NATIONAL BUREAU OF STANDARDS REPORT

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EVALUATION OF RESISTANCE STRAIN GAGES
AT ELEVATED TEMPERATURES

Progress Report No. 9

by

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

NBS

U. S. DEPARTMENT OF COMMERCE
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Engineering Mechanics Section
Division of Mechanics

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U. S. DEPARTMENT OF COMMERCE
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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.

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Chief, Engineering Mechanics Section

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SYNOPSIS

Resistance strain gages of the HT-1200 series, manufactured by High Temperature Instruments Corporation, 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 a high but somewhat erratic gage factor, low drift at temperatures up to 700° F, and a high but stable temperature coefficient of resistance.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, gages manufactured by the High Temperature Instruments Corporation were subjected to evaluation tests. The gages tested were type HT-1200. 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,

(4) Resistance-temperature relationship,

(5) Behavior under transient heating conditions, and

(6) Behavior when subjected to large strains.

The results of previous evaluations of other gage types are given in references 1 through 8.

2. GAGES

The gages which are reported on herein were purchased from the High Temperature Instruments Corporation. A drawing of the gage is shown in figure 1. The active element is a grid of platinum base alloy. The ends of the grid wire have been inserted into fine tubing which is swaged onto the wire to make a mechanical and electrical joint. The remainder of the tubing has been flattened to become the leads of the gage. A fine Chromel-Alumel thermocouple was furnished as a part of each gage. This thermocouple was installed in the cement with the gage in an attempt to obtain a more accurate measurement of the temperature of the grid material.

The gages were attached to stainless steel test strips with Allen PBX cement, also purchased from the High Temperature Instruments Corporation. The instructions furnished by the manufacturer were followed.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for the evaluation tests are described in references 5, 8, and 9.

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 tables 2 and 3 and figures 2 through 26.

4.1 Strain Sensitivity

Gage factor values were obtained at about 75° F from six 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

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

Gages 4.1200-A_3, A_5 and A_8 were tested in tension before being tested in compression. Gages 4.1200-A_4, A_7 and A_9 were tested in compression before being tested in tension.

An examination of the data of table 2 shows that there is a much greater variation of gage factor values between gages than between the various tests

on one gage. This would indicate that these gages are sensitive to variations in installation which are not readily controllable under laboratory conditions, or that there were significant differences between gages. Further examination of table 2 shows that the gage factor values for increasing load, K_u, for each gage are generally smaller and have significantly larger variations than the values for decreasing load, K_d. In all but one case (gage 4.1200-A_4 in compression) the value of K_u for the first run is lower than for subsequent runs. This could indicate that the cement is not transmitting strain to the wire properly, perhaps due to poor bonding to the gage wire.

The variation of gage factor with increasing temperature is shown in figures 2 through 5. Each curve of figures 2 through 4 represents the average change of gage factor of two gages which were mounted on opposite sides of a beam and connected in adjacent arms of a bridge circuit. These figures show considerable variation between different test runs on the same set of gages. The results for the first test run seem to be more regular than for subsequent runs, but these do not provide sufficient information for forming definite conclusions. Figure 5 shows the average of all gage factor variation tests and the envelope which would just include all of the test results. The number of test results averaged for each portion of the curve is also shown.

4.2 Drift

The drift behaviors of individual gages at each test temperature are shown in figures 6 through 18. Each curve of figure 19 represents the average of results for two gages for temperatures as high as 1200° F and the results for one gage for temperatures exceeding 1200° F. At temperatures as high as 500° F, drift trends were masked by the scatter of data due to resistance changes caused by small temperature fluctuations. At temperatures of 600° F and above a negative drift was shown. This drift was small at temperatures as high as 700° F but became quite large at temperatures of 1200° F and above.

4.3 Temperature Sensitivity

The temperature coefficient values obtained for two gages are shown in figure 20. At temperatures up to 1200° F, each point of figure 20 is the average obtained from four test runs. For temperatures exceeding 1200° F, each point is the average of two test runs. The difference between the average values obtained for the two gages and the difference between the values obtained for different test runs of one gage are generally less than the experimental error of the determinations. The high value of the temperature coefficient would necessitate accurate temperature measurements or an adequate means of compensation if large errors are to be avoided.

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 21 through 23. Figures 21 and 22 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. (The temperature changes were about 500° F to 1400° F.) These figures show that the change of resistance is large, but that the response is repeatable, especially after the first heating series.

Figure 23 compares the response of two gages for the second heating series. Comparison of this graph with figures 21 and 22 indicates that the repeatability of one gage for a number of heating cycles is somewhat better than the repeatability from gage to gage, even after the first heating series.

4.5 High Strains

The results of tests in which gages were subjected to tensile strains greater than those used for gage factor determinations are shown in figures 24 and 25. The gage factor values used to determine the strain indicated by the resistance gages, ϵ_{ind}, were determined for each gage just prior to the test. The gage factor values used are shown in the figures.

4.6 Resistance to Ground

The average resistance between the gage and the test strip for two gages is shown in figure 26. The resistance measurements were made with a Triplett vacuum tube volt-ohm meter, Model 650, using the scale range marked x 1 megΩ. The common terminal of the instrument was connected to the test strip. The readings were taken within a few minutes after the test strip had reached the test temperature. The values shown can be considered as only a qualitative indication of the insulating property of the cement since ceramic type cements would not be expected to follow Ohm's law[10].

4.7 Gages Destroyed

During the course of this evaluation, sixteen gages were either destroyed or the intended information was unobtainable from them. A list of the gages lost and the reason for the loss is given in table 3.

5. CONCLUSIONS

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

(1) The type HT-1200 gages have a high gage factor. The gage factor is, however, somewhat erratic, possibly due to poor bonding of the cement to the gage wire.

(2) The high temperature coefficient of resistance of these gages would probably limit the use of these gages to stable temperature conditions or dynamic tests where the strain rate is high compared to the rate of temperature change.

6. RECOMMENDATIONS

Because of the need for strain measurements for a variety of conditions at elevated temperatures, the exploitation of the desirable properties of all strain gage materials is needed. The results obtained from these gages show that the strain sensitive element has a high gage factor and a well defined, repeatable resistance-temperature relationship. The alloy would be expected to be corrosion resistant. It would therefore seem that additional development of this gage type is warranted. In particular, it is recommended that an effort be made to improve the bonding of the cement to the gage wire and to reduce the drift. These improvements might be accomplished by mechanical or thermal treatment of the cement, wire, or both.

Washington, D. C.
March 1960

7. 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, (ASTIA No. AD 217651).

(8) R. L. Bloss, C. H. Melton, and J. T. Trumbo, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 8) NBS Report No. 6526, August 1959, (ASTIA No. AD 227197).

(9) 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.

(10) 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 Test	Number of gages tested
Gage factor determination	6
Gage factor variation with temperature	6
Drift	2
Temperature sensitivity	2
Transient heating	2
High strain	5

Table 2 - Gage Factor Values at About 75° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		K_u	K_d	$\overline{K}$	K_u	K_d	$\overline{K}$
$4.1200\text{-}A_3$	1	2.590	2.707	2.649	2.745	2.958	2.852
	2	2.726	2.776	2.751	2.914	2.940	2.927
	3	2.731	2.770	2.750	2.859	2.901	2.880
	Average	2.682	2.751	2.717	2.839	2.933	2.886
$4.1200\text{-}A_4$	1	3.556	3.597	3.576	3.670	3.667	3.668
	2	3.598	3.626	3.612	3.607	3.625	3.616
	3	3.602	3.630	3.616	3.610	3.599	3.604
	Average	3.585	3.618	3.601	3.629	3.630	3.629
$4.1200\text{-}A_5$	1	3.012	3.129	3.070	3.434	3.633	3.534
	2	3.228	3.598	3.413	3.680	3.633	3.656
	3	3.419	3.483	3.451	3.643	3.617	3.630
	Average	3.220	3.403	3.311	3.586	3.628	3.607
$4.1200\text{-}A_7$	1	2.935	3.113	3.024	2.919	3.351	3.135
	2	3.066	3.096	3.081	3.274	3.312	3.293
	3	3.058	3.100	3.079	3.312	3.298	3.305
	Average	3.020	3.103	3.061	3.168	3.320	3.244
$4.1200\text{-}A_8$	1	3.647	3.696	3.671	3.430	3.673	3.552
	2	3.680	3.695	3.688	3.664	3.502	3.583
	3	3.676	3.692	3.684	4.000	3.651	3.825
	Average	3.668	3.694	3.681	3.698	3.609	3.653
$4.1200\text{-}A_9$	1	2.838	3.436	3.137	2.865	3.483	3.174
	2	2.994	3.305	3.149	3.549	3.585	3.567
	3	3.071	3.271	3.171	3.550	3.534	3.542
	Average	2.968	3.337	3.152	3.321	3.534	3.428
	Grand Average	3.190	3.318	3.254	3.374	3.442	3.408

Table 3 - Gages Lost Before Completing Tests

Number of gages lost	Remarks
3	Gage leads were broken during gage installation
4	Gage grids were damaged during gage installation
2	Gages shorted to test strip
1	Gage failed during preload prior to high strain test
6	Small vibratory strains produced large output signals from the gage circuits. The cause was not determined. One test involved 4 gages and another test involved 2 gages. All gages were considered lost even though it is very possible that only one gage was faulty for each test.

