indicator with the cylinder should be short and of sufficient bore, and that it should open in the cylinder at a place where the pressure in it will not be affected by the kinetic action of the inrushing steam. Frequently pipes are led from both ends of the cylinder to a central position where the indicator is set, so that diagrams may be taken from either end without shifting the instrument ; much better results are obtained, especially when the cylinder is long, by using a pair of indicators, each fixed with the shortest possible connecting pipe, or by taking diagrams succes­sively from the two ends of the cylinder with a single instrument set first at one end and then at the other. The general effect of an insufficiently free connexion between the indicator and the engine cylinder is to make the diagram too small. The first con­dition is also invalidated to some extent by the friction of the indicator piston, of the joints in the linkage, and of the pencil on the paper. The piston must slide very freely ; nothing of the nature of packing is permissible, and any steam that leaks past it must have a free exit through the cover. The pencil pressure must not exceed the minimum which is necessary for clear marking. By careful use of a well-made instrument the error due to friction in the piston and connected parts need not be serious. Another source of disturbance is the inertia of these parts, which tends to set them into oscillation whenever the indicator piston suffers a comparatively sudden displacement. These oscillations, superposed upon the legitimate motions of the piston, give a wavy outline to parts of the diagram, especially when the speed is great and when the last-named source of error (the friction) is small. When they appear on the diagram a continuous curve should be drawn mid­way between the crests and hollows of the undulations. To keep them within reasonable compass in high-speed work a stiff spring must be used aud an indicator with light parts should be selected. Finally, to secure accuracy in the pencil’s movement, the strain of the spring must be kept well within the limit of elasticity, so that the strain may be as nearly as possible proportional to the steam pressure. Care must be taken that the spring is graduated to suit the temperature (about 212° F.) to which it is exposed when in use ; its stiffness at this temperature is about 3 per cent. less than when cold.

With regard to the motion of the drum, it is, in the first place, necessary to have a reduciug mechanism which will give a sufficiently accurate copy, on a small scale, of the engine piston’s stroke. Many contrivances are used for this purpose ; in some a rigorous geometrical solution of the problem is aimed at, in others a close approximation only. Fig. 22 shows a good form of indicator gear. A pendulum rod AB is pinned at one end

to the crosshead A (the end of the piston-rod) of the engine. Its upper end is carried by a pin which is free to turn and slide in the fixed slot B. A cord from an intermediate point C leads over pulleys to the indicator drum. The pendu­lum rod should be much longer than the piston stroke, and the cord should lead off for a con­siderable distance in the direction sketched, at right angles to the mean position of the rods.

The accuracy of the drum’s motion does not, how­ever, depend merely on the geometrical condition of the gear. It depends also on the rigidity of the parts, and espe­cially on the stretching of the cord. The elasticity of the cord will cause error if it is not maintained in a state of uniform tension throughout the double stroke, and this error will be greater the longer and the more extensible the cord is. Hence short cords are to be preferred ; and fine wire, which stretches much less, may often be substituted for cord with great advantage. The stretching of the cord is perhaps the most serious and least noticed source of error the indicator is subject to in ordinary practice. The tension of the cord varies for three reasons,—the inertia of the drum, the varying resistance of the drum spring, aud the friction of the drum, which has the effect of increasing the tension during the forward stroke and of reducing it during the back stroke. This last cause of variation can be minimized only by good construction and careful use of the instrument ; but the other two causes can be made to neutralize one another almost completely. Since the motion is nearly simple harmonic, the acceleration of the drum varies in a nearly uniform manner from end to end of the stroke. The resist­ance of the drum spring also varies uniformly ; and it is therefore only necessary to adjust the stiffness of the drum spring so that the increase in its resistance as the motion of the drum proceeds may balance the decrease in the force that the cord has to exert in setting the drum into motion. This adjustment will secure an almost uniform tension in the cord throughout the whole stroke ; it must, of course, be altered to suit different engine speeds. The indicator plays so important a part in the testing of heat-engines, whether for practical or scientific purposes, that no pains should be spared to avoid the numerous and serious sources of error to which it is liable through faulty construction or unintelligent use.@@1

