NATIONAL BUREAU OF STANDARDS REPORT

9074

RESPONSE TO THERMAL GRADIENTS OF
THIRTEEN COMMERCIAL PRESSURE TRANSDUCERS

BY

Leon Horn

Paul S. Lederer,
Project Leader

Basic Instrumentation Section
Electronic Instrumentation Division

FOR OFFICIAL USE ONLY

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its three Institutes and their organizational units.

Institute for Basic Standards. Applied Mathematics. Electricity. Metrology. Mechanics. Heat. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radiation Physics. Radio Standards Laboratory:* Radio Standards Physics; Radio Standards Engineering. Office of Standard Reference Data.

Institute for Materials Research. Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.* Materials Evaluation Laboratory. Office of Standard Reference Materials.

Institute for Applied Technology. Building Research. Information Technology. Performance Test Development. Electronic Instrumentation. Textile and Apparel Technology Center. Technical Analysis. Office of Weights and Measures. Office of Engineering Standards. Office of Invention and Innovation. Office of Technical Resources. Clearinghouse for Federal Scientific and Technical Information.**

---

*Located at Boulder, Colorado, 80301.
**Located at 5285 Port Royal Road, Springfield, Virginia, 22171.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT 4252434

April, 1966

NBS REPORT 9074

RESPONSE TO THERMAL GRADIENTS OF THIRTEEN COMMERCIAL PRESSURE TRANSDUCERS

by

Leon Horn

Paul S. Lederer,
Project Leader

Basic Instrumentation Section
Electronic Instrumentation Division

Report to

Bureau of Naval Weapons
Department of the Navy

Electronic Systemys Division
Department of the Air Force

Office of Advanced Research and Technology
National Aeronautics and Space Administration

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

SUMMARY

Thirteen different flush mounted pressure transducers of seven different manufacturers were tested by applying a thermal gradient to them and recording their resultant zero shifts.

Photographs of typical outputs are shown and the results are compared. Some suggestions for possible improvements are given.

KEY WORDS

Test report, thermal gradients, pressure transducers, response.

RESPONSE TO THERMAL GRADIENTS OF THIRTEEN COMMERCIAL PRESSURE TRANSDUCERS

Introduction

An investigation of the effects of thermal gradients on the output of flush mounted pressure gages was reported at the 20th I.S.A. meeting August 1965 in California. A number of tests have since been conducted.

Thirteen flush-mounted pressure transducers of seven different manufacturers have been tested for their response to thermal gradients. The different designs have included several unbonded strain gage types, thus permitting the observation of the variation of response among similar as well as different transducers. Although the results verify earlier observations, the number of transducers tested is not yet large enough to do more than indicate the range of response that may be encountered.

Test Equipment

The tests are performed with the gradient heater described in detail in Reference[1]. Summarizing briefly, the heater makes use of an electric soldering iron altered to serve as the heat source for establishing a thermal gradient in the transducers.

The heat is transferred by conduction through thermal contact with a pool of molten metal while the temperature of all the components of the test are continuously monitored. The thermal output of the heater can be varied at any time by the test operator.

Figure 1 shows the test setup. The pressure transducer can be seen at (A). It is held by an insulated clamp (B) so that during the test, its surface is just immersed in the liquid Wood's metal pool (C) which is used as a heat-transfer medium. The heater voltage is controlled by an adjustable auto transformer and thermocouples (E) are used to measure the temperature of the heater and of the fromt and back surfaces of the transducer. A recorder is used to keep multiple continuous records of the temperature during the test.

The electrical output of the transducer is displayed on an oscilloscope and the results are photographed for a permanent record.

Test Program

Each transducer was first checked at equilibrium temperatures for agreement with the listed manufacturers specifications; after these results were recorded, the thermal gradient test was started.

1 The Response of Flush Diaphragm Pressure Transducers to Thermal Gradients. Preprint 13.3-4-65 I.S.A. 20th. Annual Conference and Exhibit; October 4-7 1965, Los Angeles.

The test produces a temperature gradient within the pressure transducer with the high temperature region at the pressure sensing end. In a typical test series one increases the temperature of the heat source in steps, running one test at each step, until the specified limiting operating temperature of the transducer is reached. The temperature differential between the transducer surfaces and the zero shift with time for each run, are recorded.

Test Results & Discussion

For purposes of comparison, the limiting conditions are generally of primary interest and they are reported. The test temperatures to date have been limited to a maximum of 600°F. Table 1.

A typical thermal gradient zero shift curve, has portions of the curve as follows: An initial change in the zero value of the transducer, often reversing direction after a few seconds which is called oil canning the negative peak value generally closely associated with oil canning, and the maximum zero-shift which may be in the same direction as the negative peak or the opposite direction.

