NATIONAL BUREAU OF STANDARDS REPORT

7588

EVALUATION OF RESISTANCE STRAIN GAGES
AT ELEVATED TEMPERATURES

Progress Report No. 14

by

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

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Engineering Mechanics Section
Division of Mechanics

Technical Report

to

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U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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 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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Synopsis

Type P20 resistance strain gages, manufactured by the Shinkoh Communications Industry Co., Ltd. of Tokyo, Japan and sold in the United States by the Metrix Company, were evaluated at temperatures up to 400° F.

The results of these tests indicate that the gage factor at 75° F is within 3 percent of the manufacturer's nominal value; that the gage factor at elevated temperatures varies considerably from gage to gage; that the gages are able to sustain strains of 0.004 without failure at temperatures as high as 300° F; that the drift is low at temperatures as high as 400° F; that the temperature sensitivity is repeatable; and that the resistance to ground is a function of the thermal history of the gage.

1. INTRODUCTION

In the continuing evaluation of resistance strain gages designed for use at elevated temperatures, type P20 gages manufactured by the Shinkoh Communications Industry Co., Ltd. were subjected to tests at temperatures as high as 400° F. These gages were subjected to tests to determine the following characteristics:

(1) Gage factor at about 75°, 200°, 300°, and 400° F,

(2) Variation of gage factor with increasing temperature,

(3) Response of the gages when subjected to high strains,

(4) Change of gage resistance with time at a constant temperature,

(5) Resistance-temperature relationship,

(6) Resistance between the gage and the test strip as a function of temperature.

The results of previous evaluations of other gage types are given in references 1 through 12.

2. GAGE DESCRIPTION

The gages which are reported on herein are type P 20 purchased from the Metrix Company, representatives for the Shinkoh Communications Industry Co., Ltd., of Tokyo, Japan. These gages are a resistance wire type having a nominal gage length of 7/8 inch. The gages are mounted on a transparent polyester base. According to the vendor they are for use at temperatures up to 400° F.

The adhesive, type SP-3, is a two part, rapid cure type sold for use with the polyester base gages. According to the vendor, the cement does not require curing at an elevated temperature. The installation procedure followed is given in an appendix to this report.

3. TEST EQUIPMENT AND METHODS

The equipment and methods used for all evaluation tests have been described in references 5, 8, 12, 13, 14, and 15.

4. RESULTS AND DISCUSSION

The number of gages subjected to the various tests and the voltages applied to the test circuits are shown in table 1. The results of the evaluation tests are given in tables 2 through 5 and figures 1 through 23.

4.1 Strain Sensitivity

Gage factor values were obtained at nominal temperatures of 75°, 200°, 300°, and 400° F from five gages for a maximum strain of about 0.001 in tension and compression. Actual temperatures were within 5° F of the nominal values. These gage factor values are given in table 2 where:

K_u = gage factor for increasing load

K_d = gage factor for decreasing load

$\bar{K}$ = average of K_u and K_d.

The results from gages 10.1-A_3 at 300° F and 10.1-A_1, -A_3, and -A_4 at 400° F are not reported because of gage failure or results which indicate that the gage was separating from the specimen during the test. Upon examination after cooling, these gages were found to be separated from their specimens. Gages 10.1-A_1, -A_3, and -A_5 were tested in tension before being tested in compression. Gages 10.1-A_2 and 10.1-A_4 were tested in compression before being tested in tension except gage 10.1-A_4 at 200° F. All gages were tested completely at a particular temperature before being tested at the next higher temperature. The testing of gage 10.1-A_2 at room temperature was interrupted during the first test run in compression due to external disturbances, and a fourth test run with compression loading was subsequently carried out with this gage.

Figure 1 shows the differences between the experimentally determined gage factor values at 75° F and the manufacturer's nominal value. These differences are expressed as a percentage of the nominal value. Values for tensile loading are plotted on the abscissa, and values for compressive loading are plotted on the ordinate. Values for the first loading cycle are shown as solid symbols. The difference between the values determined during the test and the manufacturer's nominal value are shown by the departure of the points from the origin. Departure from the diagonal line indicates a difference between gage factor values for tensile and compressive loading. The figure shows that all values at room temperature are within 3 percent of the manufacturer's nominal value except for run 2 of gage 10.1-A_4 in compression, and that the variation between gages is greater than the run to run variation for one gage.

Figures 2 through 5 show the departure from linearity of the gage response and the zero shift for the first and third loading cycles. The maximum strain was about 0.001. Open symbols connected with a dashed line indicate increasing load, and solid symbols connected with a solid line are for decreasing load. The values plotted have been corrected for temperature fluctuations. Examination of the data and figures indicates that the difference between the actual strain and values computed using the nominal gage factor value, 2.08, did not exceed 30 x 10^{-6} except for the first tests of gages 10.1-A_1 and 10.1-A_2.

4.2 Variation of Gage Factor with Temperature

The variations of gage factor with increasing temperature obtained by dynamic test methods are shown in figures 6 through 11. Each curve of figures 6 through 9 represents the average change of gage factor of two gages which are mounted on opposite sides of a beam and connected in adjacent arms of a bridge circuit. Figure 10 shows the average of the first tests of all gages, an envelope which represents the extreme values obtained during the first tests of the different test specimens, average results obtained during the static gage factor test, and the extreme values obtained during the static test as indicated by the vertical lines. Figure 11 shows a similar plot for the averages and extreme values obtained during tests two through four with values obtained during static gage factor tests superimposed. These figures indicate that the results obtained during the first test to 400° F differ somewhat from the results obtained for subsequent tests of the same gage. These figures show fair agreement between the results obtained from static and dynamic tests. The results for both methods show considerable scatter. During the first dynamic test, the change in gage factor was less than 2 percent up to 300° F, but heating the installation to 400° F appeared to have a significant effect on the results of subsequent tests.

4.3 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 12 and 13. In order to determine the strain indicated by the gage, $\epsilon_{ind} = \frac{1}{K}\frac{\Delta R}{R}$, the value of K at 75° F was taken as the grand average of the values obtained in the room temperature gage factor tests. For the tests at 300° F the room temperature gage factor value was adjusted by the average amount of change determined during the first test runs of the variation of gage factor with temperature test.

Attempts to conduct similar tests at 400° F were not successful as the gages separated from the test bars before loads were applied.

At room temperature the gages showed errors less than 50×10^{-6} for strains up to about 0.004. The gages continued to function to strains greater than 0.008, although the errors became greater.

At 300° F the errors did not exceed five percent of the indicated value at strains below 0.004. The gradual increase in error might indicate that the cement was not transmitting the strain to the strain sensitive element properly.

4.4 Drift

Records of relative change of resistance with time for single gages at several test temperatures are shown in figures 14 through 18. These results were obtained after the gage installation had been heated to the desired test temperature at about 10° F per second from room temperature or the next lower test temperature. Recording was started one minute after the desired test temperature was reached. The second test run was made after the gage had been tested once at each test temperature up to 400° F. The temperature fluctuations during the 30 minute recording periods did not exceed ±2° F except for the first test runs of gage 10.1-D_1, at 200°, 250°, and 350° F and the second test run of gage 10.1-D_3 at 250° F. In no case did the fluctuations exceed ±5° F. No attempt was made to correct the data for temperature fluctuations. The gage installation and test strip had been painted black with a high temperature paint to increase emissivity.

The drift rate during any test did not exceed 10 parts per million resistance change per minute. The drift did not seem to be affected by the previous history of the installation. Significant resistance changes were caused by temperature fluctuations. All gages remained bonded to their specimens upon completion of the drift test.

4.5 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 parts "A" and "B" of figure 19. Part "C" of figure 19 shows the difference between the average values for the two gages.

The curves from which temperature coefficient values were obtained are reproduced in figures 20 and 21. These results were obtained while the gage installation was heated at about 2° F per second by recording the relative change of gage resistance as a function of test strip temperature. An apparent instability of gage resistance at temperatures above 300° F during the first test is shown by both gages. This apparent instability may be due to characteristics of the cement.

4.6 Leakage Resistance

The resistance between the gage and the test strip as a function of temperature is shown in figures 22 and 23. The test strip was heated at about 2° F per second to the maximum test temperature. Prior to these tests, the test strips and gage installations were painted with a high temperature black paint.

The results indicate that the leakage resistance at elevated temperatures is increased by thermal cycling and that this resistance is erratic during the first heating cycle above 300° F.

5. CONCLUSIONS

For gages of this type, the data obtained from the evaluation tests covered by this report indicate that:

(1) Gage factor values determined experimentally at 75° F are in reasonable agreement with the manufacturer's nominal value. Of 60 determinations, 5 differed from the nominal value by more than 2 percent and 2 differed from the nominal value by more than 3 percent.

(2) The gage resistance is a nearly linear function of strain for strains up to 0.004 at 75° F. Departures from linearity did not exceed 50×10^{-6}.

(3) There is considerable scatter in gage factor values at elevated temperatures. Variations greater than 8 percent from average values were observed.

(4) The drift rate at temperatures up to 400° F is low. No value as high as 10 parts per million resistance change per minute was observed.

(5) The temperature sensitivity of a gage is repeatable. Average values obtained from two gages agreed within 1.5 parts per million resistance change per degree Fahrenheit.

(6) The resistance between the gage and the test strip decreases rapidly during the first heating cycle above 150° F. The leakage resistance is greatly increased by thermal cycling to 400° F.

Washington, D. C.
August 1962

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APPENDIX

The strain gages tested for this report were installed on 2024 aluminum alloy and type 302 stainless steel. Prior to gage installation all test pieces were heat treated to eliminate residual strains. The procedures were as follows:

A. Surface Preparation

1. The area where the gage was to be located was cleaned and roughened with No. 0 abrasive cloth.

2. The surface was cleaned by wiping with trichlorethylene on a gauze square.

3. Step 2 was repeated until the gauze remained clean.

B. Cement Preparation

1. A measured quantity of cement powder, usually 1 gram, was placed in the plastic cup furnished with the cement kit.

2. An appropriate amount of the liquid component (see Note below) was added to the powder.

3. The powder and liquid components were mixed together thoroughly and rapidly with a small wooden rod. Mixing was continued for about 1 minute.

Note: The original instructions from the vendor stated that the mixing ratio recommended for most work is 1.0 (liquid/powder). Since it was stated that a kit contained 20 cm^3 of each component and no units were given for the ratio, it was assumed that equal parts by volume were intended. Experience had shown that the mass of powder for a given volume can vary considerably depending upon the degree of compaction. The powder from two kits was therefore weighed and the mass per unit volume determined from the average weight, assuming each kit to contain 20 cm^3. The weights of the powder from the two kits differed by 25 percent of the average weight. The computed density was 1.0 gram/cm^3. The mixture of 1 gram of powder and 1 cm^3 of liquid was found to set in about 10 minutes instead of the 18 minutes indicated in the instructions. In correspondence the vendor stated that the instruction sheet should state "equivalent amount by weight of liquid and powder."

It was also indicated that an excess of liquid would only increase the setting time but an excess of powder could impair the bond strength. The mixing ratio was therefore changed to 1 gram of powder to 2 cm^3 of liquid. This ratio gave a setting time of about 20 minutes.

C. Gage Installation

1. The gage was placed in the desired position on the prepared surface.

2. Adhesive tape (3M No. 810) was placed along the test strip and over the gage. The tape was then rolled back so as to lift the gage from the surface. A loop formed with the tape held the gage so that it could be easily placed in the desired position after the cement was applied.

3. The back of the gage and the prepared surface were wiped with trichlorethylene on a gauze pad.

4. Cement was applied to the prepared surface and to the back of the gage.

5. The tape loop was cut and the tape extended so as to place the gage in the desired position. Excess cement was squeezed out by finger pressure on top of the tape.

6. A sponge rubber pad was placed over the gage area and a clamping pressure of about 10 psi was applied for at least 20 minutes.

7. The pressure, rubber pad and tape were removed leaving the installed gage.

8. Electrical connections were made to the gage by soldering or spot welding.

Table 1 - Number of Gages Tested and Circuit Voltage

Type of Test	No. of gages tested	Electrical input to circuit volts, d-c
Gage factor determination	5	3
Variation of gage factor with temperature	8	6
High strain	6	3*
Resistance instability (drift)	3	5
Temperature sensitivity	2	5
Leakage resistance	2	10

*a-c (1000 cps)

Table 2 - Gage Factor Values at 75° F

Gage No.	Run No.	Tension K_u	Tension K_d	Tension $\bar{K}$	Compression K_u	Compression K_d	Compression $\bar{K}$
10.1-A_1	1	2.014	2.092	2.053	2.048	2.020	2.034
	2	2.066	2.069	2.068	2.052	2.043	2.048
	3	2.053	2.077	2.065	2.074	2.034	2.054
	Average	2.044	2.079	2.062	2.058	2.032	2.045
10.1-A_2	1	2.022	2.081	2.052	(a)	(a)	(a)
	2	2.057	2.084	2.070	2.082	2.073	2.078
	3	2.058	2.076	2.067	2.084	2.086	2.085
	4	-	-	-	2.086	2.084	2.085
	Average	2.046	2.080	2.063	2.084	2.081	2.083
10.1-A_3	1	2.077	2.093	2.085	2.070	2.088	2.079
	2	2.094	2.095	2.094	2.088	2.086	2.087
	3	2.087	2.085	2.086	2.096	2.097	2.096
	Average	2.086	2.091	2.088	2.085	2.090	2.087
10.1-A_4	1	2.064	2.075	2.070	2.100	2.046	2.073
	2	2.076	2.093	2.084	2.454	2.065	2.260
	3	2.086	2.084	2.085	2.118	2.072	2.095
	Average	2.075	2.084	2.080	2.224	2.061	2.143
10.1-A_5	1	2.051	2.068	2.060	2.052	2.066	2.059
	2	2.073	2.064	2.068	2.060	2.064	2.062
	3	2.059	2.064	2.062	2.070	2.067	2.068
	Average	2.061	2.065	2.063	2.061	2.066	2.063

(a) External disturbances during test caused invalid results.

