WADC TECHNICAL REPORT 54-388, SUPPLEMENT NO. 1

A STUDY OF THERMISTOR MATERIALS FOR USE AS TEMPERATURE-SENSING ELEMENTS IN THE HIGH-VELOCITY EXHAUST GASES OF JET-TYPE ENGINES

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FOREWORD

This supplement to WADC Technical Report No. 54-388 was prepared at the National Bureau of Standards, Washington, D. C., on Delivery Order AF 33(616)53-1, Project No. 3073-30245, "Thermocouples and Pyrometric Devices." The work is administered under the direction of the Power Plant Laboratory, Wright Air Development Center, with Lt. Don G. McKee acting as project engineer.

The information reported here represents an extension of that reported previously on a joint study by Rutgers University and the National Bureau of Standards (Ref. 1). The subject matter is in two parts concerned respectively with: I. Effects of Varying Applied Voltage and Frequency on the Resistances of Four Thermistors; and II. Performance of Thermistors in Engine-Type Mountings. The temperature range covered was from 1000° to 1800°F.

Complete details of the disk- and rod-shaped thermistors used in Part I are given in the original report; these were prepared at Rutgers University. The engine-type instruments, used in Parts I and II, and described later in this report, were prepared jointly by Rutgers and the BG Corporation.

ABSTRACT

The report describes further work done on thermistors mentioned in the original report (WADC TR 54-388), and on several thermistors installed in conventional jet engine thermocouple mountings. Tests were made in still air in a furnace and in a stream of exhaust gas where the mass velocities were 4 and 6 lb/ft^2 sec. Four thermistors of different geometric configurations exhibited large apparent shunt capacitance that decreases with increasing frequency. Under conditions of comparatively large current a variable voltage-current characteristic was strongly in evidence, as indicated by large residual voltage in the detector circuit at balance. A considerable drop in resistance accompanied an increase in applied voltage. The error in measured temperature due to self heating, using the thermistor with a low-voltage calibration as a pyrometer, may be several percent, and depends on the I^{2}R loss per unit volume. None of the thermistors showed appreciable variation of resistance with frequency of the applied voltage.

Stability of ten thermistors installed in conventional jet-engine thermocouple mountings was generally good. Reproducibility of calibrations between different thermistors was not of a high enough order to satisfy the requirements for interchangeability in jet-engine service or research, but it does show promise. Although characteristic times of disk- and rod-shaped thermistors determined at a mass velocity of 6 lb/ft^2 sec were appreciably greater than those of the ordinary bare-junction thermocouple used in an engine, the smaller engine-mounted thermistors gave a chracteristic time comparable with that of a silver-shielded 22-gage Chromel-Alumel thermocouple.

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 only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

for E. C. Phillips
NORMAN C. APPOLD
Colonel, USAF
Chief, Power Plant Laboratory

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PART I. EFFECTS OF VARYING APPLIED VOLTAGE AND FREQUENCY ON THE RESISTANCES OF FOUR THERMISTORS

A knowledge of effects of varying the applied voltage and frequency on performance of thermistors is a necessity if the thermistors are to be used for measurement of temperature. A series of tests made on one body, described in Part I of the original report (WADC TR 54-388) indicates that varying frequency of the applied voltage has little effect, if any, on resistance of a thermistor exposed to fixed conditions of temperature and mass flow. Although different applied voltages were used in the same work, the effect of variation of voltage on resistance of the thermistors was not determined. It appeared desirable, therefore, to examine further the effects of both parameters on performances of thermistors of all available configurations and ceramic bodies.

I. THE THERMISTORS

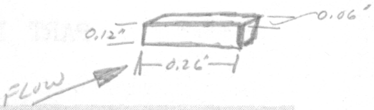
The thermistors examined are shown in the photograph of figure 1. For convenience, the shapes, dimensions, and designations of the thermistors used before are reviewed here, and those in engine-type mountings are described. Ceramic bodies used were identified as Shenango No. 4, Cone 14, Cone 14A, and Shenango No. 6. Shenango No. 4 and Cone 14A were disks 0.48 inch diameter and 0.13 and 0.11 inch thick respectively; Cone 14 was a rod 0.8 inch long and 0.12 inch diameter; and Shenango No. 6 was a rectangular parallelopiped 0.26 inch long, 0.12 inch wide, and 0.06 inch thick. Connections to the thermistors, which were by platinum wire, were made to opposite faces of the disks of Shenango No. 4 and Cone 14A, and by encircling the ends of the rod of Cone 14.

Shenango No. 6 was in an engine-type mounting consisting of a conventional Chromel-Alumel thermocouple inserted in a flanged metal tube. One difference between this mounting and the conventional couples was that the insulation in the tube was two-hole vitrified alumina instead of the generally used packed magnesia. The bead at the thermocouple junction had been cut off, and short platinum leads, extending from platinum electrodes imbedded in the ceramic were welded to the wires to make electrical connections to the thermistor. The Chromel and Alumel wires served as leads for the thermistor, and connections to the measuring system were made at the head of the mounting. The thermistor thus was permanently installed in the engine-type mounting.

Nos. 4, 14A, and 14 were inserted in similar mountings temporarily when tests were made in the exhaust gas stream.

II. APPARATUS AND PROCEDURE

Resistance measurements were made with the thermistors heated in static air in an electric furnace, and in a stream of exhaust gas at mass velocities of 4 and 6 lb/ft^2 sec. For measurements in an electric furnace



