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The Steam Engine Indicator*: Its History and Application.

THE steam engine indicator occupies a place in the long list of inventions handed down to us from that illustrious father of the trade—James Watt. The original idea of the indicator was to register the steam pressure in the cylinder at all points of the stroke and hence to enable the rate at which the engine was doing work to be known. Even to-day that is its chief function, but it tells us also scores of other things—about the setting of the valves and the condition of their working faces, the condition of the piston rings, the amount of compression, the terminal pressure, the power distribution throughout the various cylinders and so on. This little instrument is, without exaggeration, the key to the behaviour of the steam and therefore to the economical working of the entire plant.

Watt's primitive indicator consisted essentially of a cylinder of about one inch diameter, which could be connected to or disconnected from the engine cylinder at will by means of a tap at the bottom of the former; a piston was carefully fitted into this and from the top of this piston a small rod passed vertically upwards through a guide and terminated in a pencil arrangement for describing the diagrams. Between the piston and the small vertical guide a spiral spring of known strength encircled the piston rod. The pencil was made to bear on a sheet of paper fixed to a board which slid in a guiding frame

*Prize Essay by "Rocklight" (Mr. J. D. Boyle), written for the Ritchie Award—Graduate Section.

backwards and forwards, always "in step" with the engine piston—*i.e.*, when the engine piston was at the extreme end of its stroke the board also had traversed its full course in one direction, and when the engine piston was at ·4 or ·5, etc., of its travel the sliding board found itself in that same relative position. Watt derived the sliding motion of the board from one of his parallel motion radius rods by means of a cord made to connect these parts. To the other end of the board he attached another cord which passed over a pulley and then had a weight suspended from its lower end. The function of this second cord carrying the weight was to keep the driving cord always in tension. When the pressure in the indicator cylinder remained constant (*e.g.*, atmospheric pressure), and the board was made to reciprocate, a horizontal line was drawn on the paper on the pencil being applied to it. In the same manner, when the driving cord was disconnected and the pressure inside the small cylinder was altered, the application of the pencil to the paper produced a vertical line. It was the combination of these two motions that formed and that still form that celebrated outline termed the "indicator diagram."

Watt's indicator, although, no doubt, a heavy and clumsy piece of mechanism, was quite in place and all that the engineering world of that day was ready for. It involved all the elements necessary for giving a diagram to tell to what advantage the precious fluid was being utilized—yea, in its simple structure were embodied nearly all the principles of our most modern instruments by the best makers of to-day.

The next important step in indicator manufacture was taken by McNaught. He discarded Watt's sliding board arrangement and put in its place a vertical, cylindrical barrel. The paper was wrapped round this and held fast by a clip at each end. The driving cord now made the barrel rotate backwards and forwards about its axis and a volute spring placed inside was used to keep the string in tension. McNaught also continued the walls of his cylinder upwards, thus enclosing the spring, and he attached his pencil arrangement to the bottom of this latter. From these few lines it will be observed that this instrument was much more portable and compact than Watt's; hence it came far more into every-day use than ever its predecessor had done.

The man who now introduced a new design of the indicator into the market was Richards—an American. His was a vast improvement on anything that had hitherto come into use. With the McNaught and other early indicators, if a decent-sized diagram was desired, a very weak spring had to be used and hence the piston had to move through a considerable distance. Now, with the sudden rise and fall of pressure in the cylinders of many engines at the beginning and end of the stroke respectively, the reciprocating parts of the indicator had acquired considerable momentum before they reached the point of equilibrium between the force exerted by the spring on the top of the small piston and that set up by the steam pressure below. The result of this was that the pencil, instead of coming to rest immediately at the desired height, carried out a few jerky movements on either side of it, and as the horizontal motion of the paper was simultaneously going on, these vibrations of the pencil produced irregularities in the curve. With the McNaught indicator it was possible to get a smooth curve by the use of a strong spring, but then the diagram described was so small that it was of little practical value. Richards saw that a strong spring and a short stroke should be employed. He fulfilled these conditions and multiplied the piston movement at the pencil point four times by means of a system of levers. In this respect all modern designers have followed suit.