The portion of the curve due to oil canning has been explained on the basis of the differential expansion of a taut diaphragm bound by a hoop[2]. In general, this is noticeable as a very rapid reaction compared to the normal thermal response of the system, i.e., oil canning can occur in less then a second. In most instances it was least in those instruments that showed the smallest zero shift. It varied from +0.8% FS to -30% FS. Transducers with corrugated diaphragms showed less oil canning then those with flat diaphragms.

The photographs of the shifts of the zero-level outputs of the various transducers have been given numbers which represent the transducers position in the ordered sequence of effective gradient sensitivities. The photographs represent typical zero-shifts and were not chosen for maximum test conditions. The test temperature is given alongside each photograph. It was noted that while the duplicate transducers tested (Figure 2-J, K, photograph #6 same model, series number's and range) tended to give duplicate results, some units of the same manufacturer but of different pressure ranges did not.

The Statham gages in the various pressure ranges were modified in a way that altered their thermal characteristics for each pressure range (Photograph 1, 2, 10, 11.) the CEC gages however, were not; (Photographs, figure 2 a, b, s, t; 8, 9a and 9b).

The photographs, figure 2 (m,n,o,p,q,r). shown in the 9a and 9b serie are from 4-312 type CEC's. The 9a was bought in 1965, the 9b during 1954. During this time (1954 to 1965) the specifications of the upper working limit for the 4-312 pressure transducer was changed from 165°F to 250°F while the zero shift was reduced from .08% FS/°F to .015% FS/°F.

[2] Patterson, J. L., A Miniature Electrical Pressure Gage Utilizing a Stretched Flat Diaphragm, NACA Technical Note 2659 April 1962.

Tests on the transducers indicate very little change in response to thermal gradients. The EGS Value for the 1954 transducer was 0.14% FS/°F and the 1965 is now 0.10% FS/°F, a value that remains in position 9 in the sequence on table 3.

On all transducers tested, as long as a gradient existed, a zero shift could be noted and a zero shift steady state condition was possible. (Figure 2-g, h photograph 4) as a particular example.

A study of the zero shifts of the transducers indicated certain regularities. If one discounts the initial oil-canning from the zero shift, a distinct pattern separation can be seen. (See remarks on Table 4.) The division seems to be between those whose zero shift maximizes within the test period and those that show a gradual increase with time. The latter include non-compensated transducers. Those with a peak or maximum must include thermally mal-placed compensating elements.

As indicated in the earlier report and verified by the tests reported here, design differences are more important than the kind of active elements in the transducer. Although unbonded straingages are used by both CEC and Statham their performance patterns varies widely in their response to thermal gradients.

The maximum zero shift and the response time are given in Table 1 . An increase in the rate of heating from 0.8 Cal/cm^2 s to 8 Cal/cm^2 s did not alter the time to a peak zero shift in the tests, although it did alter the gradient and the maximum zero shift.

The gradient induced in a particular transducer test is a function of the temperature of the hot pool in which it is immersed and the length of time it has been immersed. The numerical value of the maximum zero shift thus depends to a great extent on the test conditions. In order to allow comparisons among transducers tested at different temperatures and with resultant different gradients a relative effective gradient sensitivity, was calculated.

The effective gradient sensitivity (EGS) was defined by dividing the maximum zero shift in percent of full scale by the temperature difference between the hotter surface of the transducer and the reference temperature for zero shift of the transducer. The results are listed in Table 3 as %FS/°F.

Since all the transducers were given the same kind of test, in each case to the limit of the expected normal operating temperature, these values (EGS) should represent a measure of their ability to perform while exposed to thermal gradients. A value that is equal to or less than the manufacturers specifications for zero shift with temperature can be treated as a transducer unaffected by thermal gradients.

Tests on the transducers indicate very little change in response to thermal gradients. The EGS Value for the 1954 transducer was 0.14% FS/°F and the 1965 is now 0.10% FS/°F, a value that remains in position 9 in the sequence on table 3.

On all transducers tested, as long as a gradient existed, a zero shift could be noted and a zero shift steady state condition was possible. (Figure 2-g, h photograph 4) as a particular example.

A study of the zero shifts of the transducers indicated certain regularities. If one discounts the initial oil-canning from the zero shift, a distinct pattern separation can be seen. (See remarks on Table 4.) The division seems to be between those whose zero shift maximizes within the test period and those that show a gradual increase with time. The latter include non-compensated transducers. Those with a peak or maximum must include thermally mal-placed compensating elements.

As indicated in the earlier report and verified by the tests reported here, design differences are more important than the kind of active elements in the transducer. Although unbonded straingages are used by both CEC and Statham their performance patterns varies widely in their response to thermal gradients.

The maximum zero shift and the response time are given in Table 1 . An increase in the rate of heating from 0.8 Cal/cm^2 s to 8 Cal/cm^2 s did not alter the time to a peak zero shift in the tests, although it did alter the gradient and the maximum zero shift.