Table 3 - Gage Factor Values at 200° F

Gage No.	Run No.	Gage Factor Values					
		Tension			Compression		
		K_u	K_d	$\bar{K}$	K_u	K_d	$\bar{K}$
10.1-A_1	1	2.075	2.094	2.084	2.117	2.050	2.084
	2	2.078	2.066	2.072	2.084	2.094	2.089
	3	2.092	2.095	2.094	2.072	2.099	2.086
	Average	2.082	2.085	2.083	2.091	2.081	2.086
10.1-A_2	1	1.982	2.121	2.052	2.086	1.982	2.034
	2	2.070	2.084	2.077	2.096	2.065	2.080
	3	2.083	2.082	2.082	1.997	2.074	2.036
	Average	2.045	2.096	2.070	2.060	2.040	2.050
10.1-A_3	1	2.076	2.087	2.082	2.100	2.116	2.108
	2	2.098	2.078	2.088	2.118	2.125	2.122
	3	2.089	2.090	2.090	2.118	2.115	2.116
	Average	2.088	2.085	2.087	2.112	2.119	2.115
10.1-A_4	1	2.087	2.098	2.092	2.103	2.086	2.094
	2	2.100	2.098	2.099	2.093	2.080	2.086
	3	2.097	2.095	2.096	2.029	1.999	2.014
	Average	2.095	2.097	2.096	2.075	2.055	2.065
10.1-A_5	1	2.076	2.090	2.083	2.090	2.104	2.097
	2	2.065	2.082	2.074	2.099	2.089	2.094
	3	2.119	2.092	2.106	2.100	2.097	2.098
	Average	2.087	2.088	2.088	2.096	2.097	2.096

Table 4 - Gage Factor Values at 300° F

Gage No.	Run No.	Gage Factor Values: Tension K_u	K_d	$\overline{K}$	Compression K_u	K_d	$\overline{K}$
$10.1\text{-}A_1$	1	1.967	2.113	2.040	2.004	2.025	2.014
	2	2.013	2.109	2.061	1.988	1.982	1.985
	3	2.007	2.006	2.007	2.016	1.988	2.002
	Average	1.996	2.076	2.036	2.003	1.998	2.000
$10.1\text{-}A_2$	1	2.039	2.124	2.082	2.079	2.134	2.106
	2	2.092	2.108	2.100	2.078	2.109	2.094
	3	2.103	2.106	2.104	2.109	2.100	2.104
	Average	2.078	2.113	2.095	2.089	2.114	2.101
$10.1\text{-}A_3$	1						
	2			Gage failed			
	3						
	Average						
$10.1\text{-}A_4$	1	2.082	2.140	2.111	2.096	2.092	2.094
	2	2.084	2.109	2.096	2.107	2.098	2.102
	3	1.964	2.017	1.990	2.090	2.078	2.084
	Average	2.043	2.089	2.066	2.098	2.089	2.093
$10.1\text{-}A_5$	1	2.071	2.124	2.098	2.091	2.117	2.104
	2	2.098	2.102	2.100	2.074	2.079	2.076
	3	2.097	2.087	2.092	2.096	2.083	2.090
	Average	2.089	2.104	2.097	2.087	2.093	2.090

Table 5 - Gage Factor Values at 400° F

		Gage Factor Values					
		Tension			Compression		
Gage No.	Run No.	K_u	K_d	$\bar{K}$	K_u	K_d	$\bar{K}$
$10.1\text{-}A_1$	1						
	2			Gage failed			
	3						
	Average						
$10.1\text{-}A_2$	1	1.983	2.080	2.032	2.164	2.124	2.144
	2	2.055	2.077	2.066	2.246	2.002	2.124
	3	2.069	2.083	2.076	2.038	2.086	2.062
	Average	2.036	2.080	2.058	2.149	2.071	2.110
$10.1\text{-}A_3$	1						
	2			Gage failed			
	3						
	Average						
$10.1\text{-}A_4$	1						
	2			Gage failed			
	3						
	Average						
$10.1\text{-}A_5$	1	2.006	2.182	2.094	2.010	2.012	2.011
	2	2.063	2.031	2.047	2.068	2.049	2.058
	3	2.019	2.073	2.046	2.077	2.057	2.067
	Average	2.029	2.095	2.062	2.052	2.039	2.045

