On a Strain Meter using a Parallel Plate Condenser.

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INTRODUCTION.

Various mechanical apparatuses have been employed for measuring the direct strain of structural metallic materials, such as bridge members or railway rails etc., and their actual results are widely known.

But it is difficult with those mechanical apparatuses to obtain accurate results especially for stresses caused by moving loads on account of friction and the inertia of various parts of them. Accordingly attention has been paid to measuring strains electrically in order to overcome those defects and an electric strain meter using a parallel plate condenser has been devised. A number of laboratory and field tests have been conducted to ascertain the sensibility and utility of the apparatus, and it is proved to be very convenient of use in practice.

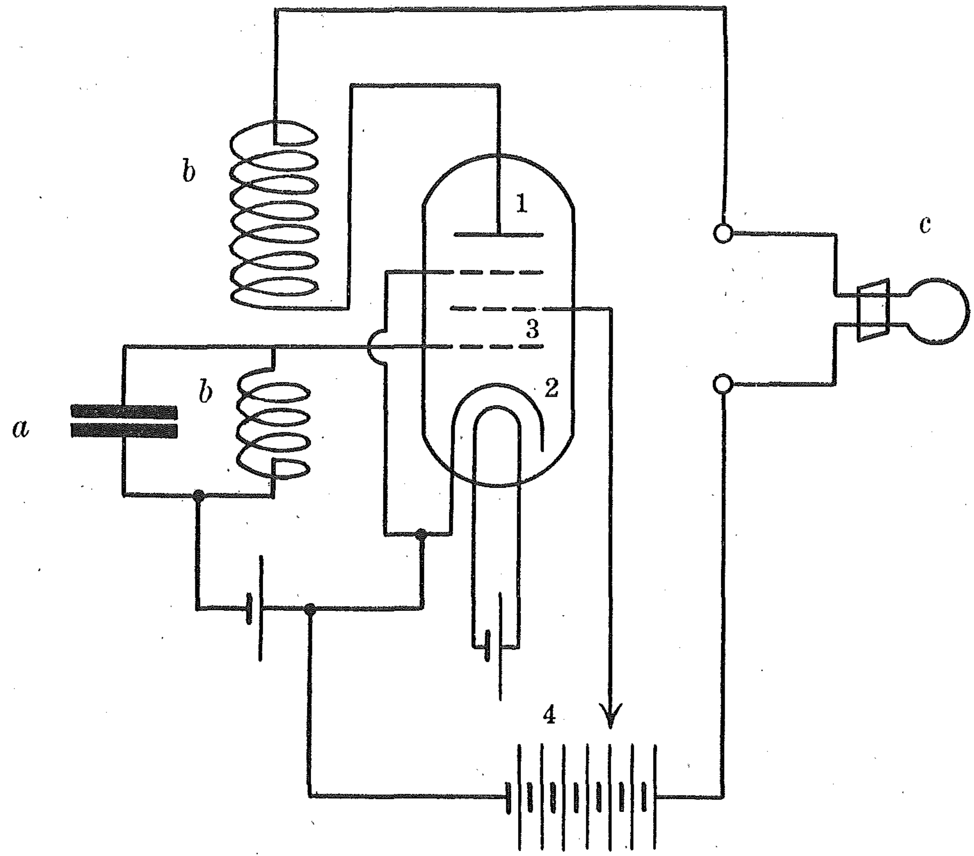
There have also been invented various electric strain meters hitherto, but they can not be considered suitable in field measurement, nor are they easy to make.

1. ELECTRIC CIRCUIT OF THE PRESENT STRAIN METER (Fig. 1).

The present writers' strain meter is such that there is produced a high frequency oscillation of several hundred thousand cycles (wave length of several thousand meters) in an oscillation circuit of a vacuum valve, and the strain of the material is changed directly into variation of capacity of a condenser in the circuit, and then the amount of plate current varying with it is observed or recorded in an oscillograph.

(1) The Vacuum Valve.

A three- or multiple-electrode vacuum valve consists of three main parts which are a plate (anode) *1*, a filament (cathode) *2* and grids *3* in Fig. 1. If the electric source *4* is connected to this valve, electrone is actively radiated from a filament to plate, that is to say, electric current flows from plate to filament in circuit. This current is called a plate current ordinarily.



a. Condenser in attachment.
b. Induction coils.
c. Oscillograph.

1. Plate (anode).
2. Filament (cathode).
3. Grids.
4. Battery.

Fig. 1. Electric circuit of writers' strain meter.

The strength of the plate current varies intensely with the voltage on the grids. This is a characteristic of a vacuum valve.

(2) Oscillation Circuit in a Vacuum Valve.

If induction coils *b* are connected to a plate *1* and grid *3* and mutually coupled and a condenser *a* is inserted parallel in the induction coils and then an electric source *4* is connected to the vacuum valve, electric oscillation occurs in them in some mutual relation between the inductance of the induction coils and the capacity of the condenser, with the result that a high frequency current is produced.

The frequency of this current is a function of inductance and capacity, so it varies with those conditions.

