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**“On the Vibratory Movements of Locomotives, and on
Timing Trains and Testing Railway-Tracks.”**

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THIS Paper contains an account of certain instruments which have been designed to register the oscillations and vibrations of trains, to give an automatic record of the run, and information as to the nature of the track passed over.

The first experiments in Japan were made by Mr. McDonald, who investigated the vibrations of a locomotive by observing the movements of a liquid in a bottle. This led to the devising of a number of instruments of various forms, commencing with short-period pendulums and modified forms of seismographs, and ending with the apparatus described in this Paper.

Permission to make the necessary experiments was kindly given by Mr. F. H. Trevithick, M. Inst. C.E., the Locomotive Superintendent of the Northern Division of the Imperial Japanese Railways.

Ordinary earthquake instruments were found to be too sensitive, their working being interfered with partly by the suddenness of the jolts to which they were subjected, and partly because they are affected by changes in inclination. After a few experiments it was clear that, especially for horizontal movements, apparatus with considerable stability was required, and that it must be compact and portable. The form adopted, although involving the same principle as many seismographs, is not suitable for recording earthquakes. It is novel as applied to the vibrations of rolling stock; and is at the same time so different in its construction from any earthquake machine, that the Authors consider it suggestive of new arrangements which might be introduced into seismometry.

VERTICAL MOTION.

The vertical movements are recorded by the apparatus shown in Plate 2, Figs. 1 and 2. A is a clock-spring, kept coiled on its axle by the lever BC, carrying the weight W. When W is depressed and then set free, it returns to its normal position, but when it is raised it tends to continue its upward motion. In order to counteract this, a small spring D may be attached to the lever E, which is so adjusted as to bring the weight back to its normal position. The spring is wound by turning the drum GG, to which one end is attached, the other end being secured to the fixed axle BB. The result of this combination is that, for up and down movements of BB, some point in W remains at rest. A pointer, pd , is attached to the spring-drum GG, at right-angles to the lever BC; and as the instrument moves up and down, this pointer moves to the left and right, giving an enlarged or diminished representation of the vertical movements, according to the distance of the pointer p and the weight W from the centre B.

HORIZONTAL MOTION.

Horizontal vibrations are recorded by means of pointers attached to two pendulums, each of which is only free to move in one plane, the two planes of motion being at right-angles to each other. The simplest form of either pendulum is shown in Figs. 3 and 4, where A is a metallic cylinder, free to swing on pivots cc on its upper edge. For a quick displacement of cc to the right or left in Fig. 3, or at right angles to the paper in Fig. 4, some line, ii in A, may be regarded as the instantaneous axis of rotation relative to cc , which is the axis of percussion.

In Fig. 3, while c is moved to the right or left, a point i in the instantaneous axis may be considered as being practically at rest; and therefore a multiplied representation of the motion of c is given at the upper end of the pointer cd , which, by means of the pin p (Fig. 4) sliding in guides, writes the movements of the pointer d on the surface S. The motions of A are made approximately dead-beat by giving a certain frictional resistance to the movements of the pointers d . This may be done by loading the writing needle p . Another method of controlling the free swing of the pendulum, adopted in the instruments constructed, is to connect the pendulum A, by a sliding joint, with a second pendulum B, as shown in Fig. 5.

For convenience of illustration, the two pendulums are here

represented as two flat bars, A and B, one pivoted at *c* and the other at *d*. They are connected by the fork *f*, attached to B, which can slide on the pin *e* projecting from A.

If the frame carrying the two pendulums is displaced to the right or to the left—say to the left, as shown by the dotted lines—inasmuch as the lower pendulum tends to fall towards the right in the direction of the arrow *g*, and the upper pendulum tends to fall towards the left in the direction of the arrow *h*, it is clear that these two pendulums may be so proportioned or suspended that the point *e* may, relative to *d* or *c*, be a centre of oscillation, and therefore the point *e* may remain practically at rest.

A more elaborate way of constructing the instrument, and one which will avoid the necessity of calculations as to the position of the instantaneous axis, is shown in Fig. 6. Here the weight A is pivoted on its axis *ii*, in the frame B, which in turn is pivoted at *cc*, in the fixed frame C; *cd* is the multiplying pointer. In this case *ii* is the instantaneous axis, which practically remains at rest while the frame C moves backwards and forwards.

It will be observed that these forms of the instrument all write with their pointers placed vertically, but by tilting the apparatus they might be made to write in any plane, even if they are placed horizontally.