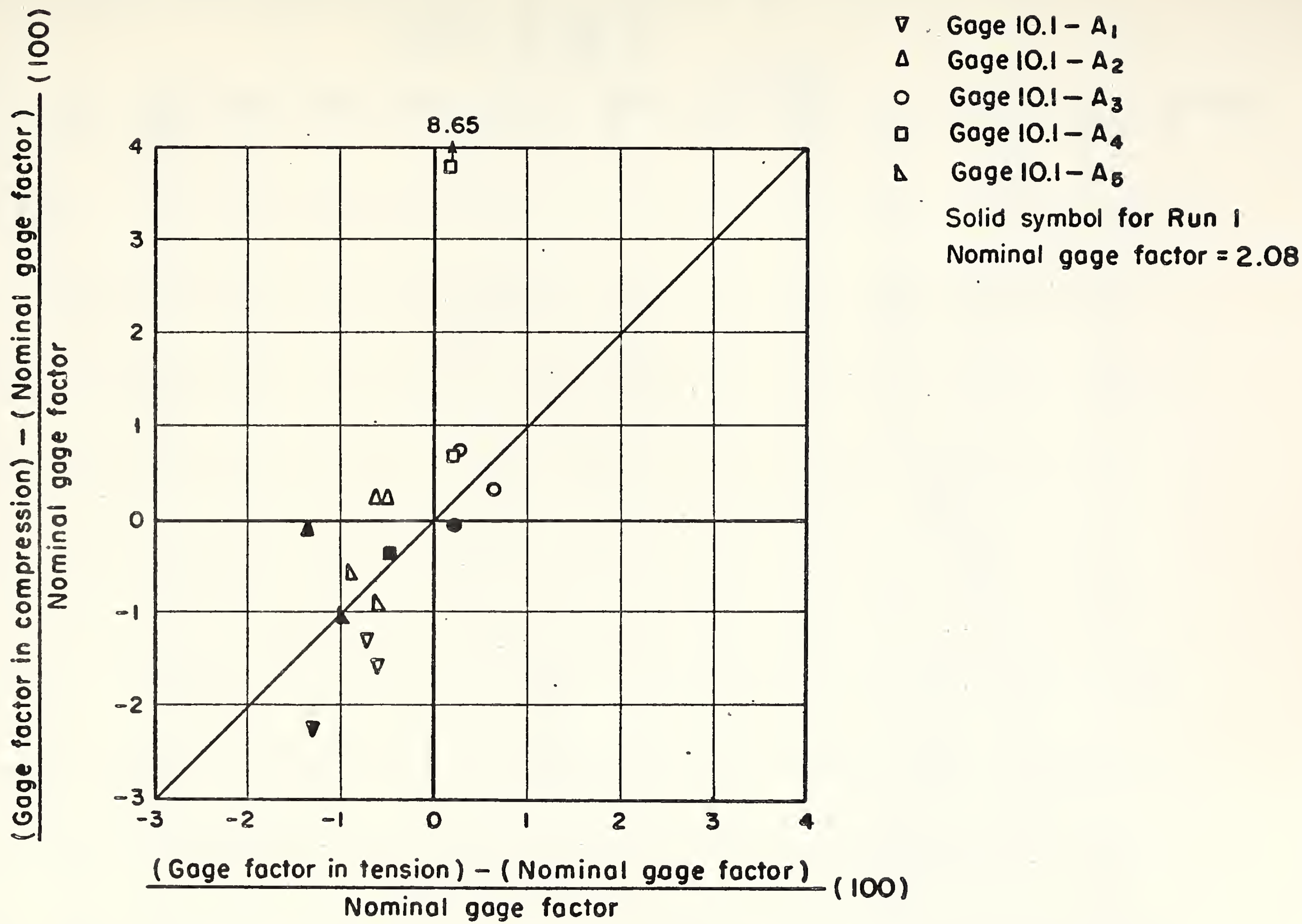

Fig. 1 Gage factor deviation at 75°F

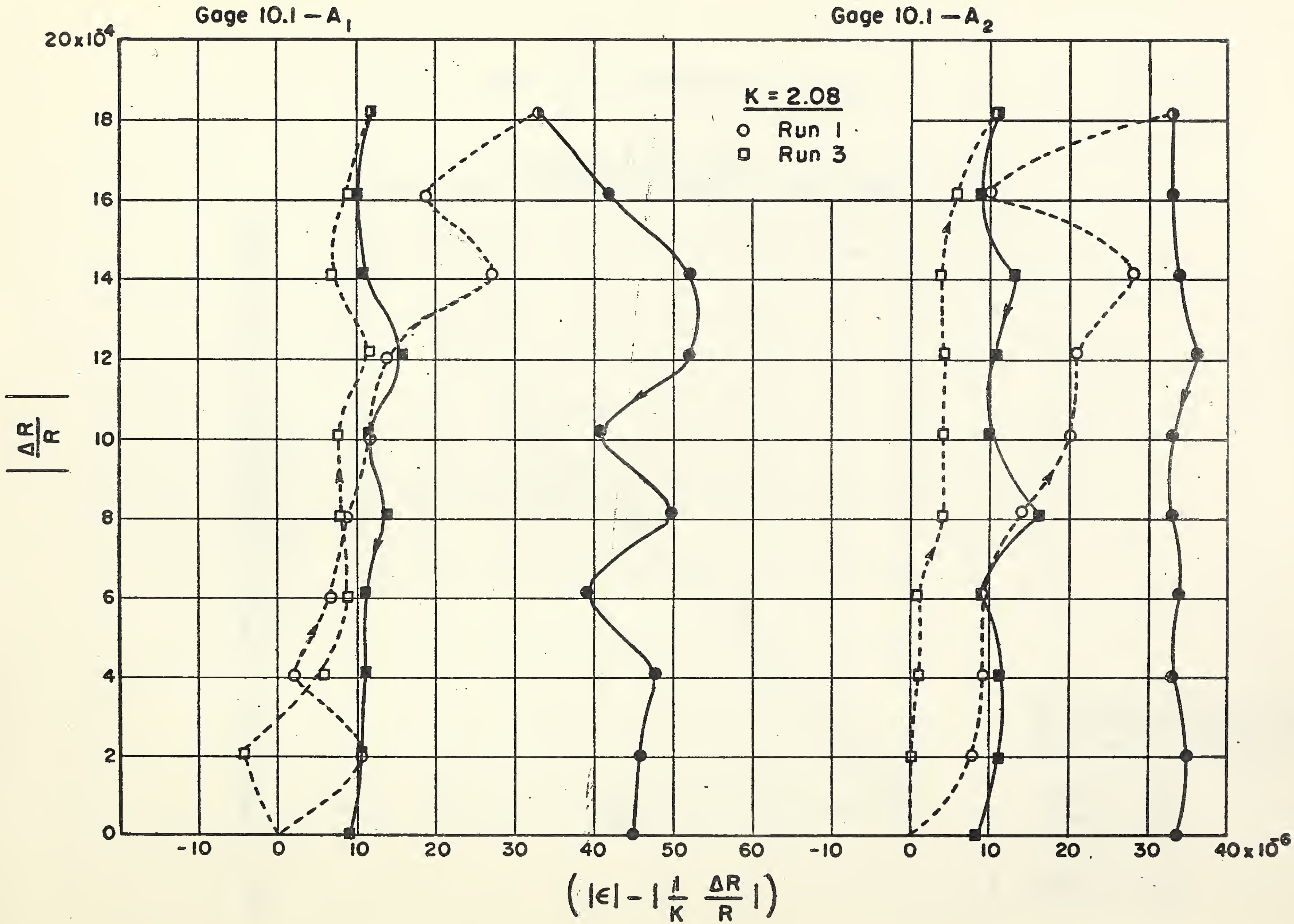

Fig. 2 Strain deviation for tension loading at 75° F

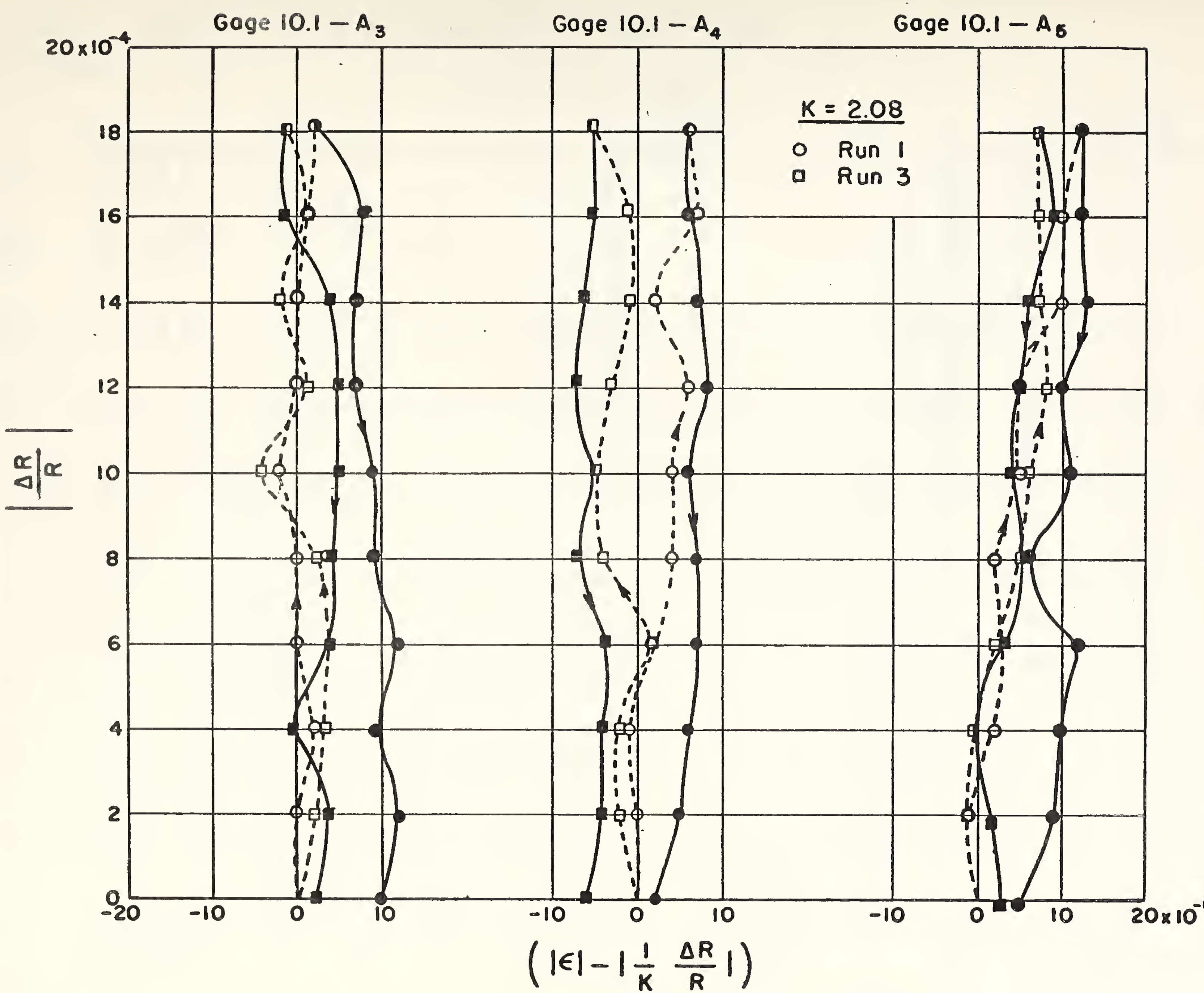

Fig. 3 Strain deviation for tension loading at 75° F

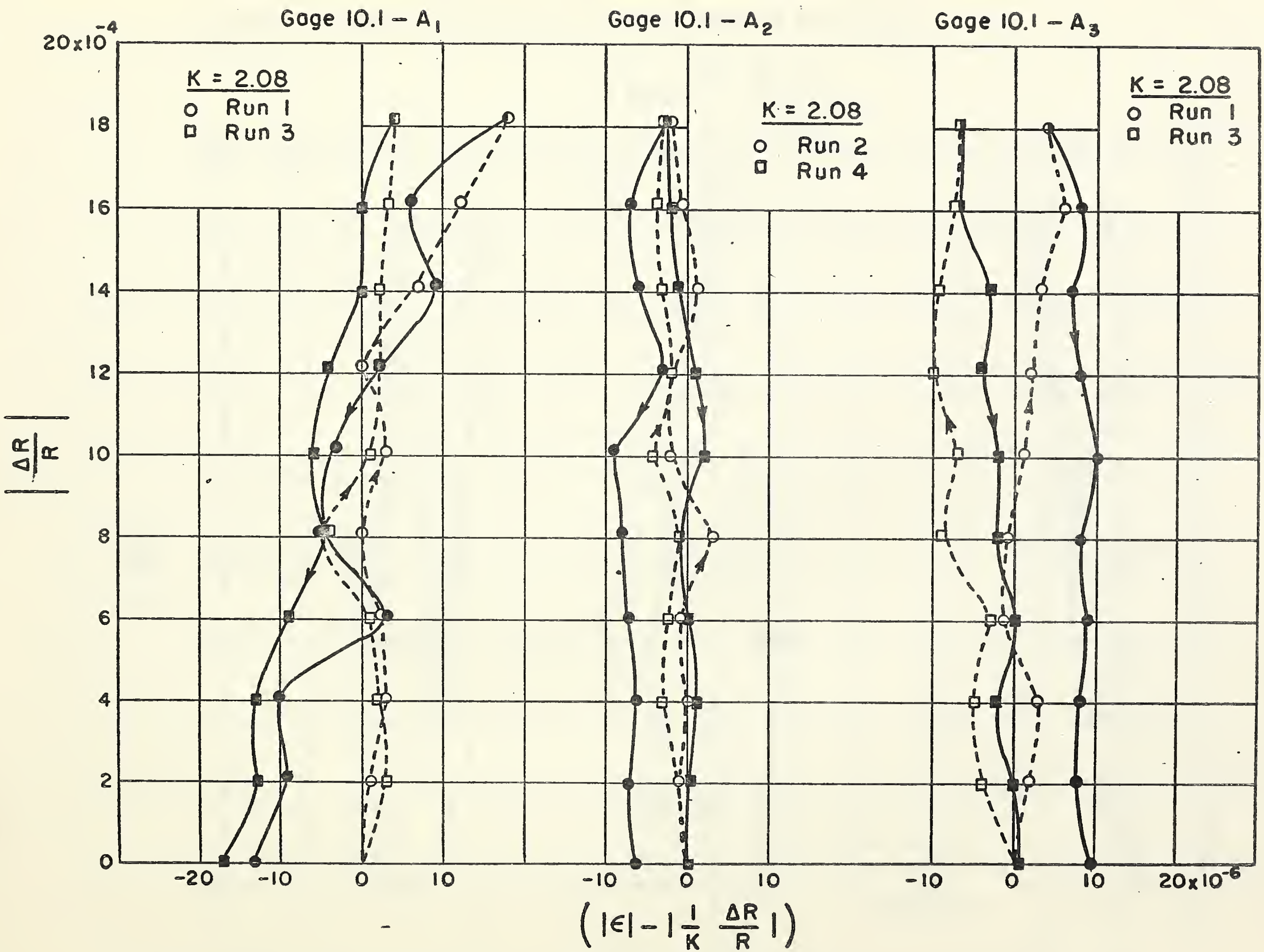

Fig. 4 Strain deviation for compression loading at 75 °F

