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TEST OF TRANS-SONICS, INC., TYPE 21-14 TEMPERATURE PICKUP

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NATIONAL BUREAU OF STANDARDS

MARCH 1953

WRIGHT AIR DEVELOPMENT CENTER

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National Bureau of Standards

March 1953

Power Plant Laboratory
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Wright Air Development Center
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United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the National Bureau of Standards, Washington, D. C., under Contract No. AF (33-616)53-1. The contract was initiated under the research and development project identified by RDO No. 540-20A, and it was administered under the direction of the Power Plant Laboratory of Wright Air Development Center with Lt. A. M. Lapides acting as project engineer.

ABSTRACT

This report presents the results of calibration and performance tests of a resistance-type temperature probe designed and constructed by Trans-Sonics, Incorporated, Bedford, Massachusetts.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained herein. It is published primarily for the exchange and stimulation of ideas.

FOR THE COMMANDER:

NORMAN C. APPOLD
Colonel, USAF
Chief, Power Plant Laboratory

TEST OF TRANS-SONICS, INC., TYPE 21-14 TEMPERATURE PICKUP

By Andrew I. Dahl and Paul D. Freeze

INTRODUCTION

The Trans-Sonics, Inc. temperature pickup comes under general classification of resistance thermometer and is applicable for the measurement and control of exhaust gas temperatures in jet engines. The tests to which the unit was subjected include: (1) Resistance-temperature calibration, (2) Evaluation of the effects of radiation and conduction on temperature indication, (3) Determination of rate of response, and (3) Determination of recovery factor.

DESCRIPTION OF TEST UNIT

Figure 1 is a photograph of the Trans-Sonics Type 21-14 temperature pickup. The constructional details are shown in figure 2. The unit is essentially a two-lead platinum resistance thermometer with the sensing element encased in an 18-8 stainless steel sheath. The element is a flat grid of platinum imbedded in a ceramic insulation and is located within 3/4" of the flattened end of the tube. The lead wires are of constantan and are protected mechanically with a flexible stainless steel sleeving which also serves as electrical shielding. A screw-type fitting attached to the protecting sheath serves as a means of mounting the instrument.

RESISTANCE-CALIBRATION TESTS

The electrical resistance versus temperature relation for the Trans-Sonics temperature pickup was determined for the range 32° to 1600°F. For observations at 32°F the bulb was immersed directly in an ice bath and the resistance of the unit measured with a Wheatstone bridge. For calibration at higher temperatures the test unit and a calibrated Chromel-Alumel thermocouple were placed in adjacent holes in a copper block immersed in a horizontal tube furnace. Corresponding values of the resistance of the bulb and its temperature were observed at intervals of about 200°F. The resistance-temperature calibration data are shown graphically in figure 1.

RADIATION AND CONDUCTION EFFECTS

When a temperature sensitive element is placed in a stream of hot gas flowing in a pipe whose walls are cooler than the gas, heat will be transferred from the gas to the element by convection and from the element to the surrounding walls by radiation and conduction. The element will, therefore, attain an equilibrium temperature representing the state at which the rates of heat gain and loss are equal. Thus the temperature indicated by the element will be lower than the true temperature of the gas by an amount depending upon such factors as the temperature difference between gas and wall, surface emissivity of the sensing element, the gas flow rate, and the physical dimensions and thermal conductivity of the element and its supporting members. Because of the number and nature of the factors involved, it is generally impractical to calculate the value of the corrections to be applied to indicated temperatures. A more reliable value can usually be obtained by a direct comparison with a calibrated laboratory-type instrument under specified conditions of temperature and gas flow rate.

The calibration of the Trans-Sonics temperature pickup for the combined effects of radiation and stem conduction was made by comparing the temperatures indicated by the pickup with the indications of a silver-shielded Chromel-Alumel thermocouple which had previously been calibrated against a radiation-compensated laboratory standard. The comparisons were made in an exhaust gas stream with gas temperatures of 1000° to 1500°F and wall temperatures of 800° to 1400°F with gas flow rates of 3, 5, and 8 lb/sec ft^2. The wall temperatures were measured by means of Chromel-Alumel thermocouples peened into the pipe wall.

