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WANL-TME-1249

August 19, 1965

Westinghouse Astronuclear Laboratory

NON-NUCLEAR QUALIFICATION TESTING OF
STRAIN GAGE TYPE DIFFERENTIAL PRESSURE
TRANSDUCERS FOR SHIELDED APPLICATION

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WANL-TME-1249

August 19, 1965

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NON-NUCLEAR QUALIFICATION TESTING OF
STRAIN GAGE TYPE DIFFERENTIAL PRESSURE
TRANSDUCERS FOR SHIELDED APPLICATION.

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Unclassified
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Authorized Classifier Date

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SUMMARY

This report presents the results of the non-nuclear qualification testing performed on CEC and Statham unbonded strain gage type differential pressure transducers. Analysis of the data from all of the tests conducted reveal that:

1. Statham Models PL 749 and CEC Models 172550 are acceptable for test car mounted, shielded application during NERVA tests. The Statham transducer is the more accurate differential pressure transducer for NERVA applications.
2. CEC transducers display zero shifts with change of pressure media and with high line pressure. Selection of units is required to provide $\pm 2\%$ measurement accuracy.
3. The CEC 4-351 and Statham PM 280 TC oil-filled high line pressure transducers are unacceptable for NERVA application in the pressure transducer panels by reason of radiation or temperature environmental problems.
4. Improved procurement requirements can by evolution provide further improvements in Models PL 749 and 172550 transducers.

INTRODUCTION

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Differential pressure measurements are required to monitor pressure drops in various segments of the flow path in NERVA test systems. These delta pressures cannot accurately be determined by absolute (or gage) pressure measurements since these differences may be 5 or 10% of the range of the instruments. A differential measurement to an accuracy of 5% would require absolute pressure measurement accuracies to within 0.2% in typical NERVA requirements. Some sacrifice in accuracy in differential measurements can therefore be tolerated.

The purpose of this report is to present the results of the non-nuclear testing performed on Consolidated Electrodynamics Corporation (CEC) and Statham differential pressure transducers. Statham Model PM280 TC, oil-filled and Model PL 749 unbonded strain gage type pressure transducers and CEC Model 4-351 oil-filled Model 172550 unbonded strain gage type pressure transducers were tested. The purpose of this effort was to establish the adequacy and possible improvements in the strain gage type pressure transducers for remote (shielded) applications on NERVA. The pressure transducers are mounted in transducer panels mounted on either side of the test car privy in the NRX tests. Similar mounting "remote" is proposed for XE tests.

BACKGROUND

Pressure transducers presently and proposed for mounting in the test car privy transducer panels are strain gage type transducers. Strain gage type transducers are used in this location for several reasons. These include:

1. The cost of strain gage pressure transducer systems is lower than variable reluctance type.
2. They do not need a demodulator, and the data system at Test Cell "A" was designed primarily for use with DC type transducers.
3. Strain gage type transducers are much easier to set up, install and calibrate.
4. Reliability is higher since no demodulator or AC voltage requirements are necessary for strain gage type transducers, there is less chance of losing signal due to related equipment failures in reactor or engine system testing.

Pressure at points of interest inside the pressure vessel is measured by extending tubing from the point of measurement to the transducers. The environmental requirements for the transducers⁵ used in the transducer panel application are given in Figure 1.

EXTERNAL PRESSURE TRANSDUCER REQUIREMENTS FOR NRX REACTOR TESTS

1. Ranges:
 - A. Differentials - 50, 100, 150, and 200 psid.
 - B. Absolute - 150, 300, and 800 psia.
2. Temperature:
 - A. Transducer Requirement - -90°F to $+300^{\circ}\text{F}$.
Actual for NRX-A3 - Left Hand Box - 127°F to 228°F .
Right Hand Box - 103°F to 155°F .
3. Radiation:
 - A. Gamma - 2.0×10^0 ergs/Gm(C)-hr. (0.055 watts/Gm(C))
 - B. Neutron ($E > 1$ Mev) - 3.5×10^{11} n/cm²-sec. (0.0028 watts/Gm(C))
4. System Accuracy: $\approx$ 2% F. S.
5. Vendors Qualification Test:
 - A. Time Constant - Less Than 5 ms.
 - B. Natural Frequency - Greater Than 5 kc.
 - C. Humidity - 100% Internal and External. No IR Loss Below Specification Limit.
 - D. Burst Pressure (2000 psi) - No Detectable Leakage Allowed.
 - E. Line Pressure - (1000 psi Applied Simultaneously to Both Ports of Differential Transducer)
Less Than 1.75% Full Range Change in Residual Unbalance Allowed
 - F. Shock - 12 Impacts of 100 g's and 11 ms Duration to Each Impact. No Defects are Permitted.
 - G. Over Pressure - (150% Full Range) - Less Than 0.5% Full Range Change in Residual Unbalance.
 - H. Temperature Exposure - One Hour Each at -320°F and at $+700^{\circ}\text{F}$.
Less Than 1.5% Full Range Change in Sensitivity and/or Residual Unbalance.

