speed the greater the weight of the wheel. It also varies inversely as the square of the diameter and inversely as the square of the number of revolutions per minute.

The foregoing investigation applies to the case where the resistance is practically uniform. If the resistance fluctuates during each revolution, as for instance when the engine is driving a two-bladed screw propeller, a proper curve of resistance would have to be drawn in lieu of the line *a a'*, fig. 47. When the resistance is liable to sudden fluctuations, as for instance in the case of factories where a large number of machines are occasionally thrown on or off, the fly wheel by itself is powerless to produce even an approximation to steady running. To effect this in such cases is the duty of the governor, which controls the actual power developed by the engine, either by throttling the steam on the way from the boiler, so that its pressure is reduced considerably by the time it enters the cylinder ; or else, by varying the rate of expansion so that the engine develops more or less power in proportion to the work it has to do. For description of various governors see p. 239.

Read to 273

CHAPTER VI.

THE MECHANISM AND DETAILS OF STEAM ENGINES.

Cylinders with their fittings—Clearance—Steam passages—Valve boxes—Jacketing—Lubricators—Pistons—Piston packings—Piston rods—Cross heads and slide bars—Connecting rods—Cranks and eccentrics—Eccentric rods—The strains in crank shafts—Journals—Shaft bearings and pedestals—Axle boxes—Governors—Fly wheels.

It is intended in this chapter to give an account of the separate parts which constitute the mechanism of the steam engine, excepting only the valves and valve-gear, which require separate treatment. The variety of form and arrangement of the parts of steam engines is so great, that it will only be possible to give a few representative examples. A more extended knowledge of the mechanism can only be gained by close observation of numerous engines, or working drawings.

The Cylinder.—The cylinder of a steam engine is the closed vessel in which the piston works backwards and forwards. It is so called because the interior is cylindrical in shape, though the form of the exterior is complicated by sundry additions. Examples of stationary engine cylinders are given in figs. 5 to 7, and of marine engine cylinders in figs. 194, 195, 197 to 200. Fig. 48 is a longitudinal section of a steam cylinder of a locomotive engine. It is made of cast iron, the interior being carefully bored so as to form a smooth and cylindrical surface for the passage of the piston. It consists of the following principal parts. The cylindrical body AA, which is cast in one piece ;—the valve box BB, in the thickness of which are formed the two steam passages SS and the exhaust passage E;—the two covers CC, which are flanged, and which are attached to the body of the cylinder by means of studs and nuts. The cover through which the piston rod works is provided with a stuffing box D and gland *e*, to prevent the steam escaping round the rod. This object is accomplished in the following manner. The space *aa* between the rod and the inner cylindrical surface of the stuffing-box is filled with plaited hemp saturated with tallow, or with one of the numerous patent packings now procurable. The gun-metal gland *e*, through which the piston rod passes, is forced up

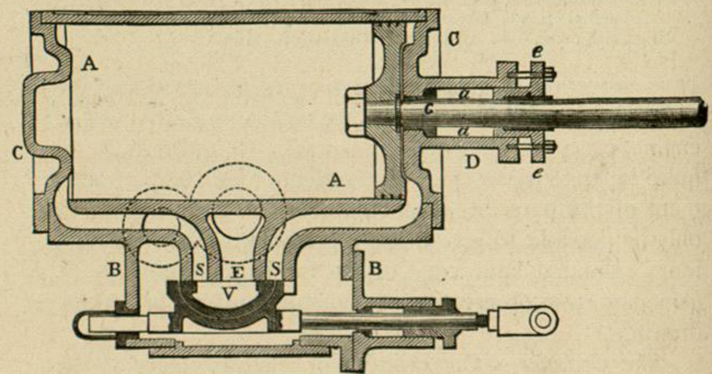

Fig. 48.

