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PERFORMANCE OF TWO MODELS OF COMMERCIAL UNBONDED STRAIN-GAGE-TYPE ABSOLUTE PRESSURE TRANSDUCER AT 260° C

by Ralph D. Lewis

Lewis Research Center
Cleveland, Ohio

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ABSTRACT

Four transducers of each model were tested. Probable error for the sample transducers was 1 percent of span if each transducer was calibrated at 260° C and zero shifts were corrected for. Zeros shifted with time, storage at room temperature after initial testing for 650 hours at 260° C, and temperature cycling. Maximum rate of zero shift was about 0.01 percent of span per hour. Rate of zero shift usually decreased with time at 260° C. Mean sensitivity change in 650 hours at 260° C was 0.07 percent of initial value. Mean nonlinearity at 260° C was 40 and 0.51 percent of span, respectively, for the two models. Mean hysteresis at 260° C was 0.55 and 0.11 percent of span.

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SUMMARY

Test show that two models of commercial unbonded strain-gage-type absolute pressure transducer will operate for 1300 hours at 260° C with a probable error of 1 percent, or less, of span. To obtain this accuracy it is necessary to calibrate each transducer at 260° C and to correct for zero shift.

Zero shift at 260° will probably occur whether a transducer is held at 260° C or cycled from a lower temperature to 260° C. The direction and rate of zero shift at 260° C are unpredictable from model or range of transducer. At 260° C, zeros shifted at rates up to 0.01 percent of span per hour. However, the rate of zero shift usually decreased with time at 260° C. The maximum zero shift in 1300 hours at 260° C was 2 percent of span. Zeros checked at 260° C before and after 5 months storage at room temperature differed by as much as 1.4 percent of span. Temperature cycling from 25° to 260° C caused zero shifts as high as 0.1 percent of span per cycle.

During 650 hours at 260° C, the average change in sensitivity was 0.07 percent of initial value, and the maximum change was 0.32 percent of initial value. During four cycles from 25° to 260° C, the change in sensitivity was less than 0.2 percent of initial value for seven of the eight transducers tested.

The mean nonlinearity at 260° C was 0.40 and 0.51 percent of span, respectively, for the two models, and the mean hysteresis was 0.55 and 0.11 percent of span. Nonlinearity and hysteresis at 260° C never exceeded their original values at 260° C by more than 0.2 percent of span.

INTRODUCTION

In the study of space power systems using liquid metals as heat-transfer media, the measurement of pressure is difficult. The liquid-metal temperature in these systems ranges from 700° to 1200° C. Pressure transducers which will operate over this temperature range are not available, and their development presents many difficulties. Transducers which will operate at lower temperatures may be used by isolating them from the high temperature. This can be done by mounting them on standoff tubes so that the liquid metal is cooled before it contacts the transducer.

When standoff tubes are used on sodium potassium (NaK) or sodium systems, they must be designed to prevent oxide plugging as well as to prevent overheating the transducers. Reference 1 points out that the use of a transducer cooled to about 300° F (149° C) on a NaK system creates a cold trap. Precipitation of sodium oxide (Na_2O) in the cold trap may eventually result in plugging. However, reference 1 further points out that the concentration of Na_2O in NaK is usually so low that plugging is not a problem without continuous migration of Na_2O to the transducer. Reference 1 shows that convection currents are the main cause of oxide migration to a transducer installed on a standoff tube. Therefore, the use of a 149° C transducer on a NaK or sodium system requires that the standoff tube include a baffle section to reduce convection currents. The baffle section must be maintained above the precipitation temperature of Na_2O so that plugging does not occur there. Reference 1 discusses the design of this type of installation. On potassium and cesium systems, the high solubility of the oxides permits transducers to operate at 149° C without danger of oxide plugging.

At 260° C, the solubility of Na_2O in NaK and sodium exceeds the concentration of Na_2O usually found in NaK and sodium systems. The use of pressure transducers which operate at 260° C can, therefore, simplify the application of standoff tubes to NaK and sodium systems. The standoff tubes may be shorter than those required for 149° C transducers, and at 260° C no baffle sections are required. In addition, the shorter, simpler standoff tubes will result in higher frequency response.

For these reasons, this investigation was undertaken to evaluate commercial absolute pressure transducers claimed to be usable at 260° C or higher. Strain-gage-type transducers were evaluated since this type of transducer has been successfully used at lower temperatures on liquid-metal systems at Lewis Research Center.

A survey of manufacturers (extensive though possibly not complete) revealed two who offered strain-gage-type transducers with our three basic requirements:

(1) They be standard catalog items

(2) The compensated temperature range extend from room temperature to at least 260° C

(3) Their materials and construction be suitable for use with liquid metals

Four transducers were purchased from one manufacturer and two from the other for these tests. Specifications were largely those listed in the manufacturers' catalogs. Also available were four transducers which had been purchased previously from the second manufacturer. These four had been previously tested for a week at 260° C. The transducers covered in this report had full-scale ranges of 15, 50, and 150 psia (10, 34, and 103 N/cm^2).

A test program was designed, for the 10 available transducers, to determine the zero unbalance, sensitivity, nonlinearity, and hysteresis at temperatures up to 260° C. Also to be determined was the stability of these characteristics when the transducers were held at 260° C for at least 500 hours.

DEFINITIONS

Since there is not universal agreement on the definitions of some characteristics of pressure transducers, some of the terms used in this report are defined below:

(1) Zero pressure, not more than 0.01 percent of full-scale pressure of the most sensitive transducer tested

(2) Complete calibration, application of known pressures to the sensing end of the transducer at 20 percent intervals from zero to full-scale pressure with increasing pressure and then at the same intervals with decreasing pressure and recording the electrical output of the transducer at each pressure

(3) Zero unbalance or zero, the mean of the two electrical output readings taken for the first and last points of a complete calibration when the sensing end of the transducer is subjected to zero pressure

(4) Zero shift, change in zero unbalance accompanying a specified change of some other variable

(5) Span, algebraic difference between zero unbalance and the electrical output at full-scale pressure

(6) Sensitivity, the ratio of the span to the excitation voltage

(7) Nonlinearity, the maximum voltage difference between any calibration point and the corresponding point on a straight line drawn through the zero unbalance point and the full-scale point for any one complete calibration

(8) Hysteresis, the maximum voltage difference between any two corresponding points of a complete calibration obtained with increasing and decreasing pressure

