M‘Naught’s indicator the pencil is directly attached to the indicator piston, in Richards’s the pencil is moved by means of a system of links so that it copies the motion of the piston on a magnified scale. This has the advantage that an equally large diagram is drawn with much less movement of the piston, and errors which are caused by the piston’s inertia are consequently reduced. In high-speed •engines especially it is important to minimize the inertia of the indicator piston and the parts connected with it. In Richards’s indicator the linkage employed to multiply the piston’s motion is an arrangement similar to the parallel motion introduced by Watt as a means of guiding the piston-rod in beam engines. In several recent forms of indicator lighter linkages are adopted, and other changes have been made with the object of fitting the instrument better for high-speed work. One of these modified forms of Richards’s indicator (the Crosby) is shown in fig. 15. The pressure of steam in the engine cylinder raises the piston P, compressing the spring S and causing the pencil Q to rise in a nearly straight line through a distance proportional, on a magnified scale, to the com­pression of the spring and therefore to the pressure of the steam. At the same time the drum D, which carries the paper, receives motion through the cord. C from the crosshead of the engine. Inside this drum there is a spiral spring which becomes wound up when the cord is pulled, and serves to turn the drum in the reverse direc­tion during the back stroke. The cap of the indicator cylinder has holes in it which admit air freely to the top of the piston, and the piston has room to descend, extending the spring S, when the pressure of the steam is less than that of the atmosphere. The spring is easily taken out and replaced by a more or less stiff one when higher or lower pressures have to be dealt with.

50. *Errors in Indicator Diagrams,*—To register correctly, an indicator must satisfy two conditions: (1) the motion of the piston must be proportional to the change of steam pressure in the engine •cylinder: and (2) the motion of the drum must be proportional to that of the engine piston.

The first of these requires that the pipe which connects the 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; better results are obtained, especially when the cylinder is long, by using a pair of indicators, each fixed with the shortest possible connecting pipe. 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. Another source of disturbance is the inertia of the moving 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. 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 and an indicator with light parts should be selected. Care must be taken that the spring is graduated to suit the temperature (about 100° C.) to which it is exposed when in use; its stiffness at this temperature is about 3 % less than when cold.

51. *Measurement of Horse-Power.—*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 ; *p1* and *p2* 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

I H P ⅛1A1+/⅛A¾)

33000

In finding the mean pressure the. area of the diagram may be conveniently measured by a planimeter. A less accurate plan, frequently followed, is to divide the diagram by lines drawn at the middle of strips of equal width and to take the mean pressure as the average height of these lines.

52. *Pests of Efficiency,—*In testing the actual efficiency of an engine the work done as determined by the indicator is compared with the supply of heat, which is calculated from the amount of steam passing through the engine. We may find the amount of steam passing through either by measuring the feed-water or, when a surface condenser is used, by collecting the condensed water from the air-pump discharge and measuring that, adding the water drained from jackets if any are used. In some trials both of these measurements have been made, and it has been found that in general the amount of feed-water exceeds the amount of steam discharged from air-pump and jackets by something like 3 or 4 %, a discre­pancy due to leakages in the boiler and the engine. The results of tests are generally stated by giving the number of pounds of steam used per horse-power-hour, or by giving the work done by each pound of steam, a quantity which is directly comparable with the amount of work ideally obtainable, if the engine followed the perfect Rankine cycle already discussed. To make a complete engine trial the engine is caused to work not only at full power, but at various fractions of its greatest load. The results are very conveniently represented (in a manner due to P. W. Willans) by drawing a curve, the co-ordinates of which are the horse-power and the total consump­tion of steam per hour. This “ Willans Line,” as it is called, is in most cases straight or nearly straight. Another useful curve is drawn by plotting the steam used per horse-power-hour in relation to the horse-power.

53. *Determination of the “Missing Quantity.*”—When the amount of steam passing through the engine is known, the indicator diagram enables the degree of wetness of the steam to be estimated at various stages in the expansion from cut-off to release, provided there is no direct passage, from steam-chest to exhaust, such as has been referred to above in connexion with Messrs Callendar and Nicolson’s researches. For this purpose we must first calculate the quantity of the working substance present in the cylinder. It is made up of two parts, namely, the amount supplied per stroke, *plus* the amount retained by being shut up in the clearance space. If we assume, as may generally be done without serious error, that at the beginning of compression the steam present in the cylinder is dry, it is an easy matter to deduce from the diagram, knowing the pressure and the volume, how much steam is shut up in the clearance. Adding that to the supply per stroke, we get the whole quantity that is present from cut-off to release. The volume which this would occupy at each pressure, if saturated, is found from the steam table. the volume actually occupied at each pressure is found from the diagram, and by comparing the two it is easy to infer how much of the substance exists as water and how much as steam. The ratio of the two volumes measures with sufficient accuracy the dryness of the steam. Any direct leakage from the steam side to the exhaust side of the valve will invalidate this calculation, which proceeds on the basis that all the steam passing through the engine passes through the cylinder.

54. *Compound Engines,—*In the original form of compound engine, invented by Hornblower and revived by Woolf, steam passed directly from the first to the second cylinder; the exhaust from the first and admission to the second went on together throughout the whole of the back stroke. This arrangement is possible only when the high and low pressure pistons begin and end their strokes together, as in engines of the “ tandem ” type, whose high and low pressure cylinders are in one line, with one piston-rod common to both pistons. Engines in which the high and low pressure cylinders are placed side by side, and act either on the same crank or on cranks set at 180° apart, may also discharge steam directly from one to the other cylinder; the same remark applies to beam engines, whether of the class in which both pistons act on one end of the beam, or of the class introduced by M‘Naught, in which the high and low pressure cylinders stand on opposite sides of the centre. By a