NATIONAL BUREAU OF STANDARDS REPORT

7003

EVALUATION OF RESISTANCE STRAIN GAGES AT ELEVATED TEMPERATURES

Progress Report No. 10

by

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

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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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 quantitities must be capable of operating satisfactorily over a wide temperature range.

In order to determine the characteristics of strain gages that 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. Results obtained from only one gage type are given in this report so that performance information may be made available without undue delay. Results obtained from other gage types have been presented in earlier reports of this series.

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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Evaluation of Resistance Strain Gages at Elevated Temperatures

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SYNOPSIS

Resistance strain gages of the S-700 series, manufactured by the Instruments Division of the Budd Company (formerly the Tatnall Measuring Systems Company) 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 when subjected to large strains and (6) behavior under transient heating conditions. The results of these tests indicate that, when attached to stainless steel, the use of these gages may be limited by the effect of gage history on the gage factor; the high drift rate at about 800° F; the high temperature coefficient of resistance, especially at about 1000° F; and the difficulty in maintaining a good bond to stainless steel at 1500° F.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, gages manufactured by the Instruments Division of The Budd Company were subjected to evaluation tests. The gages tested were type S-740. 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 when subjected to large strains, and

(6) Behavior under transient heating conditions.

The results of previous evaluations of other gage types are given in references 1 through 9.

2. GAGES

The gages which are reported on herein are type S-740 purchased from the Instruments Division of The Budd Company (formerly the Tatnall Measuring Systems Company). The gage consists of a grid of very thin foil. The grid is attached to a plastic carrier which is removed during the installation process. The gages are described in Bulletin No. BN-6000 of the Tatnall Measuring Systems Company.

The gages were attached to test strips of stainless steel (types 302 and 303) with "H" cement also purchased from the Instruments Division of The Budd Company. The instructions given in Bulletin IB-6101 of the Tatnall Measuring Systems Company were followed.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for the evaluation tests are described in references 5, 8, and 10.

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 1 through 24.

4.1 Strain Sensitivity

Gage factor values were obtained at about 75° F from four 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.

Gage 7.740-A_1 was tested in tension before being tested in compression. Gages 7.740-A_3, A_5, and A_6 were tested in compression before being tested in tension.

The gage factor values are also shown in figure 1. Differences between the manufacturer's nominal value and the experimentally determined values expressed as a percent of the nominal value are plotted. Values for tensile loading are plotted on the abscissa, and values for compressive loading are plotted on the ordinate. Departure from the diagonal line indicates a difference between gage factor values for tensile and compressive loading. The solid symbols represent the first loading cycle in each direction. In all cases, except gage 7.740-A_3 in compression, the gage factor values determined were higher than the manufacturer's nominal value. After the first loading cycle, the values obtained from any one gage were quite repeatable except for gage 7.740-A_3 in tension. The very high and erratic gage factors found for gage 7.740-A_3 for tensile loading cannot be explained from information available from the test and subsequent examination of the gage installation.

The variations of gage factor with increasing temperature are shown in figures 2 through 5. Each curve of figure 2 through 4 represents the average change of gage factor of two gages mounted on opposite sides of a cantilever beam and connected as adjacent arms of a bridge circuit. Each curve was obtained as the test temperature was increased at about 20° F per minute. After the results for Run 1 (to 1000° F) were obtained, the specimen was cooled to room temperature and the second test run was made. This procedure was repeated until all test runs were completed. These figures show that the results obtained during the first test to 1000° F are quite different from results obtained for subsequent tests of the same gages. Results for second, third and fourth test runs agree quite well. Figure 5 shows the average gage factor variation for the first and second tests to 1000° F for the six gages tested.

Figures 6, 7 and 8 show the departure from linearity of the gage response and the zero shift for the first and third loading cycles to about 1000 micro-inches per inch strain in tension and compression at room temperature. Open symbols indicate increasing load, and solid symbols are for decreasing load. Figures 6 and 7 show that, in general, the departure from a straight line relationship was less than forty micro-inches per inch. These figures also show that the gage response during the third strain cycle was nearly always better than during the first strain cycle. Figure 8 again shows the erratic behavior of gage 7.740-A_3 during tensile loading.

4.2 Drift

The drift behaviors of two gages at each test temperature are shown in figures 9 through 18. The drifts of the two gages were nearly the same at temperatures as high as 900° F. However, at 1000° F and above there was considerable difference in the behavior of the two gages. At 600 and 700° F the drift was positive and less than 250 parts per million change of resistance in an hour. At 800° F the magnitude of the drift was more than ten times as large, but in a negative direction. It then became progressively less negative with increasing temperature, as least through 1100° F.

4.3 Temperature Sensitivity

Temperature coefficient values for two gages, determined as the slope of a line drawn tangent to a recorded curve of relative change of gage resistance versus temperature, are shown in figure 19. The vertical lines show the range of values obtained during three test runs per gage at temperatures as high as 1200° F and one test run per gage above 1200° F. The curve is faired through the average values for all runs. This curve shows that there are inflection points on the gage resistance versus temperature curve at about 800° F, 900° F and 1000° F. The generally high temperature coefficient of resistance shown by these gages (greater than forty parts per million resistance change per degree Fahrenheit between about 500 and 1200° F) and the rapidly changing temperature sensitivity near 1000° F would make these gages primarily useful for dynamic strain measurements since correction or compensation for temperatures effects would be difficult.

4.4 Large Strains

The results of tests in which the gages were subjected to tensile strains greater than those used for gage factor determination are shown in figures 20 and 21. The gage factor value used for determining the strain indicated by the resistance gage, ϵ_{ind}, at room temperature was the average of the values for tensile loading for gages 7.740-A_1, A_5, and A_6. For tests carried out at 600° F, this average gage factor value was adjusted by the amount indicated for the first test run in figure 5. The upward curvature of the curves of figure 20 might indicate a failure of the cement to properly transmit strain to the gage element. It was also noted that for all tests at room temperature the bond between the cement and the test strip failed. For two gages this failure occurred at an actual strain of about 0.004, and for the third gage failure occurred at an actual strain of about 0.008. At 600° F, figure 21, both tests were terminated because of gage element failure at actual strains of about 0.007. Failure was indicated either by an open circuit within the gage or by a very rapid increase of gage resistance for a small strain increment.

4.5 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 22 and 23. Figure 22 shows 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, 800, 1000, 1200 and 1500° F in that order. (The temperature changes were about 500 to 1400° F.) This figure shows that the change of resistance is large, but that the response is repeatable, especially after the first heating series.

Figure 23 shows the results for a similar series of heating cycles of another gage. Results are only shown for one heating series since the bond between the gage and test strip failed after the first cycle to 1500° F.

4.6 Resistance to Ground

The average resistance between the strain sensitive element of the gage and the test strip for two gages is shown in figure 24. The resistance measurements were made with a Triplett vacuum tube volt-ohm meter, Model 650, using the scale range marked X 1 meg Ω. The common terminal of the instrument was connected to the test strip. The readings were taken at the start of drift tests, 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[11].

4.7 Gages Destroyed

During the course of this evaluation, thirteen gages were either destroyed or the intended information was unobtainable from them. The bond between the gage and the test strip failed for five additional gages after they had been heated to 1500° F. 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) These gages have a high gage factor at room temperature. This factor is repeatable, especially after the first strain cycle.

(2) The gage factor variation with temperature is a function of gage history. The results obtained were repeatable for the three sets of gages tested. (According to the manufacturer, a heating cycle at 1000° F changes the function, gage factor versus

temperature, and if tests were carried out only to 800° F the curve for Run 1 of figures 2, 3, 4 and 5 would be identical to that of subsequent runs.)

(3) The drift is low and positive at 600 and 700° F, is high and negative at 800° F, and then becomes less negative with increasing temperature, at least to 1100° F.

(4) The temperature coefficient of resistance is quite high, but repeatable, except between 900° F and 1100° F. In this range it is very high and changes rapidly. The change of resistance versus temperature curve shows inflection points at about 800, 900, and 1000° F.

(5) The drift and temperature sensitivity of these gages will limit their usefulness for static strain measurements.

(6) These gages, with "H" cement, cannot be expected to be useful on stainless steel (type 302) at temperatures approaching 1500° F because of the weakening of the bond between the gage and specimen.

Washington, D. C.
November 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, C. H. Melton, and J. T. Trumbo, Evaluation of Resistance Strain Gages at Elevated Temperatures (Progress Report No. 9) NBS Report No. 6900, July 1960, (ASTIA No. AD 240829).

(10) 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.

(11) 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	4
Gage factor variation with temperature	6
Drift	2
Temperature sensitivity	2
Transient heating	2
Large strains	5

Table 2 - Gage Factor Values at 75° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		K_u	K_d	$\overline{K}_t$	K_u	K_d	$\overline{K}_c$
7.740-A_1	1	2.866	2.772	2.819	2.761	2.719	2.740
	2	2.772	2.755	2.763	2.744	2.723	2.733
	3	2.768	2.753	2.760	2.749	2.718	2.734
	Average	2.802	2.760	2.781	2.751	2.720	2.736
7.740-A_3	1	4.795	4.172	4.484	2.544	2.630	2.587
	2	4.175	3.442	3.809	2.574	2.586	2.580
	3	3.291	3.002	3.146	2.572	2.583	2.578
	Average	4.087	3.539	3.813	2.563	2.600	2.582
7.740-A_5	1	2.769	2.719	2.744	2.727	2.716	2.722
	2	2.727	2.718	2.722	2.705	2.719	2.712
	3	2.722	2.709	2.716	2.711	2.709	2.710
	Average	2.739	2.715	2.727	2.714	2.715	2.715
7.740-A_6	1	2.756	2.670	2.713	2.890	2.867	2.878
	2	2.688	2.675	2.682	2.816	2.808	2.812
	3	2.704	2.679	2.691	2.817	2.807	2.812
	Average	2.716	2.675	2.695	2.841	2.827	2.834
	Grand Average	3.086	2.922	3.004	2.718	2.715	2.716
	Grand Average*	2.752	2.717	2.734	2.769	2.754	2.761

*The values shown on this line do not include the results obtained from gage 7.740-A_3. The results obtained from gage 7.740-A_3 may not be representative of the performance of this gage type since, for tensile loading, they were erratic and significantly different than the results obtained from other gages.

Table 3 - Gages Lost Before Completing Tests

Number of gages lost	Remarks
5	Grid damaged while attaching ribbon lead to gage before installation
2	Grid damaged during application of cement
1	Grid damaged while removing handling tabs
1	Gage damaged in handling before installation
1	Gage damaged in attaching leads after installation
1	Gage had high resistance (350 ohms) after installation
1	Gage shorted to the test strip
1	Open circuit in gage upon heating to 800° F
5	Bond failed during test after heating to 1500° F.

