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AN INSTRUMENT FOR CONTINUOUS WEIGHING OF FIRES

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FIRE
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SUMMARY

An instrument is described which can be used to obtain a continuous record of the weight of a fire during laboratory experiments. Essentially the device consists of a central weighing platform mounted on four beams which carry electrical resistance strain gauges arranged in a temperature compensated bridge circuit. The design and construction of the device is described and calibration curves are given for three ranges of fire weight. An example is given of the convective heat output characteristic of a fire obtained with the instrument.

KEY WORDS: Apparatus (measuring), burning rate, detector, fire.

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DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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1. Introduction

In many experiments involving the use of fires it is useful to have a continuous measure of the weight of the fire. This is of particular interest in work concerned with the detection of fires, since the rate of weight loss of the type of fire used will generally steadily increase with time until the fire is detected. This rate at the time of detection is then a measure of the size of fire and may be used to compare the performances of different types of detection equipment. The instrument described in this Note was developed to provide a means for weighing a fire continuously, using an electrical output, and was designed so that the sensitivity can be easily varied. The instrument was developed for use with relatively small fires, but could be designed for any maximum weight required.

2. Design of instrument

The instrument, which is constructed of mild steel, is shown diagrammatically in Figure 1. It consists of a central platform, 127 mm (5 in) square, to which a suitable supporting base for the fire can be attached. The platform is carried by four beams, each 76.2 mm (3 in) long and 12.7 mm (0.5 in) wide which are mounted on a 25.4 mm (1 in) square supporting frame. The whole assembly is machined from the solid so that the ends of the beams are encastré, and there are no moving parts to produce frictional hysteresis. The principal dimensions of the instrument are not critical and were chosen to be of a size which was suitable for the size of fire which was envisaged for a programme of work on smoke detection, which was about a 305 mm (1 ft) cube wood crib. Larger sizes could be constructed for fires of greater overall dimensions. It is necessary to make the beams of sufficient width so that electrical resistance strain gauges can be attached to them. The thickness of the central plate and surrounding frame should be large compared with that of the beams, to ensure that the beam ends are sufficiently constrained and the encastré condition is approached.

The thickness of the beam is determined by the maximum weight of fire which the central platform is intended to carry. In principle the thickness is designed such that maximum sensitivity is obtained with an adequate safety factor within the elastic limit of the material used. The calculation of the beam thickness is given in detail in Appendix 1.

3. Strain gauge bridge

The weight of the fire is measured by the use of electrical resistance strain gauges, mounted on the four beams as shown in Figure 1. The gauges were mounted as close to the surrounding frame as practicable, where the bending moment is at a maximum and therefore the strain at the beam surface. The gauges are arranged in pairs in the bridge circuit as shown in Figure 2, which has gauges in compression and tension in opposite arms so as to give the maximum sensitivity. The bridge is compensated for equal temperature changes to all the gauges, since the bridge will remain balanced for the resulting resistance changes.

A stabilised D.C. supply was used for the bridge and an initial balance was obtained by the use of a decade resistor box. The latter method was superior to the use of a potentiometer which did not give a stable zero position because of variable contact resistance. The stabilised D.C. supply enables a number of calibrations to be made at different supply voltages appropriate to different ranges of fire weight. When a suitable sensitivity has been determined for a particular application a battery supply would be suitable. In practice it is usual to switch a resistor across one arm of the bridge at the beginning and end of each experiment; this resistor will produce an output voltage corresponding to a known force from the calibration curve, so that any departure of the supply voltage from its nominal value will be apparent thus enabling corrections to be made.

The output from the bridge is connected through a D.C. amplifier to a pen recorder during an experiment so that the weight of the fire can be continuously recorded. Alternatively the output could be connected directly to data-logging equipment and a digital record obtained.

4. Calibration

The instrument was calibrated with loads applied at the centre of the load carrying plate, using stabilised voltages of 1.5, 2.9 and 11 volts to obtain three different sensitivities. The calibration curves obtained are shown in Figures 3, 4 and 5. Each calibration was carried out three times, and the bridge output was determined at each load point for both increasing and decreasing loading. The results showed very good agreement between the separate determinations, and the values given in Figures 3, 4 and 5 are the mean values for the three replications. There was no evidence of any hysteresis between the increasing and decreasing load characteristics, and the calibrations were all linear.

The bridge sensitivities for supply voltages of 1.5, 2.9 and 11 volts, determined from the slopes of the calibration curves, were 0.0540, 0.103 and 0.384 mV/kgf (0.0245, 0.0465 and 0.174 mV/1bf). The mean bridge sensitivity was 0.0355 mV V^{-1} kgf^{-1}(0.0161 mV V^{-1} lbf^{-1}).