No attempt was made to measure separately the radiation and conduction effects. It is believed that the conduction error would be small compared to the radiation error for gas temperatures above 1000°F.

The radiation-conduction calibration data for the Trans-Sonics temperature pickup are summarized in Table I. It is believed that the values of the corrections given in the table are accurate to ±8°F when the corrections are less than 25°F and to one third of the correction when the latter exceeds 25°F.

RESPONSE RATE TESTS

The rate at which a temperature sensing device responds to a sudden change in the temperature of the medium in which it is immersed is an important factor in control applications. This is particularly true in the case of jet engine operation, where temperature changes may occur with extreme rapidity and where an increase beyond a predetermined operating limit may cause extensive damage to the turbine.

The response rate of a temperature sensing device is usually designated by its characteristic time, which by definition, is the time required for the device to undergo 63% of the total temperature change to which it is subjected instantaneously. Since the rate of response is a function of the convective heat transfer, the gas flow rate must be specified simultaneously with the characteristic time.

Since the resistance-temperature relation for platinum is approximately linear, as can be seen from figure 1, the rate of temperature response of a platinum thermometer can be closely determined from the record of resistance versus time taken after the unit is subjected to an instantaneous change in temperature. Such records were obtained with the Trans-Sonics temperature pickup mounted in an exhaust gas stream. The change in resistance of the platinum element was recorded on a direct-inking Brush magnetic oscillograph, a schematic diagram of the test circuit being shown in figure 4. As a means of increasing the sensitivity of measuring the change in resistance, a bucking emf, E, slightly less than the potential drop across the test unit at its initial temperature, was inserted in the circuit.

Response records of the Trans-Sonics unit were obtained for gas flow rates of 3, 5, and 8 lb/sec ft^2. A typical oscillograph record and a large scale plot of the change in resistance with time, obtained from the oscillograph record, are shown in figure 5. A summary of the observations of response rate is given in Table II.

RECOVERY FACTOR TESTS

When an immersion-type instrument, such as a resistance thermometer, is used to measure the temperature of a gas moving at a velocity of about 300 ft/sec or higher, the thermal effect of the impact of the gas molecules against the sensing element becomes significant. Since the magnitude of the impact effect increases as the square of the gas velocity, errors of considerable magnitude may result at high velocities unless the impact effects are taken into account.

The effectiveness of a particular probe in indicating the total temperature of a moving gas stream is expressed by its recovery factor, r, defined as

$$r = (T_i - T_s)/(T_t - T_s)$$

where T_i = temperature indicated by the sensing element
T_s = static temperature of the gas
T_t = total temperature of the gas

The recovery factor of the Trans-Sonics probe was determined with the unit mounted at the discharge of a nozzle. From auxiliary pressure and temperature measurements, the total and static temperatures of the gas were obtained, which, together with the indications of the test probe, were used to calculate the recovery factor. Figure 6 shows the observed and calculated recovery factor data. The recovery factor of the Trans-Sonics temperature pickup was found to be 0.71.

DISCUSSION OF RESULTS

In the construction of the Trans-Sonics temperature pickup, constantan is used as lead wire. Although the change in the resistance of the constantan with temperature may be regarded as negligible, the absolute value of the resistance of the constantan leads compared with that of the platinum element is very appreciable. Since the resistance of the platinum element alone cannot be measured directly, much of the advantage of using such a material having accurately known resistance-temperature characteristics is lost. However, the only alternative is to employ a three- or four-lead arrangement.

Relatively large corrections for radiation and conduction effects are inherent in all temperature probes in which the sensing element is encased in a protecting sheath. Furthermore this construction results in high values of characteristic time.

From a mechanical standpoint, the Trans-Sonics probe appears to be a rugged instrument capable of withstanding the rigors of normal jet engine operation. No stability tests of the unit were conducted.