(3) Plate Current and Frequency of the High Frequency Current.

A vacuum valve can be considered as a resistance of large value; if high voltage is pushed between anode and cathode, plate current flows very weak. But, if high frequency occurs in the circuit, the strength of the plate current is suddenly increased and shows a marked variation of strength with change of the frequency of the high frequency current.

Using this property, a parallel plate condenser is inserted parallel to an induction coil in grid circuit, then the strain of material, which is going to be measured, is converted directly into variation of the air gap between these parallel plates and the variation of the plate current caused by it is observed or recorded. This is the principle of the writers' apparatus.

Two parallel circular copper discs are used as a condenser. They are attached to the material and their capacity is varied by lengthening or shortening the air gap between these two parallel plates according to the strain of the material. The strain or stress of the material is measured by observing or recording the variation of the plate current caused by variation of the air gap.

A pentode is used as a vacuum valve to stabilize the plate current and no amplifier is adopted.

(4) The Oscillograph.

The oscillograph used was made at the Yokokawa Electric Works and a vibrator of H-type is selected, whose sensibility is 7.5×15^{-5} D. C. Amp. per mm., period of self oscillation is 1/1,000 sec., resistance 2 ohms and safe maximum current 50 m. amp. As the initial current flows to the amount of 20 to 30 m. amp. in the circuit, it is within the safe current of the vibrator and its small tortionable range.

(5) Electric Source.

Electric source of this circuit is a battery and its strength and weight are as follows:

			Number	Weight (kg.)
For plate	100 volt	0.2 amp. hour	2	40
For filament	6 volt	60 amp. hour	1	20
For oscillograph*	6 volt	60 amp. hour	2	40
Total			5	100 kg.

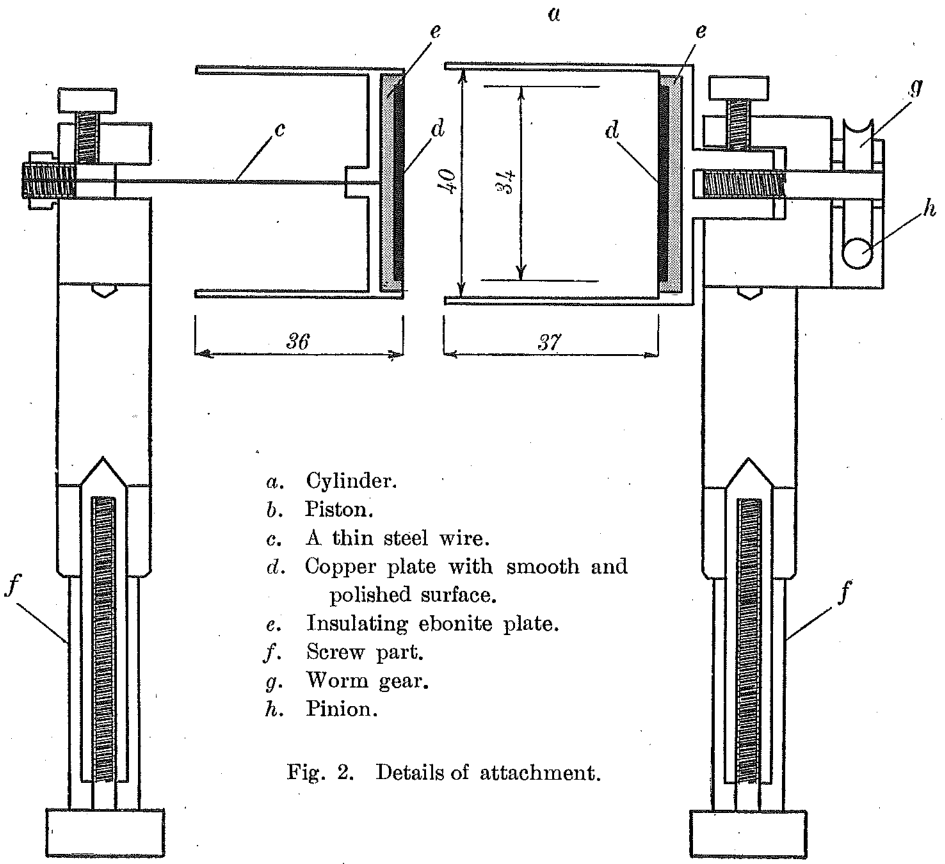
* If there is A. C. lamp source of 90, 100 or 110 volts obt inable, batteries for oscillograph are not necessary and the total weight is reduced to 60 kg., so it is very convenient for field work.

In the oscillation circuit, there are a vacuum valve, a condenser and some resistance for circuit of filament and ammeter. They are all kept in a small insulated box and rested in neighbourhood of the attachment. From the circuit box and the attachment to the batteries and the oscillograph, connection is made with lead wires. So it is possible to manipulate, observe and record at a distance, free from danger.

2. ATTACHMENT.

As the apparatus is to measure direct stresses or fibre stresses, it is necessary to avoid bending and torsion, and the movement of two parallel plates is to be always parallel.