Although it is now close on fifty years since the Richards indicator first came before the public, it is to-day, in its improved form, the chief favourite with many experienced engineers for every-day use on engines running as fast as 120 or 140 revolutions per minute. Of course, many engines of this period run much faster than that, and then, with the Richards indicator, the old vibration objections crop up again, so that it, too, in turn, is being rejected in favour of newer and finer instruments. Prominent among these modern indicators are the Thompson, the Crosby, the Tabor and the McInnes-Dobbie. The pistons of these have strokes of about $\frac{3}{8}$in. or $\frac{1}{2}$in., while the vertical movement of the pencil is generally six times that amount. Their piston springs are all of the double-coil type. This enables the spring to exert its pressure equally at two points on opposite sides of the piston, instead of on one side only, as is the case with the single-coil spring.

The moving parts in the Thompson indicator are much lighter than those of Richards'. This improvement has been safely carried out owing to the neat arrangement of levers in the

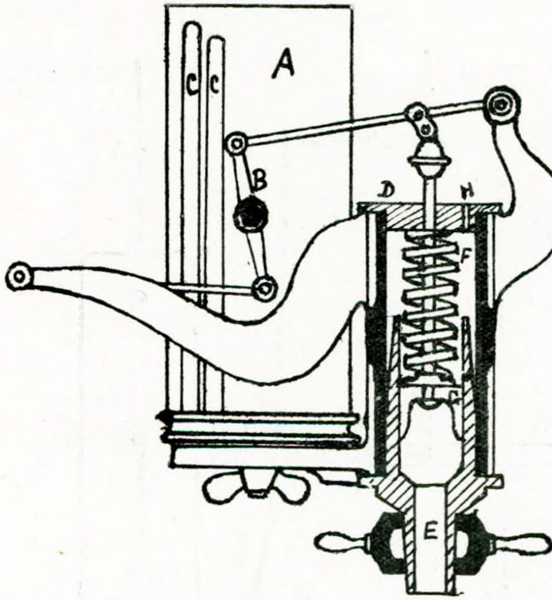

FIGURE 1.

RICHARDS' INDICATOR.

A. Revolving Drum.

B. Pencil Parallel Motion.

CC. Clips for attaching paper to Drum.

D. Cylinder Cover.

E. Steam Passage from Engine Cylinder.

F. Spring.

G. Piston.

H. Hole to allow of free escape of any steam leaking past piston.

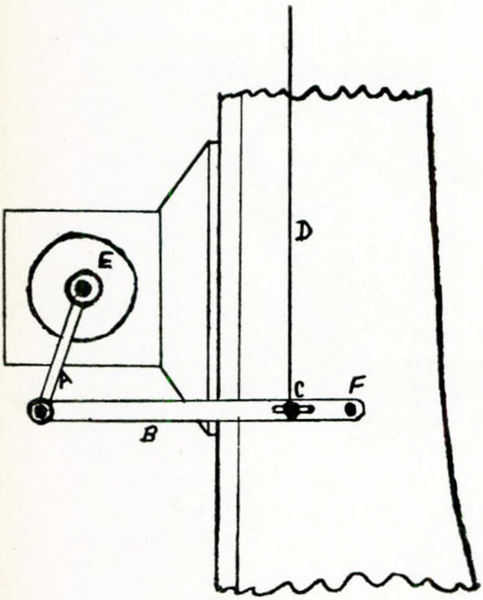

FIGURE 2.

A. Radius Link.
B. Indicator Driving Lever.
C. Driving Pin (fixed in lever slot).
D. Driving Cord.
E. Engine Crosshead.
F. Fulcrum pin (fixed to column) about which B swings.

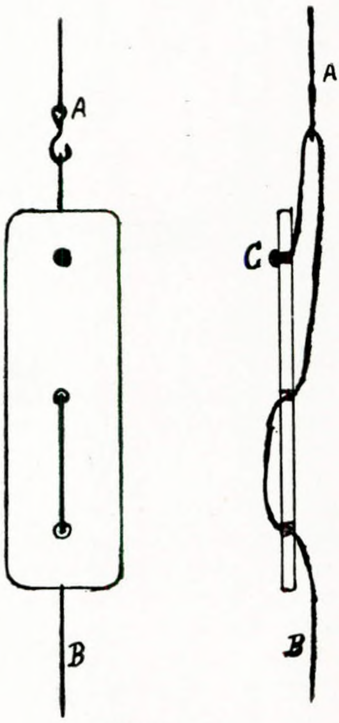

FIGURE 3.