Calibrations were also carried out at distances of 63.5 mm (2.5 in) and 101.6 mm (4 in) from the centre of the loading plate along axes of symmetry parallel to and at right angles to the axes of the bars, to examine the effects of asymmetric loading. Loading along the axis parallel to the axes of the bar produced no measurable change in the slopes of the calibration curves. Loading along the axis at right angles to the axes of the bars, however, resulted in a mean increase in the slope of the calibration curves. The change in bridge sensitivity had a mean value of 0.121 per cent/mm (3.08 per cent/in) of distance from the centre of the plate.

A change in the position of the load from the centre of the plate along either of the axes of symmetry is equivalent to a force system with an equal force at the centre, together with a couple equal to the product of the force and the distance moved by the line of application of the load. For both axes a consideration of the effects of the couple on the strain gauge bridge indicates that there will be no output arising from the couple. The calibrations would therefore be expected to be unaffected by changes in the load position. This was found to be the case for movement of the load along the axis parallel to the axes of the bars, but not for that at right angles. The reason for this is not apparent, but the error is likely to be very small in practice since a fire would normally be symmetrically placed relative to the central plate.

The observed sensitivity of the unit was found to be 17 per cent higher than that predicted from the calculations given in Appendix I, with a mean value of 35.5×10^{-3} mV V^{-1} kgf^{-1} (16.1×10^{-3} mV V^{-1} lbf^{-1}) compared with a theoretical value of 30.3×10^{-3}mV V^{-1} kgf^{-1} (13.8×10^{-3} mV V^{-1} lbf^{-1}).

5. Practical use

In practice the equipment can be used in an experiment with a fire mounted directly on the central plate. A boss was made which was made which was bolted to the centre of the plate and which carried a 152 mm (6 in) square duralumin plate on which an asbestos board can be placed. A wood crib fire can be built directly on the asbestos board, or, in the case of a flammable liquid fire a tray can be placed on the board. During the course of an experiment the weight of the fire can be continuously recorded if the bridge output is suitably amplified and fed to a pen recorder. Figure 6 shows a curve of the weight of a wood crib during the course of an experimental fire. Figure 7 shows the rate of convective heat output plotted against time which is obtained by measuring the slope of the curve of Figure 6 and calculating the convective heat output from the rate of burning. This differentiation could be performed electronically to obtain burning rate directly.

6. Conclusions

The design of a weighing device for a continuous measurement of the rate of burning of a fire during laboratory experiments is described. The device incorporated a central plate which supports the fire. Four beams are rigidly attached to the plate and their opposite ends are fixed rigidly to a surrounding frame. The weight of the fire is measured by an electrical bridge formed of strain gauges bonded to the supporting beams.

Calibrations of the instrument are given for three strain gauge bridge supply voltages. The sensitivity of the particular design used was 35.5×10^{-3} mV V^{-1} kgf^{-1}. The calibrations are linear and show no hysteresis effects.

The instrument has been shown to operate successfully for experimental fires, and differentiation of its output gives the convective heat output of the fire at any chosen time from ignition.

The unit described was designed for a fire having an initial total mass of 22.7 kg (50 lb) but any weight of fire could be accommodated by suitable design of the supporting beams.

APPENDIX I

DESIGN OF INSTRUMENT

1. Beam dimensions

The instrument was designed to support a total mass of 22.68 kg (50 lb), including supporting platforms. This means that each beam is subjected to a force of 11.34 kgf (25 lbf). Assuming that the beam behaves as a continuous beam, with its ends in an encastré condition, the maximum bending movement, M_{max}, is given by

$$M_{max} = \frac{1}{8} Wl \qquad (1)$$

where W is the load on the beam

and l is the beam length

The value of M_{max} = 0.216 kgf m (18.75 lbf in)

for W = 11.34 kgf and l = 152 mm

This maximum moment will act at the ends of each half beam.

The maximum stress, P_{max}, at the surface of each beam is given by

$$P_{max} = \frac{6M_{max}}{bd^2} \qquad (2)$$

where b is the width of the beam

and d is the thickness of the beam

If P_{max} is limited to 103 MN/m^2 (15,000 lbf/in^2), which represents a safety factor of 2 for the elastic limit of mild steel, the thickness of the beams is given by:

d = 3.12 mm (0.123 in), from equation (2) using the appropriate values for M_{max} and b

The maximum strain, $\sum_{max}$, at the beam surface is given by:

$$\sum_{max} = \frac{P_{max}}{E} \qquad (3)$$

where E is the modulus of elasticity of the material, hence for mild steel $\sum_{max} = 5 \times 10^{-4}$, putting P_{max} = 103 MN/m^2