The gradient induced in a particular transducer test is a function of the temperature of the hot pool in which it is immersed and the length of time it has been immersed. The numerical value of the maximum zero shift thus depends to a great extent on the test conditions. In order to allow comparisons among transducers tested at different temperatures and with resultant different gradients a relative effective gradient sensitivity, was calculated.

The effective gradient sensitivity (EGS) was defined by dividing the maximum zero shift in percent of full scale by the temperature difference between the hotter surface of the transducer and the reference temperature for zero shift of the transducer. The results are listed in Table 3 as %FS/°F.

Since all the transducers were given the same kind of test, in each case to the limit of the expected normal operating temperature, these values (EGS) should represent a measure of their ability to perform while exposed to thermal gradients. A value that is equal to or less than the manufacturers specifications for zero shift with temperature can be treated as a transducer unaffected by thermal gradients.

An emperical relationship based on the data taken from the thermal gradient measurements has been derived which can be used to predict, after oil canning, the zero shift expected for various conditions of initial temperatures and gradients. The equation for the actual zero shift takes the form of adding the manufacturers zero shift for the transducer, (as though the entire transducer is at the temperature of the exposed active face) and a value due to the gradient between the front and back of the transducer. The results have been found to hold to 10%.

For example, suppose during a test one had monitored the front and back surfaces of the CEC while taking a pressure recording. One could state that at the time T_1 the front surface was at temperature of A°F and the back surface indicated a temperature of B°F while a pressure P_1 was being recorded.

The equation found for the CEC was 0.02%FS/°F (manufacturer's specification) plus 0.3%FS/0°F (derived). One would therefor multiply .02 by the difference between A and the reference temperature at which the zero shift is zero [In the case of this particular transducer we have .02 (A°F -0°F)= .02 (A°F)] and then add the differential term .3 (A-B). One would then convert from %FS to PSI and subtract this value from the pressure P_1 recorded at time T_1. The new pressure would be the correct value ±10% that would have been recorded if no thermal gradient had existed at that time. One can therefore make corrections for the zero shift of the transducer after the first few seconds, provided one has monitored the front and back temperatures of the transducer. In addition to this correction, there is the possibility of a change in sensitivity with temperature. The standard tests indicate that this is a factor in at least some semi conductor gages[3] although not of importance in the wire strain gage devices that have been tested.

Some of the factors that govern the effect of a temperature test gradient are: The mass of the section exposed to the heat, i.e., the thermal inertia of the case, the thermal path differences that exist between the active elements and the compensating elements and, the thermal alterations of strain members, and changes in spring positions due to temperature gradients in the supports.

From theoretical considerations one could expect zero shifts to result from oil canning, leverage shifts due to unequal expansion of parts, and variations in electrical properties with temperature. Therefore, these factors would have to be considered in any attempt to reduce or avoid the effect of thermal gradients.

A solution would require that either units not be altered by thermal gradients or that they be removed from the temperature gradient zone.

[3] Performance tests on two Piezoresistive Strain Gage Pressure Transducers, John S. Hilten, September 1965 NBS Report 8974.

To avoid the zero shift that is due to mechanical motion requires a design that allows for the thermal differences that are expected or are possible. Balanced and compensated mechanical motions and thermal buffers for sensitive springs and flexures are possibilities. Quartz or sapphire rods for extensions to provide relatively constant dimensions and still provide poor conduction of the heat would seem to be one way of separating the active elements of the transducer from the immediate vicinity of the heat source, thus producing a relatively constant environment that tends to isolate and protect the active elements for short periods of time.

One can transmit the pressure to be measured by tubes to a cooler region (with its problems and certainty of altered response,) or cool the active elements of the transducer with gas or liquid, or electrically.

A compromise that would provide the equivalent of a uniform temperature zone for the transducer would consist of preheating the transducer to within a few degrees of the expected working temperature just before the test.

Conclusions

The results described above confirm previous observations that:

1. Flush mounted pressure gages may be compensated for changes in uniform temperatures and still show large zero shifts due to thermal gradients.

2. The manufacturers design is more important than the kind of sensing element used, i.e. crystal, wire strain gages bonded or not, differential transformer etc.

3. Some transducer's can operate in a thermal gradient with very little zero shift, but no simple way to predict this without testing is available (or known).

Since the transducer's zero shift is the result of an imposed thermal gradient and is a function of the transducer design, a comparison of reactions to thermal gradients becomes a form of comparison of transducer designs. Comparison of thermal gradient design effectiveness should therefore be meaningful.

Although the rate of energy input and thermal flux density influence the magnitude and the time it takes to reach a given gradient it is the temperature gradient that is responsible for the zero shift of the instrument and this should be considered when choosing a pressure transducer for field use.