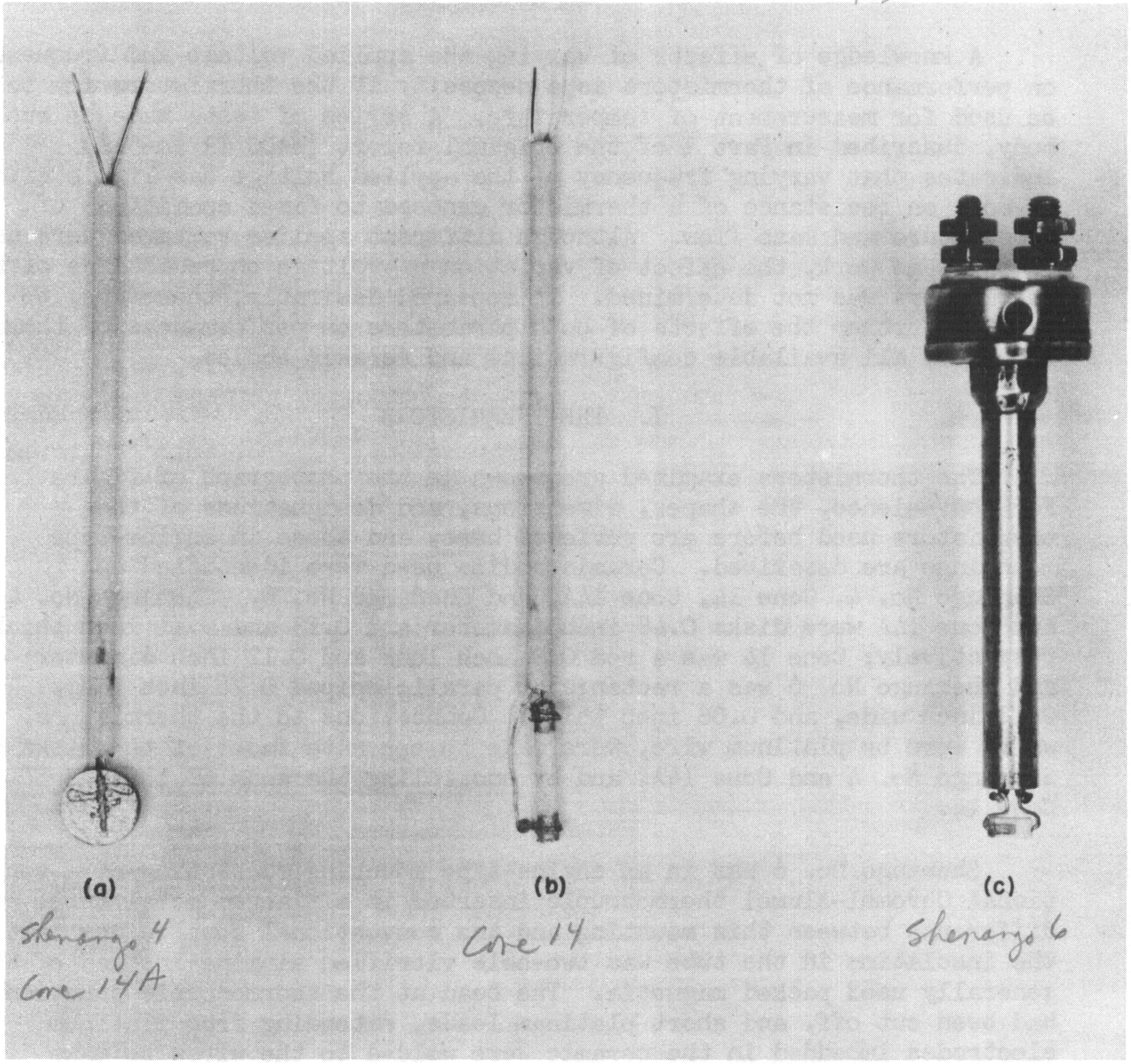


FIGURE I TYPES OF THERMISTORS EXAMINED
(a) DISK, (b) ROD, (c) RECTANGULAR PARALLELOPIPED IN ENGINE-TYPE MOUNTING

the thermistors were mounted in a copper block, and except for the engine-mounted, were supported by bare two-hole vitrified alumina tubing. A flanged Inconel tube, bolted to the pipe wall gave the alumina tube additional support when tests were made in the gas stream. Tests were made in both the furnace and gas stream at nominal temperatures of 1200°, 1500°, and 1800°F.

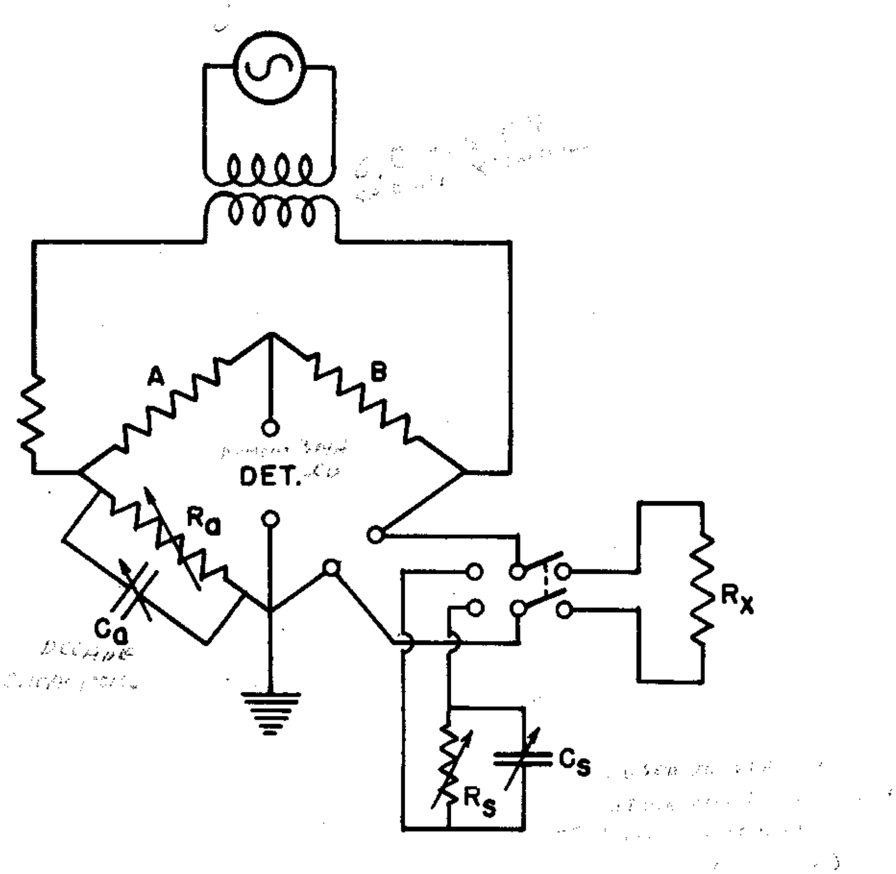
Resistance, R_x, of the thermistors was measured with a General Radio Type 650A impedance bridge. Figure 2 is a diagram of the bridge circuit. A decade capacitor, C_a, connected across the variable resistance arm, R_a, balanced capacitance in the thermistor, and thus helped to obtain a null in the detector, or to lower the attainable minimum. A cathode ray oscillograph (usually a Dumont 304H) was used as a detector. The variable vertical gain control of the oscillograph was used to adjust the sensitivity as desired. As the circuit required grounding of one side of the detector, the input had to be ungrounded; for this reason a General Radio Type 578B shielded transformer was used to isolate the bridge from grounds in the supply circuit. Voltage at 60 cycles per second was taken from the building supply line.

A General Radio Type 913B beat frequency oscillator was used for measurements at 400 and 1000 cycles per second. The voltage was measured at the thermistor terminals with an RCA Senior Volt-Ohmyst, Type WV-97A. The diagram of the bridge circuit in figure 2 includes the decade resistor R_s and decade capacitor C_s, which could be substituted for the thermistor. These were used occasionally in earlier experiments in the furnace to verify bridge measurements and to improve precision. The gain in precision did not warrant the extra time required, however, and the procedure was discontinued.

III. EFFECTS OF VOLTAGE ON PERFORMANCE

Resistances measured at three temperatures and several applied voltages are presented in figures 3, 4, and 5 for Shenango No. 4, Cone 14A, and Shenango No. 6 respectively, and in table I for Cone 14. Frequency of the applied voltage was 60 cycles per second in all cases. It was usually not possible to apply as much as 30 volts at the higher temperatures, because the current in the bridge arms would have become too high. In a few cases resistances at 20 volts and higher were derived from measurements with an AC milliammeter of the current in the thermistor. This method does not separate ohmic and reactive impedance, but at 60 cycles per second the latter was so large as to have a negligible effect on current flow.

The decrease of resistance with increasing voltage was as expected, but Shenango No. 6 showed effects on applying 20 volts or more which persisted after returning to a lower voltage. Figure 5 shows this for the case of heating in a furnace at 1800°F. The initial resistances at 3 and 10 volts were 990 and 840 ohms, but on returning to these voltages after measurements at 30 volts and over, the resistances were only about 750 and 670 ohms.