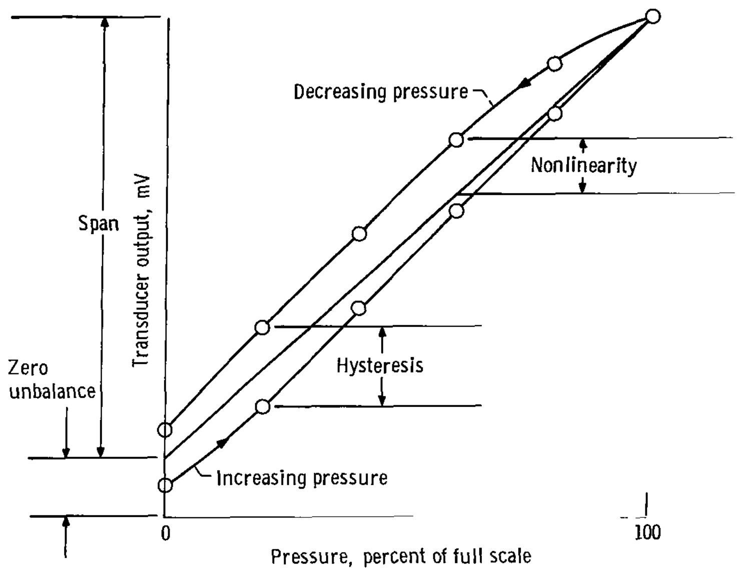


Figure 1. - Plot of hypothetical calibration illustrating definitions used for some terms.

Figure 1 illustrates the plot of a complete calibration and the terms, span, zero unbalance, nonlinearity, and hysteresis.

APPARATUS AND PROCEDURE

Transducers

Ten, unbonded strain-gage-type, absolute pressure transducers were obtained for test. Four were supplied by one manufacturer and six by another. (When it is necessary to distinguish between transducers of different manufacture, they will be called Model A and Model B. Individual transducers will be identified by the model designation followed by a number; for example, A1.) All were so constructed that the pressure medium would contact only integrally machined surfaces or welded seams Two of the transducers (B9 and B10) failed before any significant data on their characteristics could be obtained; B10 had an open bridge circuit and B9 appeared to have a leak in the sealed reference side. Therefore, data on only eight transducers are presented under results. Table I lists information on the transducers tested.

TABLE I. - MANUFACTURERS' SPECIFICATIONS FOR TRANSDUCERS TESTED AT 260° C

Transducer	Range		Temperature range				Excitation voltage, V	Full-scale output, mV
	psia	N/cm²	Compensated		Operating			
			°F	°C	°F	°C		
[a]A1	0 to 50	0 to 34	77 to 600	25 to 315	-423 to 700	-253 to 370	10	40^{+10}_{-4}
[a]A2	0 to 50	0 to 34						
[a]A3	0 to 150	0 to 103						
[a]A4	0 to 150	0 to 103						
[b]B5	0 to 15	0 to 10	70 to 600	21 to 315	70 to 600	21 to 315	5	15±0.5
[b]B6	0 to 15	0 to 10	70 to 600	21 to 315				
[b]B7	0 to 50	0 to 34	70 to 600	21 to 315				
[a]B8	0 to 150	0 to 103	77 to 520	25 to 271				
[b, c]B9	0 to 50	0 to 34	70 to 600	21 to 315				
[a, c]B10	0 to 150	0 to 103	77 to 520	25 to 271				

[a]Transducer purchased for these tests.
[b]Transducer tested at 260° C for 1 week about 16 months before these tests.
[c]Transducer failed before significant data were obtained.

Calibration System

Figure 2 is a schematic diagram of the complete calibration system.

Pressure medium. - The pressure medium chosen for these tests was the inert gas, argon. Some additional information might have been obtained by the use of liquid sodium. However, when the pressure medium was chosen, the transducers had not yet been shown to operate satisfactorily at 260° C. In view of this, it was felt that the additional information obtainable was not worth the difficulty and hazard which accompany the use of sodium.

Pressure standard. - The pressure working standard was a force-balance pressure measuring system which had been calibrated against a deadweight tester. The accuracy of this working standard is discussed later in the section Tests.

Vacuum gage. - The vacuum gage was a commercial thermocouple gage which continuously monitored the reference pressure on the pressure working standard. Also, by proper valving it could be used to check zero pressure on the transducers.

Signal conditioners. - Excitation voltages for the transducers were provided by commercial, solid-state signal conditioners stable to 0.01 percent for any combination of line voltage and load. A separate signal conditioner was provided for each transducer. Before every calibration, the excitation voltages were monitored and adjusted,

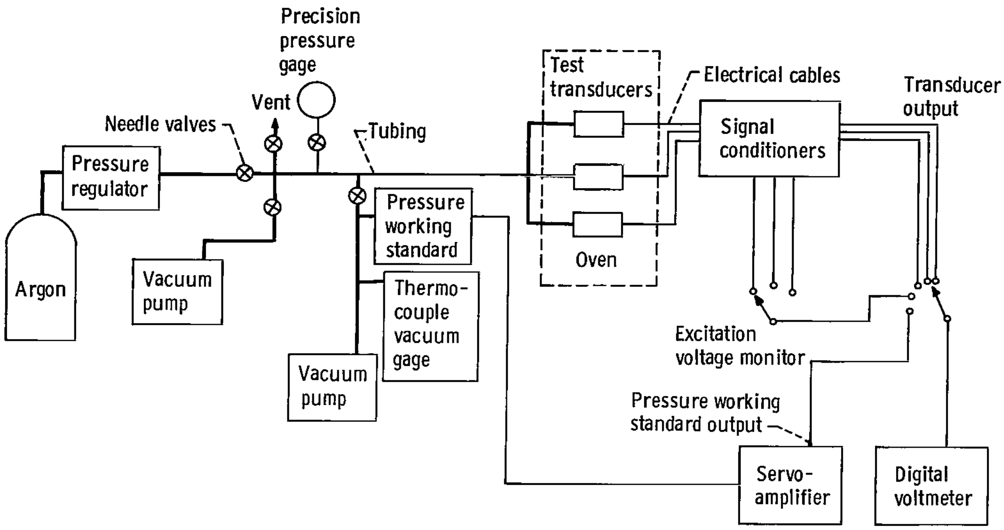


Figure 2. - Schematic diagram of calibration system for transducers of same range.

if necessary, to within 2 millivolts of specified excitation voltages.

Readout equipment. - During the tests, two readout systems were used. During the first series of tests, the transducer outputs were amplified; and the amplified voltages were read on a digital voltmeter. For the second series of tests, a more sensitive digital voltmeter was available; and the transducer outputs were read directly on the digital voltmeter without separate amplification. It is estimated that the voltage measurements made by the first system were accurate to about ±0.1 percent of the full-scale output of the transducers. For the second system, the accuracy is estimated to be about ±0.02 percent of the full-scale output of the transducers.

