F.R. Note No. 147/1954
Research Programme
Objective D1/1

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

AN ELECTRONIC OVEN CONTROLLER

by

J. H. McGuire

Summary

An electronic on-off controller has been designed for use with ovens which are required to heat specimens to a constant temperature, the rate of heating being sufficiently slow to ensure that the specimen is not subjected to severe thermal shock. An "overheat" circuit has been incorporated to lift the temperature control level of the oven during the final stage of heating to speed up the process.

December, 1954.

File No. F.1025/8/29

Fire Research Station,
Boreham Wood,
Herts.

AN ELECTRONIC OVEN CONTROLLER

by

J. H. McGuire

1) Introduction

In controlling the heating of ovens it is often necessary not only to control the final temperature of the oven but also to avoid damage to specimens by thermal shock. An electronic on-off controller has been designed to meet this requirement and yet to heat the specimen as quickly as possible by maintaining a specified temperature difference between a point on the interior wall of the oven and a point within the specimen until the oven temperature rises near to the control level. In the final stage of heating the oven temperature is allowed to rise a little above the control level in order to speed up the heating of the interior of the specimen. The oven temperature reverts to the control level when any specified internal temperature has been attained.

The present application of the controller is to a 2 Kw electric oven which is used to heat cylindrical concrete specimens 2 inches in diameter by 4 inches in height in the course of a research programme to determine the crushing strength of concrete at high temperatures. Each specimen is heated in accordance with the following criteria:-

1) The temperature difference between the oven and the centre of the specimen never exceeds 100°C.

2) If the required control temperature is t then the oven temperature is allowed to rise to and maintain a temperature of $t + 20$°C until the temperature of the centre of the specimen is $t - 10$°C. t may have any value between 200°C and 600°C.

3) When the temperature of the centre of the specimen rises to $t - 10$°C the temperature control level of the oven is lowered to t and a warning signal is given to indicate that the specimen is ready for test.

2) General description of the controller

The general principles of operation of the controller are illustrated in Figure 1. T_1 and T_2 are chromel-alumel thermocouples attached to the inner wall of the oven and cast in the centre of a specimen respectively. The potentials representing T_1 and $T_1 - T_2$ are sampled every 5 seconds or so by a D.C. amplifier and associated circuits which cut off the power supply to the furnace heater if either of the potentials is greater than those representing the control criteria described in the Introduction. A "holding circuit" ensures that, whilst a potential is not being sampled by the D.C. amplifier, the relevant circuit remains in the condition governed by the last information supplied to it.

In parallel with the circuit which operates when $T_1 - T_2 > 100$°C is a warning circuit which operates when $T_1 - T_2 < 30$°C and indicates that the specimen is ready for test. Normally the warning is intermittent. If it is continuous it indicates a failure in the apparatus or in the power supplies. Some types of failure, such as loss of emission of certain valves, have not been catered for and to counteract this deficiency, two check push buttons have been included which substitute, for T_1 and T_2, E.M.F.'s representing $T_1 > t$°C and $T_1 - T_2 > 100$°C. Lights indicate that the relevant relays have operated and that the oven heater has been switched off.

3) Circuit details

The complete circuit diagram of the controller is shown in Figure 2, which also illustrates the division of the apparatus into three units, the input unit, the D.C. amplifier and the main unit. The input circuit with its associated relay switching (B1, see Figure 2) was segregated from the main unit as it was thought desirable to reduce unwanted thermo-electric E.M.F.'s which might be introduced by proximity to components dissipating heat at substantial rates. The contacts B_1 in the input unit, which select the input to the D.C. amplifier, are of platinum which is recommended for switching very low E.M.F.'s.

The D.C. amplifier is commercially available and on the particular range appropriate to its present application an input of 1 mV (corresponding to a temperature difference of 100°C) gives an output of 25 volts ± 1 per cent.

Valves V_1 and V_2 in the main unit comprise a stable multivibrator (1), which acts as a three pole change-over switch operating approximately every 5 seconds.

The circuits associated with V_3 and V_4 are substantially identical. When T_1 is less than t and $T_1 - T_2$ is less than 100°C, V_3 and V_4 are cut off. When one of these temperature conditions is exceeded, the relevant valve, when connected to the output of the amplifier, conducts and the relay in its anode circuit operates. Whilst the valve is disconnected from the amplifier it does not revert to its previous condition because its grid is taken to a relatively high potential through relay contacts C_2 or D_2. The RC circuits in the grid of each valve serve as delay networks which are necessary due to the fact that the response of the DC amplifier to a change of input is sometimes delayed by as much as a quarter of a second.