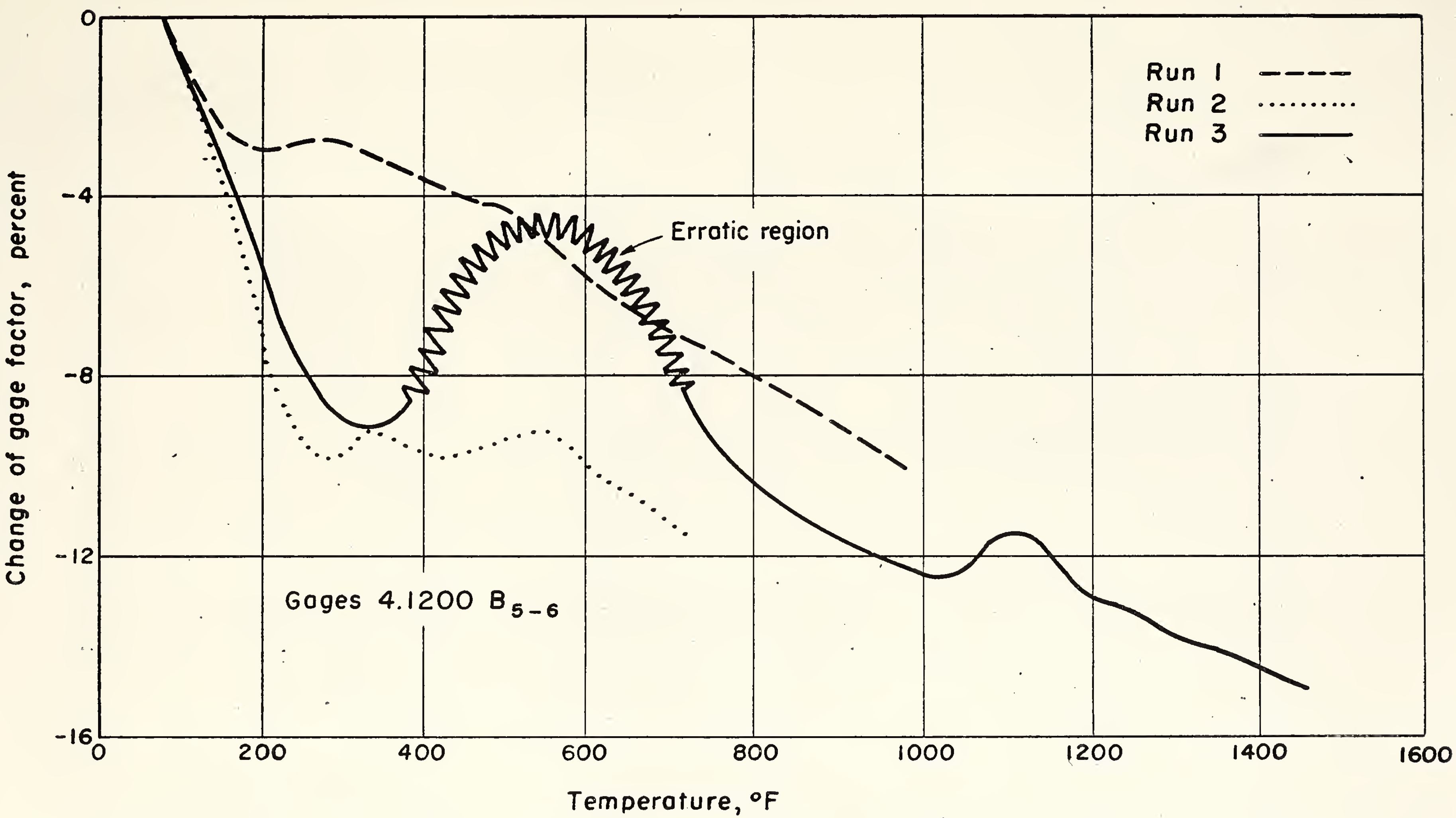

Fig. 2 Variation of gage factor with temperature

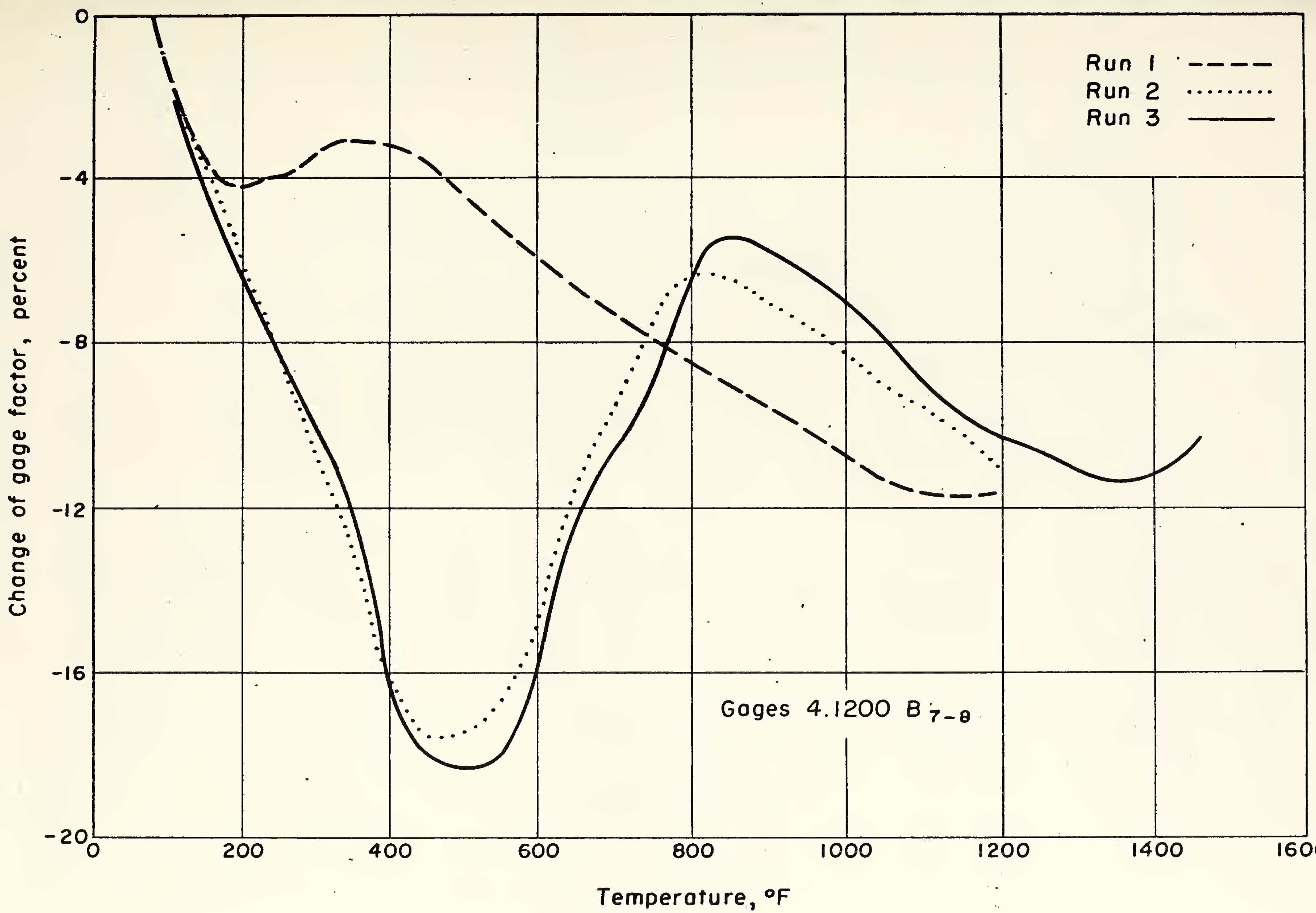

Fig. 3 Variation of gage factor with temperature

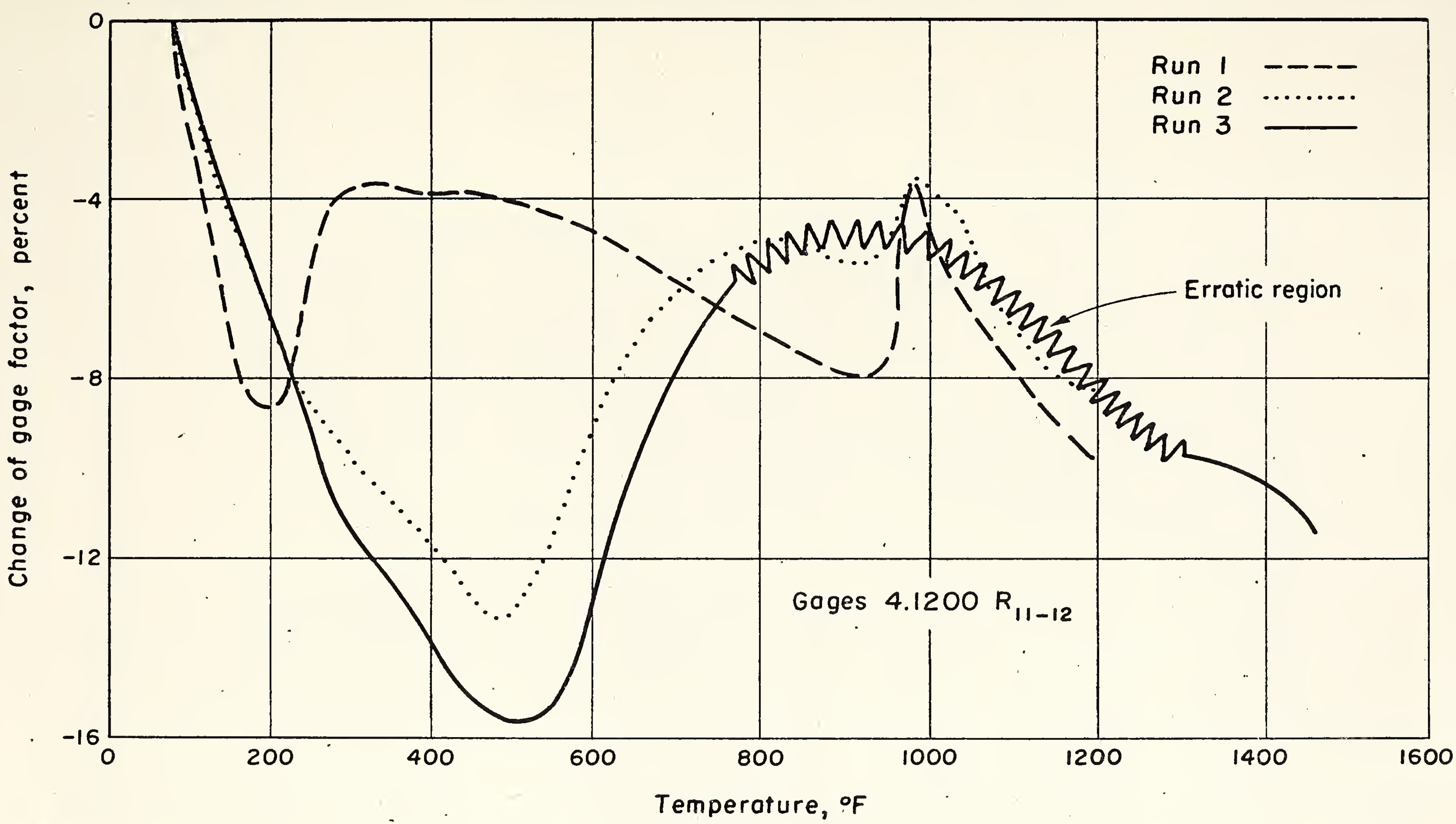

Fig. 4 Variation of gage factor with temperature

