

# NATIONAL BUREAU OF STANDARDS REPORT

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## EVALUATION OF RESISTANCE STRAIN GAGES AT ELEVATED TEMPERATURES

Progress Report No. 8

by

R. L. Bloss, C. H. Melton and J. T. Trumbo



U. S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

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NBS PROJECT

NBS REPORT

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to  
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## FOREWORD

In recent years the use of structures at elevated temperatures has increased greatly. If the safe design and efficient use of structural materials are to be assured, a knowledge of the properties of materials and of structural configurations is essential. In determining these properties, the measurement of strains and deformations is important. Strain gages to measure these quantities must be capable of operating satisfactorily over a wide temperature range.

In order to determine the characteristics of strain gages which are available for use at elevated temperatures, the Department of the Navy and the Department of the Air Force have sponsored a program for the evaluation of these gages. This report is one of a series giving the results of these evaluation tests.

There is a continuing effort on the part of manufacturers and research organizations to develop improved strain gages for use at elevated temperatures. Therefore the results given in this report would not necessarily show the performance of similar gages which may differ in characteristics due to differences in materials, treatments, or methods of fabrication.

L. K. Irwin  
Chief, Engineering Mechanics  
Division

B. L. Wilson  
Chief, Mechanics Division

## CHAPTER 1

The first part of the book is devoted to the study of the properties of the

function  $f(x)$  defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $f(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} f(x) = \frac{\pi}{2}.$$

The second part of the book is devoted to the study of the

function  $g(x)$  defined by the equation

$$g(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $g(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} g(x) = \frac{\pi}{2}.$$

The third part of the book is devoted to the study of the

$$h(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $h(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} h(x) = \frac{\pi}{2}.$$

The fourth part of the book is devoted to the study of the

$$i(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $i(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} i(x) = \frac{\pi}{2}.$$

The fifth part of the book is devoted to the study of the

$$j(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $j(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} j(x) = \frac{\pi}{2}.$$

The sixth part of the book is devoted to the study of the

$$k(x) = \int_0^x \frac{1}{1+t^2} dt.$$

It is shown that  $k(x)$  is a continuous function and that

$$\lim_{x \rightarrow \infty} k(x) = \frac{\pi}{2}.$$

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# Evaluation of Resistance Strain Gages at Elevated Temperatures

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## SYNOPSIS

Resistance strain gages of the SS-E-4D-A series, manufactured by Micro-Test, Inc., were evaluated at elevated temperatures. The characteristics determined were (1) gage factor at room temperature, (2) variation of gage factor with increasing temperature, (3) drift, (4) resistance-temperature relationship, (5) behavior under transient heating conditions, and (6) behavior when subjected to large strains. The results of these tests indicate that these gages, when attached to stainless steel, have repeatable gage factor characteristics, a very low temperature coefficient of resistance, low drift at temperatures up to 700° F, and the ability to withstand large tensile strains without failure.

## 1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, gages manufactured by Micro-Test, Inc. were subjected to evaluation tests. The gages tested were type SS-E-4D-A. The gages were subjected to tests to determine the following characteristics:

- (1) Gage factor at about 75° F,
- (2) Variation of gage factor with increasing temperature,
- (3) Relative change of resistance with time (drift),
- (4) Resistance-temperature relationship,
- (5) Behavior under transient heating conditions, and
- (6) Behavior when subjected to large strain.

The manufacturer does not recommend these gages for static strain measurements at temperatures above 850° F.



The results of previous evaluations of other gage types are given in references 1 through 7.

## 2. GAGES

The gages which are reported on herein were purchased from Micro-Test, Inc. The active element is made by etching the center section of a 0.007 inch diameter wire to a diameter of 0.001 inch. The unreduced ends form the leads of the gage, thereby producing a gage element with no internal joints. This filament is imbedded in an insulating material within a metal tube. The metal tube is welded to a thin sheet which, in turn, is attached to a structure or test specimen, usually by spotwelding. The gages tested were made from two of these elements as shown in figure 1.

The gages were attached to stainless steel test strips by spotwelding. In most cases the spotwelding was done with the hand tweezer assembly of a Unitek Model 1015 spotwelder. A small number of gages were attached with a Rollectrode\* attachment for the Unitek Model 1015 spotwelder. The installation instructions of the manufacturer were followed.

## 3. TEST EQUIPMENT AND METHODS

The equipment and methods used for all evaluation tests except those for determining the variation of gage factor with increasing temperature are described in references 5 and 8.

The variation of gage factor with temperature was determined from tests with the equipment shown schematically in figures 2 and 3. Two gages are mounted on each side of a constant strength cantilever beam near its fixed end. The four gages are then connected to form a complete bridge circuit. The free end of the beam is attached to an electro-mechanical vibrator by a rigid connecting rod. The power to the radiant heaters is controlled so that the temperature of the beam is increased at a nearly uniform rate. A low temperature gradient is maintained over the beam length by controlling the power to heating elements in the clamping fixture.

The open circuit output voltage of a bridge circuit made up of identical gages in all four arms with all gages subjected to strain of the same magnitude, two gages in tension and two gages in compression and arranged for maximum bridge unbalance, is approximately

$$E_o = E_i K \epsilon$$

---

\*  
Micro-Test, Inc.



where  $E_i$  = the input voltage  
 $K$  = gage factor of the gages  
 $\epsilon$  = strain (magnitude) to which the gages are subjected.

If the strain is periodic and the other two factors are constant or vary slowly, the output signal will be an alternating voltage of the same frequency as the vibration of the beam. Variations in the amplitude of this alternating voltage during a test in which the input voltage and vibration amplitude are constant will be due to changes in the gage factor and changes in the strain magnitude resulting from thermal expansion of the beam. Changes in the output signal due to lack of compensation for drift and for temperature coefficient of resistance will be slow compared to the frequency of vibration. These slowly varying signals will be rejected by suitable circuitry. The effect of the thermal expansion of the beam can be readily computed from beam theory and the data adjusted to correct for this effect.

In order to obtain sufficient sensitivity to show small changes of gage factor, the small output signal ( a few millivolts) is amplified, rectified, and suppressed so that a change of bridge circuit output voltage of about 20 percent of its nominal value will produce full Y-scale deflection of an X-Y recorder.

Just prior to starting a test, the sensitivity of the Y-axis of the recorder is determined in the following manner:

- (1) The amplitude of vibration is adjusted to the desired level.
- (2) The input voltage is set at its nominal value.
- (3) The amplifier gain is adjusted to give the desired signal level as indicated by the recorder.
- (4) The signal to the recorder is completely suppressed.
- (5) The recorder sensitivity (Y-axis) is increased so that a 10 percent change of signal level will produce about one-half of full scale deflection.
- (6) The input voltage to the bridge circuit is varied from about 90 percent to about 110 percent of its nominal value.
- (7) The Y-scale is marked in convenient steps. Each step usually corresponds to a change of 2 percent of the nominal input voltage.



The temperature, amplitude of vibration, and gage factor are assumed to be constant during this time. The effect of the input voltage changes is the same as would be produced by equal percentage changes of gage factor with constant input voltage and strain level. Although both gage factor and strain level usually change during a test, the combined effects of these changes can be considered to be the sum of the individual effects provided each is small.

After the Y-axis sensitivity is adjusted and calibrated, the input voltage is returned to its nominal value. The temperature of the beam is increased at about 20° F per minute while the input voltage and vibration amplitude are kept constant. As the temperature increases, the variation of bridge circuit output voltage is recorded as a function of temperature. The recorded data are adjusted to correct for the effect of thermal expansion of the beam giving a record of the variation of gage factor with increasing temperature.

#### 4. RESULTS

The number of gages subjected to the various tests is shown in table 1. The results of the evaluation tests are given in table 2 and figures 4 through 31.

##### 4.1 Strain Sensitivity

Gage factor values were obtained at about 75° F from three gages for a maximum strain of about 0.001 in tension and compression. These values are given in table 2 where

$K_u$  = gage factor for increasing load

$K_d$  = gage factor for decreasing load

$\bar{K}$  = average gage factor value.

Gages 6.4-A<sub>1</sub> and 6.4-A<sub>3</sub> were tested in tension before being tested in compression. Gage 6.4-A<sub>2</sub> was tested in compression before being tested in tension. All of the gage factor values obtained were within the range specified by the manufacturer,  $1.8 \pm 5$  percent. The average of all values obtained was within 1-1/2 percent of the manufacturer's nominal value. For any one gage, no value differed from the average for that gage by as much as 2-1/2 percent.

The variation of gage factor with increasing temperature is shown in figures 4 through 7. Each of the curves of figures 4 through 6 show the average change of gage factor for the four gages which were mounted on a





beam and connected into a bridge circuit. Each curve of figure 7 represents the average result for four tests of one set of four gages. At temperatures up to 800° F, gage factor values indicated for only two test runs differ from the average for all runs by more than 3 percent of the room temperature value. These differences exceed 3 percent only at temperatures above 780° F.

#### 4.2 Drift

The drift behavior of individual gages at each test temperature is shown in figures 8 through 17. Each curve of figure 18 represents the average of the results for two gages. The drift values at temperatures as high as 700° F were small. At temperatures of 800° F and above, the drift was much greater, and considerable difference was found between the values obtained for two gages. The greatest drifts were obtained at 1000° F and 1100° F with a much lower drift being shown at 1200° F. Since the gages were tested at each test temperature in ascending order, the lower drift shown at 1200° F might not be representative of a gage which had not been held at lower temperatures. At all test temperatures from 800° F to 1200° F the drift was too high to permit a complete evaluation of the gages for static strain conditions.

#### 4.3 Temperature Sensitivity

The temperature coefficient values obtained for two gages are shown in figure 19. The values plotted are the slopes of lines drawn tangent to recorded curves of relative change of resistance as a function of temperature. The values obtained for the first run of each gage are somewhat different than those obtained on subsequent runs. The values obtained for the second and third run were nearly the same for both gages. In all cases the temperature coefficient was small. It should also be noted that the temperature coefficient values passed through zero so that the total resistance change for a large temperature change might be very small.

Figures 20 through 22 show the relative change of resistance of three gages for five heating cycles to about 600° F followed by five heating cycles to about 800° F. The average heating rate was 5° F/sec to 10° F/sec. The behaviors of two of the gages (6.4-T<sub>4</sub> and 6.4-T<sub>5</sub>) were nearly the same, and, after the first heating cycle to each temperature, the behavior of each of these gages was repeatable. The third gage (6.4-T<sub>6</sub>) did not become repeatable until after the first heating to 800° F. The response of this gage was also somewhat different from that of the other two gages. In all cases, the apparent strain due to temperature changes was small.



#### 4.4 Transient Heating

The results of tests in which the temperature of the test strip to which the gage was attached was changed at about 60° F per second are shown in figures 23 through 29. Figures 23 through 25 show the response of one gage when subjected to three series of transient heating cycles. Each heating series consisted of five heating cycles from room temperature to a maximum temperature and back to room temperature. The maximum temperatures were about 600° F, 800° F, 1000° F, 1200° F, and 1500° F, in that order. Figures 23 and 24 show that the temperature coefficient of resistance of the installed gage was quite different after the first heating series. Figure 25 shows that a gage response is repeatable within close limits for the second and third heating series although the temperature coefficient of resistance is fairly large.

Figures 26 and 27 compare the response of two gages for the first and second heating series to maximum temperatures of 600° F and 1000° F. Although the curves for the two gages have the same general shape, the agreement between the two gages is not comparable to the repetition of one gage for two test runs as shown in figures 28 and 29. The curves of figures 28 and 29 show the maximum spread for ten heating cycles to 800° F followed by ten heating cycles to 1500° F for two gages. Except for the response during the first heating to 1500° F, the behavior of each gage was repeatable within close limits. The different behavior during the first heating to 1500° F was expected from the results shown in figure 24.

#### 4.5 High Strains

The results of tests in which gages were subjected to tensile strains greater than those used for gage factor determination are shown in figure 30. The gage factor values used to determine the strain indicated by the resistance gage,  $\epsilon_{ind}$ , were obtained from the average of values obtained for tensile strains at room temperature, table 2, and the average variation of gage factor with temperature, figure 7. The actual strain,  $\epsilon$ , was measured with an optical strain gage.

The differences between the actual strain and the strain indicated by the resistance gages were only slightly greater than 5 percent of the indicated strain at any point for gages tested at room temperature. These differences were less than 5 percent of the indicated strain for gages tested at 600° F. Errors of this magnitude would be expected since the gage factor tolerance given by the manufacturer is  $\pm 5$  percent.

The gages tested at 600° F were subjected to strains slightly more than 0.01. The gages tested at room temperature were subjected to strains of about 0.02 and 0.015. All tests were discontinued before failure of the resistance gage occurred. Errors for gages strained beyond the values



shown in figure 30 did not exceed the maximum shown for that gage in figure 30.

The results of similar tests on four other gages are not given in this report since a possible error in experimental procedure makes the validity of the results obtained doubtful. The maximum strain levels for the tests of these gages were about the same as for the gages reported except for one gage which was subjected to a strain greater than 0.037 at room temperature. None of these gages failed during the tests.

Two of the gages, 6.4-H<sub>5</sub> and 6.4-H<sub>7</sub>, were attached with standard welder attachments. The other two gages, 6.4-H<sub>6</sub> and 6.4-H<sub>8</sub>, were attached with the Rollectrode attachment. It is felt that the differences shown in figure 30 are not due to differences in the method of attachment.

#### 4.6 Resistance to Ground

It has been reported that ceramic type cements do not follow Ohm's law and that polarization effects are encountered, at least at higher temperatures.<sup>(9)</sup> It is expected that this would also be true for the insulation which forms a part of the gages tested for this report. The resistance values shown in figure 31 should therefore be considered as qualitative values only. The values were obtained during drift tests with a Triplet vacuum tube volt-ohm meter, Model 650, using the scale range marked x 1 meg $\Omega$ . The common terminal of the instrument was connected to the test strip. The values shown in figure 31 are average values for two gages. The readings were taken within a few minutes after the test strip had reached the test temperature.

#### 4.7 Gages Destroyed

During the course of this evaluation, four gages were destroyed before the intended information was obtained. Leads of two of these gages were broken while attaching the external lead wires, one gage wire broke just inside the metal tubing during the first transient heating cycle, and a lead of the other gage was accidentally cut with the Rollectrode while attaching the gage to the test strip. The first three of these failures were probably due to bending of the gage leads. This indicates that these leads are fragile and must be handled carefully. The manufacturer warns against excessive bending of the leads.



## 5. CONCLUSIONS

The data obtained from the evaluation tests covered by this report indicate that:

- (1) Gage factor values for gage type SS-E-4D-A can be expected to be within the manufacturer's stated limits at room temperature. The decrease of gage factor with increasing temperature is approximately linear, at least up to 800° F, and repeatable from gage to gage.
- (2) These gages may be useful for static strain measurements at temperatures as high as 700° F. At temperatures of 800° F and higher, the drift characteristics will probably preclude their use for many static measurements.
- (3) These gages have a very low temperature coefficient of resistance when attached to stainless steel provided the gages are not heated to temperatures above about 850° F. The temperature coefficient becomes very repeatable after the first temperature cycle. If the gages are heated to about 1500° F, the temperature coefficient becomes quite high, but it is repeatable.
- (4) The gages will indicate tensile strains as high as 0.02 with an accuracy of about 5 percent. The gages will withstand very high strains without failure.
- (5) The gages are very easily installed and require no thermal curing provided installation can be made by spotwelding.
- (6) The agreement between the predicted and actual strains indicated by the resistance gages for high strains at 600° F confirms the validity of the method used to determine the variation of gage factor with temperature.

Washington, D. C.

August 1959





## 6. REFERENCES

- (1) R. L. Bloss and C. H. Melton, An Evaluation of Two Types of Resistance Strain Gages at Temperatures up to 600° F, NBS Report No. 4676, May 1956 (ASTIA No. AD 94696).
- (2) R. L. Bloss and C. H. Melton, An Evaluation of One Type of Resistance Strain Gage at Temperatures up to 600° F, NBS Report No. 4747, July 1956 (ASTIA No. AD 101079).
- (3) R. L. Bloss and C. H. Melton, An Evaluation of Two Types of Resistance Strain Gages at Temperatures up to 600° F, NBS Report No. 4843, September 1956 (ASTIA No. AD 107662).
- (4) R. L. Bloss and C. H. Melton, An Evaluation of Strain Gages Designed for Use at Elevated Temperatures -- Preliminary Tests for Temperatures up to 1000° F, NBS Report No. 5286, May 1957 (ASTIA No. AD 135050).
- (5) R. L. Bloss and C. H. Melton, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 5), NBS Report No. 6117, August 1958 (ASTIA No. AD 202419).
- (6) R. L. Bloss, C. H. Melton, and M. L. Seman, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 6), NBS Report No. 6245, December 1958, (ASTIA No. AD 211391).
- (7) R. L. Bloss, C. H. Melton, and J. T. Trumbo, Evaluation of Resistance Strain Gages at Elevated Temperatures. (Progress Report No. 7) NBS Report No. 6395, April 1959.
- (8) R. L. Bloss, A Facility for the Evaluation of Resistance Strain Gages at Elevated Temperatures, Symposium on Elevated Temperature Strain Gages, ASTM Special Technical Publication No. 230, pp. 57-66.
- (9) J. W. Pitts, E. Buzzard, and D. G. Moore, Resistance Measurement of Ceramic-Type Strain-Gage Cements, Symposium on Elevated Temperature Strain Gages, ASTM Special Technical Publication No. 230, pp 67-75.