against the packing by means of the two nuts and screwed studs shown in the drawing. The result is that the packing can be squeezed with any desired degree of tightness round the piston rod, and can thus prevent the escape of steam. The opening by which the piston rod passes through the substance of the cover is lined with a gun-metal bush, *c*. In many engines, especially those of foreign manufacture, there is a stuffing box on the other cylinder cover, through which a prolongation of the piston rod works. The object of this arrangement is to prevent the piston bearing unequally on the lower side of the cylinder. It is also adopted in the

case of condensing engines, when the plunger of the air-pump is driven direct from the piston. It will be noticed that the interior faces of the covers are cast so as to fit into the corresponding faces of the piston. The reason of this arrangement is that the piston has in many cases to be formed in the shape shown in fig. 48, viz. with a broad rim or flange, and a thin disc; now if the cover faces were not shaped correspondingly, there would be at each end of the stroke a large space to be filled with steam before the piston began to move, which steam would do no work till expansion began.

Clearance.—The interior length of the cylinder bore, from cover to cover, is always a little longer than the stroke, plus the thickness of the piston, so that a small vacant space called the clearance is invariably left at the end of each stroke. If it were not for this precaution the covers might be knocked off whenever water accumulated in the cylinder. The clearance spaces and also the contents of the steam passages SS, between the valve face and the inner surface of the bore of the cylinder must at each stroke be filled with steam before the piston can be moved. This steam of course does no work till expansion begins, but a great portion of the loss due to this cause may be recovered by compressing the exhaust steam before the end of the stroke. This operation is called cushioning the piston, and is most essential for many reasons. It helps to bring the piston gradually to rest, and partially restores the temperature of the sides of the cylinder which become cooled during the exhaust. It further tends to produce uniformity of tangential effort on crank-pin in the case of quick running engines; see p. 193.

The joints of the covers are made steam tight by placing between the flanges a layer of red lead cement, or soft copper wire, or one of the numerous patent packings, and then tightening up the bolts.

Steam passages.—The design of the steam ports and passages is a matter of the greatest importance. It is desirable to make the length of the passage as short as possible, so that its cubic contents may not add unduly to the contents of the clearance spaces, and on the other hand it is essential that the area of the passages should be ample, so that the fresh steam may not be throttled on its way into the cylinder, nor the exhaust steam on its way out, the result of which would be a considerable loss of power by reducing the pressure of the incoming steam and increasing the back pressure. It is not easy to reconcile these desiderata with the use of a single slide valve; for, if the passages were made as short as possible, the ports would necessarily be situated near the ends of the cylinder, and a valve that would cover both of them would be of unwieldy dimensions. Again, if the ports were made very wide so as to give a very free passage to the steam, the distance which the valve would have to move over—commonly called the travel of the valve—in order to fully uncover the ports would be so great that the work of moving the valve would absorb no inconsiderable portion of the power of the engine. Consequently in engines which are worked with a short slide valve,—and these constitute the great majority of engines in actual use, —a compromise has to be effected between conflicting evils The area of the steam ports is obviously connected with the piston speed of the engine; for, the greater the speed the greater the quantity of steam which has to be admitted in a given time; and consequently a port which would be found ample for a slow running engine might be totally inadequate if the speed were considerably increased. The following empirical rule has been found to give satisfactory practical results in the case of engines having long steam passages.

The area of steam port : area of piston :: speed of piston in feet per sec. : 100.

$$\text{or area of port} = \frac{\text{area of piston} \times \text{speed of piston}}{100.}$$

In some types of modern engines, which are designed

with the object of economising fuel, the steam ports are placed quite close to the cylinder ends, and separate passages are provided for the escape of the exhaust steam. In such case the simple slide valve is, of course, dispensed with, and each passage is worked by a separate valve (see page 264 and fig. 99). The object of providing separate exhaust passages is, that the fresh steam on entering the cylinder may not be cooled down by coming in contact with the sides of passages through which the cold exhaust steam has just escaped.