2. Strain gauge bridge

The relative change of resistance of each gauge is given by:

$$\frac{\Delta R}{R} = k\varepsilon_{mean} \qquad (4)$$

where R is the change in gauge resistance

R is the gauge resistance

ε mean is the mean strain along the gauge

and k is the gauge factor

The centres of the gauges were at 9 mm (0.354 in) from the fixed ends of the beams, and from geometrical considerations it can be shown that

$$\varepsilon_{mean} = 0.764\varepsilon_{max}$$

The output voltage ΔV of the fully active bridge is given by

$$\Delta V = \frac{\Delta R}{R}V \qquad (5)$$

where V is the bridge supply voltage.

Now for the design conditions $\varepsilon_{max} = 5 \times 10^{-4}$, and for $k = 1.8$, which is the manufacturer's quoted gauge factor, from equation (4):

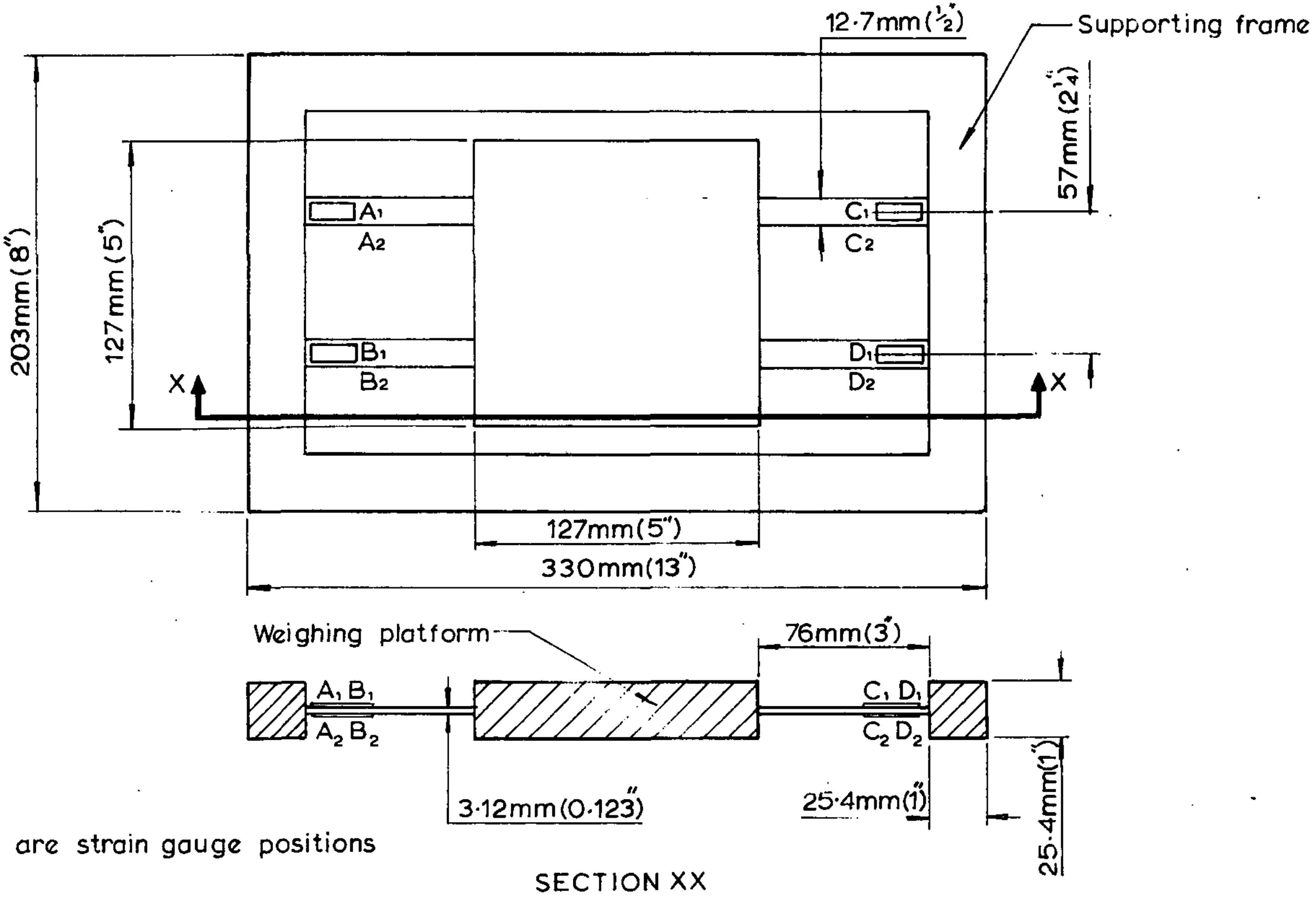
$$\frac{\Delta R}{R} = 1.8 \times 0.764 \times 5 \times 10^{-4}$$

$$= 6.87 \times 10^{-4}$$

For a design load of 22.68 kgf, using equation (5):

$$\frac{\Delta V}{V} = 30.3 \times 10^{-3} \text{ mV per volt per kgf } (13.8 \times 10^{-3} \text{ mV per volt per lbf})$$