Table 1 - Number of Gages Subjected to Tests

Type of Tests	Number of gages tested
Gage factor	3
Gage factor variation	12*
Drift	2
Temperature sensitivity	5**
Transient heating	5**
High strain	4

\*Three sets of four gages.

\*\*Three gages were subjected to transient heating tests after temperature sensitivity tests were completed.



Table 2 - Gage Factor Values at About 75° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		$K_u$	$K_d$	$\bar{K}$	$K_u$	$K_d$	$\bar{K}$
6.4-A <sub>1</sub>	1	1.842	1.845	1.843	1.865	1.864	1.864
	2	1.854	1.844	1.849	1.874	1.878	1.876
	3	1.843	1.848	1.846	1.876	1.878	1.877
	Average	1.846	1.846	1.846	1.872	1.873	1.872
6.4-A <sub>2</sub>	1	1.780	1.833	1.807	1.831	1.834	1.832
	2	1.788	1.851	1.819	1.825	1.830	1.828
	3	1.806	1.823	1.814	1.831	1.844	1.837
	Average	1.791	1.836	1.813	1.829	1.836	1.832
6.4-A <sub>3</sub>	1	1.783	1.797	1.790	1.773	1.823	1.798
	2	1.775	1.786	1.780	1.813	1.826	1.819
	3	1.777	1.786	1.781	1.807	1.819	1.813
	Average	1.778	1.790	1.784	1.798	1.823	1.810
Grand Average		1.805	1.824	1.814	1.833	1.844	1.838



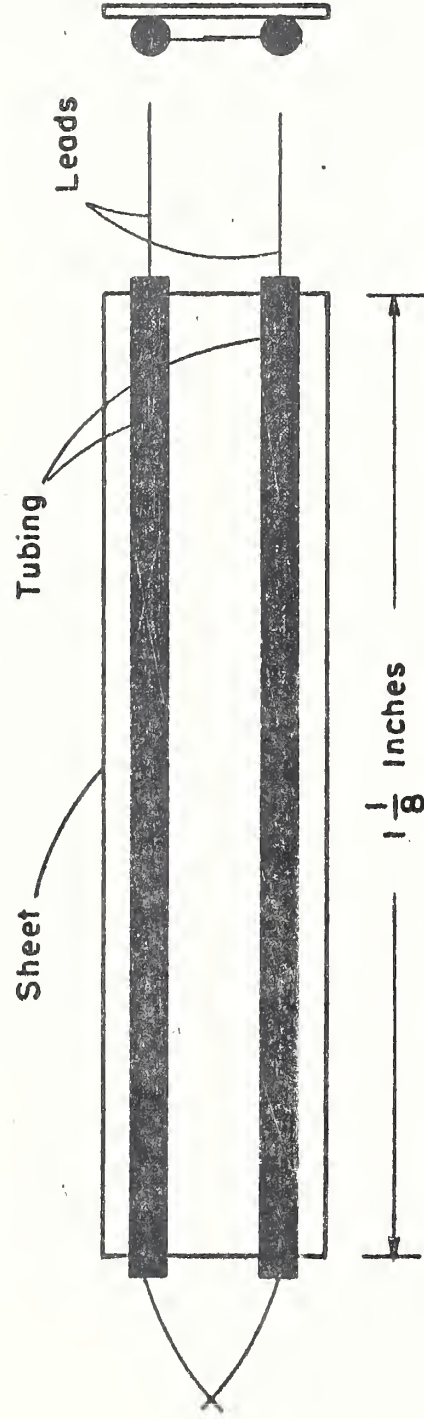


Fig. 1 Gage configuration





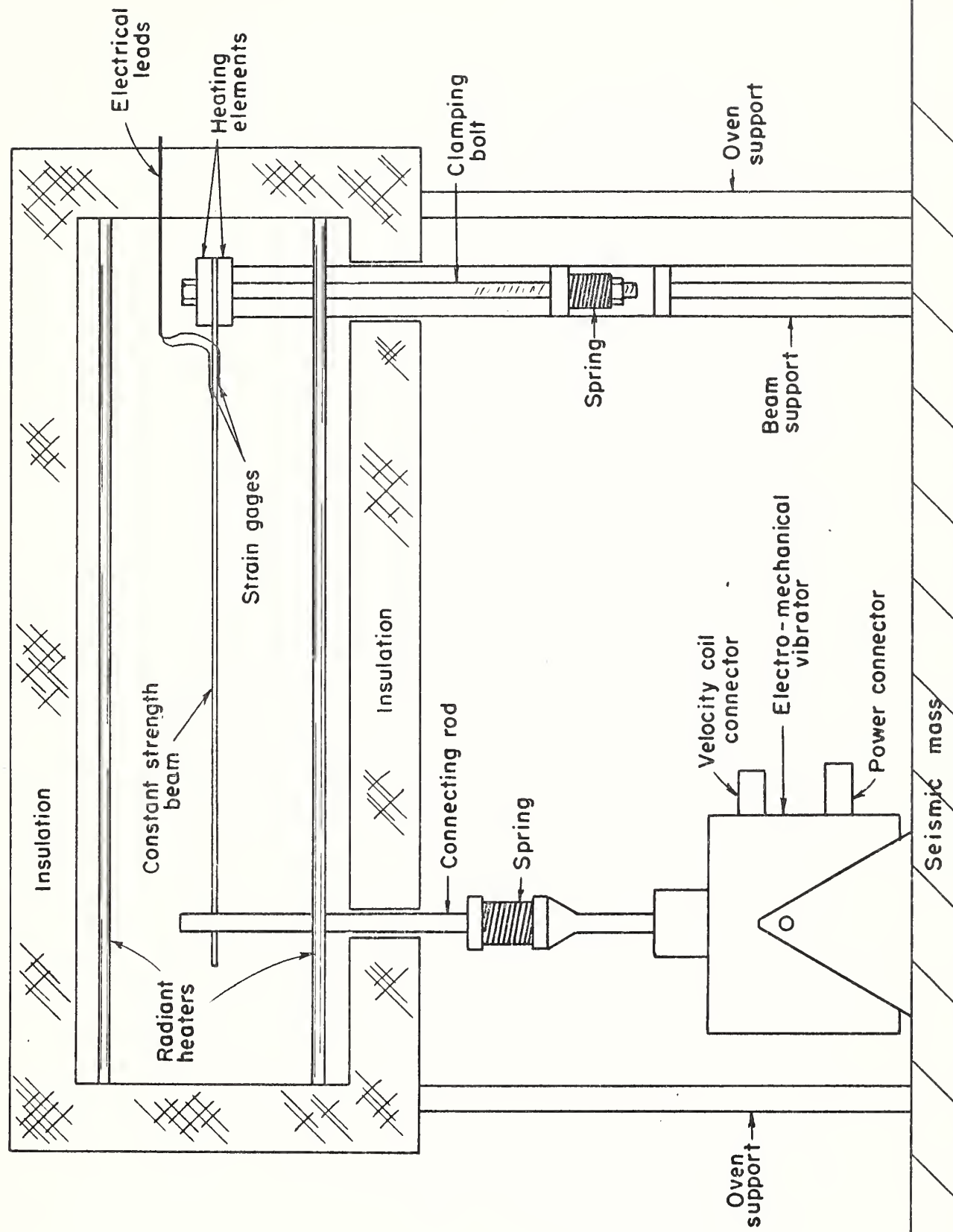


Fig. 2 Equipment for determining variation of gage factor with temperature.