Fig. 7, Plate 2, shows the instruments for vertical and for two horizontal motions at right-angles to each other, mounted in position, ready to give diagrams on a moving surface. A is an ordinary clock driving the drum B, on which the movements of the three pointers *c*, *d*, *e*, are recorded. The roller B may be covered with metallic or with ordinary paper, or may be a smoked surface, the pointers being strips of metal, pencils or pens. The apparatus H is on the principle shown in Fig. 5; but the pendulums, instead of being flat bars, are cylinders. It is represented on a larger scale in Fig. 8. The apparatus for recording longitudinal motion, I, Fig. 7, is similar to H, but so placed that the axes of its cylinders are at right angles to those of H; the pointer *e* being caused to write in the same plane as *d* by the intervention of a bell-crank lever, *k*, shown underneath. In Fig. 7, *c*, *d*, and *e* are strips of brass, writing on the cylinder B, which is covered with metallic paper. Experience has, however, proved that a brass pointer, after several hours' wear, either ceases to write, or makes only a faint mark, and for this reason metallic paper and brass pointers have now been abandoned for ordinary paper and black-lead pencils.

To obtain a continuous record, a long band of paper, rolled on a

cylinder as in the Gray-Milne seismograph, is pulled over a drum corresponding to B, Fig. 7, and wound up on another which is driven by its own system of clockwork.

The following types of instruments have been constructed:—

1. For timing trains, and giving general information respecting the condition of a line. This consists of the double-clock arrangement just described, driving a continuous band of paper about $2\frac{1}{4}$ inches broad, at the rate of 1 foot per hour. On this band only the vertical motion is written; but inasmuch as lateral jerks have usually a vertical component, these also are in part recorded.

2. For giving detailed information respecting a line. In this instrument clocks similar to those of No. 1 are employed, but the band of paper driven by them is broader, and all the components of the motion are recorded upon it. In addition to timing a train, and showing irregularities on a line, this instrument indicates curves and gradients, shows when brakes are applied, &c.

3. For testing locomotives and carriages. This only differs from No. 2 in the clockwork, which is arranged to drive the paper at the rate of about 1 inch per second for a short interval of time.

MEASUREMENT OF DIAGRAMS.

The diagrams exhibited only profess to give the absolute motion of a locomotive within short ranges.

For vertical motions up to 25 millimetres (1 inch) the diagram may be directly measured, in order to determine the vertical motion of the engine. Longitudinal and transverse motions can only be read as absolute measures up to a range of about 6 millimetres, or $\frac{1}{4}$ inch. After that they may be calculated with the assistance of the following Table, in which the measurements are in millimetres:—

—	Recorded on Diagram.	Actual motion.
Longitudinal motion . . .	5 mms.	5 mms.
	12 „	25 „
	15 „	35 „
Transverse motion	5 mms.	5 mms.
	10 „	20 „
	15 „	30 „

These figures are the result of the following experiment. The instrument was placed on a small table that could be easily shaken in any direction. The record of this shaking, as given by the apparatus, was compared with a second record made by a pointer, fixed to the table itself, and writing on a sheet of paper placed on a neighbouring table which was at rest. So long as the range of motion was not more than 6 or 7 millimetres ($\frac{1}{4}$ inch), the vibration registered by the instrument was practically equal to that of the table. For motions greater than this, it was always less than that shown upon the fixed table; the relation between the two measurements being approximately that given in the above Table. For most purposes, however, it is not necessary to determine the absolute amplitude of the oscillations.

LOCOMOTIVES AND CARRIAGES WHICH HAVE BEEN TESTED.

The only vehicles of which the Authors have details and drawings are certain locomotives in Japan. Diagrams have, however, been taken on many locomotives whilst crossing the United States, and also in Pullman cars. In England diagrams have been taken in carriages running on the London and North-Western, the Caledonian, the Great Northern, the South-Eastern, the Metropolitan railways, &c. The longest that has been obtained as yet, shows the motion of a carriage between New York and San Francisco, a distance of about 3,300 miles.¹ Between New York and Chicago the diagram was taken in a Pullman car on the Pennsylvania Central. From Chicago to Omaha the journey was made on the Burlington and Quincy Railroad, and from Omaha to the shores of the Pacific, on the Central Pacific line.

A brief description of fifty-eight locomotives now in Japan, is given in the Appendix, and Fig. 12, Plate 2, is an outline drawing of one of those from which diagrams have been taken. As the indications of the vibration-recorder are in great measure connected with the balancing of the engines, the weights of reciprocating parts and balance-weights are given in detail, together with the equivalent balance-weight, which was determined experimentally as follows: a pair of wheels, with their balance-weights and crank-pins, were placed on level rails; a large round steel ring was then hung on the crank-pin, and from this weights were suspended until a balance was obtained

¹ The original of this diagram was exhibited.

and the wheels would rest in any position. This weight hung on the crank-pin is what is here called the equivalent balance-weight. In some engines it will be seen that the sum of these weights on one side of an engine is much less than the sum of the weights of the reciprocating parts, while in other engines these two quantities are nearly equal. It will be shown that when these quantities are nearly equal—that is to say, when only the horizontal component of the energy due to the movement of the reciprocating parts is balanced—the diagrams for longitudinal motion are small.

