A machine for calculating electrically the bending moment and shear loading effect of moving loads on varying spans

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A Machine for Calculating Electrically the Bending Moment and Shear Loading Effect of Moving Loads on Varying Spans

Appareil électrique pour la détermination des moments fléchissants et des efforts tranchants exercés par des systèmes de charges mobiles sur des poutres de portée quelconque

Ein elektrisches Rechengerät zur Ermittlung der Biegemomente und Querkräfte in Trägern beliebiger Spannweiten infolge beweglicher Lastenzüge

E. K. Bridge, B. Sc., M.I.C.E., Dorking, Surrey

E. U. D. L. Machine

Introduction

Following the nationalisation of the British Railways some detailed consideration had to be given to the inter-availability of locomotives as between one region and another and it, therefore, became necessary to assess as accurately as possible the exact bending moment and shear effects of some 440 different types of locomotives taken over from the four constituent railways. In this assessment careful allowance had to be made for the hammer blow effect at various speeds on all spans, as well as the static effect, and this involved so much recalculation, once a standard method of assessment had been arrived at, that it was considered desirable to produce a machine for this purpose.

It was obvious from the beginning that the principle behind such a calculating device must be that of the influence line triangle and it was finally decided that the most practical way of tackling the problem would be electrically, so that the equivalent uniformly distributed load for any arrangement of up to 22 loads on any particular span up to 150 feet could be read directly on a suitable scale on a current measuring instrument.

The equivalent uniformly distributed load is, of course, that load which, uniformly distributed over the span, produces the same bending moment as any particular arrangement of axle weights and spacings on that span.

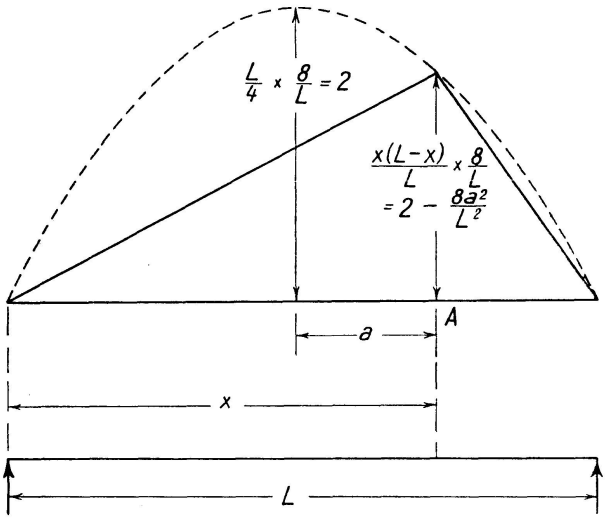

Fig. 1

The Influence Line Method

The influence line for bending moment on any point on a beam is a triangle (Figure 1), the apex of which lies above the point at which the bending moment is to be found, and the ordinate height of that apex is $\frac{X(L-X)}{L}$ where X is the distance of the point from one end. It is obvious from this expression that the locus of the apices is a parabola with a maximum ordinate of $L/4$ at mid-span. Given this influence line (Figure 2), the bending moment due to any set of loads in a certain position can be found by multiplying each load by the height of the influence ordinate at the point of application of the load and adding these products. If the loads in question represent a moving train, the bending moment at the point will vary as the train moves across the span. To find the greatest moment the calculation described must be carried out for various positions of the train until the greatest sum of the products has been found.

It can be shown that this maximum bending moment occurs under the load nearest to the resultant of all the loads on the span, when this load and the resultant are equally spaced about the centre line of the span.