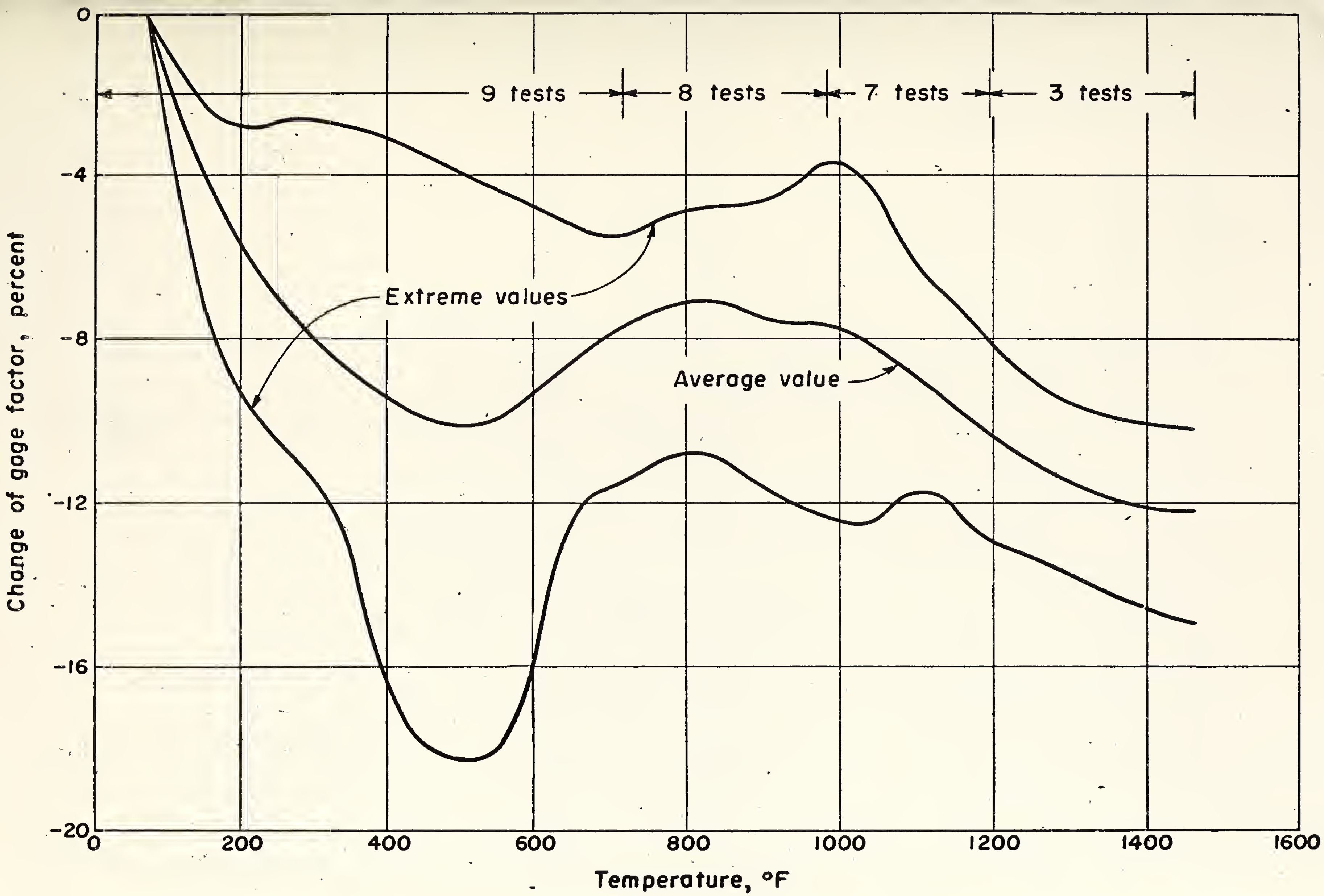

Fig. 5 Variation of gage factor with temperature

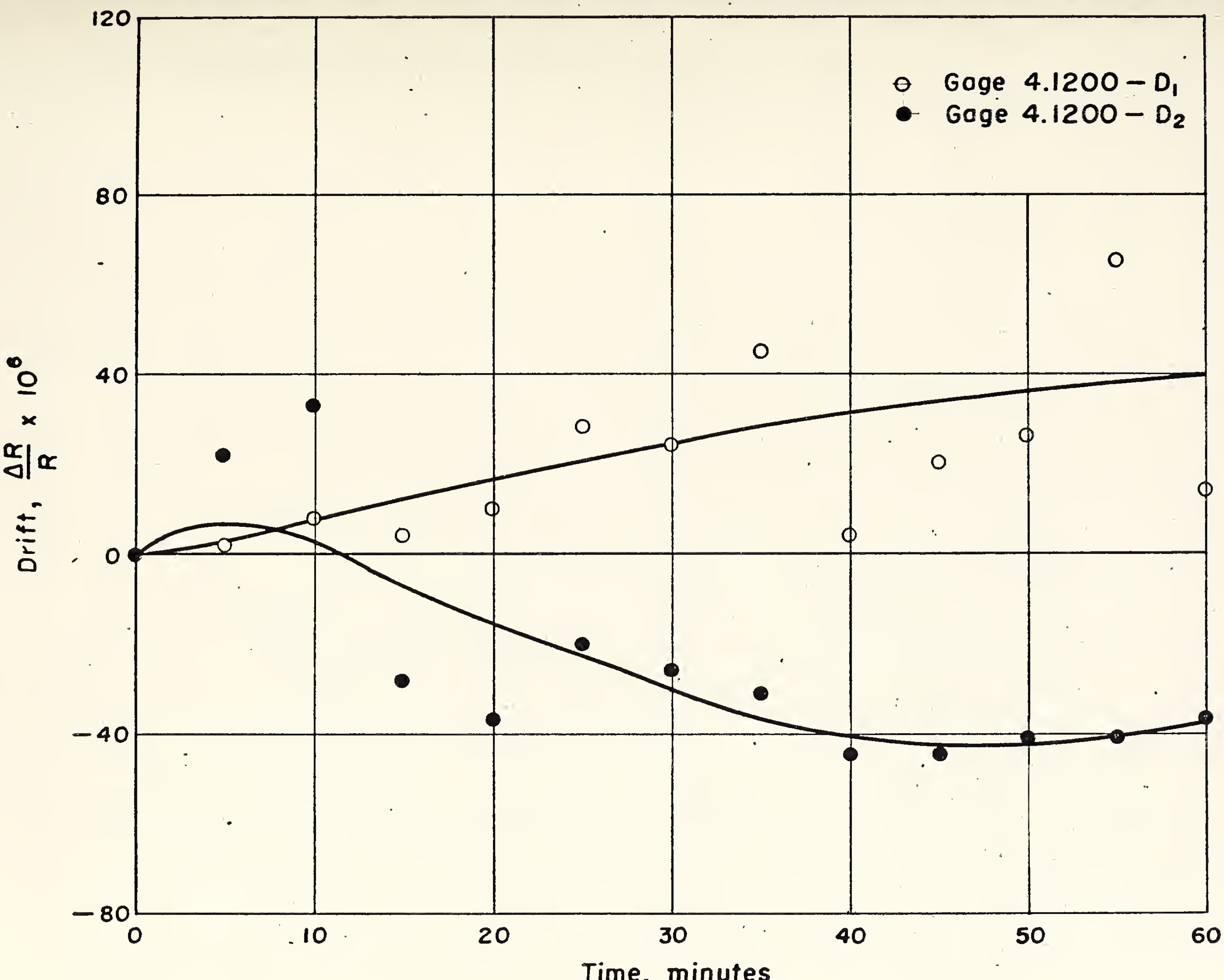

Fig. 6 Drift behavior at 300° F

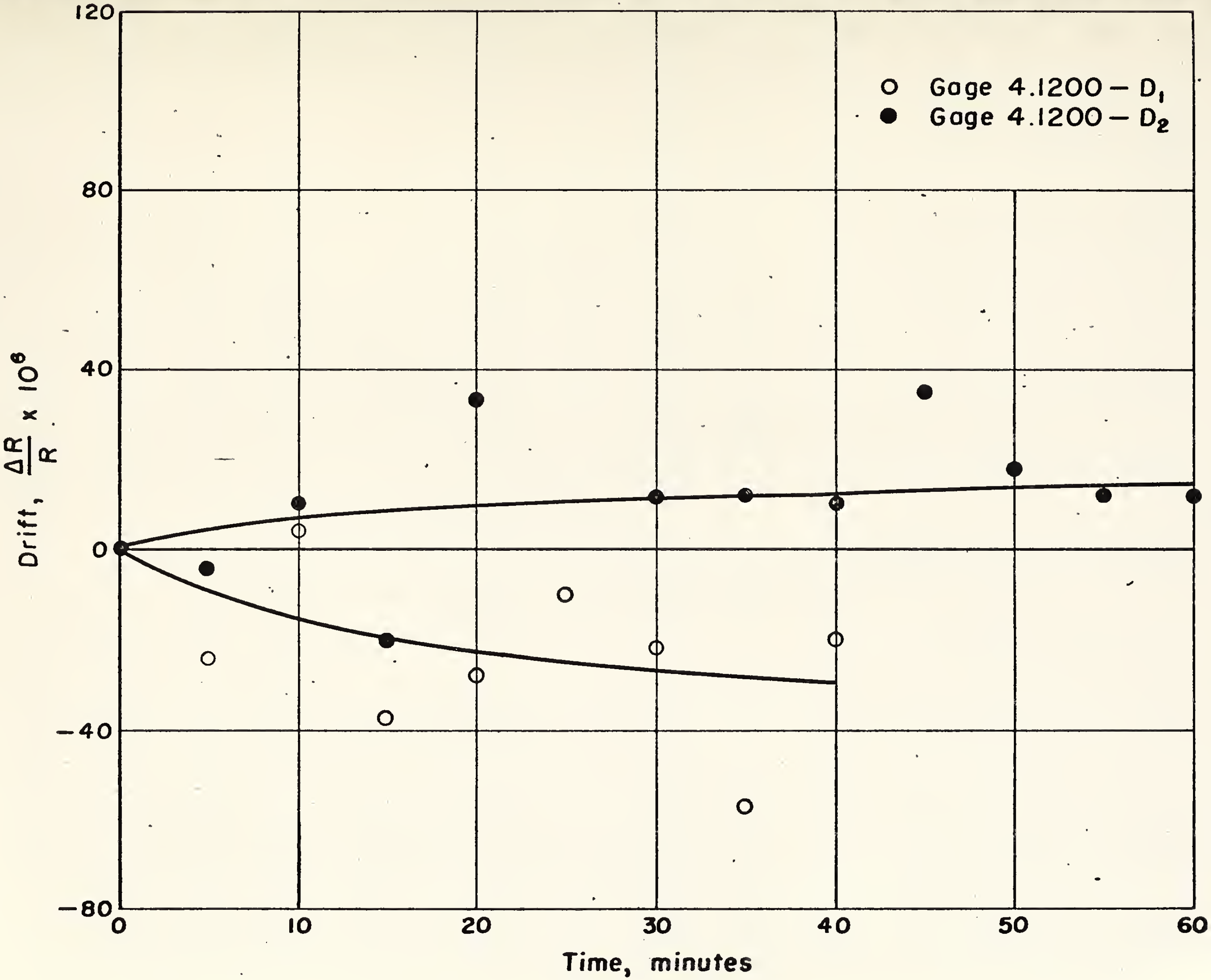

Fig. 7 Drift behavior at 400° F

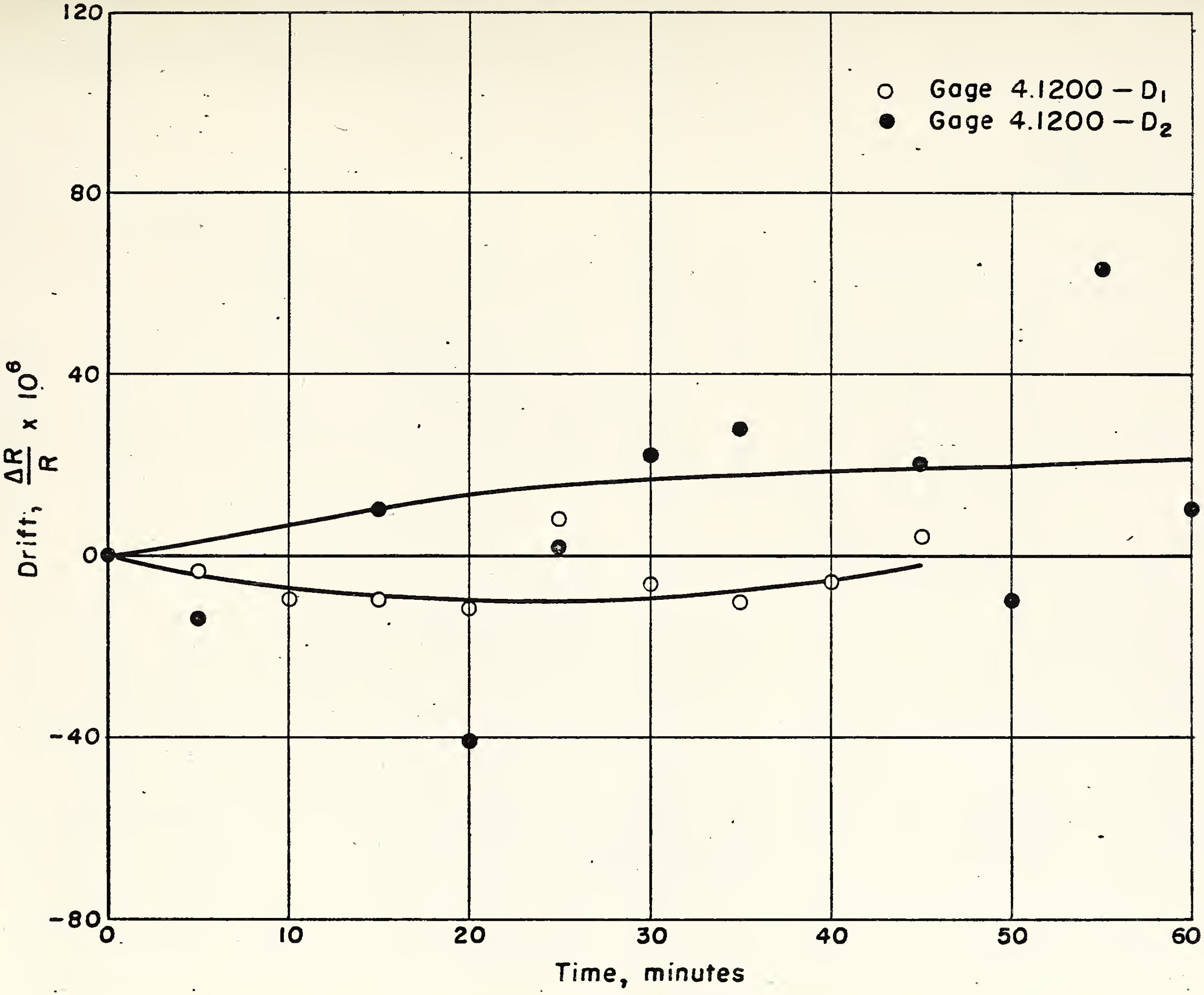