TABLE 1
Oil Canning

Transducer	Pressure Range	% FS	Time to Reach Maximum (Seconds)
Pace	0-100	-1.5 to -2.0	1.5
CEC	0-150	-23	1
CEC	0-50	-10.0	0.1
SLM	0-3000	-1.8	0.1
Statham	0-300	-1.0	8
	0-1000	-3	8
	0-50	-1	1
	0-15	-30	2
Schaevitz	0-500	None noted	
Fairchild	0-100	+2.0	5
	0-100	+1.8	5
ASCOP	0-500	-8.0	1

TABLE 2
Thermal Gradient Response

	CEC 4-316-150G	Zero Shift % FS	
Temperature Front (A)	Temperature differential (A-B)	Computed .02(A)+ .3(A-B)	Measured
228°F	47	18.7	18
180°F	63	22.5	25
300°F	60	24.0	25
253°F	120	41.0	44
545°F	120	47.0	49
360°F	160	55.0	50

TABLE 3
Effective Thermal Gradient

Photo Number	Transducer	Pressure Range	EGS %FS/°F	Manufacturer specification %FS/°F
1	Statham	0-300 PSI	.004	.01
2	Statham	0-1000 PSI	.01	.01
3	Fairchild	0-100 PSI	.01	.01
4	Pace	0-100 PSI	.018	.01
5	SLM	0-3000 PSI	.03	.01
6	ASCOP	0-500 PSI	.043	.01
7	Schaevitz	0-500 PSI	.073	none
8	CEC	0-150 PSI	.083	.02
9*	CEC (a)	0-50 PSI	.14	.04
	CEC (b)	0-50 PSI	.10	.015
10†	Statham	0-15 PSI	.16	.01
11†	Statham	0-50 PSI	.50	.01

* CEC 9 (a) Received 1954
9 (B) Received 1965

† The last two transducers require special mention. The Statham Photo #10 did return to manufacturers specifications during the test within 50 seconds after the introduction of heat. Statham Photo #11 appeared to have a loose connection which separated under the stresses developed by a thermal gradient. The transducer did not show any abnormal output for any of the standard tests and checked out within the manufacturers specifications in the normal temperature tests. (See photographs number 10 and 11)

TABLE 4
Response to Thermal Gradient

Transducer	Model & Specifications	Test Temperature °F	Maximum Zero Shift %FS	Time at Which Maximum Occurs in Seconds	Remarks
Statham	0-15 PSI PA203TC-15-350	200°	-32.0	1-3	Recovers to less than 3% FS by 51 sec.
ASCOP	500 PSI 101 - 102 5383	600°	-26.0	20	After peak at 20 sec. recovery starts.
Statham	0-50 PSI PG260TC-50 - 350	230°	+ 100	30	After peak goes off scale, require 10 min. recovery after removing from the heated zone.
Fairchild	3061-3062 Model FPTV 0-100 PSI	190°	+ 1.9	27	After peak at 27 sec. recovery starts.
Statham	0-300 PSI PG401TC-300-1700	212°			After peak at 50 sec. recovery starts.
Statham	0-100 PSI				
CEC	0-150 PSI 4-316 150G	600°	+49.0	51	After peak at 51 sec. recovery starts.
CEC	50 PSI 4-312-150A	160°	+22.0	10	After peak at 10 sec. recovery starts.
CEC	4-312-0001	250°	+26.0	8	
Statham	0-1000 PSI PG260-1M-350	400°	+ 4.0	180	Maximum shift increases with time.
Pace	0-100 P24G-100 PSI 612	250°	+ 6.0	180	Maximum shift increases with time.
Schaevitz	0-500 PSI P 478	320°	+23.0	180	Maximum shift increases with time.
Kistler SLM	0-3000-PSI P 214	373°	-10.0	7	After a peak of 7 sec. then starts to recover. (SLM test was limited to 20 sec.)