Details of the attachment are shown in Fig. 2.



a. Cylinder.
b. Piston.
c. A thin steel wire.
d. Copper plate with smooth and polished surface.
e. Insulating ebonite plate.
f. Screw part.
g. Worm gear.
h. Pinion.

Fig. 2. Details of attachment.

(1) Main Part.

The piston *b* slides along inside of cylinder *a* exactly and smoothly, and both are attached to the material which is going to be measured with the screw parts *f*. A thin steel wire *c* is attached to the piston *b*, and with it, the top of the piston and the bottom of the cylinder are able always to move relatively parallel conforming to any bending freely.

There are two circular copper plates *d* with smooth and polished surfaces in the top of the piston and the bottom of the cylinder respectively; they are insulated completely from their cheeks with thick ebonite plates *e*.

Thus strain in the direction of the axis of the material is directly turned to change the air gap between the two parallel copper plates, and there are no medium or magnifying parts, so that no margin for the occurrence of trouble exists and it is possible to transmit the strain exactly and to show the stress.

(2) Screw Part.

The main part of the apparatus is attached to the material with screws. If a point of a screw rotates when attaching to the material, it is difficult to attach in a correct position. Therefore this part is made so as not to rotate and at the same time to screw up gradually.

(3) Calibration.

This apparatus is able to be calibrated easily in position of measuring. In calibration, the cylinder can be slid quite slowly and finely with a worm gear g dropping speed from a pinion h, while the piston is fixed. This amount of movement is read with a 1/1,000 mm. dial indicator attached to the rear portion of the cylinder and compared to the readings of the galvanometer or records in the oscillograph. This is the scale of strain or stress.

After calibration thus completed, the cylinder is fixed with a screw and actual measurement is begun.

The total weight of the attachment is only 1.22 kg. including a dial indicator. After a measurement is over, the piston is removed from the screw part and is kept in the cylinder in a protected place. Fig. 3 shows the present attachment.

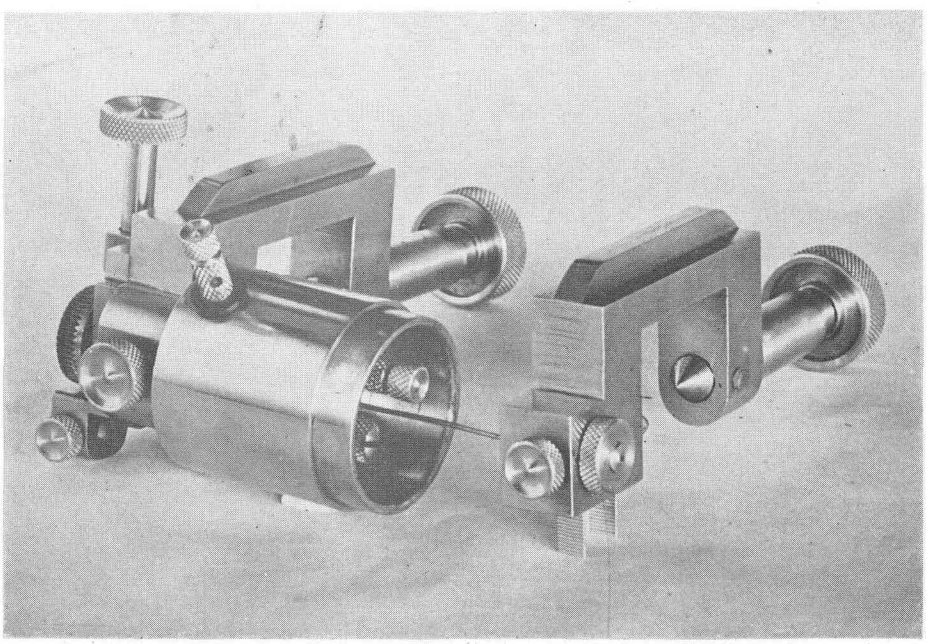


Fig. 3. Attachment.

3. SENSIBILITY.

A record of length of 1 mm. on the oscillograph film corresponds to a strain of 1/1,000 to 1/2,000 mm. or stress of 25 to 12 kg./cm.^{2} under the condition where the initial air gap between two parallel copper plates is 1/20 to 1/30 mm. and the grip distance of the present apparatus is 84 mm.

So the magnifying power may be said to be 1,000 to 2,000 times.

4. RESULTS OF ACTUAL MEASUREMENT.

A number of field and laboratory tests have been conducted to ascertain the sentibility and the utility of this apparatus.

The results are as follows.

(1) Bending Stresses in Railway I-beam Bridge.

Bending stresses are recorded at the centre of an I-beam railway bridge (18″ × 7″ × 0.55″ × 75 lb., clear span 12 feet), when a passenger or freight train was running over it at service speed.

Fig. 4 shows the apparatus attached to the lower flange of the I-beam, and Fig. 5 shows the arrangement of the oscillograph and batteries, set on the grass about 25 meters from the bridge to avoid any danger or severe vibrations caused by the passage of the train. These parts of the apparatus when disconnected and loaded on bicycle trailer can be transported by one man.

