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A STUDY OF THE OPERATION OF "RATE OF RISE" HEAT-SENSITIVE FIRE DETECTORS

by

R.W. Pickard

SUMMARY

It is shown how the design of a "rate-of-rise" heat-sensitive fire detector is governed by the conditions of performance it is required to fulfil. The operating time of a detector of this type is compared with that of a similar fixed-temperature detector.

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Fire Research Station,
Boreham Wood,
Herts.

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1. Introduction

Heat sensitive detectors fall generally into two classes. There are the fixed-temperature detectors, which operate when the temperature of the sensitive element reaches a chosen value, and also the "rate-of-rise" detectors, which operate if the rate of increase in temperature of the surrounding air exceeds a chosen minimum value, for rates of rise below the minimum, such detectors are generally designed to operate when the temperature of the sensitive element reaches a given maximum.

The purpose of this note is to examine how the operating time of a "rate-of-rise" detector, the sensitive element of which consists of a pair of bimetallic strips, varies with the rate of rise of air temperature to which it is subjected.

2. Principle of operation

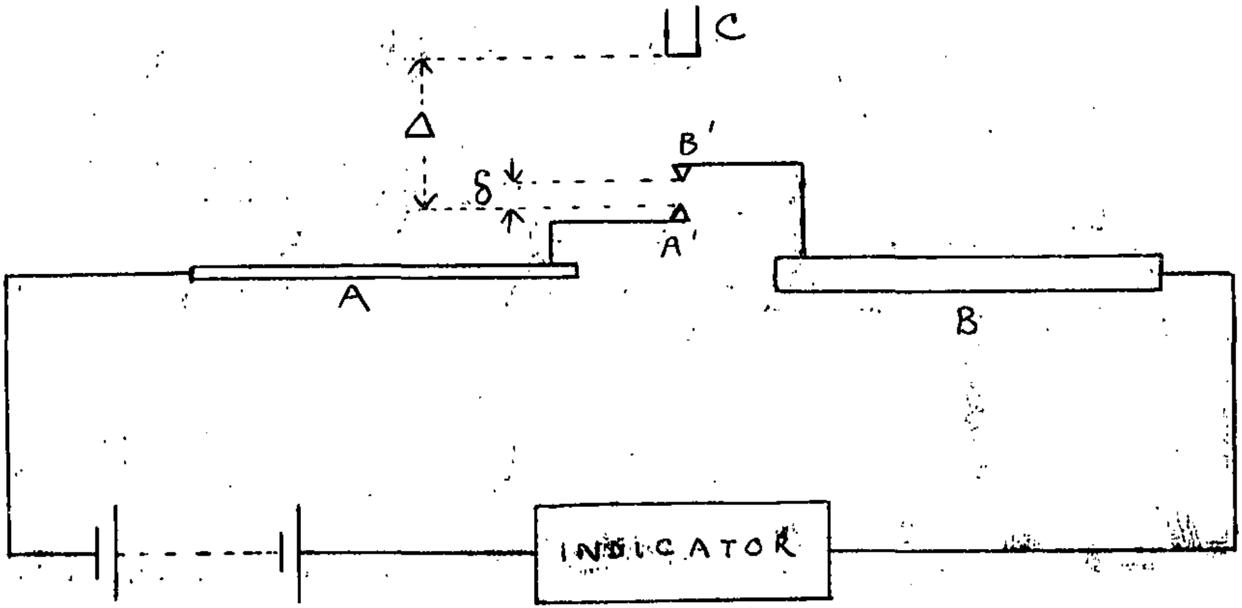

FIG.1. Arrangement of "rate-of-rise" detector

The operation of the detector is controlled by the deflection of two bimetallic strips A and B (Fig.1.) A' and B' are contacts associated with the strips A and B and initially spaced at a distance δ . C is a stop which limits the deflection of both strips and is initially spaced at from the contact A'. It is assumed that both strips are subjected to the same conditions of air temperature and velocity. The alarm will operate when A' and B' make contact.

Strip A is much thinner than strip B, and with a high rate of rise of air temperature, its deflection will be greater than that of B, so that the contacts will close after a short period of heating. With low rates of rise of air temperature, the difference in the temperatures of the two strips will be small and the spacing between the contacts will decrease only very slowly. Operation will occur under these conditions only when the movement of the contact B' has been limited by the stop C. The contacts will then close when the temperature rise of the strip A has resulted in a deflection Δ .