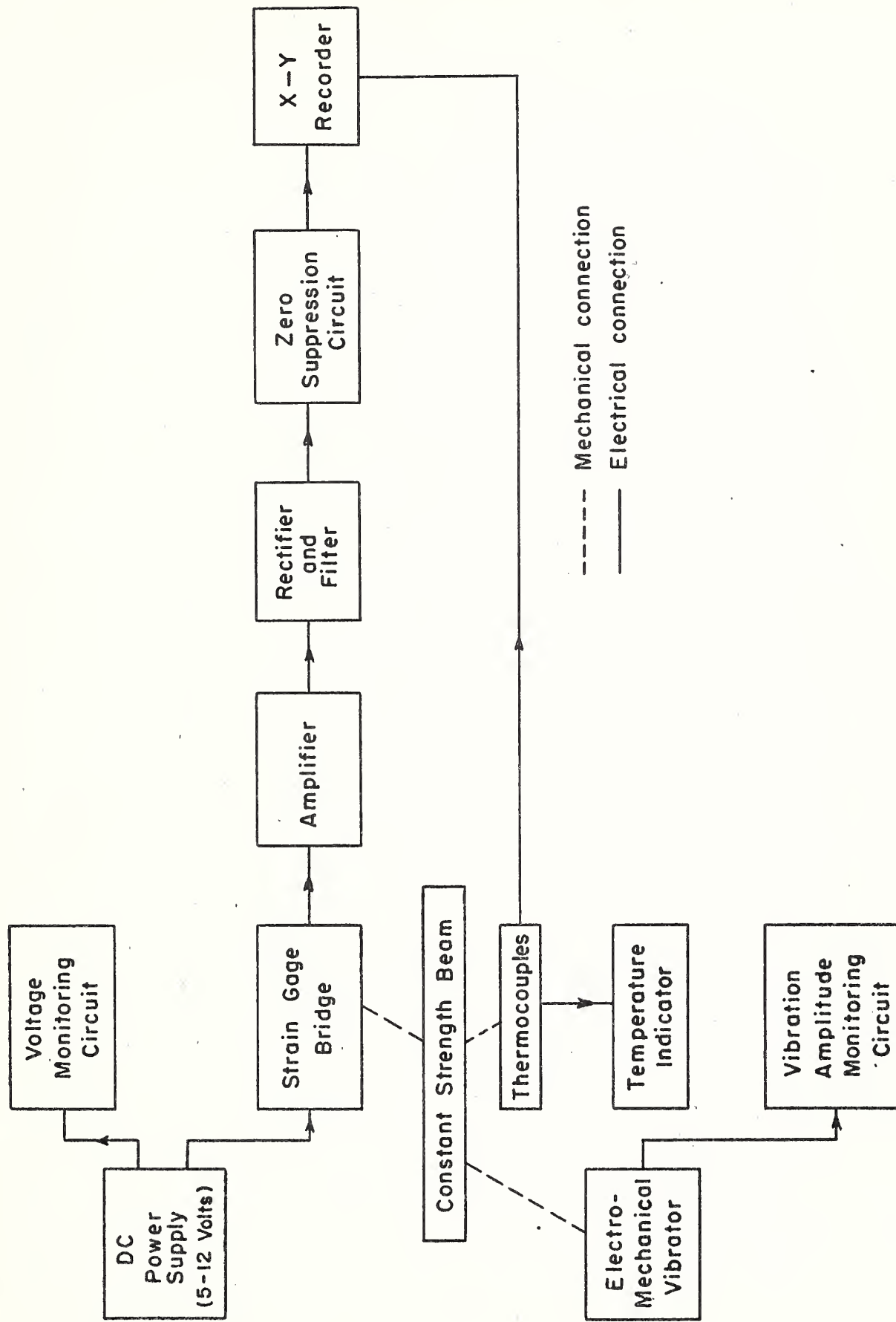


Fig. 3 Equipment for determining variation of gage factor with temperature



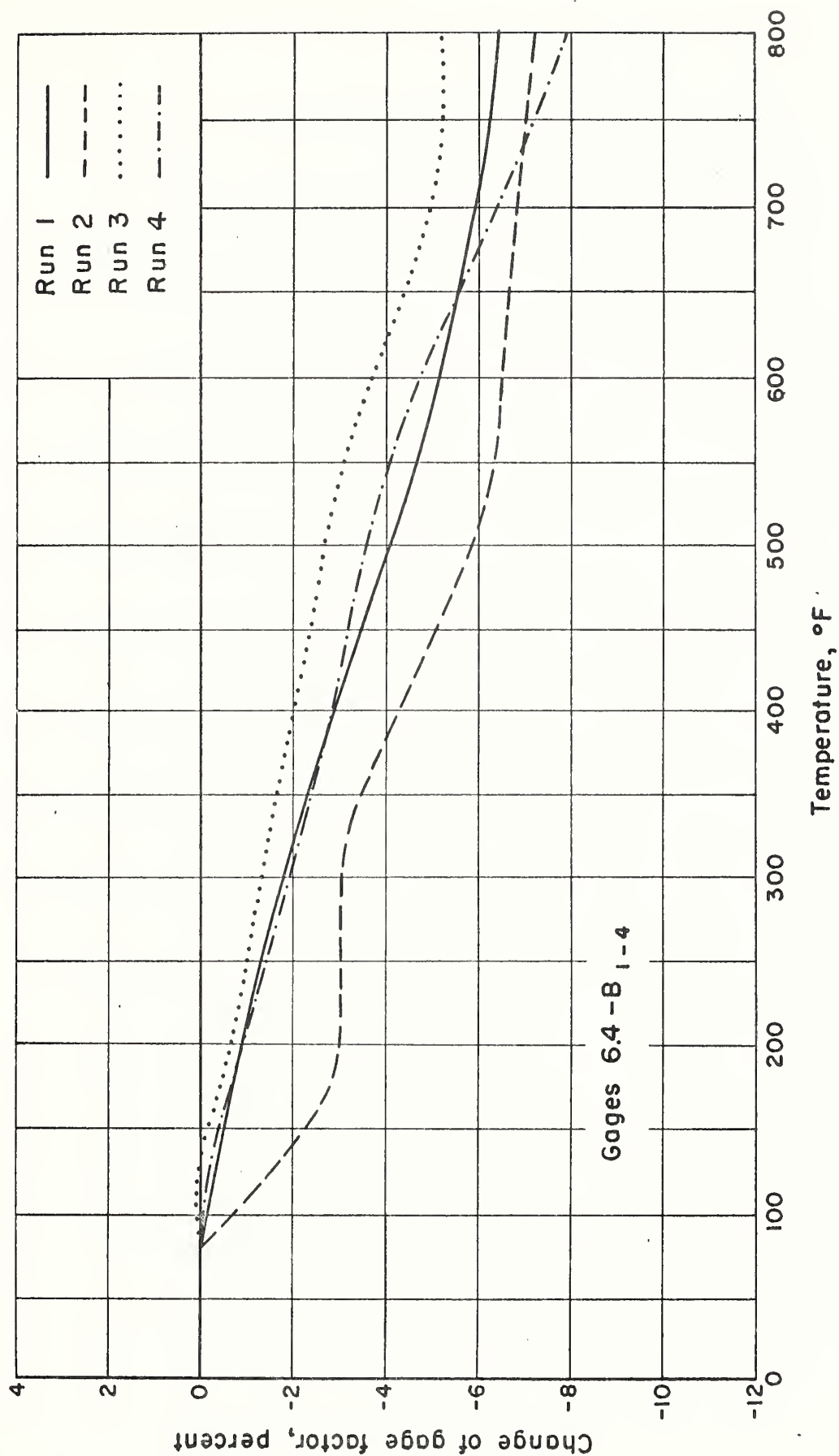


Fig. 4 Variation of gage factor with temperature



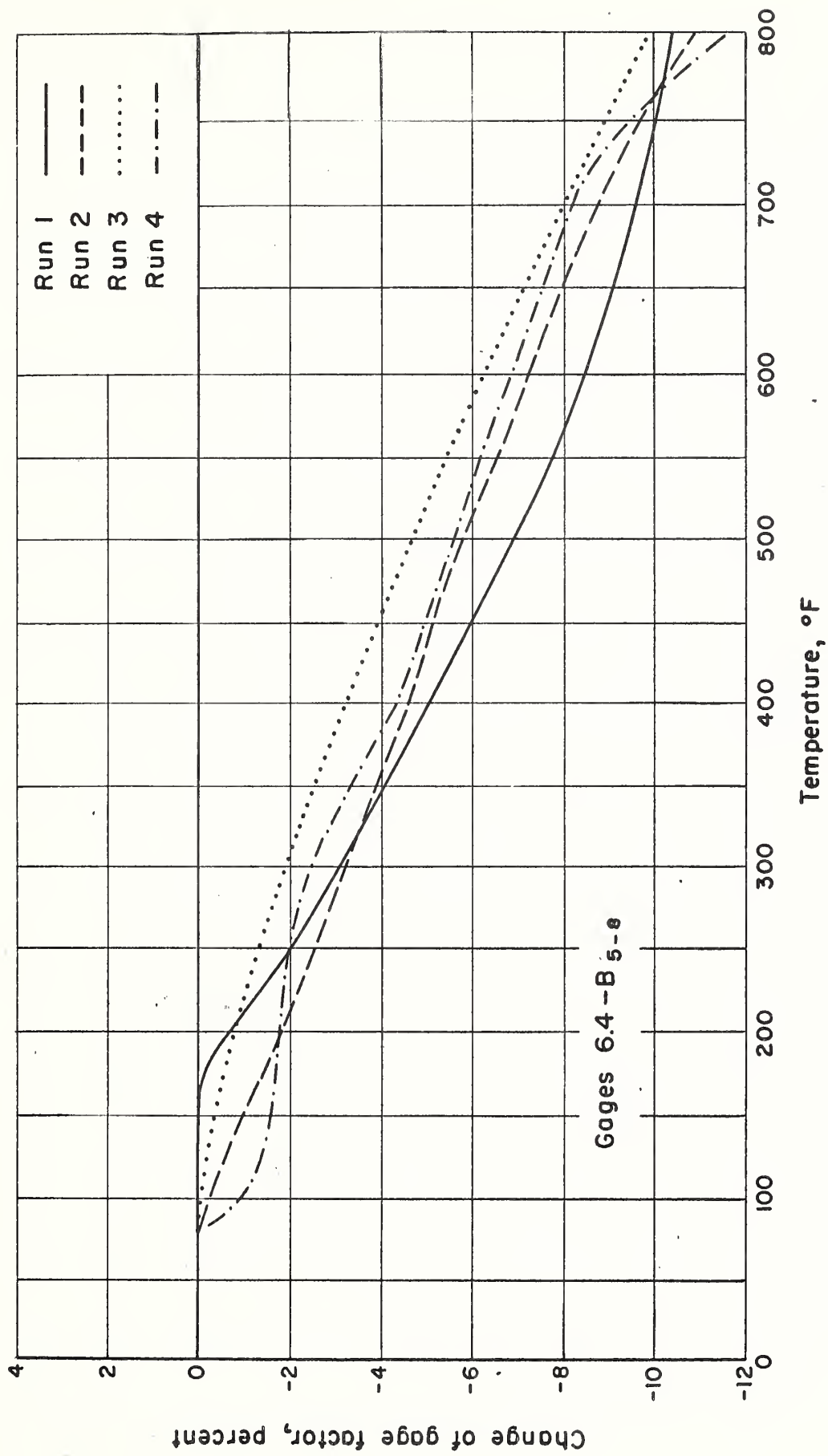


Fig. 5 Variation of gage factor with temperature





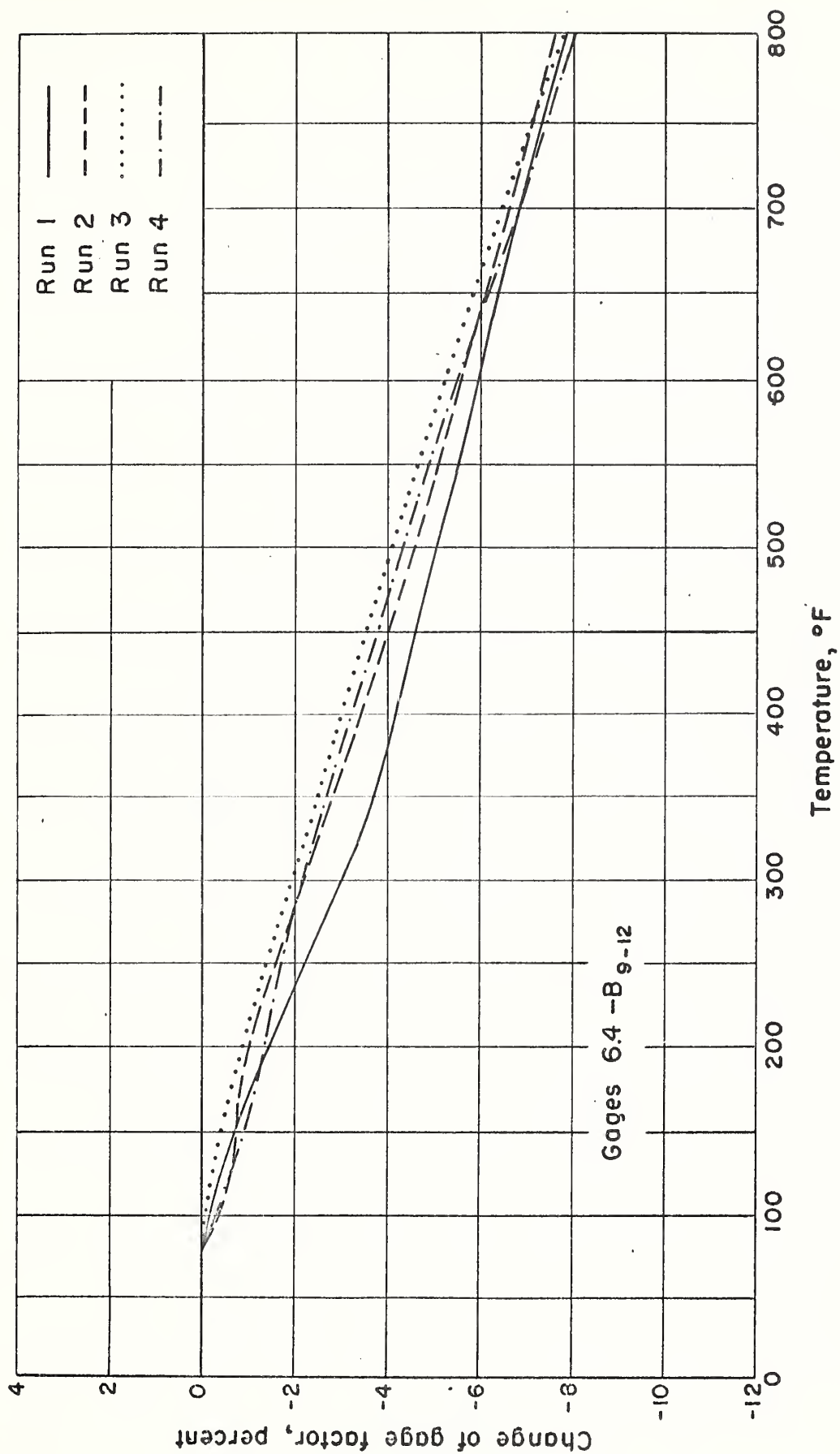