FIGURE 1

The Satham pressure transducers, Model PL 749, were selected on the basis of satisfactory testing of similar type units, PL 732.⁹ Model 749 is an improved version of earlier Model 732 transducers and is similar in characteristics of concern in NERVA applications.

The Satham unbonded strain gage pressure transducer is an electromechanical device which produces an electrical signal proportional to an applied pressure. The sensing element is a diaphragm mechanically linked to a four, active arm strain gage bridge. Only inorganic materials are used in construction. The rated excitation is 10 volts DC, but a built-in dropping resistor reduces the bridge excitation to 5 volts. The transducer output is 20 mv for full range output. Figure 2 illustrates the strain gage bridge mounting. Figures 3 and 4 are views of a disassembled Satham transducer.

The CEC unbonded strain gage pressure transducers, Model 172550, were selected on the basis of the testing of Model 171300.¹⁰ All epoxy and solder have been removed and all joints are arc welded providing a complete inorganic construction. The CEC transducer utilizes a four-active-arm, unbonded, strain gage bridge coupled to a force summing diaphragm. The bridge is excited by a 10 volt DC signal and produces a 40 mv full scale output signal. Figure 2 illustrates the diaphragm and bridge configuration.

Both the Satham and CEC transducers were purchased to the requirements of WANL Equipment Specification WANL-E-675529.³

The oil-filled pressure transducers were purchased specifically for evaluation for high line pressure application. The problem of zero shifts in making differential pressure measurements at high line pressure is a known problem with conventional strain gage type instruments.

The Stahtam, Model PM 280 TC pressure transducer was the type used successfully by Aerojet-General on NRX-A2 and the NRX-A3 test⁸ (Reference AGC drawing 701604) in a shielded transducer box. The transducer is a dual-diaphragm, bi-directional, ± 50 psid, differential pressure transducer. It is designed for high line pressure application.

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STATHAM UNBONDED STRAIN GAGE BRIDGE

CEC UNBONDED STRAIN GAGE BRIDGE

FIGURE 2

WANL-TME-1249

STATHAM PRESSURE TRANSDUCER
INTERNAL VIEW SHOWING STRAIN GAGE MOUNTING

FIGURE 3

WANL-TME-1249

STATHAM PRESSURE TRANSDUCER
INTERNAL VIEW SHOWING STRAIN GAGE MOUNTING

FIGURE 4

The CEC Model 4-357-0002 is similar to the Statham Model PM 280. It also is a dual-diaphragm, bi-directional, ± 50 psid, differential pressure transducer, and is designed for high line pressure application. The unbonded strain gage sensing principle is used.

TRANSDUCER DESIGN AND PERFORMANCE REQUIREMENTS³

The design and performance requirements of these transducers are outlined in a portion of Equipment Specification WANL-E-675529. The specified performance characteristics are listed below for reference.

Ranges (Typical): 0 - 50 psid, 0 - 100 psid, 0 - 200 psid.

Sensitivity: 40 MV $\pm$ 1% FR at rated excitation and 77°F ambient.

Linearity and Hysteresis: The combined error resulting from effects of linearity and hysteresis shall not exceed $\pm 0.75\%$ of full range output as measured from the best straight line drawn through the calibration points at any given temperature, over the compensated temperature range.

Repeatability: The output shall be within $\pm 0.10\%$ full range from the average value for three continuous full-range pressure excursions under identical conditions. The three runs shall consist of one run of ten equal pressure increments followed by two runs of four increments (20, 40, 80, 100%).

Compensated Temperature Range: -90°F to +300°F.

Thermal Zero Shift: Shall not exceed 0.01% full range per degree Fahrenheit over the compensated temperature range.

Permanent zero shift at room temperature shall not exceed .001% full range per degree Fahrenheit difference from which it has recovered within the compensated temperature range.