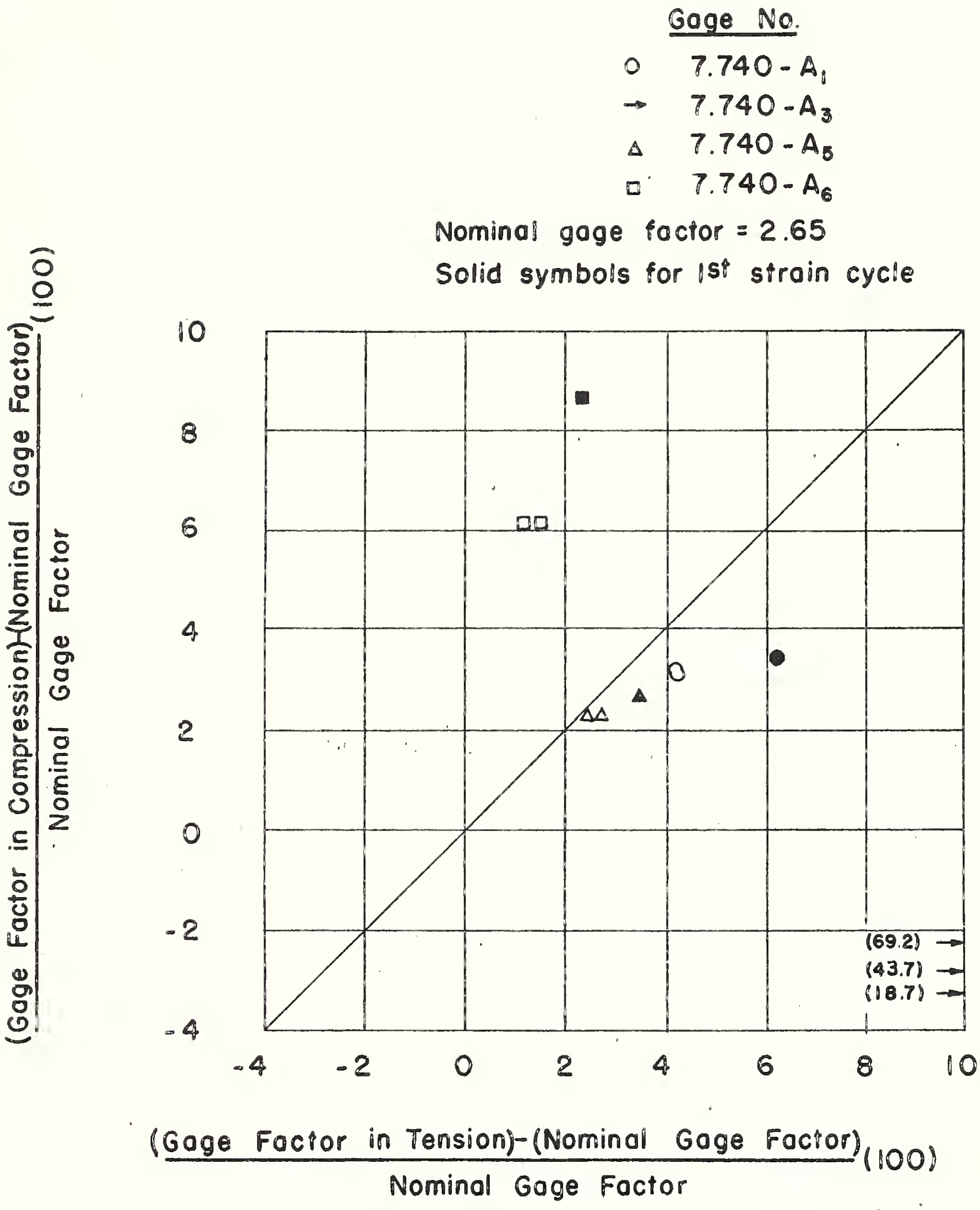

FIG. I Gage Factor Deviation at 75°F

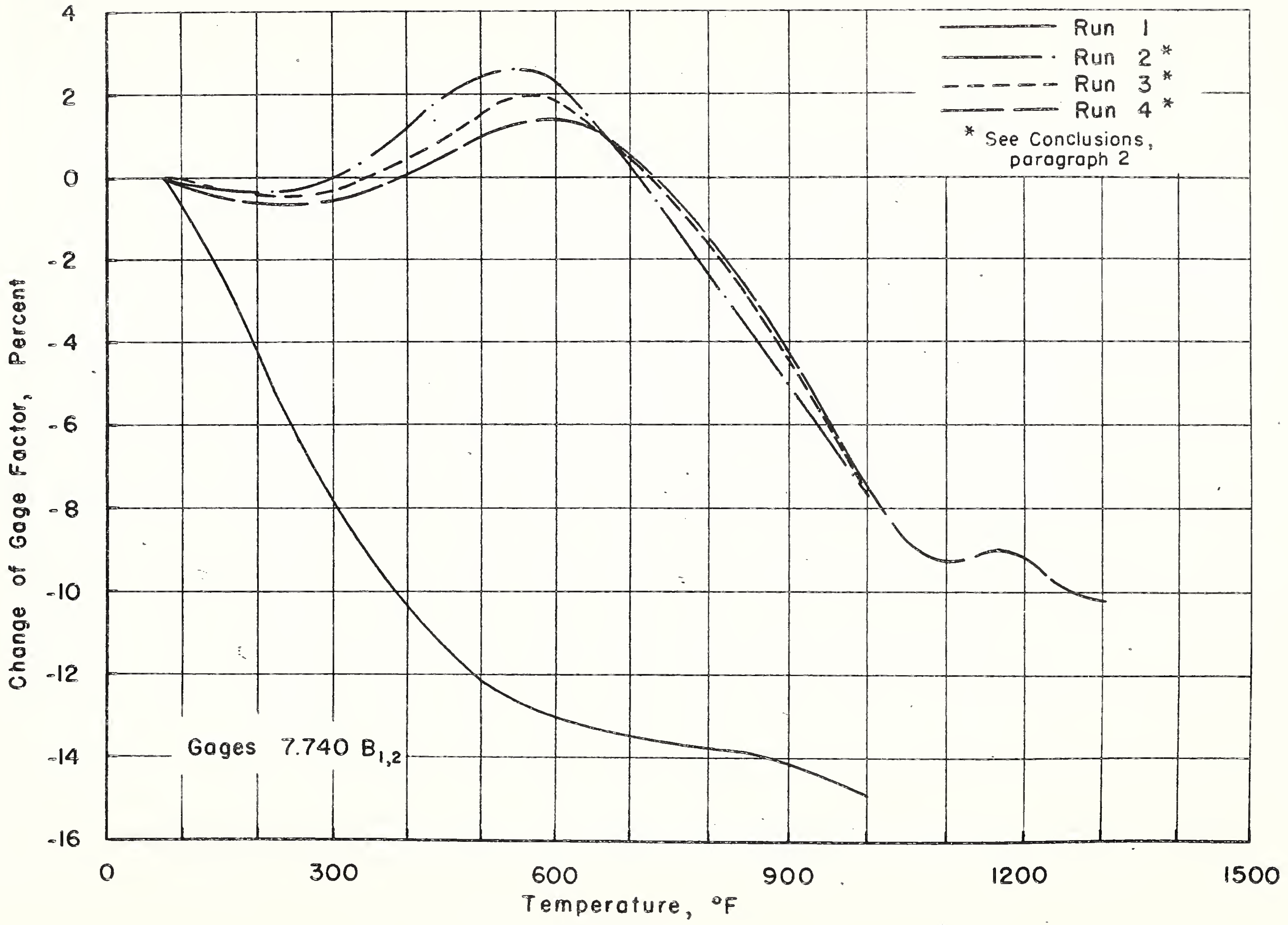

FIG. 2 Variation of Gage Factor with Temperature

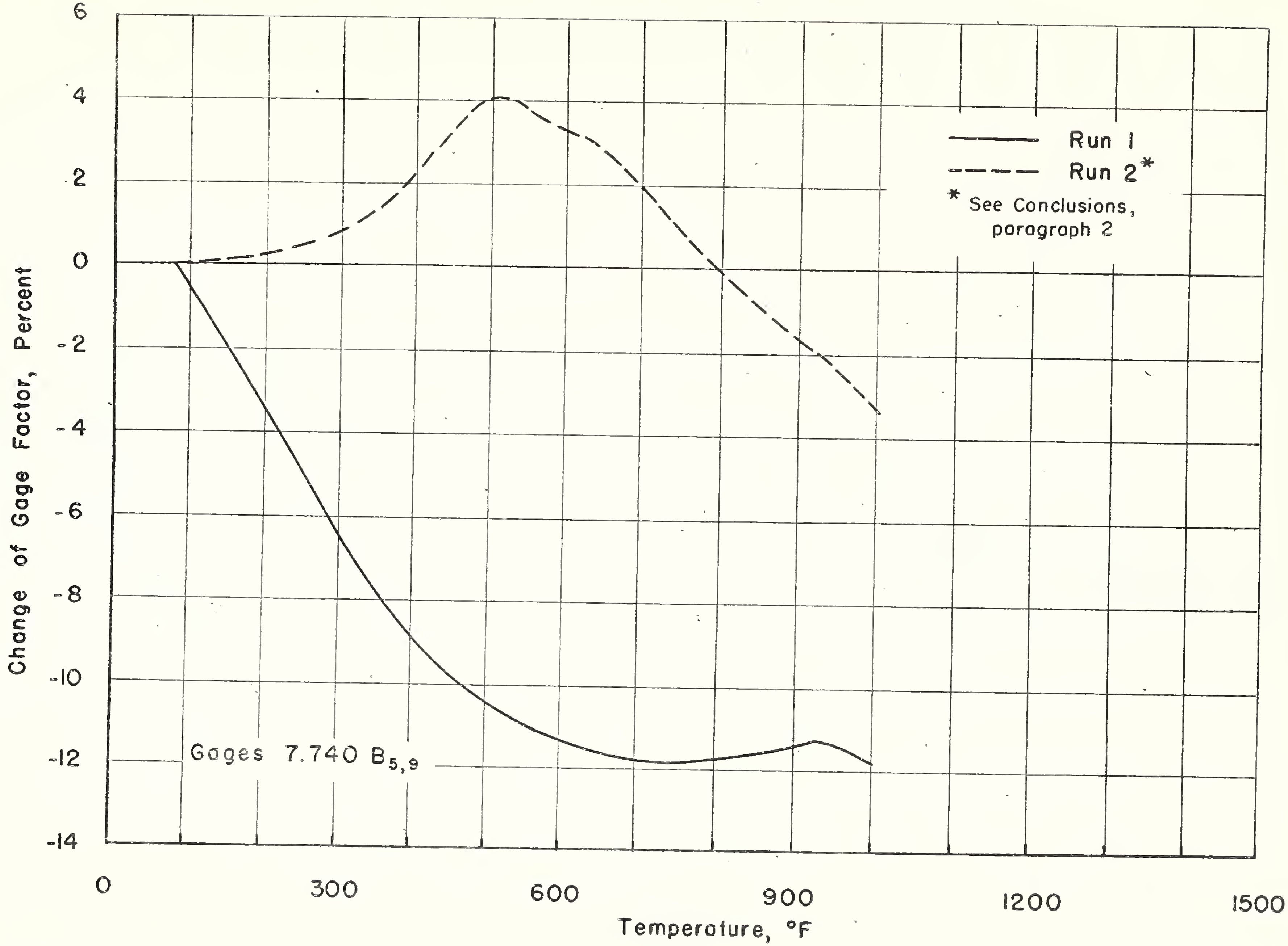

FIG. 3 Variation of Gage Factor with Temperature

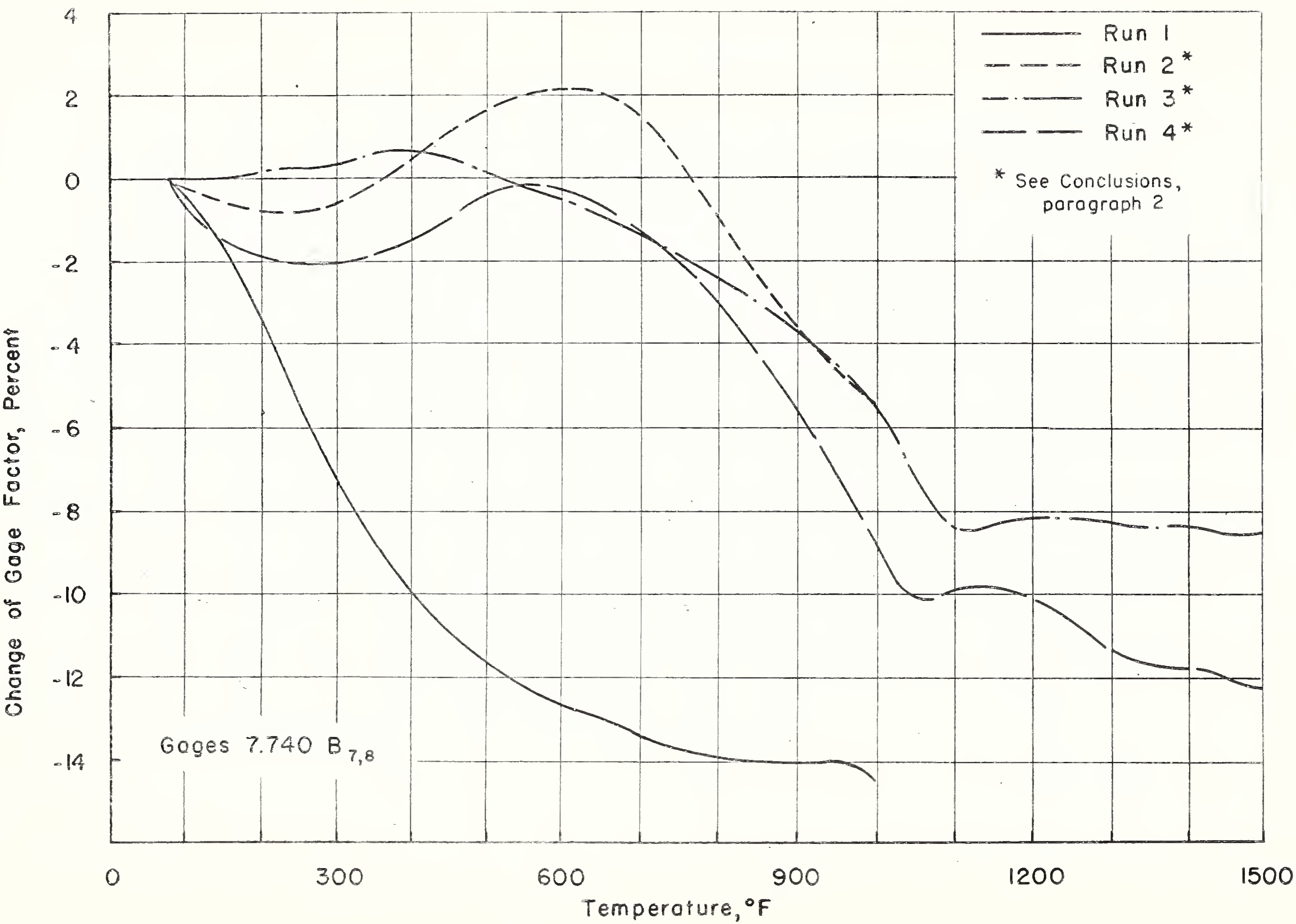

FIG. 4 Variation of Gage Factor with Temperature

