SEISMOMETRY AS APPLIED TO RAILWAY TRAINS.

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The following paper describes an instrumeut which has faithfully recorded the oscillatory movements of Railway Trains in Japan, in Europe, and twice across the American Continent. The reasons for bringing it to the notice of the members of the Seismological Society are numerous. Not only is it a useful outcome of Seismometrical work undertaken in this country, but for which work it might not yet have been designed, but it represents a type of instrument which may be employed to record earthquakes more severe than those with which we have hitherto been occustomed to deal.

My attention was first directed to the measurement of the oscillations of a train by Mr. John McDonald, of the Locomotive Department, at Shimbashi, Tokyo, who had tried to record the oscillatory movements of a locomotive by observing the movements of a liquid in a bottle. Subsequently I learnt that the same problem had been attempted by engineers in America and Europe, but for reasons very similar to those which led to the abandonment of the earlier forms of seismoscopes by the members of this society, this work appears to have terminated without success. Many experiments were made, and for permission to make then my thanks are due to Mr. F. H. Trevithick, M.I.C.E., and other officials connected with the Tokyo-Yokohama Railway. It was soon found that ordinary earthquake instruments were too sensitive, their working being interfered with by the suddenness of the jolts to which they were subjected and by their sensibility to changes in inclination.

The apparatus to be employed on a locomotive or in a train required considerable stability and at the same time, so that it could be used with convenience, it was necessary that it should be compact. Such instruments have been designed, and although they involve the same principles as many seismographs they could not be employed for recording ordinary earthquakes. Farther, on account of their stability, they must not be confounded with any apparatus of the nature of an ordinary pendulum, the movements of which are likely from time to time to synchronize with that of a train and record excessive motion when the actual range of motion may really have been very small.

The following is a description of an instrument:—

The Instrument.

The instrument consists of three parts *A*, *B*, *C*. The part *A* records the up-and-down motion, the part *B* side-motion, and the part *C* the fore-and-aft motion. These three components of movement are respectively named the vertical, transverse, and longitudinal, and according to the construction of the machine, they may be written on separte bands of paper which are moved continuously by clockwork *D*, or they may be written side by side on one broad band of paper moving from drum *E*, over *F*, which is driven by clock-work and coiled up on *G*.

The apparatus *A*, for recording vertical motion, consists of a spring coiled in a box, *a*, as in an ordinary clock; clamped to this box and extending horizontally, there is a lever *b* carrying a weight, the moment of which is so adjusted that the box with its spring is prevented from unwinding. When this arrangement is moved quickly up and down the weight by its inertia tends to remain at rest, and the box slightly turns first in one direction and then in the other. These angular deviations of the box are recorded by mean of an index, *c*, carrying a pencil which is attached to the box and stands up vertically, the pencil resting on the moving paper. By altering the length of this index, or by winding up or unwinding the coiled spring and shifting the weight along the lever, the multiplication of the instrument may be varied. The instrument can therefore be used on a locomotive where movement is great or in a carriage where it is small.

For an upward movement, that is when the weight is relatively lowered, the moment of the weight is decreased, but as the spring slightly coils, there is a slight tendency to bring the weight and its lever back to the horizontal position. In some instruments this has been overcome by increasing the moment of the weight by means of a small compensating spring, which, when the weight is depressed, acts in a direction contrary to that of the mainspring. As the rate at which the weight tends to rise is, however, very slow, compensation to obtain absolute neutrality is not required.

For a downward movement of the apparatus, or an upward motion of the weight, the weakening of the spring by uncoiling is practically equal to the decrease in the moment of the weight, and the weight therefore remains at rest. The general result of this is that for either up or down movements the weight is practically at rest, and the pointer not only follows each vertical movement of the train, but its records may be used to measure them.

The apparatus *B*, which is used to record the transverse motion, is practically the same as that which is used for the longitudinal motion, the two pieces of apparatus being placed at right angles to each other. A description of one of them will therefore be sufficient.

A solid cylinder, *d*, of metal is pivotted on its edge, forming with a given mass of material the shortest period pendulum that can be constructed. Immediately beneath this, and in a parallel position, there is a second cylinder, *e*, which relatively to the upper cylinder is pivotted on its lower edge. These two pendulums are connected together by sliding joints *f*, so that they are not free to move independently. The sizes of these two pendulums are so proportioned that if they are displaced to the right or left from their normal position, there is no tendency—or only a slight tendency—to return to that position. The moment of one is balanced by the moment of the other. When, therefore, the frame of these pendulums is rapidly moved back and forth there is a line in the system which practically remains at rest. Projecting upwards from the top of the upper pendulum there is an index, *g*, and a pencil which records each back and forth moment relatively to the fixed line in the system.

In each of the instruments now described, it will be seen that we have practically neutral equilibrium, and that movements are recorded and measured from steady points. In all other instruments which have been designed for recording railway motion great stability has been given to the suspended masses, and they have been quick vibrators, the result of which has been that the motions recorded have been compounded with the natural period or swinging of the pendulums employed.