3. Theoretical analysis

If the thickness of the strips A and B is small compared with their length, and if they are made of the same materials, it may be assumed that the deflection of each for a given temperature rise is the same and proportional to the temperature rise. Operation will occur for rates of rise of air temperature above the minimum if

$$k\left(\theta_A - \theta_B\right) = \delta \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where θ_A and θ_B are the temperature rise of strips A and B respectively and k is the deflection of each strip per unit temperature rise.

It has been shown$^{(1)}$ that the temperature rise θ , of an element at any time t, subject to a constant velocity air flow with a linearly rising temperature of α °C second is given by

$$\theta = \alpha\left\{t - \frac{C}{HA}\left(1 - e^{-\frac{HAt}{C}}\right)\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where H is the convective heat transfer coefficient to the element
C is the thermal capacity of the element
and A is its area.

C/HA is therefore a measure of the speed of response of the element. Writing its value as T_A and T_B for the strips A and B respectively, we have

$$\theta_A = \alpha\left\{t - T_A\left(1 - e^{-t/T_A}\right)\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

and

$$\theta_B = \alpha\left\{t - T_B\left(1 - e^{-t/T_B}\right)\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The operating condition is then

$$\alpha\left\{T_B\left(1 - e^{-t/T_B}\right) - T_A\left(1 - e^{-t/T_A}\right)\right\} = \bar{\theta} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where $\bar{\theta} = \dfrac{\delta}{k}$ the temperature rise of either strip to produce a deflection δ.

Expressions for the operating time of the detector may be derived from Equation (5) for a limited range of conditions.

(a) Very rapid rates of rise of temperature

Experiments have shown$^{(2)}$ that for rates of rise of air temperature above about 300°C per minute the value of t/T_A will be less than 0.65 for most detectors and Equation (5) can be approximated to give the operating time, within an accuracy of 10 per cent, as

$$t = \frac{1}{\sqrt{\alpha}}\sqrt{\frac{2\bar{\theta}\,T_A T_B}{T_B - T_A}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

This gives the temperature rise of the more sensitive strip on operating as

$$\theta_A = \bar{\theta} \cdot \frac{T_B}{T_B - T_A} \qquad \text{.............. (7)}$$

(b) Medium rates of rise of temperature

With rates of rise of air temperature up to about 30° per minute the value of t/T_A will exceed 2.5 for most detectors(2), and Equation (5), then gives the operating time to within an accuracy of 10 per cent as

$$t = T_B \log_e \frac{\alpha T_B}{\alpha (T_B - T_A) - \bar{\theta}} \qquad \text{.............. (8)}$$

This gives the temperature rise of the more sensitive strip on operating as

$$\theta_A = \alpha \left\{ T_B \log_e \frac{\alpha T_B}{\alpha (T_B - T_A) - \bar{\theta}} - T_A \right\} \qquad \text{.............. (9)}$$

(c) Rates of rise of temperature below the minimum

In this range the detector behaves as a "fixed-temperature" type operating on a temperature rise of the more sensitive strip of θ_0 °C where $\theta_0 = \frac{\Delta}{R}$. The operating time is given by(2)

$$t = \frac{\theta_0}{\alpha} + T_A \qquad \text{.............. (10)}$$

4. Design and performance of a detector

To predict the operating time of a detector from the expressions derived in the previous section, it is necessary to consider typical values of $\bar{\theta}$, T_A and T_B , which depend on the performance requirements of the detector.

For example, it may be required that a detector shall operate on a temperature rise of the more sensitive strip of 50°C at all rates of rise of temperature less than 0.1°C per second. Then, if the value of T_A is 20 seconds, the operating time of the detector at this rate of rise of temperature will be 520 seconds (Equation 10). If the initial gap between the contacts is such that $\bar{\theta}$ = 10°C, then the two contacts will close simultaneously on the stop if the temperature rise of the less sensitive strip is 40°C in this time. Equation (4) gives the value of T_B which satisfies this condition as T_B = 120 seconds.

Fig.2 shows how the operating time of this detector varies over a range of rates of rise of temperature between 0.1 and 0.7°C per second, which could occur during the development of a fire(1). For comparison, the operating time is also shown for a "fixed-temperature" detector, the element of which has the same response time as that of the more sensitive element in the "rate-of-rise" detector, and operates on a temperature rise of 50°C.

Fig.3. shows the variation in operating temperature rise of the detector, with rate of rise of temperature. For values up to 0.1°C per second, it remains constant at 50°C. Above this, the operating temperature rise decreases and reaches a constant value of 12°C at very rapid rates of rise of air temperature (Equation 7).