Transient zero shift shall not exceed 10% full range when the transducer at 77°F ($\pm 10^{\circ}$) is inserted into an oven preheated to 300°F to 325°F and allowed to stabilize at the oven temperature. The transient zero shift, one minute after insertion into the oven shall be within 5% FR of the original zero value.

Thermal Coefficient of Sensitivity: Shall not exceed 0.01% full range per degree Fahrenheit over the compensated temperature range. Permanent sensitivity shift at room temperature after temperature exposure shall not exceed .001% of full range per degree Fahrenheit difference from which it has recovered within the compensated temperature range.

Residual Unbalance: Shall not exceed $\pm 2\%$ full range output at zero applied pressure, rated excitation, and 77°F .

Acoustical Noise: The transducer shall be within stated accuracies at 150 db ambient noise level when tested in accordance with MIL-STD-810.

Line-Pressure Effects: With gaseous helium as the pressure media and with the reference pressure equal to the applied measurand pressure at 77°F , the change in residual unbalance due to internal pressure variations of from 1 psia to 1000 psia shall not exceed 0.3% FR per 100 psi.

Shock: Six impacts of 100 g in each axis with a duration of eleven milliseconds each shall not damage the transducer.

Overpressure Effect: An applied pressure 1.5 times the rated pressure held for three minutes, shall not cause a zero set to exceed 0.5% of full range output.

Time Constant: Shall not exceed 5 milliseconds for response to rise from 0 to 63% of an applied pressure-step function of rated differential or absolute pressure.

Natural Frequency: Not less than 5000 cps.

Ambient Temperature Range: The transducer shall not be adversely affected by subjection to ambient temperatures of -320°F and $+700^{\circ}\text{F}$, for periods of one hour each. Permanent zero and/or sensitivity shifts shall not exceed $\pm 1.5\%$ FR.

Radiation for One Hour of Exposure: $3.6 \times 10^{11} \text{ n/cm}^2 \text{ sec}$
 $2.0 \times 10^9 \text{ ergs/gm(c) hr}$

2. Electrical Requirements

Excitation: 10 volts (nominal) DC or AC rms; carrier frequency 0 - 20 kc subject to approval by the purchaser. Allowable excitation without damage shall be 12 volts (minimum) DC or AC rms. If the manufacturer uses padding resistors to reduce voltage across the bridge, he shall so state in his quotation.

Input Impedance: 350 ohms nominal, 330 ohms minimum, at 77°F .

Output Impedance: 350 ohms $\pm 10\%$ at 77°F .

Insulation Resistance: 50 megohms minimum at 45 volts DC between all terminals in parallel and the transducer case, over compensated temperature range.

Wire Size: The transducer shall operate with 10 mil (30-gage) leads having a nominal resistance of 10.4 ohms/100 ft.

3. Construction Requirements

Pressure Media: Gaseous hydrogen (on both sides of sensing element in differential types).

Over-Pressure Protection: The sensing element shall be capable of withstanding over pressure of 150% of rated pressure. If a mechanical stop is used for this protection, it shall be set at or above 125% of the transducer full-range pressure rating.

Pressure-Sensing Elements: Flat-or convoluted-diaphragm force-summing area with strain gage bridge consisting of four active arms is preferred.

Radiation: All materials used must be inorganic and with a combined boron and cadmium content of less than 30 ppm.

Brazing: Brazing alloys with softening point above 1000°F are acceptable. All flux must be removed after silver soldering. No soft soldering will be permitted due to high ambient environmental temperature.

TRANSDUCER TEST RESULTS

The testing included both absolute pressure as well as differential pressure transducers. The transducers are identical except the absolute units maintain a small constant pressure on the reference side of the diaphragm.

- A. Statham Pressure Transducers^{1, 6}
 Model PL 749 differential pressure transducer
 Model PA 749 absolute pressure transducer

The qualification test program was conducted to determine compliance of the Statham pressure transducers to the WANL Specification. It was required that qualification tests be performed on three Model PL 749 transducers (one of each range ordered) and one Model PA 749 transducer in accordance with WANL-E-Specification 675529, paragraphs 3.3.5 and 3.3.11 through 3.3.19 inclusive. The transducers tested included a 50 psid, 150 psid, 200 psid and an 800 psia unit. The test specimens were randomly selected.

The requirements the Statham transducers were tested to and the results include:

1. Resolution

Requirement: The transducer shall be capable of resolving a 0.01% of full scale output change stimulated by a 0.01% of full range pressure change.