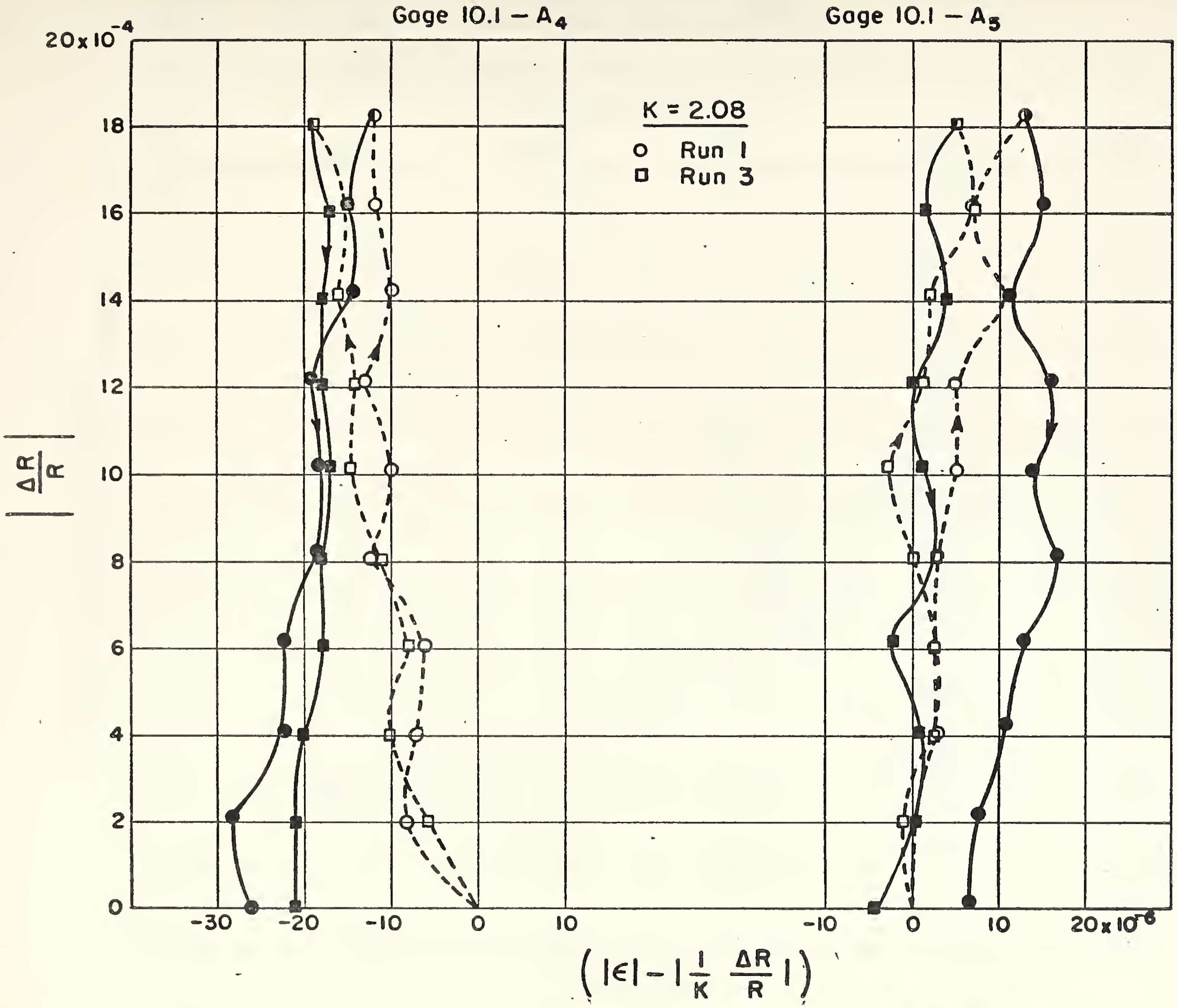

Fig. 5 Strain deviation for compression loading at 75 °F

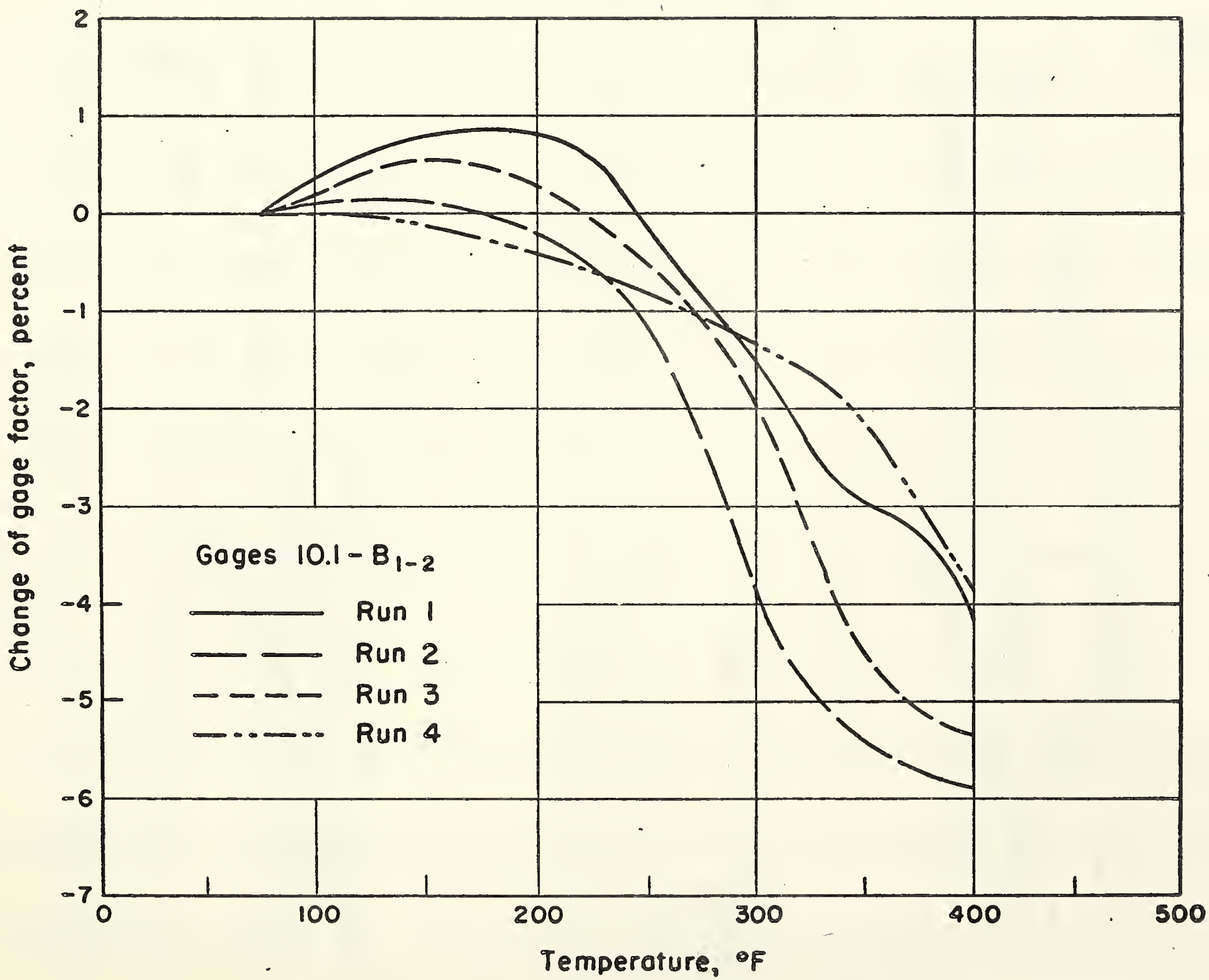

Fig. 6 Variation of gage factor with temperature

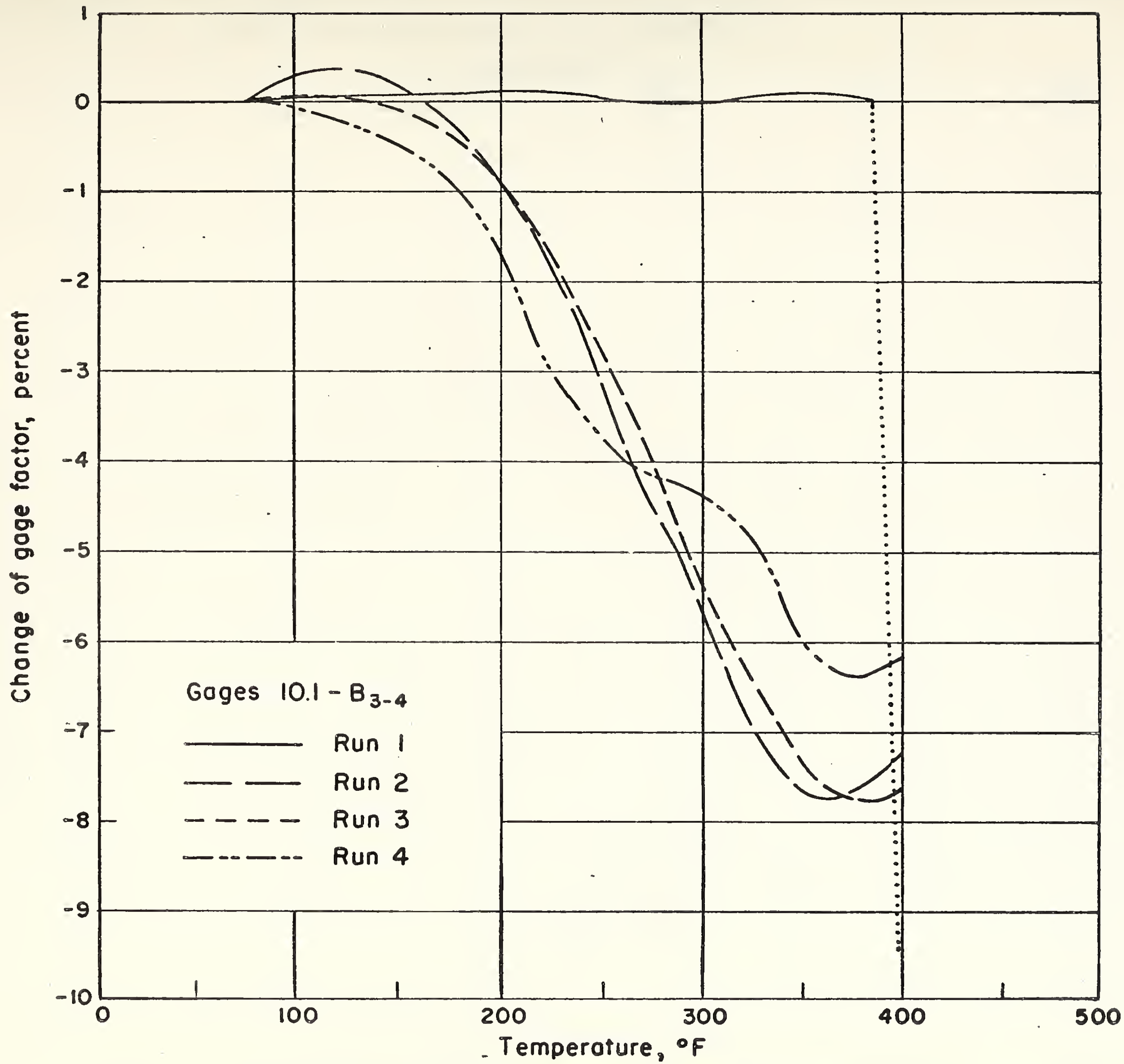

Fig. 7 Variation of gage factor with temperature

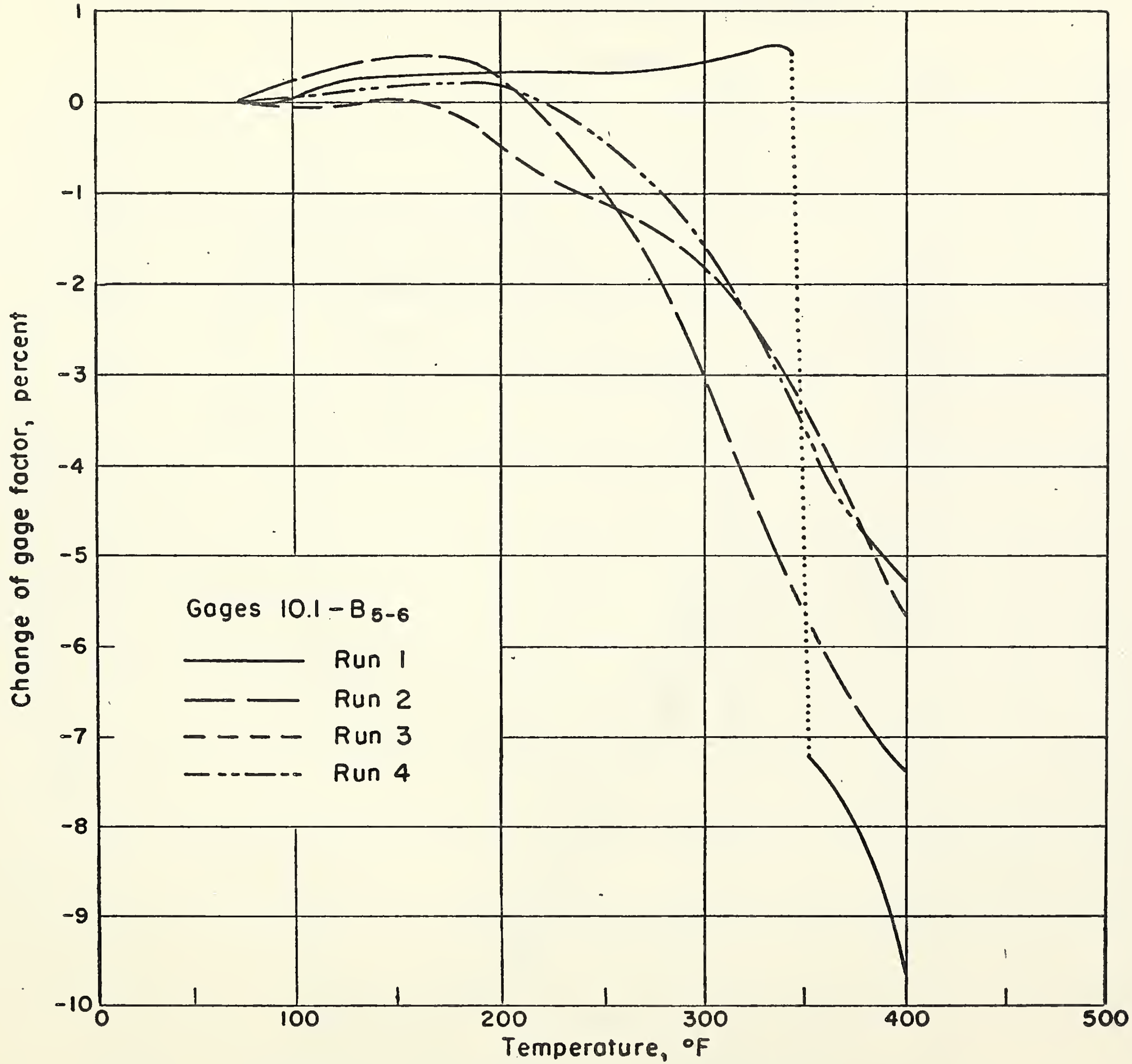