5. Conclusions

Expressions have been derived for the operating time of a "rate-of-rise" detector whose sensitive elements consist of two bimetallic strips. The operating temperature rise of the more sensitive strip has also been derived. The results have shown that:

(1) Above the minimum rate of rise of temperature, the operating temperature rise of the detector decreases as the rate of rise of air temperature is increased.

(2) At very rapid rates of rise of air temperature, the operating temperature rise reduces to a constant value which is dependent on the relative response times of the two strips and the initial gap between the contacts.

(3) The operating time of a comparable fixed-temperature detector is larger at rates of rise of air temperature above the minimum.

Although the results obtained in this note have been derived for that type of rate-of-rise detector consisting of a pair of bimetallic strips, they can be applied to any type which depends for operation on some physical property which varies linearly with temperature, such as resistance or length.

References

(1) Pickard, R.W., Hird, D. and Nash, P. The thermal testing of heat sensitive fire detectors. F.R. Note No.247/1956.

(2) Hird, D., Pickard, R.W. and Ross, W. Thermal tests on some heat sensitive fire detectors. F.R. Note No.275/1956.

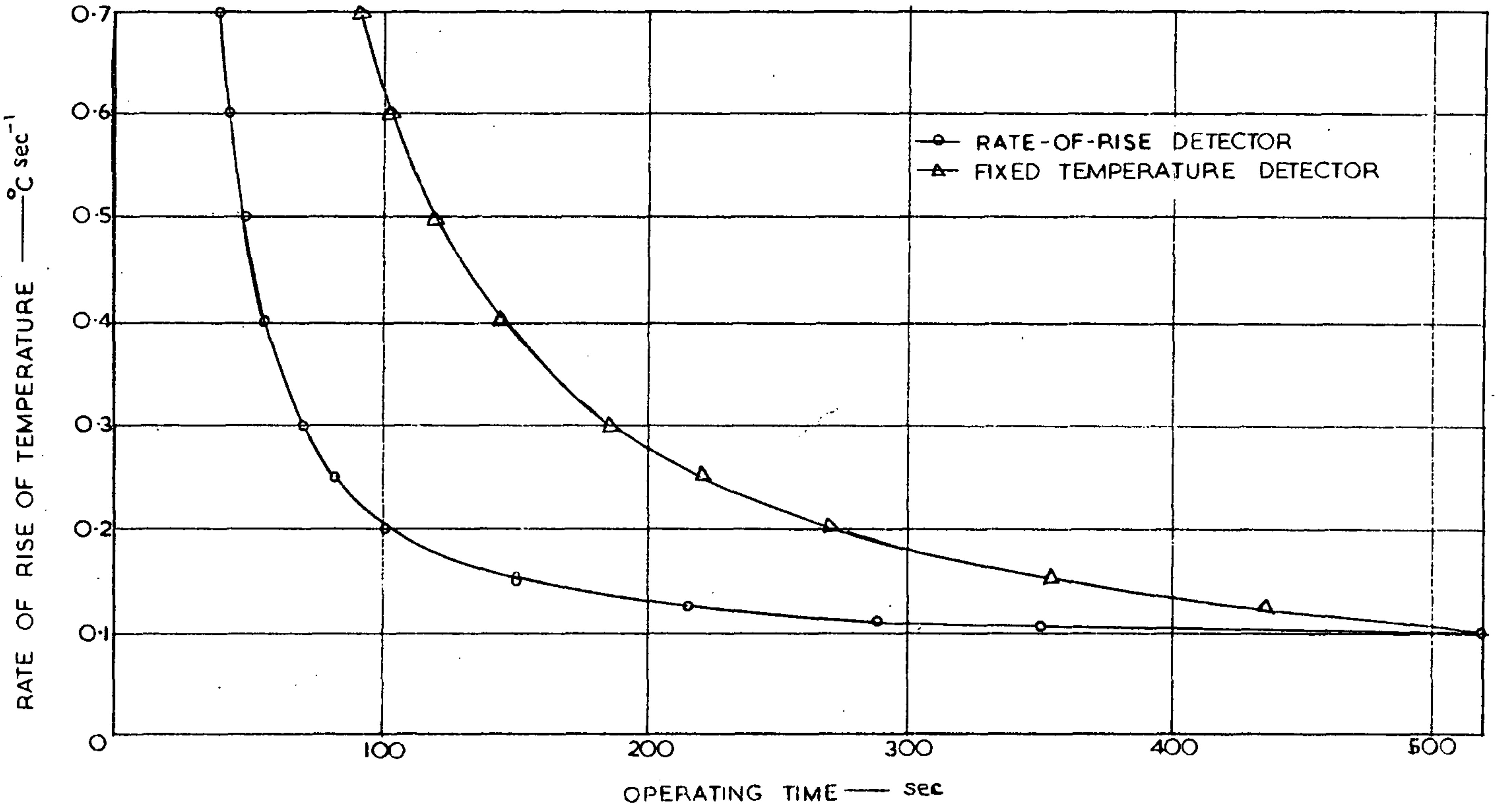

FIG. 2. OPERATING TIME OF DETECTORS

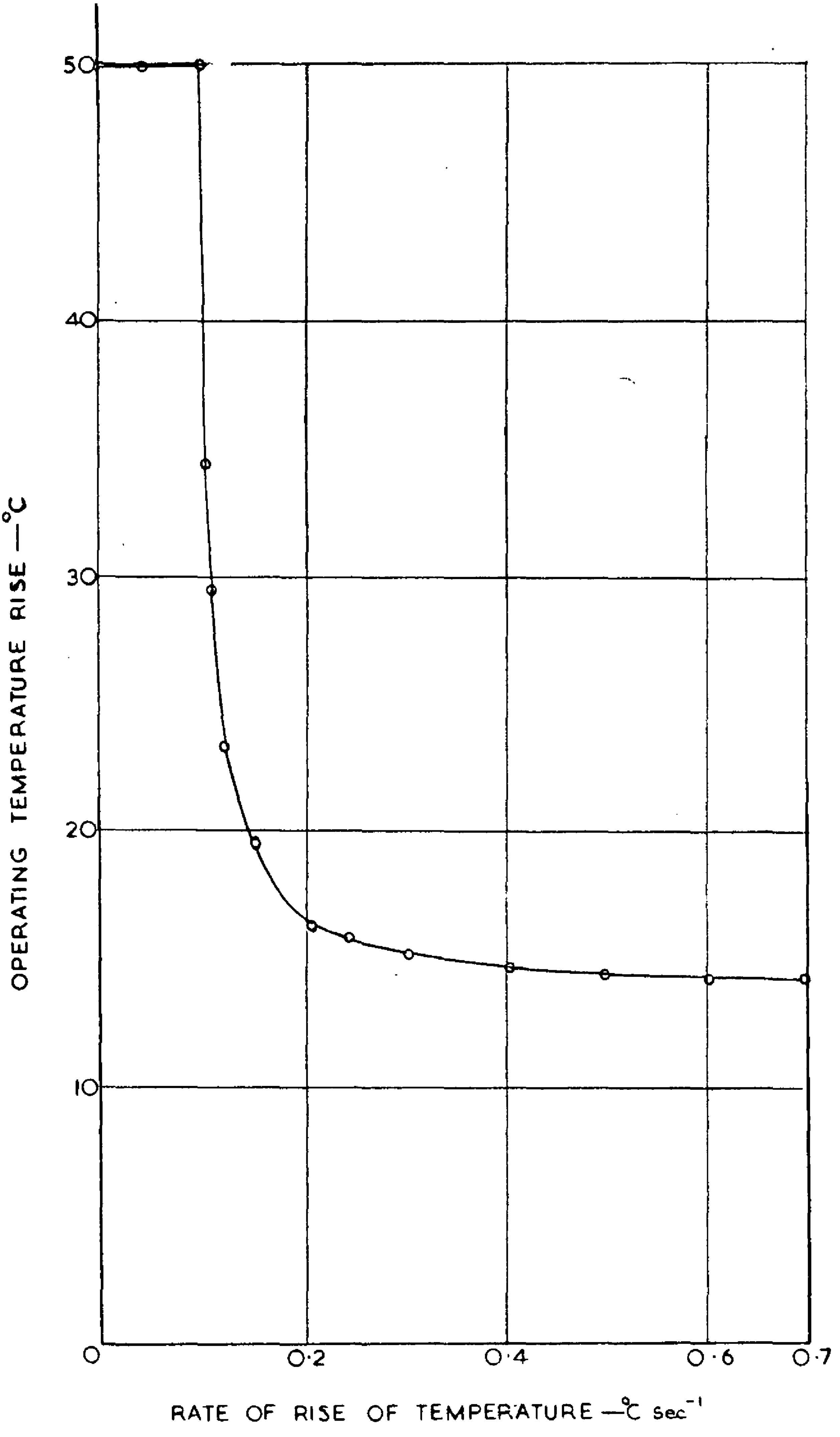

FIG. 3. VARIATION IN OPERATING TEMPERATURE RISE OF A RATE-OF-RISE DETECTOR

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