Such instruments are more closely related to seismoscopes than seismometers.

The Diagrams.

I will now describe the diagrams which have obtained and the nature of the information which they furnish.

1. As Train Timers.—Inasmuch as vibrations only occur while a train is in motion, the portions of a diagram when no vibrations are recorded indicate the time that a train has stopped. The length of these blank spaces show, in minutes or fractions of a minute, the duration of stoppages. By inspecting a diagram we can determine how long a train was on a given journey, whether it stopped at stations or signals, and from the length of

* Paper read before the British Association.

the diagram on a known line it can be seen where the train went quickly and where it went slowly. The train is automatically timed. As the distances between stations are known it is an easy matter to determine average speeds. The speed at any position of a journey requires a mark to be made on the moving band of paper, say at every hundred revoluntions a wheel of the carriage in which the machine is placed. This is done by a simple contrivance now being applied to instruments in Japan. When passing curves, if the train is running at a speed exactly suited to the cant of the rails the diagram is written to the right and left of a central line. If it is going too slow, the diagram is written on the left of such a line, but if it is going too fast, or, in other words, if the speed is dangerous, the rollers are thrown outwards and the diagram is written on the right of the central line.

Grades are indicated by the tipping of the fore and aft rollers, and therefore they are shown by deviation to the right or left of the path traced by the writer when on a level track.

2. AS THE RECORDER OF THE CONDITION OF A LINE.—No matter what the speed at which the train is travelling, or in what character of carriage it is placed, any abnormal motions show themselves as excrescences on the general diagram. For instance, the jolts at facing points are particularly well marked. Irregularities due to variations in gauge, want of ballast, springy portions of the road, faults in ties or sleepers, irregular motions on bridges,—are all faithfully recorded. Sometimes movements are recorded which cannot be felt by passengers. For example, in crossing the Kawasaki Bridge, on the Tokio-Yokohama line, it was noticed that on the down track on or about the second span there was always one large vertical movement recorded. The bridge, which is of iron, consists of a number of 100 ft. and a long series of 40 ft. spans. The movement, inasmuch as it could not be felt, must have been of the nature of an easy spring-like bending.*

* The cause of this movement has been discovered and the necessary repairs made.

From the long series of diagrams which have been taken in Japan, America, and in England, it is clear that the diagrams give a report on the state of a line, and if these are repeated at intervals they show if changes are taking place.

3. As a Means of Testing Locomotives and Carriages.—For testing locomotives and carriages they should be run under similar conditions over the same line. The diagrams are drawn upon a band of paper running at a rate of about 1 inch per second. The result of this is that the vibrations are drawn out as a series of successive waves; with this diagram before us, we can measure not only the range of motion of any given wave, but also the time taken to describe this wave. Having measured these quantities, it is an easy matter to calculate the suddenness with which each movement commences to be made, and this is a quantity which may be taken as a measure of the jerks which are experienced. For example, the following two sketches are small portions of reduced diagrams of fore and aft motion taken from two different locomotives run over the same line at a similar speed, and under the same conditions respecting "notching," &c. These particular locomotives have the same dimensions, and one drawing, *excepting details relating to balancing*, represents both engines.

Fig. 1.

Fig. 2.

In the case of No. 1 we see that the range of motion, half of which, or the amplitude of motion which we call r, has been three milimetres. The time taken for a complete vibration, or the period which we call, T, has been .25 seconds. If a equals the maximum acceleration per sec. per sec., we find that

$$a = \frac{4\pi^2 r}{T} = 480 \text{ milimetres per sec. per sec.}$$

In the case of No. 2, the maximum acceleration only equals about 200 milimetres per sec.

These quantities are measure of the jerkiness of the engine. Engine No. 1, where there is a great difference between the moment of the balance weight and what would be the moment of the reciprocating parts if they were hung on the crank-pin, pulls its load by a series of jerks or tugs, whereas in engine No. 2, where the above moments are more nearly equal, the jerks or tugs are relatively small. Engine No. 1 is moving a load in an uneconomical way, and *that this is the case is seen by a reference to the coal accounts.*

For economy in fuel it would appear that diagrams of fore-and-aft motion ought to be kept small.

In a similar manner a Pullman car may be compared with an ordinary car. In the one case we have a large range of motion and a long period, while in the latter a small range and a short period.

Types of Instruments.

1. For Timing Trains and giving General Information respecting a Line.—This consists of a somewhat peculiarly constructed clock driving a narrow band of paper at the rate of 1 ft. per hour. On this band only the vertical motion is written, but inasmuch as lateral jerks have a vertical component these also are recorded.

2. For giving Detailed Information respecting a Line.—Here a clock similar to that in No. 1 is used. It drives a broad band of paper on which all components of motion are recorded. In addition to timing a train and showing irregularities on a line, it indicates curves, grades, and shows when brakes are applied, &c.

3. For Testing Locomotives and Carriages.—This only differs from No. 2 in the clockwork, which drives a drum at a high speed for a short interval of time.