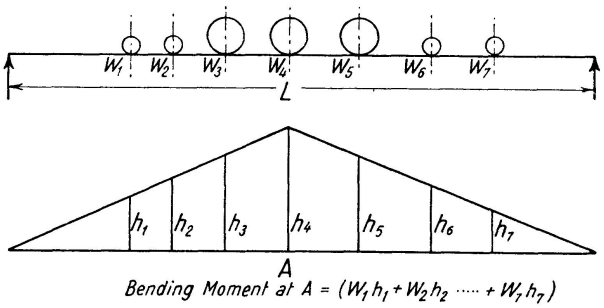

Fig. 2

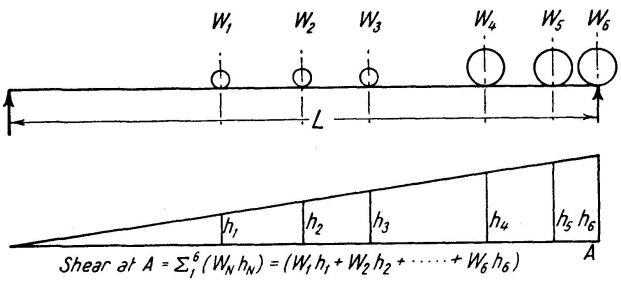

Fig. 3

To obtain the equivalent uniformly distributed load from this moment it must be multiplied by $8/L$ since the centre bending moment for a uniformly distributed load W is $W.L/8$. This multiplication can be performed on the ordinates of the influence line which changes the value of that at mid-span from $L/4$ to "2".

In the case of end shear (see Figure 3) the influence line is a right angled triangle with one vertical side of magnitude unity. The method for finding the greatest end shear is similar to that used for finding the greatest bending moment, although the position of the load train will be different.

Electrical Analogy of an Influence Line

If a voltage is applied between any point on a resistor and its ends, the voltage which can be tapped off at any intermediate point is proportional to the distance between that point and the end. By making the input voltage represent to some scale the height of the apex of the influence line triangle, the voltage tapped off at any intermediate point represents to the same scale the ordinate of the influence line triangle at that point.

If the end points of each span are represented by tappings on the resistor and contact rollers are spaced to represent the position of the loads to the same scale, the voltage tapped off at each contact would represent the influence line ordinate for that load position on that span. By passing this voltage through a transformer and using a potentiometer in the secondary circuit of the transformer to tap off a proportion equivalent to the particular load, the product of this load and the height of its ordinate on the influence line triangle is obtained. By connecting these potentiometers in series with a voltmeter the total of these products which, of course, represents the total E.U.D.L. is obtained.

The calculating machine is based on this principle.

The voltage between a point on the resistor "*B*" and the end point is applied to a transformer "*T*" (see Figure 4), the secondary of which is connected across a potentiometer "*P*" from which any fraction of the original applied voltage can be tapped. One such unit is provided for each axle load to be represented. The tapping points of the potentiometers are connected in series to a voltmeter which reads the sum of the voltages on the individual potentiometers.

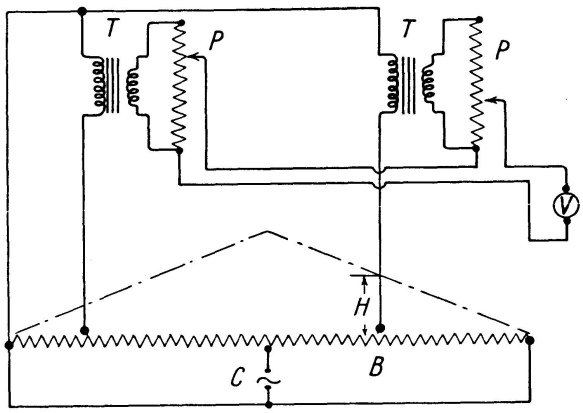

Fig. 4

The voltage supplied to each potentiometer through the transformer is proportional to the voltage at the pick-up point on the resistor and thus to the height of the influence line ordinate "*H*" at that point. If the fraction of that voltage tapped from the potentiometer is proportional to an axle load "*W*", the total voltage measured by the voltmeter will represent the total E. U. D. L. due to a number of loads placed in the positions of the contacts on the resistor on a span of the length it represents.

By selecting end tappings spaced to represent the span under consideration, and setting out to the same scale roller contacts to represent the positions of the loads, the E. U. D. L. representing the greatest value of the bending moment at the centre of the span (where the contact *C* is located) can be obtained by passing the system of rollers along the resistor and observing the highest reading.