Table I, Appendix, gives the relation between the balance weights and the equivalent balance.

THE TOKYO-YOKOHAMA LINE.

Most of the diagrams were taken on locomotives running on the line between Tokyo and Yokohama, a distance of $17\frac{3}{4}$ miles.

The following is a brief description of the track, commencing at the Shinbashi station in Tokyo. There are two lines of rails, and the gauge is 3 feet 6 inches.

Shinbashi to Shinagawa ($3\frac{1}{4}$ miles; time, eight minutes).—The line runs round the edge of the bay on an embankment, on either side of which, up to this year, the tide rose. At the present time, however, the greater portion of the water-area on the land side has been filled up. The ground beneath this embankment, being the mud of the bay, is probably very soft. There are nine bridges or culverts (Nos. 1, 2, 3, 4, 5, 6, 7, 8, and 9), the largest girders having a 44-foot span. No. 9 bridge is overhead. There are three small curves, from 40 to 44 chains radius. With the exception of slight rises to the bridges, this section of the line is practically flat.

Shinagawa to Omori ($2\frac{3}{4}$ miles; time, nine minutes).—On passing out of Shinagawa station, there is a cutting and a rise of $\frac{1}{300}$. Shortly after this there is a rise of $\frac{1}{100}$, and thence a gentle descent of $\frac{1}{300}$ down to the Omori station. There are three small curves of 180, 40, and 40 chains radius, and three small bridges, Nos. 10, 11, and 12. No. 10 is a 30-foot span; No. 11 is a 56-foot span; No. 12 is a 15-foot span.

Omori to Kawasaki ($4\frac{1}{4}$ miles; time, twelve minutes).—On this section, with the exception of a rise of $\frac{1}{100}$, and a descent of $\frac{1}{168}$ to the Kawasaki bridge, the line is practically level. There are three small curves—one of 40 chains, one of 60 chains leading to

the bridge, and one of 40 chains leading off the bridge. There are three bridges, Nos. 13, 14, and 15, the first of which consists of three 16-foot spans; the second, which is the waterway to, and continuous with, the Kawasaki bridge, of twenty-four 40-foot spans; and the third is the bridge made up of six 100-foot Warren girders, designed by Dr. William Pole, F.R.S.

Kawasaki to Tsurumi (2 miles; time, eight minutes).—This line, with the exception of slight rises at the bridges, is practically level. There is one 32-chain curve, and one bridge (No. 16), consisting of six spans of 42 feet 8 inches.

Tsurumi to Kanagawa (4 miles; time, 12 minutes).—With the exception of three small inclines of $\frac{1}{200}$, the line is practically level. Outside the station there is a 40-chain curve. About half-way there are three other 40-chain curves, continuous with each other, so as to form an S. A fourth 40-chain curve is at a cutting just entering the Kanagawa station. There are three bridges (Nos. 17, 18, and 19). No. 17 is a 48-foot span; No. 18 is 47-foot 6-inch span; and No. 19, which is over the line, consists of two 16-foot spans. From Omori station to a point about half-way between Tsurumi and Kanagawa, the line runs across the delta of the Kanagawa River.

Kanagawa to Yokohama ($1\frac{1}{2}$ mile; time, six minutes).—Here the line, which is practically level, runs for a considerable distance on made ground round the edge of the bay, there being water on both sides of the line. There are three bridges (Nos. 20, 21, and 22). No. 20 consists of two 32-foot 3-inch spans; No. 21 of three 20-foot spans, and No. 22 of two 20-foot spans. There is one 40-chain curve.

The distances given are only approximate, and the time includes stoppages. The greatest speed between stations is about 25 miles per hour.

The diagram of vertical motion (Fig. 9), taken on locomotive No. 131, running on the line from Shinbashi to Kanagawa, shows that there is a relationship between the character of the line and the recorded movements. Soft ground can be distinguished from hard ground; while the effects of bridges and culverts have been indicated. On this line, which is remarkable for its solidity, this diagram is repeated on all the locomotives, the variations in range of motion, at different points along the line, being reproduced in similar proportion.

THE DIAGRAMS.