Table I. Calibration of Trans-Sonics Temperature Pickup for Effects of Radiation and Conduction

Thermometer Reading	Pipe Wall Temperature	Corrections to Thermometer Readings for the following gas flows in lb/sec ft^2: 3	5	8
Degrees - Fahrenheit				
1500	1500	0	0	0
1500	1400	51	40	31
1500	1300	95	74	58
1500	1200	131	103	80
1500	1100	162	127	99
1400	1400	0	0	0
1400	1300	44	34	27
1400	1200	80	63	49
1400	1100	111	87	68
1300	1300	0	0	0
1300	1200	37	29	22
1300	1100	67	53	41
1300	1000	93	73	57
1200	1200	0	0	0
1200	1100	31	24	19
1200	1000	56	44	34
1200	900	78	60	46
1100	1100	0	0	0
1100	1000	25	20	15
1100	900	46	36	28
1100	800	64	49	39
1000	1000	0	0	0
1000	900	21	16	13
1000	800	37	29	23

Table II. Response Rate of Trans-Sonics Temperature Pickup

Run No.	Characteristic Time - Seconds at flow rates in lb/sec ft^2: 2	5	8
1	14.2	12.0	10.0
2	14.5	12.0	9.8
3	14.5	12.5	9.5
4			9.8
Average	14.3	12.2	9.8