RESISTANCE, OHMS

R_X	A	B
>100 K	100 K	1 K
10 K–100 K	100 K	10 K
1 K–10 K	10 K	10 K
<1 K	1 K	10 K

NBS

FIGURE 2. BRIDGE CIRCUIT FOR MEASURING RESISTANCE OF THERMISTORS

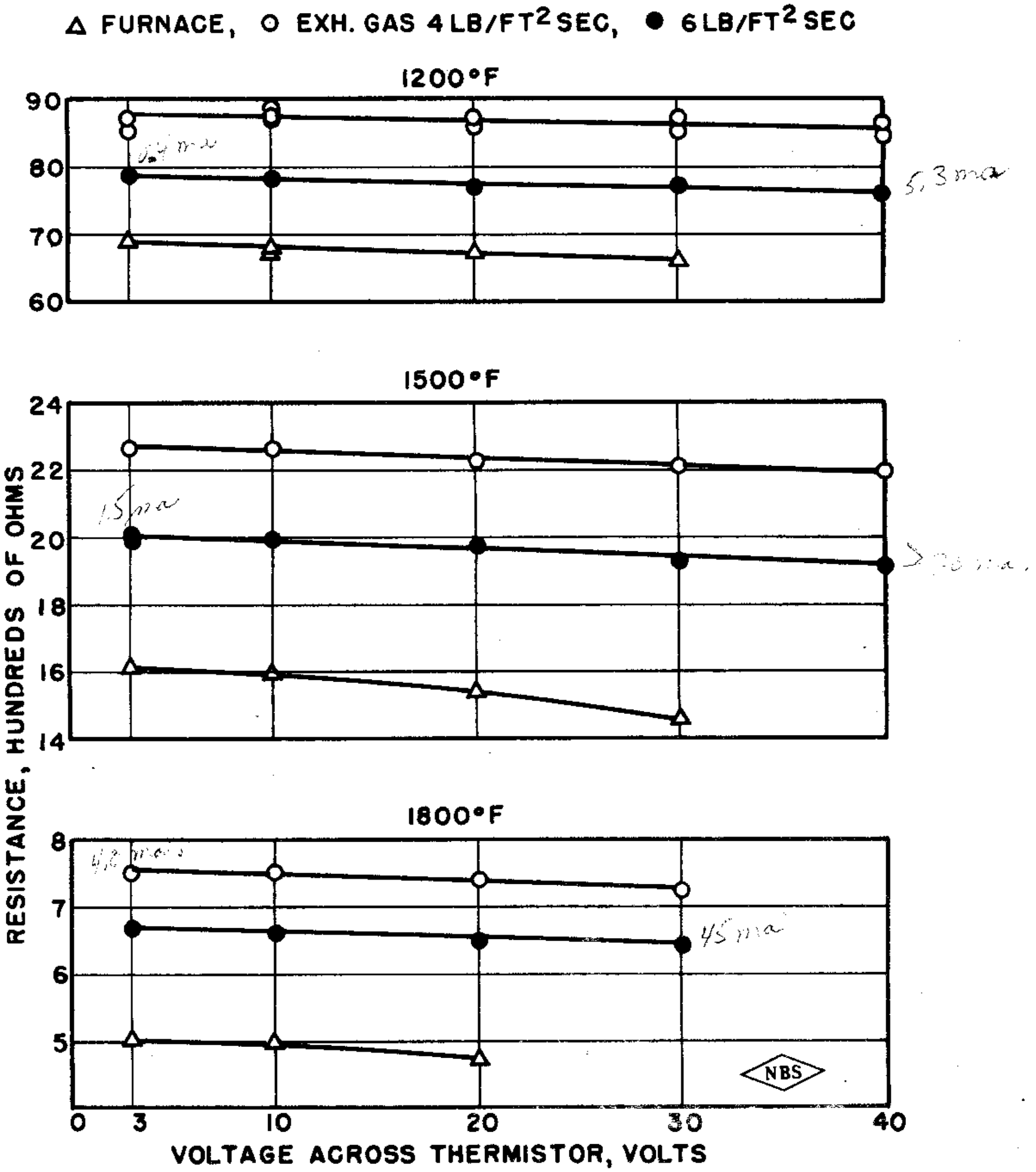


FIGURE 3. VARIATION OF RESISTANCE WITH APPLIED VOLTAGE OF SHENANGO NO. 4 THERMISTOR

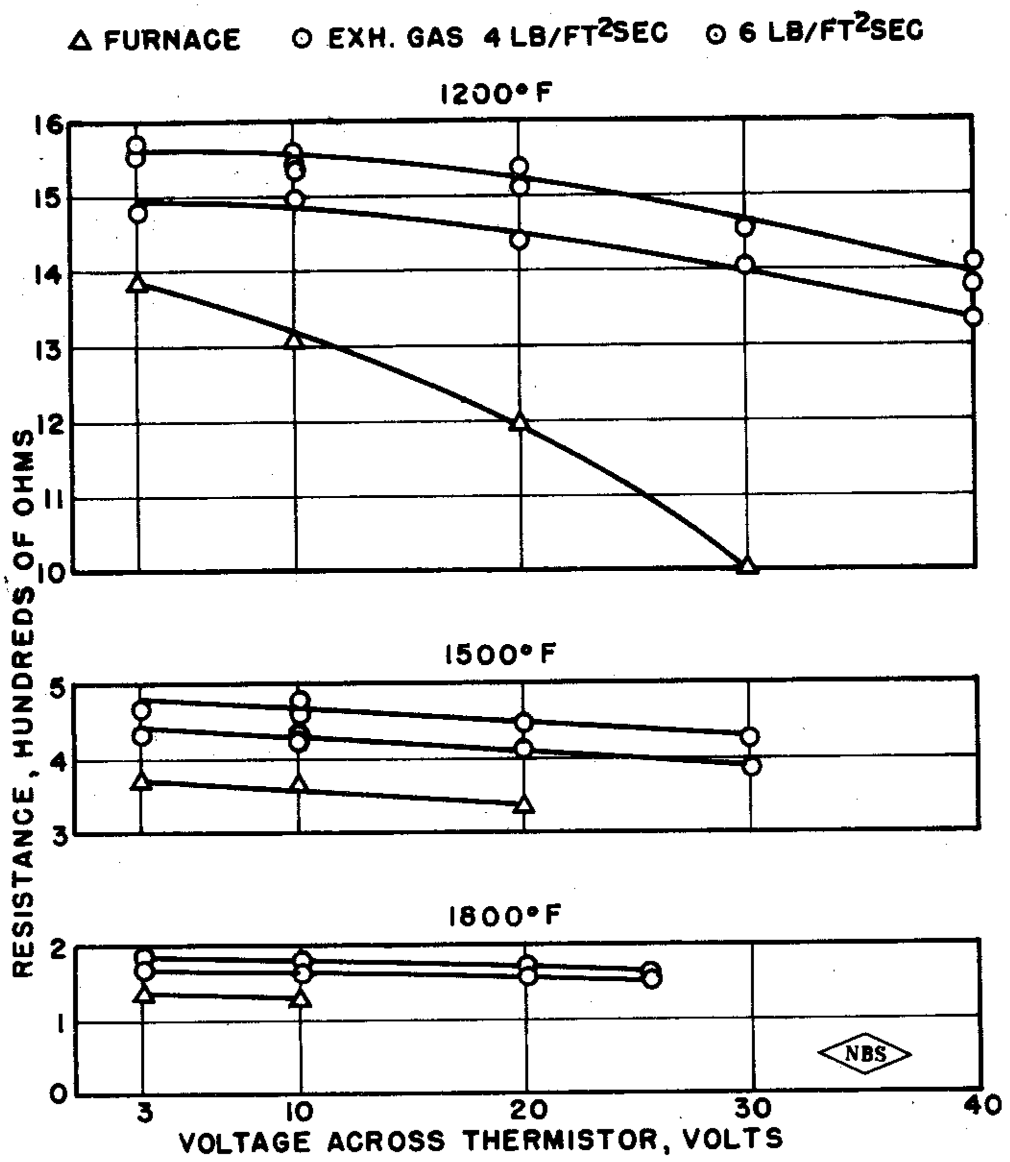


FIGURE 4. VARIATION OF RESISTANCE WITH APPLIED VOLTAGE OF CONE 14A THERMISTOR

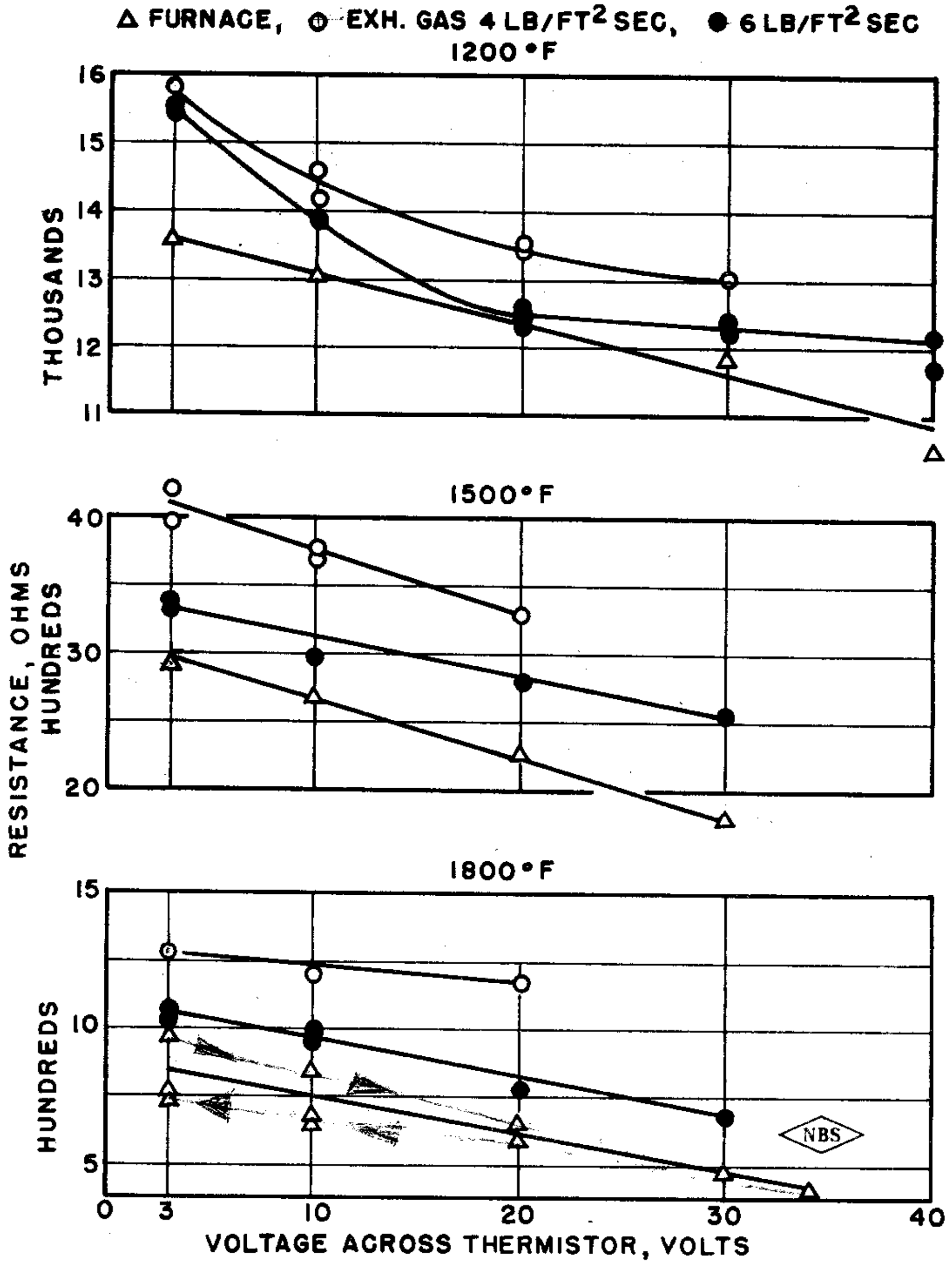


FIGURE 5. VARIATION OF RESISTANCE WITH APPLIED VOLTAGE OF SHENANGO NO.6 THERMISTOR

This specimen behaved erratically at times in exhaust gas; for example at 1200°F resistances measured at mass velocity of 4 lb/ft^2 sec were occasionally, immediately after 20 or 30 volts had been applied for a minute or so, as much as 5000 ohms above the values shown at the low-voltage end of the upper curve in figure 5. In all such cases frequency components appeared in the detector circuit which could not be reduced to a low level by varying resistance and capacitance in the bridge arms, and the amplitude of these components became larger, the longer high voltage was applied.

The data for Cone 14 (table I) show that there is only a small change in resistance of this thermistor as the applied voltage is changed.

Table I

Resistance of Cone 14 Thermistor

	Volts				
	3	10	20	30	40
	Thousands of ohms				
1200°F					
Furnace	203.2	200.3	201.0	199.7	199.7
Exh. gas, 4 lb/ft^2 sec	220.6	217.6	215.2	216.6	219.0
Exh. gas, 6 lb/ft^2 sec	------	206.5	210.0	204.6	208.4
1500°F					
Furnace	45.4	44.7	45.0	44.9	44.5
Exh. gas, 4 lb/ft^2 sec	58.2	57.0	57.6	57.8	57.7
Exh. gas, 6 lb/ft^2 sec	54.4	54.0	54.3	54.0	52.3
1800°F					
Furnace	14.1	14.1	14.0	14.1	13.9
Exh. gas, 6 lb/ft^2 sec	18.5	19.0	18.7	18.5	18.4

IV. EFFECTS OF FREQUENCY ON PERFORMANCE

Resistance measured at 60, 400, and 1000 cycles per second for furnace heating are given in table II. As the voltage output of the oscillator used for 400 and 1000 cycles was such that not more than two or three volts could be obtained across the thermistors of lower resistance, the data in table II are for three volts or less at each frequency.

Table II

Resistance in Furnace of Four Thermistors at 60, 400, and 1000 Cycles Per Second

Temperature °F	Frequency cps	Shenango No. 4	Cone 14A	Shenango No. 6	Cone 14
		ohms			
1200	60	6965	1380	13,560	203,200
	400	6915	1395	12,250	198,400
	1000	6635	1390	11,970	199,700
1500	60	1620	374	2,885	45,460
	400	1590	370	2,665	45,540
	1000	1600	367	2,575	44,270
1800	60	512	134	-----	21,230*
	400	500	134	-----	20,000*
	1000	485	132	-----	20,500*

*1700°F

In addition to the data of table II on Shenango No. 6, measurements were made on this thermistor in exhaust gas at 60 and 400 cps. At the same time another engine-type thermistor of the Shenango No. 6 composition was run. The results are given in table III, in which the second thermistor is designated specimen B. Voltage applied was 10 volts. Each value is the average of from two to four measurements.

Table III

Resistance of Two Specimens of Shenango No. 6 Composition in Streaming Gas

		$4\ lb/ft^2$ sec		$6\ lb/ft^2$ sec	