All diagrams on the same line show the same characteristics. For example, a diagram of vertical motion taken on March 14th, on engine No. 129, a reproduction of which is shown in Fig. 10, and which may be compared with Fig. 9, shows that after leaving Shinbashi and as Shinagawa is approached, the vibrations grow larger and larger. In fact they are larger than on any other portion of the line, and notably larger than between Shinagawa and the next station. This may be explained by the fact that this portion of the track rests on the mud of Tokyo Bay, and is therefore soft and yielding. Here and there a sudden increase in the size of the diagram may be observed, as, for instance, at the third minute after starting. This particular twitch in the motion of the pointer occurs at one of the culverts, but the cause of it has not been determined. Judging from the diagram, it appears that the train did not leave Shinagawa until 1.41, whereas it ought to have left at 1.39, that is to say, two minutes were lost at this station. From Shinagawa five and a half minutes were required to climb the incline, before descending to Omori, which is marked by the largeness of the diagram. At Omori there was a stoppage of a minute and a half, whereas, had the train kept schedule time, it should have been one minute only. Between Omori and Kawasaki there are several irregularities in the diagram, indicating soft places in the track. One of these occurs at twenty-seven and a half minutes after starting, and is probably on one of the culverts; or it may have been a sleeper that required packing, such marks being often made upon the diagrams when passing a gang of workmen engaged in repairs. The most important mark, however, occurs in the second span of the 40-foot girders, forming the waterway leading up to the large bridge at Kawasaki. This occurs regularly in all the diagrams, two and a half minutes before running into Kawasaki station. The whole of the waterway has been examined by a staff of workmen who knew nothing of the diagrams, and they reported that a sleeper on the second span of the down-track, when a train passed, yielded twice as much as any of the other sleepers. Between Kawasaki and Tsurumi, with the exception of one or two soft places, there is nothing remarkable; but between Tsurumi and Kanagawa, especially at certain points, the diagram is rather larger; and at forty-six and a half minutes after starting it is nearly as large as

it is on the Kawasaki Bridge. It is evident that there is here a soft place that requires attention. By examining the indications of the instrument along this section of the line, it may be seen that abnormal movements take place at the entrance to several of the culverts. From Kanagawa to Yokohama the track appears to be firm and solid, with perhaps one exception at a point three minutes after leaving Kanagawa. Yokohama is reached in fifty-nine minutes, whereas it ought to have been reached in fifty-five minutes, so that there has been a loss of four minutes on the journey. Where two and a half minutes were lost has already been pointed out, and the remaining one minute and a half may be accounted for on a close examination of the diagram. Information respecting loss of time and stoppages may, of course, be equally well obtained from the record of transverse or longitudinal motion.

Fig. 9 is a diagram of the same track, taken on engine No. 131. It shows the same general features as the one described.

The Tokyo-Yokohama Railway is probably as solidly built as any line, but still it exhibits irregularities. On nearly all the railroads in America and England, on which the instrument has been tried, irregularities are more numerous.

The longitudinal motion is the one which most clearly shows differences in balancing. For instance, the size of diagrams taken with an engine of type A, compared with those given by one of type B, has been as 6 to 27. Again, with No. 135 and No. 129 the longitudinal motion was 5 millimetres; with No. 90 it was 7 millimetres, and with No. 94, 6 millimetres; these engines were of class 141, type A. On the same track, with a similar load, No. 137, an engine of the same class, type B, twice gave a diagram of 10 millimetres. In all instances these locomotives have been run under similar conditions respecting speed, notching, &c. A striking feature in the diagram of longitudinal motion is that it clearly indicates ascents and descents, by deviating to the right and left of a median line. This is illustrated by Fig. 13, which represents part of the American diagram.

Curves are marked in a similar manner by the portion of the instrument recording transverse motion (Fig. 13).

With the aid of this description the remaining diagrams shown in Fig. 11, *a, b, c, d, e, f, g*, will be readily understood. It must not be overlooked that, on the same line, each carriage or locomotive will produce the type of diagram peculiar to itself; the irregularities on a line showing as excrescences upon it. Further, because the motion in a Pullman is greater than in an ordinary

carriage, it must not be concluded that the latter is the better. Whether a carriage is dangerous or uncomfortable, depends upon what may be called its "jerkiness," a quantity dependent not only upon the range, but also upon the period of the motion.

ON THE CONSUMPTION OF COAL AND OIL.

The observation that certain locomotives gave a larger longitudinal diagram than others, indicating that the work was done by a series of jerks, rather than by a steady pull, suggested the idea that such engines were not exerting their power in an economical manner, and were consequently consuming more fuel than those which moved uniformly. To test this, the Authors examined several Tables showing the consumption of coal and oil on certain sections of the Imperial Japanese Railways. The results, for locomotives of similar construction (Plate 2, Fig. 12), on which diagrams have been taken, are given in Table II, Appendix.

From an examination of this Table, it appears that the engines of type A have always burnt less coal than those of type B; and when both classes of these locomotives have been doing similar work on the same line, the difference in favour of Type A has been, in one instance, as much as 4.04 lbs. of coal per mile, which means a saving of about 14 per cent. The only difference between these two classes of locomotives appears to be in their balancing. (See diagram of wheels in Fig. 12a.)