Fig. 8 Variation of gage factor with temperature

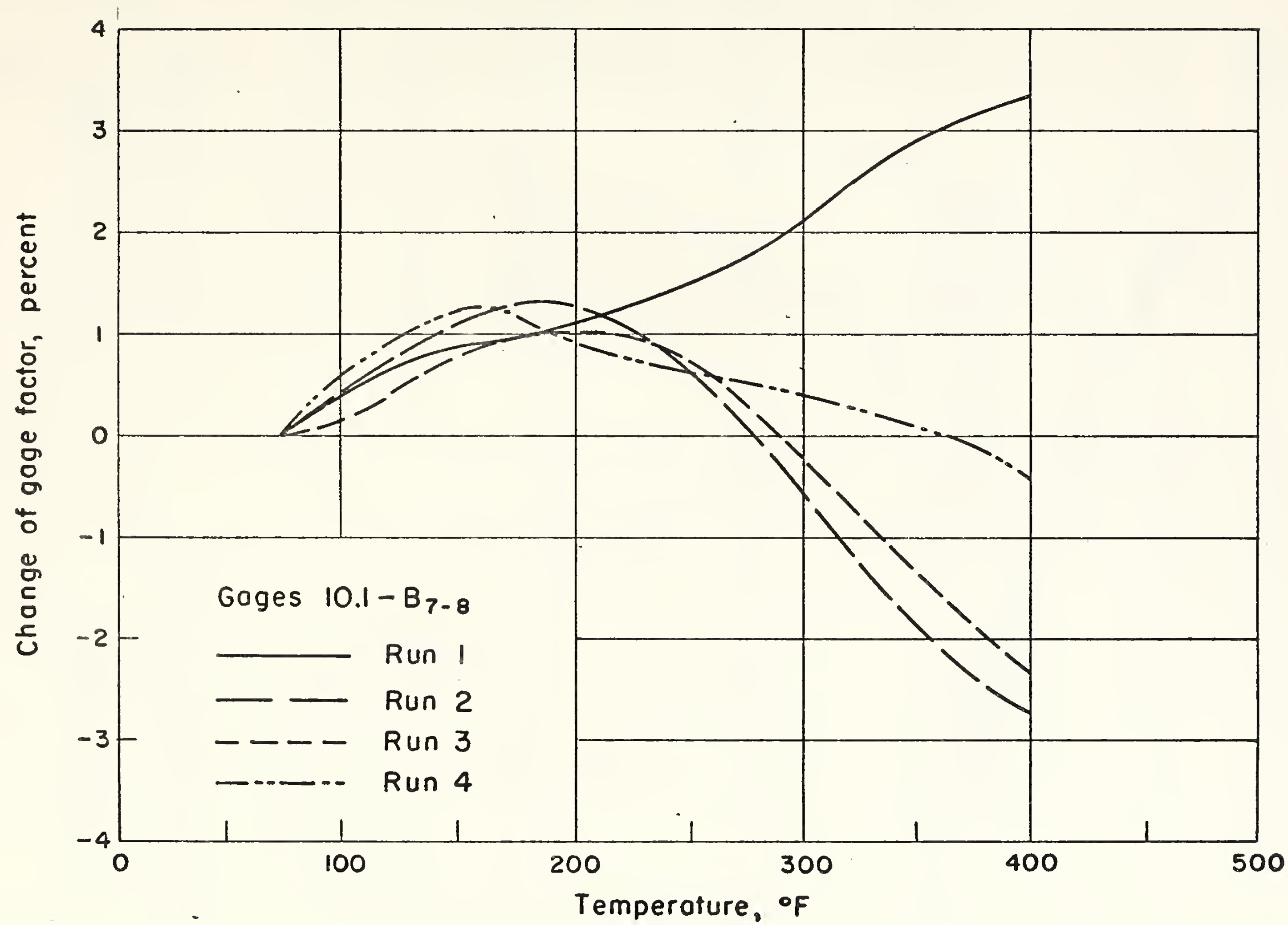

Fig. 9 Variation of gage factor with temperature

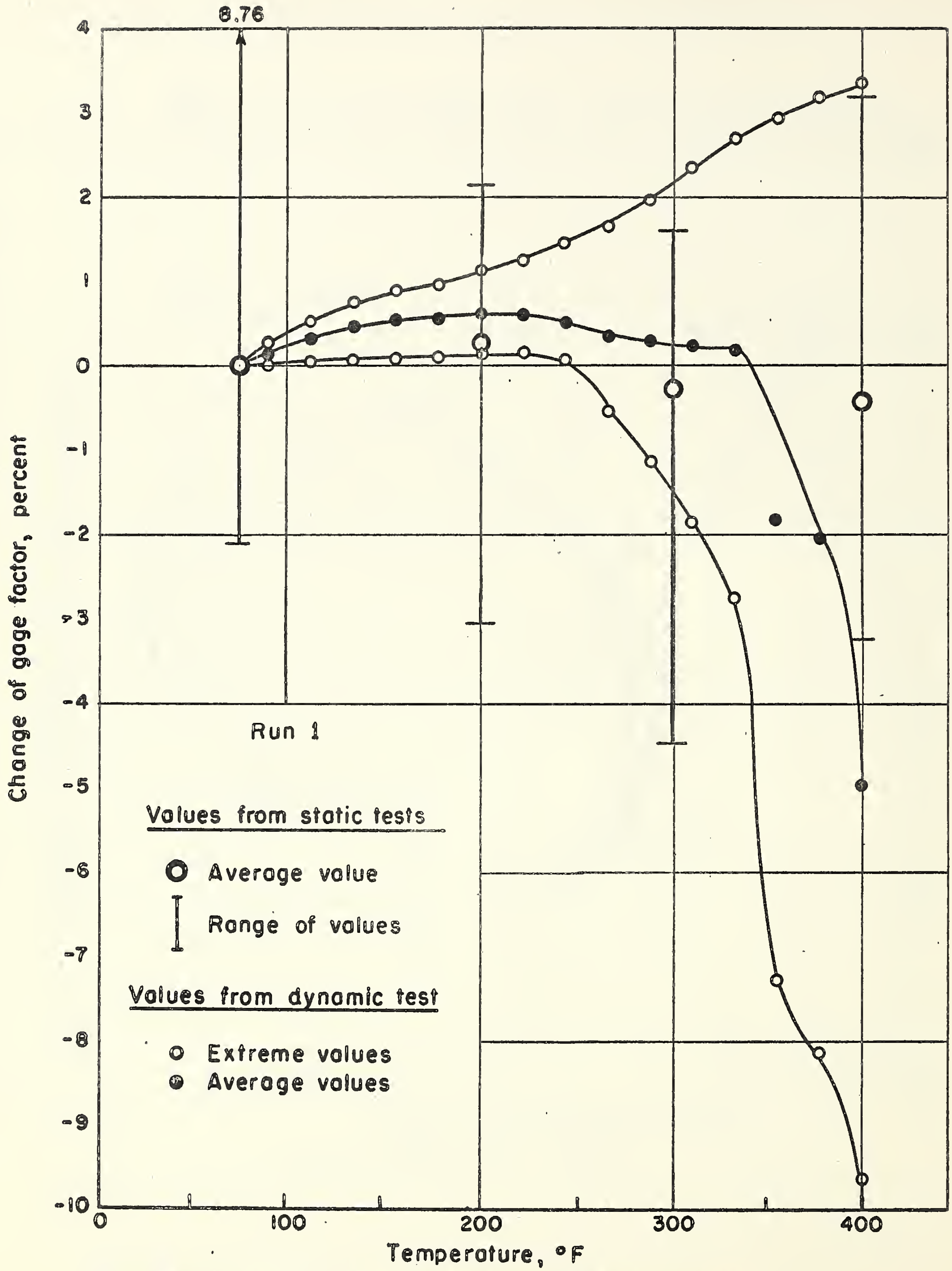

Fig. 10 Variation of gage factor with temperature

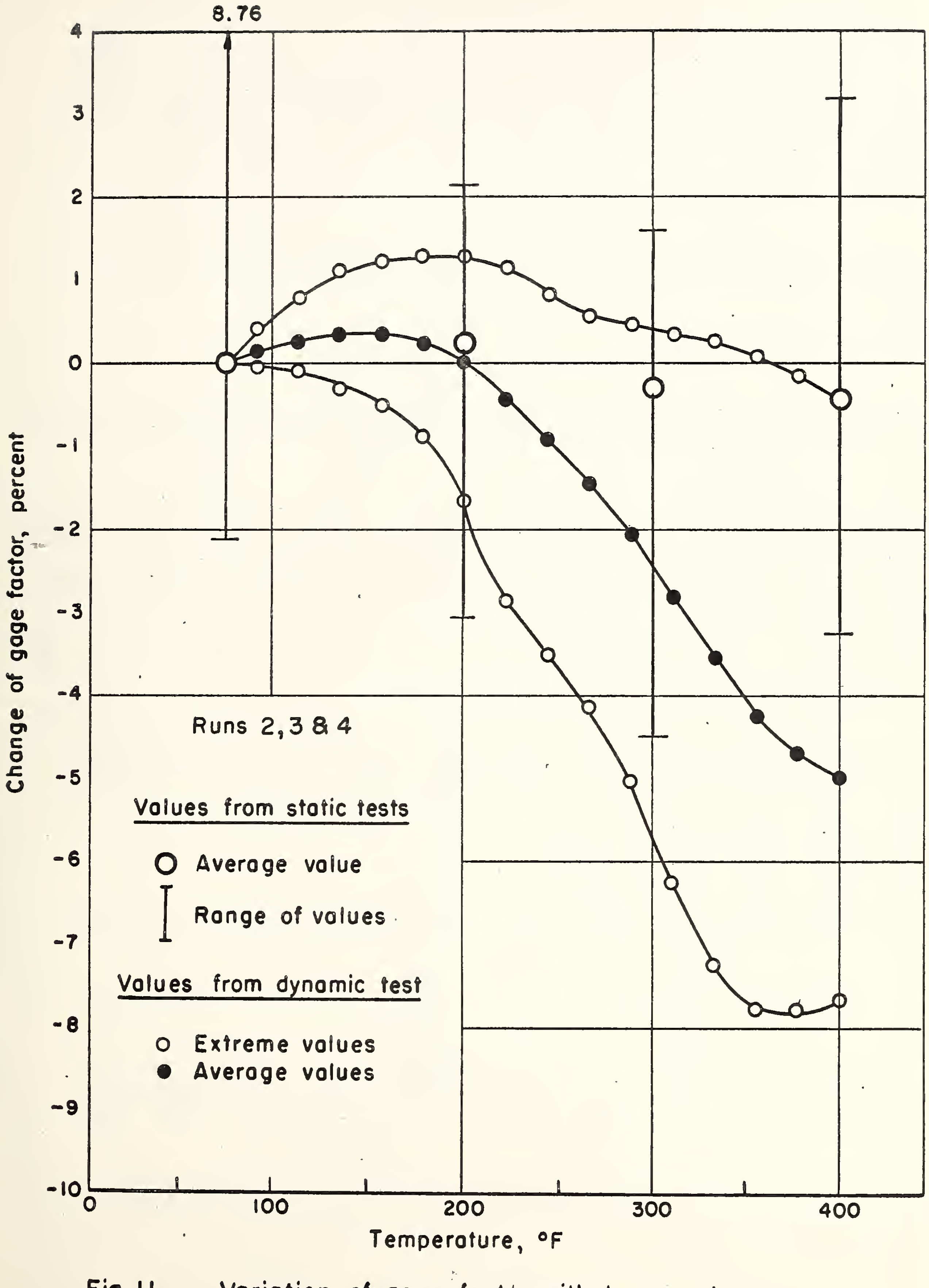

Fig. 11 Variation of gage factor with temperature

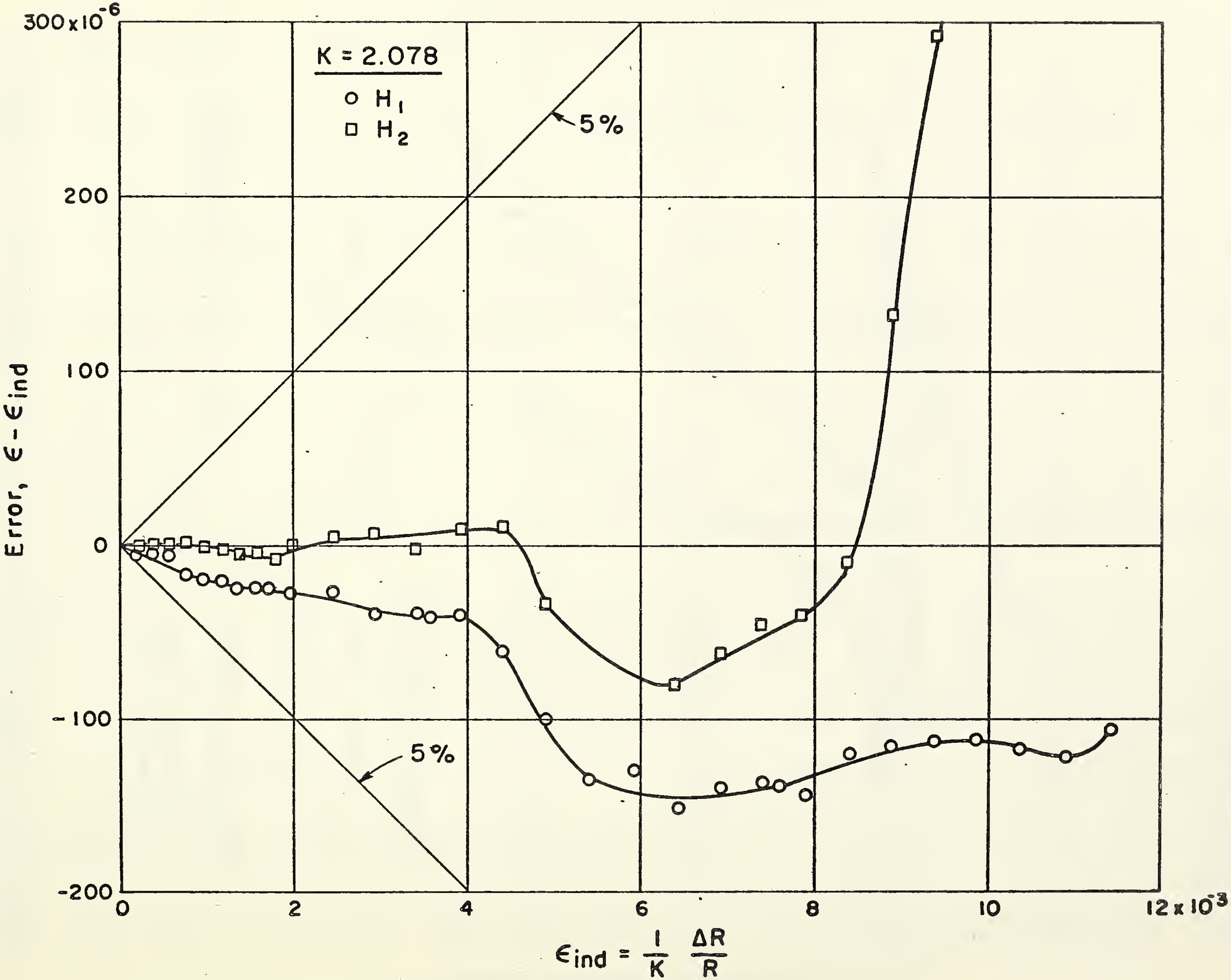