Temperature °F	Frequency cps	Spec. A	Spec. B	Spec. A	Spec. B
		ohms			
1200	60	16,140	----	19,510	19,940
1200	400	15,280	----	18,810	18,840
1500	60	4,045	4850	4,380	4,865
1500	400	3,960	4880	4,465	4,785
1800	60	1,305	1695	1,360	1,625
1800	400	1,365	1590	1,360	1,520

V. DISCUSSION

The graphs and table I show the effect of the thermal environment on the thermistors. Effects of radiation are smallest in the furnace, and except for relatively small losses by conduction, a thermistor immersed in the furnace is at substantially the same temperature as the surrounding gas. Where heat is imparted from moving gas in a duct whose walls are relatively cool, radiation loss may be appreciable. Consequently the thermistor is cooler, and its resistance is higher than when it is in a furnace at the same temperature as the gas stream. The effect of increasing applied voltage would be expected to be greater when the thermistor is heated in the furnace because the temperature rise due to electrical self-heating under these conditions is greater than it is when the moving gas is available to remove a part of the self-heat. In general, effects of changing voltage were, in varying degrees, as expected.

The erratic behavior of the Shenango No. 6 specimen is probably associated with the high rate of energy input per unit volume at a given applied voltage in comparison with the other thermistors. The volume of No. 6 is only about 27 mm^3, but that of the disk-shaped thermistors is more than 300 mm^3. Whereas in the latter the electrical power expended did not exceed 3 milliwatts per cubic millimeter, in the Shenango No. 6 it was as high as 70 milliwatts per cubic millimeter of conducting material. Whether through the increased thermal activation or high local electrical fields, the distribution of charge carriers in No. 6 may have suffered a change that persisted after removal of the voltage, thus resulting in higher apparent resistivity.

Since Shenango No. 4 and Cone 14A are of nearly the same shape and size, their average temperatures under the same operating conditions should be approximately the same. It is of interest in studying this to compare temperature changes of these thermistors at conditions of figures 3 and 4; namely in the furnace (R_o,T_o) and in exhaust streams of 4 and 6 lb/ft^2 sec, (R_4,T_4 and R_6,T_6).

These changes may be found by assuming that the temperature of the thermistor in the furnace was the same as that of the furnace, and by dividing the difference in resistance between conditions of furnace and exhaust gas by the rate of change of resistance with temperature (dR/dT). This method is not exact because dR/dT depends on R as well as on T, and will be slightly higher when the thermistor is immersed in flowing gas than when in a furnace at the same temperature.

The data used in determining the values, and the derived temperature changes are presented in table IV where ΔT, the change in temperature, is the change in resistance divided by dR/dT. It is seen that fair agreement exists between temperature differences derived from differences in resistance.