Valve boxes.—The valve box is generally flanged and provided with a cover, which is bolted to the face of the box, just as are the covers to the cylinder ends. The valve box is provided with a stuffing box, through which works the rod which actuates the valve, and also with an opening to which is attached the steam pipe from the boiler. The exhaust steam, after it has done its work, escapes through each steam passage alternately, and passes through the hollow portion of the valve V into the exhaust port E, whence it is led through an exhaust passage cast on the body of the cylinder, and is suffered to escape through a pipe into the open air, or else in the case of condensing engines, is conducted by a pipe to the condenser.

The face on which the slide valve works is, in large engines, often cast separately from the body of the cylinder, to which it is attached by bolts. In this manner it is possible to secure a sound face for the valves to work on, and to renew it when it becomes worn.

Jacketing.—In many engines of the better class, the cylinder is surrounded by an outer casing, sometimes cast in one piece with it, and sometimes attached to it, in such a manner as to leave an annular chamber between casing and cylinder. In this case the cylinder is said to be jacketed. The annular chamber is filled with fresh steam direct from the boiler. The object of this arrangement is to keep the body of the cylinder proper at, as nearly as possible, a uniform temperature, and thus to avoid the injurious effects due to the cooling of the cylinder sides by the expanding and exhaust steam. Fig. 49 illustrates, in a longitudinal section, a jacketed cylinder. Where jacketing is carried out very thoroughly, the covers are jacketed as well as the body of the cylinder. For further examples of jacketed cylinders see pages 456 to 463.

In many modern marine engines, the inner surface or barrel of the cylinder is cast as a separate piece and fitted into the outer body. One end is attached by a flange to the outer body, while the other end is left free to expand and contract with the variations in temperature that take

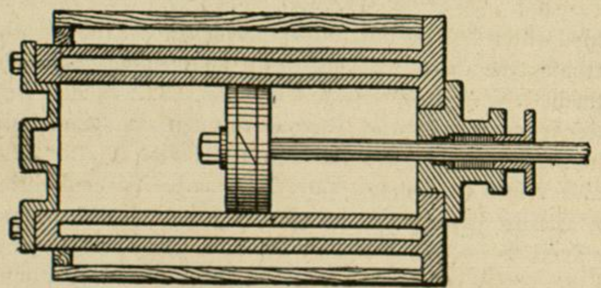

Fig. 49.

place. The free end must be packed steam tight. This inner portion is called the liner. There is usually a space between the liner and the body which forms the steam-jacket. Cylinders thus constructed possess many advantages. They are easier to make. When the inner surface wears down, it can be easily taken out, and a new one inserted. The cylinder is not unequally strained by variations of temperature in its different parts. Lastly, the liner can be made of cast steel, which is the strongest and most durable material for the purpose. For further on the subject of jackets, see page 450. The exterior surface of the cylinder, or of the jacket casing, should always be covered with a layer

of non-conducting material, such as wood, felt, or asbestos cloth, to prevent losses by radiation.

In order to discharge condensed water, or water which may have lodged in the cylinder on account of priming in the boiler, a small opening is made in the bottom of each end of the cylinder, and is provided with a cock called the 'pet-cock.' Sometimes, instead of the pet-cocks, small relief valves are provided, which open outwards, whenever the pressure within the cylinder exceeds the pressure which holds the valve down.

In order to lubricate the rubbing surfaces of the piston

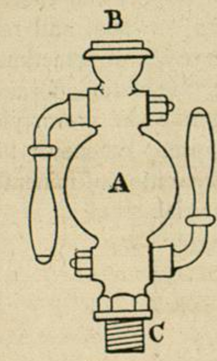

Fig. 50.