Fig. 12 Gage behavior at high strains at 75° F

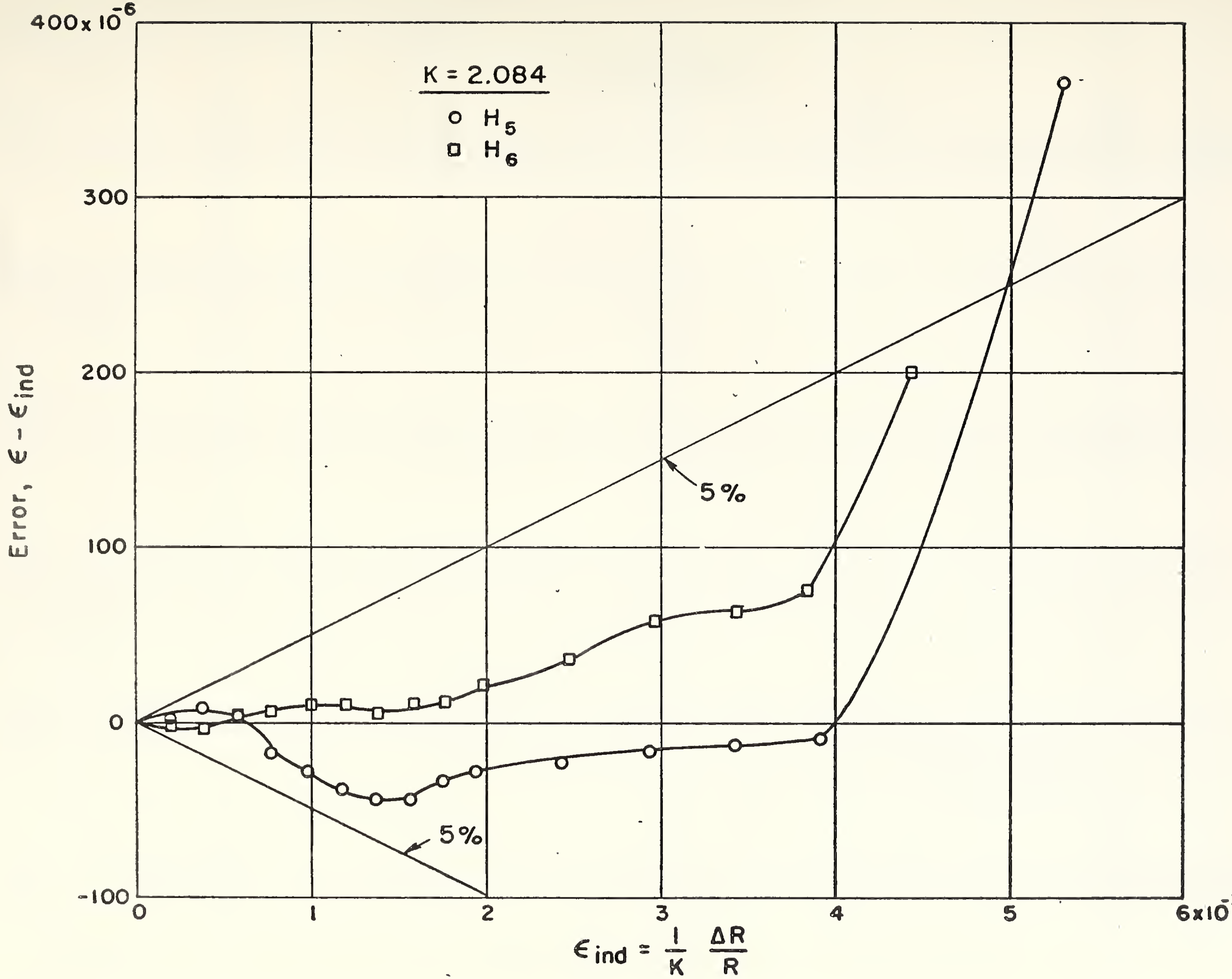

Fig. 13 Gage behavior at high strains 300°F

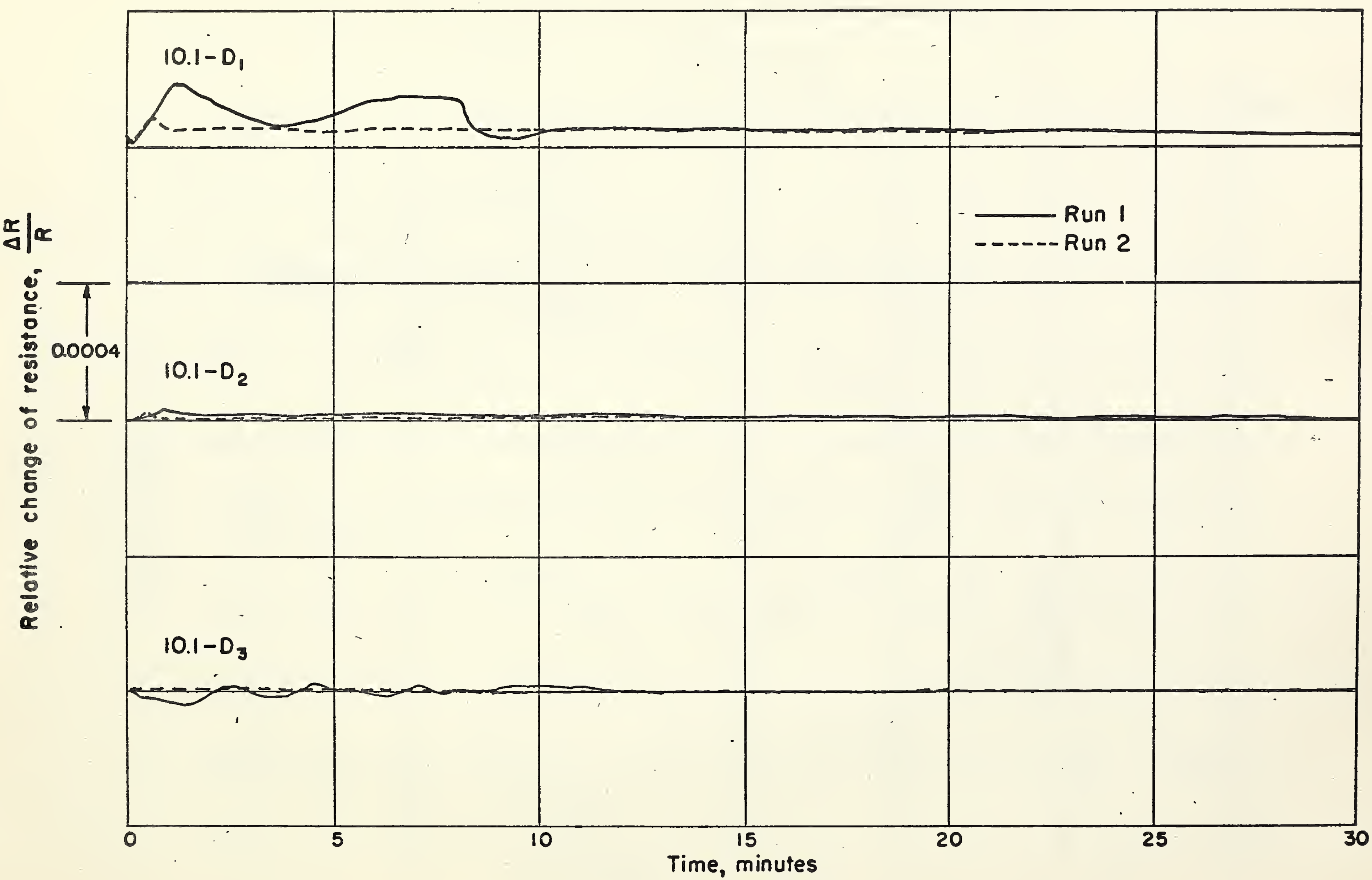

Fig. 14 - Drift behavior at 200° F

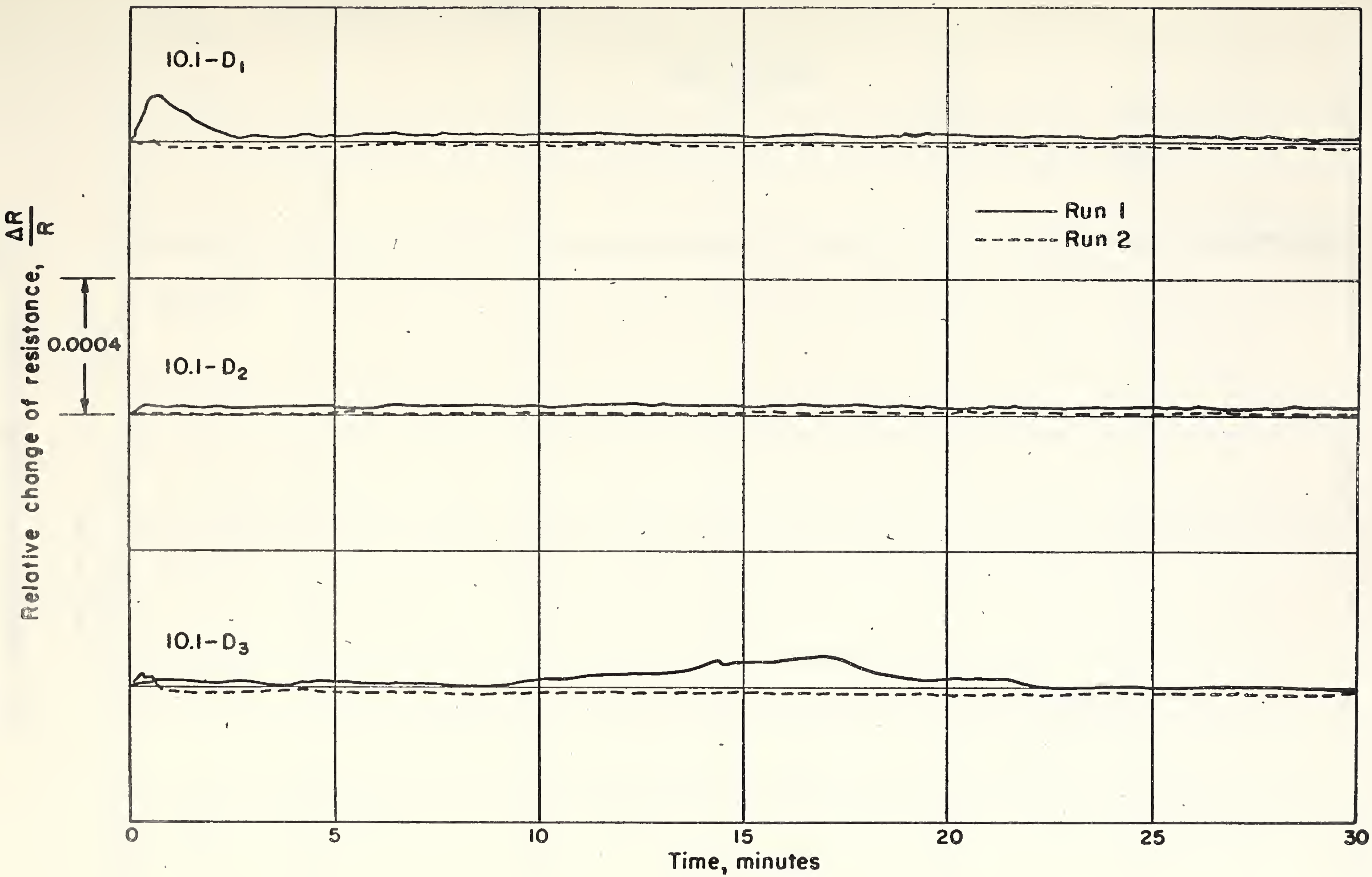

Fig. 15 Drift behavior at 250 °F

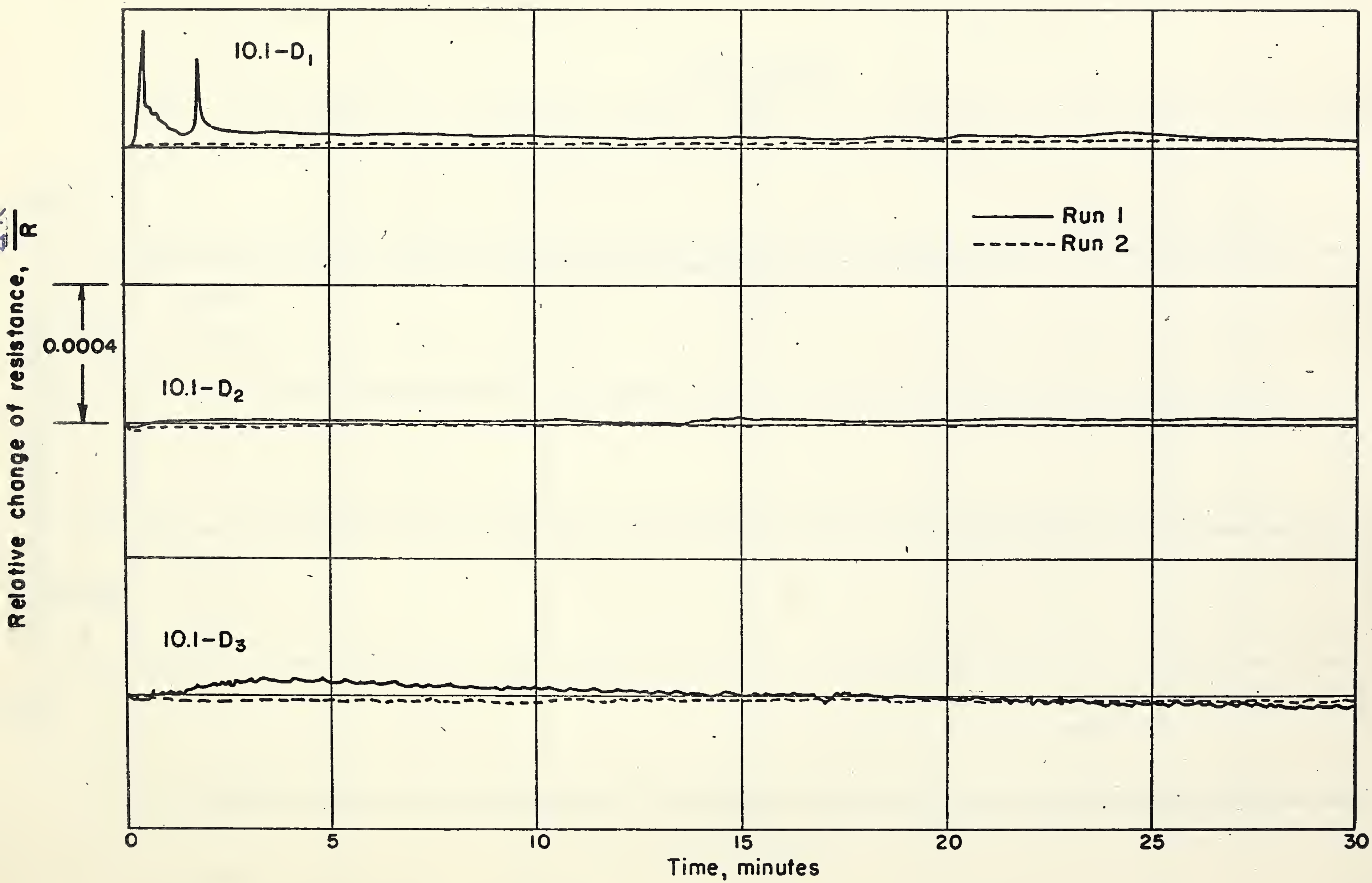