100. To determine the indicated horse-power, the mean effective pressure is found by dividing the area of the diagram by the length of its base. This gives a mean height, which, interpreted on the scale of pressures, is the mean effective pressure in pounds per square inch. This has to be multiplied by the effective area of the piston in square inches and by the length of the piston stroke in feet, to find the work done per stroke in foot-pounds on that side of the piston to which the diagram refers. Let A1 be the area of the piston on one side and A2 on the other ; *p*1 and *p*2 the mean effective pressures on the two sides respectively ; L the length of the stroke in feet ; and *n* the number of complete double strokes or revolutions per minute. Then the indicated horse-power

j up \_lι,b(p1A1 + p¾A2)

' ' ' 33000

In finding the mean pressure the area of the diagram may be con­veniently measured by a planimeter or calculated by the use of Simpson’s rule. A less accurate plan, frequently followed, is to divide the diagram by lines drawn at the middle of strips of equal width, as in figs. 23 and 24, aud to take the mean pressure as the average height of these lines.

101. Space admits of no more than a few illustrations of actual indicator diagrams. Fig. 23 is a diagram taken from an antiquated non-condensing engine working without ex­

pansion. The line AB has been drawn at a

height which represents the boiler pressure, in

order to show the loss of pressure in admission.

The line CD is drawn at atmospheric pressure

by the indicator itself. In this engine ad­

mission continues till the end of the forward

stroke, and as a result the back pressure is

great, especially during the first stage of the

exhaust. The diagram shows a slight amount of oscillation pro­duced by the sudden admission of steam. This feature, however, is better illustrated by fig. 24, which is another

diagram taken from the same engine, at the same boiler pressure, but with the steam much throttled.

Fig. 25 shows a pair of diagrams taken from a condensing engine in which the distribution of steam is effected by a common slide valve (chap. VIII.). The two diagrams refer to opposite ends of the cylin­der and are taken on the same paper by the plan already alluded to (§ 99) of fixing the indi­

cator about midway be­tween the ends of the cylinder, with a pipe leading from it to each end. Steam is cut off at *a* and*a'*, release occurs at *b* and *b'* and compres­sion begins at *c* and *c'.*

The gradual closing of the slide valves throttles the steam considerably before the cut-off is complete. The line of no pressure EF is drawn 14·7 lb per square inch below CD, which is the atmospheric line ; and the line of no volume AE or BF is drawn (for each end of the cylinder) at a distance (from the end of the diagram) equal to the volume of the clearance.

Fig. 26 is a diagram taken from a Corliss engine working with a large ratio of expansion. The Corliss valve-gear, which will be described in chap. IX., causes the admission valve to close suddenly, and consequently defines the point of cut-off’ pretty sharply in the diagram. Through this point a dotted curve has been drawn (by aid of the equation PV*n*= const., § 67), which is the curve that would be fol­lowed if the expansion were adiabatic. In drawing this curve it has been assumed that at the end of admission the steam contains 25 per cent. of water. The actual curve first falls below and then rises above this adiabatic curve, in conse­quence of the continued condensation which takes place during the early stages of the expansion and the re-evapora­tion of condensed water during later stages (§ 82). Fig. 27 is another diagram from a Corliss engine, running light, and with the condenser not in action. Dia­grams of this kind are often taken when engines are first erected, for the purpose of testing the setting of the valves. Other indicator diagrams, for compound engines,

will be given in chap. VI.

@@@1 A valuable discussion and experimental investigation of tho errors of the indicator will he found in papers by Prot. Osborne Reynolds and Mr H. W.

Brightmore *(Min. Proc. Inst. C.E.,* voi. lxxxiii., 1886). In the discussion which followed the reading of the papers a description will be found of an ingenious apparatus which the makers of the Crosby indicator employ to test the uniform­ity of the cord's tension throughout the stroke.