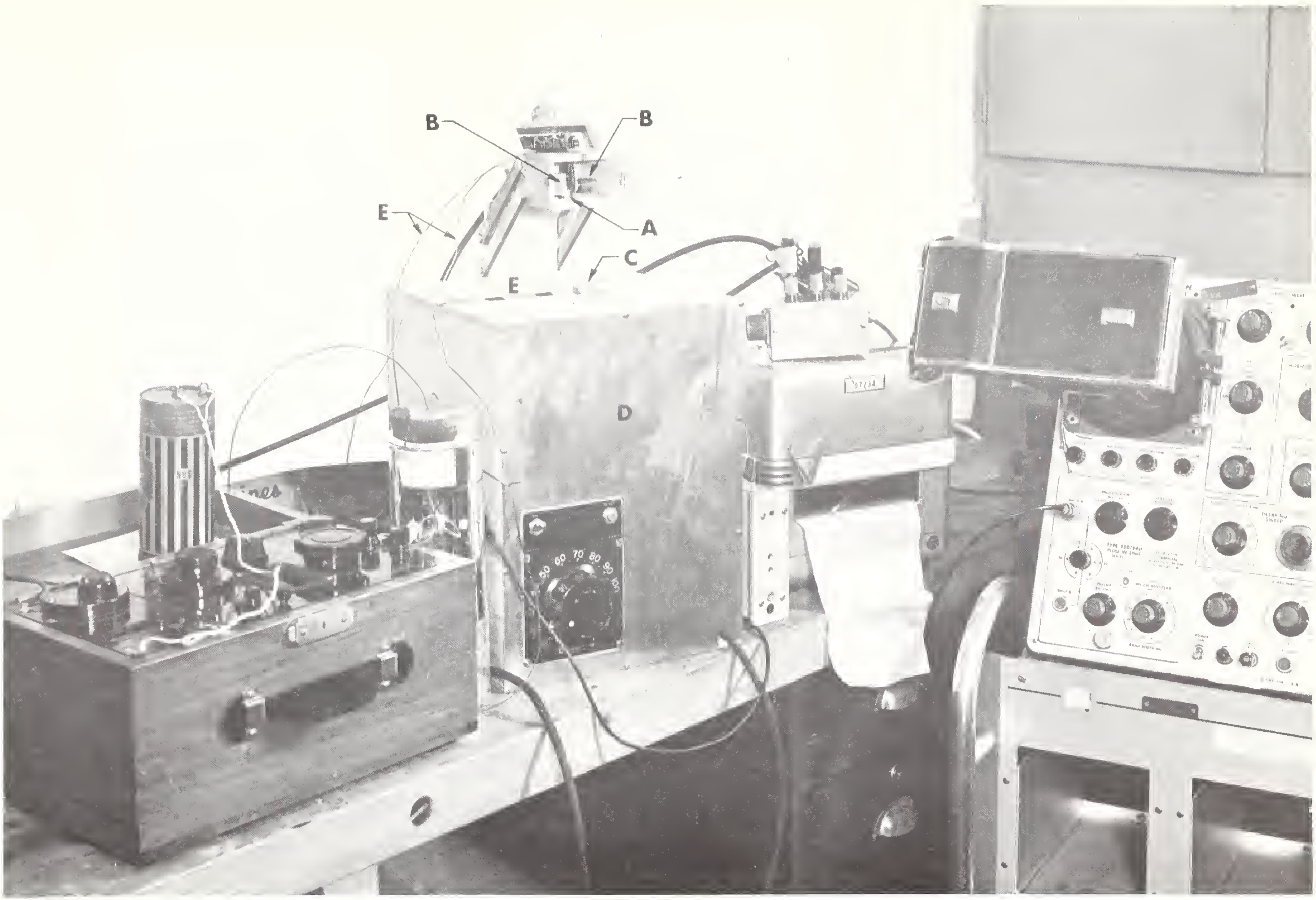
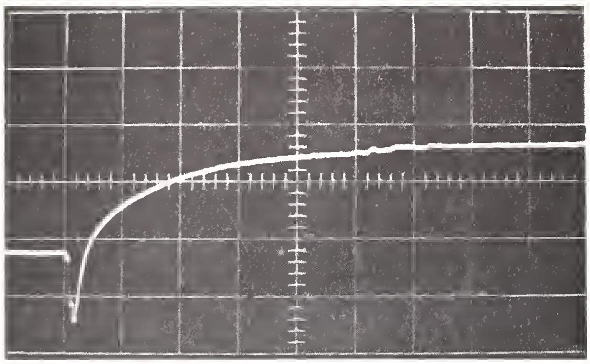
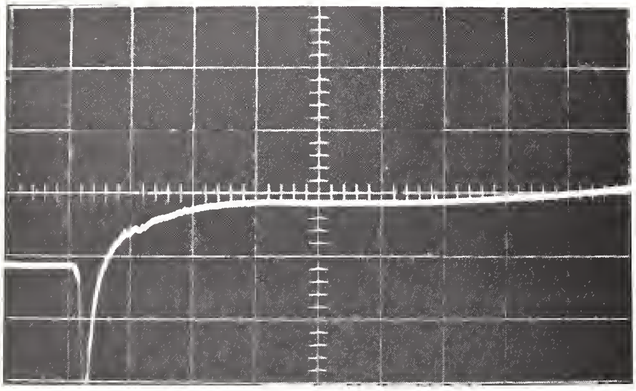


FIGURE 1 THERMAL GRADIENT TEST SYSTEM



(f)

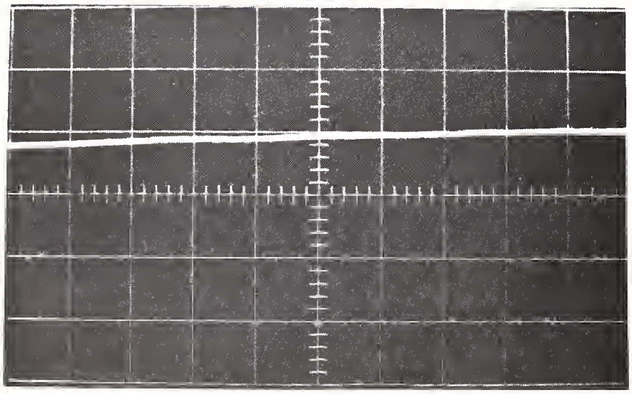
(4) PACE P 24 G
RANGE 0-100 PSI
TIME 17 Sec/cm
TEST TEMP. 250°F
max.zero shift 4.5% FS