The output voltage of the bridge can be conveniently varied by changing the supply voltage. This is limited however by the current rating of the gauges which is dependent on the degree of continuity of use of the device.



ABCD are strain gauge positions

FIG.1 DIAGRAM OF WEIGHING DEVICE

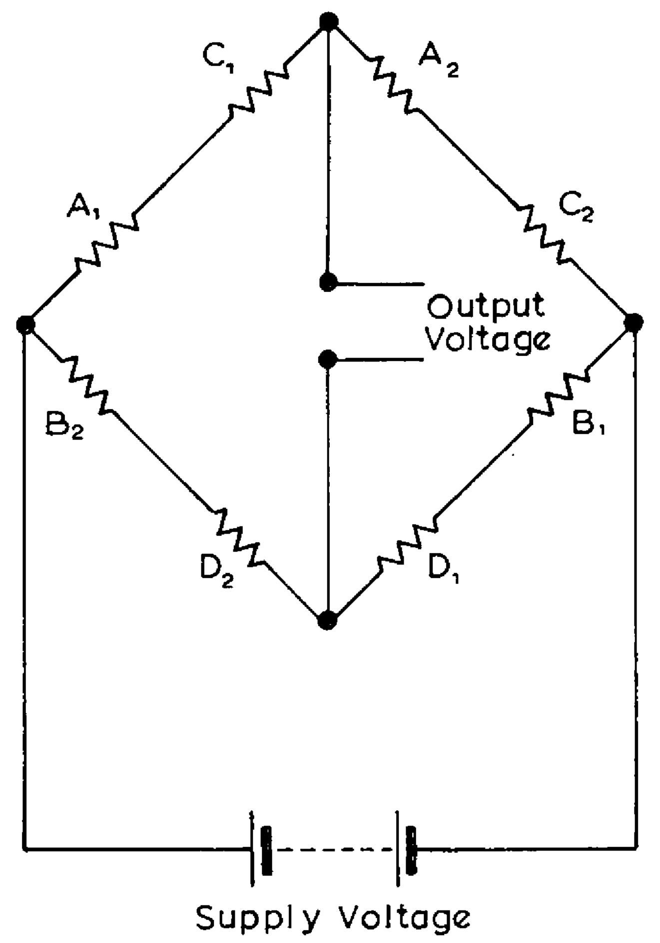


