around the centre O, the force necessary to accelerate or retard it is always W H, or, in other words, equals the horizontal component of the centrifugal force due to an equal weight rotating in a circle.

This is what happens in the case of a weight such as a piston and crosshead actuated in a horizontal line by a connecting rod, as in Fig. 2; here the distance of the weight P from the centre of the stroke corresponds with the horizontal distance of the crank pin C from the centre O, and the force accelerating or retarding it is equal to C H when C O equals the centrifugal force which P would exert if moving on the path of C.

Since P in this case is moving entirely in a horizontal plane, it gives rise to no vertical forces whatever, and it is

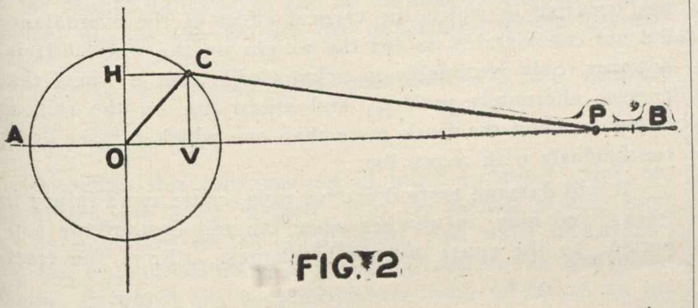

FIG. 2

this fact that introduces all the difficulties in connection with balancing an engine; before, however, discussing that question, the connecting rod must be referred to. It is evident that this has at one end a circular, and at the other a reciprocating movement, while between the ends, the motion of any part is of an intermediate nature; the result is the same as though part of its weight were concentrated at the crank pins and had a circular motion, while the remainder was concentrated at the crosshead and had a reciprocating motion.

In a paper read before the Northwest Railway Club, in 1893, I suggested that four-fifths of the weight of the back end should be taken at the crank pin, and the weight of the front end and one-fifth of the back end at the crosshead, figures that were obtained by calculations from two or three types of rod; this question was, however, treated in an exceedingly ingenious and scientific way in a paper read before the New York Railway Club, by Mr. R. A. Parke.

He developed an accurate method for obtaining the exact division of weights for any rod, and his results showed for modern types of rod that five-sixths of the weight of the back end of the rod should be considered as concentrated at the crank pin with reasonable accuracy. I would refer anyone interested in this subject to his paper, as it is a most interesting example of the application of a really difficult mathematical analysis, by which an absolutely simple method is deduced for obtaining correct results. I consider, however, for practical purposes, that five-sixths of the weight of the back end is sufficiently accurate, and that figure is used on the Canadian Pacific.

There is one more elementary statement to make, namely that a weight of W pounds at a radius 2r has the same effect as a weight of 2W pounds at a radius r; this follows immediately from the value of the centrifugal force $\frac{M V^2}{32.2r}$ for with the same number of revolutions V is proportional to r, so that for equal forces Mr must be a constant. For simplicity, therefore, all balance weights will be assumed to be placed at the same distance from the centre as the crank pin.

With these facts in mind, let Fig. 3 represent an ordinary engine, and let all the rotating weights be concentrated at the crank pin W, say 1,000 lbs.; let the reciprocating weights be concentrated at the crosshead at P, say 1,500 lbs. The rotating weight can be balanced by a weight of 1,000 pounds placed at C, diametrically opposite W on the other side of the centre; evidently, whatever be the position of the crank, the forces caused by the two weights are equal and opposite, and there is no resulting force to disturb the axle at O.

When, however, attempting to balance the 1,500 lbs. at P, by placing 1,500 lbs. at C, the condition is entirely different; the horizontal forces caused by the movement of P are exactly equal and opposite to those caused by the 1,500 lbs. at C, but as no vertical forces are caused by P's movement, the vertical forces caused by the movement of the 1,500 lbs. at C are left entirely unbalanced, and the effect is the same as though a weight of 1,500 lbs. at C were entirely unbalanced vertically.

Whatever weight then is introduced at C to balance the horizontal forces caused by P, causes vertical forces equal in amount to the extent by which those due to P are reduced; there is no possible combination by which this can be avoided, except by using crank pins that are not at right angles to each other.

For instance, if there were a crank pin at C and a connecting rod as shown by the dotted line C L, then if the weights at L and P were in substantially the same plane and equal, they would practically balance each other, as is the case with four-cylinder engines, which can be almost perfectly balanced without introducing any vertical forces, while three-cylinder engines can be balanced longtitudinally, but are, with respect to nosing, almost in the same class as two-cylinder engines. The latter are the engines now under consideration, and in their case the question of counterbalancing is a compromise.

If P is left unbalanced the engine is said to be badly balanced, if P is completely balanced the engine is said to be well balanced, but vertical forces are introduced which certainly may be injurious to track or bridges.

The extent of the force due to any unbalanced weight may be calculated at any speed, but is usually taken at 40

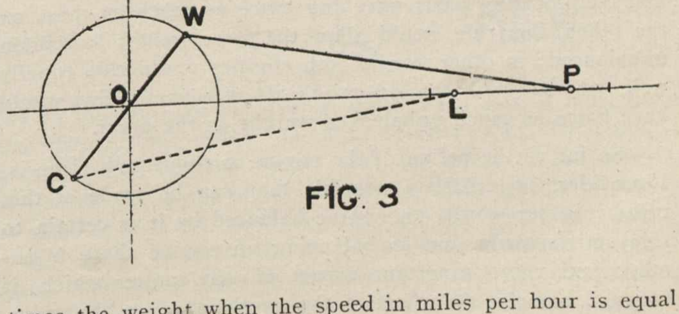

FIG. 3

times the weight when the speed in miles per hour is equal to the diameter of drivers in inches; it really varies with the stroke; and the exact figures are 38.5 for a 24" stroke, 41.7 for a 26", and 44.9 for a 28"; taking 40 for an approximate figure, 500 lbs. at C above that required to balance the rotating weights, or, as it is termed, "as overbalance," means a force of 20,000 lbs. acting upwards and downwards at each revolution, and while this seems a high figure, it is occasionally found.

The speed of 69 miles per hour is high for a 69" wheel, but it represents a possible condition, and it must be remembered that while the factor of 40 is not reached until that