Fig. 6 Variation of gage factor with temperature



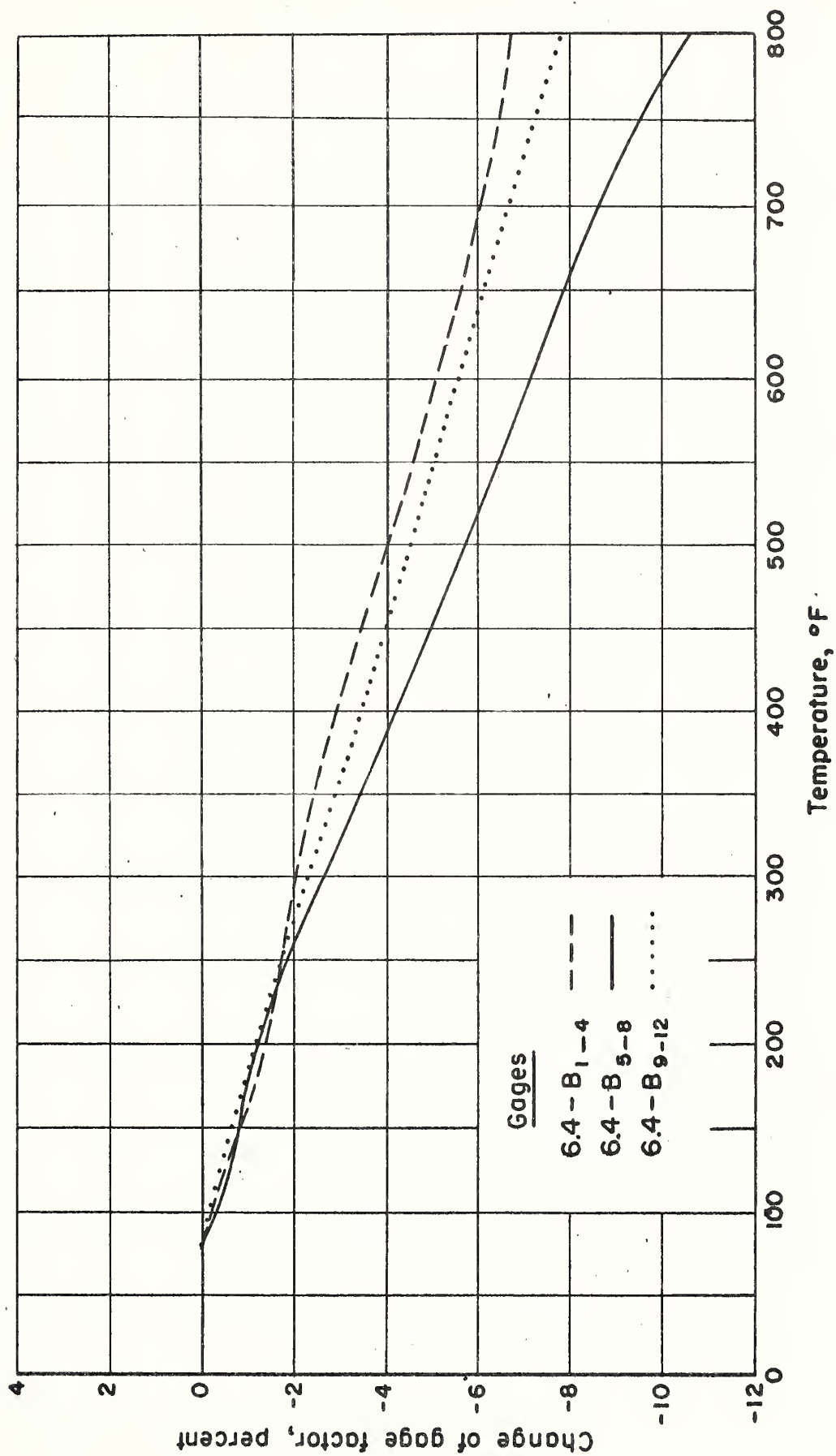


Fig. 7 Average variation of gage factor with temperature for four tests



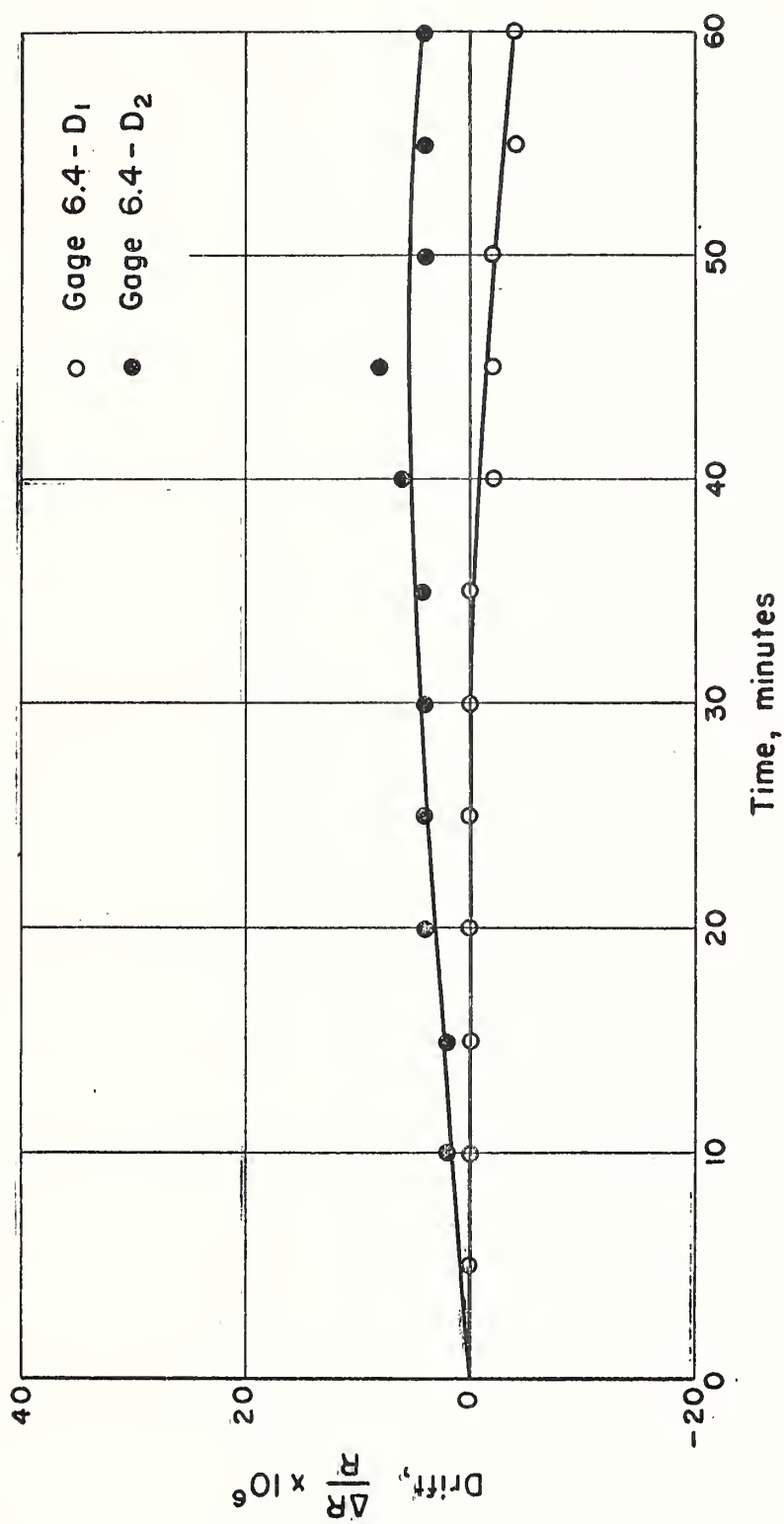


Fig. 8 Drift behavior at 300° F



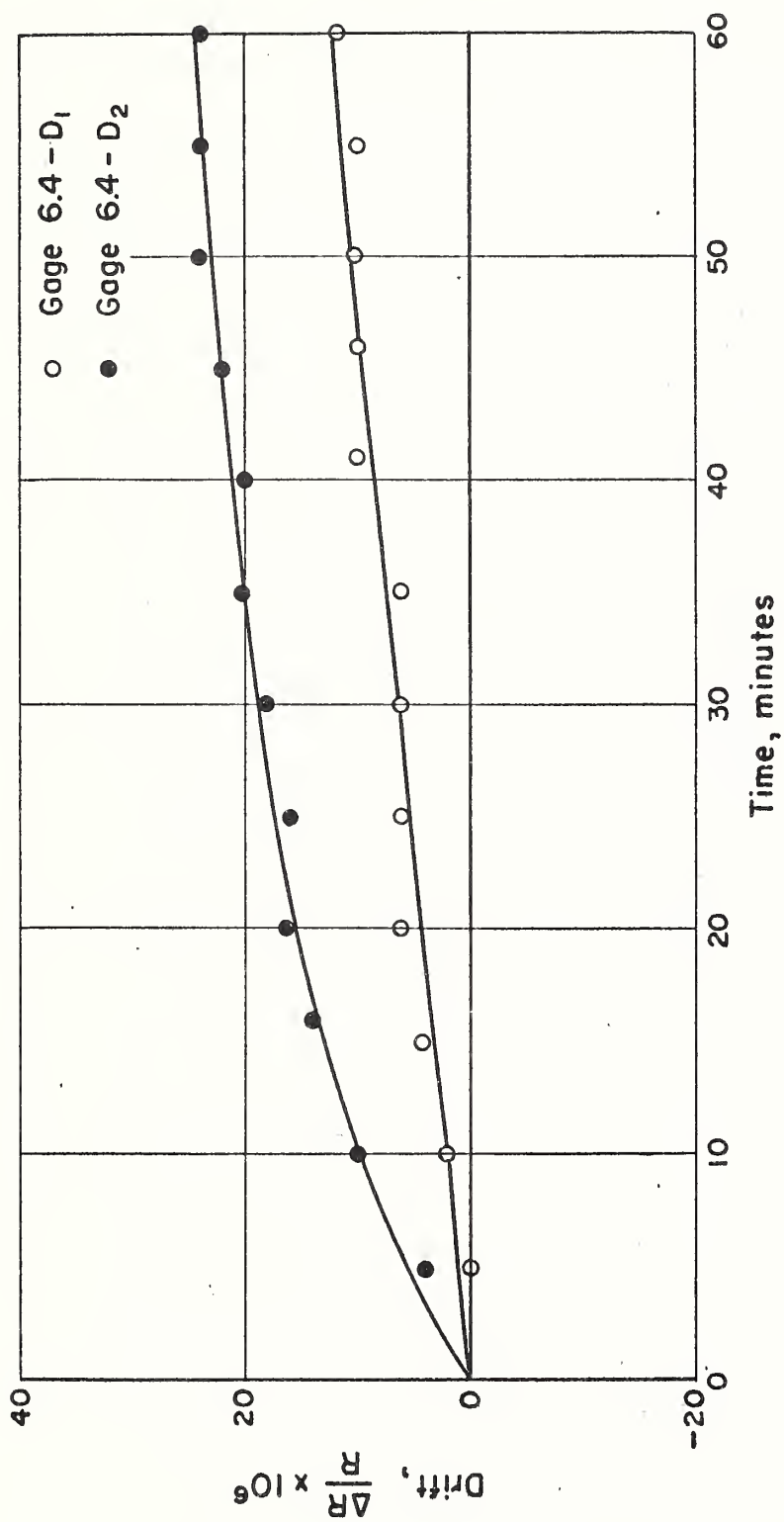


Fig. 9 Drift behavior at 400° F





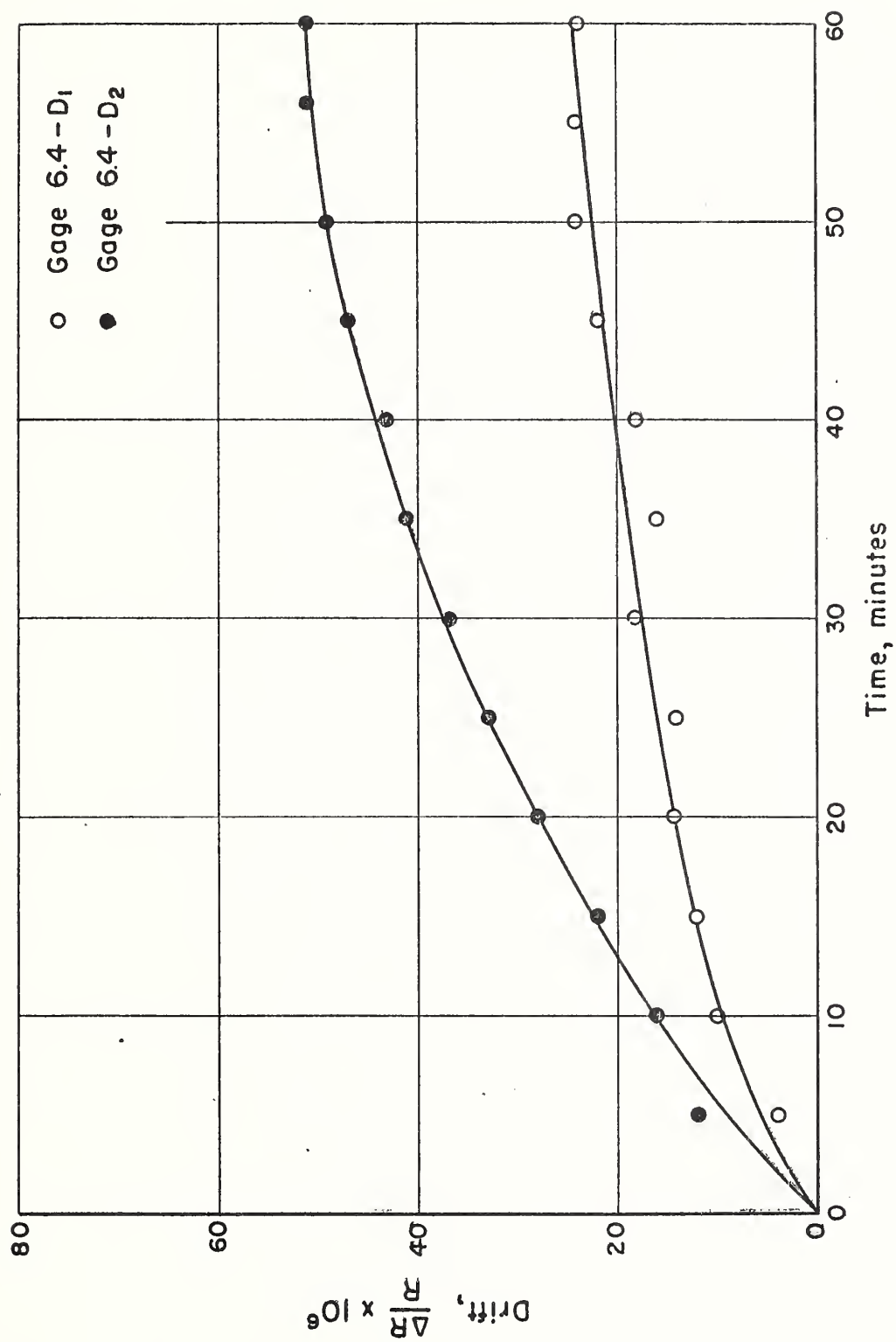