As the maximum bending moment on the span will generally occur slightly to one side of this centre line, the input contact must be moved relative to the ends of the span, and the input voltage must be adjusted to correspond with the reduced height of influence line triangle it will then represent.

As, however, the greatest bending moment always occurs under a load and this load is the same for any position on the span close to the centre, this procedure may be simplified by moving the load train with the centre supply contact once the position for greatest mid-span bending moment has been found. If the voltage is automatically adjusted to the correct value at the same time as this movement is carried out, the voltmeter will always indicate the correct greatest E. U. D. L. at this point, without any further movement of the load train relative to the centre supply contact "*C*". This process amounts to moving the ends of the resistor relative to the load train and contact "*C*" and is the method actually used in the machine.

The adjustment for the varying height of the influence line is effected by a circuit which takes the place of the simple voltmeter (Figure 5). This is achieved by using only half wave rectification for the main instrument and feeding a fraction of the negative half cycle of the alternating current into the

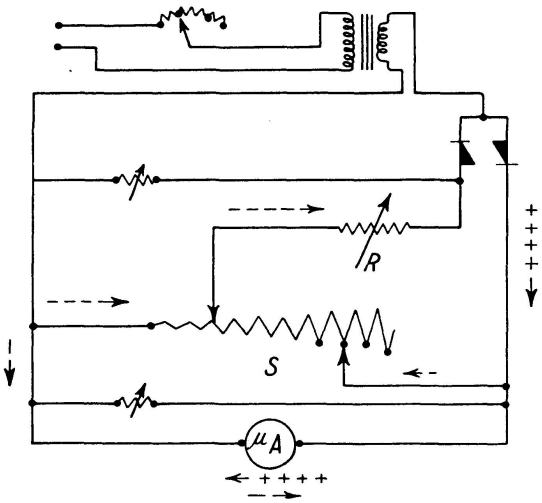

Fig. 5

instrument through a variable shunt "*S*" this fraction corresponding to the required amount of voltage drop.

The amount of negative current supplied to the instrument for a given movement along the shunt resistor can be controlled in two ways, first by varying the total resistance of the shunt and secondly by introducing a series resistance "*R*" between the rectifier and the shunt. Both methods are employed in the circuit.

Since the voltage drop required is to be proportional to the square of the distance moved along the span, the shunt used has to be such that the resistance introduced is proportional to the square of the distance moved along it. In the machine this was done by winding resistance wire on to a conical former.

Other resistances have been added to compensate for changes in total circuit resistance.

Description of the Machine

Figure 6 shows a general view of the machine, the axle loads being set up in tons and cwts., on the potentiometer scales on the front of the machine. An enlarged detail is shown at the top left hand side of the diagram.

In addition to the potentiometers for setting the load in tons and cwts., respectively, each load unit panel has two switches; one of these enables it to be switched out or to represent an upward or downward load, the other switch enables the load set on the two upper potentiometers to be increased by a further 10 tons. The lower potentiometer is merely a compensator.

The load spacing is set out on the top of the machine against a scale and these pointers position the contact rollers on the resistor. Each pointer is numbered to correspond with the load panel to which it is connected.

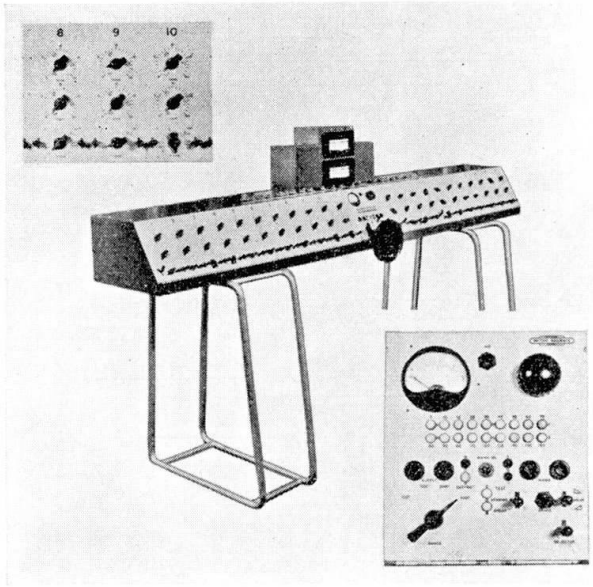

Fig. 6

The large handle in the front of the machine moves the resistor along the contact rollers to represent movement of the loads across the span.