Test Methods: The high side of the transducer was pressurized to a pressure equal to or less than 0.01% of full range pressure. The galvanometer was brought to a null indication with the K-3 potentiometer. The pressure was then released bringing the high side of the transducer back to ambient pressure.

As the pressure on the transducer returned to ambient pressure, the deflection of the galvanometer was noted.

Test Results: The transducers were able to resolve a pressure change of less than 0.01% of their full range pressure, which satisfies the requirements of this specification.

2. Line Pressure

Requirements: With gaseous helium as the pressure media and with the reference pressure equal to applied pressure measured at 77°F, the change in residual unbalance due to internal pressure variations of from 1 psia to 1000 psia shall not exceed 0.2% full range per 100 psi. This test applies only to the three differential pressure transducers.

Test Method: With the transducer excited with rated voltage, the pressure on both ports was reduced to 1 psia and the outputs of the transducers were measured and recorded in 200 psia increments to 1000 psia. Above atmospheric pressure helium was used as the pressure media.

Test Results: The resulting output change for each instrument was converted into per cent of full range output per 100 psi to prove conformance to the specification.

The change in residual unbalance of all test specimens were within the requirements of this specification. The greatest change of 0.173% FR/100 psi was found at the 201 psia pressure point on the 50 psid unit.

Additional high line pressure tests were performed on two 50 psid units to verify results. Pressure was applied to both sides of the diaphragm in 100 psi steps to 800 psi. What was thought to be zero shift due to line pressure was actually due to change of pressure media. High line pressure tests performed after the system was purged with the test gas showed the transducers to be insensitive to line pressure (Figure 7).

3. Time Constant

Requirement: 5 millisecond maximum response time to 63% of applied step function. Note: During time constant testing the 800 psia transducer failed in an unbonded strain gage of the "zero-gage length" design the strain wire is protected against overtravel by the zero-gage spring, which is adjusted to a load below the breaking point of the wire. This protection is only valid for a deflection at a frequency which the spring can follow. In an 800 psi transducer the diaphragm natural frequency is greater than the spring frequency. If the diaphragm travels in the negative direction at a frequency greater than the spring frequency the strain wire in compression will break. With the pressure step function close to the full range of the transducer this phenomenon occurred. The unit was taken apart and found to have broken compression elements. Another substitute transducer was used for another shock tube test with the step function pressure adjusted to 400 psi, half the rated full range of the transducer, to avoid negative travel.

Test Method: The transducer was installed in the expansion section of a shock tube. The driver section of the shock tube was pressurized and the diaphragm separating the driver section was ruptured. The response of the transducer to the shock wave (generated when the diaphragm was ruptured) was recorded on an oscilloscope.

Test Results: Using photographs from the oscilloscope camera, the response time from 0 to 63% of the applied step function was calculated. Results are tabulated below:

<u>Pressure Range</u>	<u>Response Time</u>
50 psid	1.7 msec
150 psid	0.4 msec
200 psid	0.2 msec
800 psia	0.3 msec

The response time of all the test items was within the 5 millisecond response requirement.

4. Natural Frequency

Requirement: The natural frequency of the transducer will not be less than 5000 cps.

Test Method: With 10 volts DC applied to the input terminals of the transducer, the output terminals were connected to the vertical axis of an oscilloscope. The transducer was then gently rapped with a plastic mallet and the sinusoidal output noted on the oscilloscope. The horizontal sweep frequency was adjusted to obtain one cycle per centimeter. Without re-adjusting the oscilloscope's sweep frequency, an oscillator was connected to the vertical axis of the oscilloscope and adjusted to give a frequency equal to the frequency obtained from the transducer.

Test Results: The frequencies of the oscillator which are the calibrated natural frequencies of the transducers, are tabulated in the following table:

<u>Pressure Range</u>	<u>Natural Frequency</u>
50 psid	9.8 KC
150 psid	9.95 KC
200 psid	12.2 KC
800 psia	15.3 KC

5. Humidity

Requirement: The transducer shall operate within the limits of performance at 0 to 100% relative humidity, liquids or condensed gases need not be in contact with the strain elements during humidity test.

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STATHAM PRESSURE TRANSDUCER
DEFINITIONS OF AXES FOR MECHANICAL SHOCK TESTS

FIGURE 5

Test Method: The transducers were placed in a humidity chamber. Tubing was connected to the pressure and reference ports of each transducer and was vented to the outside of the chamber. The chamber was raised to 130°F in a one hour period. During the next three hour period, the temperature of the humidity chamber was decreased to 100°F +0, -20°F. The transducers were pressurized and their outputs recorded.