The grid of V_5 is connected to the same input as the grid of V_4 and during the greater part of a heating cycle this valve is conducting and the relay E operated. When however the grid circuit is connected to the amplifier and the output voltage is low, representing $T_1 - T_2$ less than 30°C, V_5 is cut off and the warning is sounded. This warning is intermittent as V_5 conducts when it is disconnected from the amplifier. Continuous warning indicates failure of the HT supply or loss of emission of V_5.

During the course of a heating cycle V_4 must operate at least once, representing $T_1 - T_2 \geqslant 100$°C and when it does so the relay F in the input unit operates. An additional backing-off potential, representing 20°C, is connected in series with the main backing-off unit. The control level of T_1 is therefore raised 20°C and this condition is maintained until the warning is sounded and the circuit thereby automatically disconnected.

As the controller does not "fail to safety" in the event of failure of valves V_3 and V_4 a circuit has been included in the input unit to allow a rapid check that the equipment is functioning satisfactorily. E.M.F.'s representing $T_1 = t$ (or $t + 20$°C) and $T_1 - T_2 = 100$°C may be substituted for the thermocouples by pressing the appropriate push buttons.

4) Performance

Oven time-temperature records often exhibit oscillatory variation, with a maximum amplitude of ± 7°C, from the curve which would represent perfect control according to the criteria specified. This is due to the fact that the thermocouple T_1 is not directly attached to the oven heater but to a wall of the oven which is separated from the heater by a quarter of an inch of refractory material. There is thus a time lag in the response of T_1 to variations in the temperature of the heater. Since the controller links T_1 and the electrical power supplied to the heater the system constitutes a relaxation oscillator.

If T_1 were to register the oven heater temperature, an accuracy of control of $\pm$ 2°C (both short and long term) could be expected.

A typical time-temperature record of a test is illustrated in Figure 3 where the oscillatory variation in the oven wall temperature is immediately apparent.

The time-temperature curve of the interior of the specimen, between 100°C and 400°C, is not quite linear and this is due to the fact that the oven was not completely sealed from the atmosphere and that the cooling was thus subject to variation. Under such conditions efficient manual control of the oven heater was practically impossible.

The equipment has now been operating satisfactorily for approximately a year.

5) Acknowledgement

Acknowledgement is due to Mr. I. C. Emson for part of the design of the equipment.

6) Reference

1. J. H. McGuire. "A stable multivibrator". Letter to "Electron. Engng", 1954, 26, 321, p. 504.

PC.