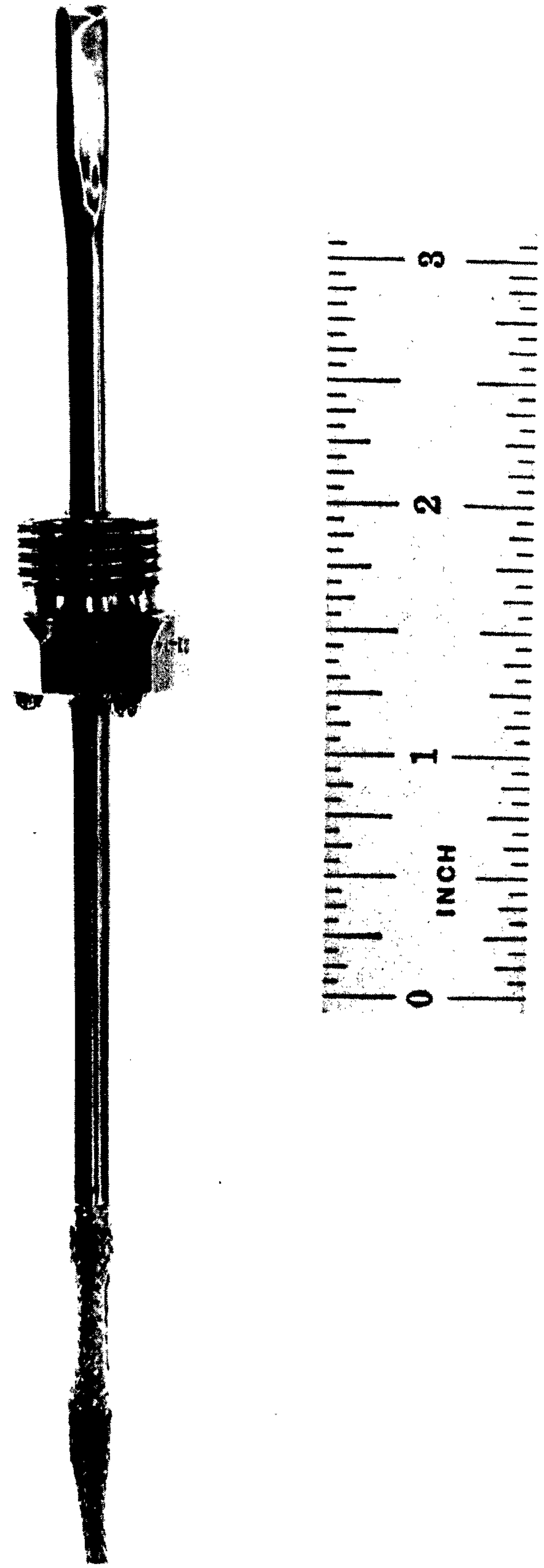
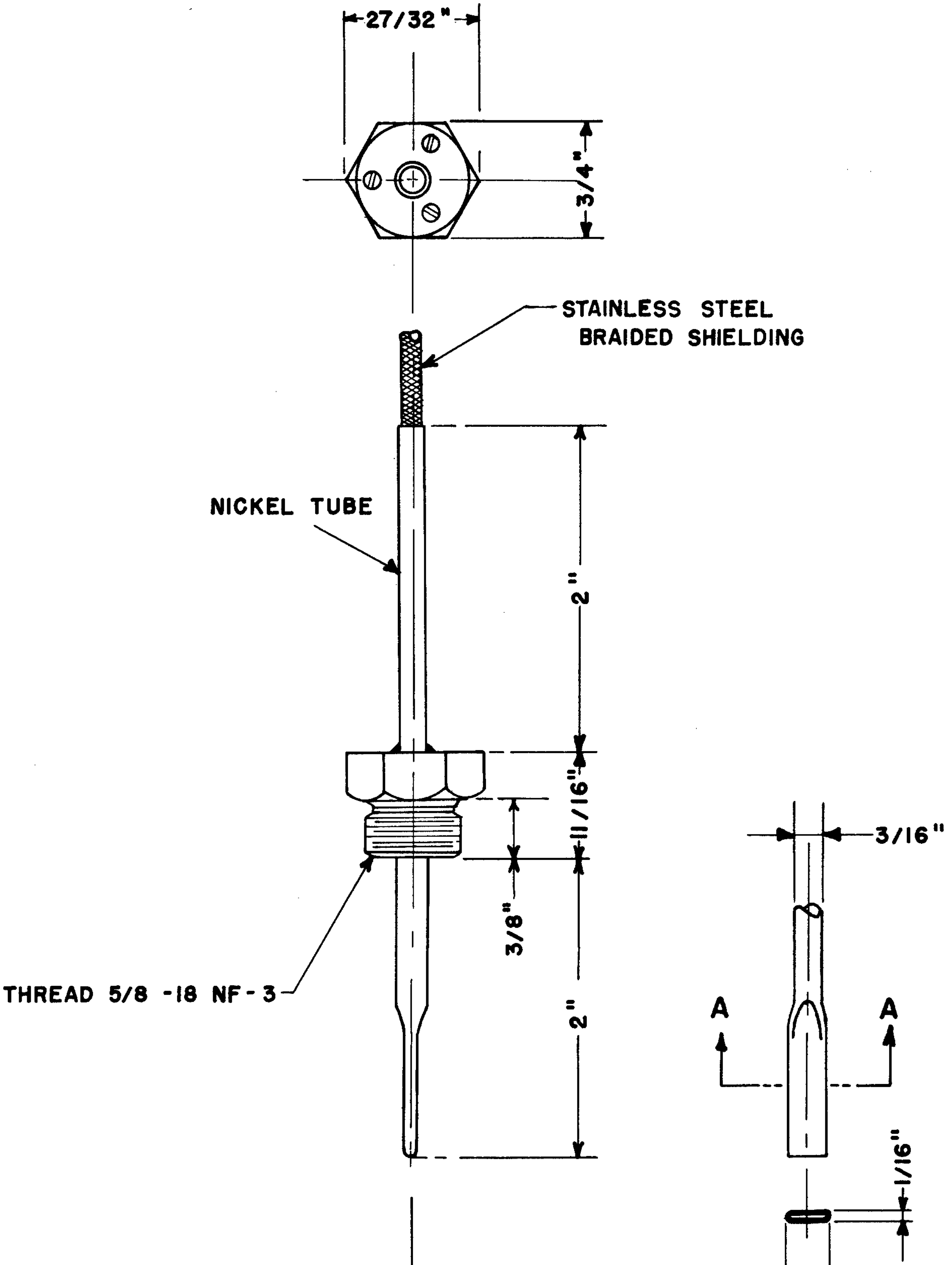