Ovens. - The transducers were mounted in ovens to hold them at the desired temperature. Blowers in the ovens circulated air over heating elements and in the test compartments. Thermocouples attached to the transducer cases monitored their temperatures. Records of the thermocouple outputs showed that the oven controllers held the temperature within ±0.6° C of the desired level for the duration of a test.

Tests

The test program adopted to determine the various characteristics affecting the accuracy of pressure transducers was as follows:

(1) Make complete calibrations at 25°, 93°, 149°, 204°, 218°, 232°, 246°, and 260° C. Just before each complete calibration, the transducers were exercised three times from zero to full-scale pressure and back.

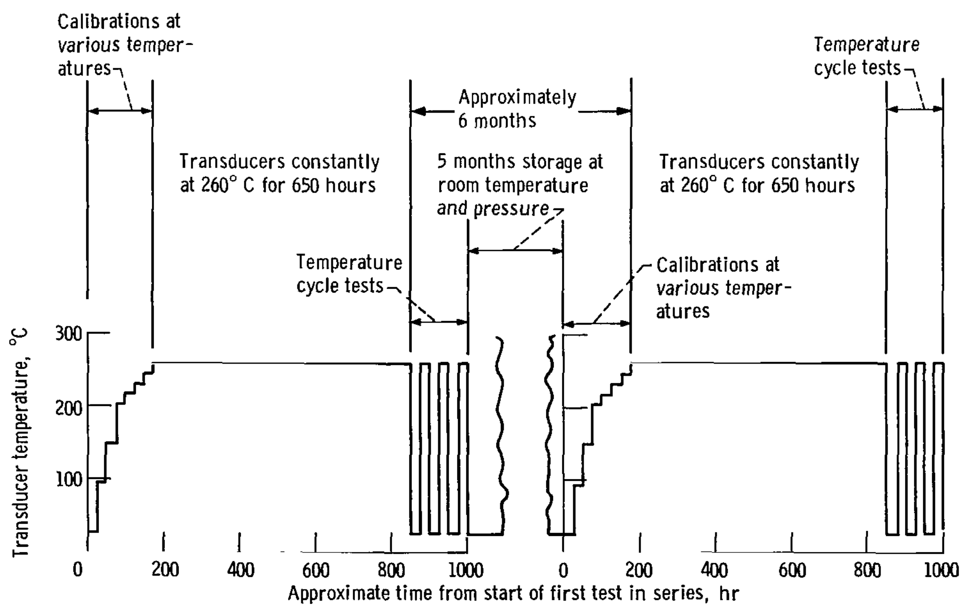
(2) Hold temperature at 260° C for about 500 hours with a complete calibration each working day. Hold pressure between calibrations at 0, 50, and 100 percent of full scale in that order, approximately one-third of the time at each pressure.

(3) Hold temperature at 260° C and pressure at 80 percent of full scale for 150 to 250 hours. Read output, at that pressure only, once each working day.

(4) Make complete calibrations alternately at room temperature and 260° C through fourth calibration at 260° C.

The different pressure levels were maintained between calibrations in step 2 to simulate conditions a transducer might encounter if used on a liquid-metal system. However, the necessary daily calibrations in step 2 impose a condition not usually encountered in use. Once a transducer is in use on a liquid-metal system it is usually used over long periods, without interruption, to measure a pressure which changes only slightly. Step 3 simulated this condition.

Transducers A1, A2, A3, A4, B7, and B8 were put through the entire test program twice. The second series of tests started about 6 months after the end of the first, and transducers B5 and B6 were included in this series. Figure 3 shows the history of the transducer temperature from the start of the first series of tests to the end of the second series. The second series was conducted partly to obtain more data. But it was also necessary because the sensitivity of the pressure working standard changed about 1/2 percent on all ranges during the first series of tests. This change was shown by



(a) First series of tests. Transducers A1,. A2, A3, A4, B7, and B8.

(b) Second series of tests. Transducers A1, A2, A3, A4, B5, B6, B7, and B8.

Figure 3. - Temperature history of transducers. Transducers either new or stored 16 months at room temperature and pressure before first series of tests.

deadweight calibrations of the pressure working standard before and after the first series of tests. Because of this change in sensitivity of the pressure working standard, no sensitivity data from the first series of tests are presented. For the second series of tests, the cause of the sensitivity shift had been eliminated. Also before each test in the second series, a point on the pressure working standard calibration was compared to the reading of a precision pressure gage accurate to about 0.1 percent of full scale. It is estimated that, for tests in the second series, pressures above zero were known to about ±0.2 percent of transducer range. By proper valving, the zero pressure could be checked with the thermocouple gage. In all cases, it is estimated that a nominal pressure of zero did not exceed 0.01 percent of full-scale pressure of the most sensitive transducer tested.

From the first series of tests it was noticed that, in most cases, the changes in nonlinearity and hysteresis were small compared to the zero shift. Therefore, during the second series of tests at 260° C, calibration points were taken only at zero, 60 percent of full scale, and full scale. Exceptions to this were the first and last calibrations of the period at 260° C and calibrations taken during temperature cycle tests. These were full calibrations. The definitions of nonlinearity and hysteresis used herein require that a calibration be examined at 20 percent intervals over the entire range. Therefore, these characteristics for the second series were computed only at the beginning and end of the time at 260° C.

RESULTS AND DISCUSSION

Transducers A1, A2, A4, B5, B6, B7, and B8 were still operating at the conclusion of the tests; A1, A2, A4, B7, and B8 had survived both series of tests. Thus, transducers A1, A2, A4, B7, and B8 had been subjected to a temperature of 260° C for 1300 hours. Transducers B5 and B6 were in the test setup for only the second series of tests, and thus were subjected to 260° C for 650 hours. Transducers B5, B6, and B7 had been subjected to a temperature of 260° C for about 170 hours before any of the tests. Transducer A3 survived both series of tests (1300 hr at 260° C) until the final temperature cycling tests during which its bridge opened.

Accuracy at 260° C

If it is assumed the transducers tested are a representative sample, a limit of error of 2 percent of span or a probable error of 1 percent of span may reasonably be expected at 260° C from a transducer of either model picked at random, if the following two requirements are met:

(1) A calibration is made at 260° C. This is necessary because from room temperature to 260° C the zero may shift 5 percent of span and the sensitivity may change as much as 2 percent of initial value.

(2) Zero shift is corrected for when necessary. This will require a zero check at 260° C whenever the transducer has been cooled below 260° C and a zero check after every 48 hours at 260° C until experience indicates otherwise.