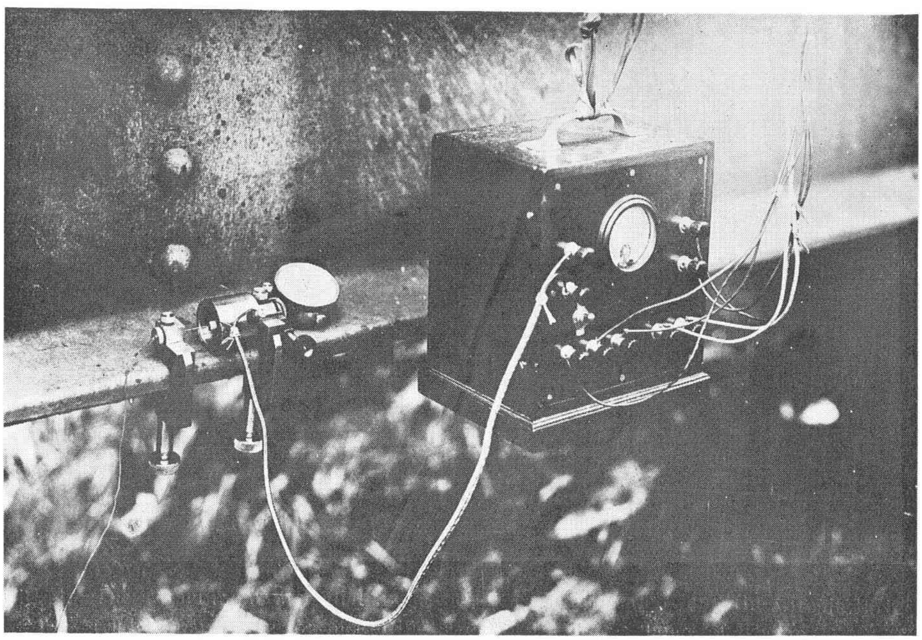


Fig. 4. The Attachment with dial indicator for calibration (left and the Circuit Box (right) in position for measuring stress of the lower flange of I-beam.

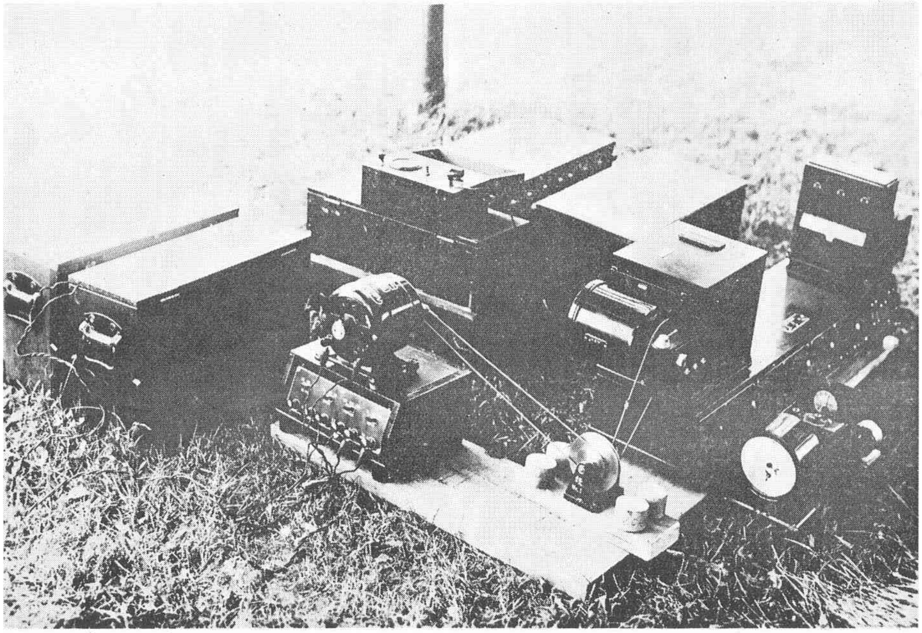
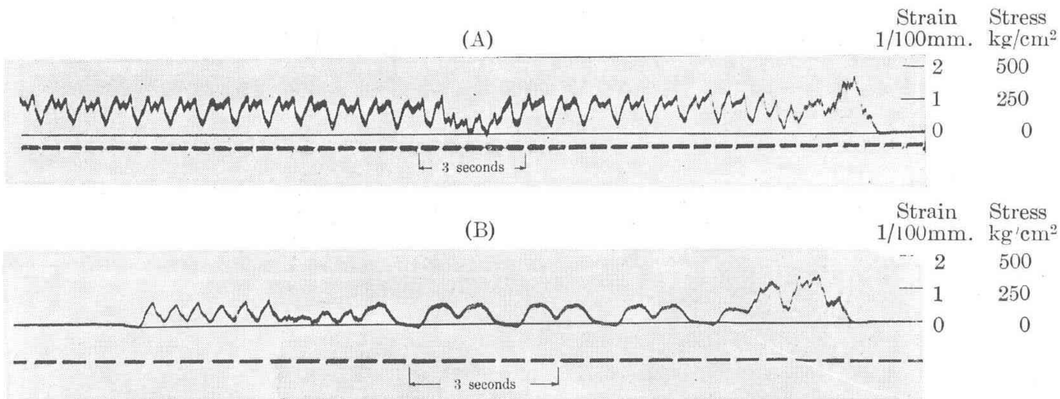


Fig. 5. The oscillograph and batteries arranged 25 meters distant from the I-beam bridge.