A. Hook Connection to Indicator.
B. Connection to Driving Pin.
C. Knotted end of Cord.

former. Several modifications of this instrument are now on the market. For very high pressures it may be had with a very small piston area, while for specially high speeds a smaller size of rotating drum may be used.

The Crosby indicator has a very light and compact multiplying gear so that this instrument is specially adapted for high speeds. The double-coil spring carries a ball at its lower end, which fits into a socket at the top side of the piston ; this forms a very neat connexion and is much lighter than the usual brass collar arrangement.

In the Tabor indicator radius links have been done away with and a vertical plate with a curved slot in it acts as a guide. A small roller fixed to the pencil lever moves in this slot and the design is such that the line of motion of the pencil point is always parallel to the axis of the paper drum.

Up to the present time, as far as every-day use and ordinary wear and tear instruments go, Messrs. Dobbie, McInnes, Ltd., seem to have said the last word in indicator manufacture. In their latest designs the parallel motion gear and other moving parts have been reduced to the limit in weight consistent with strength and rigidity. The parts exposed to heat are sheathed in vulcanite—this enables the instrument to be handled much more comfortably. The piston spring is away from the cylinder and well-exposed to the temperature of the atmosphere ; as the strong springs used in this twentieth century are considerably weakened by having their temperatures raised, this change is, without doubt, a step in the right direction. Like a few other modern manufacturers this Company has inserted a strong, adjustable spiral spring inside the cylindrical drum in place of the volute spring introduced by McNaught many years ago. A case-hardened, practically non-expensive, steel piston, with a special arrangement, for lubricant and the accumulation of dirt, is fitted in this type of indicator. It possesses also a very large connexion to the engine cylinder—hence there is no excuse for the passages becoming choked up.

When the indicator is to be used it is generally screwed on to a three-way cock which is fixed to a pipe connecting the two ends of the engine cylinder. As has already been mentioned, the indicator barrel must move always "in step" with the engine piston ; hence the cross-head is the favourite part from which to borrow a motion for the former. Fig. 2 is an illustration of one of the commonest forms of reducing gear. The motion here imparted to the barrel is hardly an exact duplicate of that of the cross-head, but provided the radius link is fairly long and the driving cord not too short either, the error arising from the use of this motion may easily be neglected. The cord is connected to the driving pin as shown and thence to the indicator. It is adjusted to its proper length—so that the barrel rotates an equal amount on either side of the pencil—by means of a clip. A simple form of clip is shown at Fig. 3: it consists of a plate, generally of brass, with three holes in it. The cord is passed through the holes as illustrated and a hook on the end of the piece of cord attached to the barrel is slipped into this upper loop.

The indicator is generally heated through to begin with, then the three-way cock is opened to the atmosphere and the atmospheric line is described by the application of the pencil to the paper. The instrument is now connected to first one and then the other end of the cylinder and thus diagrams from the two sides are described. These "cards" show the work done during each of the two different strokes of the engine, or taken together, they tell the amount of work the prime mover is doing per revolution—hence the power is easily calculated.

If too great a "drop" of pressure is occurring between the boiler and the cylinder, the indicator may be applied to the steam chest or to some other part in the passage of the steam between the two first mentioned spaces, so that the position of throttling may be spotted and steps be taken to have things rectified. During the taking of a steam chest diagram the motion of the barrel should be exactly the same as when the instrument is being applied to the cylinder in order that the points of maximum and minimum pressure, etc., in the chest may be accurately noted. The indicator, of late years, has been used also to give diagrams off various types of pumps.

Many new types of indicators have lately been patented and brought into the market. Some of these are almost perfect instruments. Their chief departure from the old lines is that a beam of light, which is cast from a lamp by means of a system of mirrors on to the paper, moves up and down and shapes out the diagram. The engineer, however—at least the British engineer—delights more in things mechanical than in purely scientific arrangements, and that explains, perhaps, why we do not see these magic pencils of light, instead of those ordinary metallic points, focussed on the diagram paper in every large and important engine-room, both ashore and afloat.

So we see that the indicator, like its parent the steam engine, has had quite a varied life during the last few score years. Watt got it to slide along, McNaught made it go round, Richards made it go smoother and faster, and our experts of to-day are still attempting to accelerate its speed without increasing the momentum produced in the moving parts.

"ROCKLIGHT."