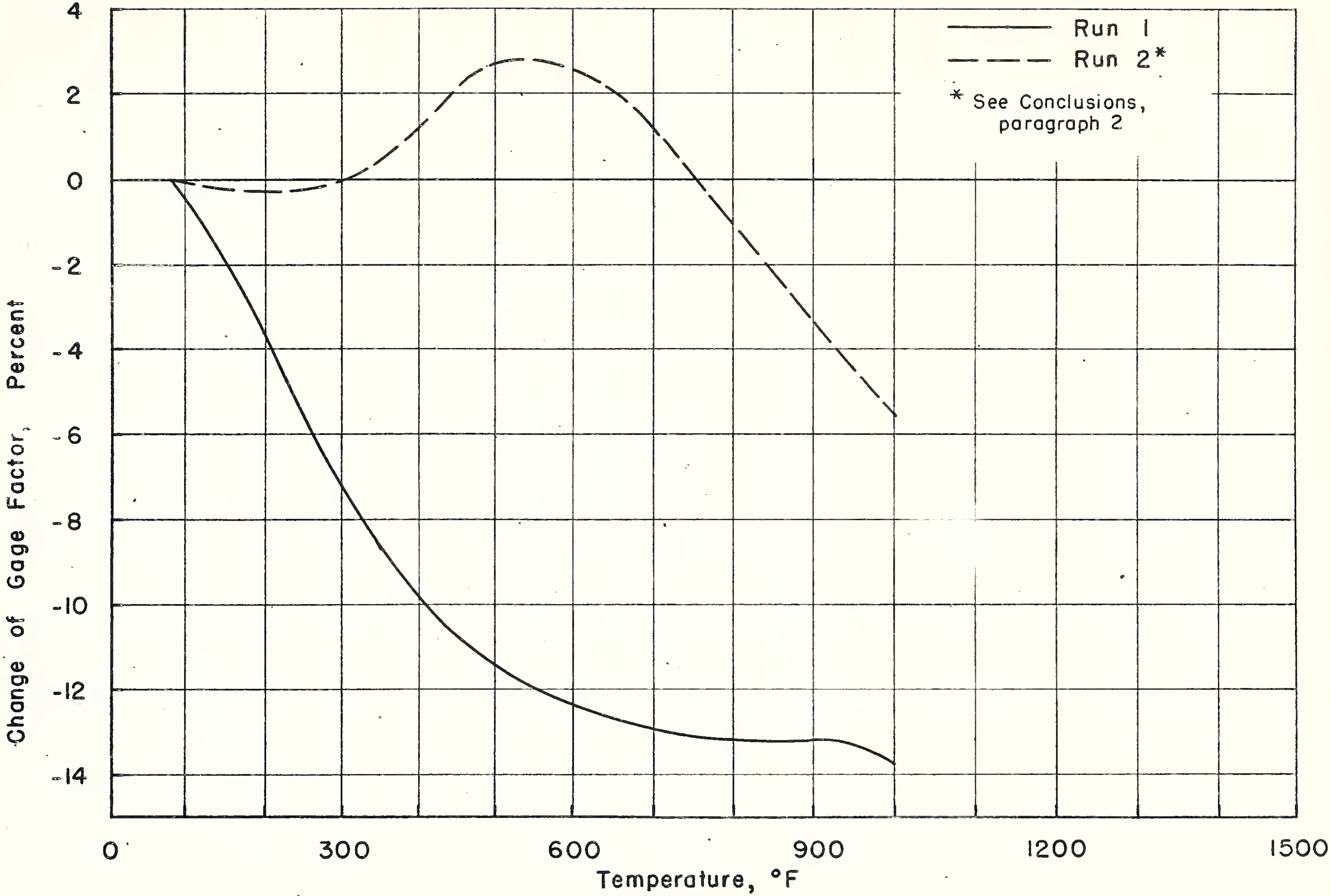

FIG. 5 Average Variation of Gage Factor with Temperature for Six Gages

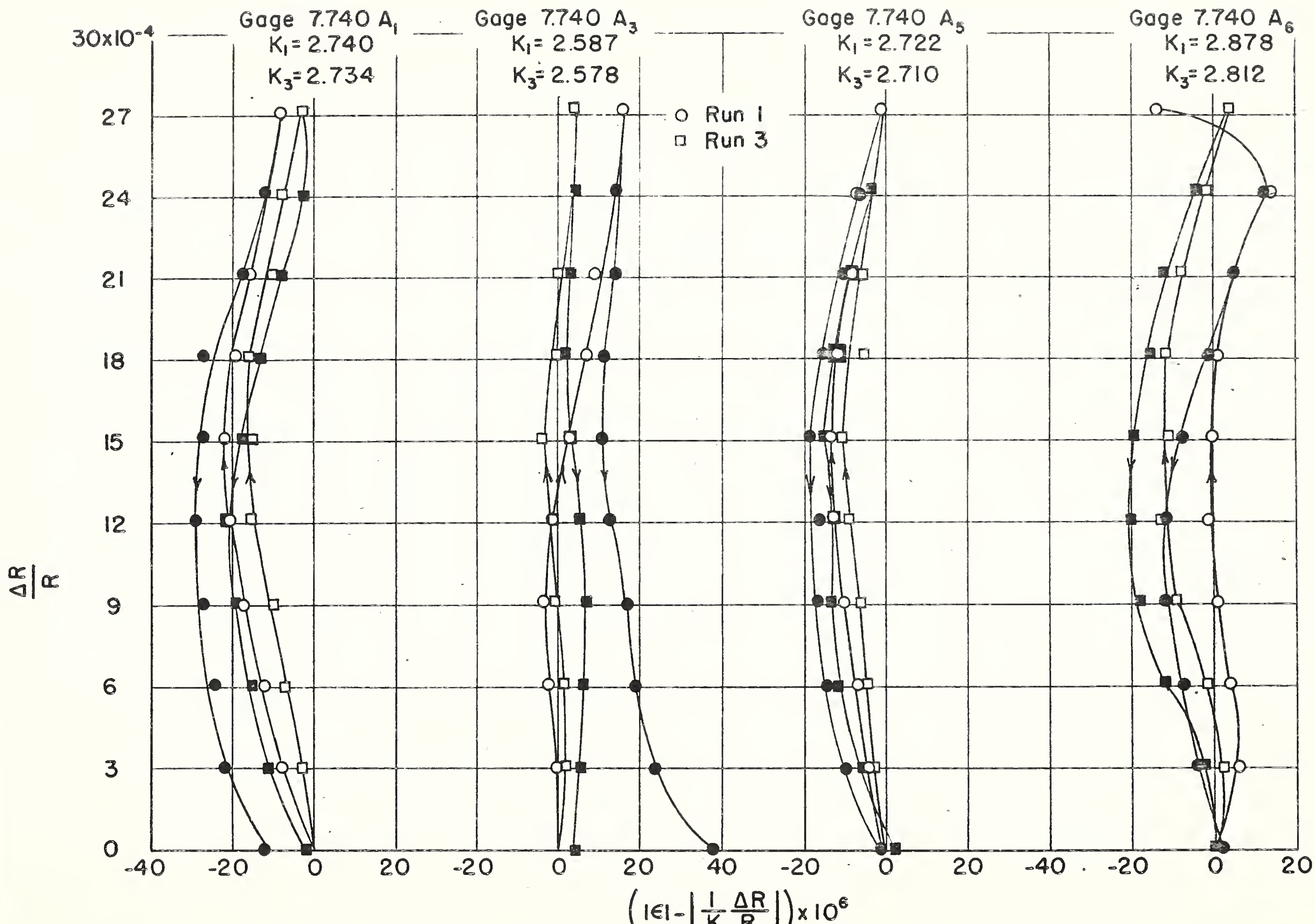

FIG. 6 Strain Deviation for Compression Loading

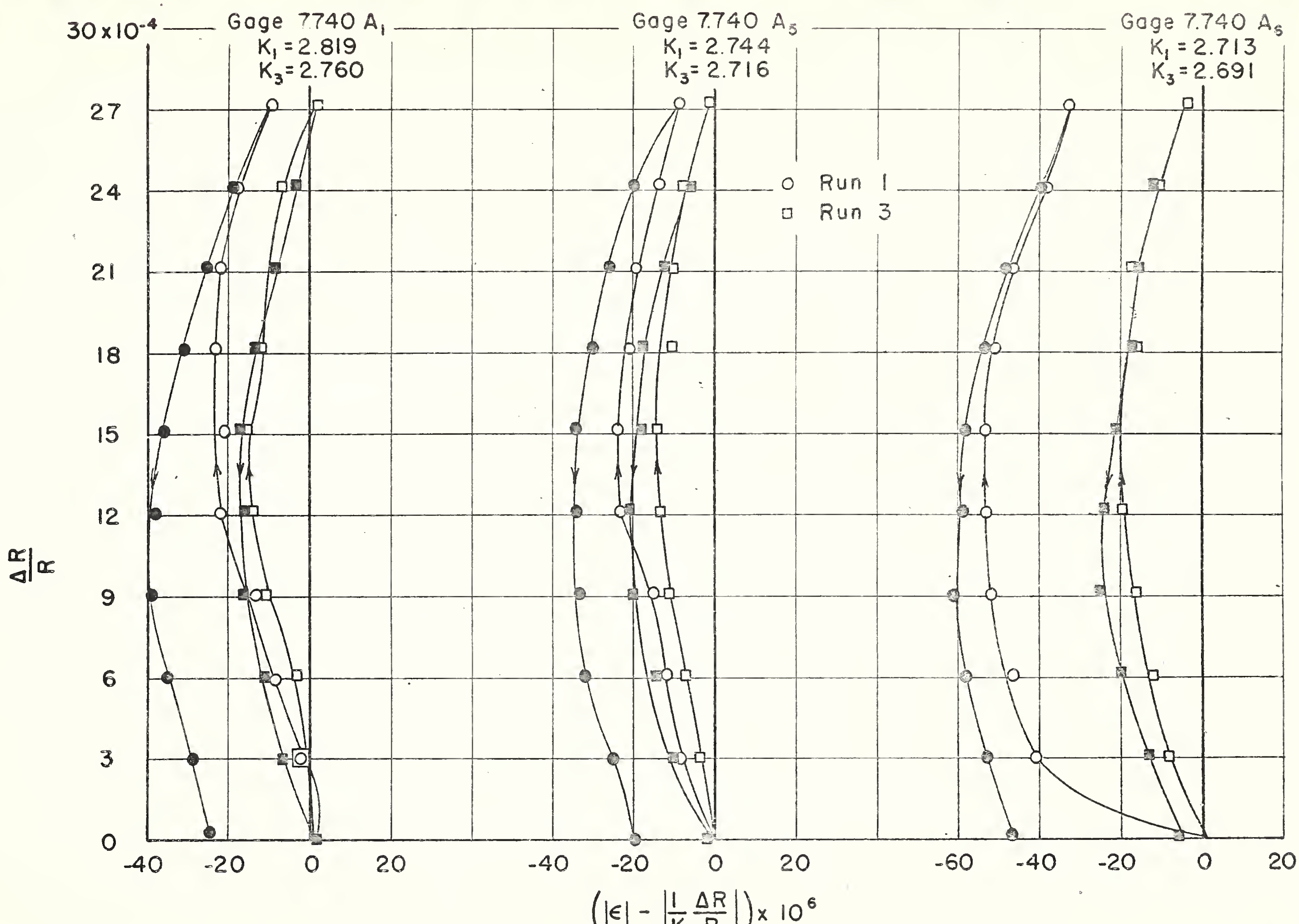

FIG. 7 Strain Deviation for Tension Loading

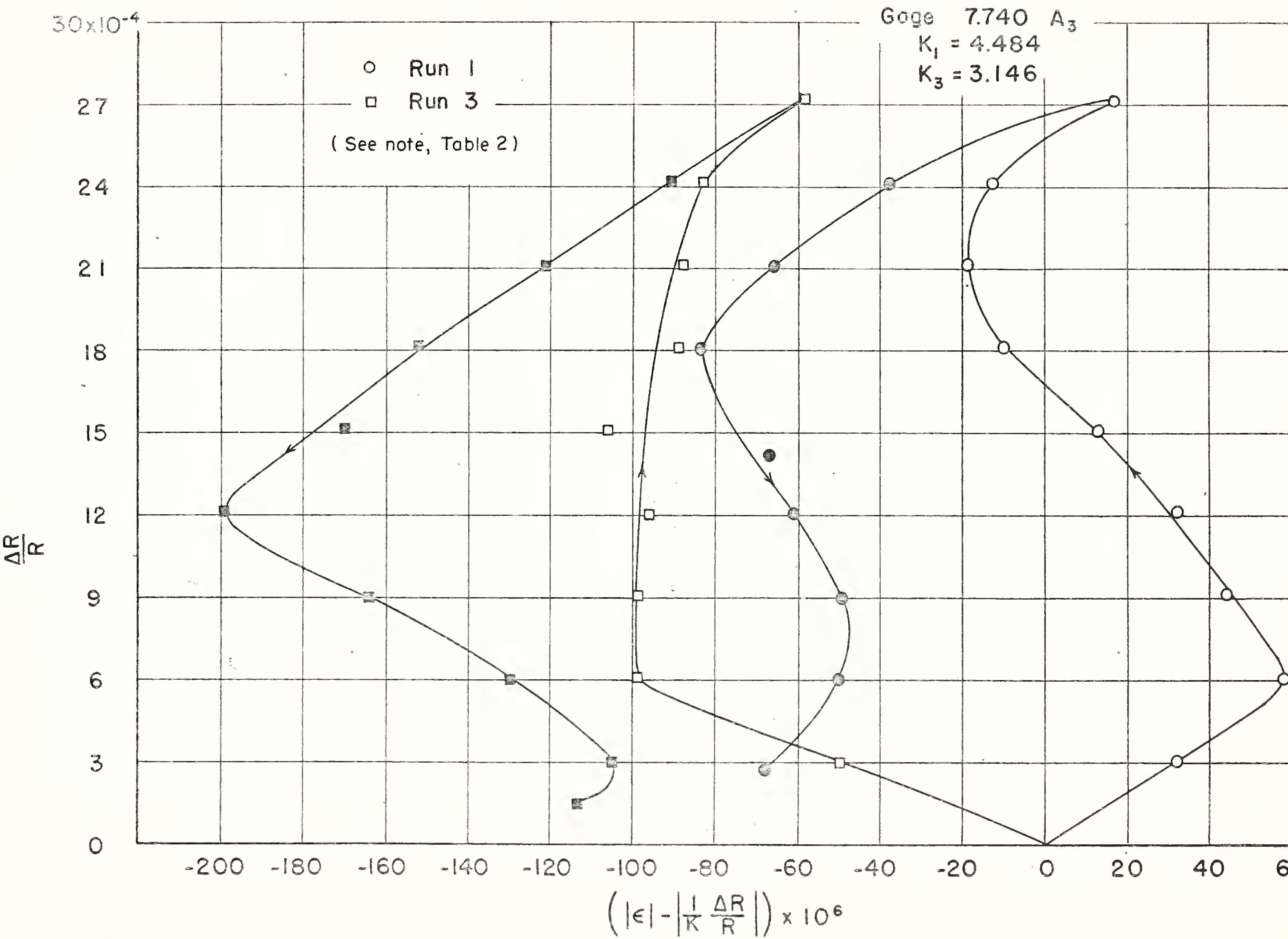

FIG. 8 Strain Deviation for Tension Loading