Fig. 16 Drift behavior at 300°F

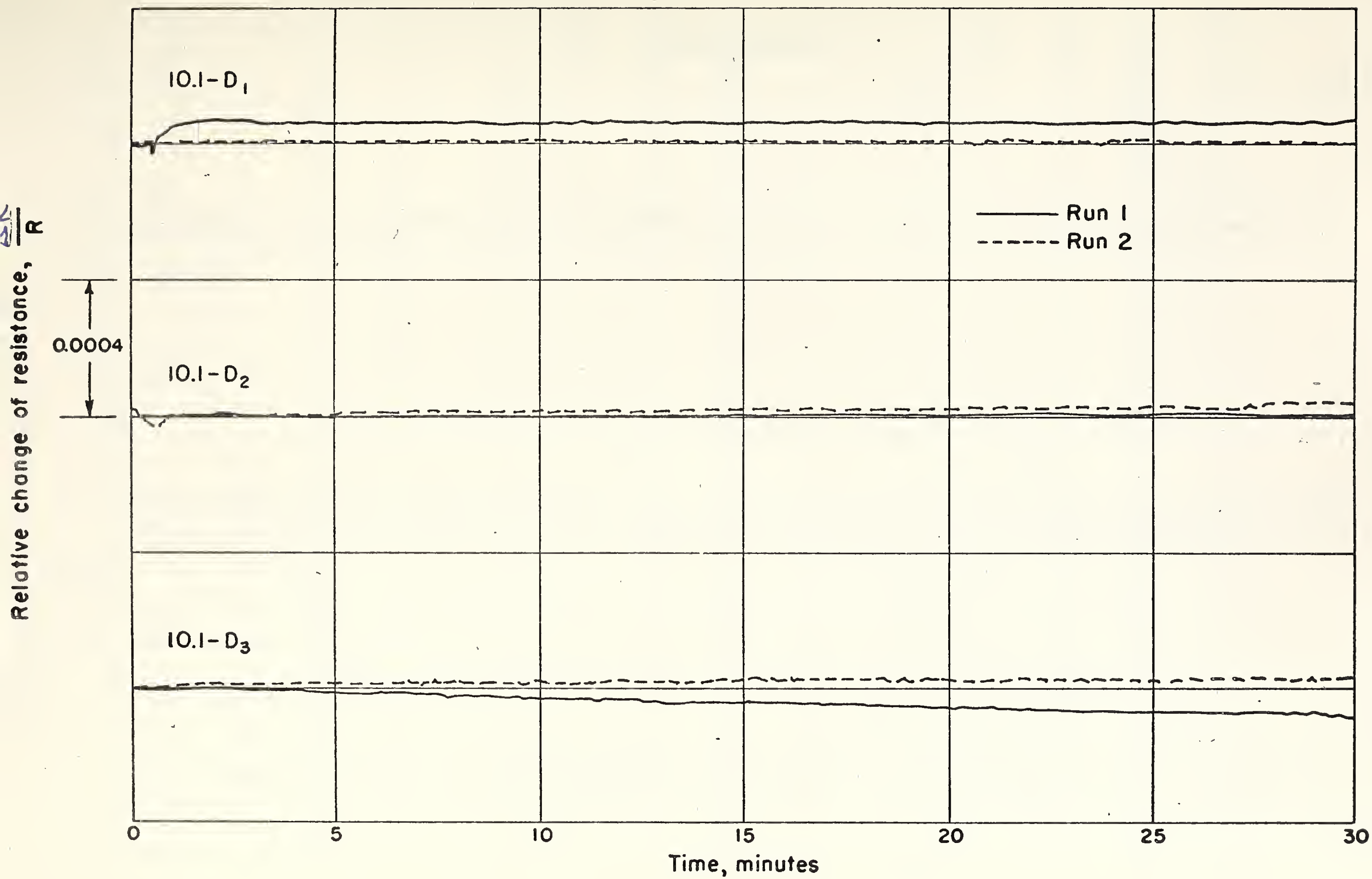

Fig. 17 Drift behavior at 350°F

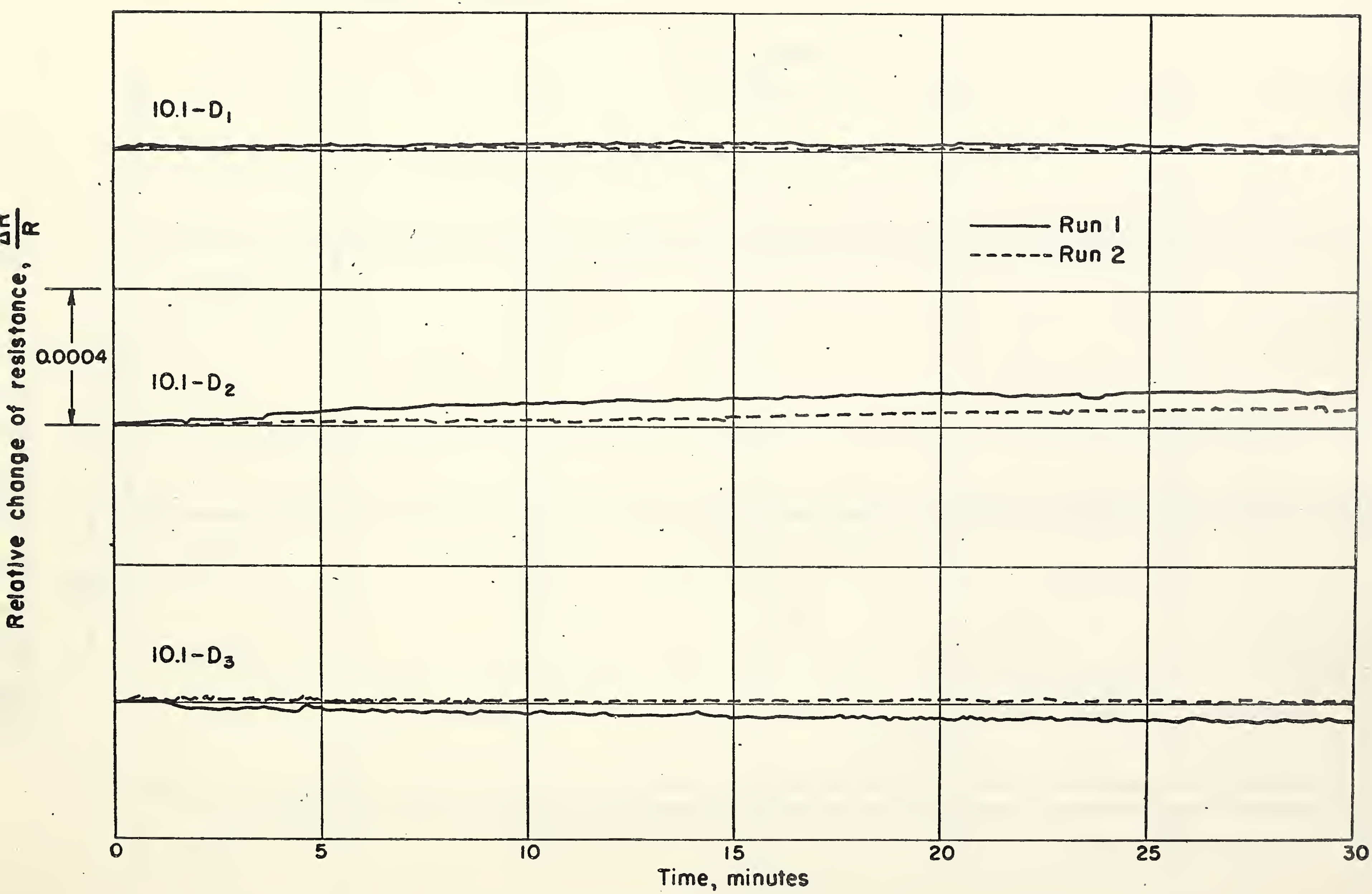

Fig. 18 Drift behavior at 400 °F

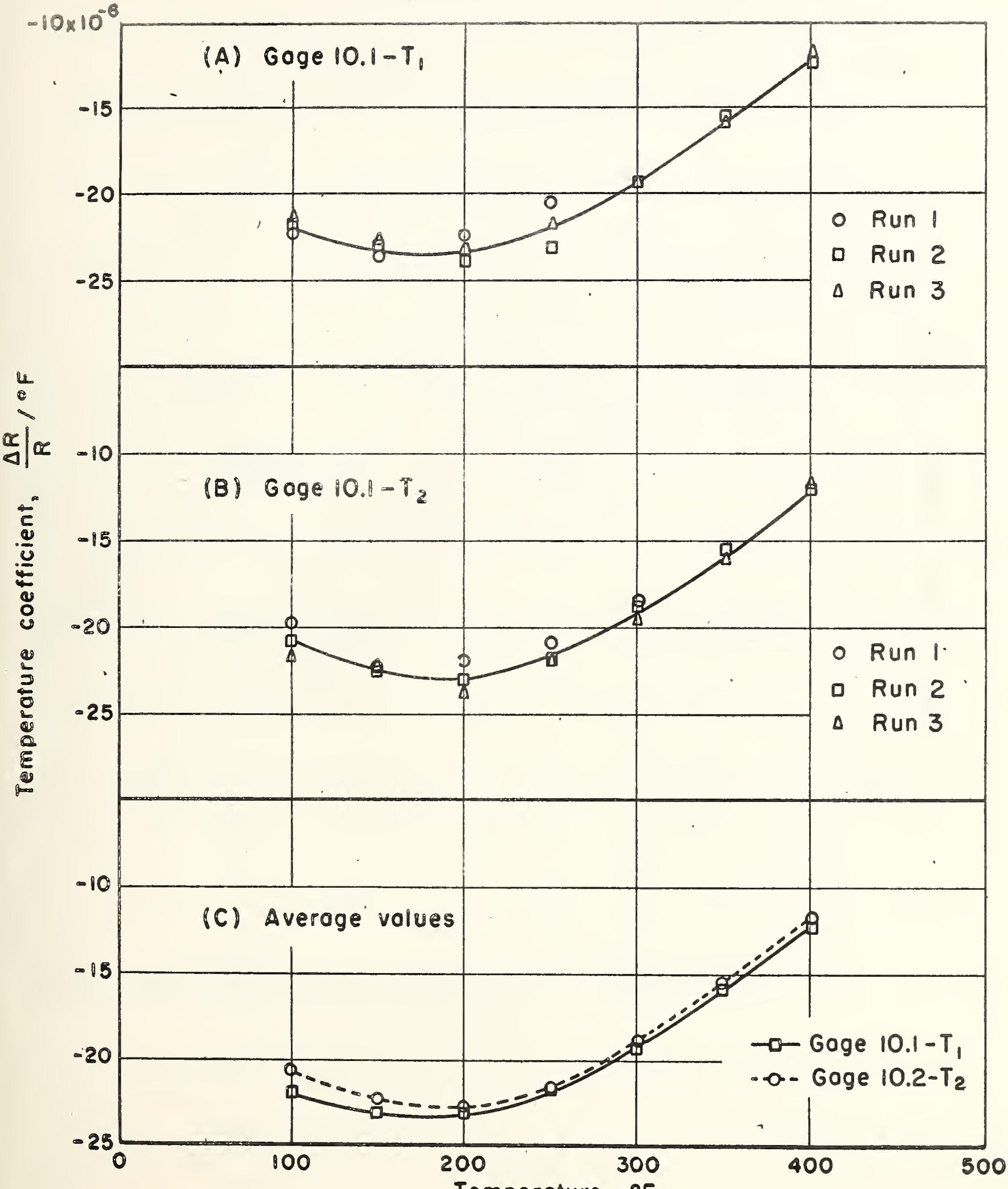

Fig. 19 Temperature sensitivity

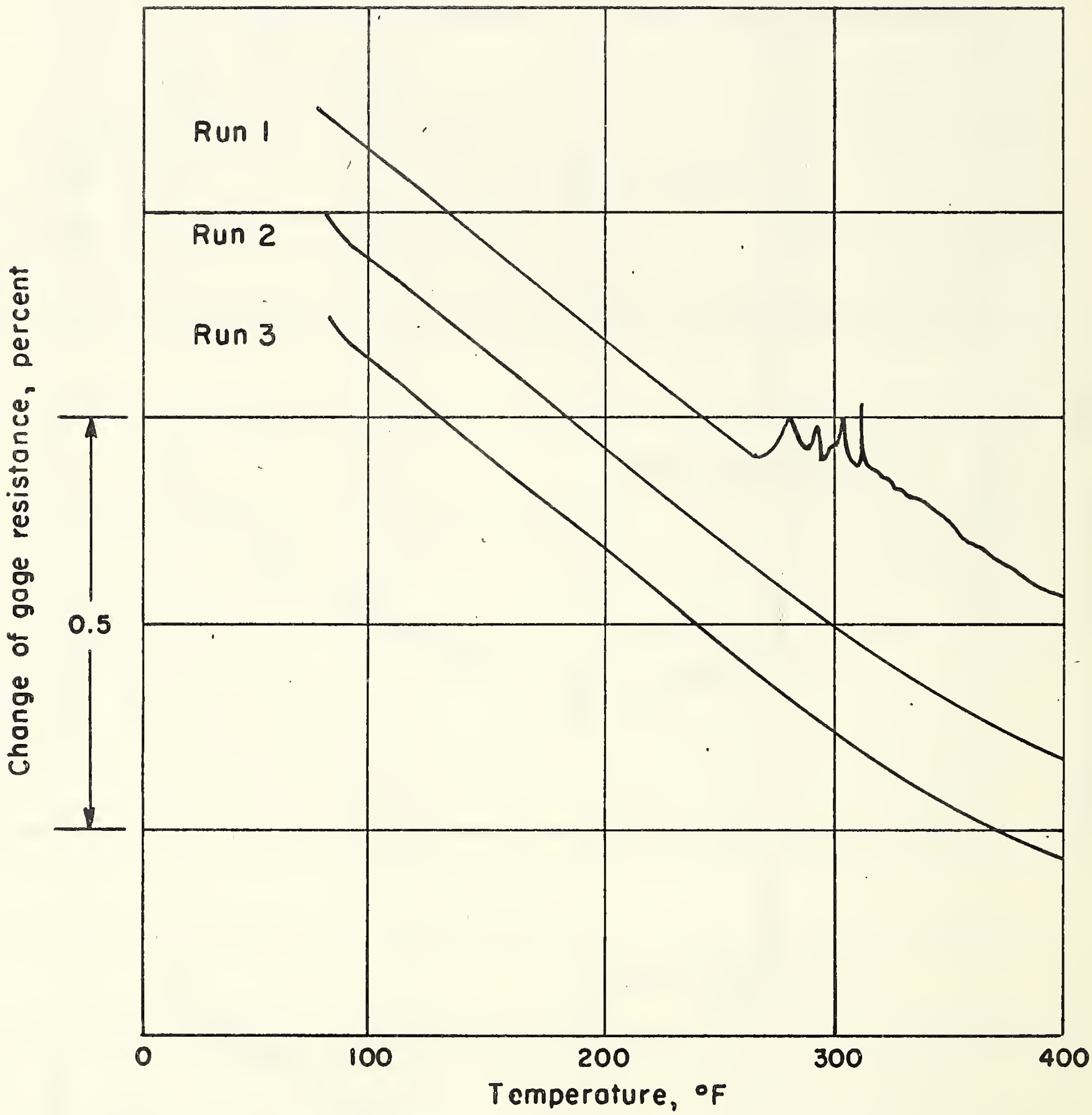

Fig. 20 Temperature sensitivity of Gage 10.1-T_1