The records are shown in Fig. 6 and Fig. 7. Fig. 6 shows the tensile stresses of the lower flange caused by a train of coal-waggons (A) and by a composite train (B). Fig. 7 shows the compressive stresses of the upper flange by composite trains. In records, the spacings of short strips at the right end represent the scale of strains of every 1/100 mm. or stresses of every 250 kg/cm^2, where the



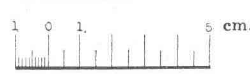


Fig. 6. Tensile stress of lower flange of the I-beam bridge caused by a running train of coal-waggons (A) and a composite train (B).
The short strips at the right end are the scale showing 1/100 mm. of strain or 250 kg/cm^2 of stress, recorded in oscillograph in working condition with the dial indicator attached to the attachment.
The dotted line is the timing mark of every 3/5 seconds.

modulus of elasticity of the I-beam is adopted as 2.1×10^6 kg/cm². On account of the short span length of the I-beam in comparison to the axle distances of the train, the stresses caused by the wheel loads individually can be observed clearly.

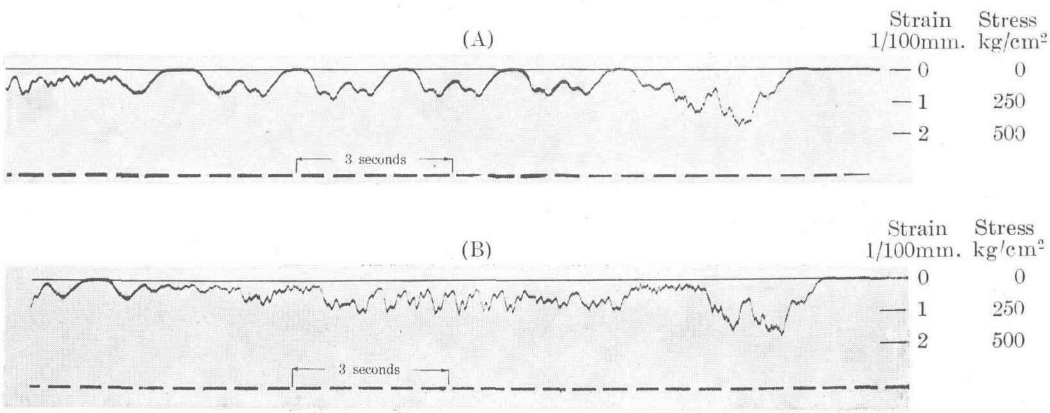
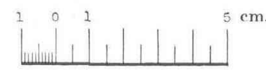


Fig. 7. Compressive stress of upper flange of the I-beam bridge by the passage of a composite train.
The short strips and the dotted lines are the same as in Fig. 6.



(2) Bending Stresses of Railway Rails.

Bending fibre stresses of the lower flange of 37 kg. railway rails at midpoint between ties on the I-beam bridge above described, were recorded. Figs. 8 and 9 show the apparatus attached to the rail, Fig. 10 (A) and 10 (B) the bending stresses caused by running passenger and freight trains respectively.

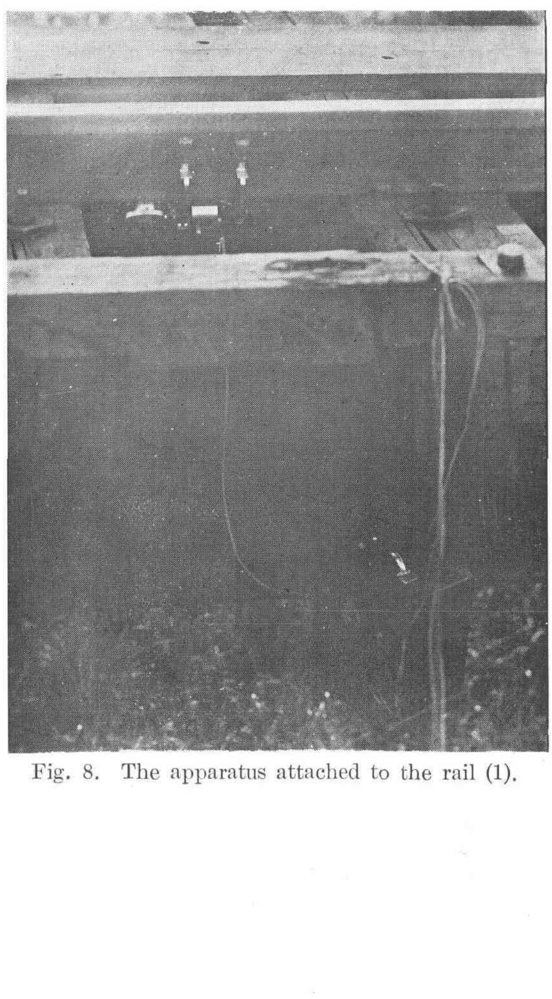


Fig. 8. The apparatus attached to the rail (1).