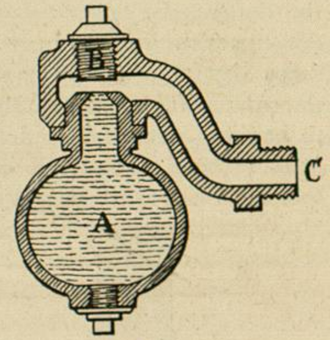

Fig. 51.

and slide valve, small openings have to be provided, into which are screwed lubricators containing oil or tallow. Fig. 50 represents a form of lubricator in common use. The bulb A contains the oil or tallow which is introduced through the funnel B. The lubricator is screwed into the cylinder or valve box by means of the screw C. The cocks, shown in the sketch, make or close communication between the bulb and cylinder, or bulb and funnel.

Fig. 51 represents Mr. Ramsbottom's continuous feed lubricators. The bulb A is filled with oil introduced by the plug B. The pipe C is screwed into the cylinder. The steam, entering this pipe, condenses by degrees on the surface of the oil, and the water thus formed sinks to the bottom of the bulb, displacing a small quantity of oil. This process continues till the bulb becomes entirely filled with water, which can then be drawn off through the lower plug.

Great care should be devoted to the choice of a good material for lubrication. Tallow, even of the best quality, and animal oils generally, are unsuited for use with high-pressure steam, as they are decomposed by the high temperature into stearic and other acids, which readily attack the iron of the cylinders. If the waste steam from the cylinders is mixed with the feed water for the boilers, the effects of the decomposed tallow on the boiler are fatal and rapid. Sometimes the iron plates are eaten away, and sometimes a soapy deposit, of a very non-conducting nature, forms on the crowns of the furnaces, which permits the crown plates to become overheated, and to collapse. Whenever high-pressure steam is employed, some preparation of mineral oil should be used as the lubricating material.

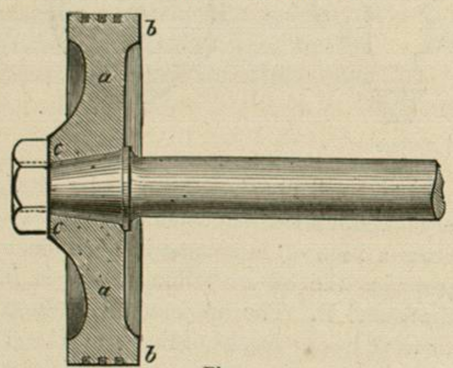

Fig. 52.

Pistons.—The piston is the metallic disc or moveable diaphragm which accurately fits the bore of the cylinder, and which receives and transmits the pressure of the steam to the other moving parts of the engine. Fig. 52 illustrates

in section a piston which is used for locomotives on the London & North-Western Railway. It consists of three principal parts, viz. the central disc *a*, *a*, which forms the body of the piston, the circumferential portion *b*, *b*, which contains the packing that enables the piston to move steam-tight along the cylinder, and which is so shaped as to form a large surface of contact with the sides of the latter, and the central boss *c*, *c*, which receives the coned end of the piston rod.

The forms of pistons are innumerable, and depend altogether upon the purpose for which the engine is intended, and the size of the cylinder, which in different classes of engines varies from a few inches to over 9 feet in diameter. The chief points to attend to in the design of a piston are the following:—it should be strong enough to withstand the pressure of the steam, and to hold the end of the piston rod immovably;—the packing round the circumference should be steam-tight, without causing undue friction, and not liable to get out of order;—the width of the circumferential portion should be such that the pressure per square inch—due, in the case of horizontal engines, to the weight of the piston—be not sufficient to cause undue wear of the inner surface of the cylinder. In many engines the weight of the piston is taken off the surface of the cylinder by prolonging the piston rod backwards through the back cover of the cylinder; in such cases the weight is partly transferred to the stuffing-boxes and slide-bars, which are easily got at for purposes of examination and adjustment.

The importance of keeping the surface of the cylinder true, and of keeping the piston in steam-tight contact with it, will be readily recognised when it is borne in mind that a leakage of steam past the piston means that during the whole time the engine is at work there is an open passage from the boiler to the condenser or outer air, through which steam is continuously escaping without doing any work.

Methods of packing pistons.—In the early days of steam engines, when the pressure used was low, a good packing was