Test Results: All test specimens complied with the requirements of the performance specifications listed below, during humidity testing:

Linearity and Hysteresis:	Less than $\pm 0.75\%$ FS
Residual Unbalance:	Less than $\pm 2.0\%$ FS
Sensitivity:	19 to 20 millivolts
Insulation Resistance:	50 megohms minimum

6. Mechanical Shock

Requirement: Six impacts of 100 g, eleven milliseconds in each of the three mutually perpendicular axes shall not cause a zero set in excess of 0.5% of full scale.

Test Methods: The fixture was mounted on the shock machine. A 100 g shock of eleven milliseconds duration was applied three times in both directions of the three mutually perpendicular axes. Before the test and after completion of the shock test, the zero balance of the transducers was recorded. The insulation resistance was also measured after shock testing. Figure 5 shows the definition of the instruments' axes.

Test Results: Zero unbalance of the transducers before and after shock testing is given in the following table:

<u>Pressure Range</u>	<u>Zero Prior to Shock Test</u>	<u>Zero After Shock Test</u>	<u>Zero Set mv</u>	<u>Zero Set % FS</u>	<u>Insulation Resistance</u>
50 psid	- .122 MV	- .080 MV	+ .042	+ .217	160 megohms
150 psid	- .320 MV	- .308 MV	+ .012	+ .060	10K megohms
200 psid	- .262 MV	- .240 MV	+ .022	+ .108	2000 megohms
800 psia	- .123 MV	- .117 MV	+ .006	+ .030	1800 megohms

There was no evidence of physical damage as a result of the shock tests.

7. Acoustical Noise

Requirement: The transducer shall be within stated accuracies at 150 db ambient noise level when tested in accordance with MIL-STD-810.

Test Method: During the acoustic test, the transducers were excited with rated voltage and the output voltages were monitored on an oscillograph. Upon completion of the test, the transducers were calibrated.

Test Results: There was no evidence of physical damage as a result of the test. The performance of the transducers following the noise exposure was within the requirements of the specification.

8. Ambient Temperature

Requirement: The transducer shall not be adversely affected by subsection to ambient temperatures of -320 and 700°F for a period of one hour each. Permanent zero and/or sensitivity shifts shall not exceed $\pm 1.5\%$ full scale.

Test Method: The transducers were connected to a dead weight tester. A potential of 10 volts DC was applied to each transducer. The outputs of the transducers were measured and recorded at four equally spaced pressure increments, ascending and descending, through the full pressure range at room temperature. The transducers were subjected to a temperature of -320°F and 700°F for a one hour period. (After the -320°F condition the transducers were allowed to return to room temperature ambient conditions before being subjected to the 700°F temperature.) After being subjected to the extreme temperatures, the transducers were again calibrated at room temperature and the data evaluated for zero and sensitivity shifts. The insulation resistance was measured at the end of each extreme temperature exposure.

Test Results: Four transducers were tested and found to be within specification on sensitivity shift after ambient temperature testing, but their zero unbalance shift was out of specification. The results are listed in the following table:

<u>Model</u>	<u>Sensitivity Shift</u>	<u>Zero Shift</u>
PL749TC-50-350	1.2% FS	+15.4% FS
PL749TC-150-350	0.0% FS	+ 5.8% FS
PL749TC-200-350	0.0% FS	+ 8.0% FS
PA749TC-800-350	0.1% FS	+18.2% FS

The 150, 200, and 800 psi transducers were subjected to more testing to determine the reason of the zero balance shift after ambient temperature. The 50 psi transducer was subjected to a 2000 psi burst pressure as called out in one of the other requirements and could not be used as one of the units for the failure analysis. The

terminal covers were machined off of the three transducers so access could be made to the zero balance and zero compensation resistors.

Jumper wires were then placed across the resistors to obtain the true unbalance of the strain gage bridge. The transducers were again subjected to an ambient temperature of 700°F and the zero unbalance recorded. After nine temperature cycles to 700°F the transducers stabilized and were within specification. See Table 1. It was found that the zero shift of the transducers was less with the compensation and balance resistors out of the circuit. It was also found that the transducers with the larger resistance value for the compensation circuits had the largest zero shifts. Transducer No. 52 had approximately one-third the resistance value in the compensation circuit as did the others. From these two facts it was concluded that most of the zero set due to the 700°F exposure was due to the resistance change in the balance and compensation circuit.