Fig.10 Drift behavior at 500° F



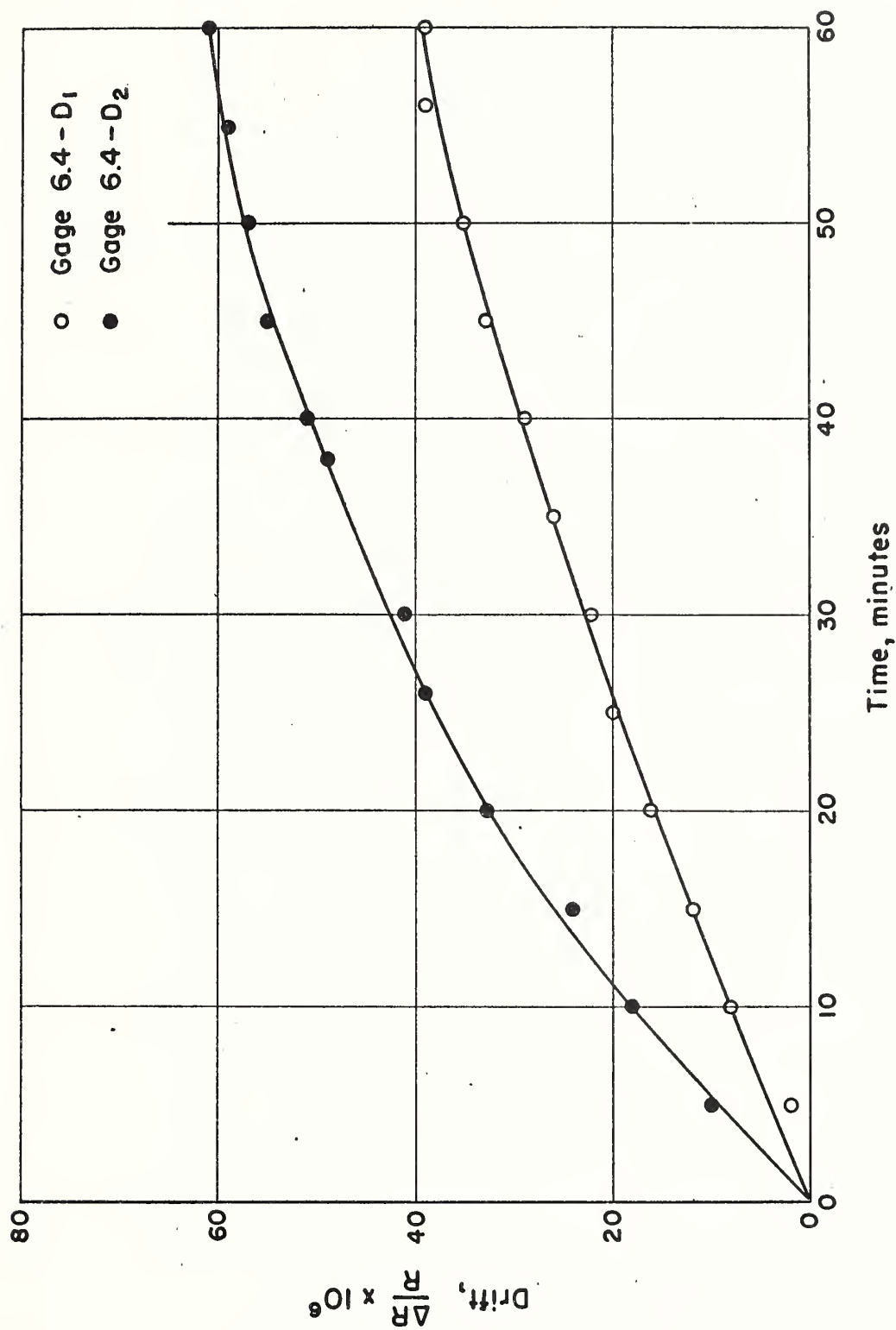


Fig. 11 Drift behavior at 600°F



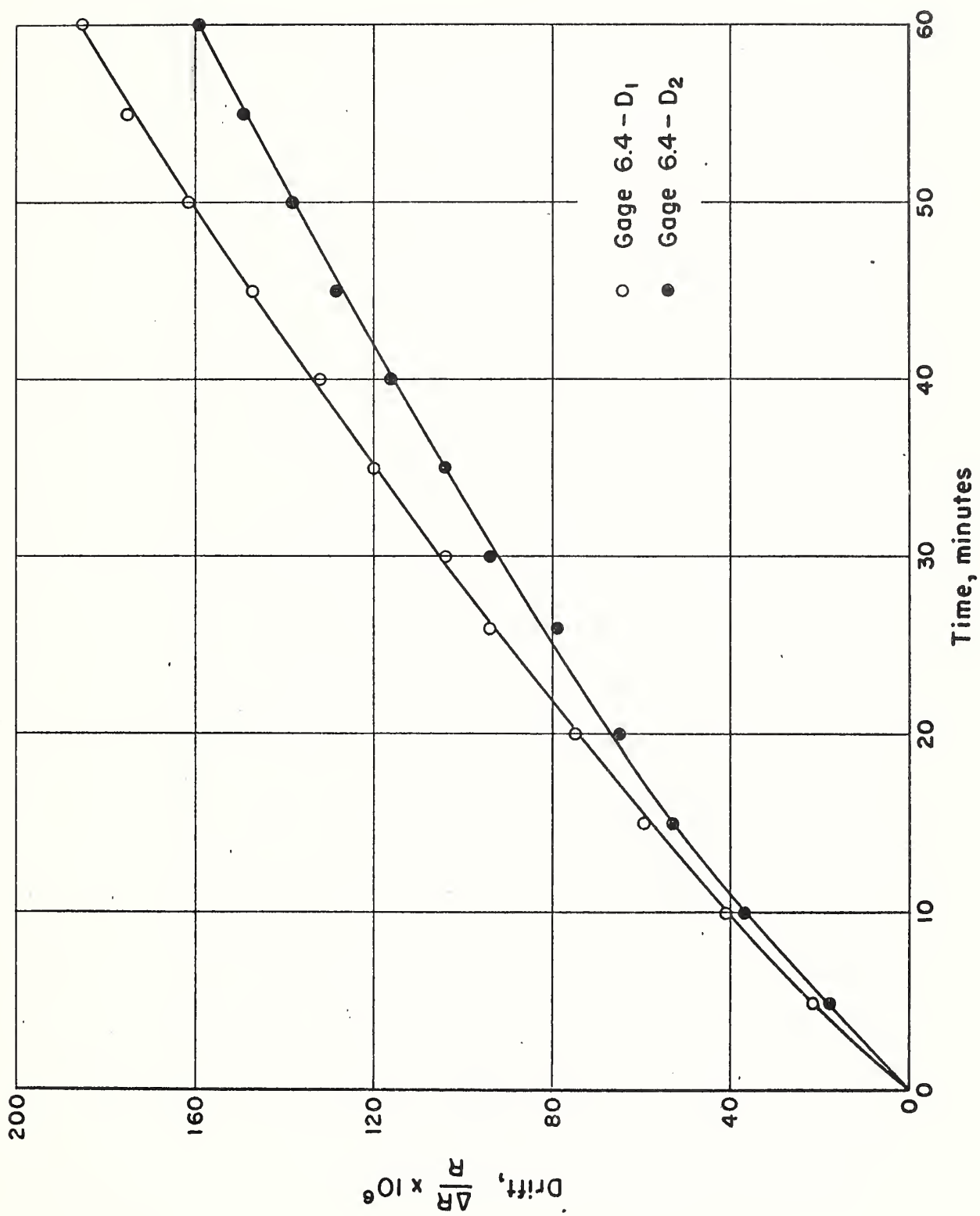


Fig. 12 Drift behavior at 700°F



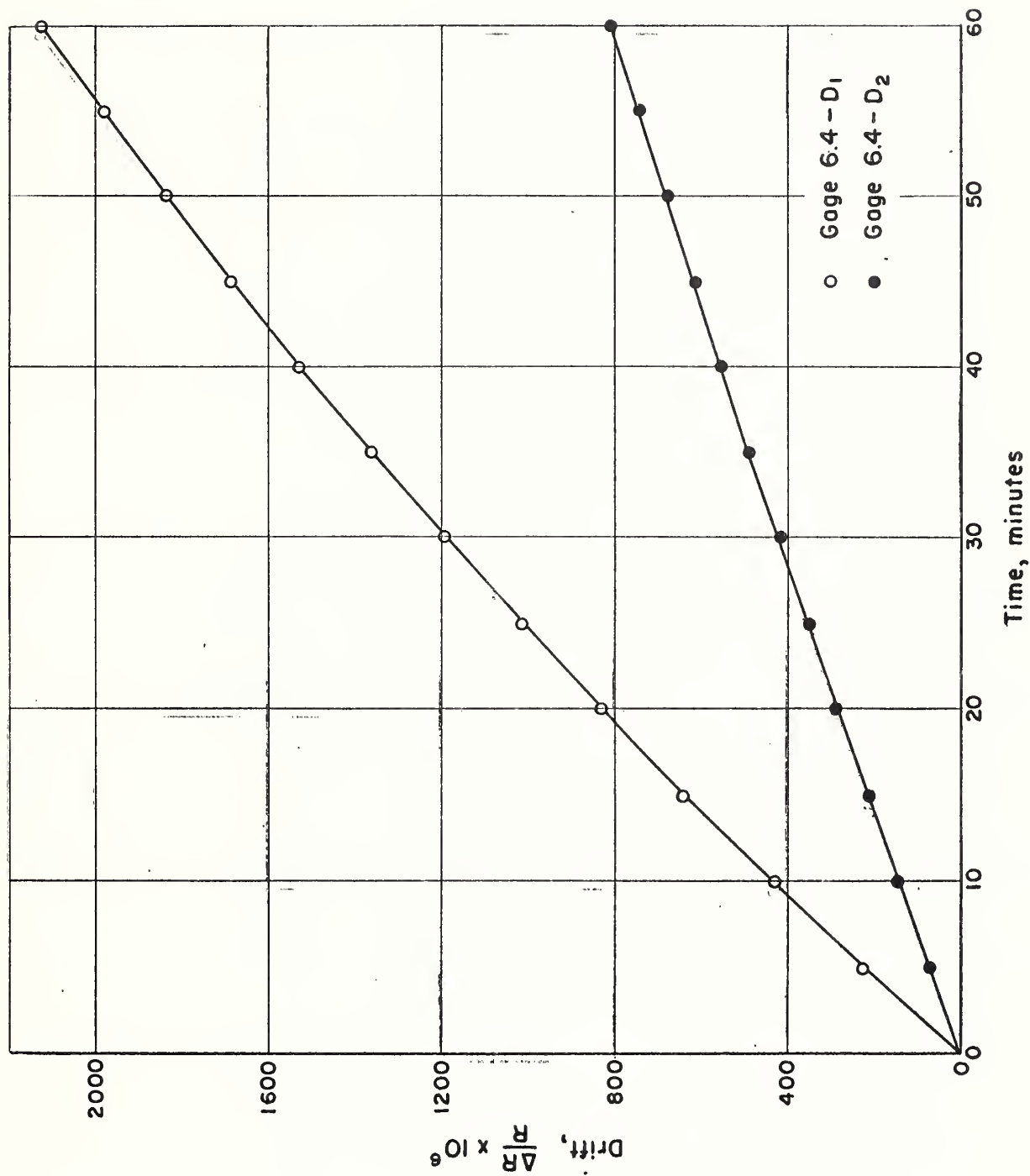


Fig. 13 Drift behavior at 800° F





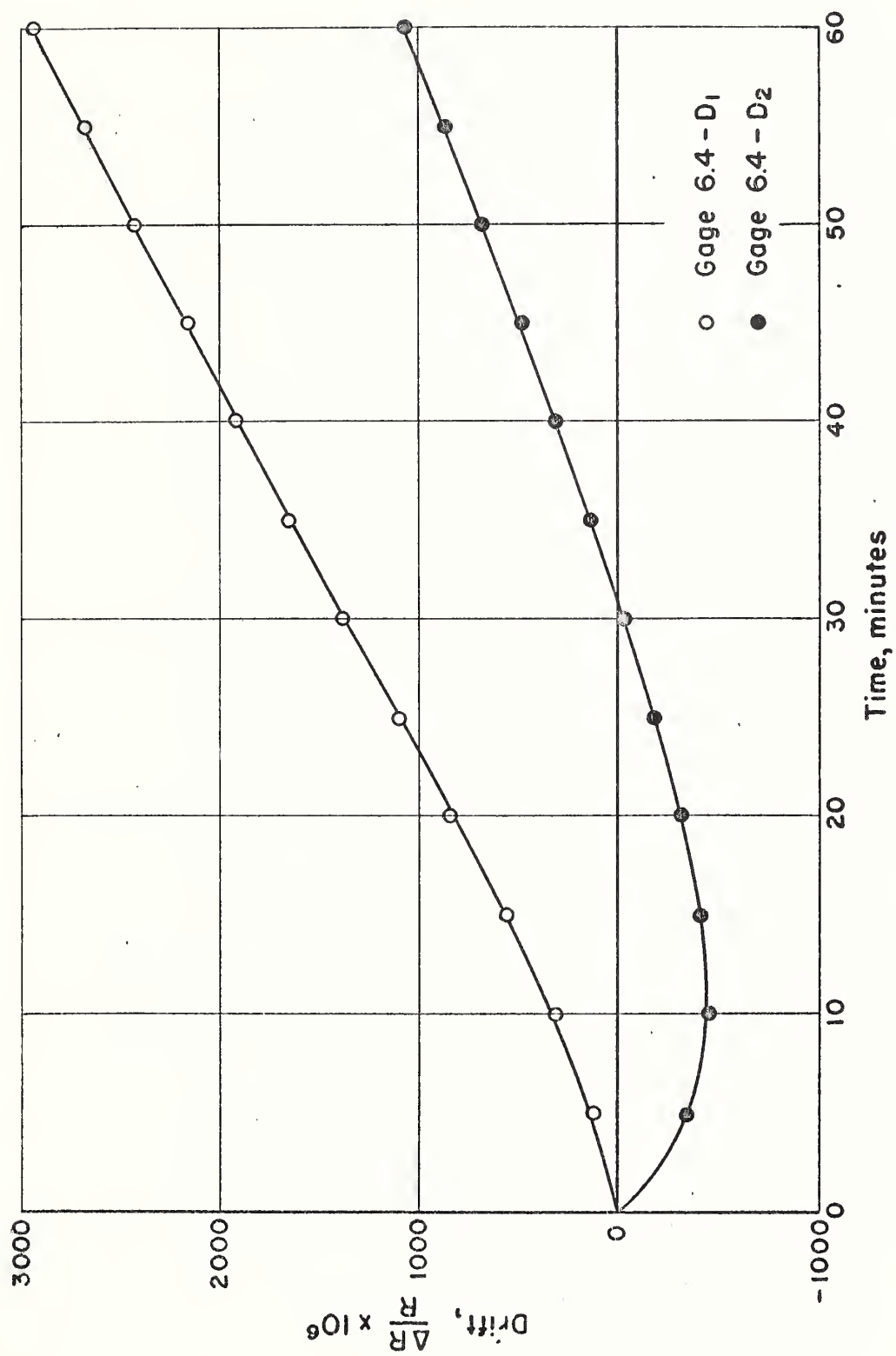


Fig. 14 Drift behavior at 900°F