The middle panel in the front of the machine contains the various control switches, one of which selects the span under consideration which is indicated by the lighting of the appropriate panel lamp. The upper meter on the top of the machine indicates the answer in the form of an equivalent uniformly distributed load.

Figure 7 shows the front of the machine with the front panels open. The potentiometers and switches in the load panels are clearly shown. The resistor is just visible through the holes in the centre stiffening girder in the frame and the setting pointers of the contact rollers are shown along the top.

In the top left hand corner of this figure are shown the two micro-ammeters, the upper one of which records the E.U.D.L. For greater accuracy four ranges are provided which can be set by a switch in the centre front panel, and are indicated by the lighting up of a panel light above the instrument; these panel lights being of the same colour as the scale which should be used for that range. The lower instrument records any variations of input voltage to enable adjustments to be made in this.

Figure 8 shows the back of the machine with the covers off. The resistor, which consists of "Eureka" resistance wire wound on a square Tufnol former, has tappings on its underface to represent each of the various spans from 10 to 150 feet. It is supported on a roller carriage to enable it to be moved freely in a longitudinal direction by means of a rack and pinion operated by the large wheel in the front of the machine. Since too many connecting wires to this resistor would have restricted its movement, a multibank selector switch was

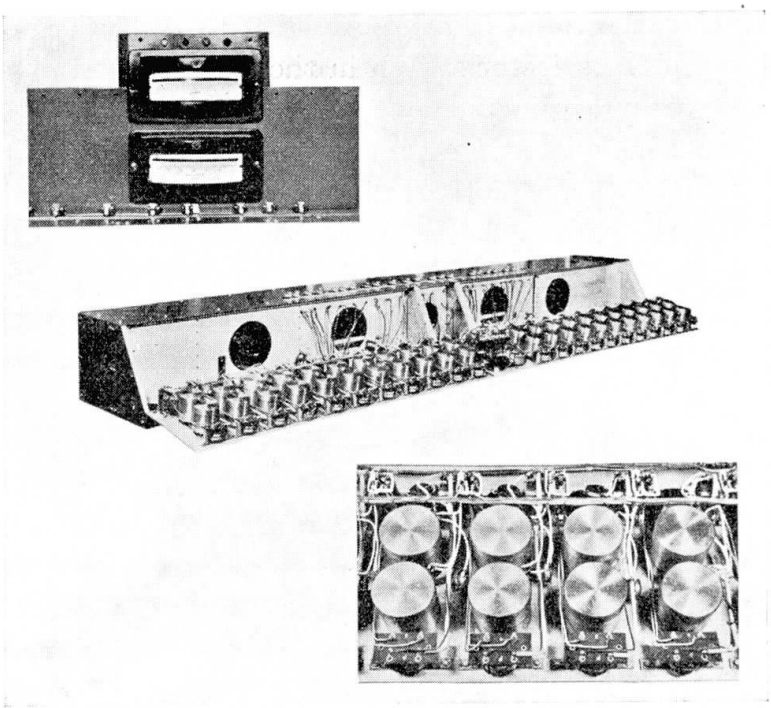

Fig. 7

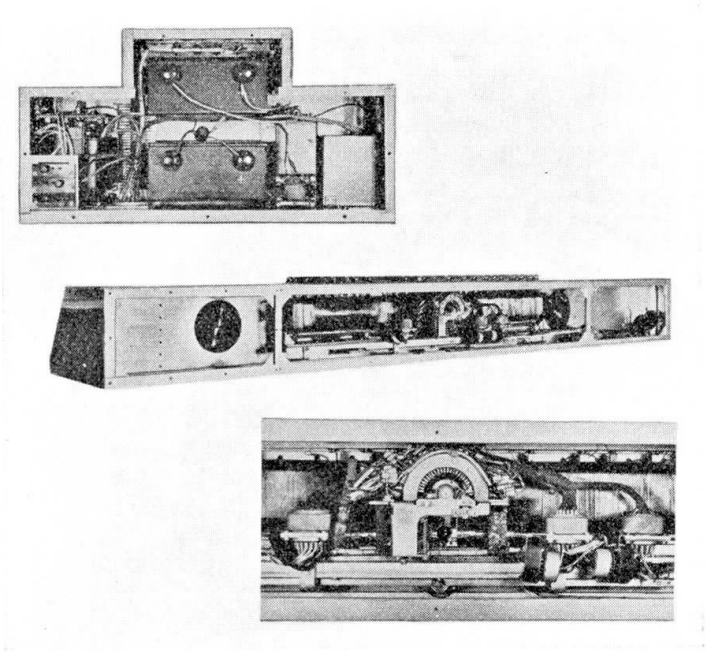

Fig. 8

incorporated, so that the connections required for any particular span can be selected by means of the selector switch in the centre panel in the front. The wiring is brought to multi-pin plugs at suitable points in the instrument to facilitate the removal of any part for maintenance or repair.

Figure 9 shows the small conical resistor for reducing the height of the influence line triangle parabolically as already described.

When the machine has been set up (see Figure 6) with the loads and spacings of the axles, the selector switch is set to the span to be considered and the range switch set to enable the most suitable instrument scale to be used. The resistor is then made to travel along under the contact rollers by means of the large handle on the front until the maximum reading is obtained. This figure will be the E.U.D.L. for maximum bending moment at the centre of the span.

To ascertain whether a greater reading than this can be obtained, the centre contact to the resistor, which is normally held against it by a catch and travels with it, is electro-magnetically detached and secured to the frame, so that this input point remains in the same position relative to the load when the resistor is moved slightly in either direction. The resistor is then moved slightly each way and this movement also operates the sliding contacts on the conical resistor incorporated in the measuring circuit, so as to effect the necessary adjustment in the height of the influence line triangle.

By this machine the full range of E.U.D.L. span curves for a locomotive covering static effect, hammer blow at half and full speed and double or single-heading can be calculated, together with the end shears, in a small fraction of the time otherwise required.