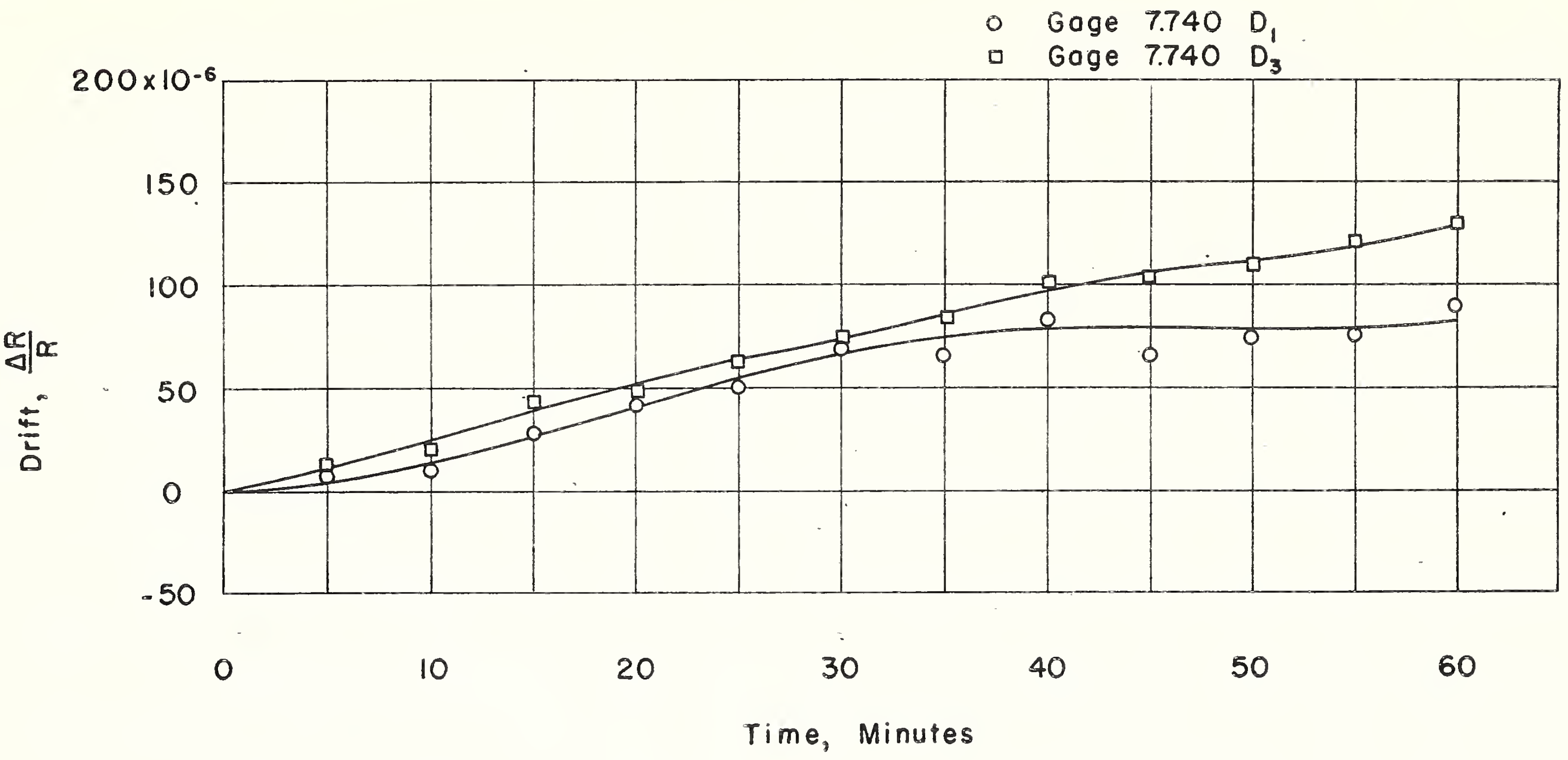

FIG. 9 Drift Behavior at 600°F

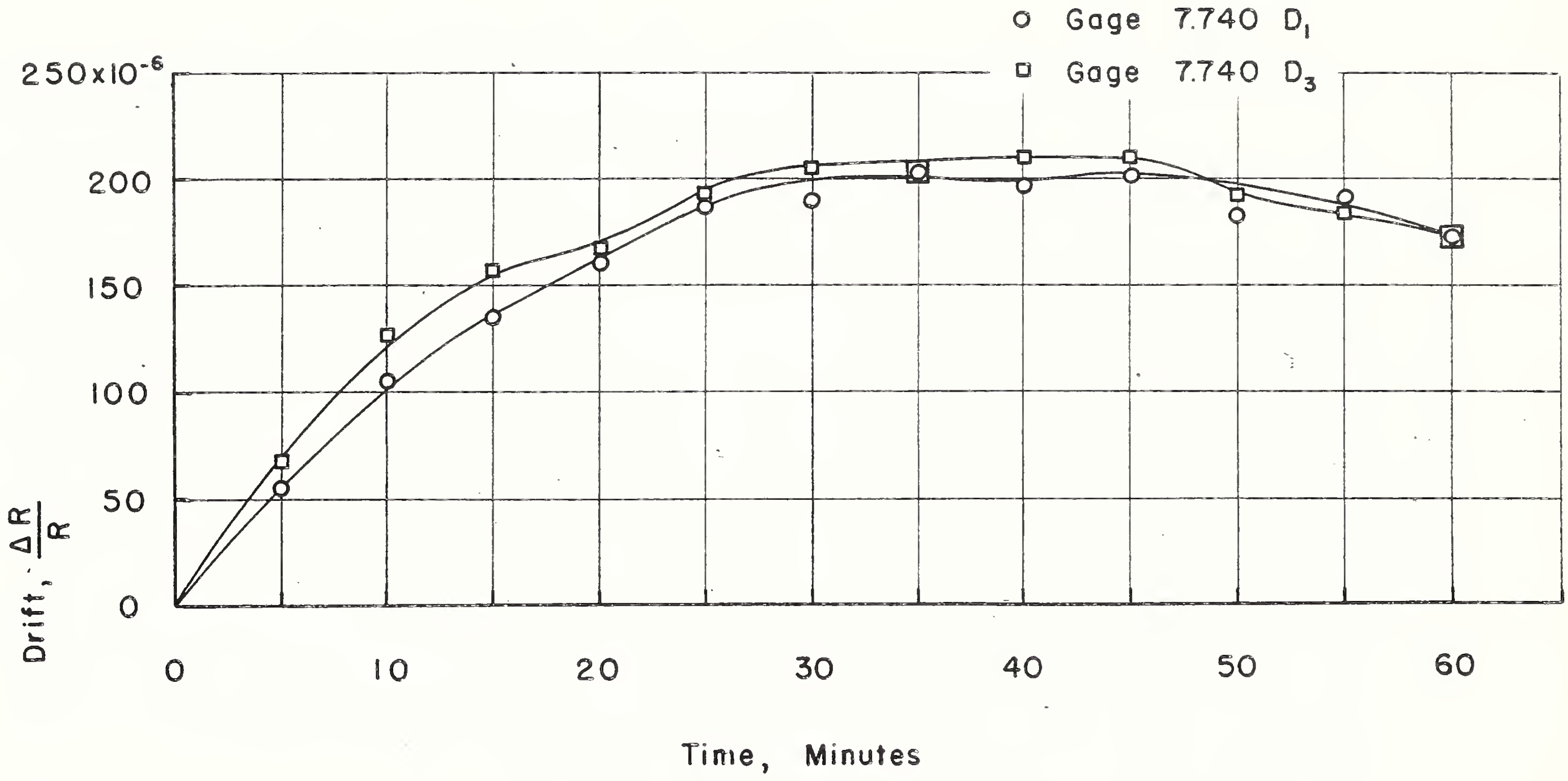

FIG. 10 Drift Behavior at 700 °F

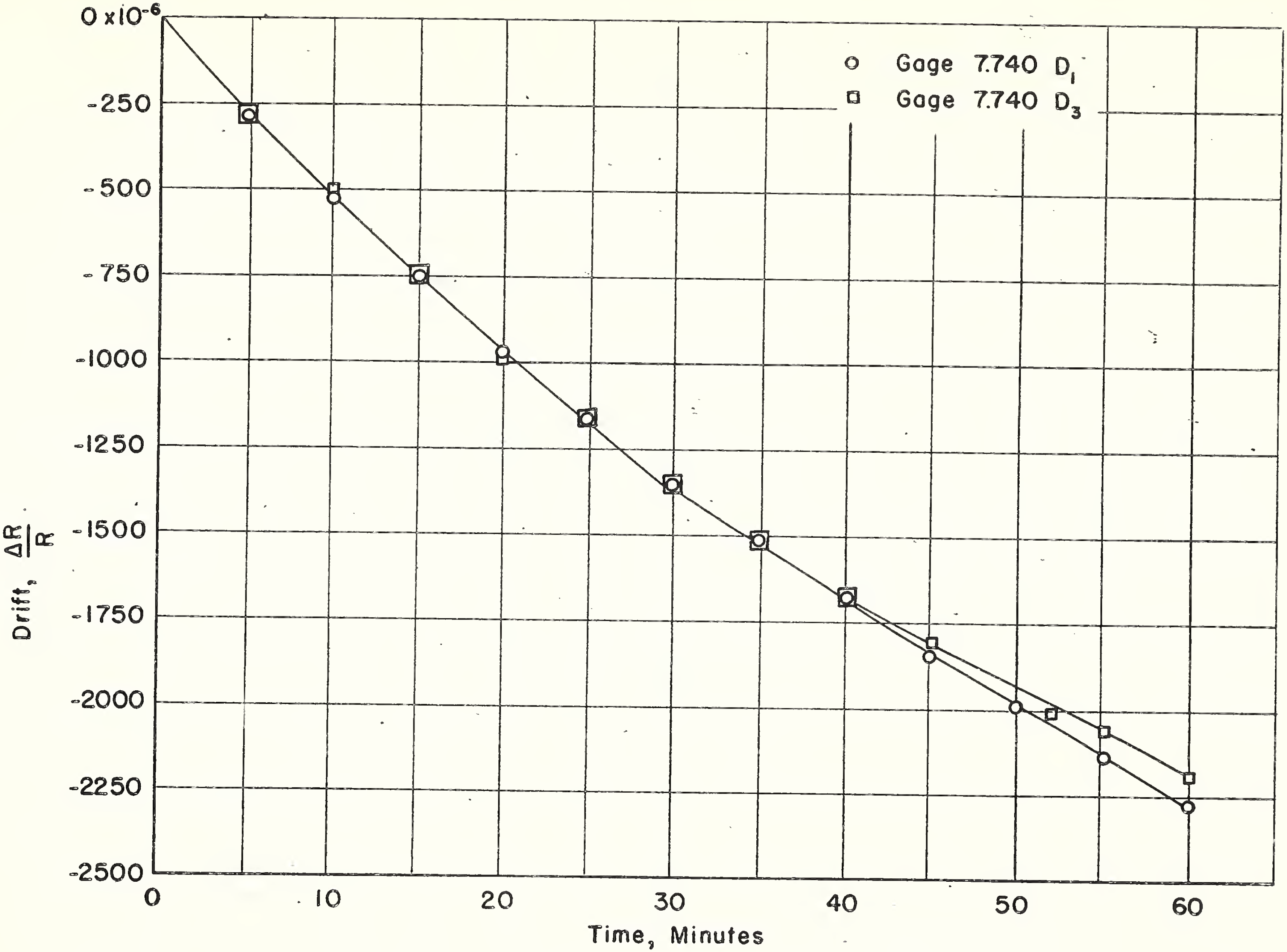

FIG. 11 Drift Behavior at 800°F

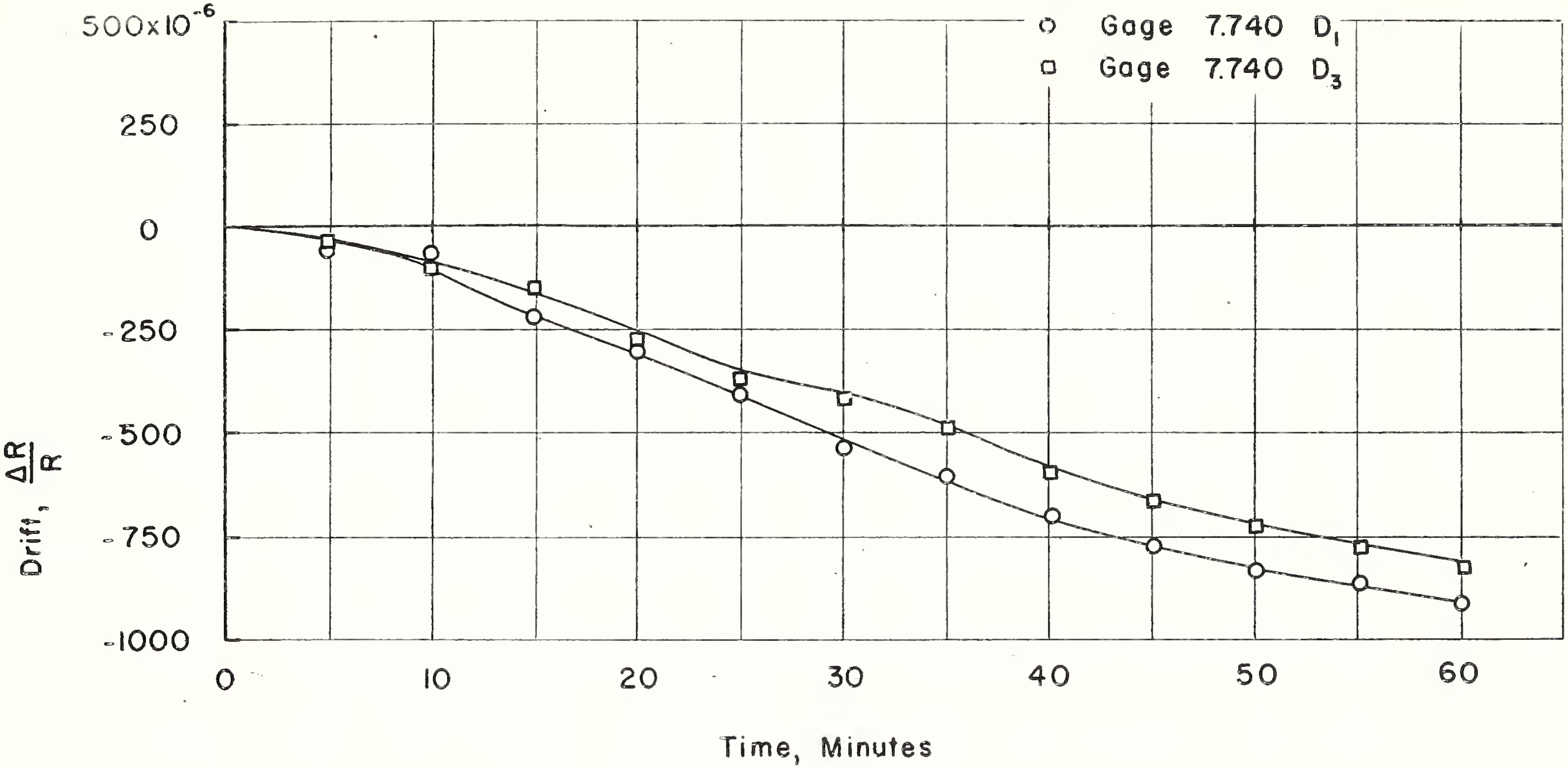

FIG. 12 Drift Behavior at 900°F

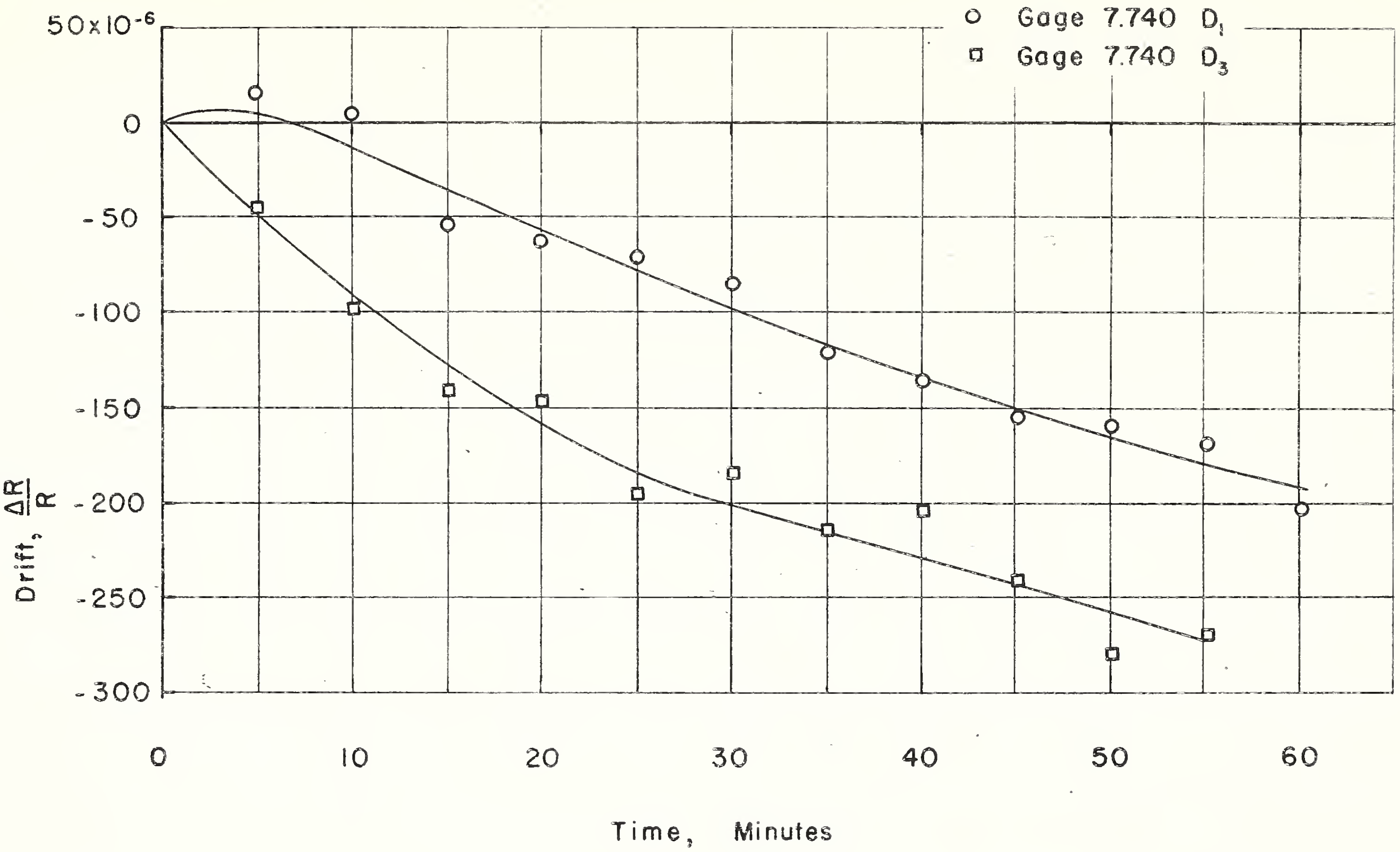