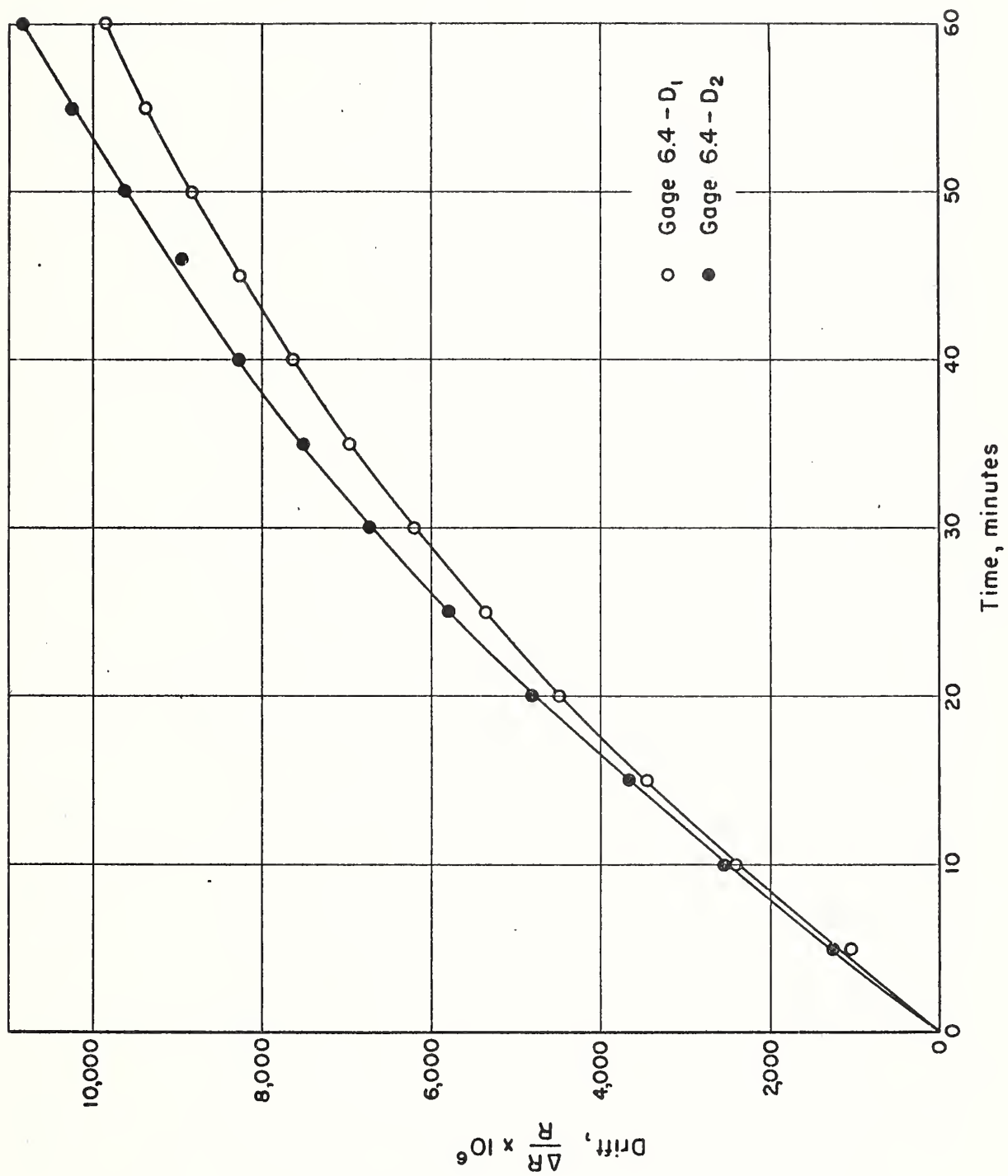


Fig. 15 Drift behavior at 1000° F



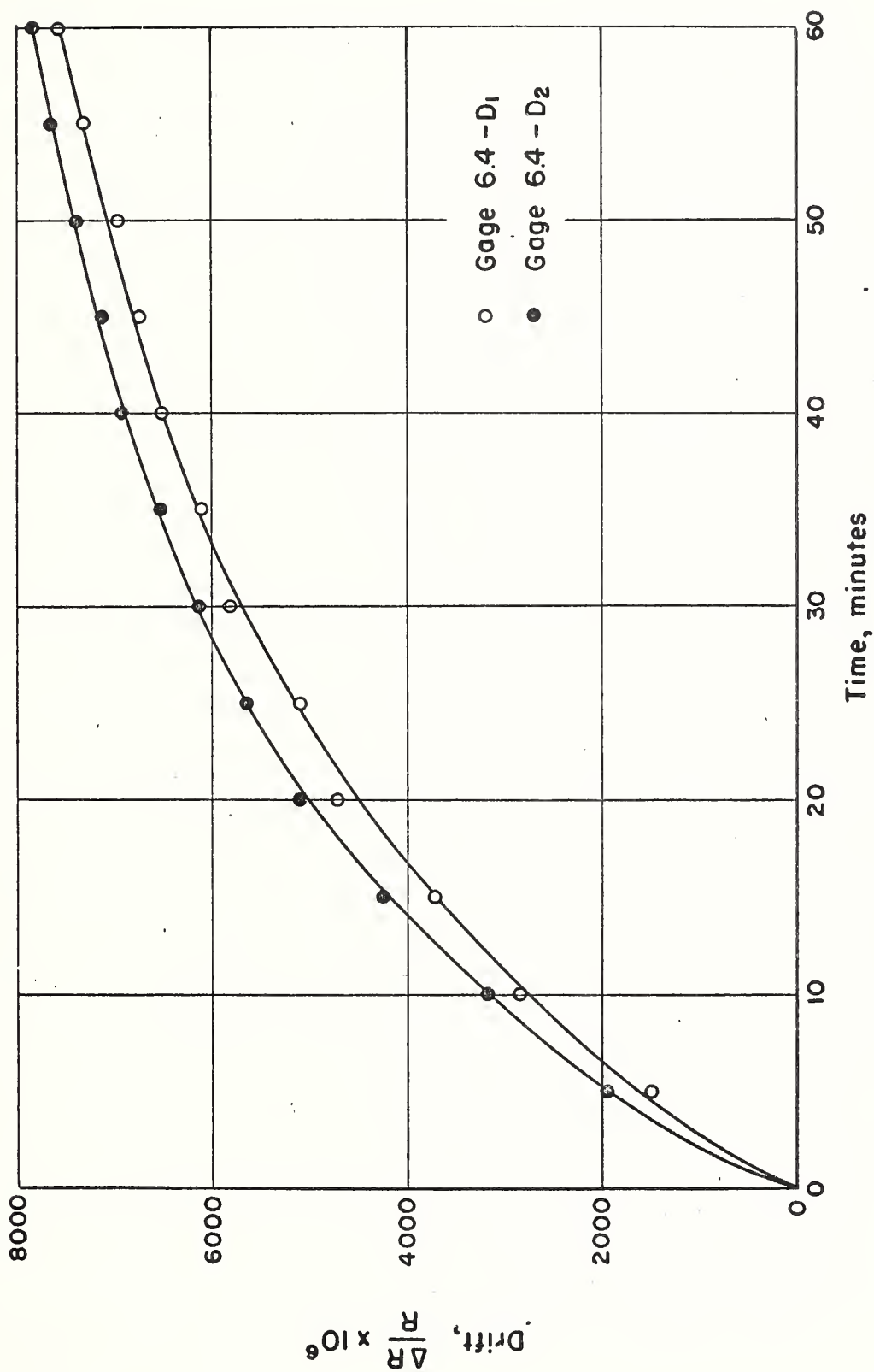


Fig. 16 Drift behavior at 1100°F



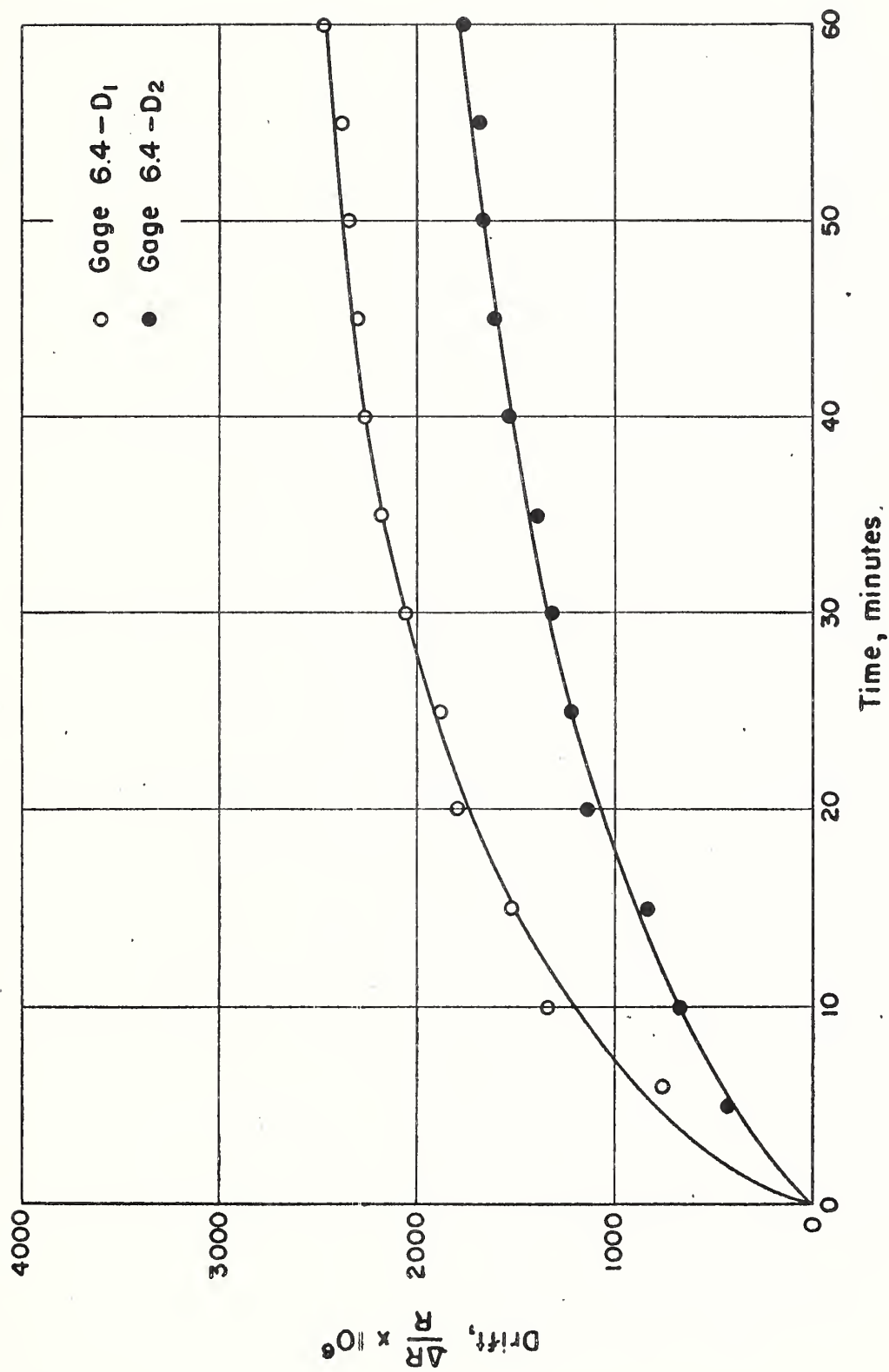


Fig. 17 Drift behavior at 1200° F





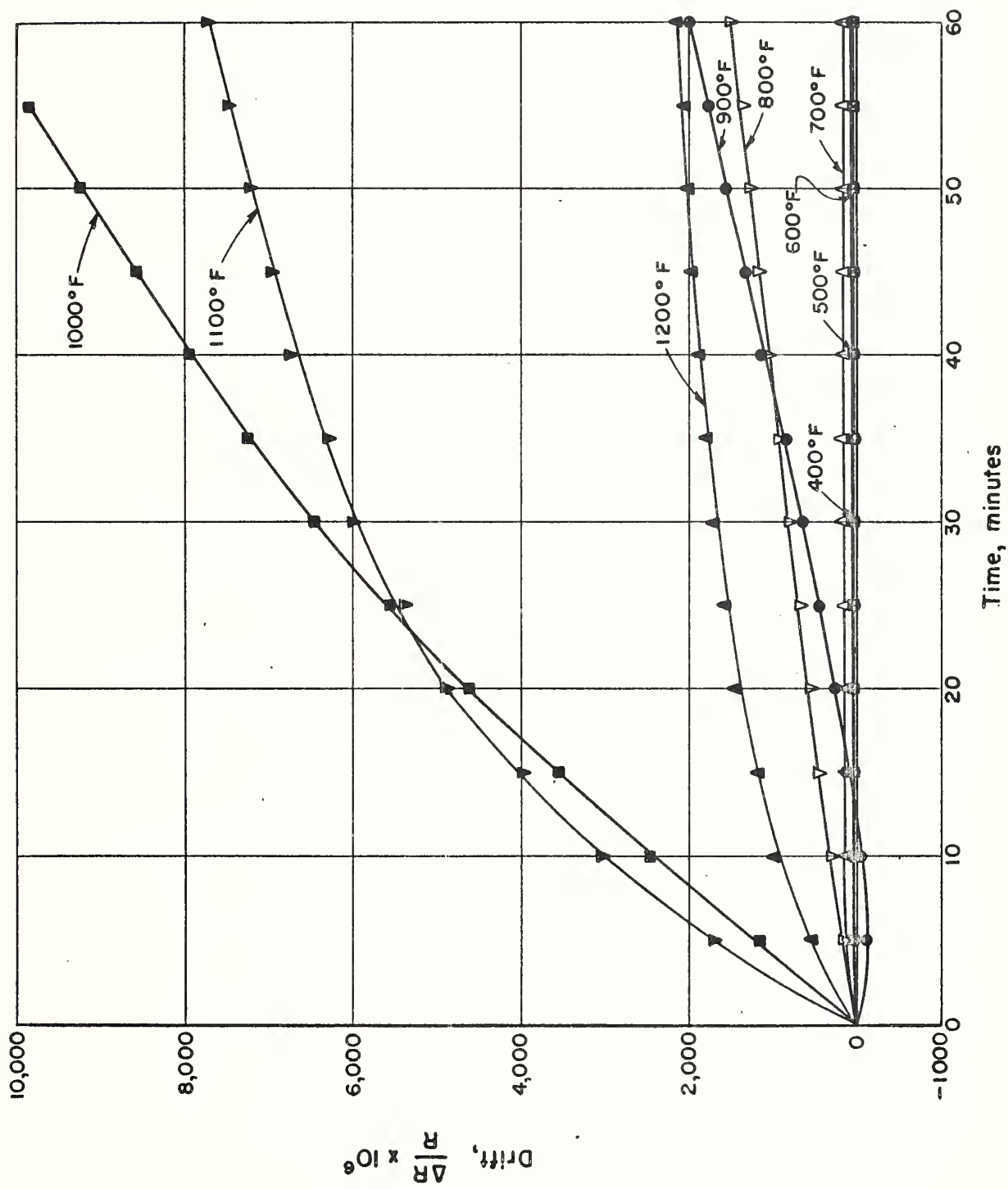


Fig. 18 Average drift of two gages (6.4-D<sub>1</sub> and 6.4-D<sub>2</sub>)