(a)
TIME 17 Sec/cm

(g)

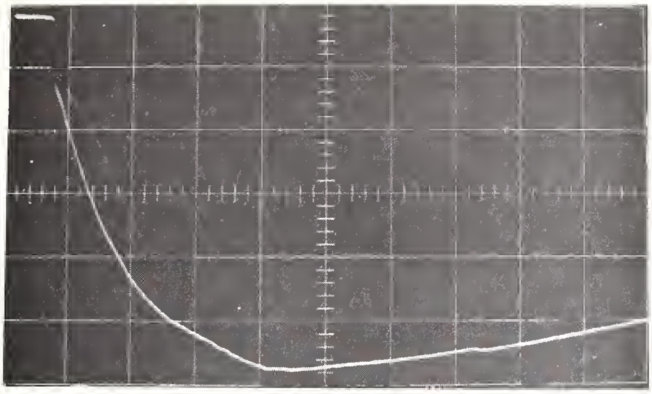
(4) PACE P 24 G
CONDITIONS SAME AS ABOVE
(a) FIRST 3 MINUTES
(b) 12th TO 15th MINUTES



(b)
TIME 17 Sec/cm

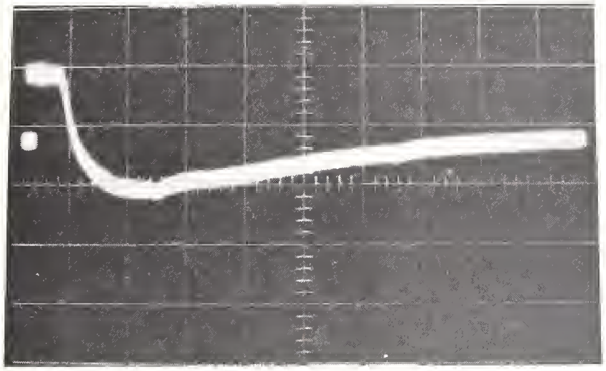
(h)

Figure 2 (a-t) Zero Shift Records



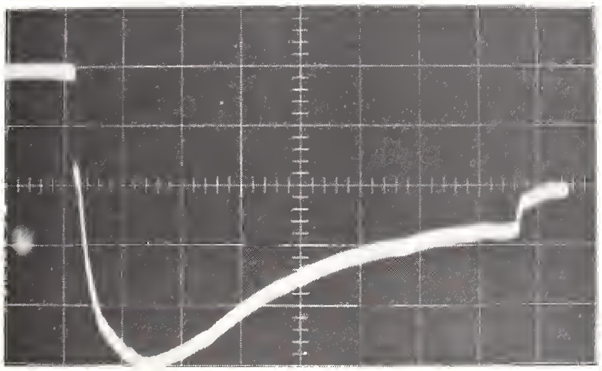
(i)

(5) KISTLER SLN PZ14
RANGE 0-3000 PSI
TIME 2 Sec/cm
TEST TEMP. 373°F
MAX.ZERO SHIFT -10% FS



(j)

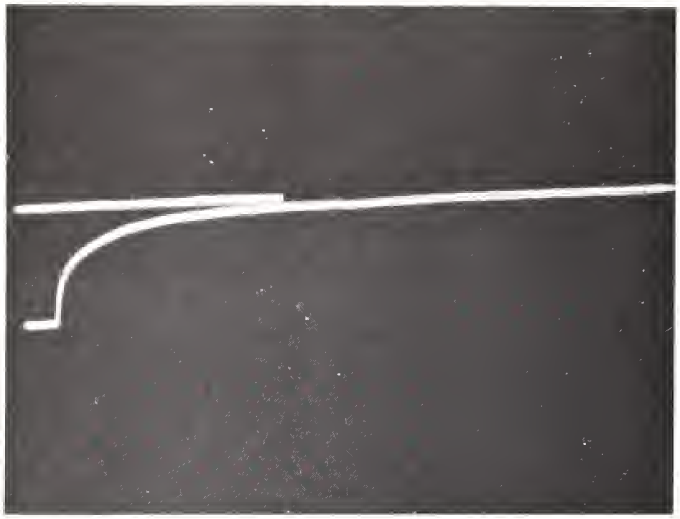
(6) ASCOP 538-0500-0
RANGE 0-500 PSI
TIME 17 Sec/cm
TEST TEMP. 600°F
MAX.ZERO SHIFT -26% FS
SERIAL 101



(k)