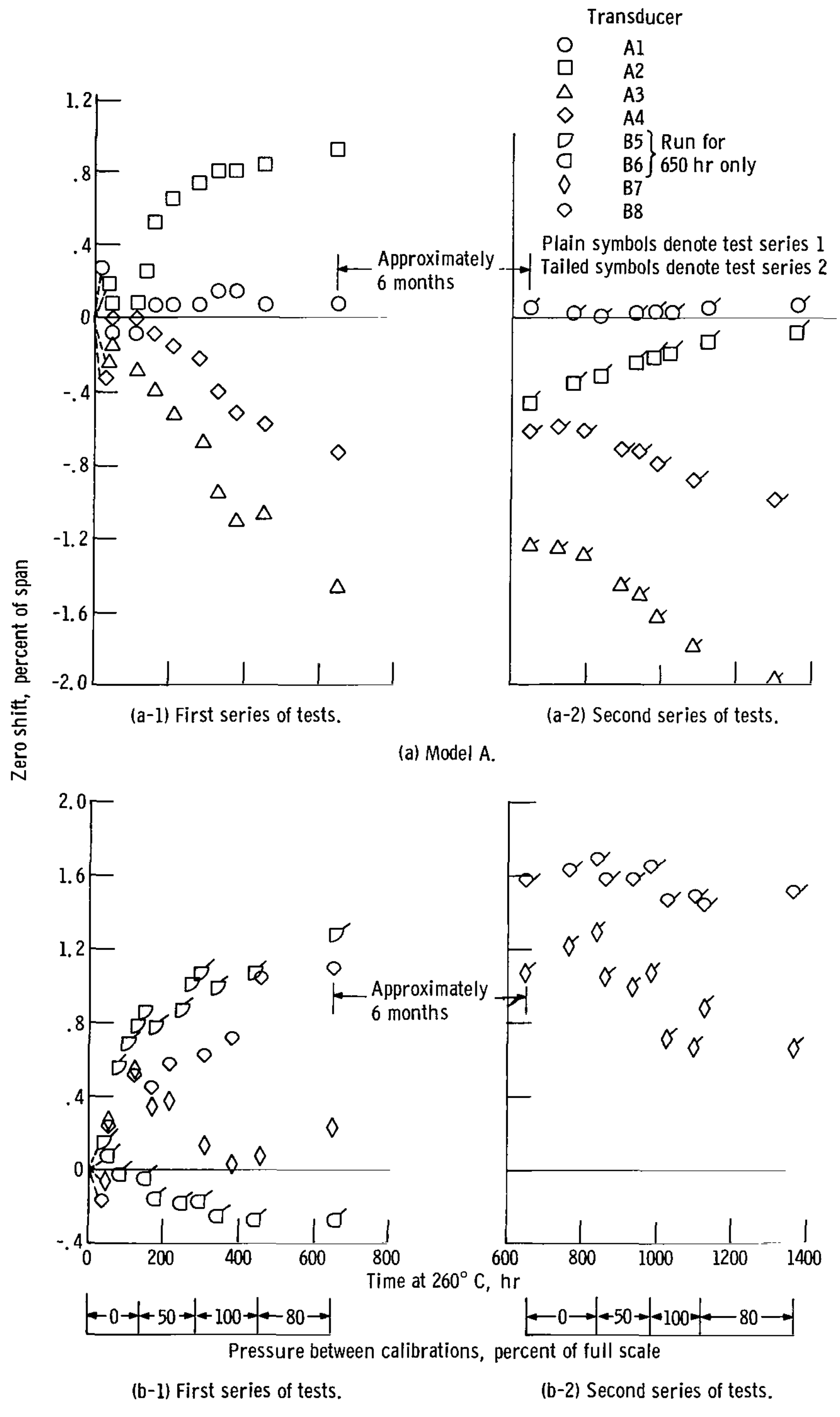
The values suggested for the limit of error and probable error were arrived at by considering what is probably a conservative estimate of random errors likely to be encountered in use. These random errors are listed in table II:

TABLE II. - RANDOM ERRORS

Error	Magnitude, percent of span
Nonlinearity	0.7
Uncertainty in calibration	.2
Span change with time	.3
Thermal variations (assuming ±3° C temperature control)	.2
Zero shift in 48 hours at 260° C	.5

Computing limit of error and probable error from these values gives 1.9 percent of span for the limit of error and 0.95 percent of span for the probable error. Nonlinearity is a random error when a straight line between the end points is used as a calibration. The value of nonlinearity exceeded 0.7 percent of span only twice in the 152 determinations made during the tests.

As the results of the tests are presented in detail, it will become apparent that transducers could be selected with smaller errors than those listed. Zero shift errors could be reduced by more frequent checks or, in most cases, by conditioning the transducers at 260° C before use. On the other hand, if zero checks cannot be made, zero shift errors may be as high as 2 percent of span after 1300 hours of use at 260° C. This would increase the limit of error to about 3.4 percent of span and the probable error to 2.1 percent of span. Here again, conditioning the transducers at 260° C would help. For example, the maximum zero shift during the second 650 hours at 260° C was about 0.7 percent of span. Hence, conditioning for 650 hours at 260° C and then making a zero check before use would permit 650 hours of use at 260° C without further zero checks with a limit of error of 2.1 percent of span or a probable error of 1.1 percent of span.



(a) Model A.

(b) Model B.

Figure 4. - Zero shift at 260° C.

TABLE III. - ZERO SHIFT AT 260° C

Transducer			Zero shift, percent of span						Maximum rate of zero shift, percent of span per hour
Number	Range		During first 650 hours at 260° C		During second 650 hours at 260° C		During 6 months between series of tests (fig. 3), net	During tests, net	
	psia	N/cm^2	Net	Maximum from start of tests	Net	Maximum from start of tests			
[a]B8	0 to 150	0 to 103	1.10	1.10	-0.07	1.69	0.47	1.51	0.0044
B5	0 to 15	0 to 10	1.28	1.28	-----	-----	-----	-----	.0070
B6	0 to 15	0 to 10	-.28	-.28	-----	-----	-----	-----	-.0030
B7	0 to 50	0 to 34	.23	.56	-.41	1.29	.84	.66	.0100
A1	0 to 50	0 to 34	.07	.14	.01	.06	-.02	.06	.0027
A2	0 to 50	0 to 34	.91	.91	.38	-.47	-1.38	-.09	-.0080
A3	0 to 150	0 to 103	-1.47	-1.47	-.73	-1.98	.21	-1.98	-.0048
A4	0 to 150	0 to 103	-.73	-.73	-.38	-1.00	.11	-1.00	-.0030
[a]B8	0 to 150	0 to 103	1.10	1.10	-.07	1.69	.47	1.51	.0044

[a]Transducer B8 is listed twice to facilitate comparing transducers of the same model or the same range.