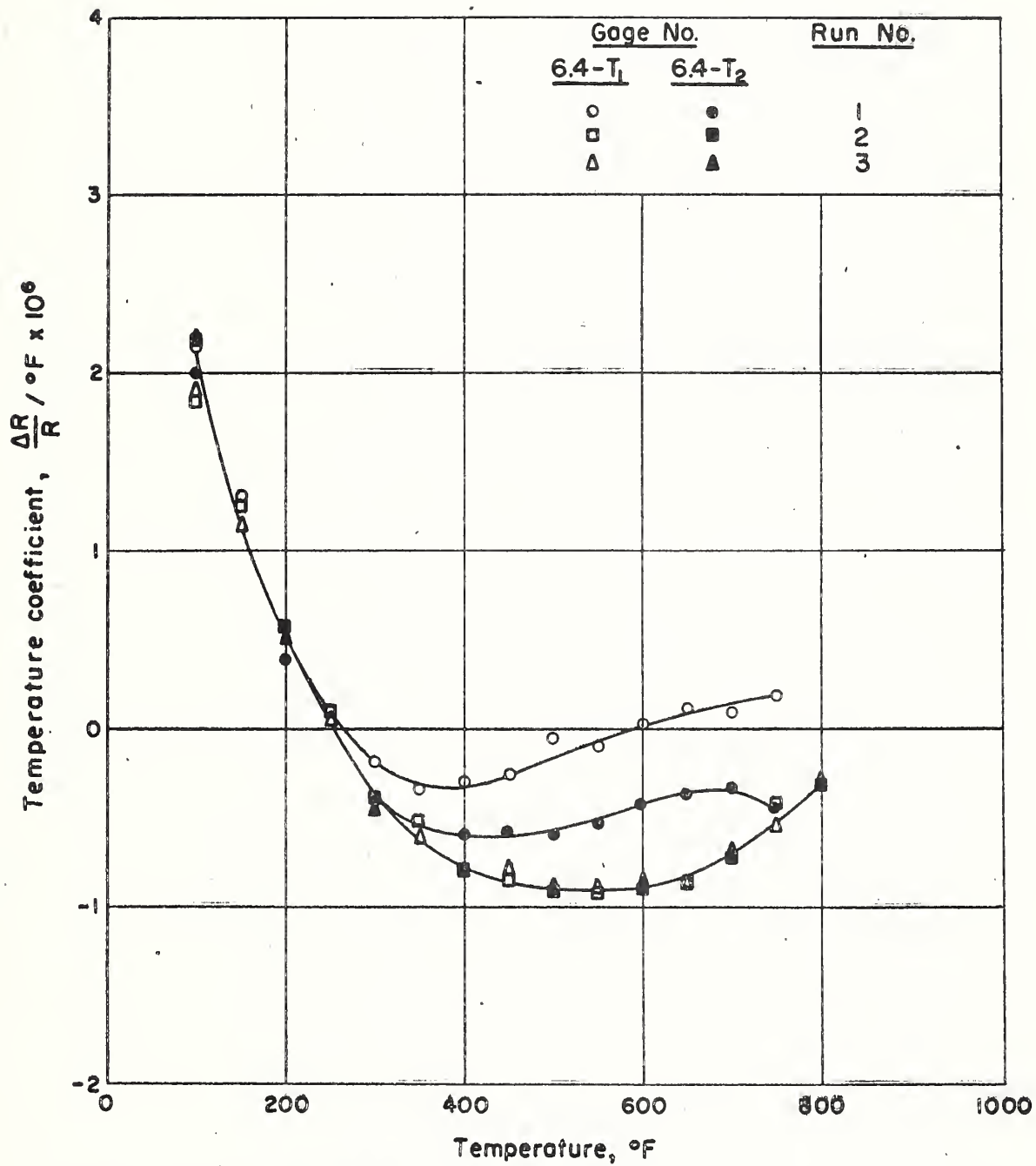


Fig. 19 Temperature coefficient of two gages



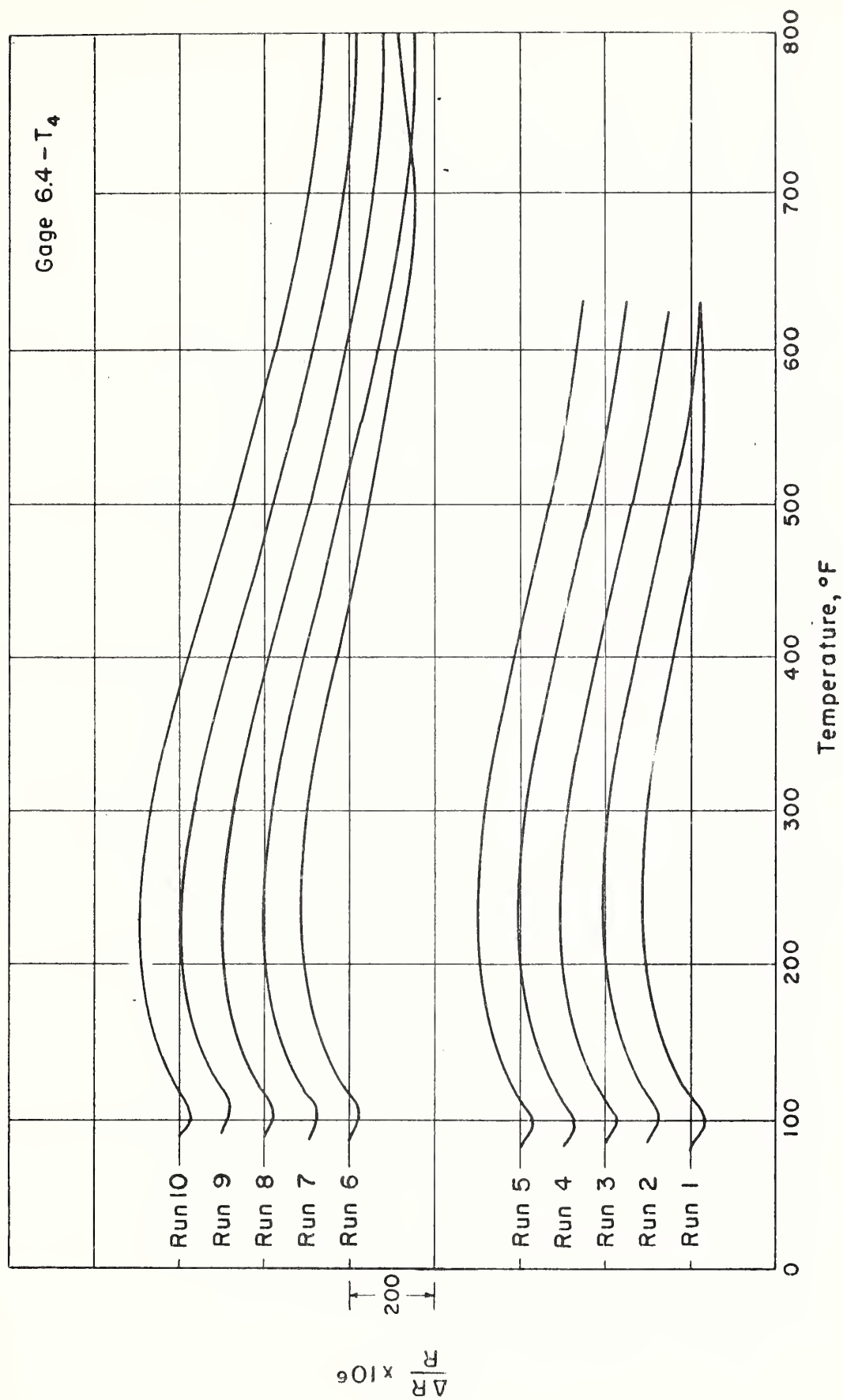


Fig. 20 Variation of gage resistance with increasing temperature



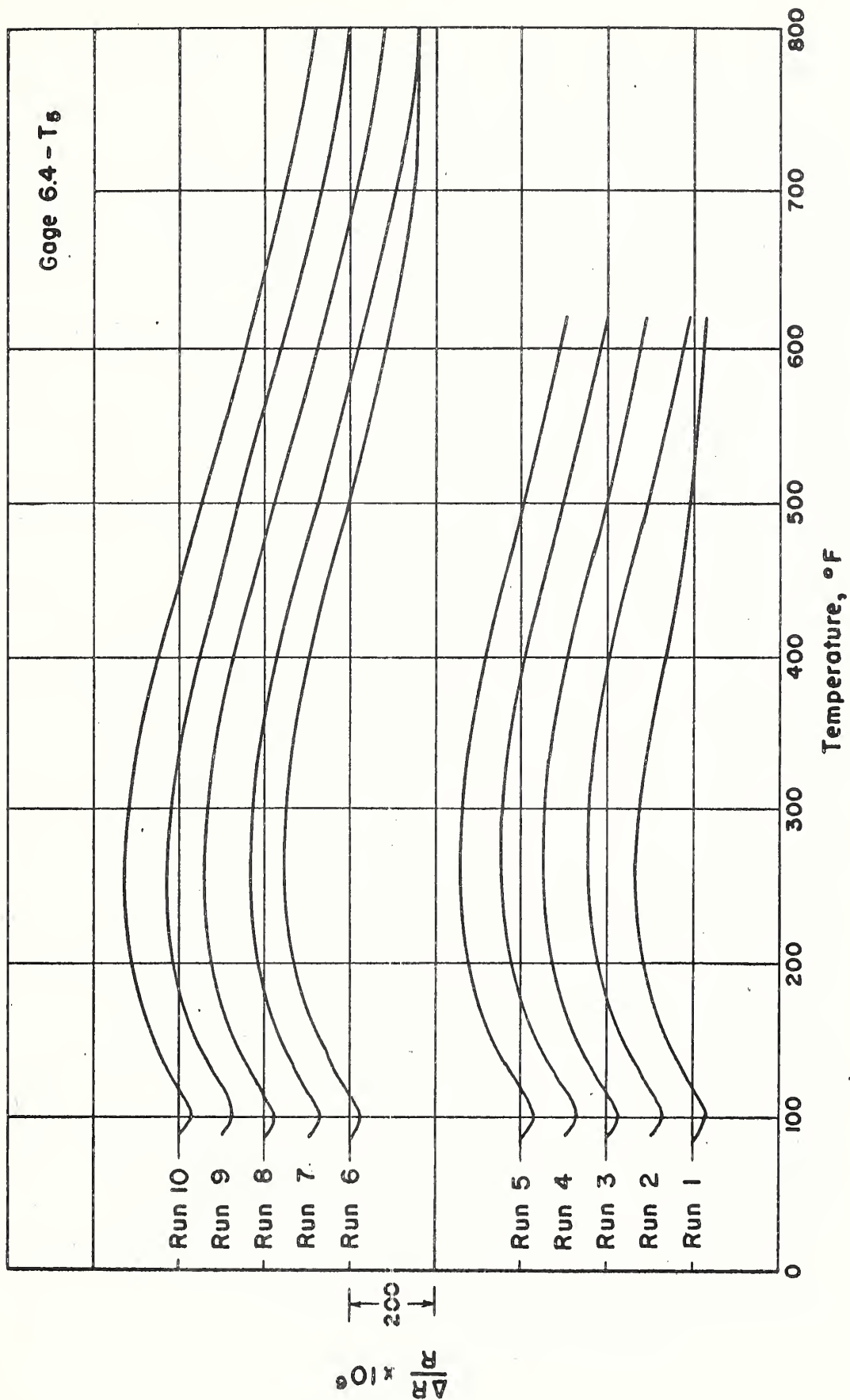


Fig. 21 Variation of gage resistance with increasing temperature





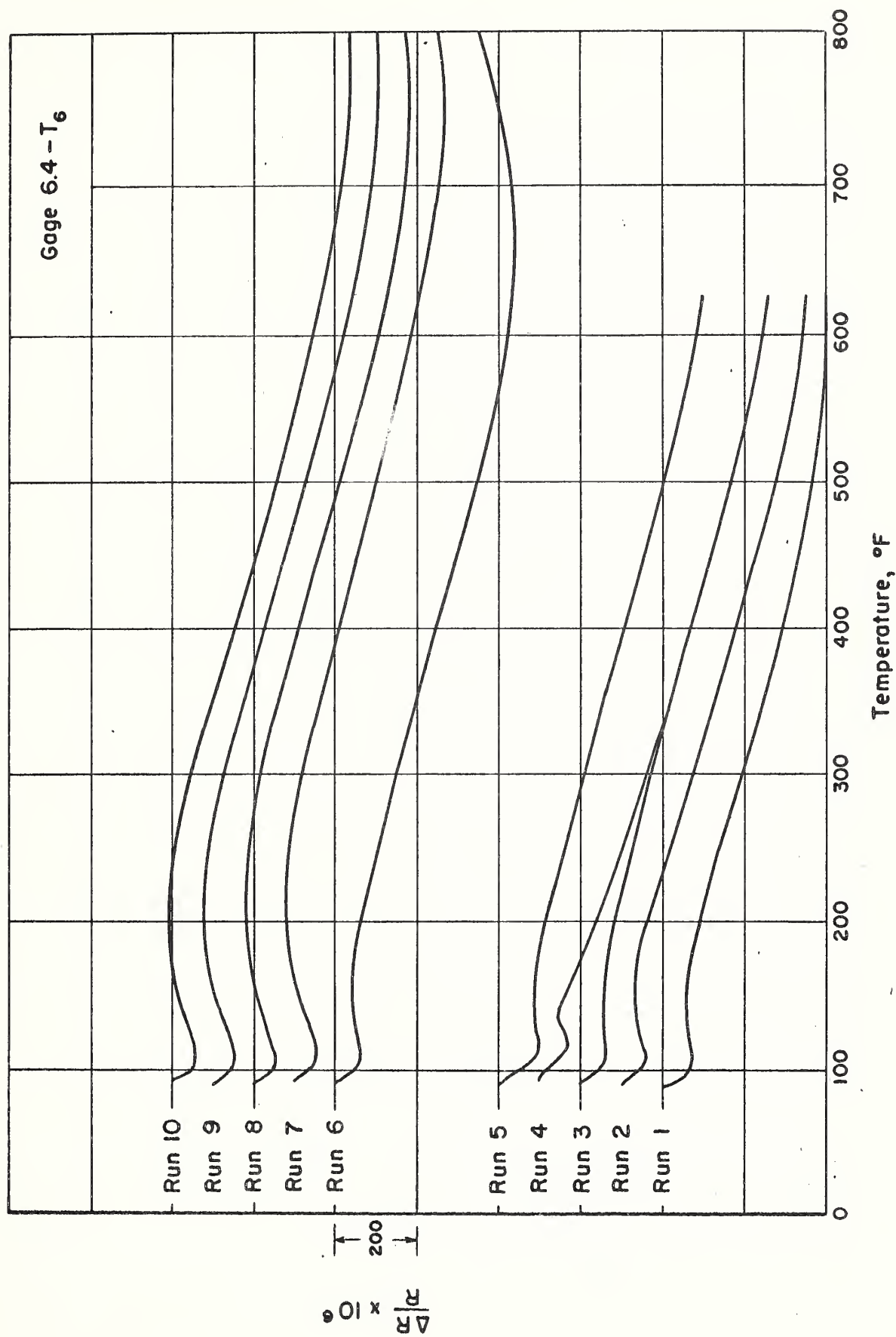


Fig. 22 Variation of gage resistance with increasing temperature



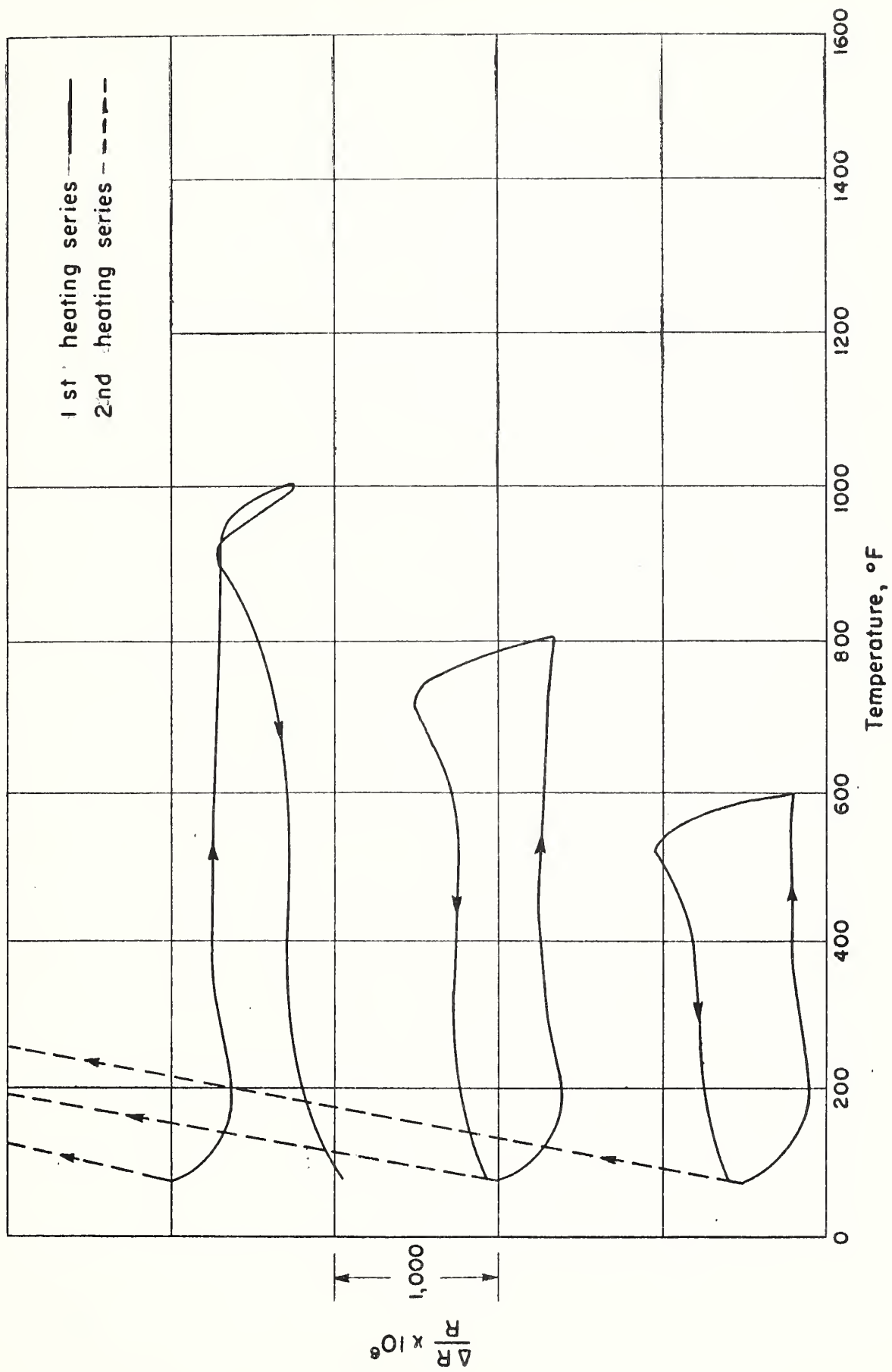


Fig. 23 Gage response with transient heating.



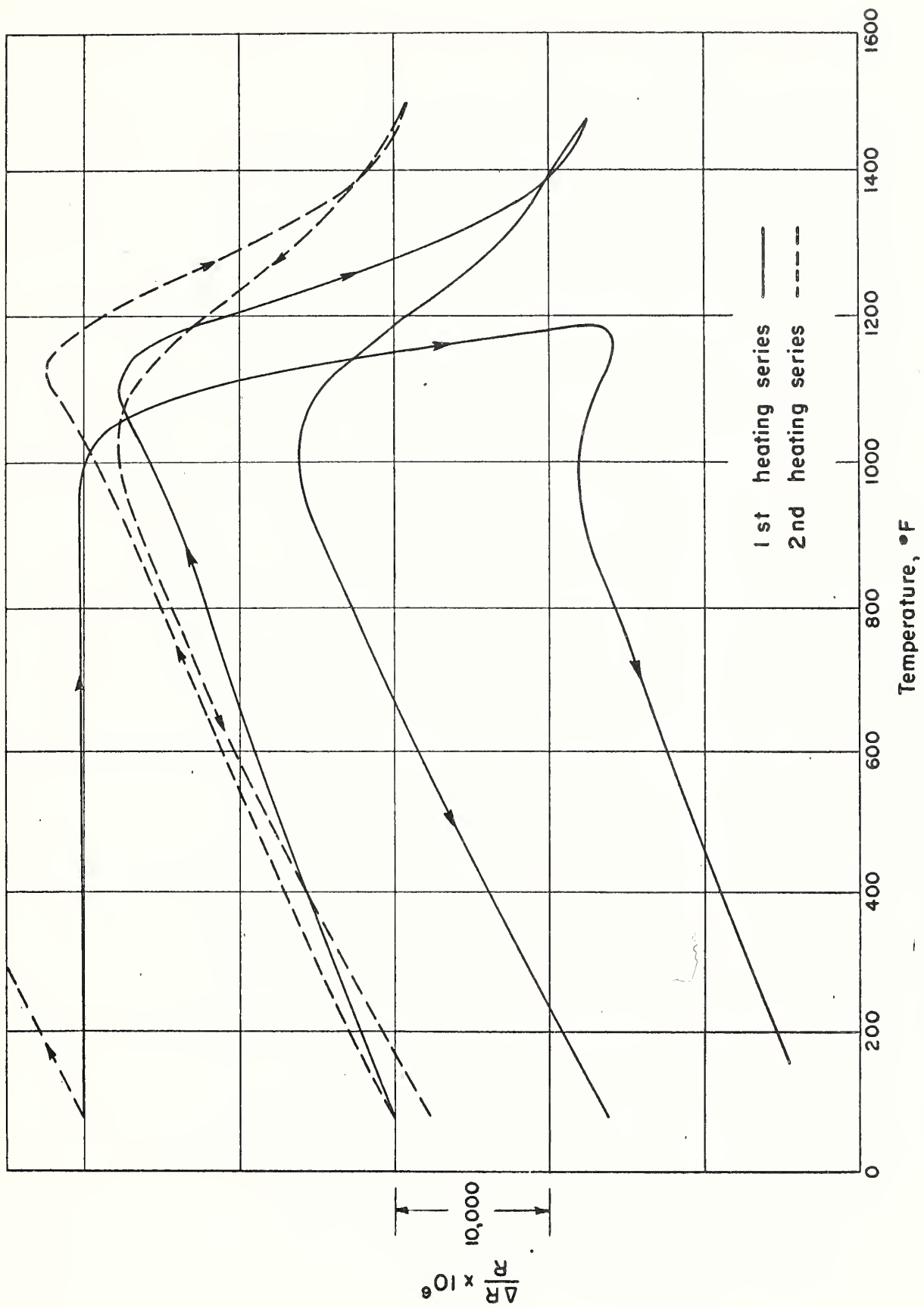


Fig. 24 Gage response with transient heating.



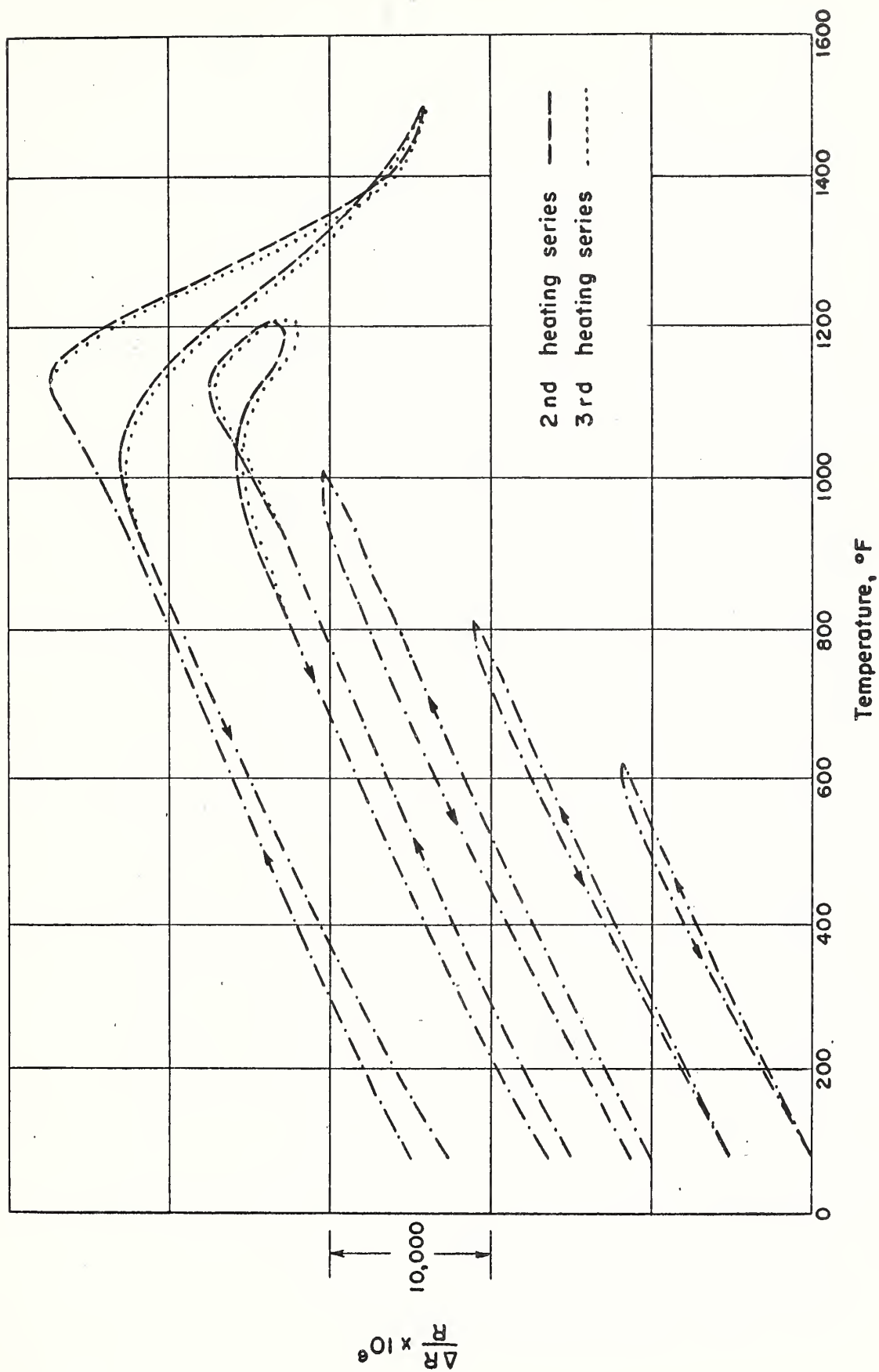


Fig. 25 Gage response with transient heating.