FIG. 2 ARRANGEMENT OF STRAIN GAUGES IN BRIDGE CIRCUIT

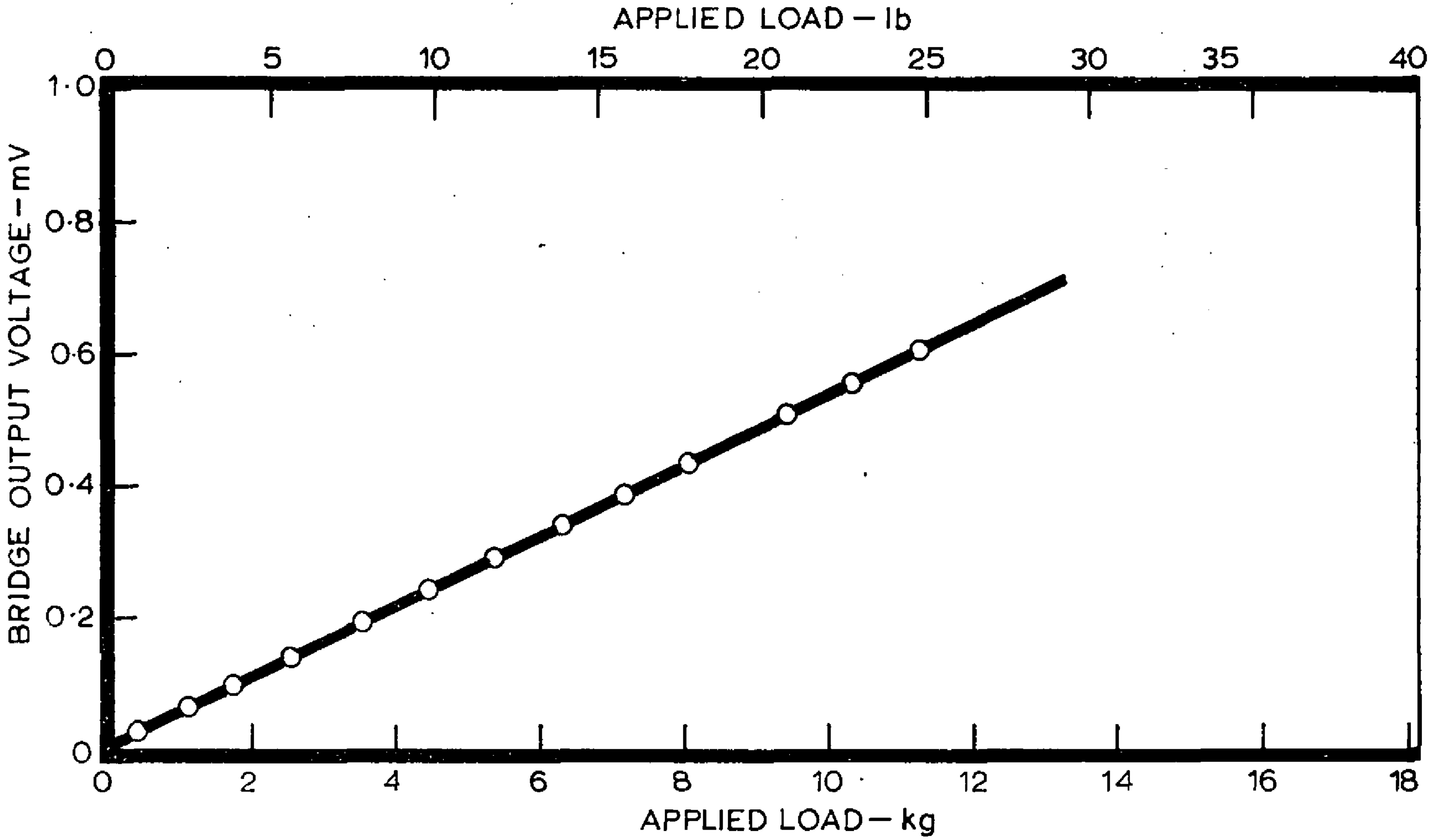


FIG. 3 CALIBRATION FOR BRIDGE SUPPLY VOLTAGE OF 1·5v

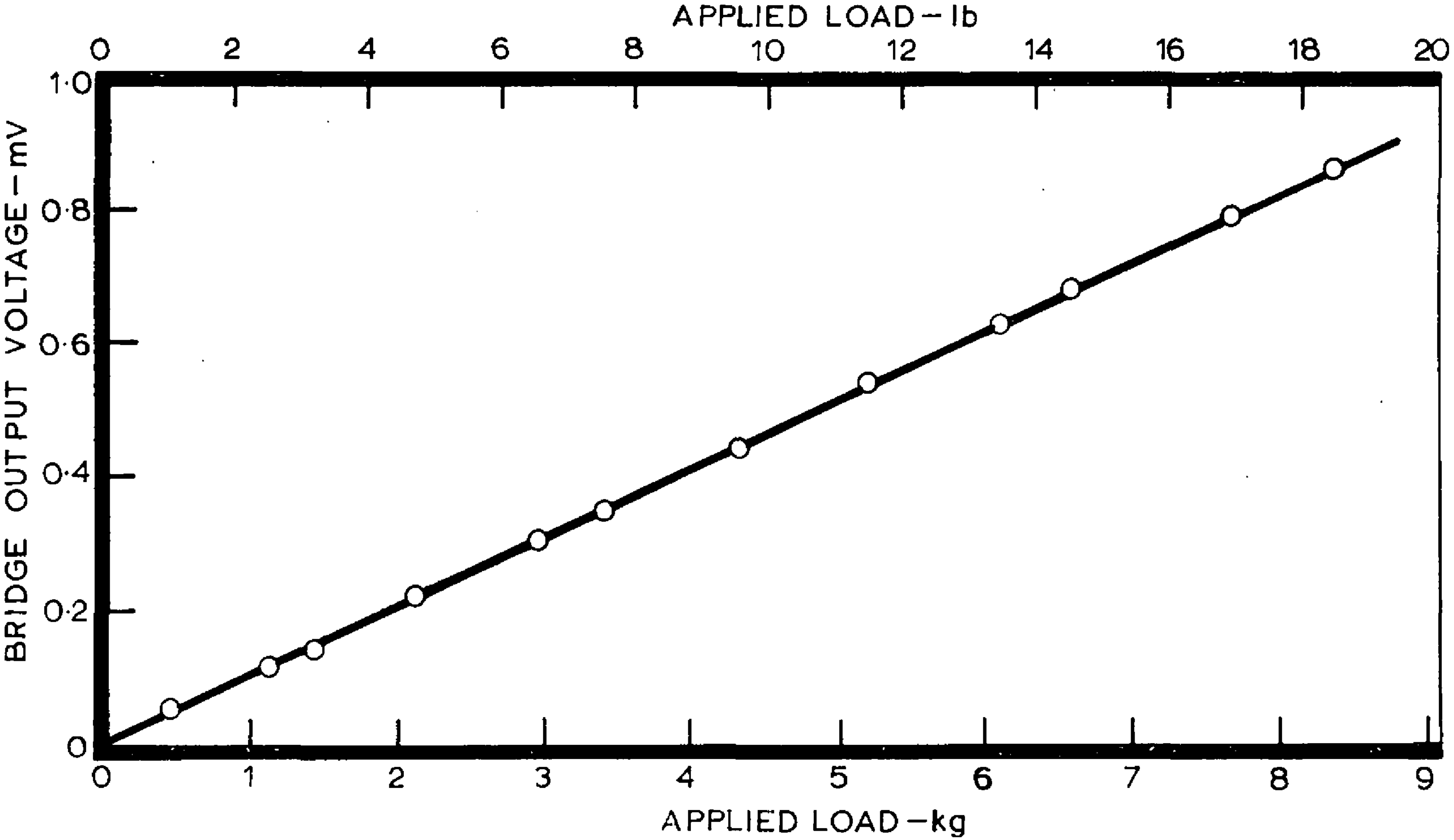


