speed for that size of wheel, that it increases with the square of the speed, so that it is not advisable to consider a lower speed.

Evidently, then, it is desirable to keep the overbalance as small as possible, and yet on the other hand the reciprocating parts must be partially balanced for the comfort of the men, and the various rules of counterbalancing have really indicated the nature of the compromise.

The rule most commonly used in America has been that recommended by the committee on the subject at the M.M. Convention in 1882, in which two-thirds of the reciprocating parts are balanced; this compromise has, on the whole, given very satisfactory results, and constituted a great advance on one of the methods given as an answer to the inquiry made by the committee, which was "to figure a little and then guess at it."

The two-thirds rule, however, is not necessarily satisfactory; it proves so in the majority of cases, because the relations between the weight on drivers, weight of engine, and reciprocating parts do not vary greatly in engines of ordinary types, but the first great advance was made when Mr. G. R. Henderson, in a report made to the Norfolk and Western Railway, in 1895, pointed out that the allowable weight of unbalanced reciprocating parts was a factor of the weight of the engine.

Assuming only, that the maximum speed is proportional to the diameter of the drivers, and that it is desired to construct engines that will be reasonably comfortable for the men at that speed; in other words, that will vibrate to the same amount, then evidently the disturbing forces, or the weights of the unbalanced parts, may vary in direct proportion to the weight of the engine.

Mr. Henderson showed that engines in which $\frac{1}{400}$ of the weight of the engine was unbalanced rode satisfactorily, and that $\frac{1}{360}$ can be left unbalanced without objectionable vibration; we have then in this rule a scientific method of determining the weight of reciprocating parts that may be left unbalanced, and yet allow the engine to ride reasonably well, which is applicable to engines of widely varying types; for instance, if two engines were of the same weight, but one had reciprocating parts weighing twice as much as those on the other, this rule would allow the same weight to remain unbalanced; in other words, both engines would ride equally well, whereas with the old two-thirds rule one engine would have twice as much unbalanced weight as the other.

So far as the action of the engine is concerned, there is, I consider, no criticism possible that can be made of this rule; in other words, an engine balanced by it is certain to ride satisfactorily, but in balancing an engine there is another and very important aspect of the matter which it ignores, namely, the effect of the overbalance on the track. This side of the question has often been referred to, and its effect discussed in a general way, but so far as I am aware, locomotive builders have never really established any rule limiting its amount, although they have recommended balanced compound engines or the utilization of the weight of the tender, which I shall refer to later. On the other hand, no maintenance of way engineer has, I believe, defined the limit of overbalance which he considers permissible, although he will cheerfully advocate none being used; neither is he able, except in extreme cases, to show any definite evidence of damage from this cause.

Taking, however, the maximum speed before referred to, an overbalance of 500 lbs. in a wheel carrying 20,000 lbs. causes the pressure between that wheel and the rail to vary from 40,000 lbs. when the overbalance is down to nothing when it is up, and any greater overbalance would tend to lift the wheel from the rail.

Testing plant experiments show that when the calculated effect of the overbalance exceds the weight on the wheel that it does actually leave the rail, and that there is a definite blow when it strikes it again.

I have analysed this action (see "American Engineer" for February, 1909), and have shown that this blow may, in extreme cases, be severe and sufficient to account for the damage that is occasionally met with; on the other hand, I do not believe that any case of repeated bending of rails has occurred in which the vertical effect of the overbalance did not considerably exceed the weight on the wheel. It is, however, only reasonable to acknowledge that a wheel that presses alternately nothing, and 40,000 lbs. on the rail, is going to effect the track more than one which presses down continuously with 20,000 lbs.

It will damage more defective rails, cause more injury to tracks, and may, in weather when the rail is unevenly supported, be the cause of rail breakages. From the track

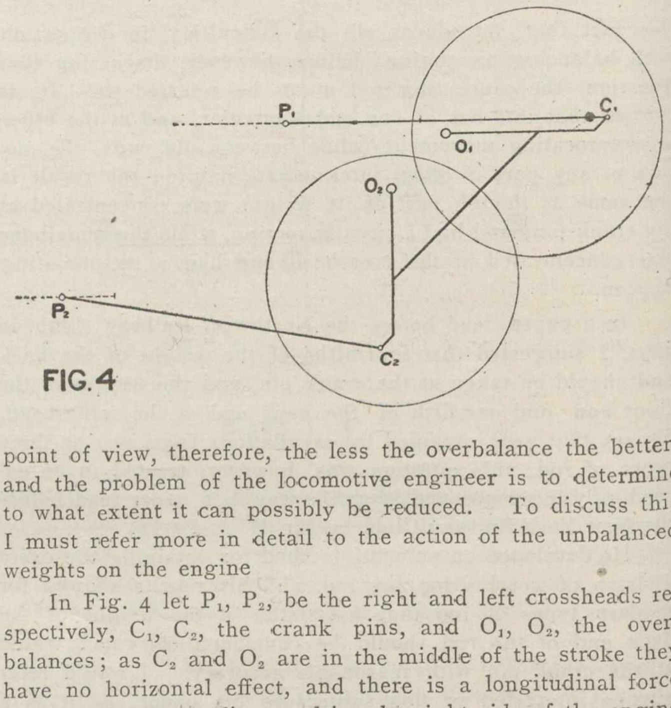

FIG. 4

point of view, therefore, the less the overbalance the better, and the problem of the locomotive engineer is to determine to what extent it can possibly be reduced. To discuss this I must refer more in detail to the action of the unbalanced weights on the engine

In Fig. 4 let P_1, P_2, be the right and left crossheads respectively, C_1, C_2, the crank pins, and O_1, O_2, the overbalances; as C_2 and O_2 are in the middle of the stroke they have no horizontal effect, and there is a longitudinal force equal to P_1—O_1 tending to drive the right side of the engine backward; as P_2 comes to the end of its backward stroke there is a similar force tending to draw the left side of the engine backward, and at that time the effect of P_1 and O_1 is nothing.

This action is repeated at the back of the stroke, so that the action of the unbalanced weight is to drive the engine backwards and forwards as a whole, and also to cause the ends of it to vibrate transversely; or, as it is usually called, "make it nose."

There are then two distinct actions of the unbalanced weight in an engine, which I will call the longitudinal and transverse movements; the latter you will agree, I believe, is not generally very noticeable, but on small 8-wheel engines it is objectionable when running at a high rate of speed.

Some years ago, when working on this subject, I noticed, as I dare say you have, that on the longer, heavier engines,