The engines which used the least coal per mile, although their mileage has been great, have been those in which the difference between the weight of the reciprocating parts and the equivalent balance has been small; for instance, with locomotives No. 9 and No. 11, where the difference is only 3 lbs., the average consumption of coal has been about 16 lbs. per mile. (See Table III, Appendix.) On the contrary in engines No. 102 and No. 104, where the difference is 566 lbs., the consumption of coal has been on the average about 39.4 lbs. per mile. With a difference of 353 lbs., as in engine No. 93, the consumption of coal has been on the average about 34.2 lbs. per mile, and generally the more nearly the weight of the reciprocating parts approaches that of the equivalent balance, other conditions being equal, the less fuel appears to have been consumed.

A similar result was found with regard to the quantity of oil required. It should, however, be noted that the only fair tests are

those between engines of the same class running under the same conditions, which is only the case in the instances first cited.

WEAR OF TIRES.

It occurred to the Authors that engines yielding different diagrams might show a difference in the wear of their tires. The few engines which have been running sufficiently long to require re-tiring, belong to No. 9 class and No. 13 class.

Comparing together these two classes of engines it was found that with engines of No. 13 class, where the reciprocating parts on either side are 70 lbs. heavier than the moment of the balance weight, 1 inch of tire was destroyed in runs varying between 156,039 and 244,806 miles. This is equivalent to wearing away $1\frac{1}{4}$ inch in from 195,048 and 306,007 miles.

Engines of No. 9 class, in which the weight of the reciprocating parts on either side is $2\frac{1}{2}$ lbs. lighter than the moment of the balance weight, so that these two quantities may be considered practically equal, were found to have worn away $1\frac{1}{4}$ inch of their tires in running from 271,299 to 328,927 miles, that is to say, from 22,920 to 76,251 miles farther than engines of No. 13 class.

These comparisons apparently indicate that these engines which run farther without steam, and which give a small diagram for longitudinal motion do not wear out their tires so rapidly as others. The Authors do not, however, lay particular stress upon these observations because the data on which they have founded their conclusions are extremely meagre, and also because it would seem that the class of engine where the vertical component of energy due to rotation is unbalanced, ought to be the class in which the greatest wear should be found.

CONCLUSIONS.

Amongst other things which the vibration-recorder accomplishes the following appear to be of importance :

1. All the diagrams show variations in the speed of a train, as for instance, in ascending or descending an incline, or when approaching or leaving a station. They show on what part of a journey time was gained and where it was lost.

Stoppages, whether at stations, at signals, or at other places are clearly indicated, and the duration of such stoppages is accurately

recorded. As the distances between stations are known it is an easy matter to determine average speeds. Information of this description may possibly be of value to those who have to deal with the management of traffic.

2. The instrument may also be useful to engineers whose duty it is to inspect lines. At curves the writing point for transverse motion is thrown to the right or to the left of a central line. Curves are therefore indicated by a characteristic deviation of the diagram (Fig. 13). Variations due to carelessness on the part of the plate-layers are recorded.

Ascents and descents and even slight variations in grading are clearly shown by the pointer for longitudinal motion writing to the right or to the left of the line it would describe when in its normal position (Fig. 13).

Lastly, what is perhaps of the greatest importance, faults in sleepers, irregular yieldings on bridges, soft portions of the track, and other imperfections are definitely marked. For example, it has been shown that on the Shinbashi-Yokohama Railroad the diagram for vertical motion for the first $3\frac{1}{4}$ miles is always greater than it is on the rest of the track, indicating that that portion of the road-bed is more spongy than the rest (Fig. 9).

At the entrance to the Kawasaki Bridge, on the second span of the down-track, Mr. McDonald observed that the vertical pointer always made a sudden movement of twice the usual amplitude. Here the line runs on 40-foot girders. At this place it was found that when a train passed, the sleepers yielded about $\frac{1}{2}$ inch, while the sleepers on the other spans only yielded $\frac{1}{4}$ inch. The Authors would draw special attention to this particular fault because it could not be seen, and on account of the easy spring-like yielding it could not be felt; it was discovered by the instrument, and its existence has been announced every time a diagram has been taken on a passing train. That there is an abnormal yielding at the entrance to several other bridges on the Shinbashi-Yokohama line, and at several places along the track, has also been indicated by this instrument. Whether spring-like yieldings, which probably exist on many bridges, are dangerous, is a matter for engineers to decide.

An engineer with one of these diagrams before him, may, if he has familiarized himself with the use of the instrument, form a fair idea as to the state of the line, and by taking fresh ones at intervals he may at once detect any changes in the permanent way.

3. The vibration-recorder is also capable of furnishing infor-

mation of value with regard to the manner in which a locomotive should be balanced.

When the moment of the balance-weights is small, relative to what would be the moment if the weights of the reciprocating parts were hung on the crank-pin, the longitudinal motions are markedly great, whereas when these moments are about equal, the longitudinal motions are small. The transverse and vertical motions are not affected to so great an extent.