FIG. 13 Drift Behavior at 1000°F

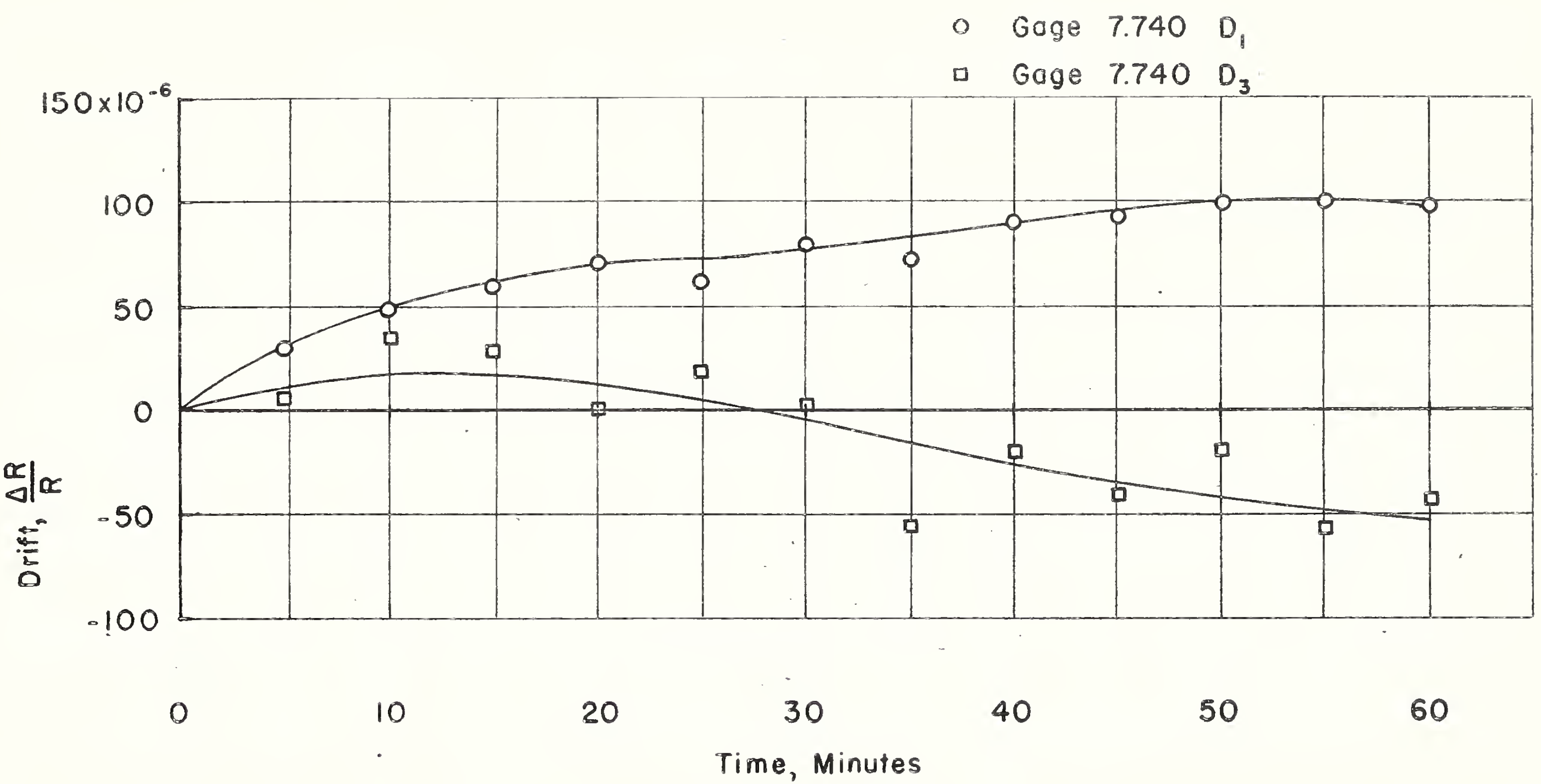

FIG. 14 Drift Behavior at 1100°F

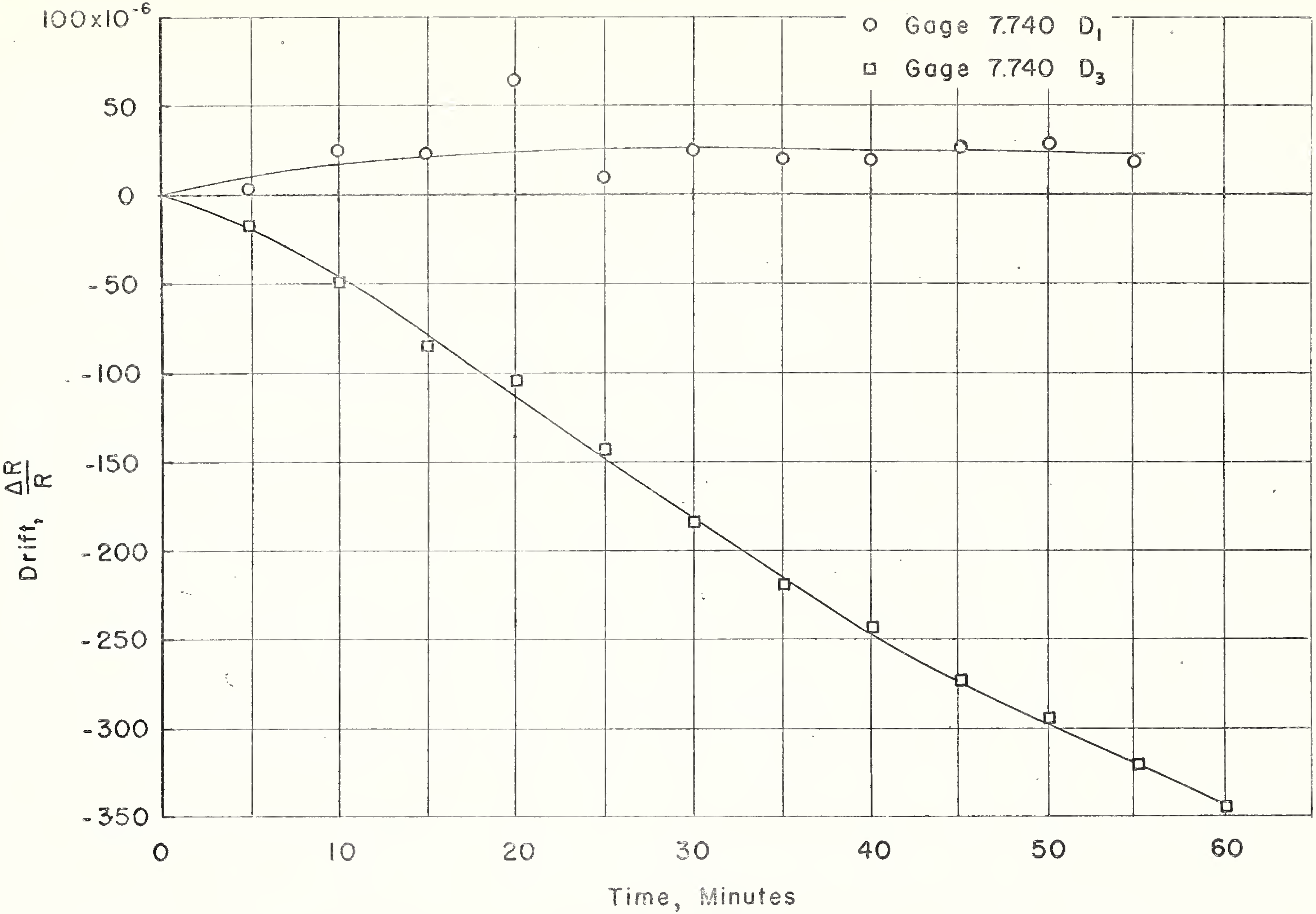

FIG. 15 Drift Behavior at 1200°F

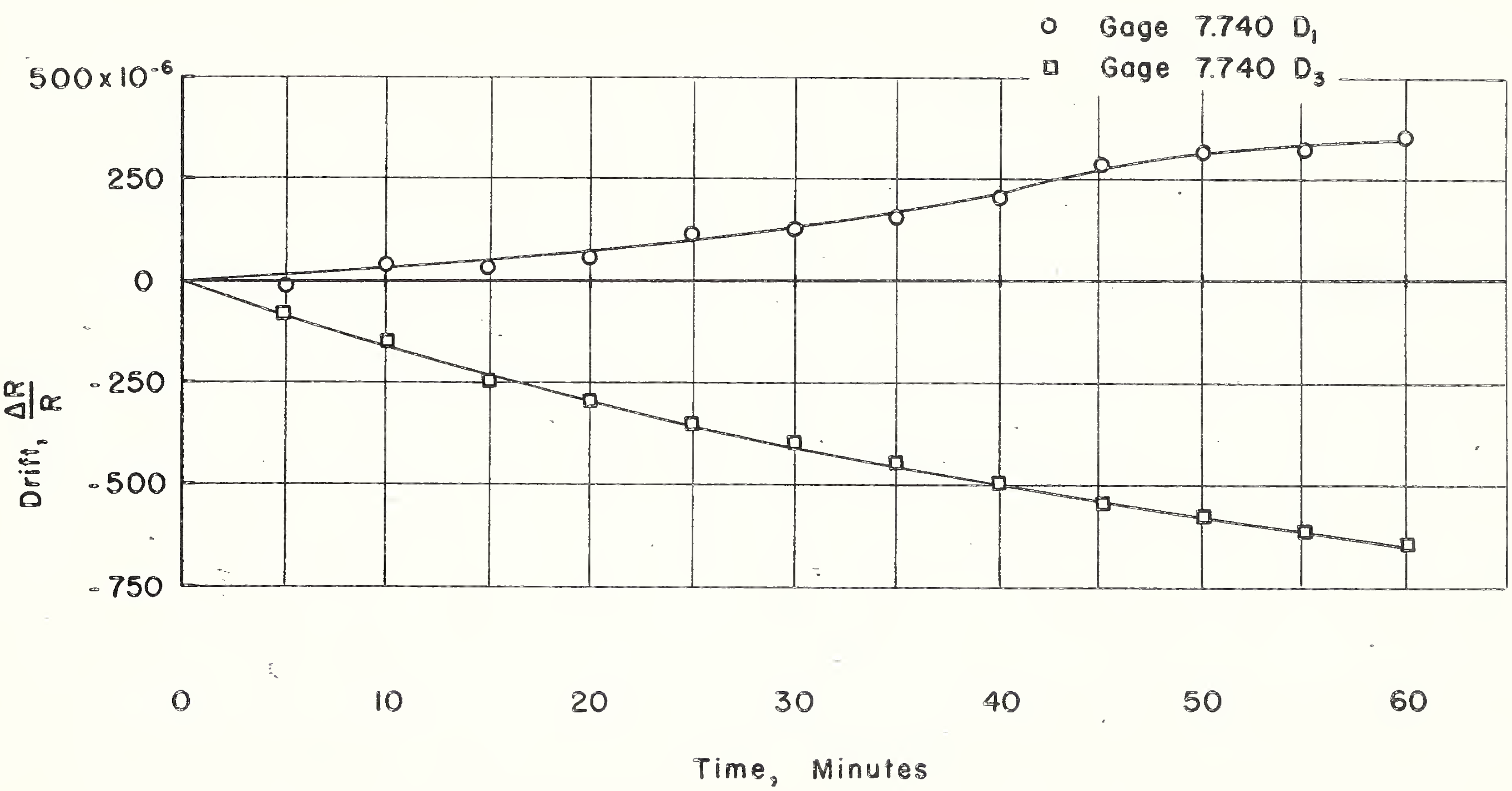

FIG. 16 Drift Behavior at 1300°F

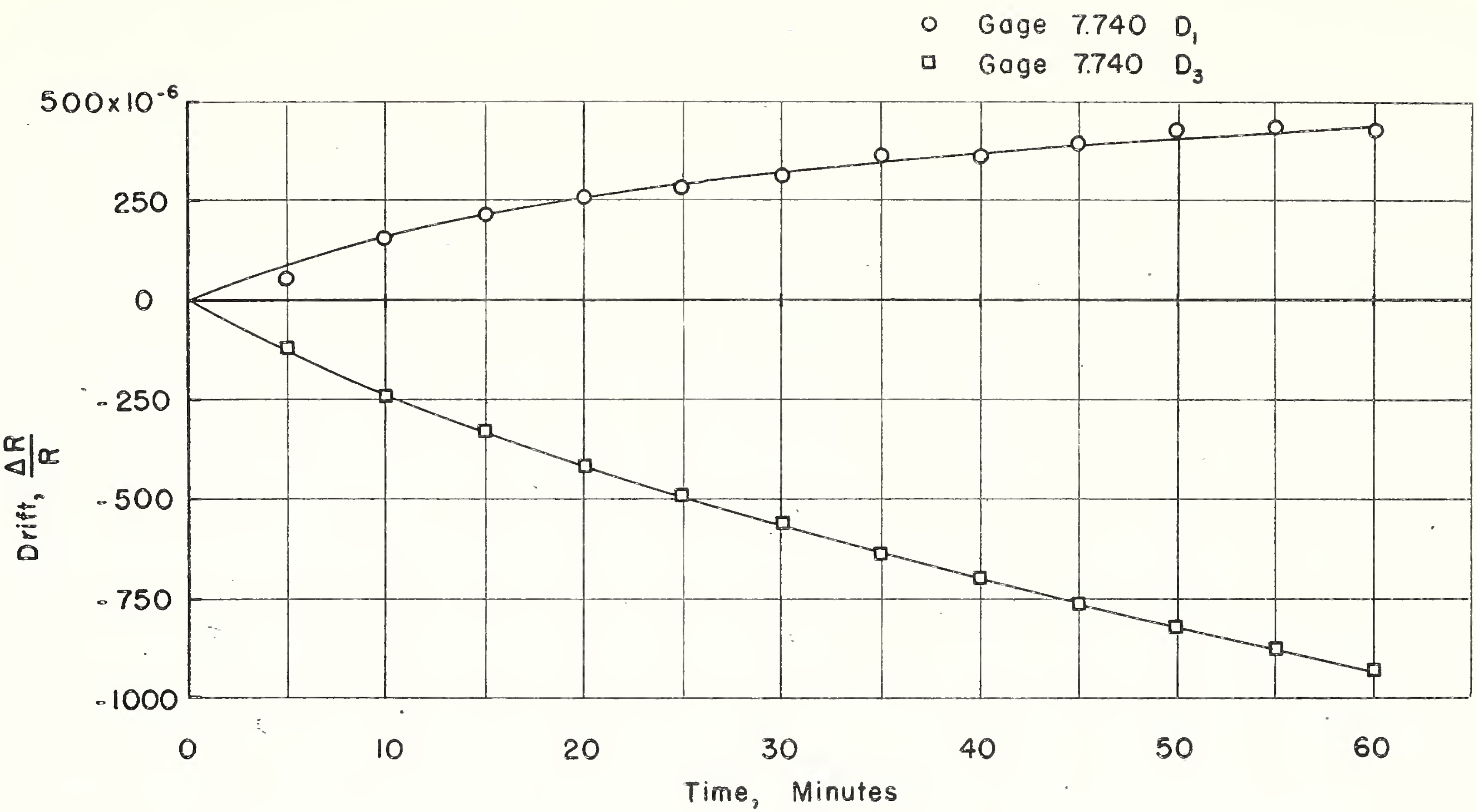

FIG. 17 Drift Behavior at 1400