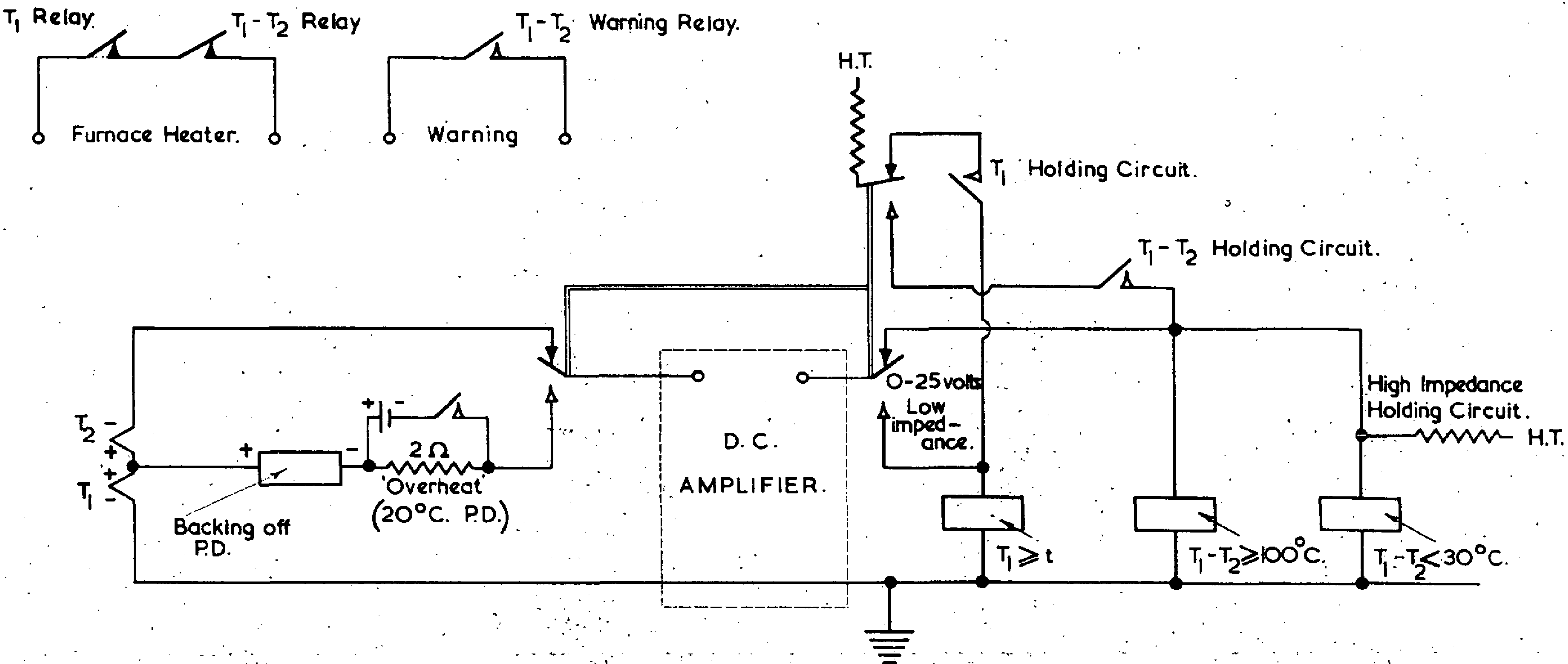

FIG. 1. FUNCTIONAL DIAGRAM OF OVEN CONTROLLER.