The 700°F is required only if there is a system malfunction. The maximum expected pressure panel temperature is 300°F in NERVA applications.

9. Over Pressure

Requirement: An applied pressure to 1-1/2 times the rated pressure range held for three minutes shall not cause a zero set to exceed 0.5% of full scale output.

Test Method: The transducers were connected to a dead weight tester. A potential of 10 volts DC was applied to each transducer. The outputs of the transducers were measured and recorded at four equally spaced pressure increments, ascending and descending through the full scale pressure range. Pressure equal to 1-1/2 times the pressure range was applied to each transducer for a period of three minutes. The output at the over pressure was recorded. After the over pressure, the transducers were recalibrated and the data evaluated for zero sets.

Test Results: There was no evidence of physical damage or zero set exceeding the 0.5% FS specification limit after over pressure.

TABLE 1
ZERO STABILITY TEST

Test No.	Test Description	Room Temperature Zero Shifts, % Full Scale					
		PL749TC-150 Shift This Cycle	No. 5 Total Shift	PL749TC-200 Shift This Cycle	No. 22 Total Shift	PA749TC-800 Shift This Cycle	No. 57 Total Shift
1	Original Qualification Test	+5.85	+ 5.85	+ 8.03	+ 8.03	+18.16	+18.16
2	1 hour 700°F Exposure	+2.70	+ 8.55	+16.20	+24.23	+ 4.50	+22.66
3	1 hour 700°F Exposure	+1.60	+10.15	+ 6.60	+30.83	+ 3.30	+25.96
4	1 hour 700°F Exposure	+0.95	+11.10	+ 1.72	+32.55	* ---	-----
5	2 hour 700°F Exposure	+1.01	+12.11	+ 3.05	+35.60	+ 1.67	+27.63
6	1 hour 700°F Exposure	+0.50	+12.61	+ 2.22	+37.82	+ 0.66	+28.29
7	1 hour 700°F Exposure	+0.30	+12.91	- 0.20	+37.62	+ 0.20	+28.49
8	1 hour 700°F Exposure	+0.56	+13.47	* ---	-----	+ 0.15	+28.64
9	1 hour -320°F Exposure	-0.36	+13.11	+ 0.69	+38.31	- 0.15	+28.49
10	1 hour 700°F Exposure	+0.71	+13.82	+ 0.20	+38.51	+ 0.51	+29.00

* Lead on terminal ring broke prior to zero balance reading.

10. Burst Pressure

Requirement: A pressure of 2000 psia on differential transducers, or 1-1/2 times range to 2000 psia, whichever is greater, on absolute transducers will not cause a leakage.

Test Method: A 50 psid transducer was connected to a hydraulic pressure hand pump. The pressure was slowly increased to 2000 psia. After reaching 2000 psia, the pressure was held on the unit for a period of 5 minutes while the transducer was examined for leakage.

Test Results: There was no evidence of leakage during burst pressure testing. Abbreviated electrical testing following burst pressure indicated the transducer was still electrically operable although the transducer indicated a change in output characteristics which were beyond the limits of the specification.

11. Pressure Media

Test Method: Two 50 psid pressure transducers were tested to observe the effects on zero balance as the pressure media is varied. Nitrogen, helium and hydrogen were used respectively, with the system purged before each test.

Test Results: The zero balance was not affected by changing the pressure media. This indicates that the heat transfer from the strain wires to the case through the pressure media is insignificant.

12. Temperature Characteristics

In preparing the pressure transducers for the NRX-A3 test, they were calibrated at 77°F and +300°F. Figure 6 shows the typical calibration of a 50 psid transducer at these two temperatures. The difference between the two curves is less than 1.0% full scale.

FIGURE 6

B. Statham Model PM 280 TC

This Statham transducer is a dual-diaphragm, bi-directional, ± 50 psid, differential pressure transducer designed to measure small bi-directional pressures with high line pressure. The unbonded strain gage principle is used with a four-active-arm spring type sensing element in an oil damping fluid and a force summing diaphragm.

1. Materials

The materials in this type of transducer limits its use in a radiation environment. Hooker Chemicals' Fluorolube oil for damping and teflon are used. When Fluorolube is exposed to 0.9×10^8 rads, an appreciable amount of acidic material (HCL) is liberated. This can cause corrosion of iron and copper components. This radiation level is slightly less than the expected radiation level for a test car mounted pressure transducer. However, it is close enough to declare these units unsuitable for use in the privy mounted transducer panels.