Table IV

Temperature Difference between Thermistor and Gas Stream, Based on Change of Resistance of Two Thermistors of Similar Size and Shape

	R_o	$R_4 - R_o$	$R_6 - R_o$	dR/dT $\frac{\text{ohms}}{°F}$	ΔT_4	ΔT_6
	---Resistance, ohms----				----°F---	
			1200°F			
Shenango No. 4	7000	1700	800	48	35	17
Cone 14A	1380	180	120	7	26	17
			1500°F			
Shenango No. 4	1600	650	380	8	81	48
Cone 14A	365	100	65	1.5	67	43
			1800°F			
Shenango No. 4	500	255	175	2.2	116	80
Cone 14A	130	55	40	0.45	122	89

The data of table II show that there is little if any change of resistance with frequency in the range 60 to 1000 cps. Although Shenango No. 6 shows more consistently a decrease in resistance with increase in frequency (see table III also), even in this case differences are small and are sometimes obscured by experimental error.

On referring to the earlier discussion as to the effects of moving gas, it will be observed in table III that the resistance of specimen A is higher at the 6 lb than at the 4 lb flow. The reason for this is not known, since the opposite is to be expected, and in all other cases was found to be true. It is suspected that specimen A was undergoing some change during the measurements, but the fact that specimen B shows little difference between the two flow rates suggests that one or both flow rates for specimen A may have been slightly different from the indicated rate.

Capacitance of the order of a few thousandths to a few tenths of a microfarad, for the different thermistors, had to be added in parallel with the variable resistance arm of the bridge in order to balance. For a given thermistor, the required capacitance increased as temperature increased, i.e. as resistance decreased. For example, with Shenango No. 4 at 60 cps it was 0.006, 0.03 and 0.12 microfarad at 1200, 1500 and 1800°F, respectively. It is also an inverse function of the frequency. For Shenango No. 4 at 1500°F for example, the values at 60, 400 and 1000 cps were respectively 0.03, 0.002 and 0.00065 microfarad. Since this property is probably of little interest in the use of thermistors as temperature-sensing devices, the capacitances observed are not presented in full. They are in all cases so large that the dielectric constant computed from them and the dimensions of the thermistors is several orders of magnitude higher than the values commonly observed on ceramic insulating materials. In an extreme case, the Cone 14A thermistor at 1800°F and 60 cps required 0.8 μf in the opposite bridge arm to balance. From this capacitance and the dimensions (0.48 inch diameter and 0.11 inch thick), the apparent dielectric constant is calculated to be more than 2×10^6.

In research on the properties of semi-conductors a large dielectric constant has been observed on certain oxidic materials, as well as a dependence of resistance on frequency (Ref. 2). This behavior was interpreted by assuming that the material was composed of elements of fairly high conductivity separated by thin layers of low conductivity, the whole electrically comprising a network of series- and parallel-connected resistors and capacitors. It seems probable that the behavior of the present thermistors may be attributed to a similar configuration of conducting and non-conducting particles, even though resistance depends little or not at all on frequency in the range 60 to 1000 cps.

PART II. PERFORMANCE OF THERMISTORS IN ENGINE-TYPE MOUNTINGS

Among properties required of any temperature-sensing device used in an engine are (1) stability over a long period of use, (2) reproducibility to the extent that it could be interchanged with another without affecting accuracy of indication or control, and a (3) sufficiently rapid response rate. It must produce a usable signal to actuate controls and to indicate temperature, and a means should be provided to average the output of several devices so that the system will continue to operate effectively and accurately if one or more sensors fails. This section is concerned with the first three requirements named; the others undoubtedly are of equal importance, but are not within the scope of this work, and so are not considered here.

I. THE THERMISTORS

Mountings of the thermistors examined previously were designed merely for insertion in a furnace or gas stream, and no provision was made to adapt them for any specific use. When, however, it appeared that it would be advantageous to make tests in an engine, and the necessity for a practical mounting arose, the most direct approach was to use the thermocouple mounting mentioned previously for which provisions for installation are already available on the engine. Consequently twelve thermistors, designated Nos. 1 through 12, were installed in the thermocouple mountings using the vitrified alumina insulating tubes instead of packed magnesia for insulation. The information presented in this part was obtained during tests of these thermistors.

II. APPARATUS AND PROCEDURE

Equipment used in determinations of resistance of the thermistors is the same as that described in Part II of the original report. The rate of response of one thermistor was measured at a flow rate of 6 lb/ft^2 sec by the method described in Air Force Technical Report A.T.I. No. 42188.

In review, the theoretical equation relating resistance, R in ohms, and absolute temperature, T, of thermistor materials is

$$\log_e R = A + B/T \tag{1}$$

which may be expressed in common logarithms as

$$\log_{10} R = A/2.303 + B/2.303T = a + b/T \tag{2}$$

This equation was fitted to data obtained on each thermistor.

The thermistors were calibrated alternately in still air in the furnace and in the stream of exhaust gas for several cycles over the range 1000 to 1800°F. Since an empirical equation was to be fitted to the experimental data obtained in the gas stream, additional observations were taken at the ends of the range covered in order to improve precision of these points through which the curve would be passed.

In these tests, as in others in which the measuring element is at a temperature appreciably different from that of the walls of the exhaust gas duct, an error exists due to radiation and conduction from the element to the cooler wall. Again in these tests, this error was unknown, but it was held constant or nearly so for all observations at a particular temperature by maintaining a constant mass velocity throughout a test and operating long enough at each point to permit the walls of the duct to reach a constant temperature.

III. TEMPERATURE-RESISTANCE RELATIONS

Temperature-resistance relationships of ten of the thermistors either became stable after a short period of heating, or remained so from the beginning, and the results with a given unit generally were surprisingly reproducible. No. 2, which had appeared stable in the furnace, became unstable in the gas stream. Its resistance increased in succeeding calibrations, and an examination indicated the possibility that a weak bond between the platinum electrode and the thermistor body may have been responsible. Thermistor No. 1 was expended, and no information on it is presented.

Data obtained in the furnace for No. 5, which changed more on initial heating than any other, are presented in figure 6. The scatter of the original calibration is unexplained, but the greatest change is seen to have occurred sometime during the first five hours of exposure to temperatures in the range 1000 to 1800°F. Only a very slight additional shift was caused by a further 15 hours of heating in both the furnace and stream of exhaust gas.

As an example of stability of one of the best units, data obtained in the furnace on thermistor No. 7 are seen in figure 7. No appreciable change has occurred in this case after twenty hours of heating.

Constants of equation 2, passed through averages of values observed in the stream of exhaust gas at 6 lb/ft^2 sec and at 1000 and 1800°F are given in table V. Calculated resistances of the thermistors are presented in table VI.

Significance of the variation of resistance between thermistors at a given temperature is apparent from table VII. Values of temperature have been calculated from the empirical equation for each thermistor, using the observed resistances at 1000 and 1800°F for thermistor No. 7.