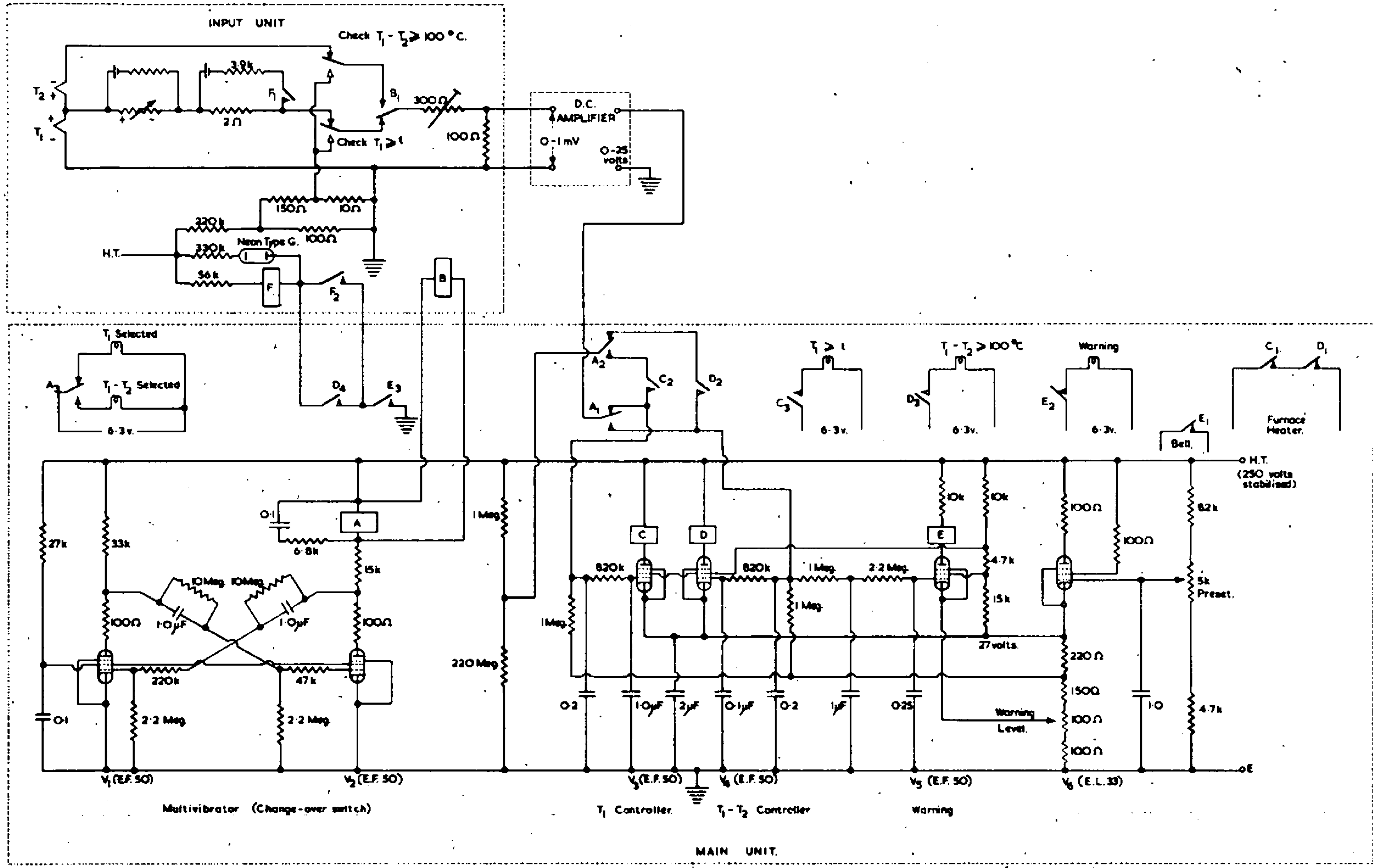

FIG. 2. CIRCUIT DIAGRAM OF OVEN CONTROLLER.

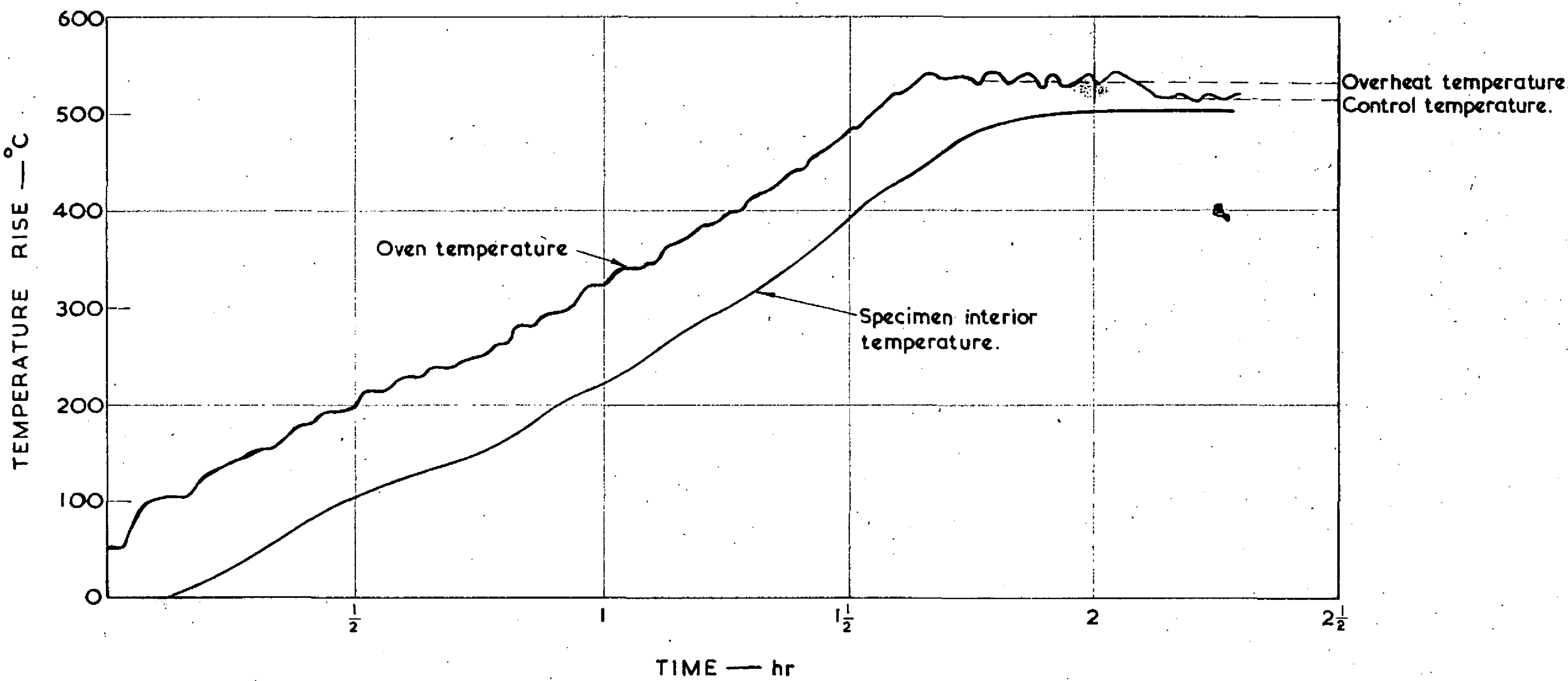

FIG. 3. A TYPICAL TIME-TEMPERATURE RECORD OF A TEST