Improper balancing may lead to swaying or "nosing" of a locomotive, which in turn has led to derailment. It has often been pointed out that at each revolution of a driving-wheel there is a sudden stress, described as a "blow" upon the rail, the magnitude of which varies with the nature of the balancing. It is supposed that these suddenly applied forces result in a wear of tires and rails, and cause undesirable and possibly dangerous vibrations in bridge-work.¹

The diagrams for longitudinal and vertical motion may be used in measuring these so-called "blows." When longitudinal motion is great, it indicates that the locomotive is doing its work by a series of jerks or impulses, which in all probability mean that force is being expended in an uneconomical manner; that such is the case is further shown by the fact that locomotives with a pronounced longitudinal movement burn more coal per mile than those of which the longitudinal motion is small. The same diagrams apparently show when there is a waste of oil, or a wear of tires or rails.

Some experiments of considerable value were made with the instrument, by causing the surface on which the diagrams were taken to run at the rate of about 1 inch per second. In this case, each vibration of the locomotive was recorded separately, and from these diagrams the maximum acceleration or the suddenness with which each backward and forward motion is commenced has been calculated (*Figs. 1, 2, 3*).

If r equals the amplitude or half the range of motion in any given vibration, and T equals the time taken to perform the backward and forward motion, the jerk, suddenness of movement, or maximum acceleration per second, is measured by the quantity

$$\frac{4\pi^2 r}{T^3}.$$

Such diagrams, obtained under similar circumstances from

¹ See "Shocks on Railway Bridges," by John W. Cloud, Altoona, Pa. Transactions of the American Institute of Mining Engineers, vol. ix. p. 375.

Fig. 1. *Fig. 2.* *Fig. 3.*

different locomotives, ought to give valuable and accurate information about their vibratory movements. Carriages may be tested in a similar manner.

In short, the instrument furnishes a log of the run of a locomotive; it automatically records irregularities in the track, and it shows whether a carriage is running easily, or a locomotive is working safely and economically.

The Paper is accompanied by seven sets of small scale tracings, from which Plates 2 and 3 and the *Figs.* in the text have been engraved.

APPENDIX.

LOCOMOTIVES IN JAPAN.

No. 95 Engine Class.—There are ten of this class on the Northern Division ; cylinders 15 inches diameter by 22 inches stroke ; a 4-foot wheel ; six wheels coupled.

Trailing 132 lbs. + driving 124 lbs. + leading 132 lbs. = 388 lbs., total on crank-pins, or equivalent balance.

Reciprocating parts on one side are :—

	Lbs.
Side-rod, complete	289
Connecting-rod, complete	175
Slide-blocks, cross-head, and small-end pin	129
Piston, complete	148
Total	741

No. 102 Engine Class.—There are two of this class ; ten-wheel tank engine ; six wheels coupled. Bank engines. Cylinders, 16 inches diameter by 22 inches stroke ; wheels 4 feet diameter ; pressure 160 lbs.

Trailing, 120 lbs. + driving 120 lbs. + leading 120 lbs. = 360 lbs. total on crank-pins, or equivalent balance.

	Lbs.
Side-rod, complete	400
Connecting-rod, complete	118
Pump-holder, two slide-blocks, one cross-head small- end pin	199
Piston, complete	209

Total weight on one side of reciprocating parts 926

Diagrams have been taken on No. 104.

No. 141 Engine Class.—Radials ; four wheels coupled with a radial wheel at either end, with a total lateral motion of $2\frac{1}{2}$ inches ; cylinder 14 inches diameter by 20 inches stroke ; wheels 4 feet 4 inches diameter.

Type A.—Trailing 256 lbs. + driving 200 lbs. = 456 lbs., total on crank-pins, or equivalent balance.

	Lbs.
Connecting-rod, complete	160
Side-rod, complete	171
Two slide-blocks	44
One cross-head	72
Small end pin and cotter	10
Piston, complete	128
Total reciprocating parts	585

Type B.—Trailing 165 lbs. + driving 155 lbs. = 320 lbs. total on crank-pins, or equivalent balance.

	Lbs.
Connecting-rod, complete	150
Side-rod, complete	165½
Piston, complete	133½
Two slide-blocks, cross-head, and pin	101
Total reciprocating parts	550

No. 35 Engine Class.—These are four-wheels-coupled tender-engines. Cylinders, 15 inches diameter by 22 inches stroke; wheels, 4 feet 6 inches.

Trailing 262 lbs. + driving 246 lbs. Total on crank-pins 508 lbs., or equivalent balance.

No. 77 Engine Class.—These are six-wheels-coupled tank-engines for ballast-ing work. Cylinders, 13 inches diameter by 20 inches stroke; wheels, 3 feet diameter. It was found on a trial trip that the vibrations of these engines were extraordinary, and it was decided to take off the balance-weights and put on heavier ones.