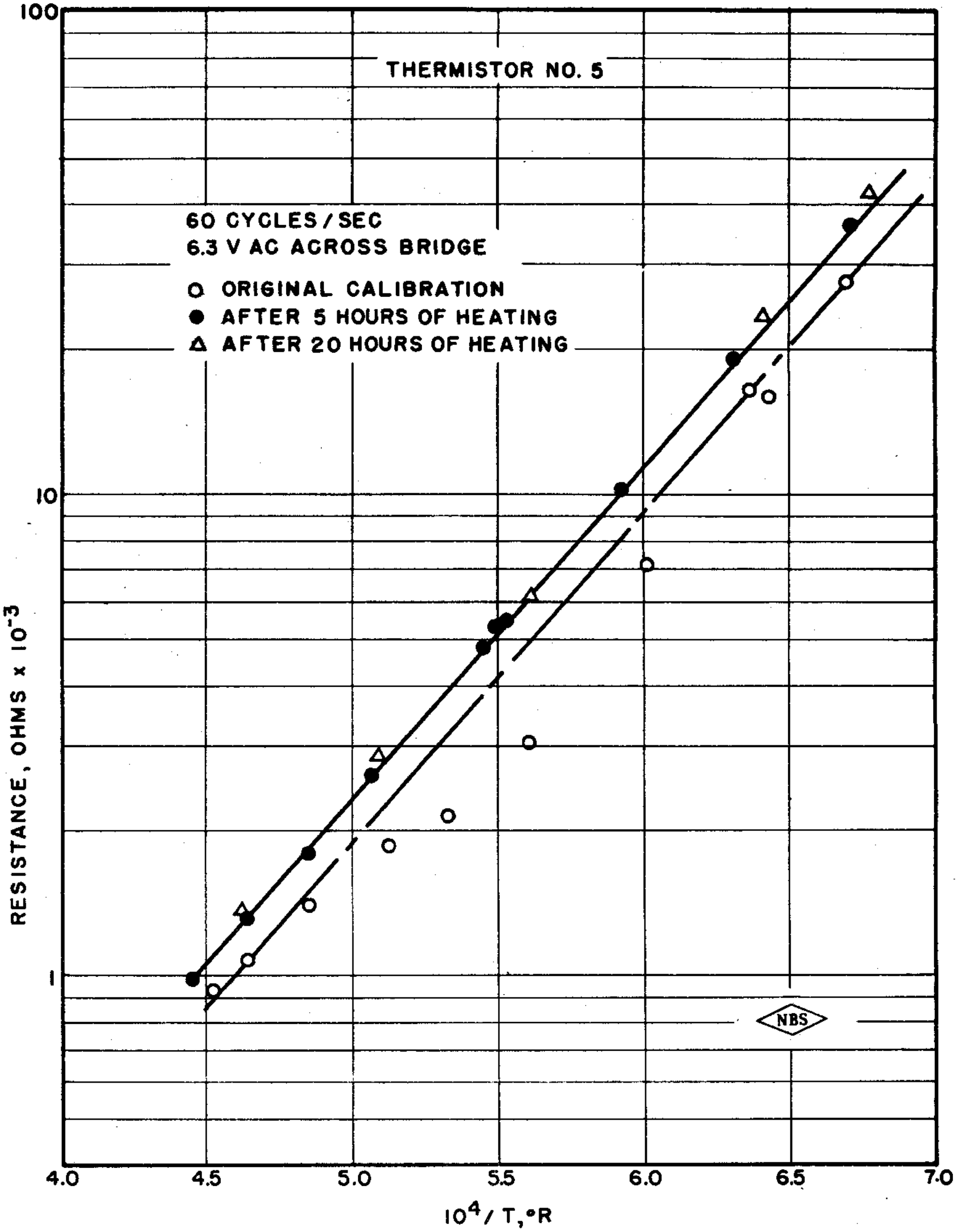


FIGURE 6. EFFECTS OF HEATING ON THERMISTOR SHOWING GREATEST CHANGE

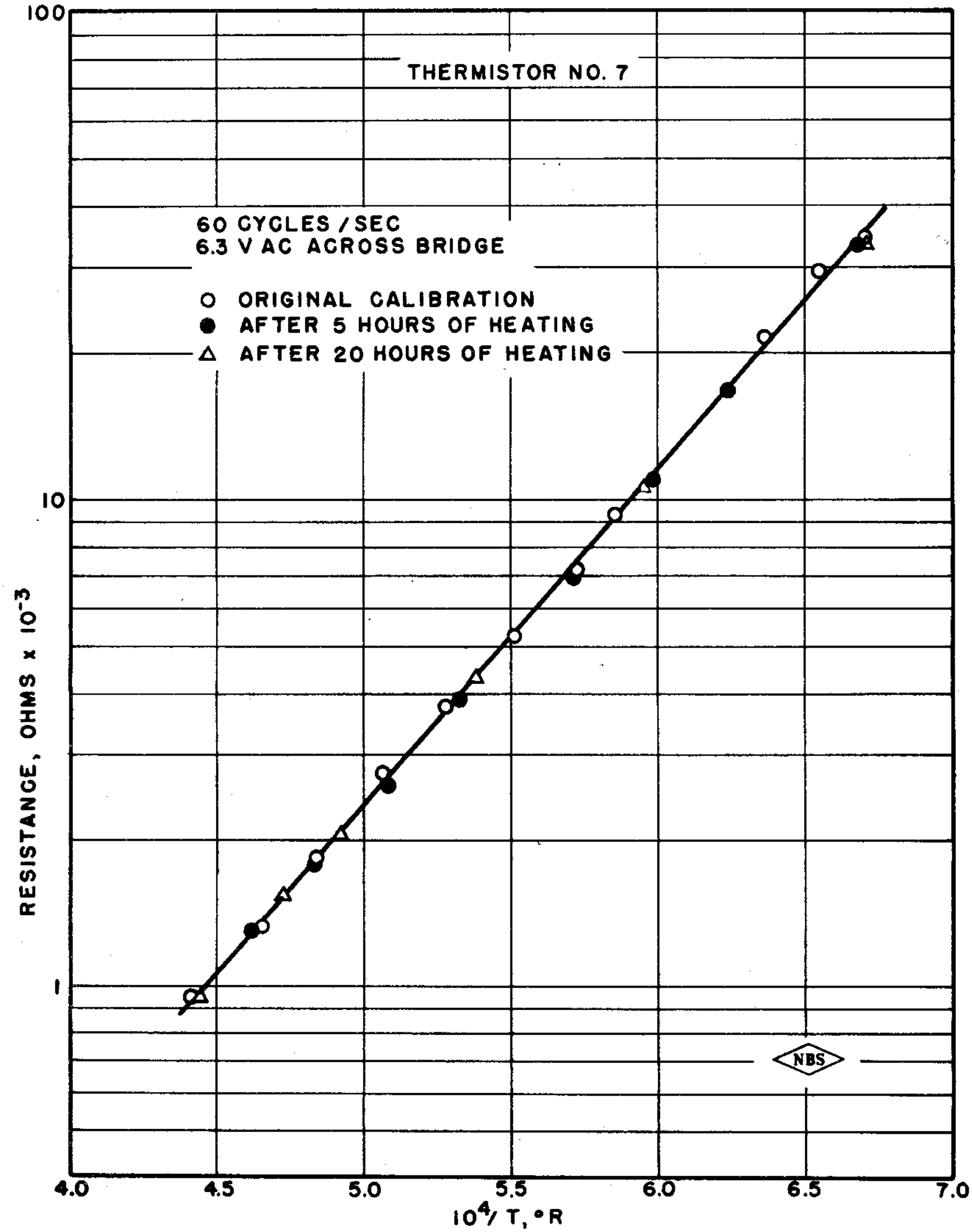


FIGURE 7. EFFECTS OF HEATING ON THERMISTOR SHOWING LEAST CHANGE

Table V

Constants in Equation $\log_{10} R = a + b/T$ Obtained from Observations in Exhaust Gas Duct at 6 $\mathrm{lb/ft^2}$ sec

Thermistor No.	Constants a	Constants b
3	.4443	6276
4	.3000	6336
5	.3018	6448
6	.3816	6224
7	.3230	6282
8	.4612	6118
9	.6162	5888
10	.3653	6272
11	.5959	5937
12	.3741	6462

Table VI

Gas Temp. °F	Calculated Resistance in Exhaust Gas Stream, 6 $\mathrm{lb/ft^2}$ sec, of Thermistor Number									
	3	4	5	6	7	8	9	10	11	12
	ohms									
1000	55,296	43,612	52,238	44,147	42,212	44,819	44,559	45,833	45,969	63,085
1100	29,319	22,984	27,220	23,530	22,508	24,146	24,571	24,311	25,222	32,827
1200	16,781	13,084	15,343	13,529	12,796	14,026	14,557	13,919	14,877	18,480
1300	10,235	7,942	9,230	8,283	7,799	8,654	9,152	8,490	9,318	11,105
1400	6,581	5,086	5,865	5,346	5,014	5,628	6,049	5,462	6,137	7,049
1500	4,428	3,408	3,903	3,609	3,372	3,824	4,170	3,675	4,218	4,687
1600	3,096	2,378	2,702	2,530	2,357	2,699	2,981	2,570	3,006	3,242
1700	2,237	1,711	1,936	1,833	1,703	1,966	2,198	1,859	2,211	2,321
1800	1,664	1,269	1,428	1,367	1,266	1,473	1,665	1,382	1,671	1,711

Table VII

Degree of Interchangeability of Thermistors, Indicated by Spread of Temperatures Calculated for Each Thermistor from Observed Resistances of No. 7 at 1000 and 1800°F in Exhaust Gas, 6 lb/ft^2 sec

Thermistor No.	Temperature, °F Calculated for Nominal Temperatures of 1000°	1800°
3	1041	1901
4	1005	1801
5	1031	1842
6	1006	1828
7	1000	1800
8	1009	1856
9	1009	1908
10	1012	1831
11	1013	1909
12	1060	1908

Since this unit has the lowest resistance of any, a comparison of calculated temperatures will show the error involved if any thermistor were interchanged with any other. The maximum error is seen to be 60° at 1000°F and 109° at 1800°F. These values are presented for illustrative purposes only; the spread of the error would be slightly different if another thermistor than No. 7 were used for the reference.