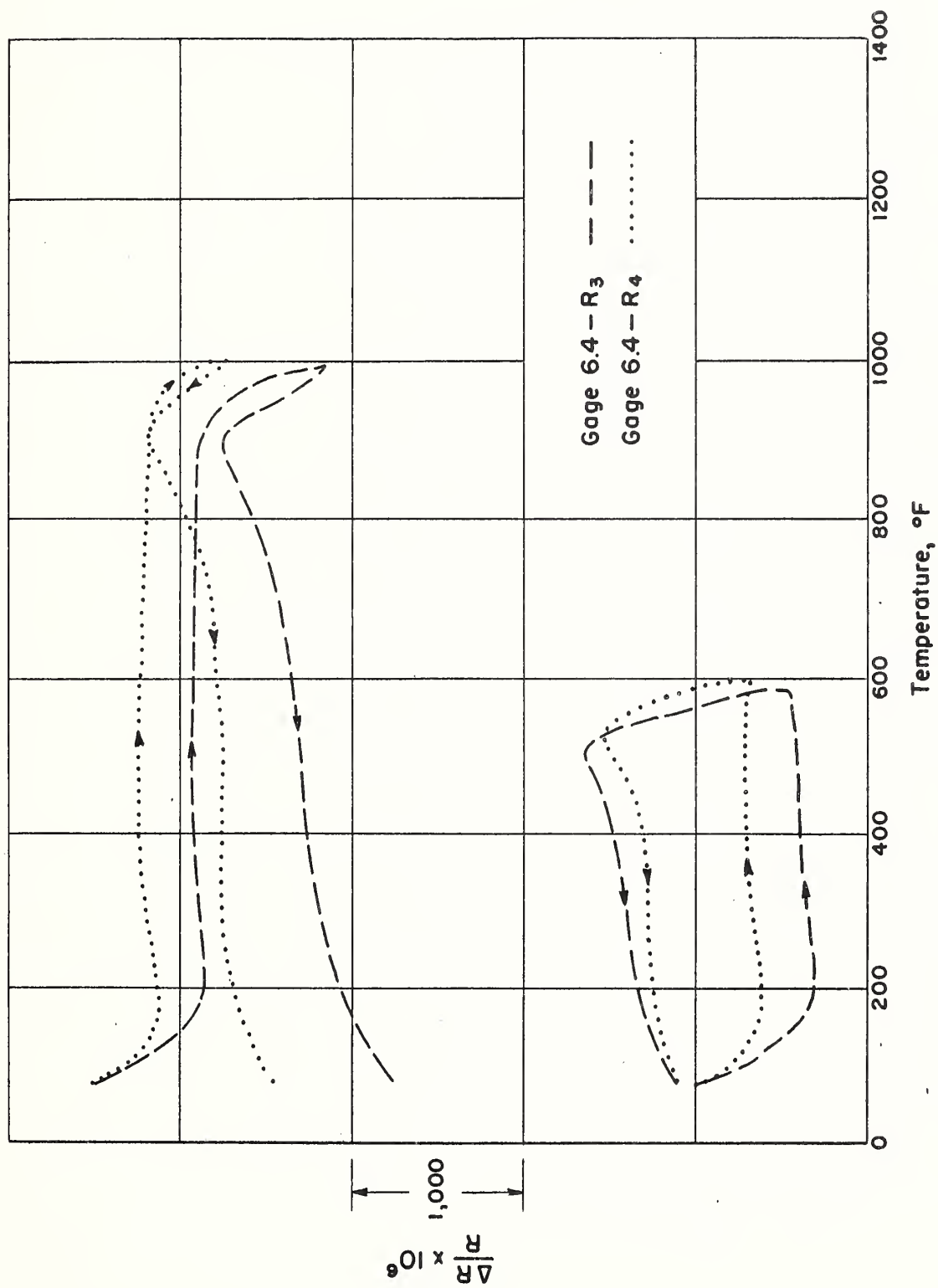


Fig.26 Response of two gages with transient heating. 1st heating series



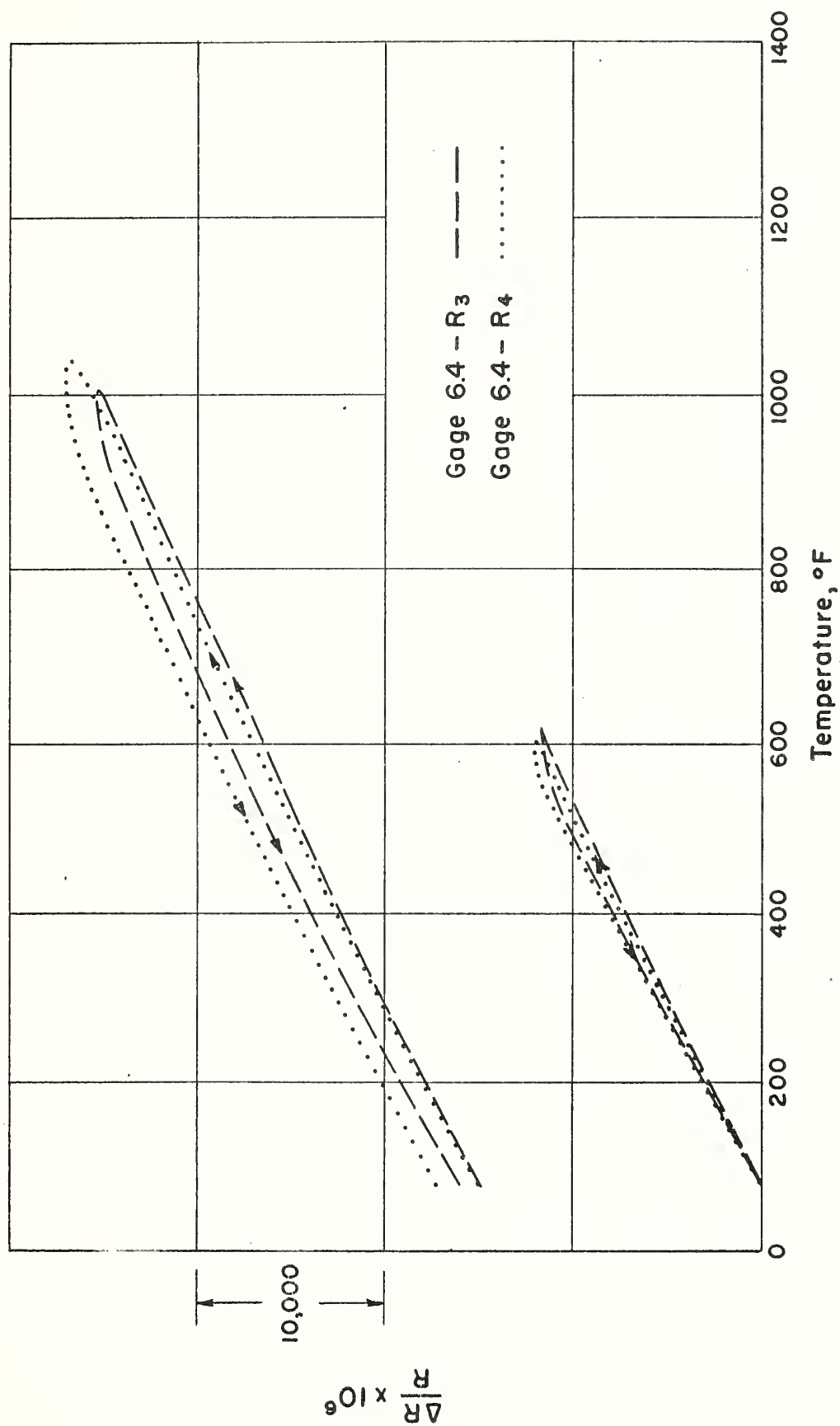


Fig. 27 Response of two gages with transient heating. 2nd heating series



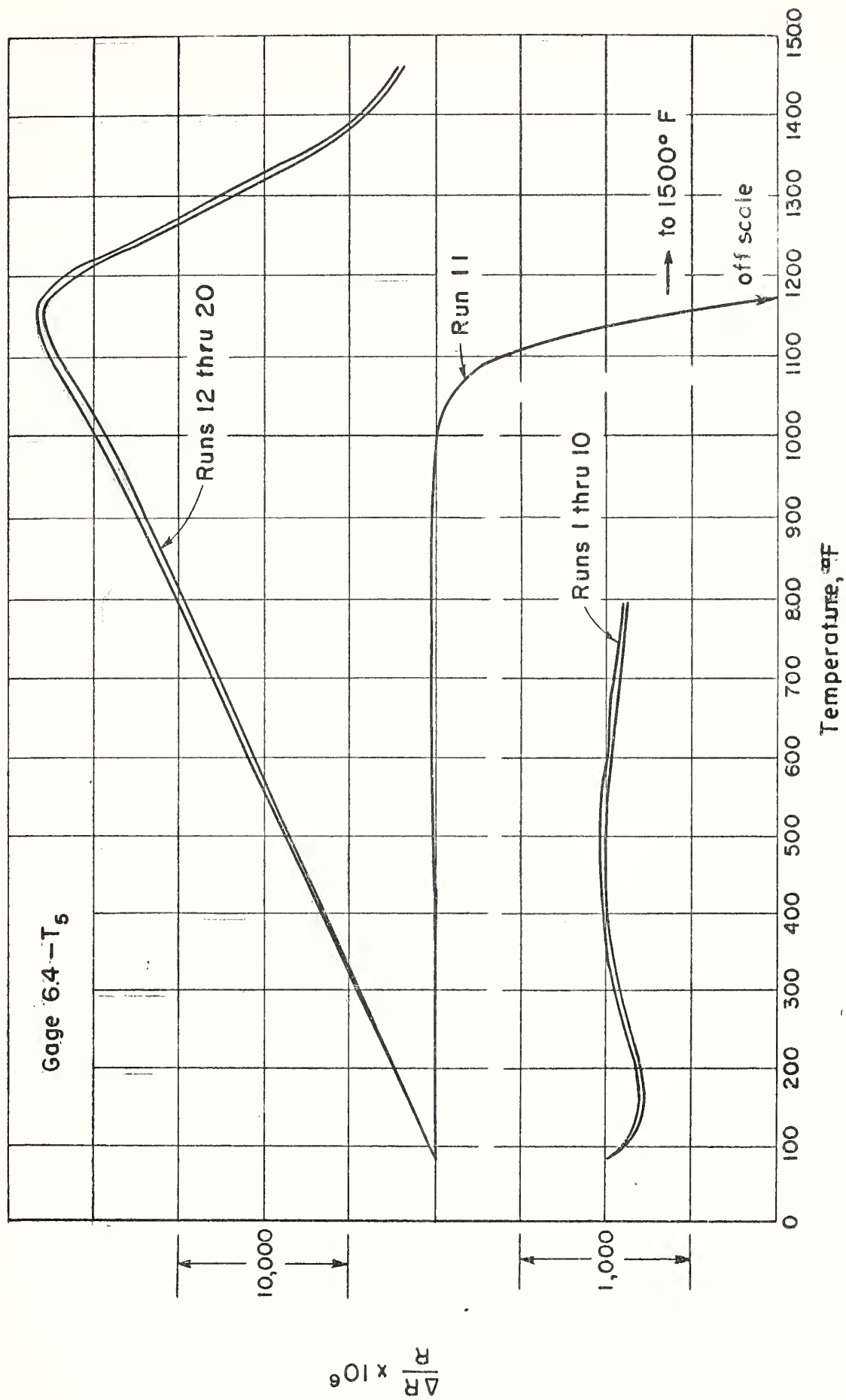


Fig. 28 Variation of gage response with transient heating



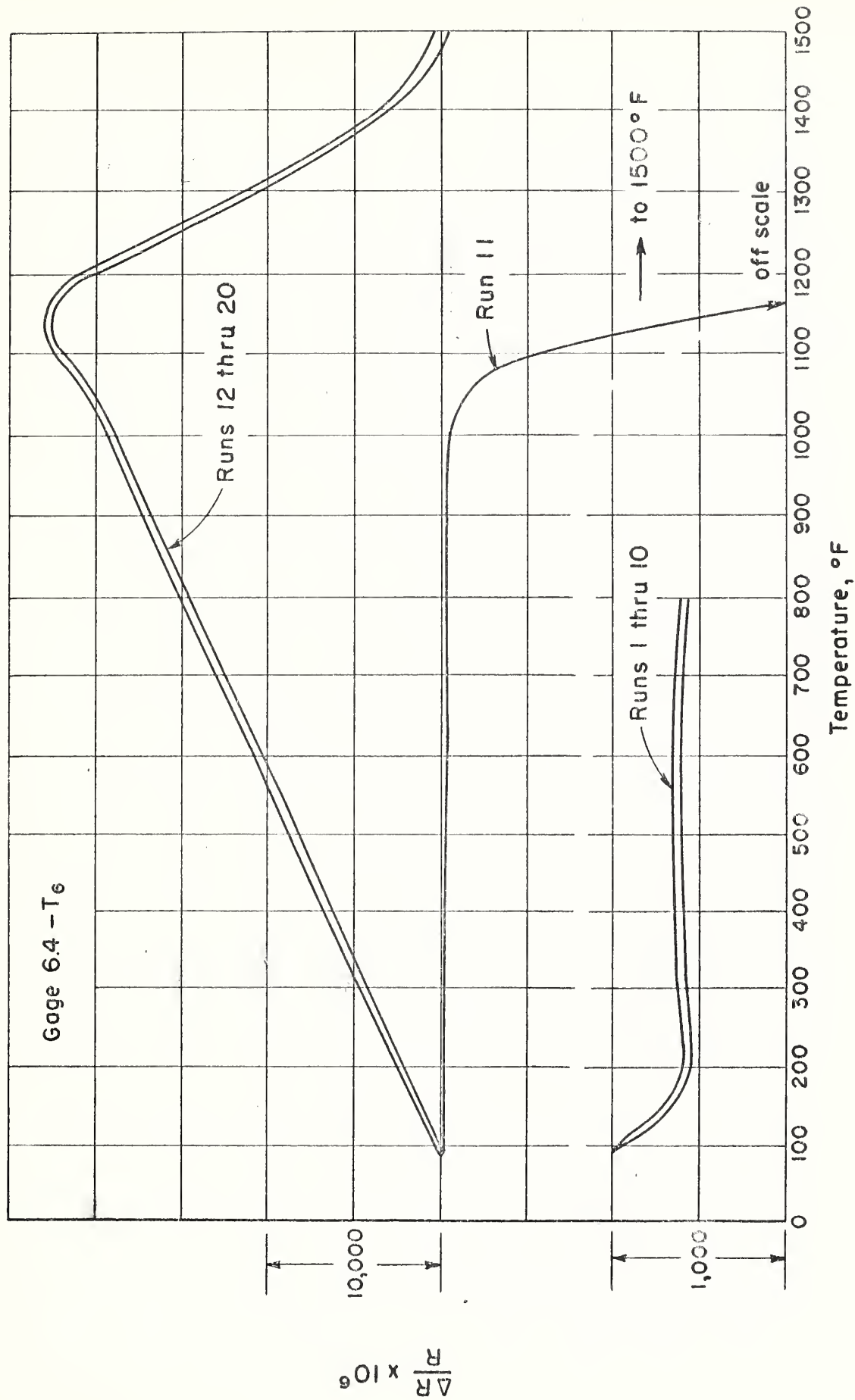


Fig. 29 Variation of gage response with transient heating





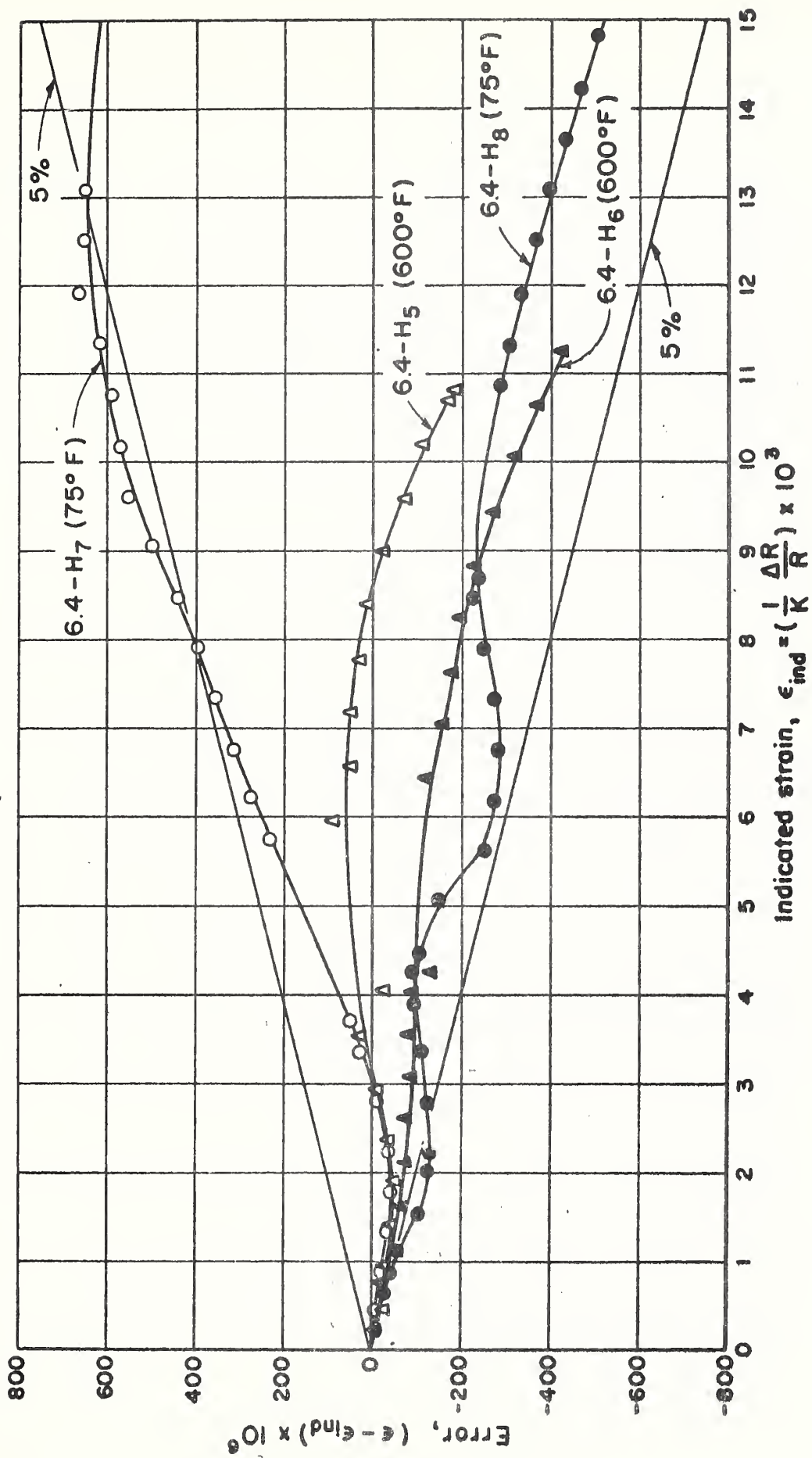


Fig. 30 Gage behavior at high strains.



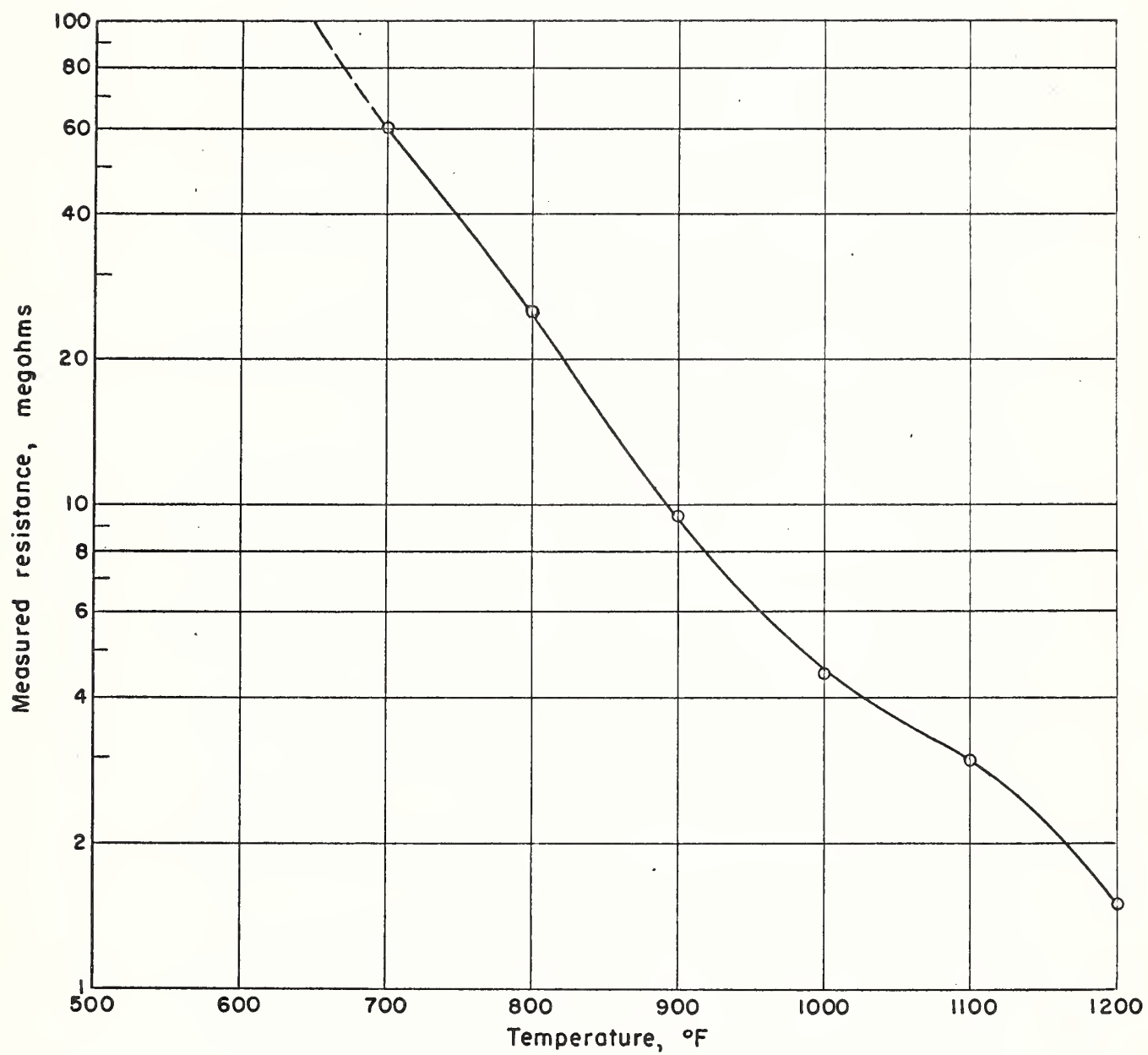


Fig.31 Resistance between gage and test strip



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