Fig. 8 Drift behavior at 500° F

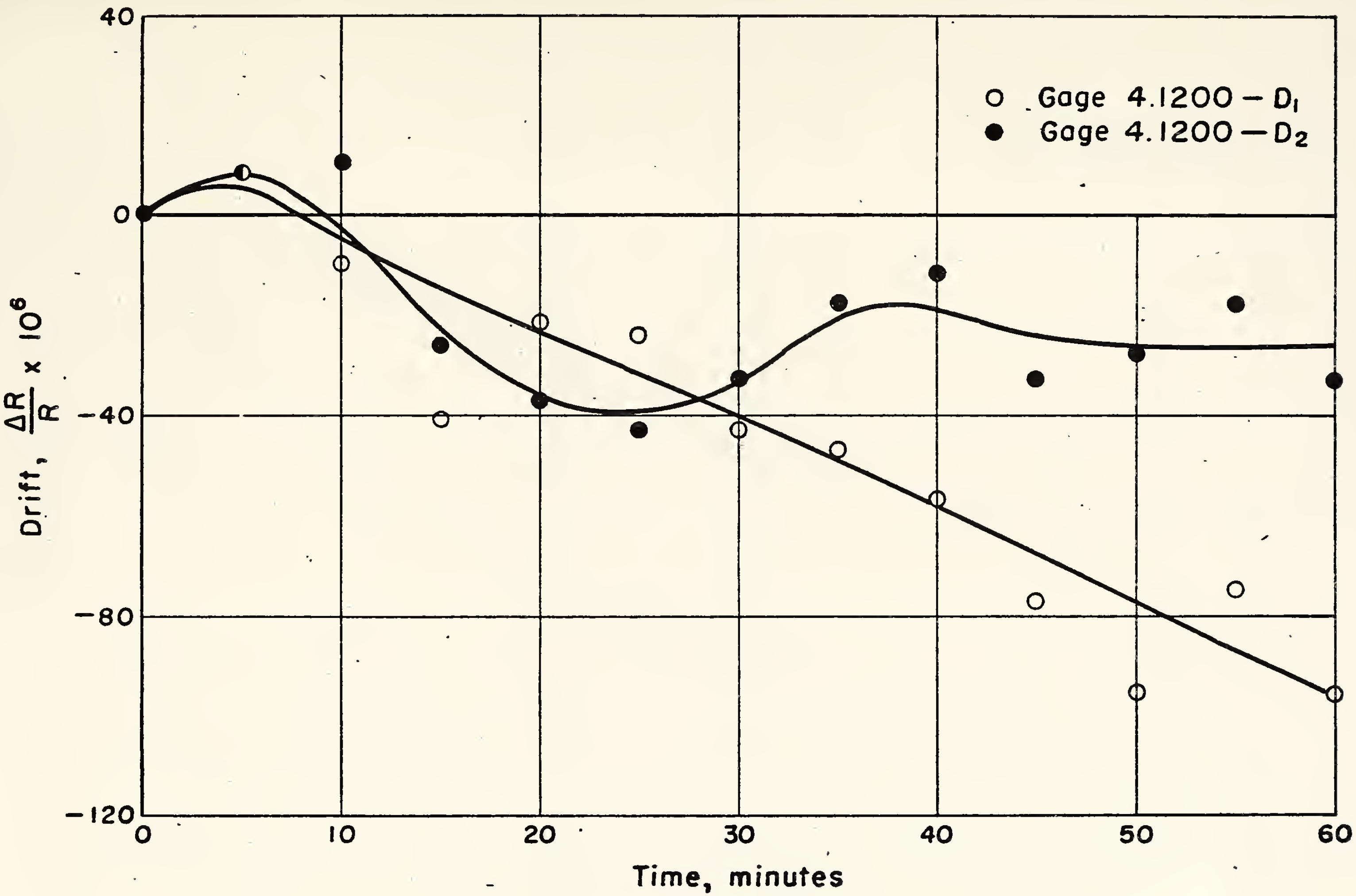

Fig. 9 Drift behavior at 600° F

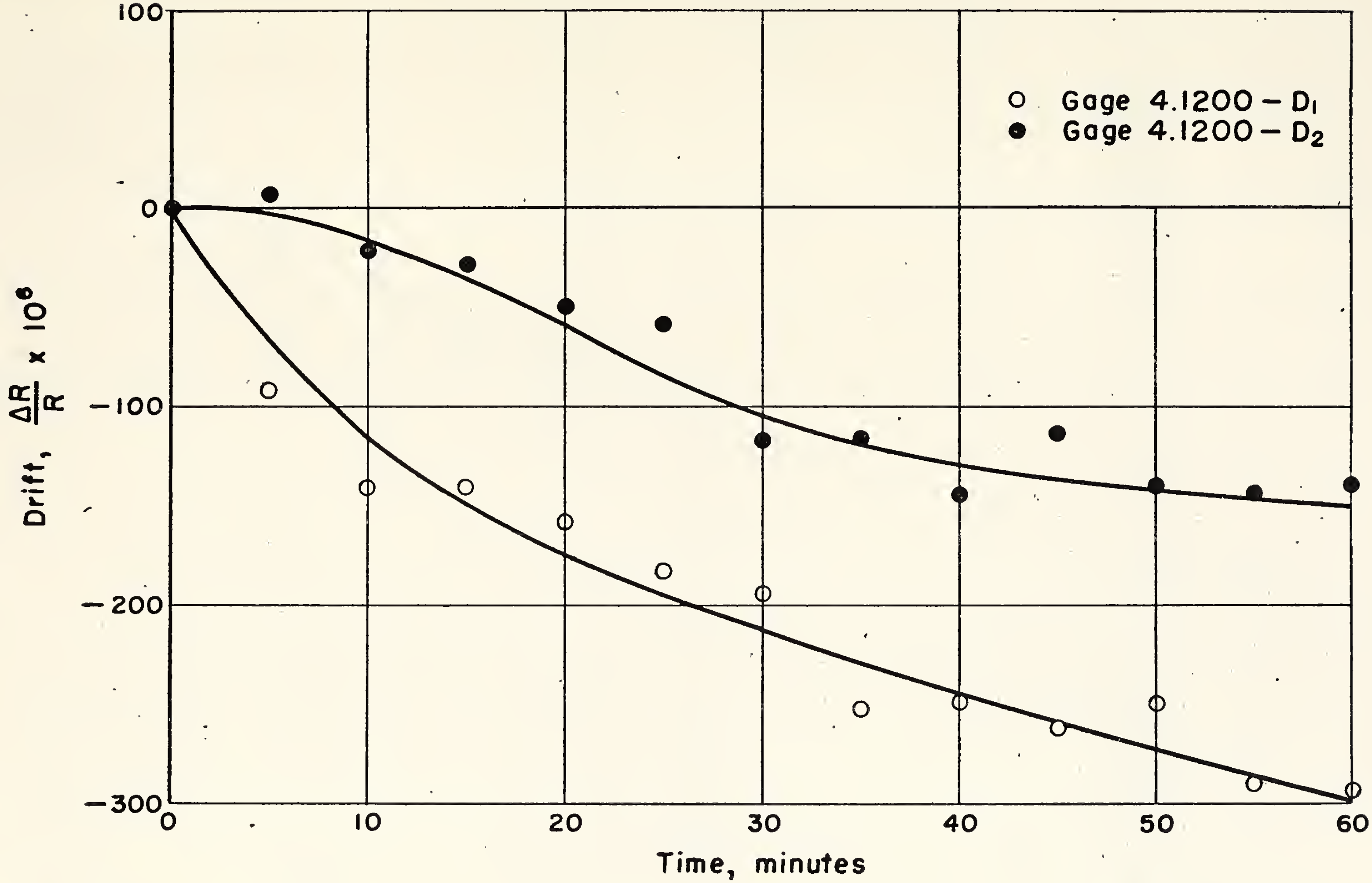

Fig. 10 Drift behavior at 700° F

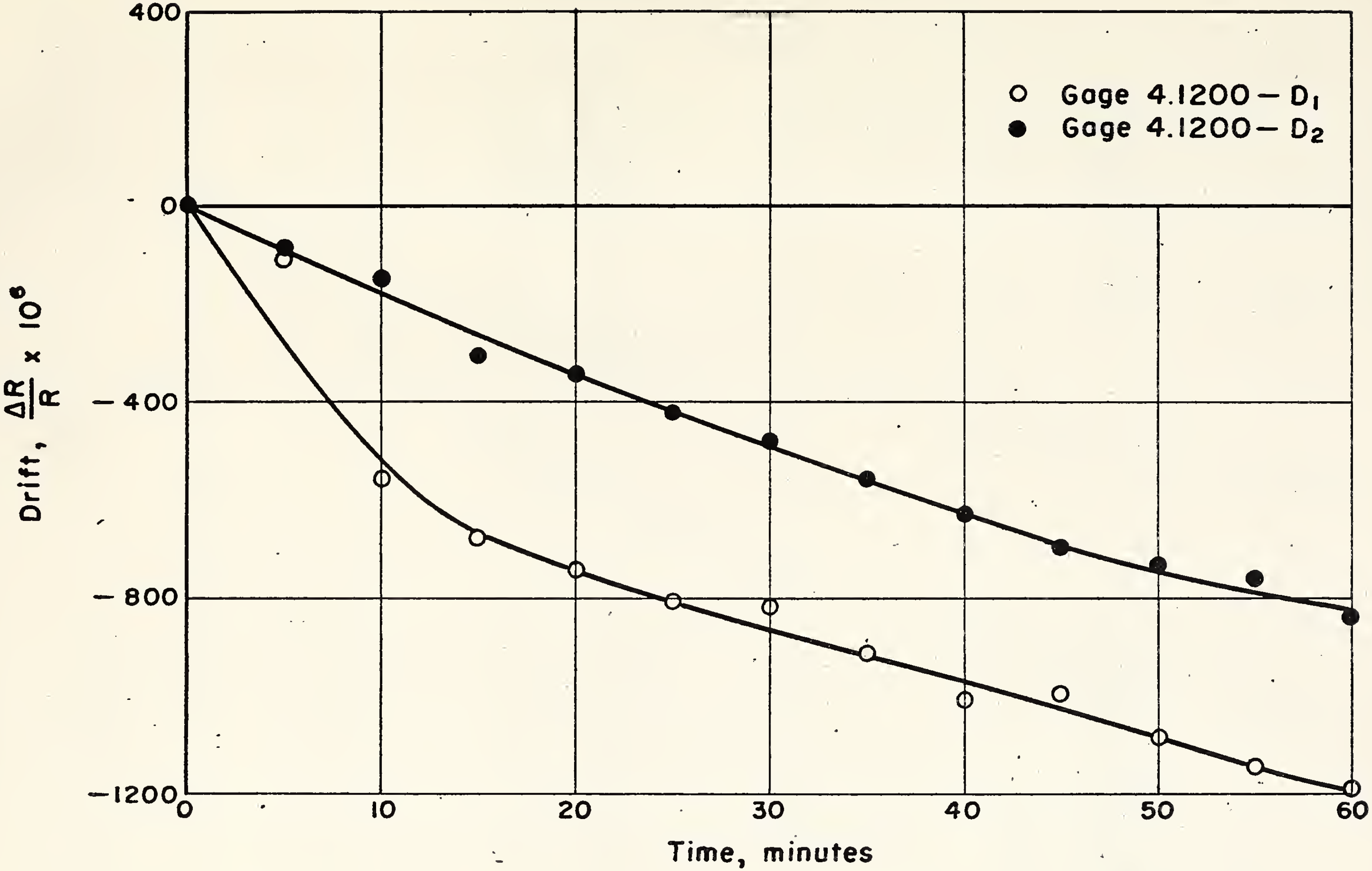

Fig. 11 Drift behavior at 800° F

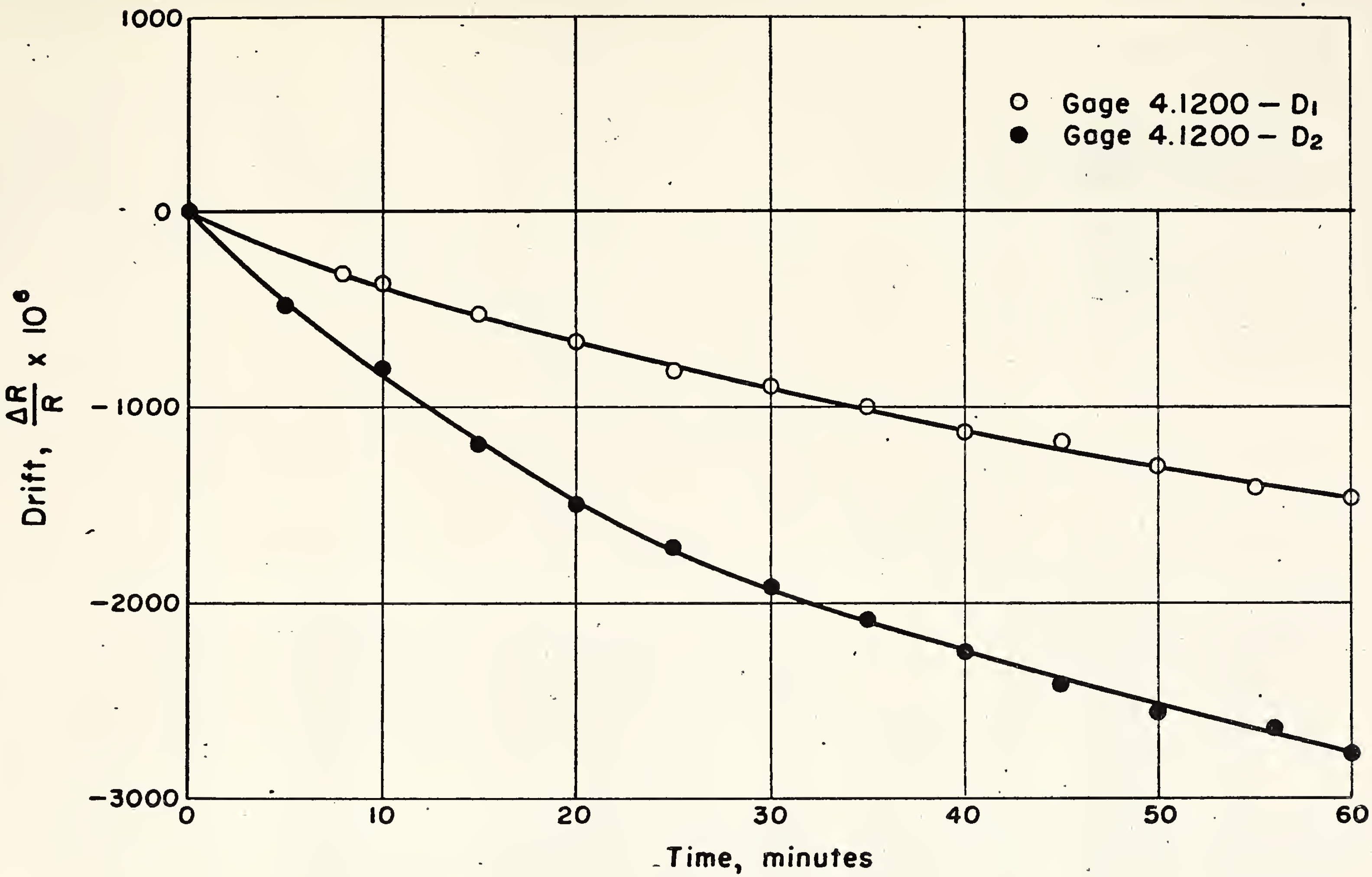

Fig. 12 · Drift behavior at 900° F

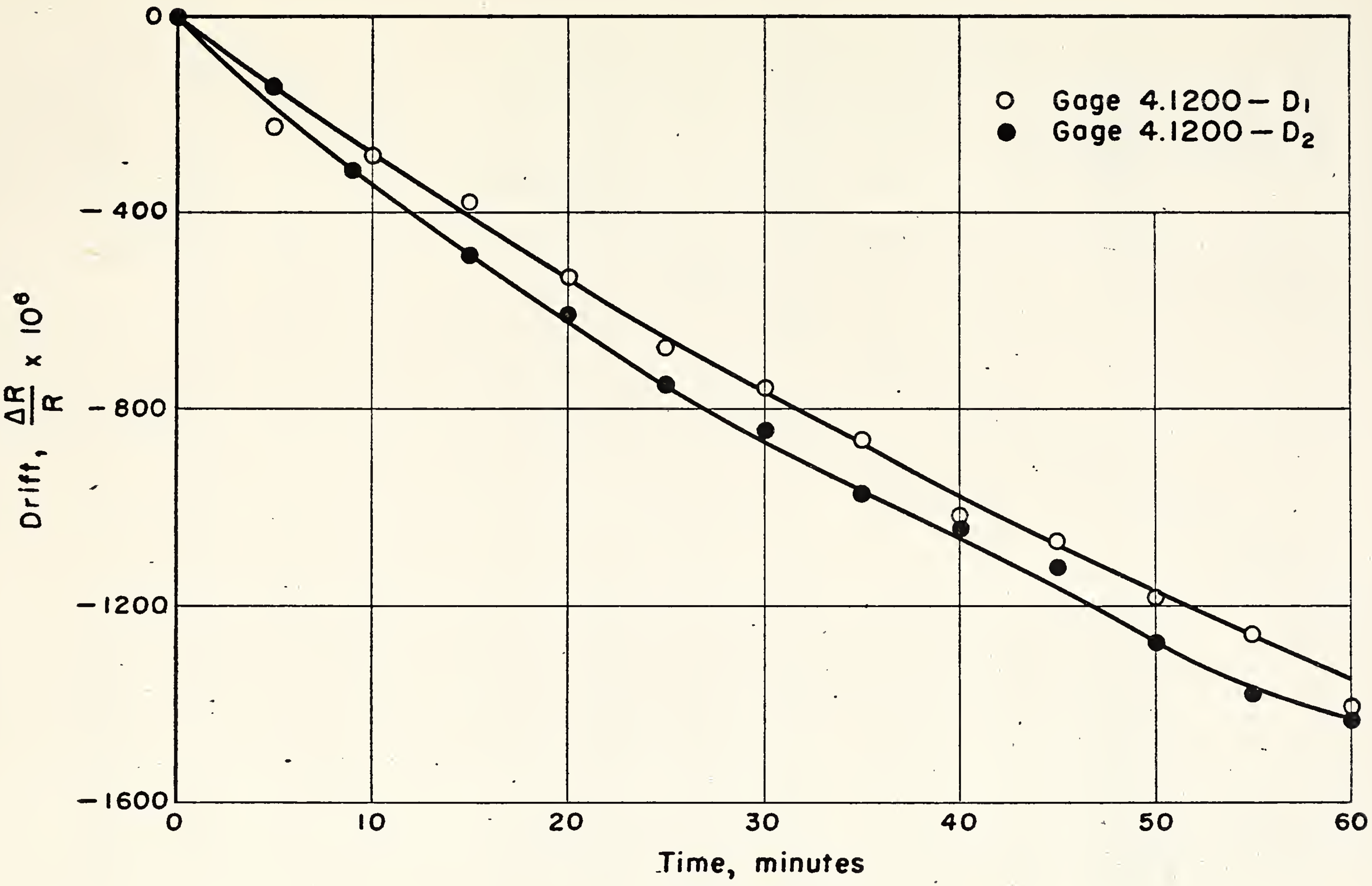

Fig. 13 Drift behavior at 1000° F

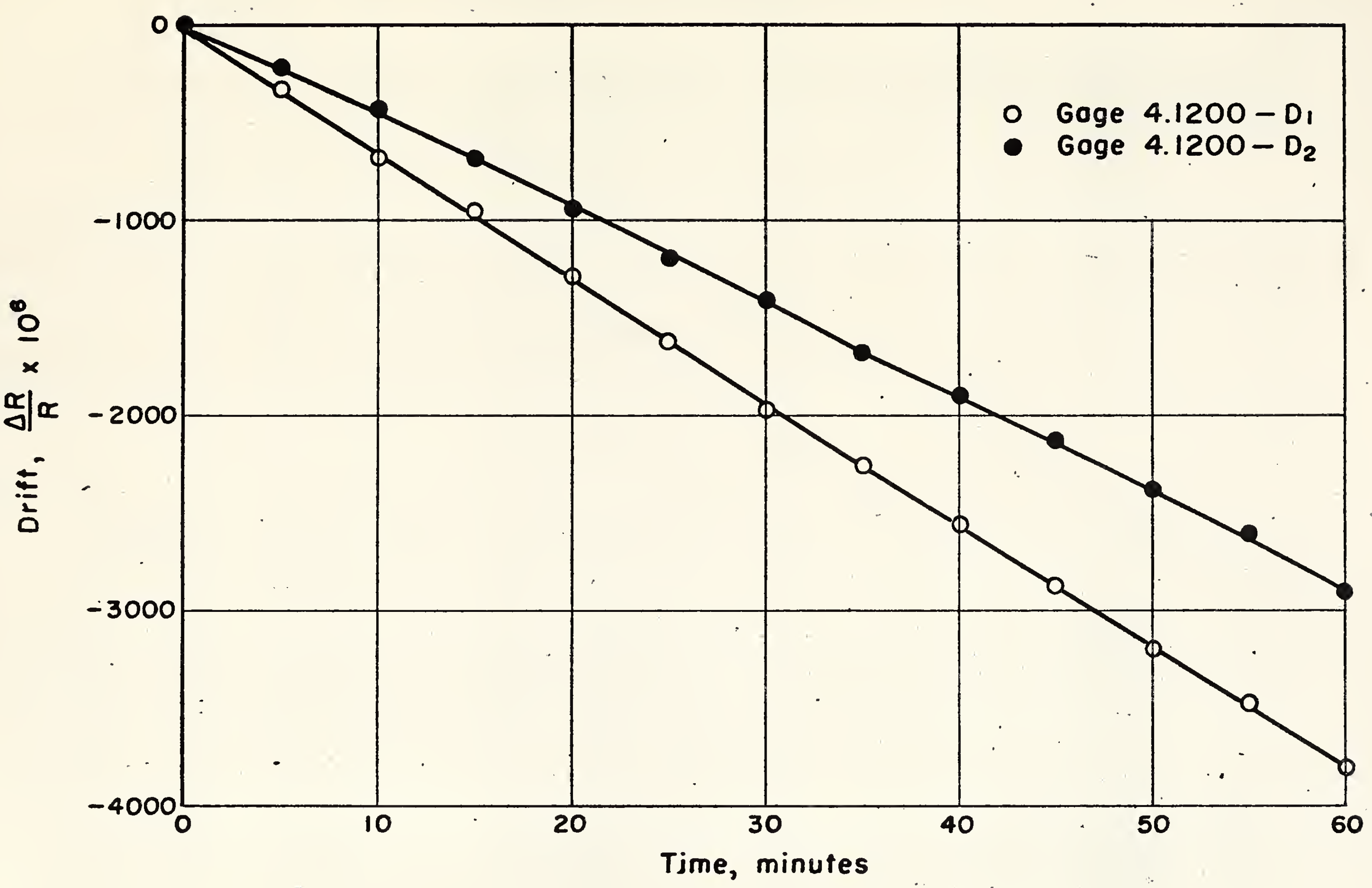

Fig. 14 Drift behavior at 1100° F

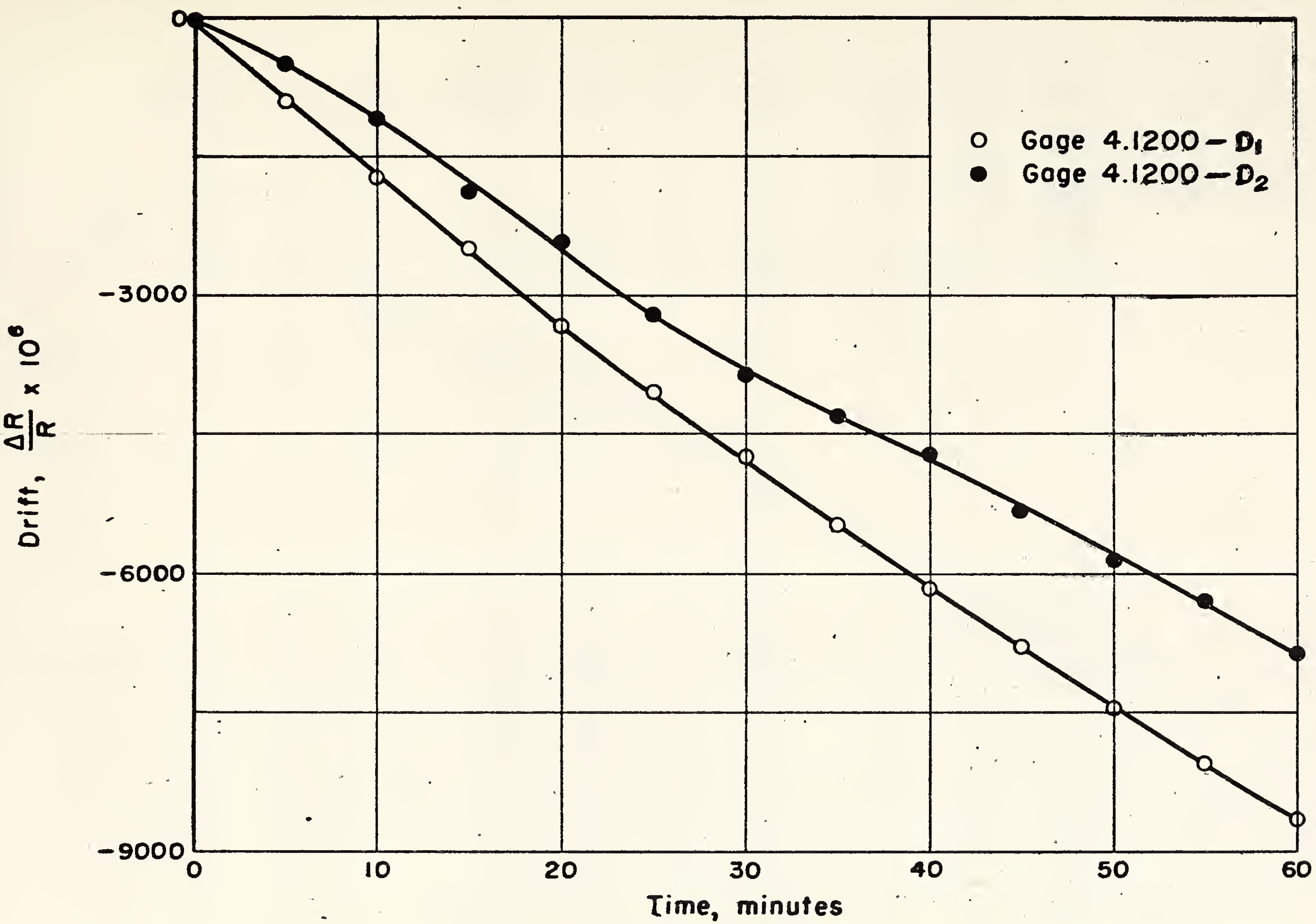

Fig. 15 Drift behavior at 1200 °F

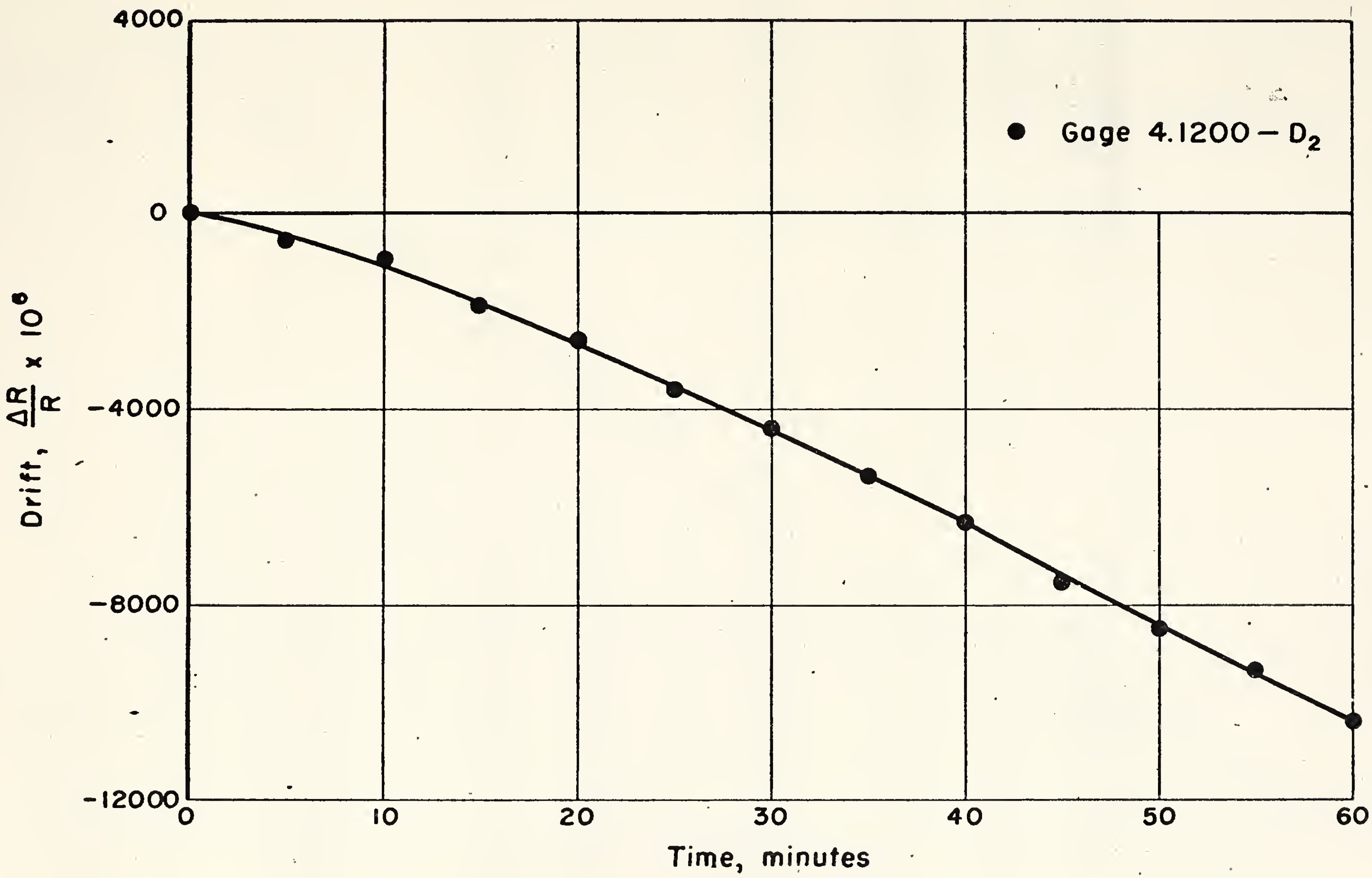

Fig. 16 Drift behavior at 1300° F

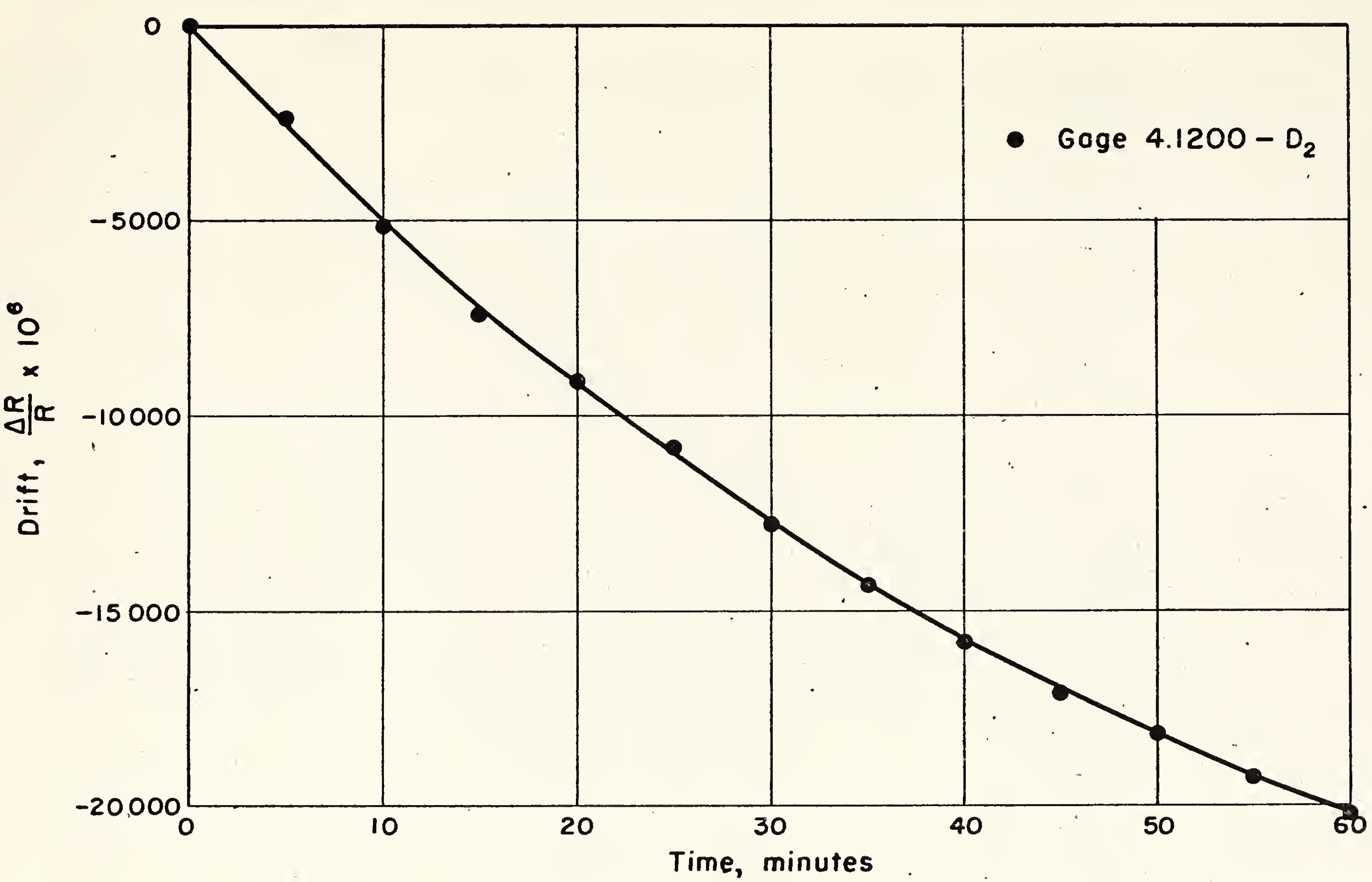

Fig. 17 Drift behavior at 1400 °F

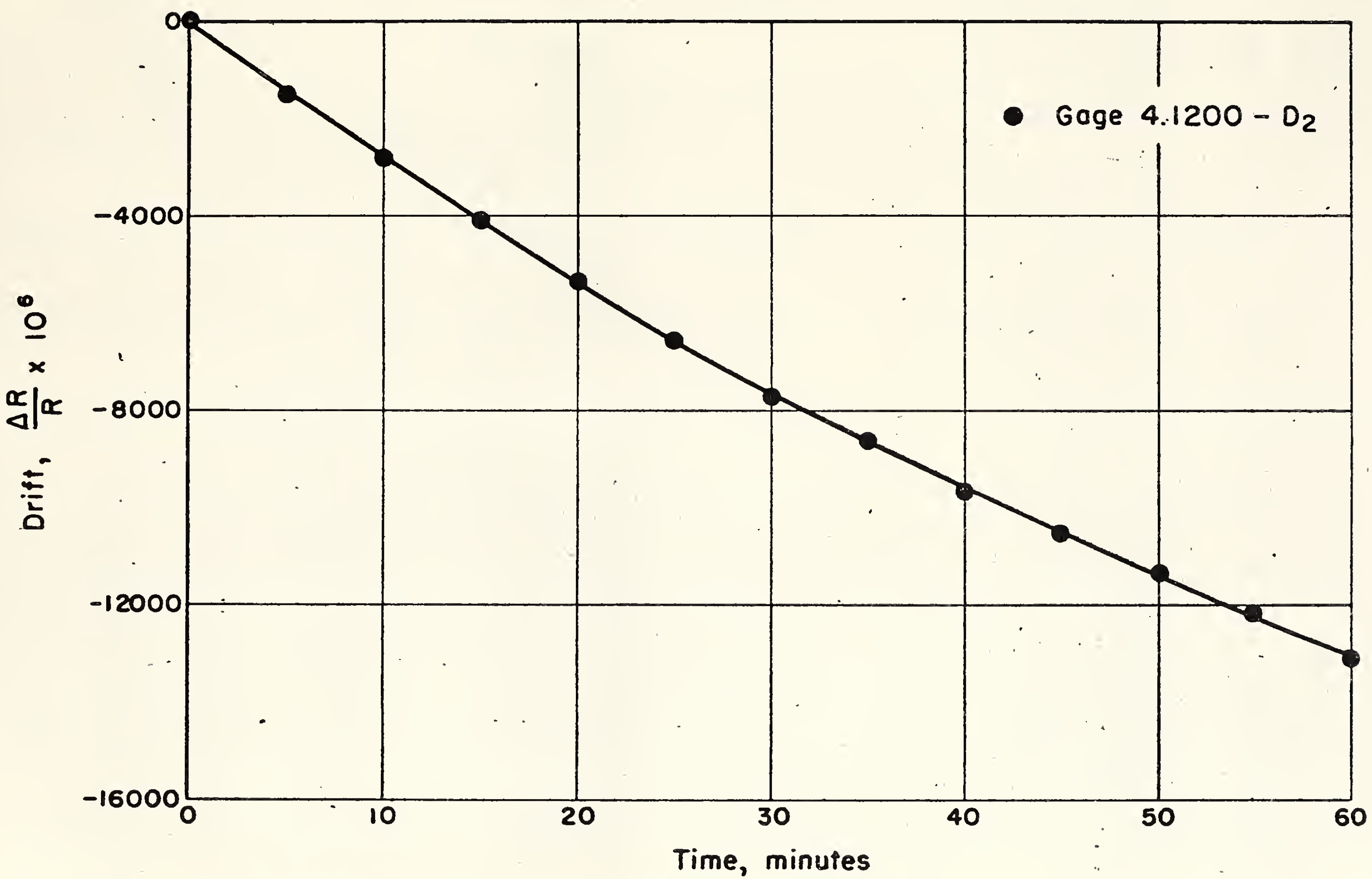

Fig. 18 Drift behavior at 1500° F

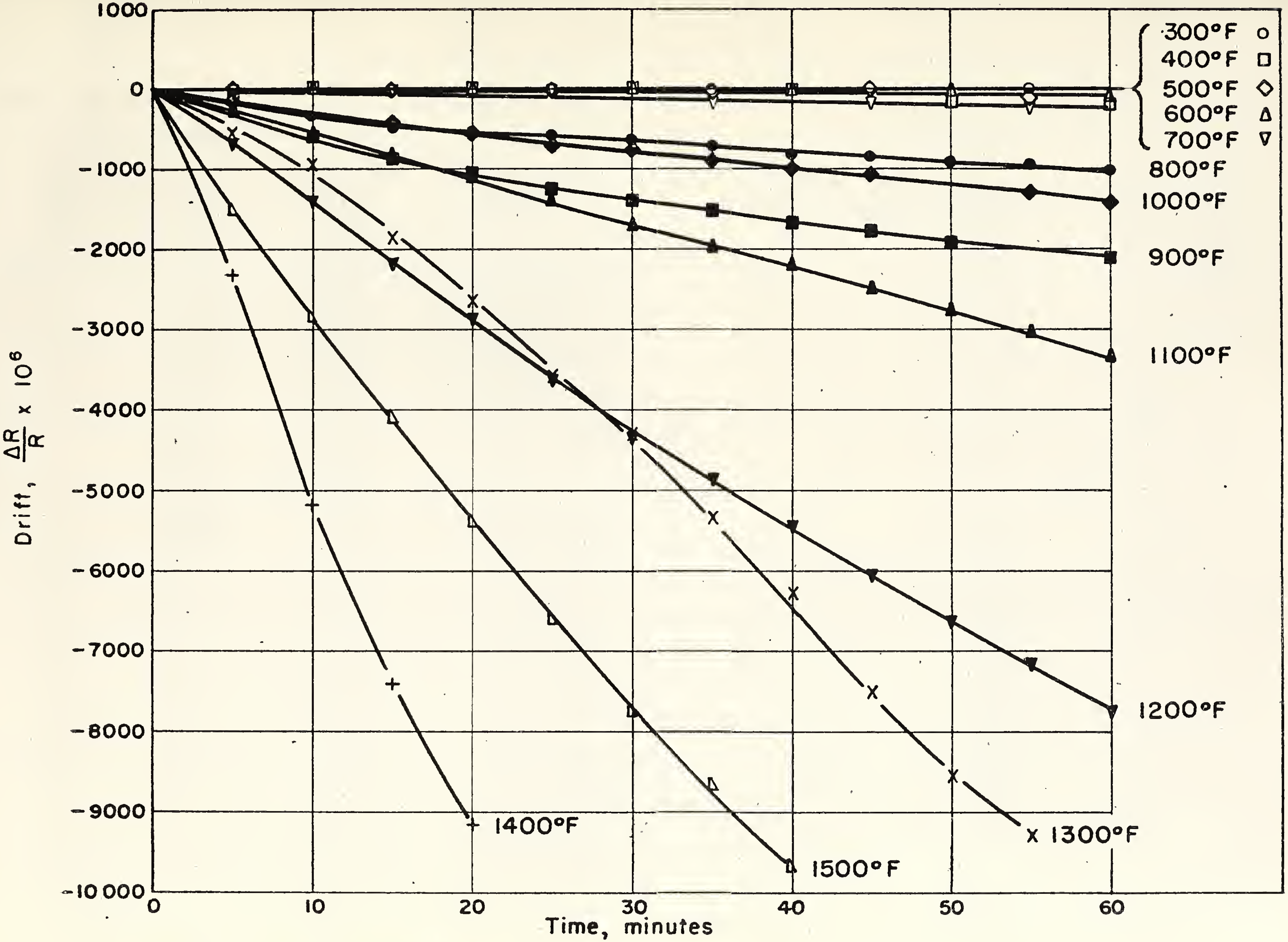

Fig. 19 Drift behavior.

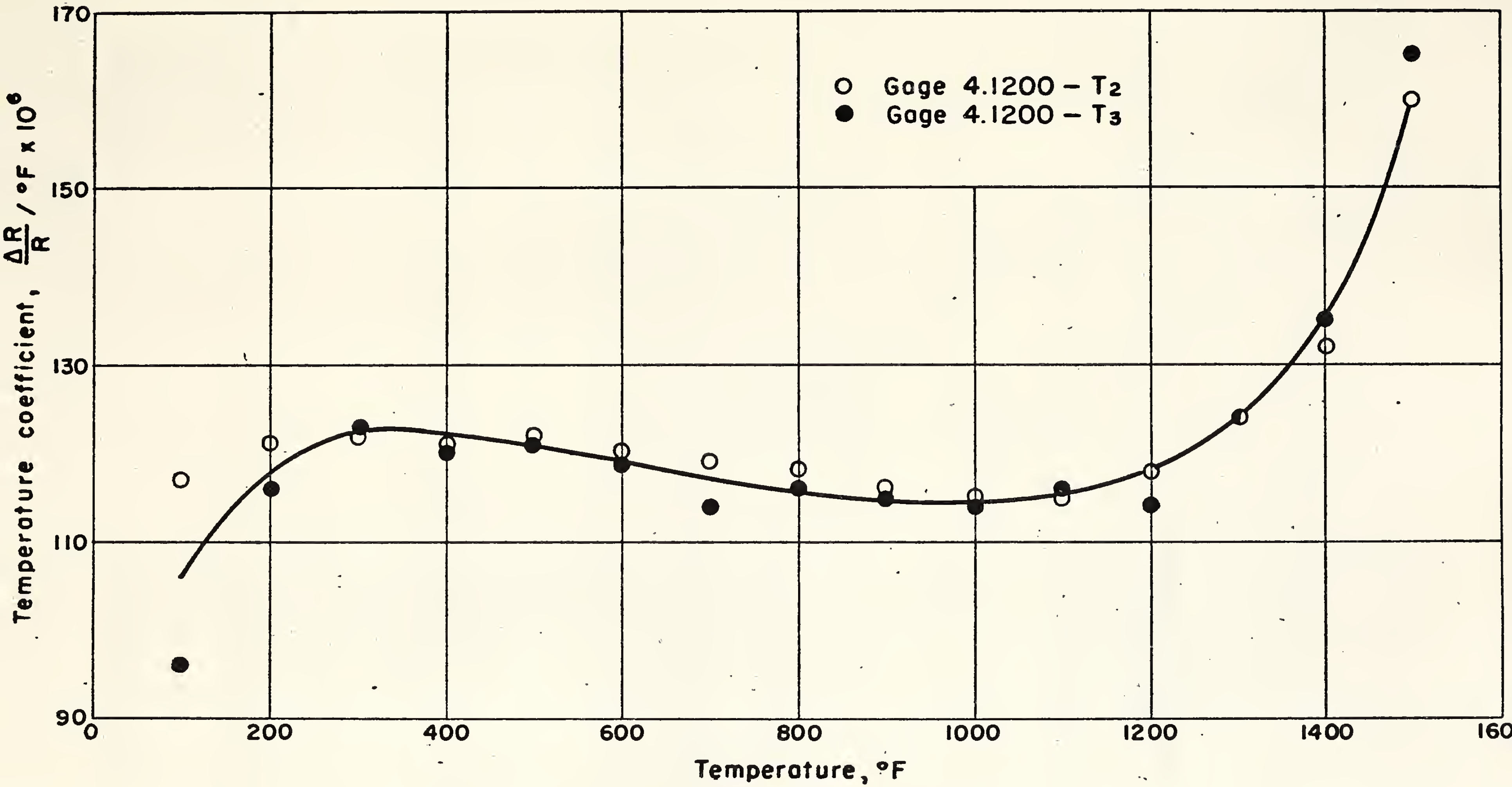

Fig. 20 Temperature coefficient of two gages

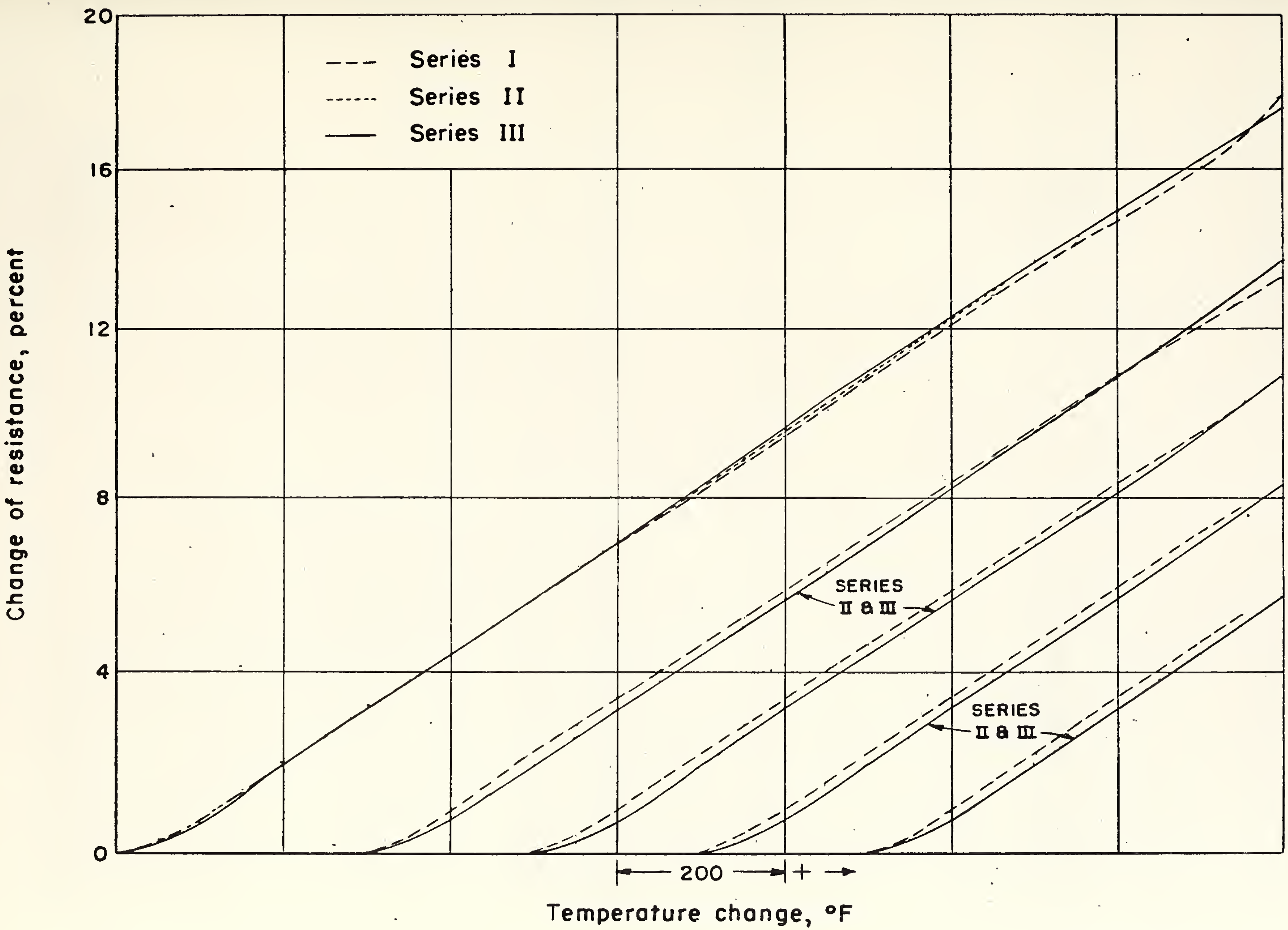

Fig. 21 Response of gage 4.1200-R_1 with transient heating

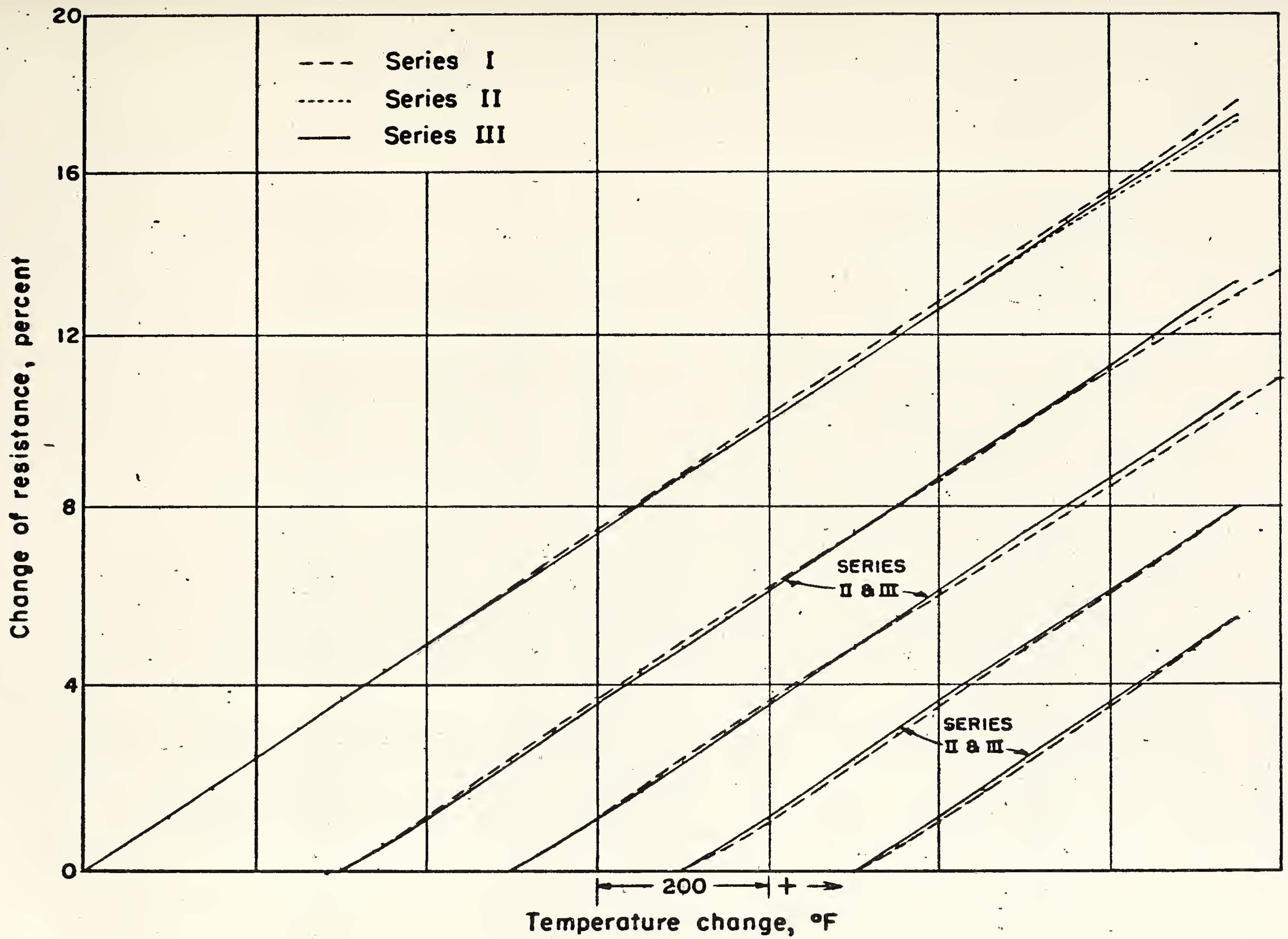

Fig. 22 Response of gage 4.1200–R_2 with transient heating

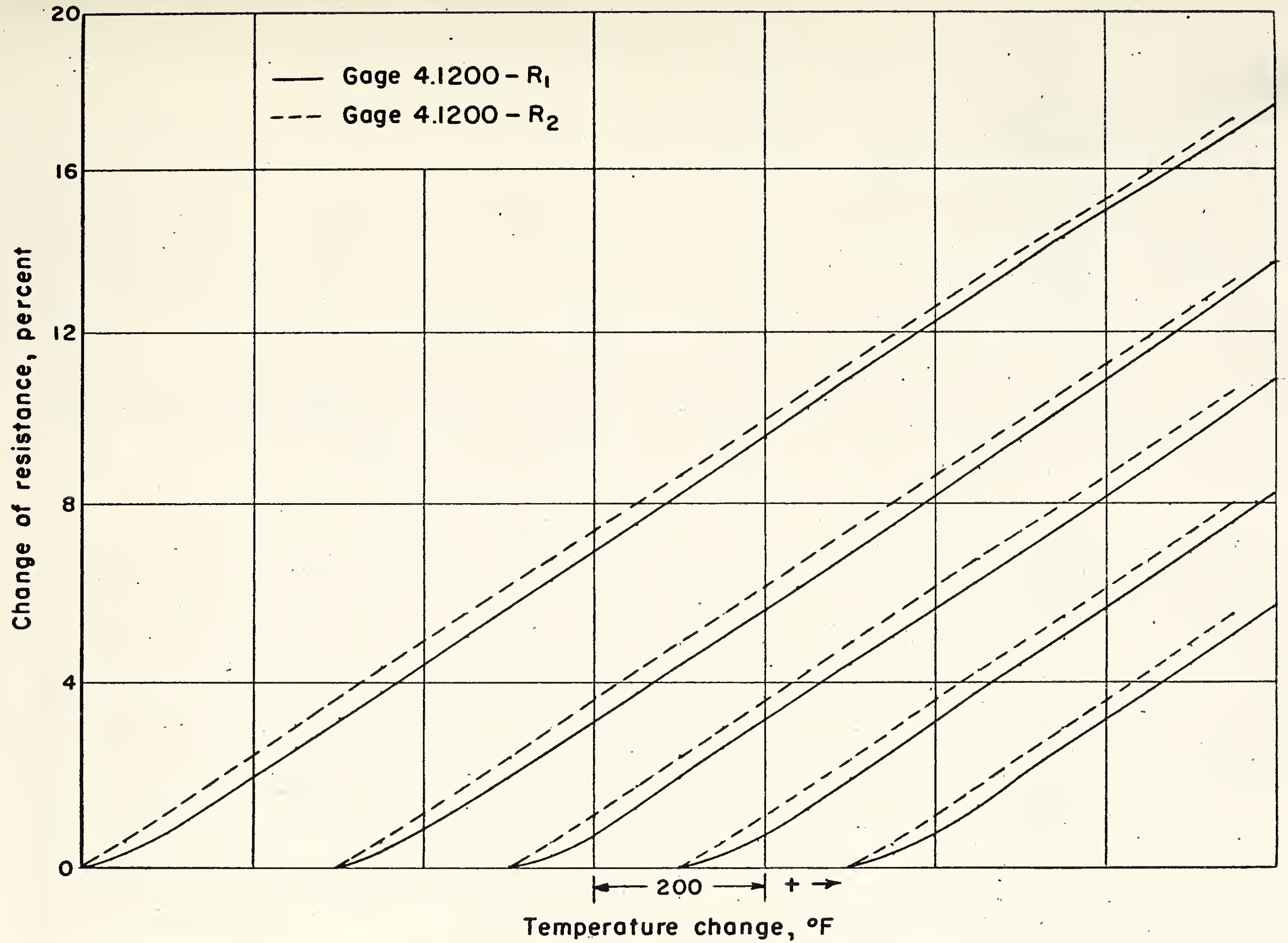

Fig. 23 Response of two gages with transient heating. Second heating series.