Deviations of values of resistance observed in the exhaust gas duct at a mass velocity of 6 lb/ft^2 sec from calculated values are shown in figure 8. One chart has been made for each thermistor, and the charts are identified with the thermistors to which they apply by the numbers in the lower right-hand corners. Of 244 observations made on the ten thermistors, 217 or 89 percent differed from values obtained from the empirical equation by not more than 10°F, and the maximum deviation was 28.5°F. One hundred sixty-five observations were made at the ends of the range covered, 1000 to 1800°F, and 79 were made at intermediate points. Of the 79 observations, 58 gave deviations of 10°F or less, 19 gave deviations of 10° to 20°F, and there were two deviations of 20° and 22°F.

Calculated resistances of the thermistors, obtained in the furnace, are presented in table VIII. Constants for the empirical equations for the furnace data on each thermistor were obtained by plotting the observations on semi-log paper, passing a straight line through them, and deriving the equation through two points read from the line. Because

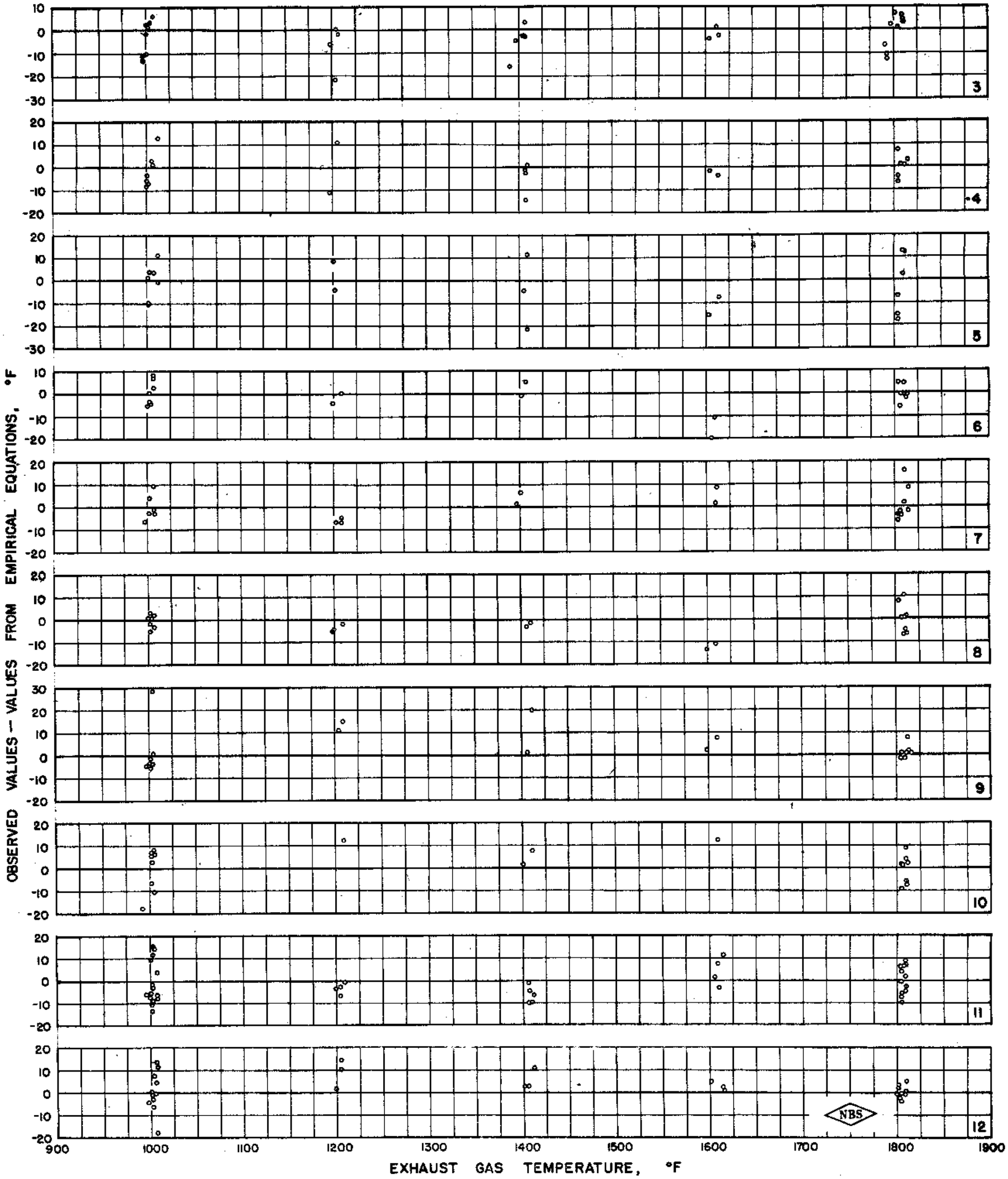


FIGURE 8 DIFFERENCE CHARTS SHOWING PERFORMANCE OF THERMISTORS IN EXHAUST GAS STREAM

Table VIII

Furnace Temp. °F	Calculated Resistance in Furnace of Thermistor Number									
	3	4	5	6	7	8	9	10	11	12
	ohms									
1000	62,806	45,186	44,875	44,055	42,364	43,652	54,702	47,206	54,954	61,376
1100	29,813	22,408	22,289	21,692	21,272	22,009	27,196	23,004	26,810	30,234
1200	15,481	12,095	12,048	11,633	11,609	12,056	14,710	12,227	14,263	16,222
1300	8,664	7,001	6,986	6,699	6,787	7,071	8,533	6,982	8,155	9,343
1400	5,153	4,294	4,289	4,088	4,199	4,387	5,243	4,231	4,945	5,704
1500	3,237	2,772	2,771	2,627	2,731	2,862	3,389	2,701	3,159	3,667
1600	2,125	1,865	1,866	1,761	1,851	1,944	2,284	1,800	2,106	2,458
1700	1,452	1,304	1,306	1,227	1,302	1,371	1,599	1,247	1,461	1,712
1800	1,026	940	942	881	944	995	1,153	891	1,045	1,230

of the smaller number of points taken in the furnace than in the exhaust gas system, and the method used to obtain the equations, the accuracy of the equations for the furnace data is not as high as that of the equations passed through observations obtained in the exhaust duct. Constants in the empirical equation are given in table IX.

Table IX

Constants in Equation $\mathrm{Log}_{10} R = a + b/T$
Obtained from Observations in Furnace

Thermistor No.	Constants a	b
3	-.2511	7372
4	-.0975	6939
5	-.0889	6922
6	-.1565	7009
7	-.0406	6815
8	+.0005	6774
9	+.0026	6914
10	-.1970	7112
11	-.1228	7100
12	-.0097	7005

These equations have been used to show the differences due to radiation and conduction error between temperatures indicated by the thermistors in the furnace and in the exhaust gas stream. The actual temperature of the sensing element of the thermistor always should be the same function of its resistance, regardless of whether it is in a furnace or stream. Assuming then, that the furnace data represent true relations between temperature of the ceramic element and its resistance, the correction for radiation and conduction to the cooler walls of the pipe can be obtained in the following manner.

Using the equations for furnace calibrations, temperatures are calculated for each of the resistances of table VI, obtained in exhaust gas. A table of stream temperature vs temperature of the sensing element thus is obtained, and the difference between stream and calculated temperatures is the desired correction. The curve of figure 9 represents the average at each temperature of values obtained on all ten thermistors. The spread of the values at a given temperature, ranging from 29 to 47°F probably is a result to a large degree of the way in which the constants for the furnace data were obtained. Average temperature of the wall of the exhaust duct when observations were made is plotted in figure 10, and the spread is indicated by the horizontal lines. This spread will have a slight effect on the temperature of a thermistor, but it is most unlikely that it could be responsible for a large part of the spread of 29 to 47°F mentioned before.