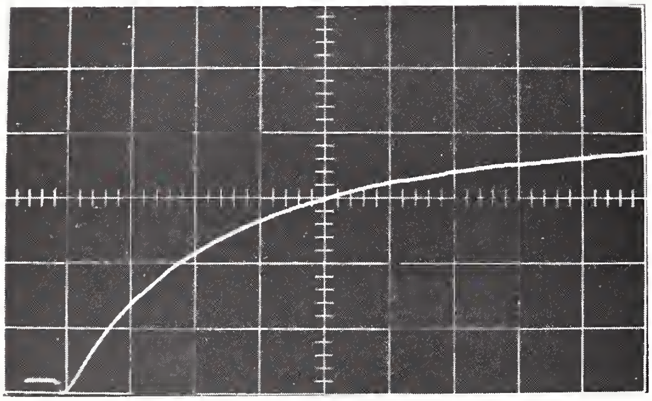
(6) ASCOP 538-0500-0
RANGE 0-500
TIME 17 Sec/cm
TEST TEMP. 600°F
MAX.ZERO SHIFT -25.6% FS
SERIAL 102

Figure 2 (a-t) Zero Shift Records



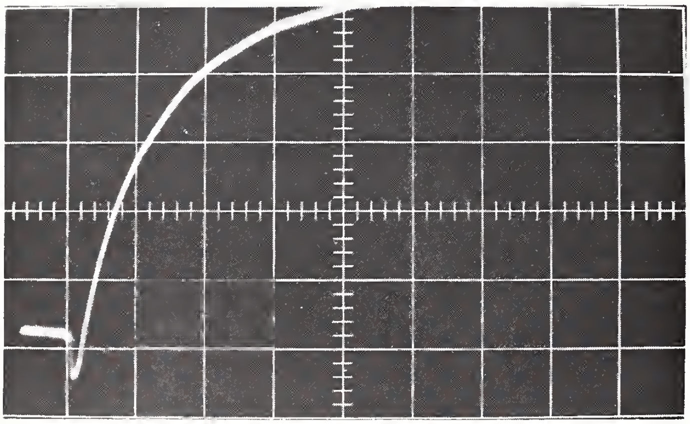
(ℓ)

(7) SCHAEVITZ TYPE P478
RANGE 500 PSI
TIME 17 Sec/cm
TEST TEMP. 320°F
MAX.ZERO SHIFT =23.4% FS



(m)

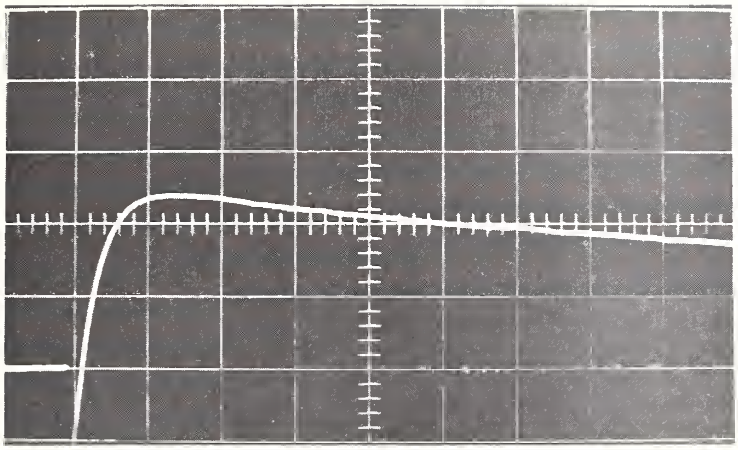
(8) CEC 4-316-150G
RANGE 0-150 PSI
TIME 18 Sec/cm
TEST TEMP. 568°F
MAX.ZERO SHIFT 26.4% FS
BACK END AIR COOLED



(n)

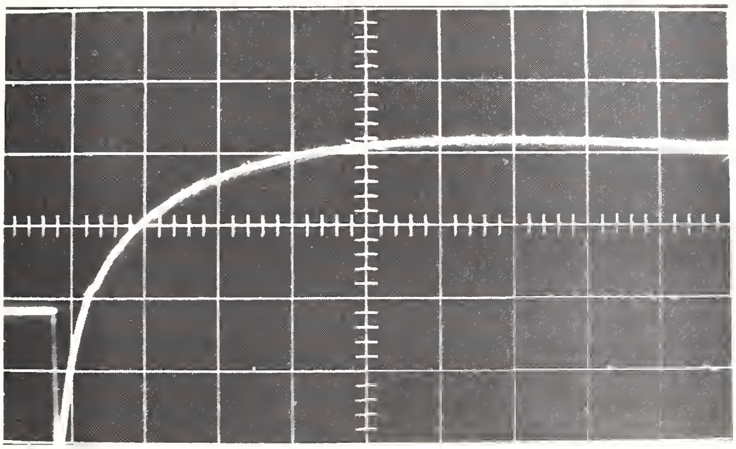
(8) CEC 4-316-150G
RANGE 0-150 PSI
TIME 18 Sec/cm
TEST TEMP. 590°F
MAX.ZERO SHIFT 44% FS

