determined from actual indicator diagrams) combined with the moments due to the inertia of the reciprocating parts. The line marked 0 is the steam line without inertia—or, in other words,

the curve corresponding to an indefinitely slow speed. The other curves refer to the number of revolutions per minute marked on them.

189. To determine the fluctuations of speed during a revolution, the resultant diagram of work done *on* the crank-shaft is to be compared with a similar diagram drawn to show the work done *by* the shaft in overcoming its own friction, and in overcoming the resistance of the mechanism which it drives. In general the re­sistance may be taken as constant, and the diagram of effort exerted by the crank-shaft is then a straight line, as EFGHIJKL in fig. 118. At F, G, H, T, J, and K the rate at which work is being done on and by

the shaft is the

same ; hence at

these points the

fly - wheel is

neither gaining

nor losing speed.

The shaded area

above FG is an

excess of work

done on the crank, and raises the speed of the fly-wheel from a mini­mum at F to a maximum at G. From G to H the fly-wheel supplies the defect of energy shown by the shaded area below GH, by which the demand for work exceeds the supply ; its speed again reaches a minimum at H, and again a maximum at I. The excesses and de­fects balance in each revolution if the engine is making a constant number of turns per second. In what follows it is assumed that they are only a small fraction of the whole energy held by the fly-wheel.

Let ∆E be the greatest single amount of energy which the fly­wheel has to give out or absorb, as determined by measuring the shaded areas of the diagram ; and let ω1 and ω2 be the maximum and minimum values of the wheel’s angular velocity, which occur at the extremes of the period during which it is storing or sup­plying the energy ∆E. The mean angular velocity of the wheel *ω*0 will be sensibly equal to 1/2(ω1 + ω2) if the range through which the speed varies is moderate. Let E0 be the energy of the fly-wheel at this mean speed. Then

E0=1/2I*ω*02,

where I is the moment of inertia of the fly-wheel.

∆E≈⅛3~ .I⅛,o(⅛>1 \_ ft,2) = 2E0.

Z ω0

The quantity ——which we may write *q,* is the ratio of the ωa

extreme range of speed to the mean speed, and measures the degree of unsteadiness which the fly-wheel leaves uncorrected. If tho problem be to design a fly-wheel which will keep *q* down to an assigned limit, the energy of the wheel must be such that

E0= ∆E/2*q*

The Moscrop recorder, alluded to in § 182, exhibits the degree of unsteadiness during a single revolution by the width of the line

which it draws. On the other hand, any bending of the line implies the quite independent characteristic of unsteadiness from one revolution to another. The former is due to insufficient fly-wheel energy, the latter to imperfect governing.

190. An interesting consequence of the periodic alternations in crank-effort which occur in each revolution has been pointed out by Mr M. Longridge.@@1 The fly-wheel receives its alternate ac­celeration and retardation through changes of the torsional stress in the shaft. If these occur at intervals nearly equal to the period of free torsional vibration which the fly-wheel possesses in virtue of the torsional elasticity of the shaft between it and the crank, strains of great amplitude will arise ; and Mr Longridge has suggested that this may account for the observed fact that engine- shafts have been ruptured when running so that the fluctuations of crank-effort occurred with one particular frequency, although the greatest effort was itself much less than the shaft would safely bear.

XI. Examples of Steam-Engines.

Stationary Engines.

191. In classifying engines with regard to their general arrangement of parts and mode of working, account has to be taken of a considerable number of independent characteristics. We have, first, a general division into *condensing* and *non-condensing engines,* with a subdivision of the condensing class into those which act by surface condensation and those which use injection. Next there is the division into *compound* and *non-compound,* with a further classification of the former as double-, triple-, or quadruple-expansion engines. Again, engines may be classed as *single* or *double-acting,* according as the steam acts on one or alternately on both sides of the piston. Again, a few engines—such as steam-hammers and certain kinds of steam-pumps—are *non-rotative,* that is to say, the reciprocating motion of the piston does work simply on a reciprocating piece ; but generally an engine does work on a continuously revolving shaft, and is termed *rotative.* In most cases the crank-pin of the revolving shaft is connected directly with the piston-rod by a con­necting-rod, and the engine is then said to be *direct-acting ;* in other cases, of which the ordinary beam-engine is the most important example, a lever is interposed between the piston and the connecting-rod. The same distinction applies to non-rotative pumping engines, in some of which the piston acts directly on the pump-rod, while in others it acts through a beam. The position of the cylinder is another element of classification, giving *horizontal, vertical,* and *inclined cylinder* engines. Many vertical engines are further distinguished as belonging to the *inverted cylinder* class ; that is to say, the cylinder is above the connecting- rod and crank. In *oscillating cylinder engines* the connect­ing-rod is dispensed with ; the piston-rod works on the crank-pin, and the cylinder oscillates on trunnions to allow the piston-rod to follow the crank-pin round its circular path. In *trunk engines* the piston-rod is dispensed with ; the connecting-rod extends as far as the piston, to which it is jointed, and a trunk or tubular extension of the piston, through the cylinder cover, gives room for the rod to oscillate. In *rotary* engines there is no piston in the ordinary sense ; the steam does work on a revolving piece, and the necessity is thus avoided of afterwards converting reciprocating into rotary motion.

192. In the single-acting atmospheric engine of New­comen the beam was a necessary feature; the use of water-packing for the piston required that the piston should move down in the working stroke, and a beam was needed to let the counterpoise pull the piston up. Watt’s improve­ments made the beam no longer necessary ; and in one of the forms he designed it was discarded—namely, in the form of pumping-engine known as the Bull engine, in which a vertical inverted cylinder stands over and acts directly on the pump-rod. But the beam type was generally

@@@1 *Proc. Inst. Mech. Eng.,* May 1884, p. 163.