Zero Shift

With time at 260° C and during storage. - The tests show that zero shift with time at 260° C is unpredictable either from model or range of transducer. Figure 4 shows the history of the zero shifts of the sample transducers during 1300 hours of testing at 260° C and 5 months storage at room temperature. There was a period of 6 months between series of tests, including 5 months storage at room temperature, the time required for the temperature cycle tests at the end of the first series of tests, and the time required for the calibrations between room temperature and 260° C at the start of the second series of tests. This period is labeled "Approximately 6 months" in figures 3 to 5. Table III summarizes some of the more important information to be gained from figure 4. Rates of zero shift as high as 0.01 percent of span per hour occurred. For all but one transducer (B7) the maximum rate of zero shift occurred during the first 400 hours of tests. The average net zero shift (disregarding sign) during the first 650 hours at 260° C was more than twice that for the second 650 hours. In the section Accuracy at 260° C, it was suggested that the zero be checked every 48 hours, to allow for the highest rate of zero shift encountered during the tests. In most cases, zeros tend to stabilize as transducers are held at 260° C. Such frequent zero checks are not necessary after the transducers have been at 260° C for 400 hours or more. In five cases out of six (for transducers A1, A2, A4, B7, and B8), zeros did not shift more than 0.4 percent of span from their initial values during the second 650 hours of testing at 260° C. However, if an interruption occurs in use at 260° C during which the transducer must stand at room temperature, the zero should be checked before use is resumed. The importance of this is shown in table III by the zero shifts that occurred during the period labeled "Approximately 6 months" in figures 3 to 5.

With temperature cycling from room temperature to 260° C. - Figure 5 shows zero shift with temperature cycling. The shift in this case is from the zero at the end of the first 650-hour period of testing at 260° C. The time between cycles was from 1 to 3 days, except between cycles 4 and 5. The time between cycles 4 and 5 was the 5 months storage at room temperature plus the time for calibrations at various temperatures plus the second 650-hour period at 260° C. The small changes which usually take place when the time between cycles is short may seem to make zero checks each cycle unnecessary when a transducer is used under similar conditions. However, it should be emphasized that all of the zero shifts shown in figure 5 occurred after a period of 650 hours or more at 260° C. As pointed out before, holding the transducers at 260° C appeared to have a stabilizing effect on the zeros.

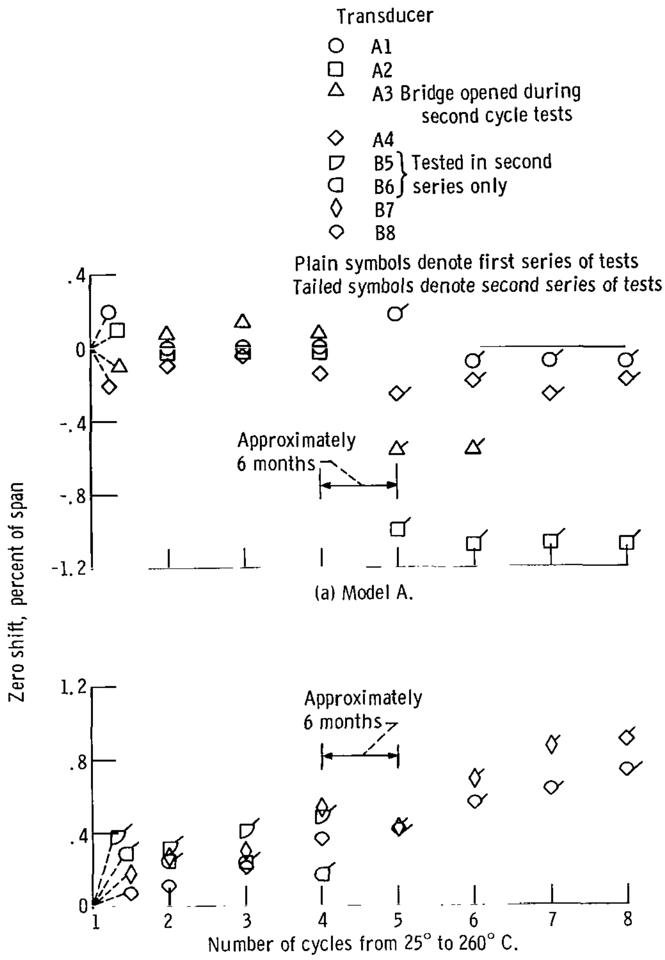
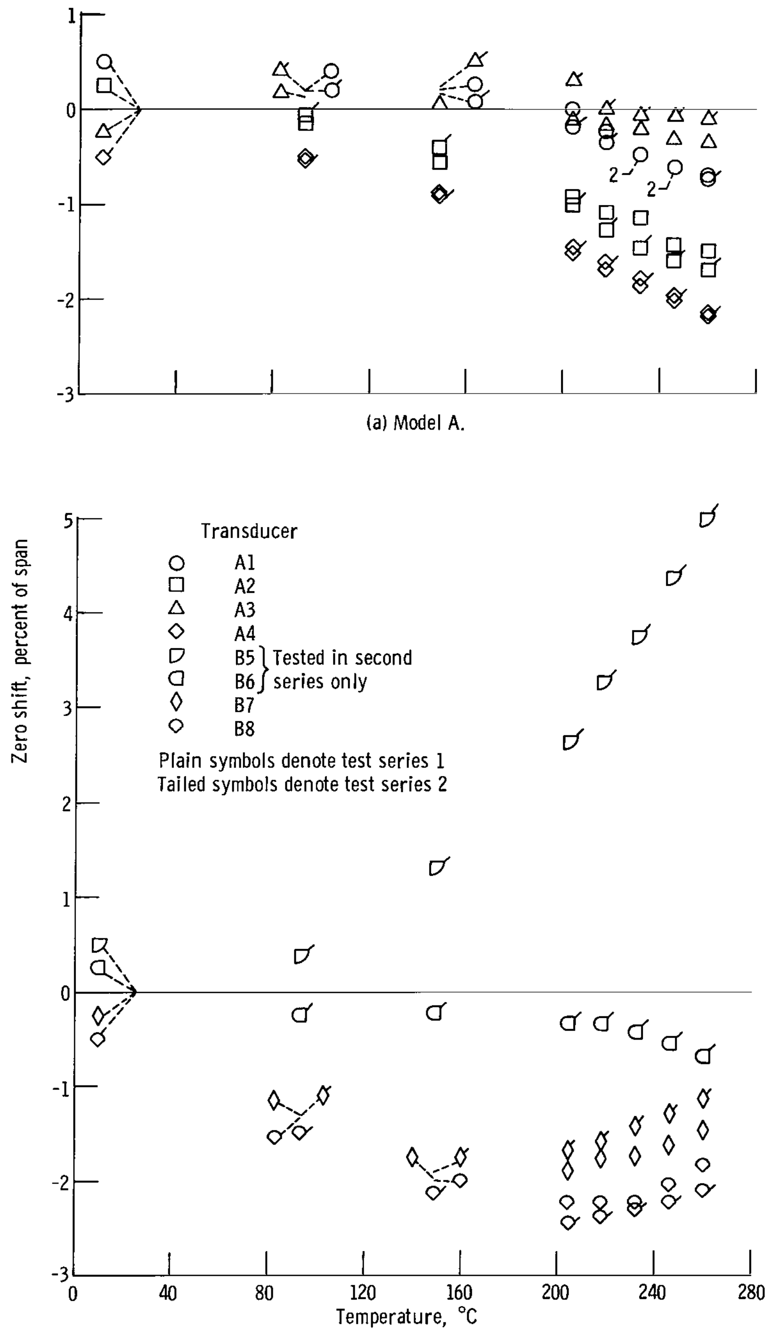


Figure 5. - Zero shift with temperature cycling.