Equivalent balance as originally sent out:—

Trailing 37 lbs. + driving 14 lbs. + leading 37 lbs. = 88 lbs.

The balance-weight taken off each wheel was 78 lbs., or a total of 234 lbs.

Equivalent balance as altered:—

Trailing, 90 lbs. + driving 71 lbs. + leading 90 lbs. = 251 lbs.

The new balance-weights weighed, before putting in place, 205 lbs. per wheel. There was no room for more weight, but after this there was a marked improvement.

	Lbs.
Small end-pin, cross-head, slide blocks, and cotter	81½
Piston	108½
Leading side-rod	135½
Trailing „	90½
Connecting-rod	126½
	542½

These engines still appear to be under-balanced.

No. 31 Engine Class.—Four-wheels-coupled tender-engines. Cylinders 15½ inches by 22 inches stroke; wheels, 4 feet 6 inches diameter.

Trailing, 145 lbs. + driving 301 lbs. = 446 lbs. on crank-pins, or equivalent balance.

	Lbs.
Piston, complete	169
Connecting-rod, complete	201
Side-rod, complete	156
Cross-head and slide-blocks	83
Weight of reciprocating parts	609

No. 1 Engine.—"The first and only one," built in 1871, and now working on the Kobe section. Cylinders, 12 inches by 18 inches stroke; wheels, 4 feet 3 inches diameter. Four-wheels-coupled tank-engine.

Trailing, 15 lbs. + driving 210 lbs. = 225 lbs. on crank-pins or the equivalent balance.

	Lbs.
Connecting-rod, complete	132
Side-rod, complete	108
Piston, "	71
Cross-head and slide-blocks	40
Small end pin	8
	<hr/>
Weight of reciprocating parts	359

No. 13 Engine Class.—There are six of these engines, built also in 1871. They are four-wheels-coupled tank-engines. Cylinders, 12 inches diameter by 17 inches stroke; wheels, 4 feet 3 inches diameter.

The balance of these engines is as follows:—

Equivalent balance: trailing 150 lbs. + driving 150 lbs. = 300 lbs. on crank-pins.

	Lbs.
Connecting-rod, complete	104½
Side-rod, complete	119
Cross-head and slide-blocks	50
Piston, complete	96½
	<hr/>
Total reciprocating parts	370

No. 9 Engine Class.—There are two of these engines, four-wheels-coupled tank-engines. Cylinders, 12 inches diameter by 18 inches stroke; wheels, 4 feet 6 inches diameter.

The balancing is as follows:—

Trailing, 120 lbs. + driving 303 lbs. = 423 lbs. on crank-pins.

	Lbs.
Connecting-rod, complete	93
Side-rod, complete	106
Piston, complete	133
Cross-head, two slide-blocks, and small end pin	87
Cross-head cotter	1½
	<hr/>
Total reciprocating parts	420½

TABLE I.

Engine Class.	Reciprocating Parts.	Equivalent Balance.	Difference.
95	741	388	+353
102	926	360	566
141 (Type B) . .	550	320	230
141 (Type A) . .	585	456	129
35	601½	508	93½
77	542½	88	454½
77 ¹	542½	251	291½
31	609	446	163
1	359	225	134
13	370	300	70
9	420½	423	-3½

¹ Re-balanced in Japan.

TABLE II.
CONSUMPTION OF COAL PER MILE.

1889. Month.	Number of Engine.	Type.	Miles.	—	Lbs. per Mile.	Average of Type.	Location of Engine.
February .	121	B	2,195	518	26·43	..	Kodzu.
" .	137	"	2,494	635	28·52	..	Yokohama.
" .	139	"	2,090	521	27·92	..	"
" .	143	"	2,348	599	28·57	27·86	"
" .	129	A	2,802	592	23·66	..	Yokohama.
" .	131	"	2,946	643	24·44	..	"
" .	133	"	2,846	586	23·06	..	"
" .	135	"	2,461	530	24·12	23·82 ¹	"
March .	121	B	2,407	546	25·41	..	Kodzu.
" .	137	"	2,828	588	23·30	..	Yokohama.
" .	139	"	1,310	318	27·00	..	"
" .	143	"	2,280	553	21·16	24·22	"
" .	129	A	3,293	750	23·70	..	Yokohama.
" .	131	"	3,702	752½	22·77	..	"
" .	133	"	3,193	694	24·22	..	"
" .	135	"	3,559	646½	20·35	22·74 ²	"
April .	121	B	2,520	612	27·70	..	Kodzu.
" .	137	"	3,718	669	20·15	..	Yokohama.
" .	139	"	3,960	725	20·51	22·80	"
" .	129	A	2,528	621	23·50	..	Kodzu.
" .	131	"	1,514	291	21·53	..	Yokohama.
" .	133	"	3,814	691	20·29	..	"
" .	135	"	3,505	617	19·72	21·26 ³	"
May .	137	B	4,571	843	20·65	..	Yokohama.
" .	139	"	2,920	683	26·19	23·42	"
" .	129	A	2,960	665	25·15	..	Kodzu.
" .	131	"	3,774	693	20·50	..	Yokohama.
" .	133	"	2,916	601	23·46	..	"
" .	135	"	3,863	649	18·81	21·98 ⁴	"
June .	131	A	3,453½	657	21·31	..	Yokohama.
" .	133	"	2,621½	507	21·66	..	"
" .	135	"	3,896	645	18·54	20·50	"
" .	137	B	3,348	660	22·08	..	"
" .	139	"	2,822¾	637	25·27	23·67 ⁵	"