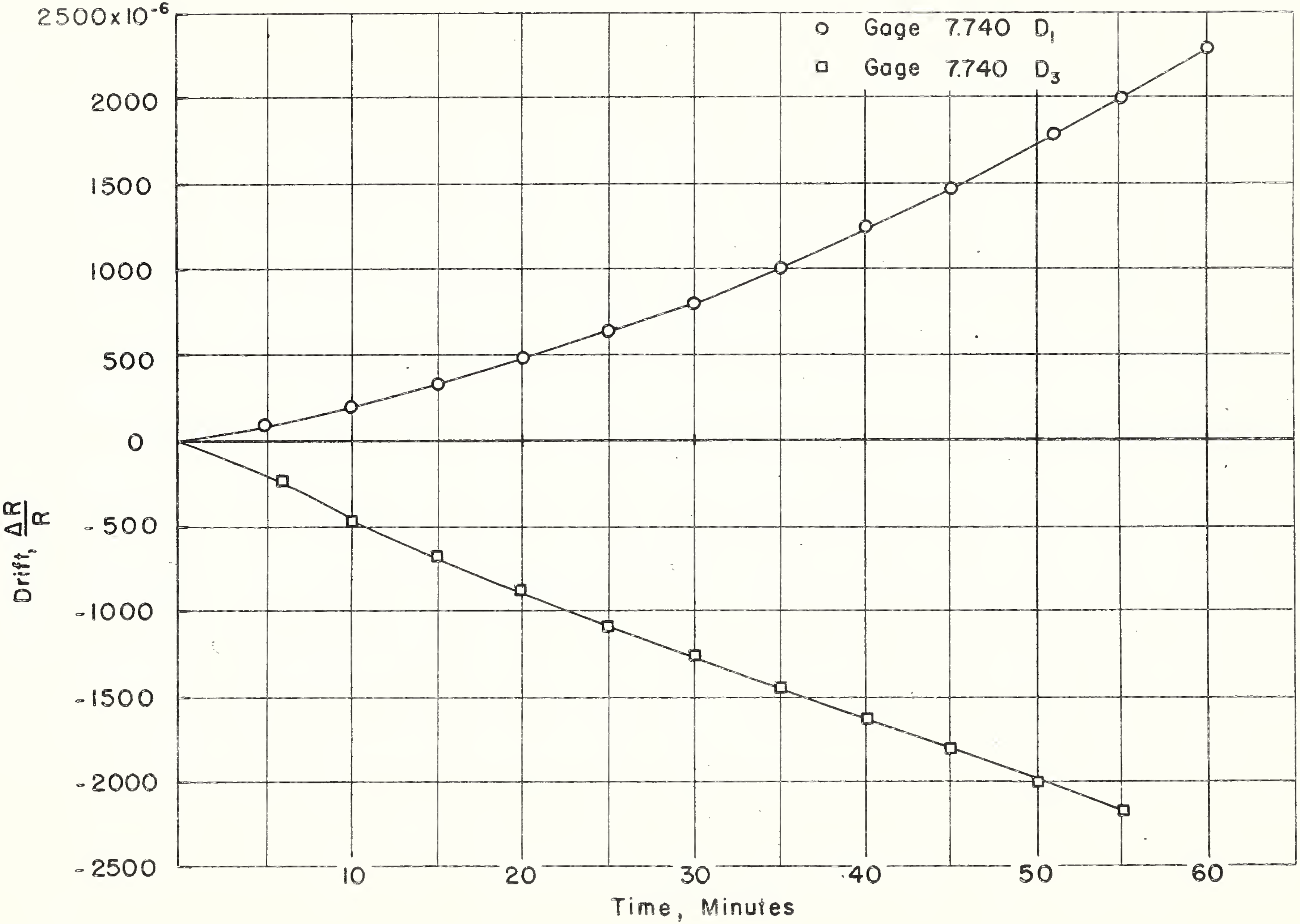

FIG. 18 Drift Behavior at 1500° F

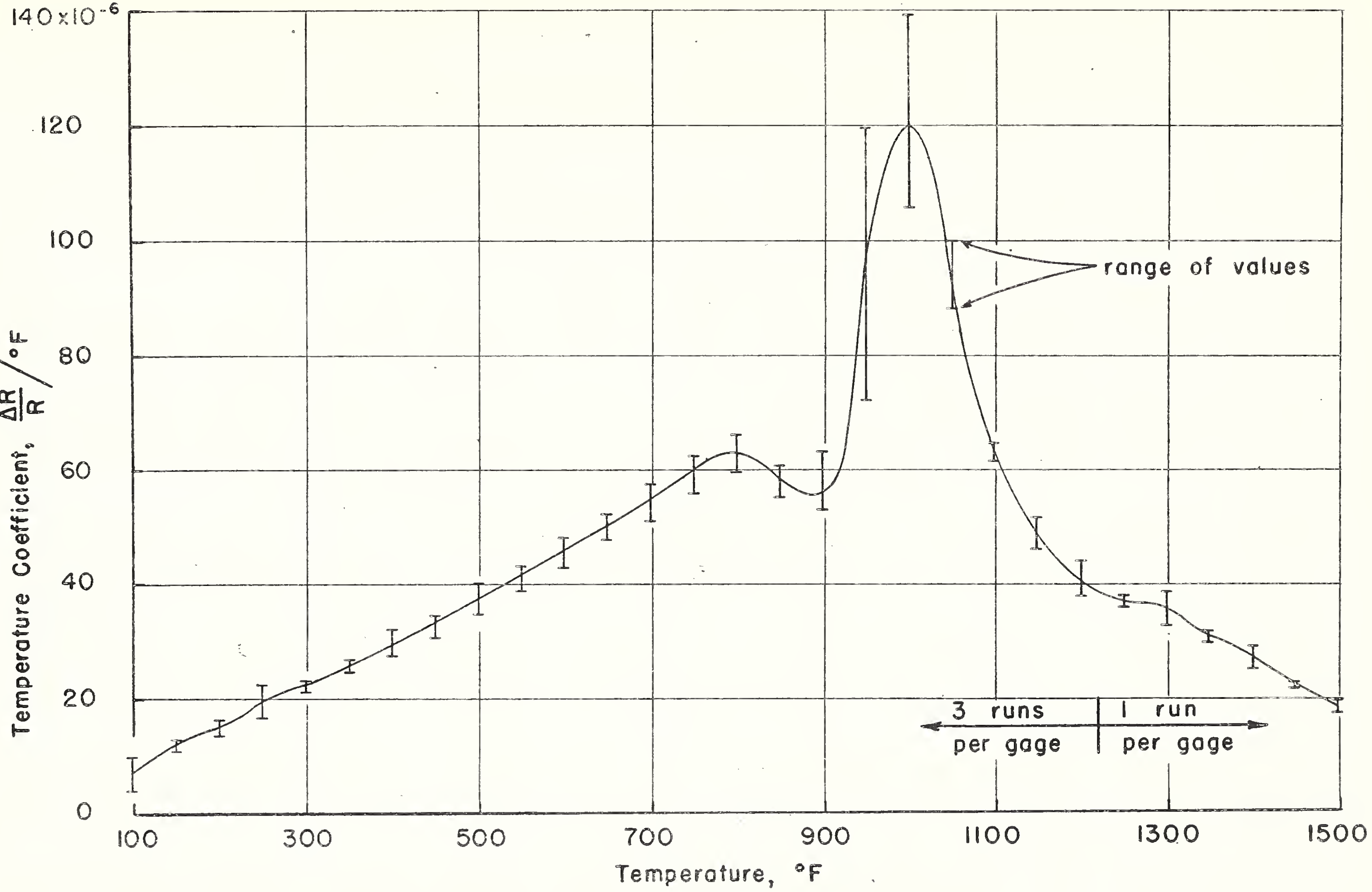

FIG. 19 Temperature Coefficient For Two Gages

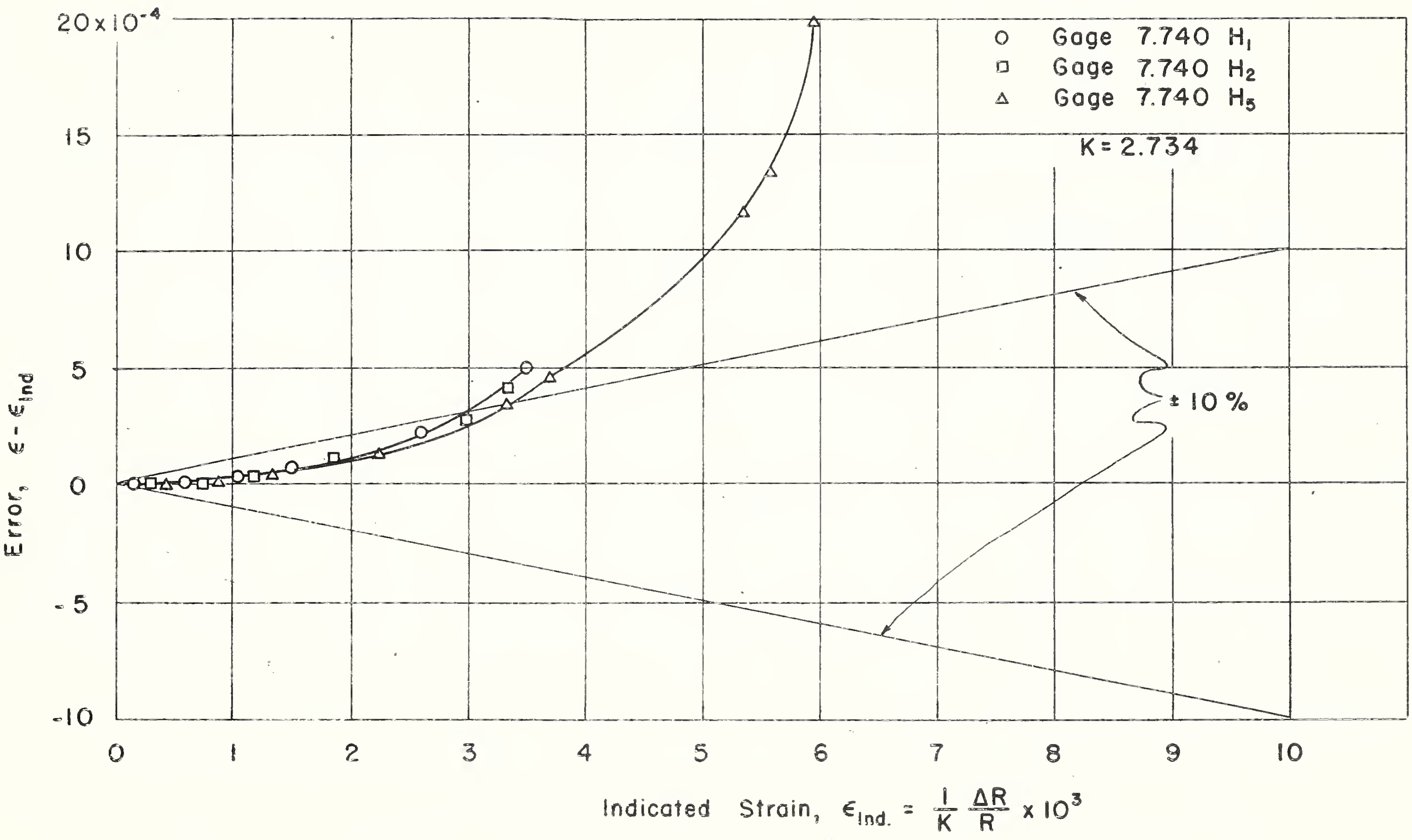

FIG. 20 Gage Behavior at Large Strains at 75°F

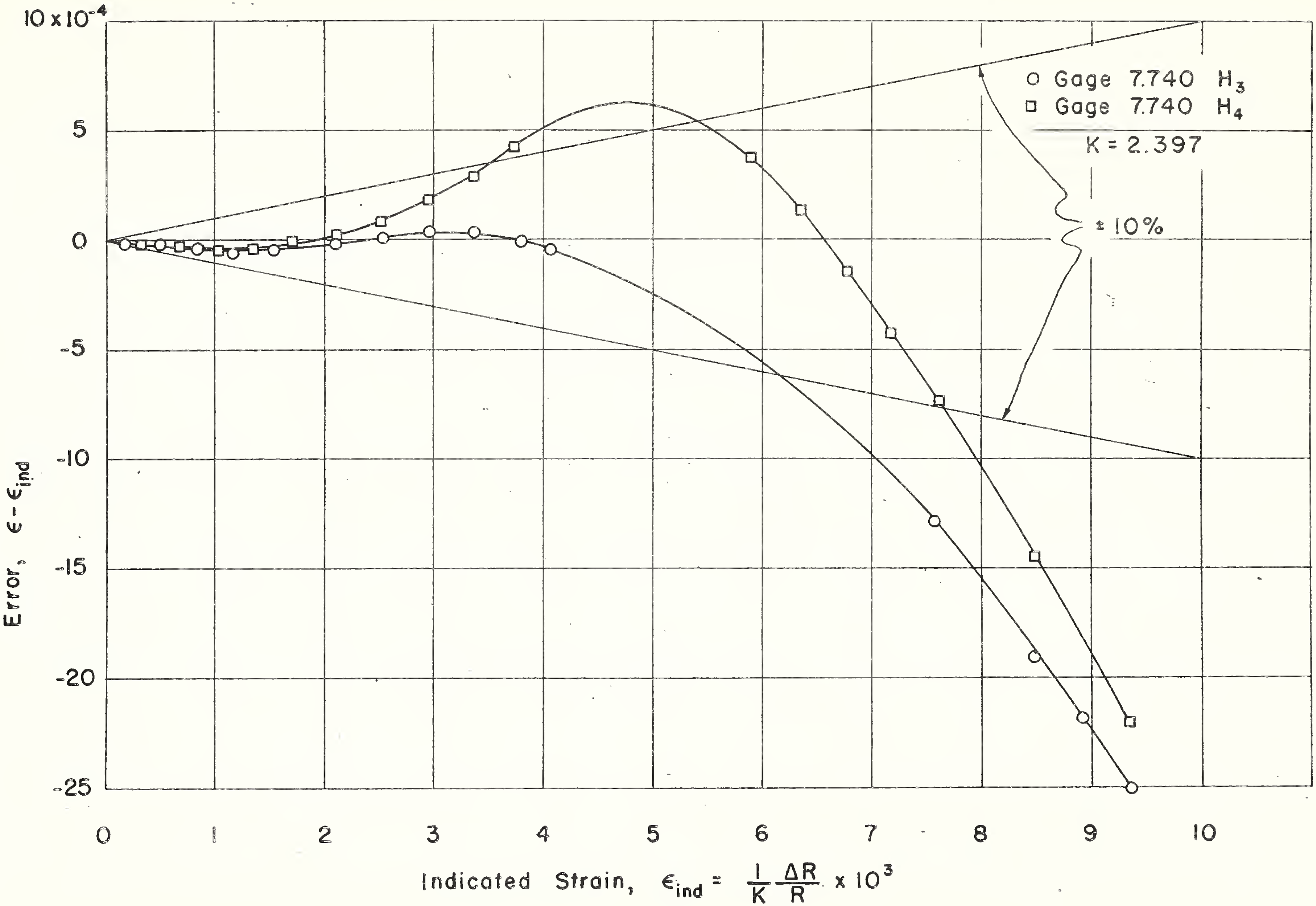

FIG. 21 Gage Behavior at Large Strains at 600°F

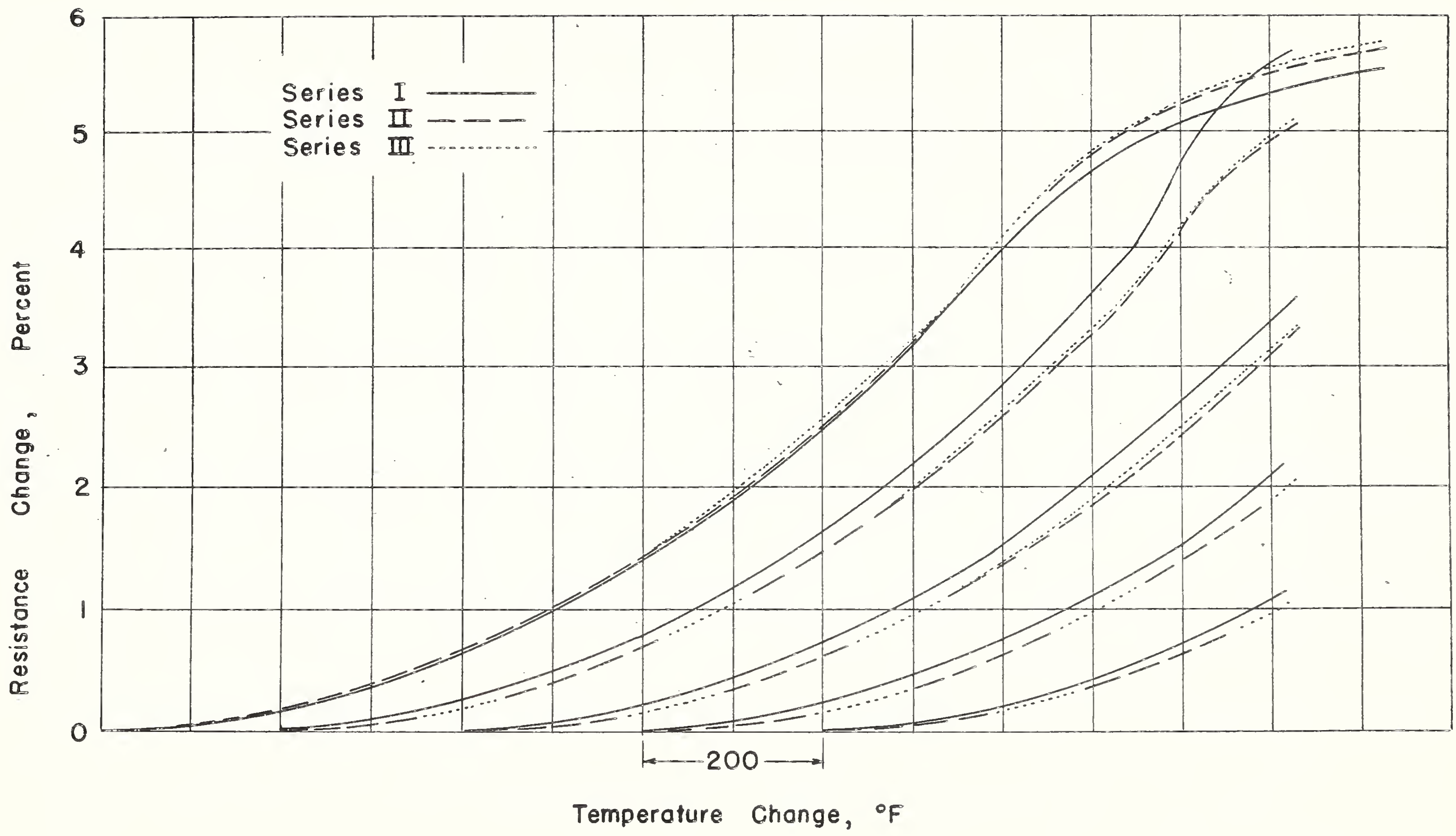