Figure 2 (a-t) Zero Shift Records



(o)

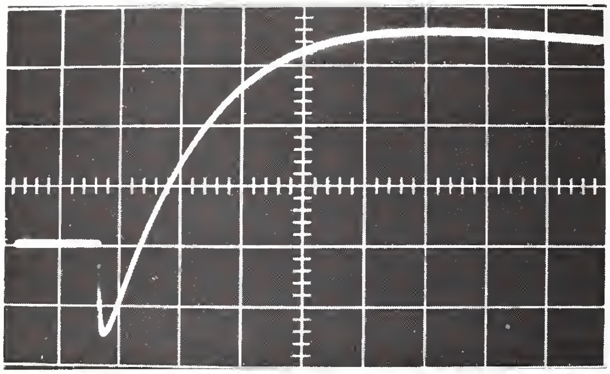
9(a) CEC 4-312-0001
RANGE 0-50 PSI
TIME 17 Sec/cm
TEST TEMP. 231°F
MAX.ZERO SHIFT +30% FS



(p)

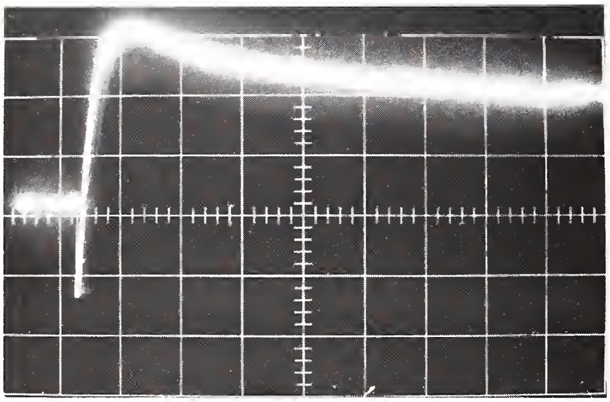
9(a) CEC 4-312-0001
RANGE 0-50 PSI
TIME 3.6 Sec/cm
TEST TEMP. 231°F
MAX. ZERO SHIFT +30% FS

Figure 2 (a-t) Zero Shift Records



(q)

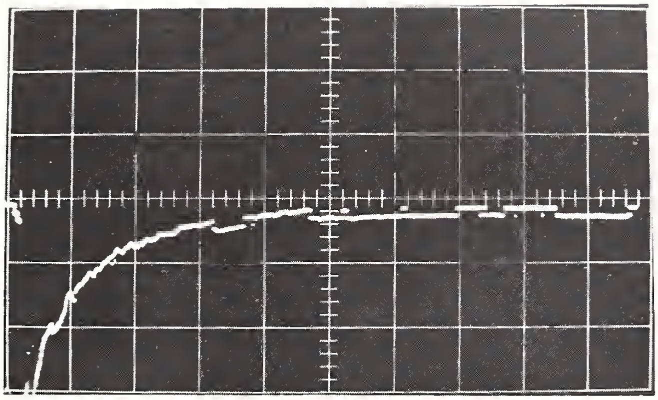
9(b) CEC 4-312
RANGE 0-50 PSI
TIME 2 Sec/cm
TEST TEMP. 165°F
MAX.ZERO SHIFT 23% FS



(r)

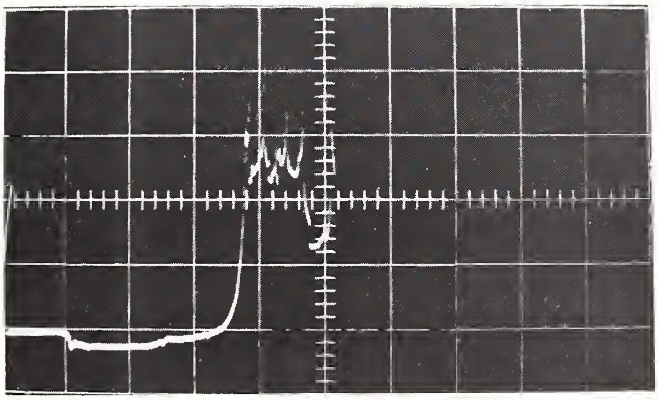
9(b) CEC 4-312
RANGE 0-50 PSI
TIME 17 Sec/cm
TEST TEMP. 170°F
MAX.ZERO SHIFT 23% FS

Figure 2 (a-t) Zero Shift Records



(s)

(10) STATHAM PA203TC-15-350
RANGE 0-15 PSI
TIME 18 Sec/cm
TEST TEMP. 200°F
MAX.ZERO SHIFT -32.7% FS



(t)

(11) STATHAM PG260TC-50-350
RANGE 0-50 PSI
TIME 12 Sec/cm
TEST TEMP. 230°F
MAX.ZERO SHIFT +100% FS

SEE NOTATION AT BOTTOM
OF TABLE 3

Figure 2 (a-t) Zero Shift Records

DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS ★