from friction, only one position of the governor would be possible for any one value of *n.* It is obvious that neither this governor nor any other *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 change of *n* w'hich suffices to alter the configuration of the governor from the position which gives no steam-supply to the position which gives full steam-supply ; and the governor is said to be sensitive if this range is a small fraction of *n.*

168. If the governor is loaded, let M' be the amount of the load per ball, and *q* the velocity ratio of the vertical movement of the load to the vertical movement of the ball. Then *q*M'*g* is the equi­valent increase in the weight of each ball. The effect of the load is to increase the controlling force F from M*gr*∕*h* to (M + *q*M')*gr*∕*h*, and the speed at which the governor must now turn, to maintain any assigned height *h,* is

*n*=1/2π√(M+*q*M')*g/M*h

The speed of the loaded governor must therefore be greater than that of an unloaded governor of the same height in the ratio √(M + *q*M') to ∖∕M.

The sensibility is then the same as that of an unloaded governor of the same height *h,* but the loaded governor has an important advantage in another respect—namely, its *power* or capability of overcoming frictional resistance to a change of configuration. This quality in a governor is increased whenever the controlling force F is increased, whether by the addition of a load or by the use of springs.

For let *f* be the frictional resistance to be overcome per ball, resolved as a force resisting the displacement of each ball in the direction of the radius *r.* Then if *n* be the speed normal to any configuration this speed must change by a certain amount Δ*n* before friction is overcome and the balls begin to be displaced. The controlling force is now F *+f* when the balls are moving out­wards, and F - *f* when the balls are moving inwards. Hence

n + Δn=1/2π√F+*f*/M*r*,

and n - Δn=1/2π√F-*f*/M*r.*

From this, if *Bn* be small compared with *n,* we have Δn∕n=*f*∕2F.

Thus, when a given amount of frictional resistance is to be over­come before the governor can act, the limits within which this friction allows the speed to vary are less the greater is the con­trolling force F. A loaded governor is more powerful in this respect than an unloaded governor of the same configuration in the proportion in which F is greater—namely, as M + *q*M' is to M. A loaded governor may therefore have much lighter revolving masses without loss either of sensibility or of power.

169. The same results are applicable to governors in which the controlling force is supplied by springs as well as by gravity, or by springs alone. To find tho configuration which the governor will assume at any particular speed, or the speed corresponding to a particular configuration, it is only necessary to determine the whole controlling force F per ball acting along the radius towards the axis for various values of *r.* Let a curve *ab* (fig. 97) be drawn showing the relation of F to *r.* At any assigned

value of *r* set up an ordinate QC = 4π2*n*2*r*M. Join

OC. The point c, in which OC cuts the curve, de­

termines the value of *r* at which the balls will

revolve at the assigned speed *n.* Or, if that is

given, and the value of *n* is to be found, the line Oc

produced will determine C, and then n2 = QC∕4π2*r*M.

The sensibility of the governor is determined by

taking points *a* and *b* corresponding to full steam

and no steam respectively, and drawing lines through them to de­termine the corresponding values of QA and QB.@@1 When the fric­tional resistance *f* is known, an additional pair of curves drawn above and below *ab,* with ordinates F + *f* and F - *f* respectively, serve to show the additional variations in speed which are caused by friction. The governor is stable throughout its whole range when the curve *ab* has a steeper gradient than any line drawn from O to meet it.

170. By § 167 it is evident that, if, when the balls are displaced, the controlling force F changes proportionally to the radius *r,* the speed is constant. In other words, the equilibrium of the gover­nor is then neutral; it can revolve in equilibrium at one, and only at one, speed. At this speed it assumes, indifferently, any one of its possible configurations. The slightest variation of speed drives it to the extremity of its range ; hence its sensibility is indefinitely

great. Such a governor is called *isochronous.* A gravity governor is isochronous when *h* is constant for all positions of the balls (since *n*∞ √*g*∕*h*). This will be the case if the balls are constrained to move in a parabolic path (fig. 98), it being

a property of the parabola that the subnormal QM, which is *h,* is constant. A useful ap­proximation to the same condition, through a limited range, is secured in Farcot’s gover­nor by the device of hanging the balls by crossed links from the distant ends of a T piece (fig. 95). If each centre of suspension were at the centre of curvature of a parabolic arc which coincided with the actual circular locus of the balls at the position of normal speed, the governor would be sensibly isochronous at that speed ; by taking the centres of suspension rather nearer the axis, a suitable margin of stability is se­

cured, but the governor is still nearly enough iso­chronous to be exceedingly sensitive.@@2 Where springs furnish the controlling force, an approach to iso­chronism can be secured by adjusting the initial tension of the springs, and this forms a convenient means of regulating the sensibility. Thus, in Mr Hartnell’s apparatus (fig.

99), where the balls move in a nearly horizontal di­rection, and gravity has little to do with the con­trol, the governor can be made isochronous by screwing down the spring, so ∣ that the initial force ex­erted by the spring is to its increase by displace­ment of the balls as the initial radius of the balls’ path is to the increase of radius by displacement.

When the initial force is increased beyond this the governor becomes unstable.

In fig. 97 the condition of isochronism is secured when the line *ab* coincides with a straight line through O.

171. In practice no governor can be absolutely isochronous. It is indispensable to leave a small margin of stability for the sake of preventing violent change in the supply of steam, especially when there is much frictional resistance to be overcome by the governor, or where the influence of the governor takes much time to be felt by the engine. An over-sensitive governor is liable to fall into a state of oscillation called *hunting.* When an alteration of speed begins to be felt, however readily the governor alters its form, the engine’s response is more or less delayed. If the governor acts by closing a throttle-valve, the engine has still a capacious valve-chest on which to draw for steam. If it acts by changing the cut-off, its opportunity is passed if the cut-off has already occurred, and the control only begins with the next stroke. This lagging of effect is specially felt in compound engines, where that portion of the steam which is already in the engine continues to do its work for nearly a whole revolution after passing beyond the governor’s control. The result of this storage of energy in an engine whose governor is too nearly isochronous is that, whenever the demand for power suddenly falls, the speed rises so much as to force the gover­nor into a position of over-control, such that the supply of steam is no longer adequate to meet even the reduced demand for power. Then the speed slackens, and the same kind of excessive regulation is repeated in the opposite direction. A state of forced oscillation is consequently set up. The effect is aggravated by the momen­tum which the governor balls acquire in being displaced, and also, to a very great degree, by the friction of the governor and the regulating mechanism. Hunting is to be avoided by giving the governor a fair degree of stability, by reducing as far as possible the static frictional resistances, and by introducing a *viscous* resistance to the displacement of the governor, which prevents the displace­ment from occurring too suddenly, without affecting the ultimate position of equilibrium. For this purpose many governors are furnished with a *dash-pot,* which is an hydraulic or pneumatic brake, consisting of a piston connected to the governor, working loosely in a cylinder which is filled with oil or with air.

172. In some high-speed engines the governor balls or blocks re-

@@@1 See a paper by Mr W. Hartnell, “ Οn Governing Engines by Regulating the Expansion,” *Proc. Inst. Mech. Eng.,* 18S2.

@@@2 See also a paper by Mr J. Head *Proc. Inst. Mech. Eng.,* 1871.