FIG. 22 Response of Gage 7.740 R_1 With Transient Heating

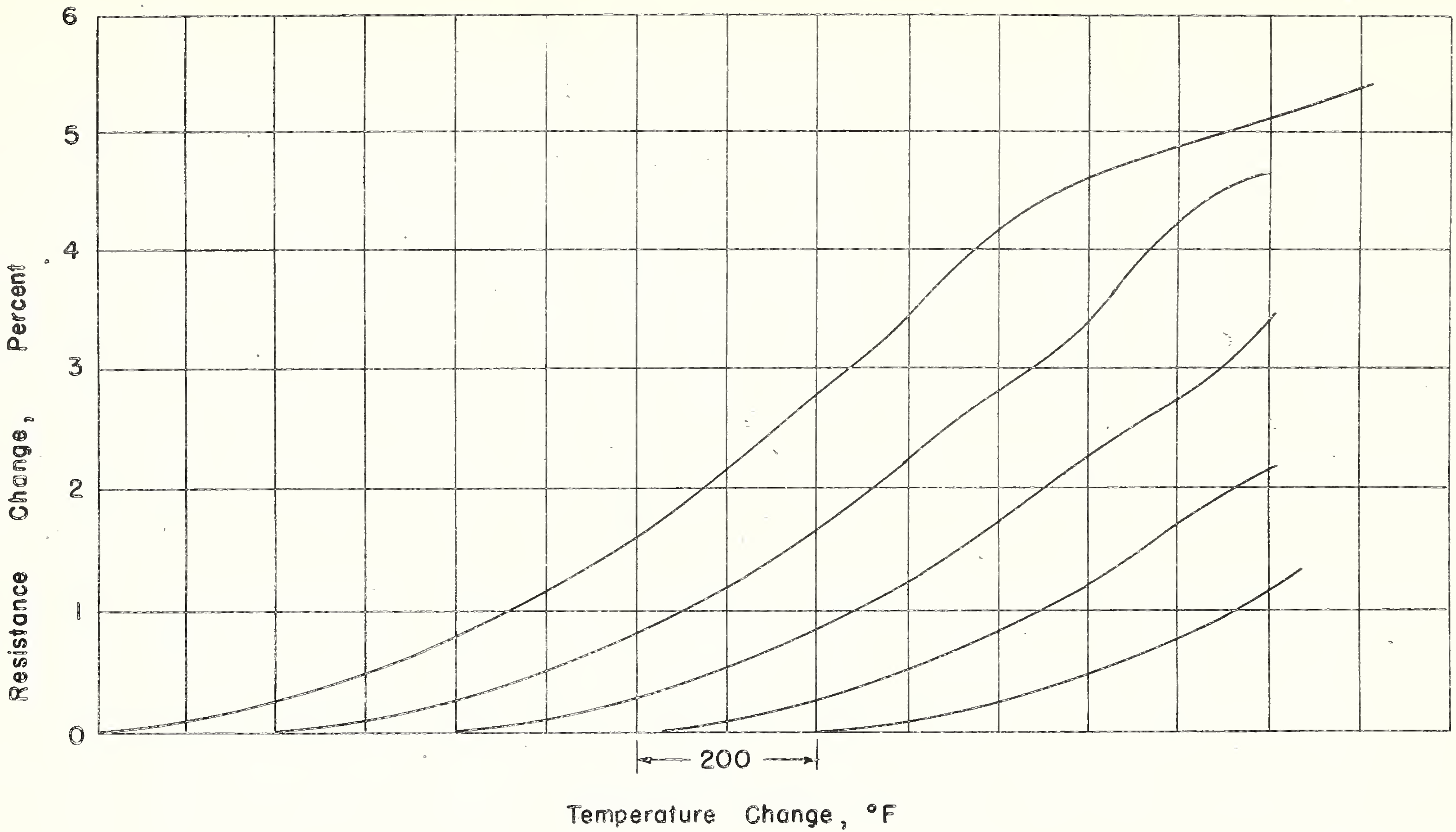

FIG. 23 Response of Gage 7.740 R_4 With Transient Heating

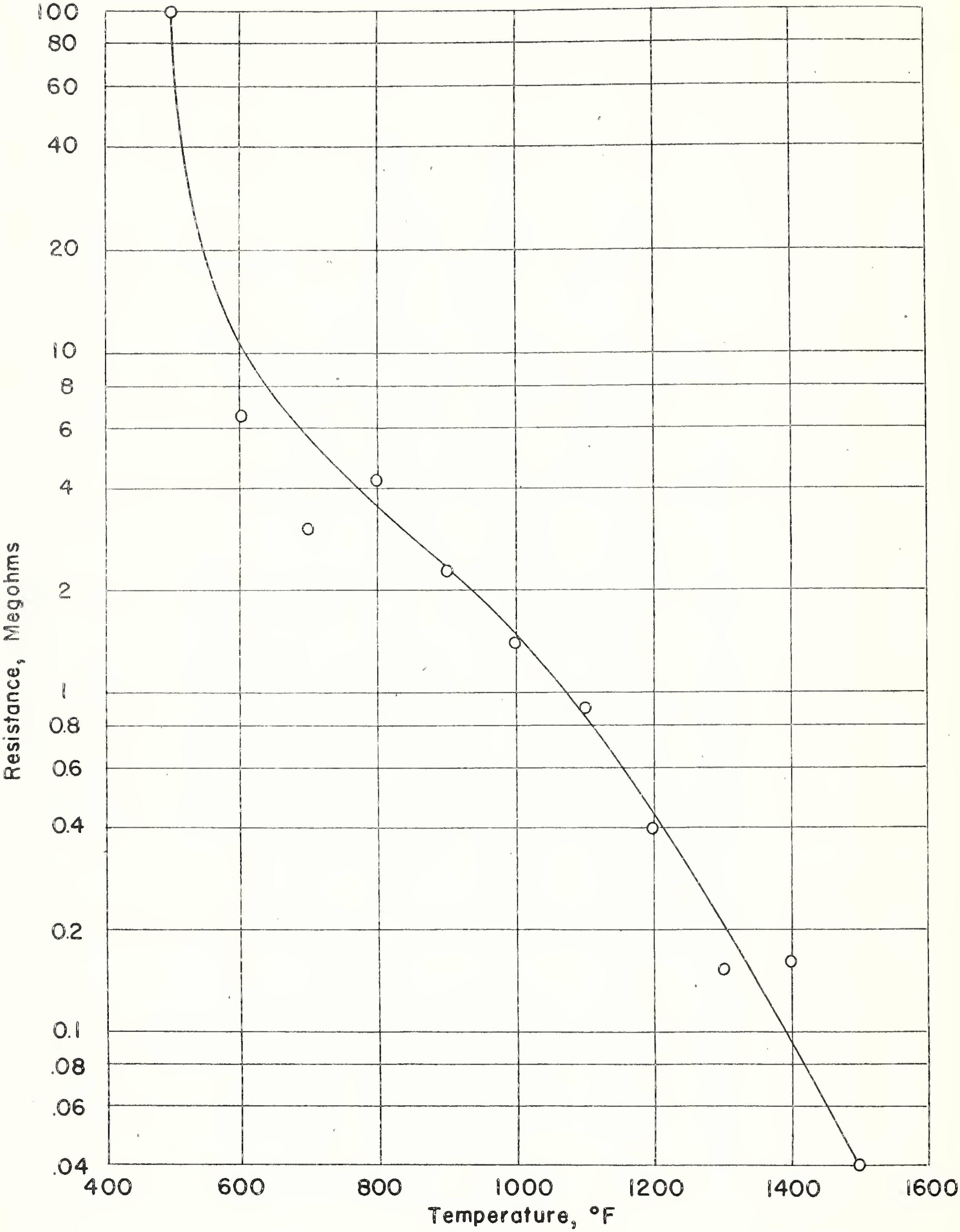

FIG. 24 Resistance Between Gage and Test Strip, Average for Two Gages

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Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

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Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

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Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

• Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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