With temperature. - Figure 6 shows zero shift with temperature. Duplicate runs were made on transducers A1, A2, A3, A4, B7, and B8. Where duplicate runs were made, the test points repeated to 0.3 percent of span or better. For transducers A1, A2, A3, A4, B6, B7, and B8, the maximum rate of zero shift computed from points at 25° and 260° C is less than the 0.01 percent of span per $^{\circ}$C. For transducer B5, the rate is 0.02 percent of span per $^{\circ}$C. Specifications require the rate of thermal zero shift to be within 0.018 percent of span per $^{\circ}$C over the compensated range.



(b) Model B.

Figure 6. - Zero shift with temperature.

Sensitivity

Specifications and conformance. - Specifications for sensitivity of the transducers were as follows:

(1) For Model A, full-scale of $4\begin{cases}+1\\-0.4\end{cases}$ millivolts per volt of excitation voltage (excitation voltage, 10 V)

(2) For Model B, full-scale output of 3±0.1 millivolts per volt of excitation voltage (excitation voltage, 5V)

All of the transducers conformed to their sensitivity specification.

Change with temperature and conformance to specification. - The maximum rates of sensitivity change with temperature were 0.01 percent of initial value per $^{\circ}$C for Model A and 0.016 percent of initial value per $^{\circ}$C for Model B. Specifications for both require the thermal sensitivity shift to be within 0.018 percent of initial value per $^{\circ}$C.

The maximum changes in sensitivity from room temperature to 260° C were 1.0 percent of initial value for Model A and 2.3 percent of initial value for Model B. Figure 7 shows the change of sensitivity with temperature.

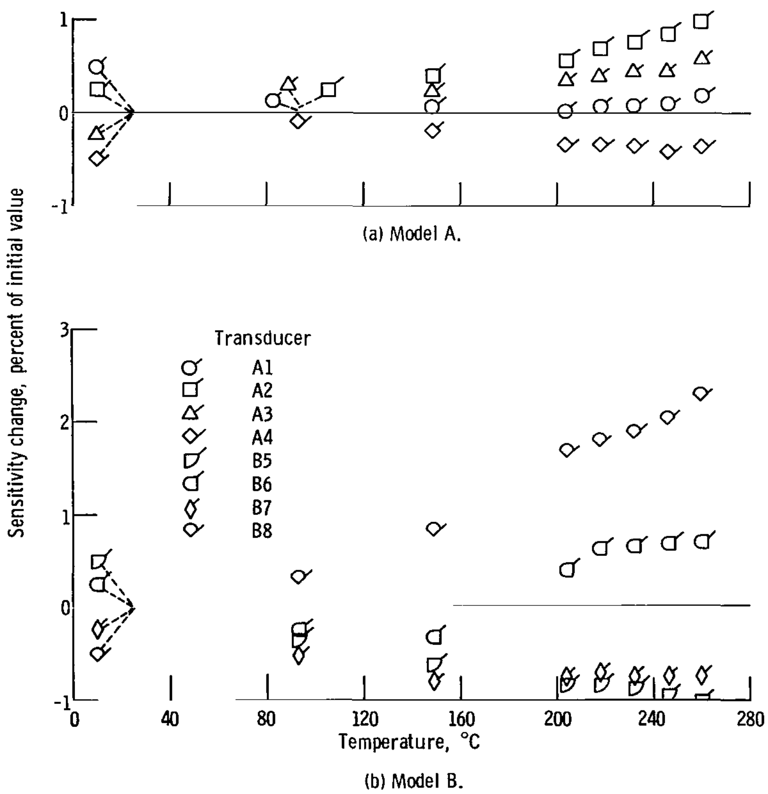


Figure 7. - Sensitivity change with temperature; data from second series of tests only.

Changes with time at 260° C and temperature cycling. - As can be seen from figures 8 and 9, sensitivity at 260° C appears to be quite stable. Practically all data points on both of these figures lie within the estimated accuracy of the pressure standard. The average change in 650 hours at 260° C (disregarding sign) for all transducers was 0.07 percent of initial value and the maximum change was 0.32 percent of initial value. The maximum change in sensitivity at 260° C caused by temperature cycling was 0.47 percent of initial value in four cycles. However, for seven of the eight transducers (A1, A2, A3, A4, B5, B7, and B8), the maximum change in four cycles was less than 0.2 percent of initial value. It should be emphasized that only data from the second series of tests were plotted for figures 7 to 9. As explained earlier, an unexpected sensitivity change in the pressure working standard took place during the first series of tests.

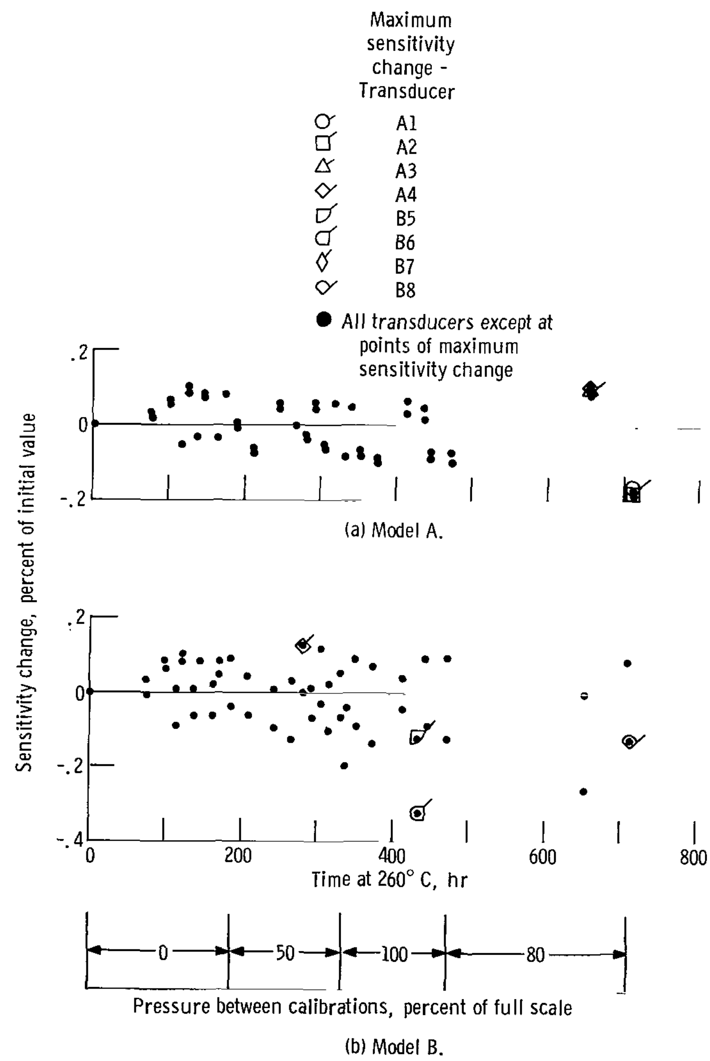


Figure 8. - Sensitivity change at 260° C; data from second series of tests only.

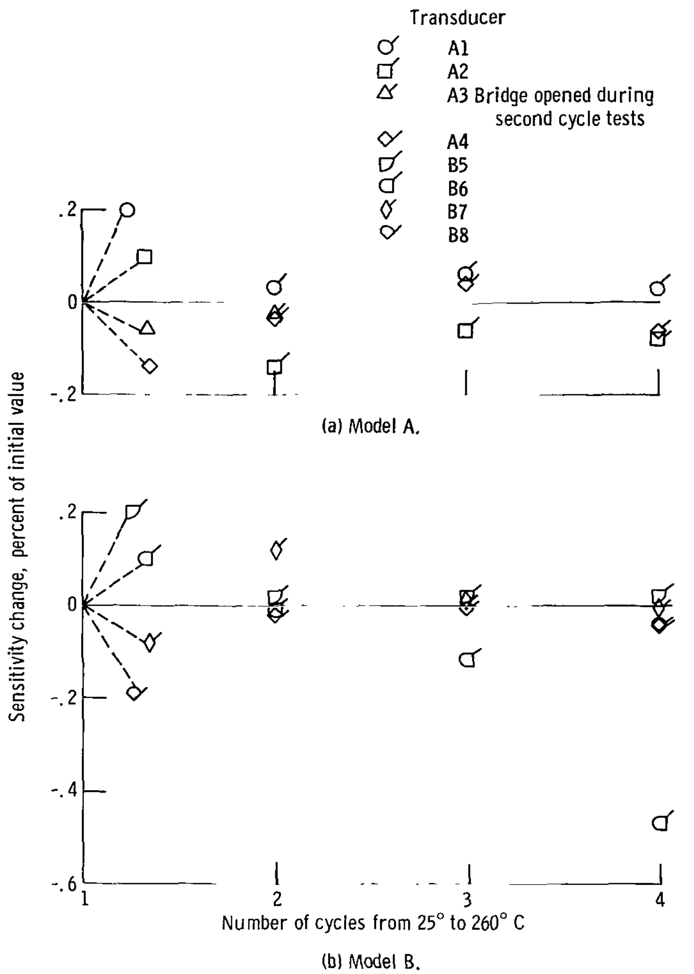


Figure 9. - Sensitivity change with temperature cycling; data from second series of tests only.

Nonlinearity and Hysteresis

Specifications and conformance. - Specifications for Model B require that nonlinearity not exceed 0.50 percent of full-scale output and hysteresis not exceed 0.25 percent of full-scale output. Specifications for Model A do not separate nonlinearity and hysteresis. However, they provide that the deviation, caused by the two combined, from the best straight line through the calibration points shall not exceed ±0.75 percent of full range. Acceptance tests made at room temperature showed that all of the transducers purchased for these tests complied with these specifications.

Mean values. - Since either nonlinearity or hysteresis is a measure of the smallest, theoretical limit of error in using a transducer, the mean values of these characteristics are of interest.

Ninety-four complete calibrations at 260° C were made on Model A transducers and 58 on Model B. Nonlinearity and hysteresis were determined for each complete calibration. Transducer A1 exhibited excessive nonlinearity and hysteresis over its entire range on two calibrations. On 22 other calibrations of the same transducer, nonlinearity and hysteresis were regarded as normal. Two other transducers of the same range, which were tested simultaneously on the pressure manifold with A1, never gave any unusal results. No explanation can be offered for this erratic behavior. Table IV shows the mean values of the nonlinearity and hysteresis at 260° C and their standard deviations for each type of transducer:

TABLE IV. - NONLINEARITY AND HYSTERESIS AT 260° C - MEAN VALUES AND STANDARD DEVIATION

Model	Nonlinearity, percent of span		Hysteresis, percent of span	
	Mean	Standard deviation	Mean	Standard deviation
[a]A	0.43	0.22	0.59	0.25
[b]A	.40	.07	.55	.09
B	.51	.13	.11	.05

[a]All calibrations included.
[b]Two calibrations of transducer A1 not included because of erratic behavior of transducer.

Changes in nonlinearity and hysteresis. - Figures 10 and 11 show nonlinearity and hysteresis plotted against temperature. Between room temperature and 260° C, changes in nonlinearity as high as 0.53 percent of span occurred. However, at 260° C, nonlinearity of a transducer never increased by more than 0.13 percent of span after the first calibration at 260° C. Between room temperature and 260° C, the largest change in hysteresis for any transducer was 0.25 percent of span. At 260° C, hysteresis never exceeded its original value at 260° C by more than 0.2 percent of span.

Calibrations examined for increases in nonlinearity and hysteresis at 260° C include all complete calibrations while transducers were held at 260° C for extended periods in both series of tests. They also include calibrations made at 260° C during temperature