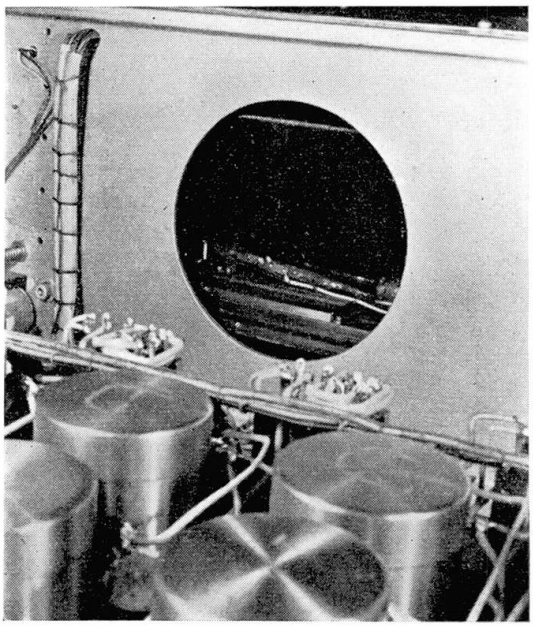

Fig. 9

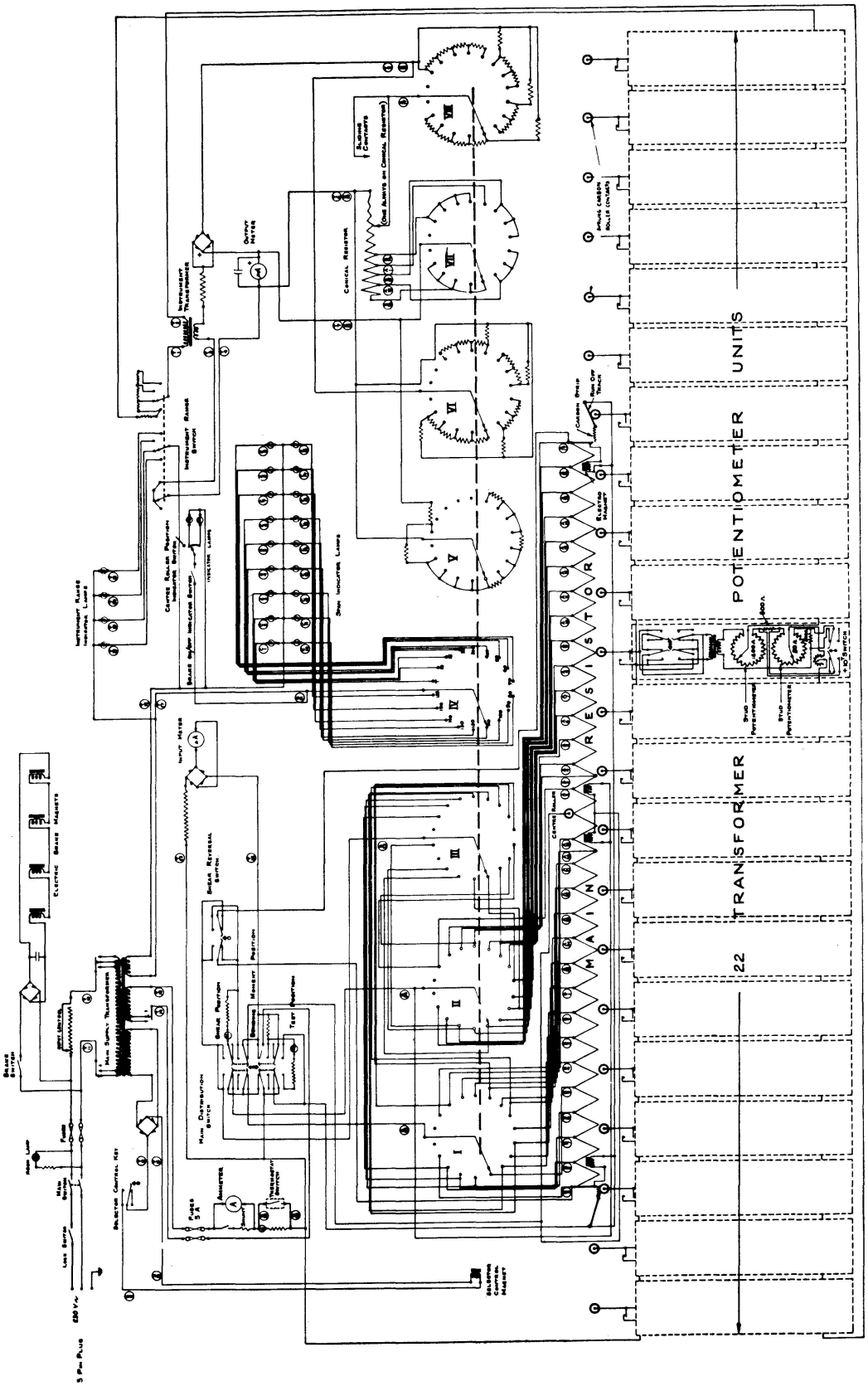
22 TRANSFORMER POTENTIOMETER UNITS
MAIN RESISTOR
Input Meter
Output Meter
Instrument Transformer
Instrument Range Switch
Instrument Ranges Indicating Lamps
Centre Roller Position Indicating Lamps
Relays after Indicator Switch
Indicating Lamps
Show Indication Lamps
Canonical Resistor
Electric Brake Magnets
Main Supply Transformer
Main Distribution Switch
Brake Reversal Switch
Position
Brake Position
Magnet
Brake
Test Position
Ammeter
Resistance Switch
Fuses
Main Switch
Line Switch
Main Line
Fuse
Selector Control Key
Selector Control Magnet
Electric Brake Magnets
Brake Switch
Electric Magnet
Carbon Roller
Run Off Track
Brush Carbon Roller Contacts
Brush Contacts
Canonical Resistor
(One Adjusts on Canonical Resistor)
Centre Roller
Run Off Track
Lamp
Switch
Brush Potentiometer
Brush Potentiometer

Fig. 10

It will be appreciated that the foregoing can only be an outline description of the machine.