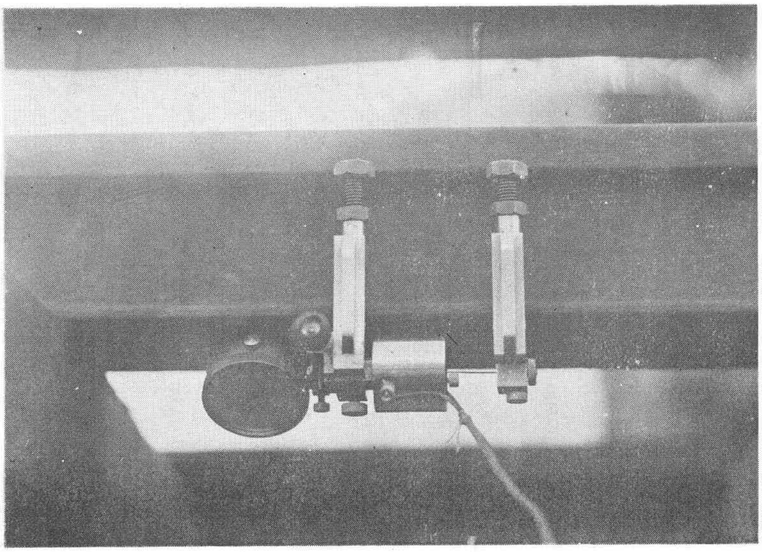


Fig. 9. The apparatus attached to the rail with dial indicator for calibration (2).

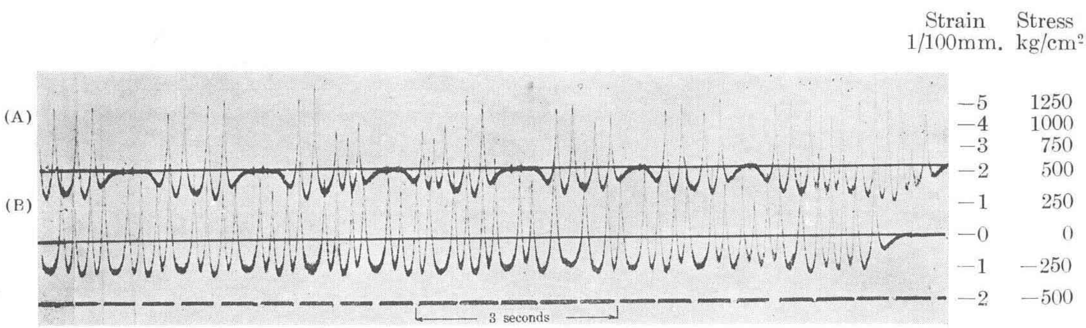
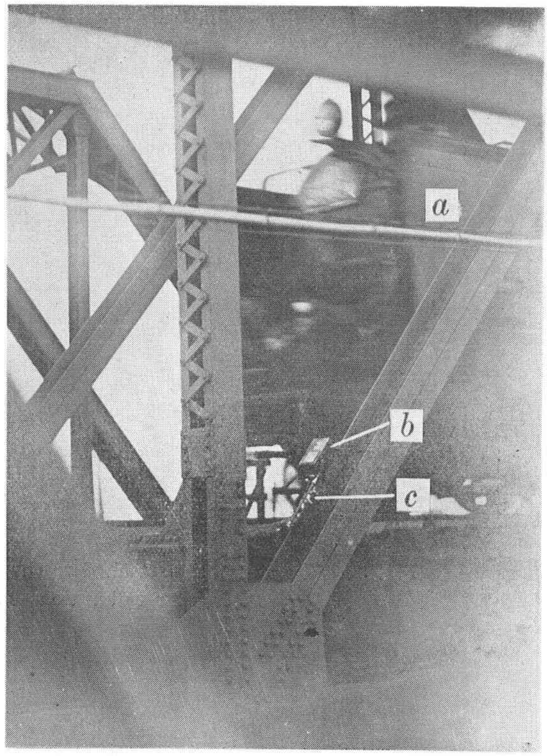


Fig. 10. Bending stresses of the lower flange of a railway rail caused by a running passenger train (A) and a train of coal-waggons (B).

(3) Direct Stresses of a Member of a Truss Bridge.