FIG. 4 CALIBRATION FOR BRIDGE SUPPLY VOLTAGE OF 2·9v

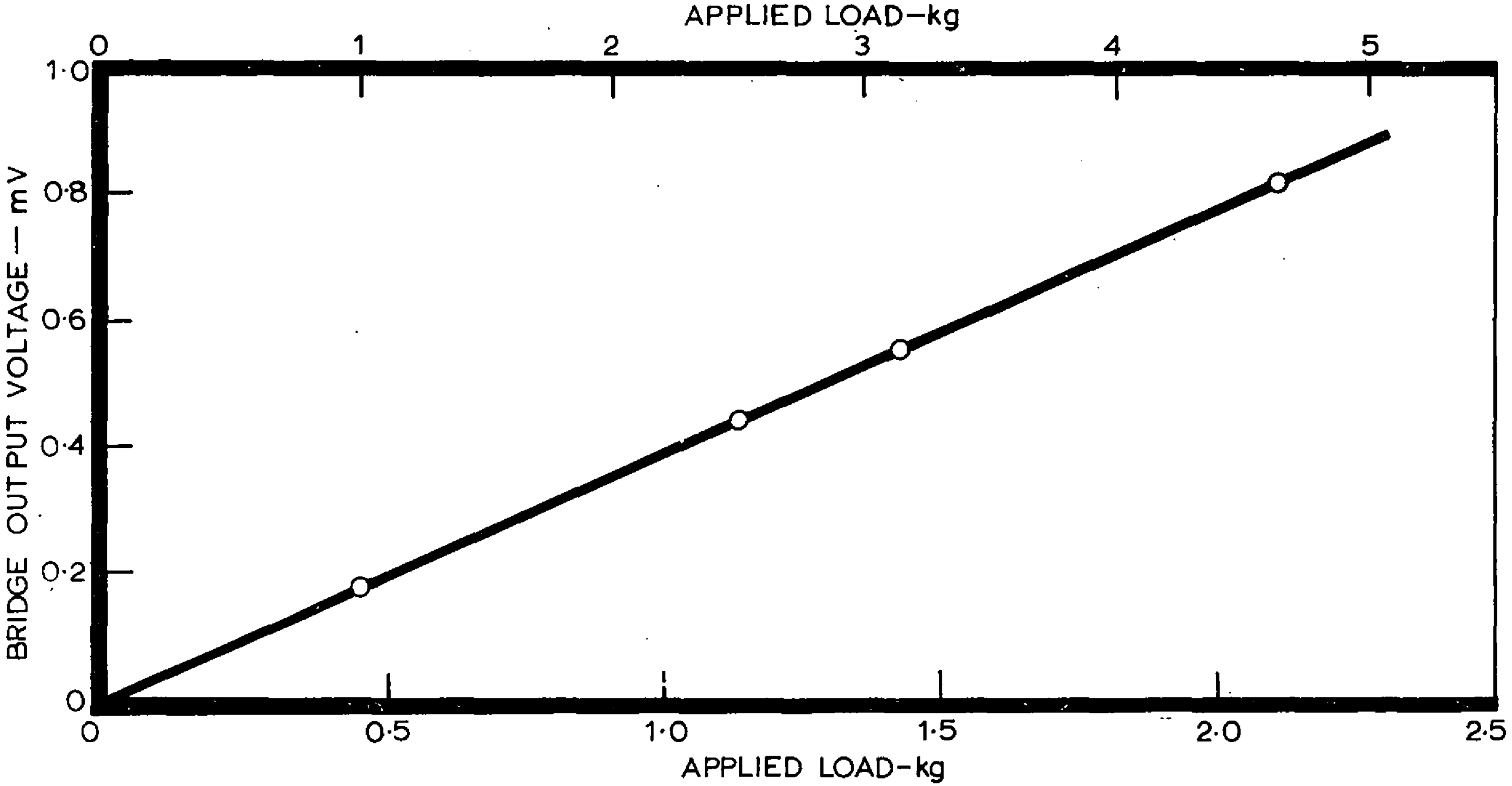


FIG. 5 CALIBRATION FOR BRIDGE SUPPLY VOLTAGE OF 11v

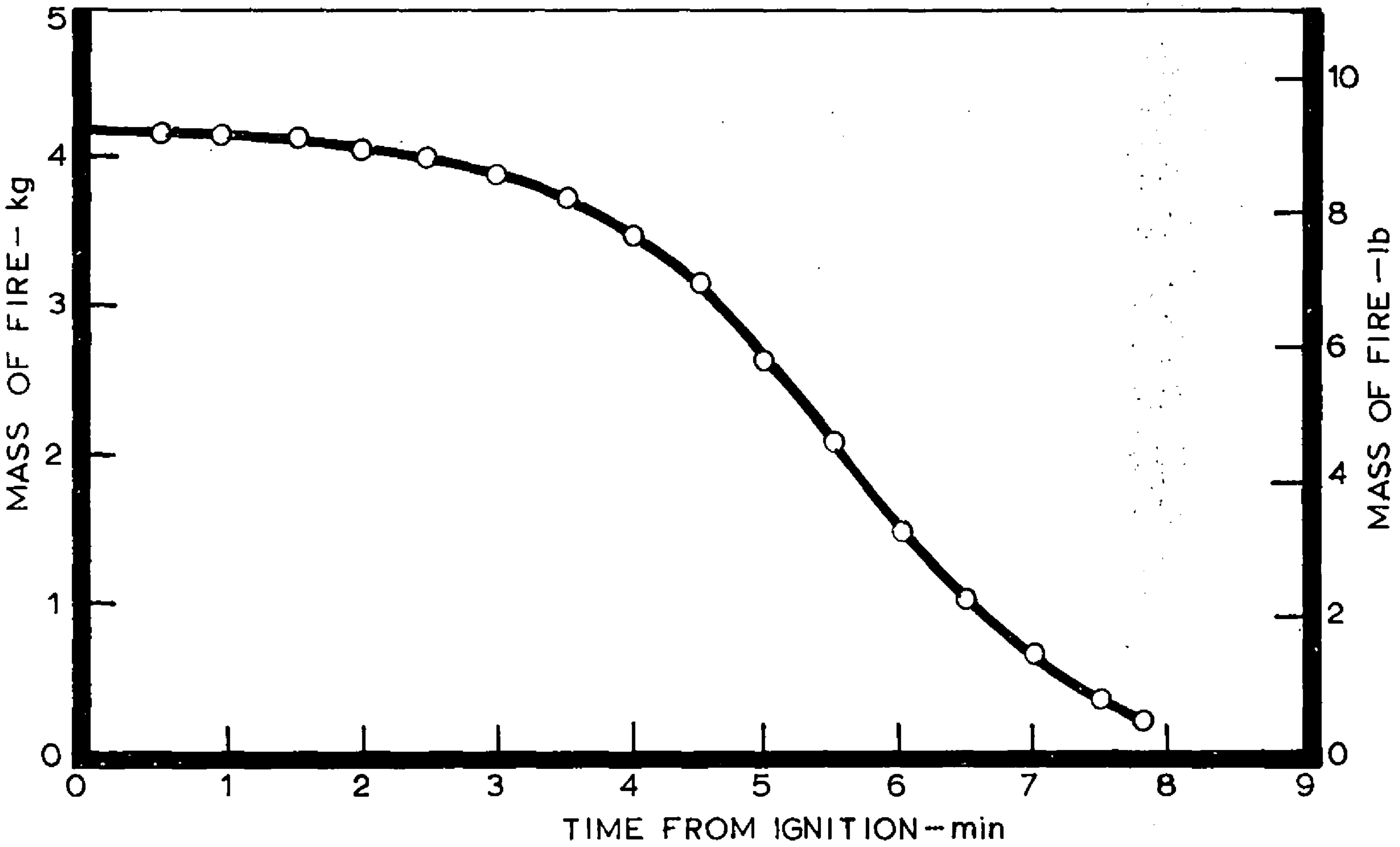