The dashed curve of figure 9 represents the corrections that would be obtained if the sensing element had a surface emissivity of 1.00, and indicated wall temperatures were the same as those observed in the exhaust duct at 6 lb/ft^2 sec. The surfaces of the thermistors are partially the white ceramic from which they are made, and partially platinum applied as connecting electrodes. Obviously, the high correction in the upper range cannot be caused by radiation. Conduction to the cooler wall of the duct would increase the magnitude of the correction, but it is improbable that it is responsible in this case. Similarly, the negative correction at the lowest temperatures represents an impossible condition if effects of only radiation and conduction are considered. The causes of these anomalies are not known, but probably lie partially in the manipulation of observed data in deriving the constants of the equations. In the lower range, catalytic action or surface combustion at the platinum electrodes may be a contributing cause. The point to be made, however, is that the emissivity of the sensing elements appears to be high, at least in the upper range.

IV. CHARACTERISTIC TIME

Among the properties of a sensor influencing its characteristic time are its mass, shape, and heat capacity. The mass of an engine-type thermistor is only a small fraction of that of any of the thermistors described in the original report, and the thickness is only about one-half that of the earlier thermistors. Although the properties of the bodies themselves are not known, they probably are nearly enough the same that the smaller size of the engine-type thermistor would be expected to provide a faster response to changes of temperature. Orientation of a

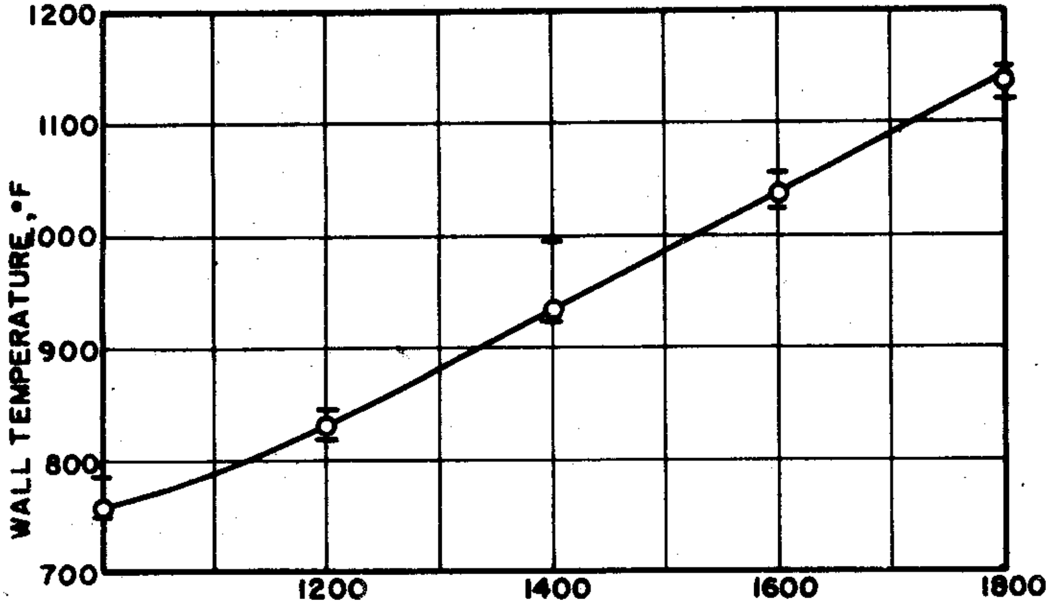


FIGURE 10. VARIATION OF WALL TEMPERATURE WITH GAS TEMPERATURE

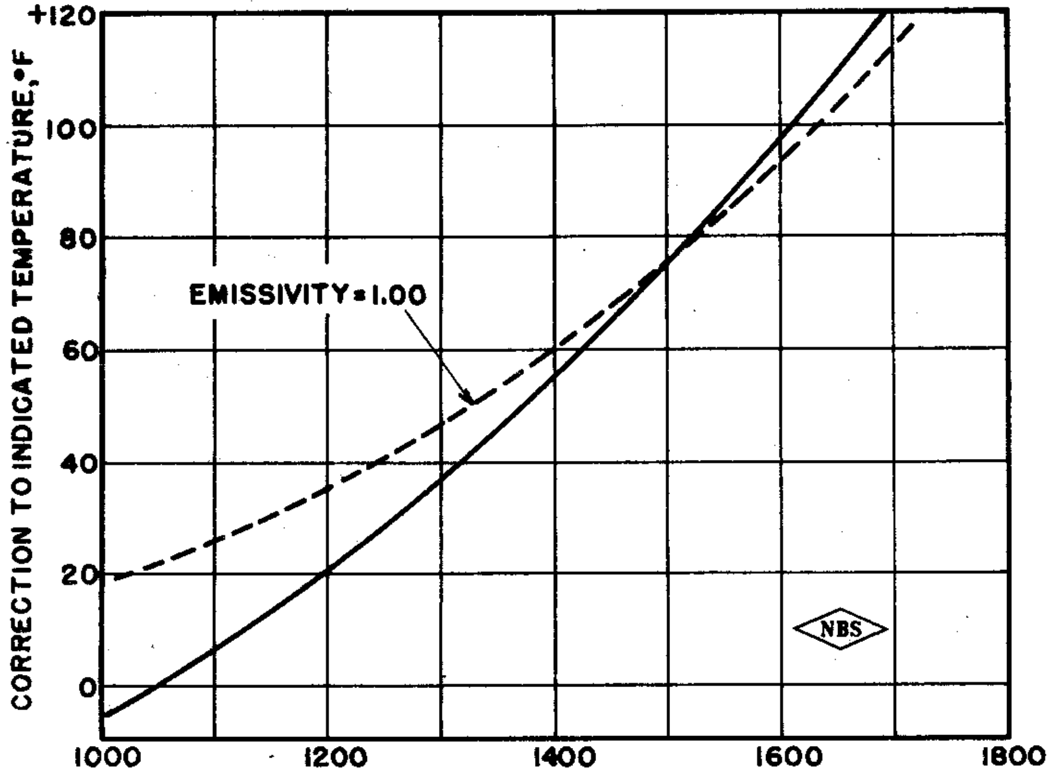


FIGURE 9. CORRECTION TO INDICATION OF THERMISTOR IN GAS STREAM TO OBTAIN TRUE GAS TEMPERATURE

thin sensing element in the stream has an effect on response time; in this case the thermistor was mounted with a large face of the parallelopiped perpendicular to the direction of gas flow.

The characteristic time of the engine-type thermistor suddenly exposed to a temperature of 1605° from an initial temperature of 1080°F in a stream of exhaust gas flowing at a mass velocity of 6 lb/ft^2 sec was 2.0 seconds. Since the characteristic time of the larger disk- and rod-shaped elements ranged from 5 to 7 seconds, the benefit obtained from the smaller sensor is obvious. The characteristic time of 2.0 seconds is about that to be expected from a bare V-type Chromel-Alumel thermocouple made of 15-gage wire. A 22-gage Chromel-Alumel thermocouple fitted with a silver shield 0.020 inch thick has a characteristic time of about 1.85 seconds at the same mass velocity.

V. DISCUSSION

Stability of the thermistors, indicated by the charts of figure 8 is generally good, although it does not match that required of thermocouples in engines.

Reproducibility of sensing elements, deduced from tables VI and VII falls far short of engine requirements. This, however, does not appear to be an insurmountable problem, but one that probably can be met by close attention to details in the manufacturing processes.

The stability of the thermistors and examination of the units after test indicated that, except in the one case, the platinum electrodes remained in good contact with the ceramic bodies throughout the tests.

Comments presented in the original report on the use of two-hole insulator for support of the thermistor leads, and on the use of platinum leads and electrodes for making electrical connections to the thermistors are applicable also to the engine-mounted units. The leads are subject to erosion, particularly at the point where they emerge from the insulating tube. Surface heating on the platinum, which occurs at temperatures below 1200°F, still must be considered, although it is likely that temperatures met in service normally would be 1200°F or above.

The thermistors are subject to large corrections similar to those for bare oxidized thermocouples.

The characteristic time of the engine-type elements, 2.0 seconds, is comparable to that of some thermocouples now in use. This time is not prohibitive, but could be reduced further by making the sensing element still thinner, probably without reducing its strength too much.

VI. REFERENCES

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