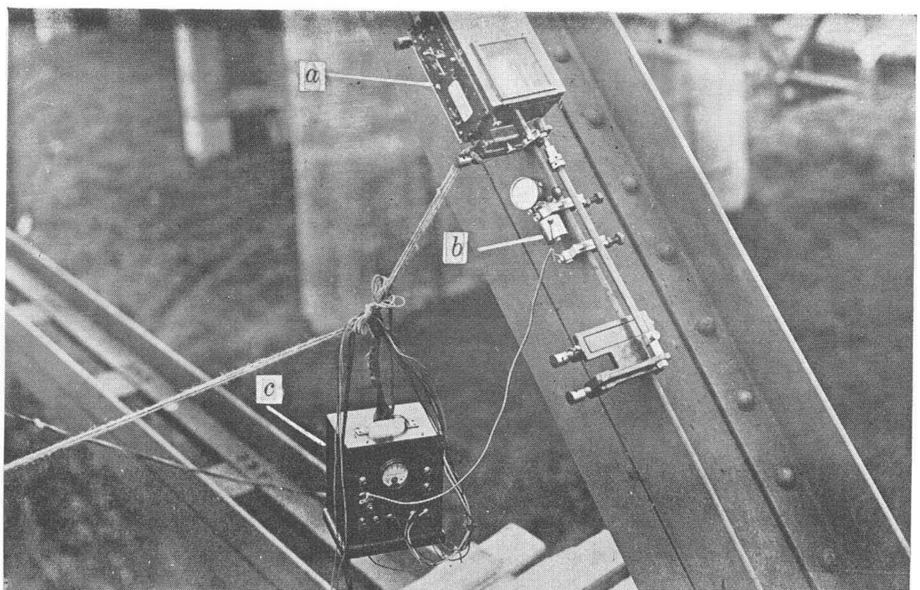
Direct Stresses of the members of a parallel chord bridge truss of Pratt type, 7 panels 154 feet centre to centre of end bearings, were observed.

In this case, a Leuner's strain meter was used for comparing the stresses recorded with ours. Figs. 11 and 12 show the present strain meter and Leuner's attached to the second diagonal of the truss, and Fig. 13 and 14 show the direct stresses recorded in the writers' meter (grip distance 84 mm.) and Leuner's (grip distance 700 mm., magnifying power 139) respectivly. In these records, (A) and (B) represent the stresses caused respectively by a train of coal-waggons and a passenger train running at service speed.



a. Running locomotive.
b. Leuner's strain meter.
c. Writers' strain meter.

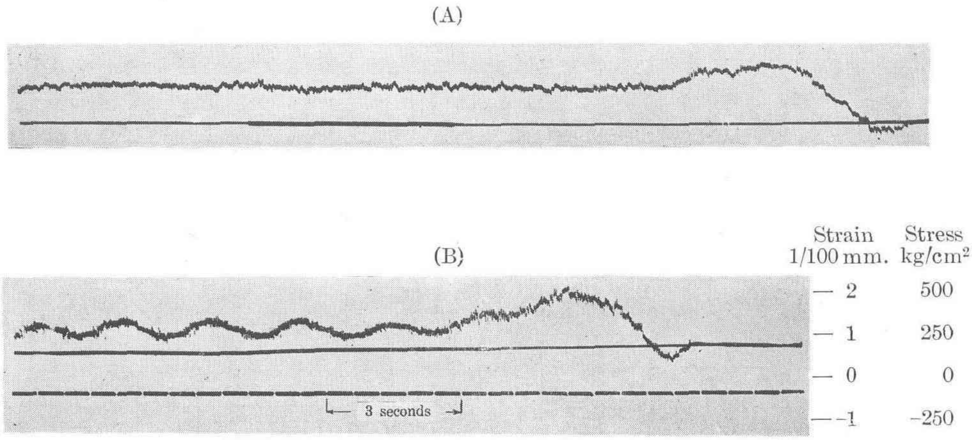
Fig. 11. Strain meters of the writers' and Leuner's in working position.



a. Leuner's strain meter.
b. Attachment } Writers' strain meter.
c. Circuit box }

Fig. 12. Detail of Fig. 11.

It is evident that the record of the writers' meter is larger and more minute than that of Leuner's, in spite of the fact that the grip distance is 1/8.3.



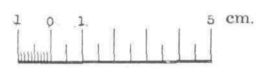


Fig. 13. Direct stresses of the second diagonal member of a 154 foot span railway truss bridge of parallel chord Pratt type, recorded by the writers' strain meter, when trains of coal-waggons (A) and passenger cars (B) were passing.