FIG.6 RECORD OF VARIATION OF WEIGHT OF A FIRE WITH TIME

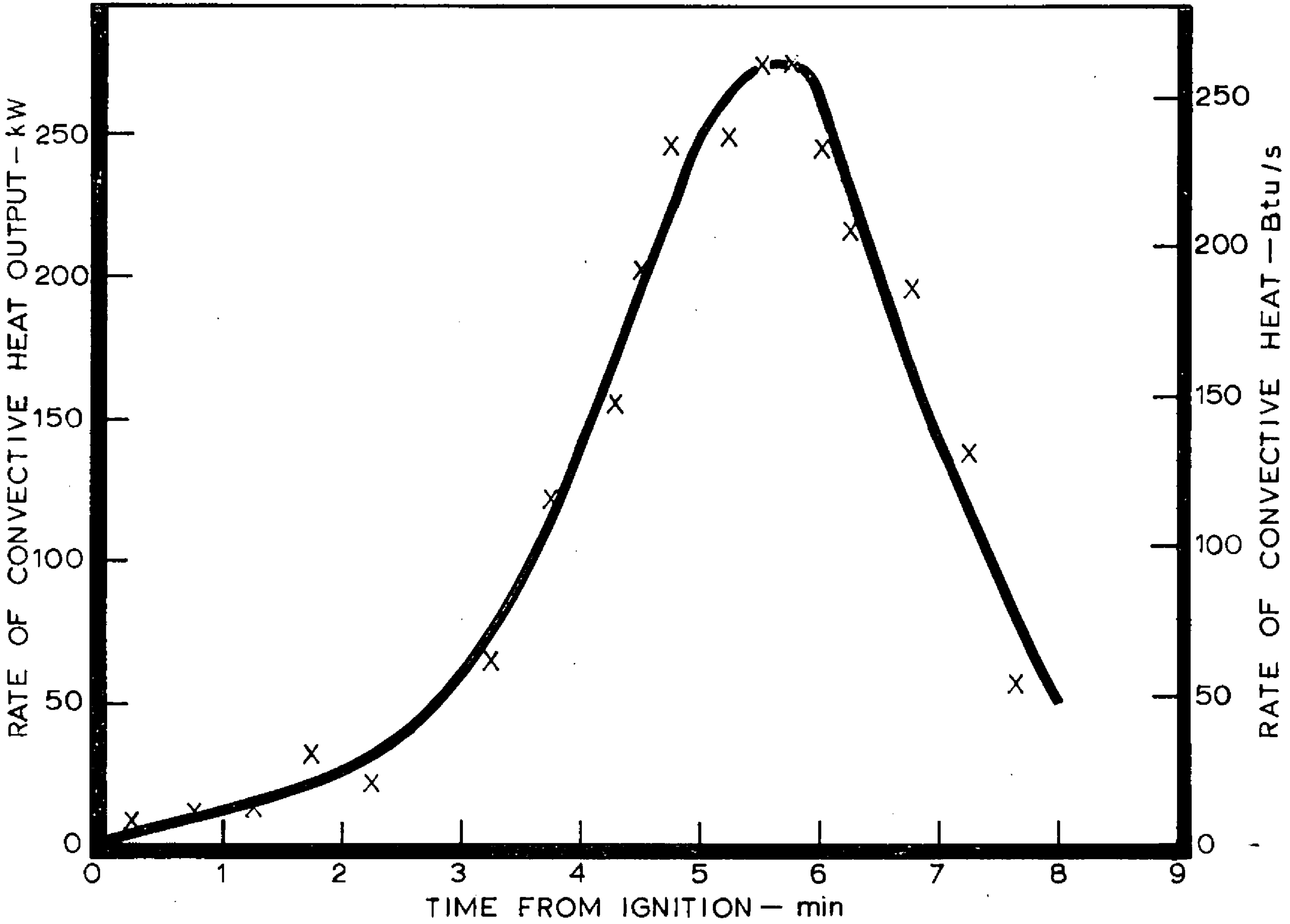


FIG.7 VARIATION OF CONVECTIVE HEAT OUTPUT OF FIRE WITH TIME