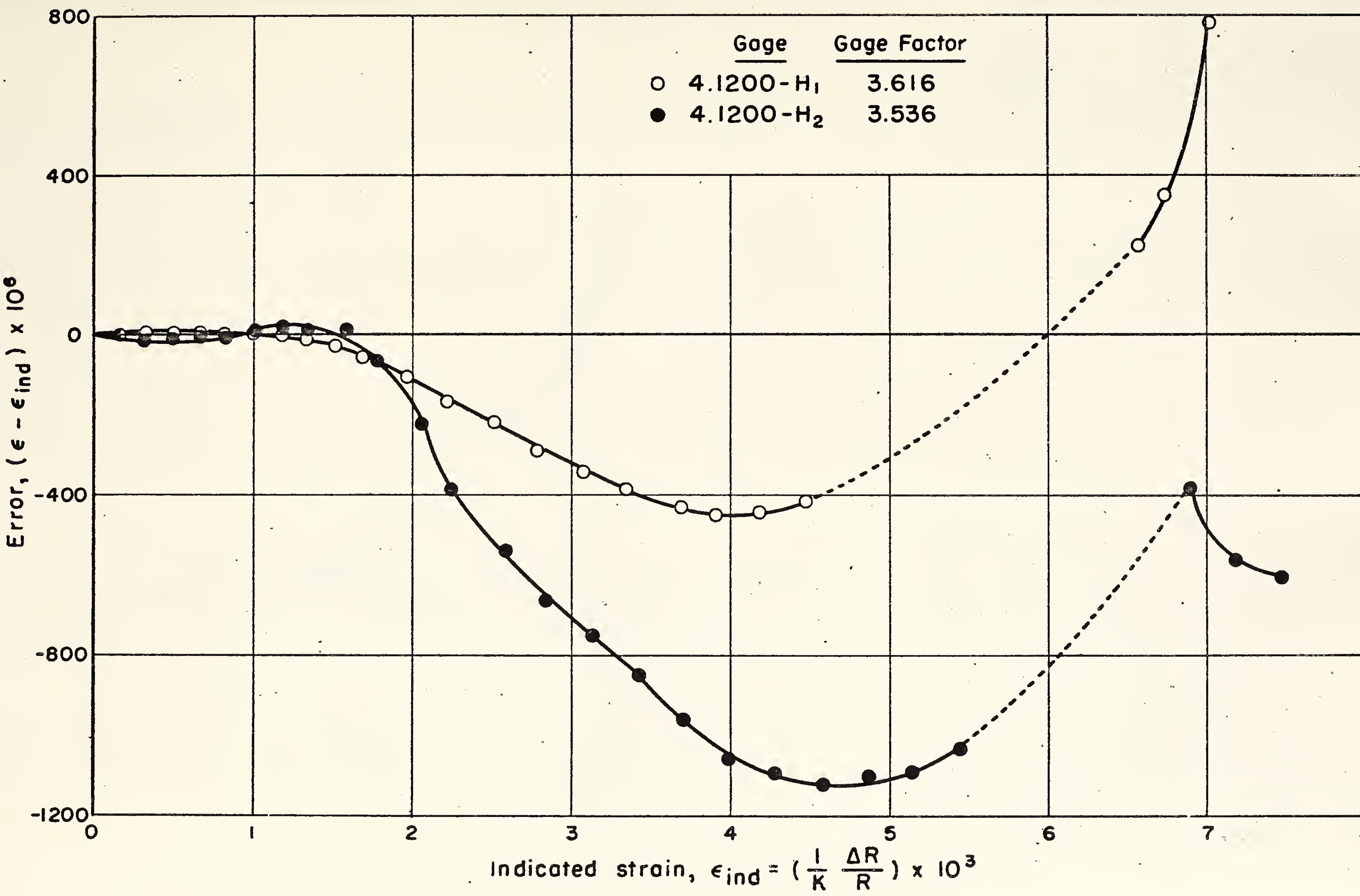

Fig. 24 Gage behavior at high strains at 75° F

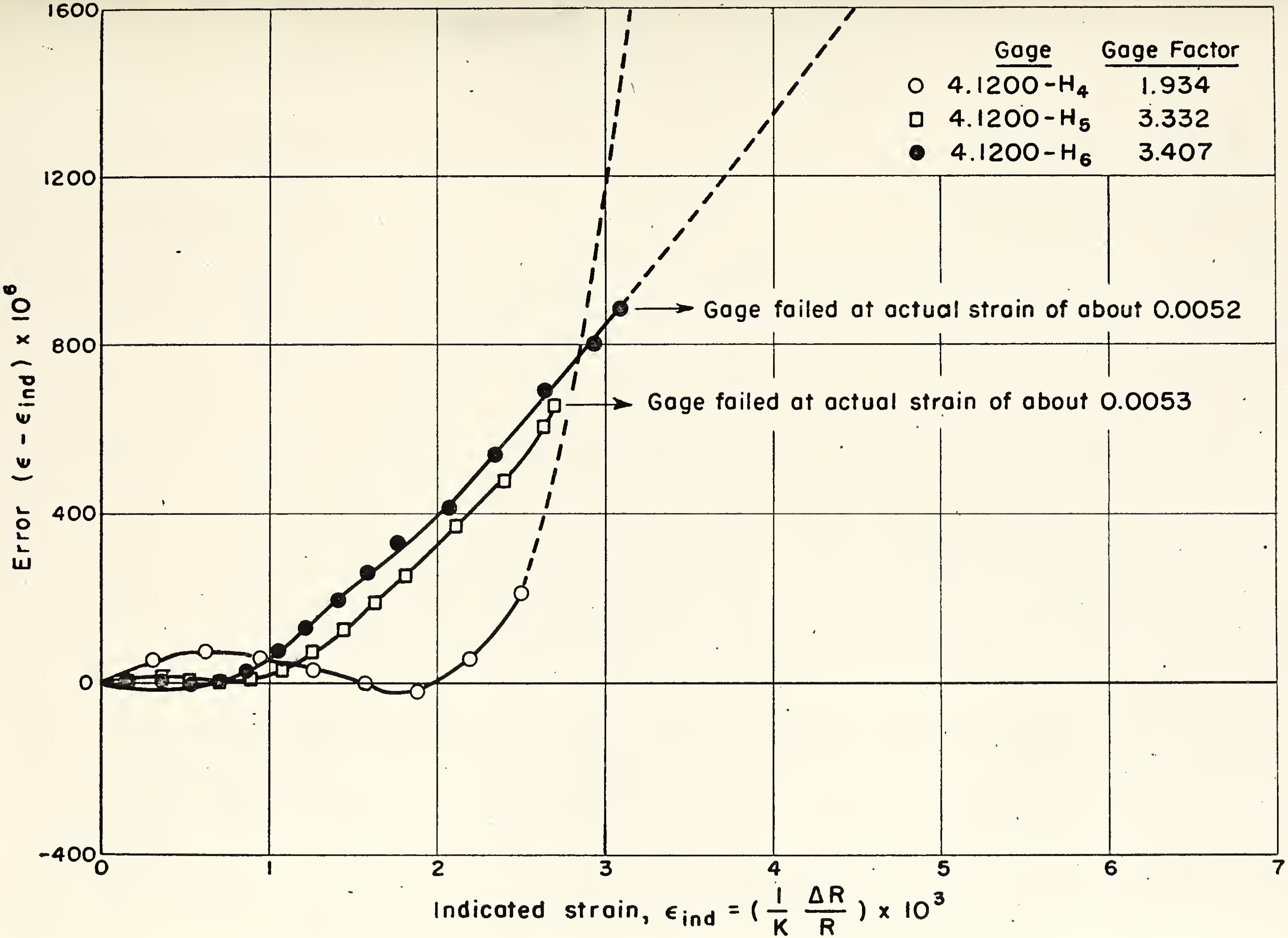

Fig. 25 Gage behavior at high strains at 700° F

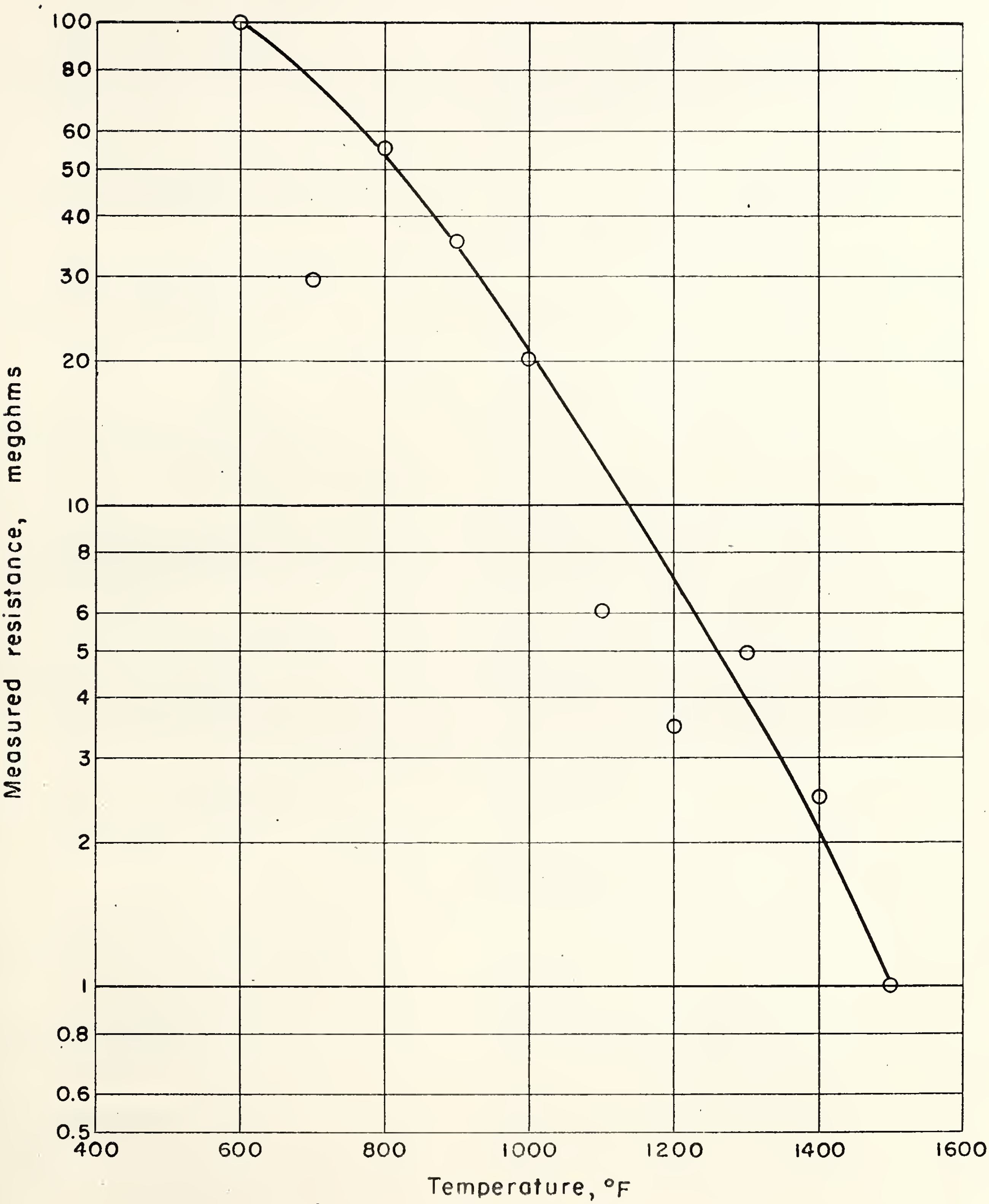

Fig. 26 Resistance between gage and test strip. Average values for two gages.

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Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

- Office of Basic Instrumentation.
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