FIGURE I



SCALE : FULL SIZE

SECTION A-A

FIGURE 2

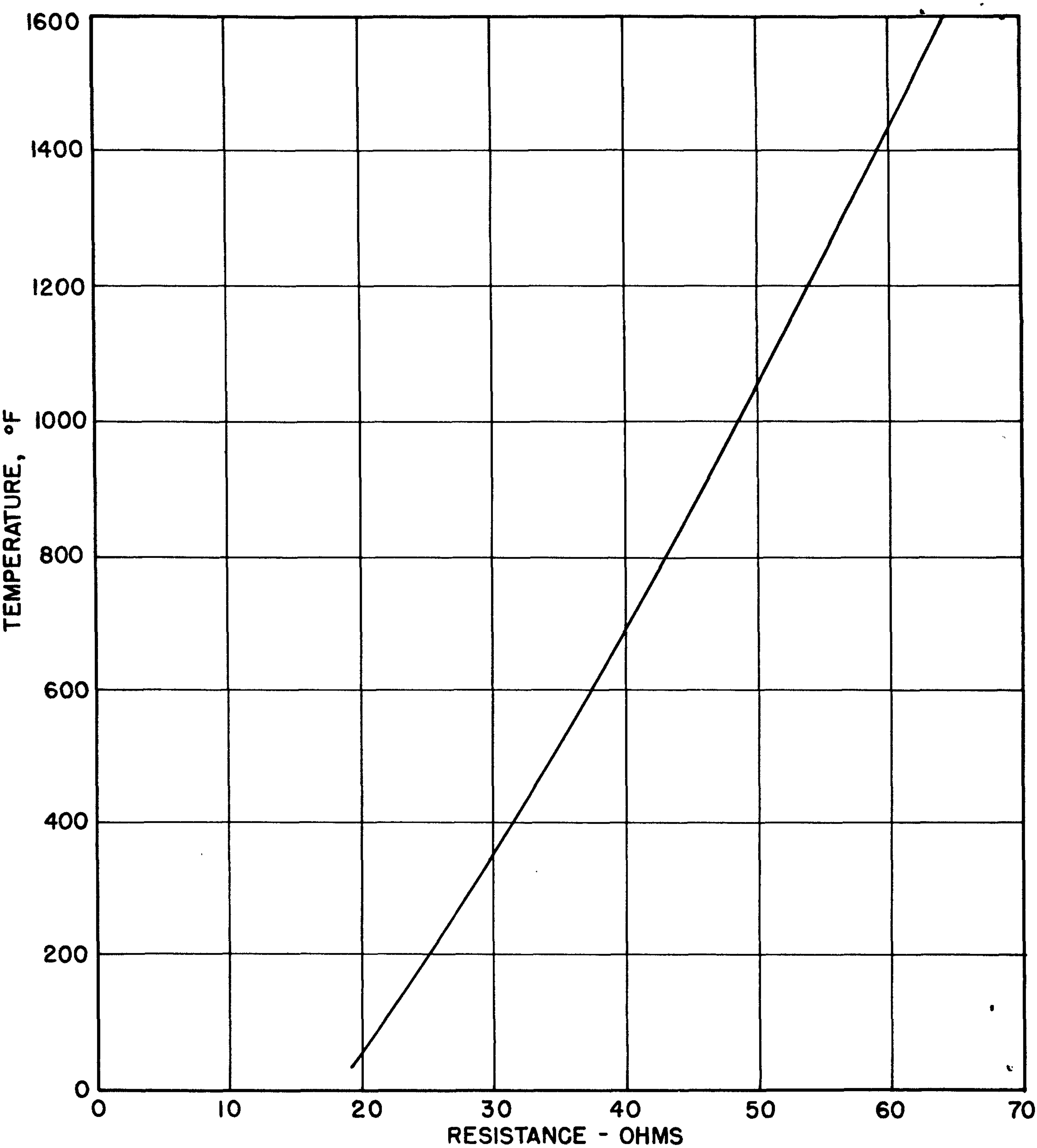


FIGURE 3 RESISTANCE-TEMPERATURE RELATION FOR TYPE - 21 ELEMENT

