in which the valve face is curved to form a complete cylinder, round whose whole circumference the ports extend. The pistons are packed like ordinary cylinder pistons by metallic rings, and the ports are crossed here and there by diagonal bars to keep the rings from springing out as the valve moves over them. Figs. 86 and 87 show two forms of piston valve designed by Mr Kirk for the supply of high-pressure steam to large marine engines. P, P are the cylinder ports in each.

Fig. 85 illustrates an arrangement common in all heavy slide- valves whose travel is vertical—the *balance-piston,* which is pressed up by steam on its lower side and so equilibrates the weight of the valve, valve-rod, aud connected parts of

the mechanism.

162. The slide-valve sometimes takes the form of a disk revolving or oscillating on a fixed seat, and sometimes of a rocking cyl­inder (fig. 88). This last kind of sliding motion is very usual in stationary engines fitted with the Corliss gear, which will be described in the next chapter, in which case four distinct rocking slides are commonly employed to effect the steam distribution, one giving admission and one giving exhaust at each end of the cylinder (see fig. 127).

163. In many stationary engines *lift* or *disk* valves are used, worked by tappets, cams, or eccentrics. Lift valves are generally of the Cornish or double-beat type (fig. 89), in which equilibrium is secured by the use of two conical

faces which open or close together.

In Cornish pumping engines,

which retain the single action of

Watt’s early engine, three double­

beat valves are used, as steam-

valve, equilibrium-valve, and ex­

haust-valve respectively. These

are closed by tappets on a rod

moving with the beam, but are

opened by means of a device called

a cataract, which acts as follows.

The cataract is a small pump with

a weighted plunger, discharging

fluid through a stop-cock which can be adjusted by hand when it is desired to alter the speed of the engine. The weighted plunger is raised by a rod from the beam, but is free in its descent, so that it comes down at a rate depending on the extent to which the stop­cock is opened. When it comes down a certain way it opens the steam and exhaust valves, by liberating catches which hold them closed; the “out-door ” stroke then begins and admission continues until the steam-valve is closed: this is done directly by the motion of the beam, which also, at a later point in the stroke, closes the exhaust. Then the equilibrium-valve is opened, and the “in-door” stroke takes place, during which the plunger of the cataract is raised. When it is completed, the piston pauses until the cataract causes the steam-valve to open and the next “out-door” stroke begins. By applying a cataract to the equilibrium-valve also, a pause is introduced at the end of the “ out-door ” stroke. Pauses have the advantage of giving the pump time to fill and of allowing the pump-valves to settle in their seats without shock.

IX. Governing.

164. To make an engine run steadily an almost continuous pro­cess of adjustment must go on, by which the amount of work done by the steam in the cylinder is adapted to the amount of external work demanded of the engine. Even in cases where the demand for work is sensibly uniform, fluctuations in boiler-pressure still make regulation necessary. Generally the process of government aims at regularity of speed; occasionally, however, it is some other condition of running that is maintained constant, as when an engine driving a dynamo-electric machine is governed by an electric regula­tor to give a constant difference of potential between the brushes.

The ordinary methods of regulating are either (*a*) to alter the pressure at which steam is admitted by opening or closing more or less a throttle-valve between the boiler and the engine, or (*b*) to alter the volume of steam admitted to the cylinder by varying the point of cut-off. The former plan was introduced by Watt and is still common, especially in small engines. From the point of view of heat economy it is wasteful, since the process of throttling is essen­tially irreversible, but this objection is to some extent lessened by the fact that the wire-drawing of steam dries or superheats it, and consequently reduces the condensation which it suffers on coming into contact with the chilled cylinder walls. On the other hand, to hasten the cut-off involves a gain rather than a loss of efficiency unless the ratio of expansion is already very great. The second plan of regulating is much to be preferred, especially when the engine is subject to large variations of load, and is very generally followed in stationary engines of the larger types.

165. Within certain limits regulation by either plan can be

effected by hand, but for the finer adjustment of speed some form of automatic governor is necessary. Speed governors are commonly of the *centrifugal* type: a pair of masses revolving about a spindle which is driven by the engine are kept

from flying out by a certain controlling

force. When an increase of speed occurs

this controlling force is no longer able

to keep the masses revolving in their

former path ; they move out until the

controlling force is sufficiently increased,

and in moving out they act on the regu­

lator of the engine, which may be a

throttle-valve or some form of automatic

expansion gear. In the conical pendu­

lum governor of Watt (fig. 90) the re­

volving masses are balls attached to a

vertical spindle by links, and the con­

trolling force is furnished by the weight

of the balls, which, in receding from the spindle, are obliged to rise. When the speed exceeds or falls short of its normal value they move out or in, and so raise or lower a collar C which is in connexion by a lever with the throttle-valve. The suspension-links may be hung from a cross-bar (figs. 94, 95) instead of being pivoted in the axis of the spindle.

166. In a modified form of Watt’s governor, known as Porter’s, or the loaded governor, a sup­plementary controlling force is given by placing a weight on the sliding collar (fig. 91). This is equivalent to increasing the *weight* of the balls without altering their *mass.* In other governors the controlling force is wholly or partly produced by springs. Fig. 92 shows a gover­nor by Messrs Tangye in which the balls are controlled partly by their own weight and partly by a spring, the tension of which is regulated by turning the cap A.

167. In whatever way the revolving masses are controlled, the controlling force may be treated as a force F acting on each ball in the direction of the radius towards the axis of revolution. Then, if M be the mass of the ball, *n* the number of revolutions per second, and *r* the radius of the ball’s path, the governor will revolve in equilibrium when F = 4π2*n*2*r*M (in absolute units), or

*n*=1/2π√F/M*r*

In order that the configuration of the governor should be stable, F must increase more rapidly than r, as the balls move outwards. In the simple conical pendulum governor, any of the three forms shown in figs. 93, 94, and 95, where the balls have no load to raise

but their own weight, the controlling force F is the resultant of T, the tension in the link, and M*g*, the weight of the ball (fig. 96). Let the height of the pendulum, that is, the distance above the plane of the balls of the point where the suspending-link, or the link produced, cuts the axis, be called *h.* Then F:M*g*::r:*h*. Hence

F=M*gr*/*h* and *n*=1/2π√*g*/*h*

Any change of *n* tends to produce a change of *h,* and, if the governor itself and the regulating mechanism attached to it were free