2. Test Results

The results of the tests conducted are given in Table II. The transducers were tested for high line pressure effects indicating no zero shifts with pressure to 800 psi applied to both diaphragms. Because these transducers were purchased on an Aerojet-General Corporation drawing, (701604), they were tested to the specified temperature range of $+30^{\circ}\text{F}$ to $+130^{\circ}\text{F}$ (Table II). The thermal zero shift is greater than the specified .001% per degree F. (See Table)

C. CEC Pressure Transducers^{2, 6, 7}

Model 172550 differential pressure transducer

Model 172549 absolute pressure transducer

The qualification test program was conducted to determine compliance of the CEC pressure transducers to the WANL Specification. One 150 psia transducer and two 100 psid transducers were submitted for qualification testing.

TABLE II

Transducer	Sensitivity (mv)	Ambient Linearity (% F.R.)	Ambient Hysteresis (% F.R.)	Thermal Zero Shift (% F.R. Amb./°F)	Thermal Sens. Shift (% F.R. Amb./°F)	High Line Pressure Zero Shift (% F.R. Amb)
CEC ± 50 D S/N 1012 Type 4-351-0002 0 to +50 psid	+39.9	-0.2	+0.25	0.0	0.016	0.0
CEC ± 50 D S/N 1012 Type 4-351-0002 0 to -50 psid	-39.9	+0.2	-0.25	0.0	0.0	0.0
Statham ± 50 D S/N 2597 Type PM280TC 0 to +50 psid	+30.3	+0.25	-0.66	0.013	0.006	0.0
Statham ± 50 D S/N 2597 Type PM280TC 0 to -50 psid	-29.9	-0.87	+1.0	0.013	0.007	0.0
Statham ± 50 D S/N 2598 Type PM280TC 0 to +50 psid	+30.4	+0.4	-0.16	0.0	0.0	0.0
Statham ± 50 D S/N 2598 Type PM280TC 0 to -50 psid	-28.5	-2.46	+1.05	0.0	0.007	0.0

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The requirements of the CEC transducers were tested to and the results include:

1. Resolution

Specified as "Infinite" by CEC and accepted without testing by WANL.

2. Line Pressure

Requirement: With gaseous helium as the pressure media and with the reference pressure equal to the applied measurand pressure at 77°F, the change in residual unbalance due to internal pressure variations of from 1 psia to 1000 psia shall not exceed 0.3% FR per 100 psi.

Test Method: With the unit connected such that the reference port is measuring the same pressure as the positive pressure port, measure and record the residual unbalance at the following pressures (using helium pressure media): Atmospheric pressure, 1 psia, atmospheric pressure, 200, 400, 600, 800, and 1000 psia.

Test Results: Change in unbalance of all test specimens were within requirements of the specification.

<u>Pressure Range</u>	<u>% FR/100 psia</u>
0-100 psid	0.154
0-100 psid	0.095

Three additional 100 psid units were tested for verification of the above results. The results of that test are given below and in Figure 7.

	<u>Pressure Range</u>	<u>% FR/100 psia</u>
0-	0-100 psid	0.256
	0-100 psid	0.088
	0-100 psid	0.21

3. Time Constant

Requirement: Shall not exceed 5 milliseconds for response to rise from 0 to 63 per cent of an applied full scale step pressure.

LINE PRESSURE TESTS ON DIFFERENTIAL PRESSURE TRANSDUCERS

FIGURE 7

Test Methods

Install the unit in the shock plate with the unit pressurized, release the pressure by bursting the diaphragm and record the decay time.

Test Results

The units tested were all within specification.

<u>Pressure Range</u>	<u>Time Constant (ms)</u>
0-150 psia	2.0
0-100 psid	1.4
0-100 psid	1.6

4. Natural Frequency

Requirement

The natural frequency of the transducer will not be less than 5000 cps.

Test Method

Tap the unit lightly to excite the natural frequency and record the output.

Test Results

All of the units tested had a natural frequency greater than 5000 cps.

<u>Pressure Range</u>	<u>Natural Frequency (cps)</u>
0-150 psia	20,600
0-100 psid	19,400
0-100 psid	18,600

5. Humidity

Requirement

The transducer shall operate within specified limits of performance at 0 to 100% relative humidity. Liquids or condensed gases need not be in contact with the strain elements during humidity testing.