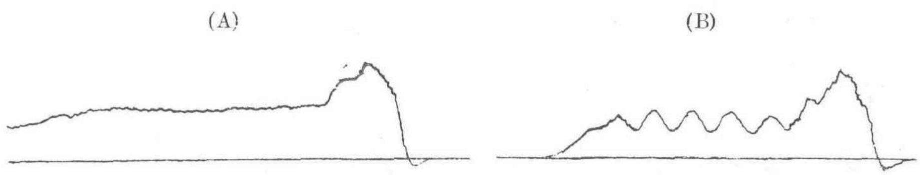
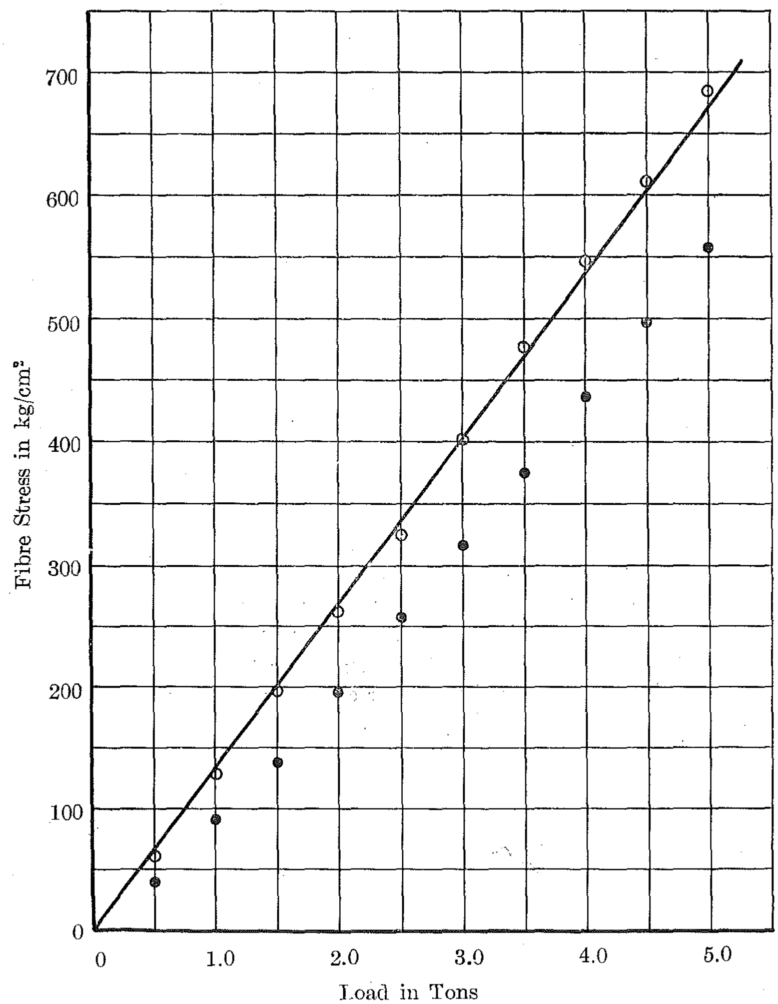


Fig. 14. Same as in Fig. 13, recorded by Leuner's strain meter.

(4) Comparison of the Stresses of I-beam under Statical loading with Berry's Strain Meter.

The specimen was an I-beam of 180 mm. × 100 mm. × 6 mm. × 23.6 kg/m. and it was loaded on the centre of 1 meter span to 5 tons, at every 0.5 ton the stresses being observed. The records are compared also to the calculated values and they are expressed graphically in Fig. 15.

In the latter figure, the full line denotes the results of calculation, the white points and black dots are the results of the observations with the writers' strain meter and Berry's respectively. The records of the Berry's meter show small values, which may be caused by the frictions of the parts of that apparatus.



Notations.; — Calculated Values.
○ Measured Values with the writers' strain meter.
● Measured Values with Berry's strain meter.

Fig. 15. Comparison of test results by writers' strain meter and Berry's with the calculated values.

5. SUMMARY AND CONCLUSIONS.

The specific characters of the writers' herein described new strain meter are as follows.

(1) The circuit has not amplifiers and is so simple, that there are no apprehensions of the occurrence of any hinderances, and even if any obstacle should occur, it is easy to find out and repair it in the field.

(2) The attachment is so small, compact and without complicated mediums,

that it is quite easy to manufacture, to transport, to manipulate and is fit for any severe vibration. It is free from inertia or friction in the parts of the apparatus.

(3) The calibration can be performed with a dial indicator properly at the time of measurement in the field.

(4) Observations or recordings can be made at a far distance from the attachment or the measured place by means of the lead wires, owing to the nature of electricity.

(5) The sensibility is very high, as the magnifying power can be said to be 1,000 to 2,000.

(6) The grip distance is ony 84 mm., which is convenient for measuring stresses of a steel member, whose modulus of elasticity is assumed as 2.1×10^6 kg/cm^2, and even this distance can be shortened to some degree.

(7) The shorter the grip distance or the air gap between the two copper plates is, the sharper the sensibility becomes. This is the inimitable character for any other instrument of this kind.

Precautions to be taken in the construction and manipulation of this aparatus are as follows:

(1) The length of the sealed wire connecting the circuit box and the attachment is to be shortened as much as possible.

(2) The circuit box is to be kept away from violent vibration, it is easily secured by suspending the box with an elastic string as in Fig. 4, 8 or 12.

(3) Let the circuit alone for some ten minutes after making the switch-in and wait for the plate current to be stabilized.

Finally, the present authors offer their grateful thanks to Prof. Yoshihiro Asami, K. H. and Assist. Prof. Tatsuo Katayama, who have kindly explained electric technology.