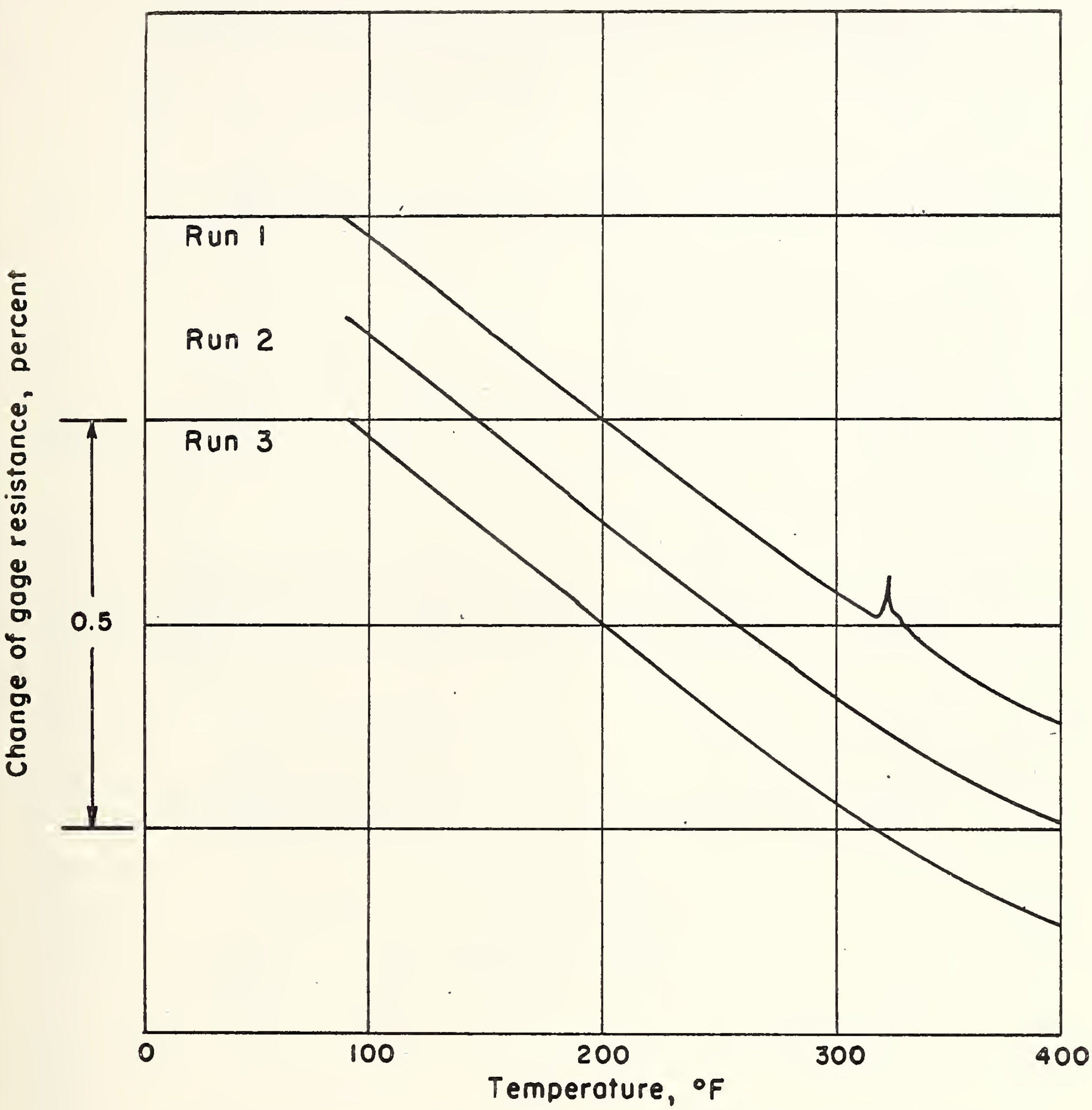

Fig. 21 Temperature sensitivity of gage 10.1 - T_2

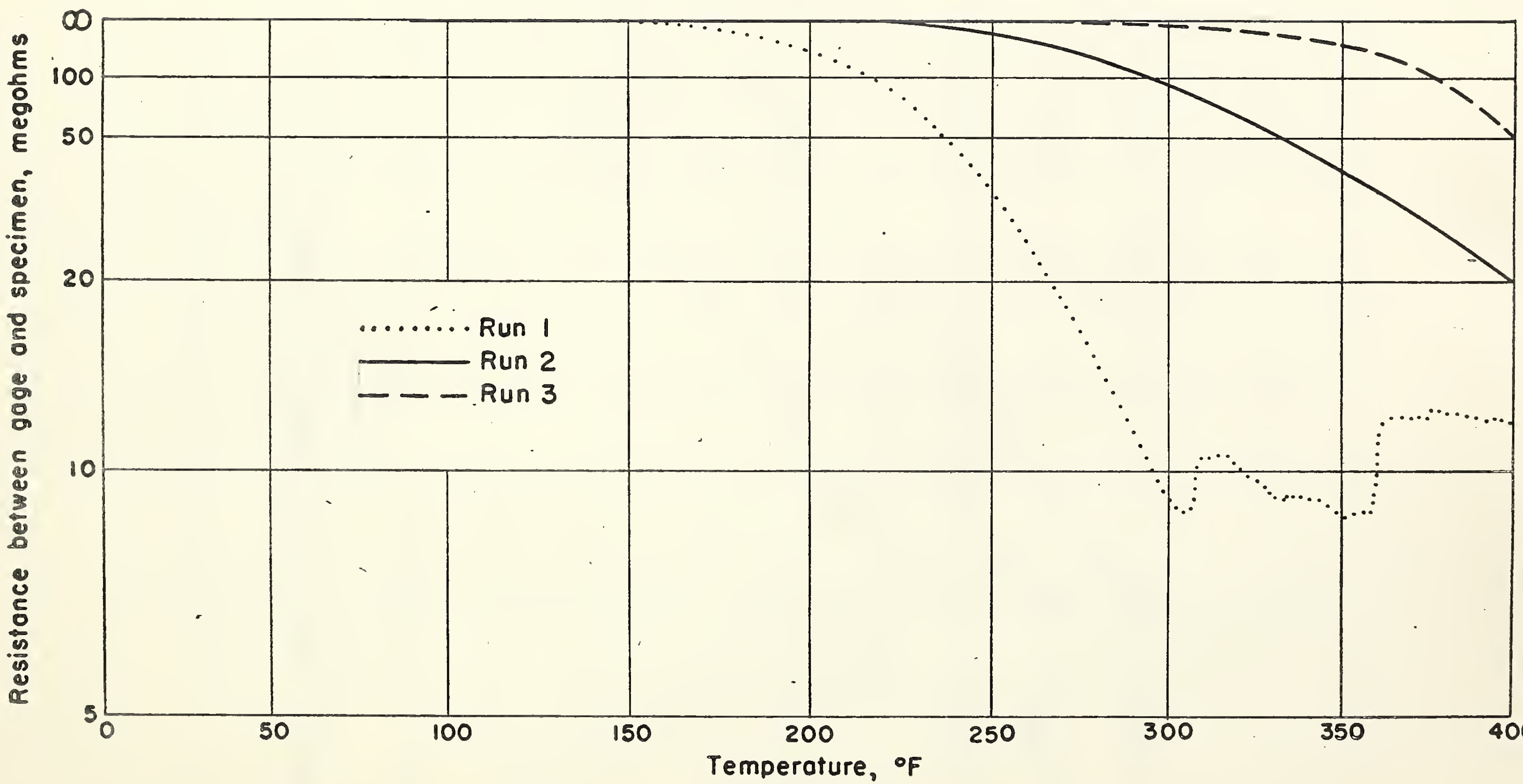

Fig. 22 Resistance between gage and specimen, Gage No. 10.1-L_1

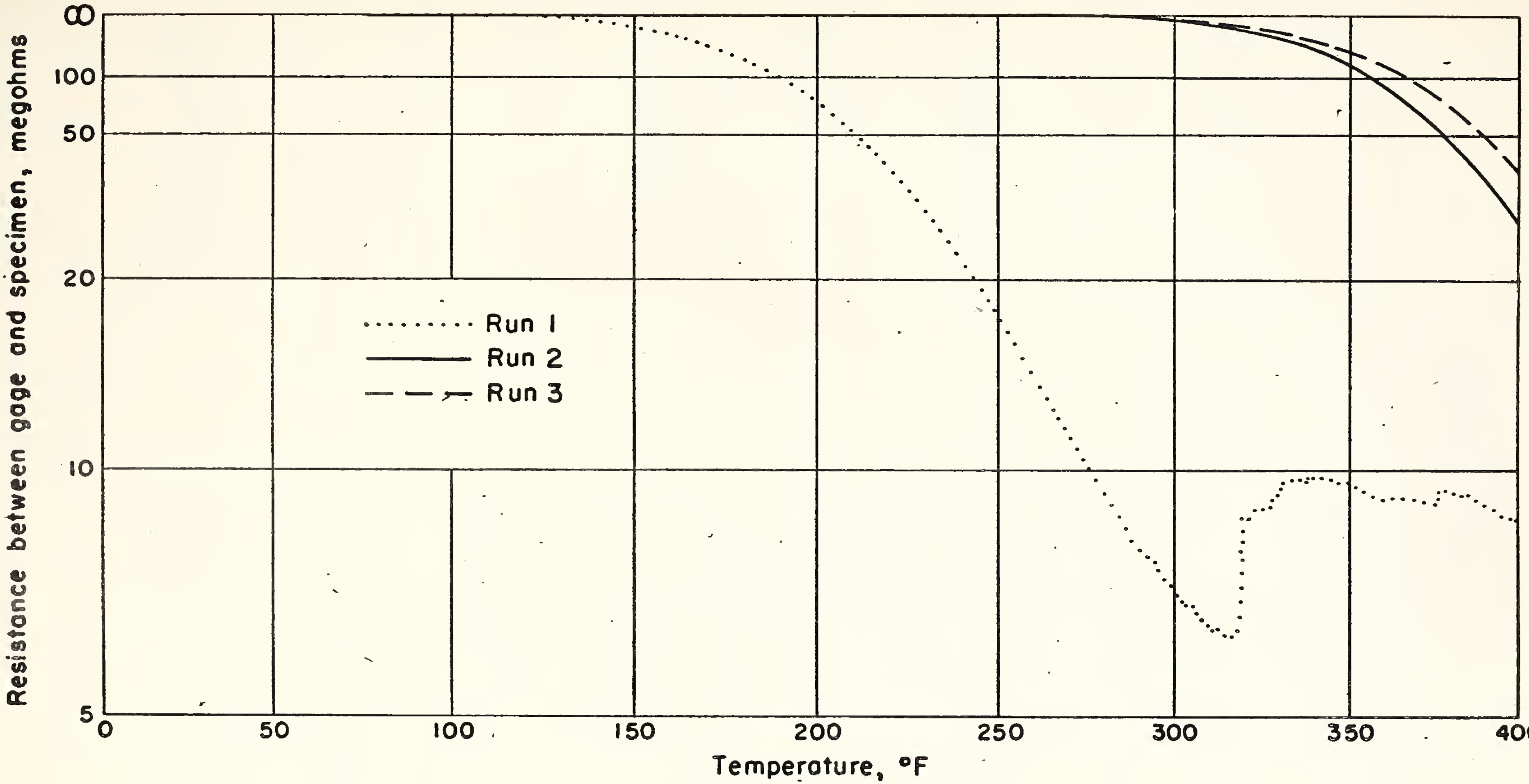

Fig. 23 Resistance between gage and specimen, Gage No. 10.1 – L_2

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