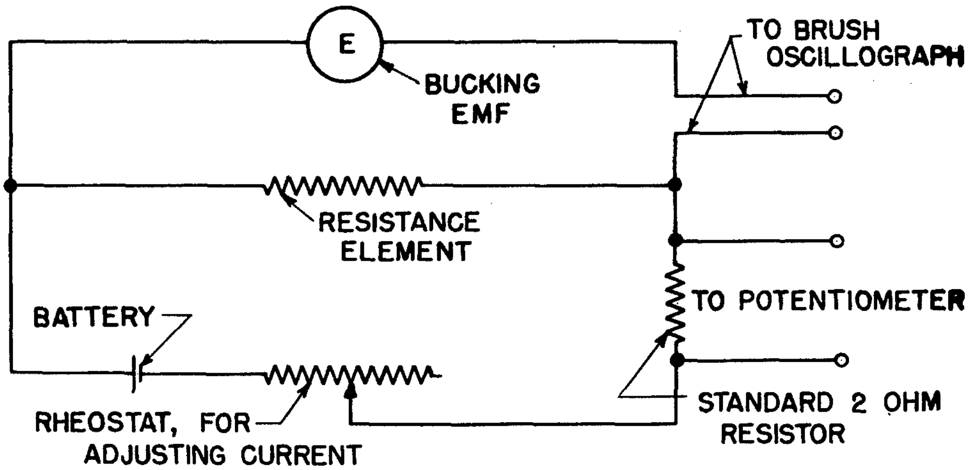
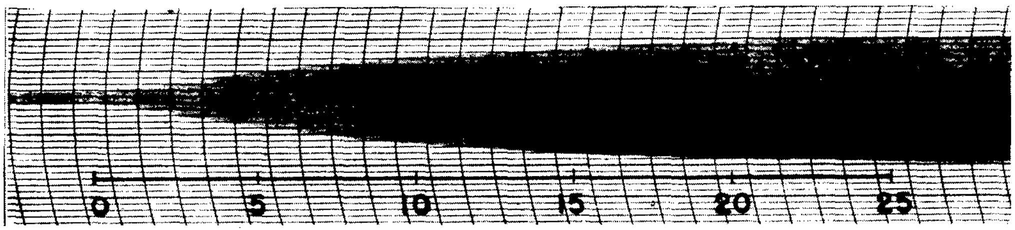
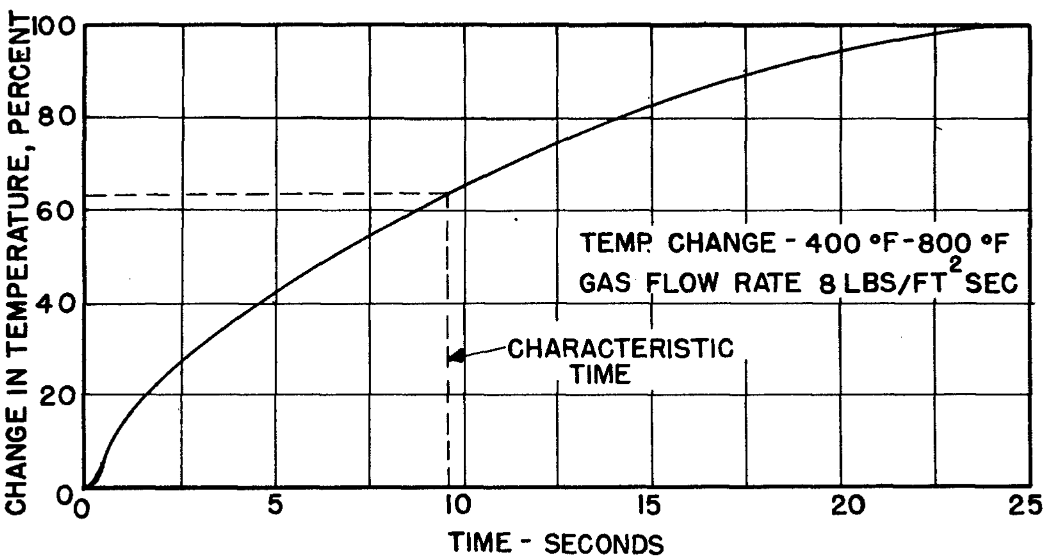


