angle *φ,* which brings the resultant eccentric into the direction CQ and makes the relative displacement of the two valves equal to the distance *l.*

Expansion-valves furnish a convenient means of *varying* the expansion, which may be done by altering their lap, travel or angular advance. Alteration of lap, or rather of the distance *l* in the figures, is often effected by having the expansion-valve in two parts (as in fig. 37) and holding them on one rod by right- and left-handed screws respectively ; by turning the valve-rod the parts are made to approach or recede from each other. In large valves the adjustment is more conveniently made by varying the travel of the valve, which is done by connecting it to its eccentric through a link which serves as a lever of variable length.

72. *Relief Rings.—*To relieve the pressure of the valve on the seat, large slide-valves are generally fitted with a steam-tight ring, which excludes steam from the greater part of the back of the valve. The ring fits steam-tight into a recess in the cover of the steam-chest, and is pressed by springs against the back of the valve, which is planed smooth to slide under the ring. Fig. 39 show’s a relief ring of this kind fitted on the back of a large double-ported slide-valve for a marine engine. Another plan is to fit the ring into a recess on the back of the valve, and let it slide on the inside of the steam-chest cover. Steam is thus excluded from the space within the ring, any steam that leaks in being allowed to escape to the condenser (or to the intermediate receiver when the arrangement is fitted to the high- pressure cylinder of a compound engine). A flexible diaphragm has also been used, instead of a recess, to hold the ring.

73. *Piston Slide-Valve.—*The pressure of valves on cylinder faces is still more completely obviated by making the back of the valve similar to its face, and causing the back to slide in contact with the valve- chest cover, which has recesses corresponding to the cylinder ports. This arrangement is most perfectly carried out in the piston slide-valves now very largely used in the high-pressure cylinders of marine engines. The piston slide-valve may be described as a slide- valve 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. Fig. 40 shows a form of piston valve for the supply of high-pressure steam to a large marine engine. P, P are the cylinder ports.

74. *Balance Piston.—*Fig. 39 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 and connected parts of the mechanism.

The valve sometimes takes the form of a rocking cylinder. This last kind of sliding motion is very usual in stationary engines fitted with Corliss gear, 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.

75. *Double-Beat Valve.—*In many stationary engines, especially on the con­tinent of Europe, *lift* or *mushroom* valves are used, worked by tappets, cams or eccentrics. Lift-valves are generally of the Cornish or double-beat type (fig. 41),

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 exhaust-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 stop-cock 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.

76. *Methods of Regulating.—*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 cither (*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. The second plan of regulating is generally preferred, especially when the engine is sub­ject to large variations of load. 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 regulator of the engine, which may be a throttle- valve or some form of automatic expan­sion gear. In the conical pendulum governor of Watt (fig. 42) the revolving masses are balls attached to a vertical spindle by links, and the controlling 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.

77. *Loaded Governor.—*In a modified form, known as the loaded governor, a supplementary controlling force is given by placing a weight on the sliding collar (fig. 43). 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. The use of springs to provide controlling force allows the axis of rotation to be horizontal, and governors of this class are frequently attached directly to the hori­zontal shaft in high-speed engines.

78. *Equilibrium of Governor.—*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 = 4π2n2rM (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. It is obvious that no *stable* governor maintains a strictly constant speed in the engine which it controls. If the boiler pressure or the demand for work is changed, a certain amount of permanent displace­ment of the balls is necessary to alter the steam-supply, and the balls can retain their displaced position only by virtue of a permanent change in the speed. The maximum range of speed depends on that amount of chance of *n* which suffices to alter the configuration