The full circuit diagram is as shown on Figure 10.

The machine is now employed in the Bridge Office of the Southern Region for calculating the full range of particulars for all types of locomotives at present in use on the British Railways as well as travelling cranes and other special loads.

The author wishes to acknowledge the assistance given by the research staff of the General Electric Company in suggesting that the influence line might be represented by a voltage distribution.

The machine was designed and constructed mainly from second-hand parts by the Bridge Office on the Southern Region of British Railways and was assembled and wired in the Workshops of the Signal and Telecommunications Engineer at Wimbledon. Valuable assistance in the construction was given by the Mechanical and Electrical Engineer and a number of the mechanical details were made by the Research Assistant's staff.

The author wishes to express his thanks to Mr. F. E. Campion, M.I.C.E., Civil Engineer, Southern Region, British Railways, for permission to present this paper and to Mr. J. E. Spindel, B.Sc. (Eng.), of his Bridge Office both for his work in translating the idea of such a machine into a reality and for the assistance given in the preparation of this paper.

Summary

The paper describes a special calculating machine which indicates on an electrical instrument that uniformly distributed load which gives the same bending moment or shear force as any given arrangement of up to 22 point loads from 0.05 to 31.0 tons on bridge spans up to 150 ft.

The loads are set up on the machine and then the span to be examined is switched on.

The bridge is then moved under the load train and the greatest reading on the instrument noted.

The apparatus is based on the principle of influence line triangles. Its use reduces the time needed for such calculations to a fraction of that required when using mathematical or graphical methods for the purpose.

Résumé

L'auteur décrit un appareil spécial de calcul qui permet de déterminer immédiatement, sur la graduation d'un dispositif mobile de mesure, la charge uniformément répartie qui met en jeu le même moment fléchissant et le même effort tranchant que la charge effective considérée. Cette dernière peut affecter

une disposition arbitraire, allant jusqu'à vingt deux différentes positions des essieux avec charge d'essieu allant de 0,05 à 31,5 tonnes, ceci pour des portées de pont arbitraires jusqu'à 45 mètres.

Après avoir réglé la machine sur les charges en tenant compte de leur intervalle, on peut faire également intervenir la portée à étudier.

On peut ensuite faire varier le système de charge sur le pont et déterminer la valeur maximum.

Le mode de fonctionnement de cet appareil repose sur le principe du triangle des lignes d'influence. Son emploi permet de réduire la durée des calculs par rapport au temps qu'exige la mise en œuvre d'un procédé mathématique ou graphique.

Zusammenfassung

Es wird ein besonderes Rechengerät beschrieben, welches auf der Skala einer elektrischen Meßeinrichtung unmittelbar diejenige gleichmäßig verteilte Belastung abzulesen gestattet, welche dasselbe Biegemoment oder dieselbe Querkraft ergibt, wie irgend eine Lastanordnung von bis zu zweiundzwanzig verschiedenen Achsen mit Achsdrücken von 0.05 bis 31.0 Tonnen, dies alles für eine beliebige Brücken-Spannweite bis zu 45 m.

Sind einmal die Lasten mit ihren gegenseitigen Abständen auf der Maschine eingestellt, so kann auch die zu untersuchende Spannweite eingeschaltet werden.

Nun bewegt man die Brücke unter dem Lastenzug und ermittelt dabei den größten Ablesewert.

Die Wirkungsweise des Gerätes beruht auf dem Prinzip der Einflußliniendreiecke. Seine Verwendung beschränkt die für solche Berechnungen aufzuwendende Zeit auf einen kleinen Bruchteil der Zeit, die bei Anwendung eines rechnerischen oder graphischen Verfahrens zum selben Ziele führen würde.

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