FIGURE 4 WIRING DIAGRAM FOR RESPONSE TEST



TIME - SECONDS

A. OSCILLOGRAPH RECORD



B. RESPONSE CURVE

FIGURE 5 TYPICAL RESPONSE-RATE TEST RECORD

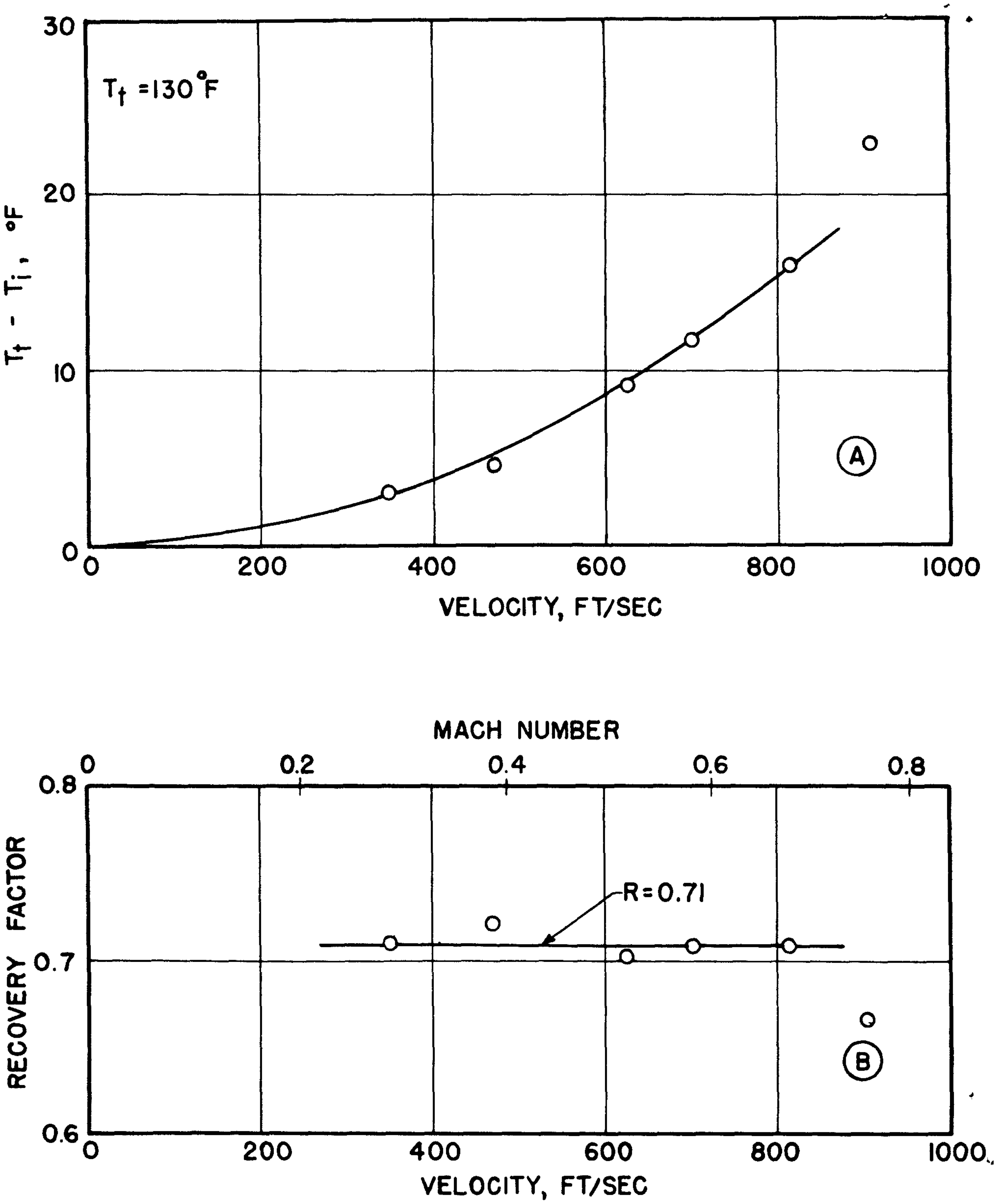


FIGURE 6 RESULTS OF RECOVERY FACTOR TEST