned to the right diameter, is bolted down upon a face plate or surface; the tire expands with the heat, and when at a cherry red, it is dropped over the wheel, for which it was previously too small, and it is also hastily bolted down to the surface plate; the whole mass is then quickly immersed by a swing crane in a tank of water five feet deep, and hauled up and down till nearly cold; the tires are not afterward tempered. The tire is attached to the rim with rivets having countersunk heads, and the wheel is then fixed on its axle.

530. *Q.*—Is it necessary to have the whole tire of steel?

A.—It is not indispensable that the whole tire should be of steel; but a dovetail groove, turned out of the tire at the place where it bears most on the rail, and fitted with a band of steel, will suffice. This band may be put in in pieces, and the expedient appears to be the best way of repairing a worn tire; but particular care must be taken to attach these pieces very securely to the tire by rivets, else in the rapid revolution of the wheel the steel may be thrown out by the centrifugal force. In aid of such attachment the steel, after being introduced, is well hammered, which expands it sideways until it fills the dovetail groove.

531. *Q.*—Is any arrangement adopted to facilitate the passage of the locomotive round curves?

A.—The tire is turned somewhat conical, to facilitate the passage of the engine round curves—the diameter of the outer wheel being virtually increased by the centrifugal force of the engine, and that of the inner wheel being correspondingly diminished, whereby the curve is passed without the resistance which would otherwise arise from the inequality of the spaces passed over by wheels of the same diameter fixed upon the same axle. The rails, moreover, are not set quite upright, but are slightly inclined inward, in consequence of which the wheels must be either conical or slightly dished, to bear fairly upon the rails. One benefit of inclining the rails in this way, and coning the tires, is that the flange of the wheels is less liable to bear against the sides of the rail, and with the same view the flanges of all the wheels are made with large fillets in the corners. Wheels have been placed loose upon the axle, but they have less stability, and are not now much used. Nevertheless this plan appears to be a good one if properly worked out.

532. *Q.*—Are any precautions taken to prevent engines

from being thrown off the rails by obstructions left upon the line?

A.—In most engines a bar is strongly attached to the front of the carriage on each side, and projects perpendicularly downward to within a short distance of the rail, to clear away stones or other obstructions that might occasion accidents if the engine ran over them.