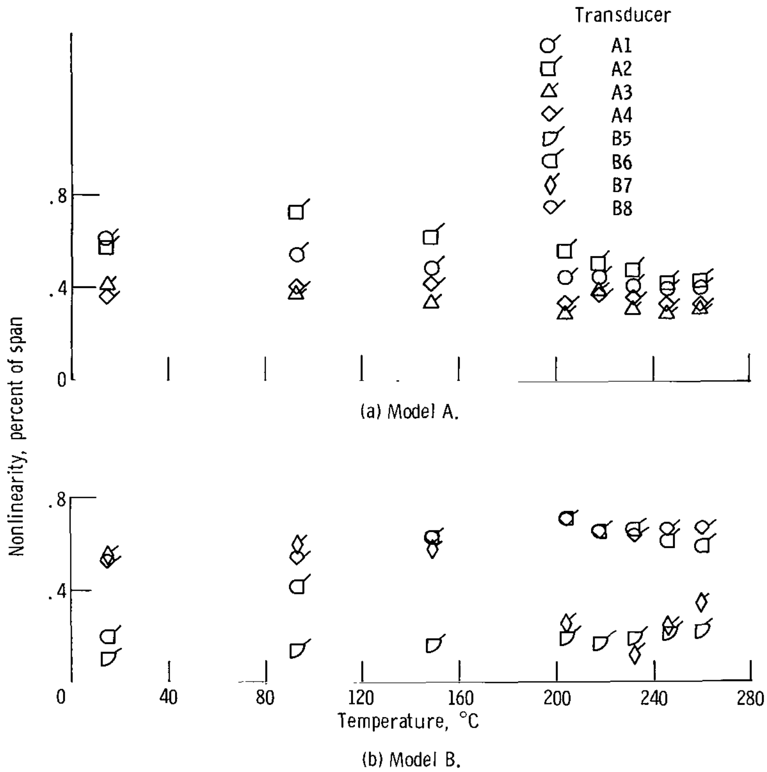


Figure 10. - Nonlinearity from 25° to 260° C; data from second series of tests only.

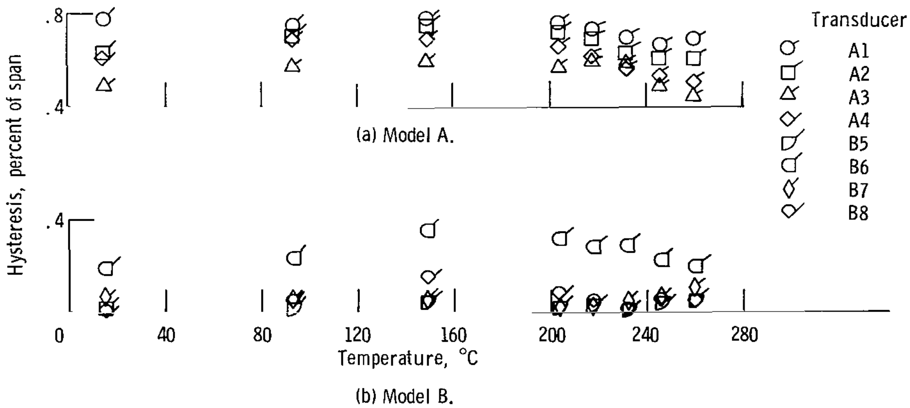


Figure 11. - Hysteresis from 25° to 260° C; data from second series of tests only.

TABLE V. - NONLINEARITY AND HYSTERESIS - EXTREME VALUES

Transducer	Complete calibrations at 260° C	Nonlinearity, percent of span				Hysteresis, percent of span			
		25° to 260° C		At 260° C		25° to 260° C		At 260° C	
		Maximum	Minimum	Original	Maximum	Maximum	Minimum	Original	Maximum
A1	24	[a]0.90	0.37	[a]0.42	0.55	[a]0.91	0.66	[a]0.76	0.76
A2	24	.72	.33	.38	.45	.75	.50	.51	.71
A3	22	.41	.28	.40	.50	.64	.44	.43	.50
A4	24	.73	.32	.55	.59	.77	.56	.58	.64
B5	5	.23	.11	.23	.23	.06	.02	.06	.06
B6	5	.70	.20	.59	.59	.36	.19	.20	.20
B7	24	.60	.13	.55	.57	.14	.03	.13	.20
B8	24	.70	.45	.64	.72	.16	.01	.13	.26

[a]Excluding two erratic calibrations. Since one of these was the original 260° C calibration, the second 260° C calibration was considered the original for transducer A1 in this table.

cycle tests in both series. Table V shows the extreme values of nonlinearity and hysteresis for individual transducers. In some cases, nonlinearity and hysteresis decreased during the 650 hours at 260° C and then increased with temperature cycling. However, they never increased beyond their values at the beginning of the first 650-hour period at 260° C by more than 0.13 percent of span for nonlinearity or 0.2 percent of span for hysteresis.

Output Drift at 80 Percent of Full-Scale Pressure

Over a 7- to 10-day period at 260° C with the pressure held continuously at 80 percent of full scale, the maximum drift in output for any transducer was less than 0.2 percent of span. However, it should be noted that these data were taken over a period of minimum zero shift. Had this test been made, for example, during the first 200 hours at 260° C, the output at 80 percent of full scale would undoubtably have changed much more for most transducers.

CONCLUSIONS

Four each of two models of commercial, unbonded strain-gage-type, absolute pressure transducer have been evaluated for use at 260° C with the following conclusions:

1. A transducer of either model will probably operate for at least 1300 hours at 260° C. Eight sample transducers operated successfully at 260° C; six of these were tested at 260° C for 1300 hours, and the other two for 650 hours. Only one of the sample transducers failed, and the failure occurred after 1300 hours of operation at 260° C.

2. Using a straight line between the end points as a calibration, a limit of error of about 2 percent of span and a probable error of about 1 percent of span may reasonably be expected at 260° C under the following conditions:

a. The transducer has been calibrated at 260° C.

b. Zero shift is corrected for whenever the transducer has been cooled below 260° C and after every 48 hours at 260° C.

3. Zero unbalance at 260° C may differ from that at room temperature by as much as 5 percent of span. Also the sensitivity may change as much as 2 percent from room temperature to 260° C. The direction and magnitude of these changes are unpredictable.

4. At 260° C, the most likely cause of large error is zero shift. Zeros shifted at rates up to 0.01 percent of span per hour. In 1300 hours at 260° C, zero shifts as high as 2 percent of span occurred. Zeros checked at 260° C before and after storage at room temperature for 5 months differed as much as 1.4 percent of span. Temperature cycling from 25° to 260° C caused some zeros to shift at a rate of about 0.1 percent of span per cycle.

5. The rate of zero shift at 260° C usually decreases with time. For seven of the eight sample transducers, the maximum rates occurred during the first 400 hours at 260° C. The average rate (disregarding sign) during the first 650 hours at 260° C was more than twice that for the second 650 hours.

6. Sensitivity at 260° C is quite stable. The average change for all transducers in 650 hours at 260° C was 0.07 percent of initial value and the maximum change was 0.32 percent of initial value. Maximum change during four cycles from room temperature to 260° C was 0.47 percent of initial value but for seven of the eight transducers the change was less than 0.2 percent of initial value.

7. Neither nonlinearity nor hysteresis at 260° C is likely to exceed the value originally determined at 260° C by more than 0.2 percent of span. This is true whether the temperature is held at 260° C, cycled from room temperature to 260° C, or stored at room temperature.

Lewis Research Center,
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