¹ 4·04 lbs. per mile in favour of A.

² 1·88 " " " "

³ 1·54 " " " "

⁴ 1·44 " " " "

⁵ 3·17 " " " "

TABLE III.

Month.	Miles.	Lbs. per Mile.	No. of Engine.
February	2,635 $\frac{1}{2}$	10·75 (?)	9
"	2,944	18·46	11
"	2,642 $\frac{1}{2}$	25·34	102
"	2,030 $\frac{3}{4}$	51·24	104
"	990 $\frac{1}{2}$	29·10	93
March	4,026 $\frac{1}{2}$	17·98	9
"	1,700	15·65	11
"	2,962 $\frac{3}{4}$	33·40	102
"	2,634 $\frac{1}{2}$	31·71	104
"	2,635	41·53	93
April	4,529 $\frac{3}{4}$	14·67	9
"	1,755 $\frac{1}{2}$	19·46	11
"	2,547 $\frac{1}{2}$	46·07	102
"	1,450	28·04	104
"	2,942	32·94	93
May	4,152 $\frac{1}{2}$	15·56	9
"	4,163	17·25	11
"	4,600	44·42	102
"	4,010	50·71	104
"	2,544 $\frac{3}{4}$	40·26	93
June	3,291 $\frac{1}{2}$	14·96	9
"	4,163	15·06	11
"	3,049 $\frac{1}{2}$	41·72	102
"	3,010 $\frac{1}{2}$	41·65	104
"	2,506	27·41	93

THE VIBRATORY MOVEMENTS OF LOCOMOTIVES.

PLATE . 2 .

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 7.

Fig. 129.

Fig. 5.

Fig. 6.

Figs. 8.

Fig. 12.

Cylinder	14" x 20"
Diameter of Wheel, (Leading & Trailing)	3' 7"
Wheel Base	19' 6"
Total Length of Engine	33' 3"
Heating Surface of Boiler	724 sq. ft.
Fire Grate Area	12 "
Leading & Trailing Wheels have EW Radial Boxes.	

Weight on Wheels, (Leading)	6. 14.
" " " (Driving)	9. 2.
" " " (Coupled)	9. 4.
" " " (Trailing)	6. 15.
Capacity of Tanks	1000 Gallons.
Fuel carried	45 Cubic feet.
Working Steam Pressure	140 lbs. per sq. inch.

Fig: 9.

VERTICAL MOTION.

Scale 1 Inch = 10 Min.

TOKIO-YOKOHAMA RAILWAY.

Fig: 10.

VERTICAL MOTION.

Scale 1 Inch = 10 Min.

Locomotive 129.

WABASH ST LOUIS AND PACIFIC RAILWAY.

Middle of a Pullman.

Fig: 11^a.

VERTICAL MOTION.

Scale 1 Inch = 10 Min.

Lexington Junction.

Fig: 11^b.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

NORTH EASTERN RAILWAY.

3rd Class Carriage, Sept 13th 1889.

Fig: 11^c.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

MIDLAND RAILWAY.

3rd Class Carriage, Sept 13th 1889.

Fig: 11^d.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

CHICAGO BURLINGTON AND QUINCY.

Pullman "Liverpool"

Fig: 11^e.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

PENNSYLVANIA CENTRAL.

Pullman "New Zealand"

Fig: 11^f.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

UNION PACIFIC RAILWAY.

Pullman "Quiero"

Fig: 11^g.

VERTICAL MOTION.

Scale 1 Inch = 5 Min.

UNION PACIFIC RAILWAY.

Pullman "Merlin"

Figs: 13.

VERTICAL MOTION.

Scale 1 Inch = 10 Min.

ATLANTIC AND PACIFIC RAILWAY.

Locomotive 54.

TRANSVERSE MOTION.

Scale 1 Inch = 10 Min.

LONGITUDINAL MOTION.

Scale 1 Inch = 10 Min.

Running up and down Inclines.

Running round Curves.