Test Methods

Install the unit in the humidity chamber and subject the transducer to 0 to 100% relative humidity for a minimum of 5 hours. Measure and record the insulation resistance at the end of 5 hours.

Remove the unit and check the insulation resistance, residual unbalance, sensitivity, linearity and hysteresis.

CEC PRESSURE TRANSDUCER
DEFINITION OF AXES FOR MECHANICAL SHOCK TESTS

FIGURE 8

Test Results

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The transducers were not adversely affected.

<u>Pressure Range</u>	<u>Insulation Before</u>	<u>Resistance During</u>	<u>(Megohms) After</u>
0-150 A	80	50	90
0-100 D	800	100	800
0-100 D	10,000	50	900

Calibration After Humidity Test

<u>Residual (mv)</u>	<u>Sensitivity (mv)</u>	<u>L & H % FR</u>
-0.460	41.892	± 0.37
-0.725	41.329	± 0.37
+0.400	42.155	± 0.48

6. Mechanical Shock

Requirements

Six impacts of 100 G in each axis with a duration of eleven milliseconds each shall not damage the transducer. Figure 8 defines the transducers' axes.

Test Method

Install the unit on the shock table. Subject the unit to six (6) impacts in each of the two axes (sensitive and cross). Figure 8. The shock level shall be 100 g's half sine with a duration 11 ± 2 milliseconds.

Recheck residual unbalance, sensitivity and insulation resistance.

Test Results

The transducers were not adversely affected by the shock test.

<u>Pressure Range</u>	<u>Residual (mv)</u>	<u>Sensitivity (mv)</u>	<u>Insulation Resistance (Megohms)</u>
0-150 A	-0.060	41.674	> 10,000
0-100 D	-0.530	41.500	2,000
0-100 D	+0.120	42.323	> 10,000

7. Ambient Temperature

Requirement

The transducer shall not be adversely affected by subjection to ambient temperatures of -320°F to $+700^{\circ}\text{F}$, for periods of one hour each. Permanent zero and/or sensitivity shifts shall not exceed $\pm 1.5\%$ FR.

Test Method

The outputs of the transducers are recorded at the 20% F.R. increments and decrements at room temperature. The transducers are subjected to -320°F for one hour, returned to room temperature and calibrated as described above. This procedure is repeated at 700°F . The insulation resistance and zero and sensitivity shifts are recorded.

Test Results

All transducers were within specification after the temperature tests.

<u>Pressure Range</u>	<u>Thermal Zero Stability (% F.R.)</u>	
	<u>After -320°F</u>	<u>After $+700^{\circ}\text{F}$</u>
0-150 psia	+0.07	-1.08
0-100 psid	-0.04	+0.40
0-100 psid	-0.04	+0.79
<u>Pressure Range</u>	<u>Thermal Sensitivity Stability (% F.R.)</u>	
	<u>After -320°F</u>	<u>After $+700^{\circ}\text{F}$</u>
0-150 psia	+0.11	+0.23
0-100 psid	+0.26	-0.31
0-100 psid	+0.13	-0.67
<u>Pressure Range</u>	<u>Insulation Resistance (Megohms)</u>	
	<u>-320°F</u>	<u>$+700^{\circ}\text{F}$</u>
0-150 psia	> 10,000	90
0-100 psid	> 10,000	80
0-100 psid	> 10,000	80

8. Over Pressure

Requirement

An applied pressure 1.5 times the rated pressure held for three minutes, shall not cause a zero set to exceed 0.5% of full range output.

Test Method

Measure and record the residual unbalance.

Apply 1.5 times rated pressure and release.

Recheck residual unbalance, sensitivity, linearity and hysteresis.

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Test Results

All transducers were within specification after the test.

Pressure Range	Residual Unbalance (mv)		Residual Shift (% FR)
	Before Overpressure	After Overpressure	
0-150 A	-0.065	-0.075	-0.02
0-100 D	-0.590	-0.579	+0.03
0-100 D	+0.080	+0.110	+0.07

9. Burst Pressure

Requirement

A pressure of 2000 psia on differential transducers or 1-1/2 times range to 2000 psia, whichever is greater, on absolute transducers will not cause a leak.

Test Method

A 0-100 psid transducer was placed in a pressure bomb for this test. The pressure was increased to 2000 psia and the transducer was examined for leaks. An additional leak test was performed after the 2000 psia had been removed.

Test Results

There were no detectable leaks at 2000 psia and no leak through the diaphragm after the 2000 psia burst pressure test.

10. Pressure Media Effects

Three 100 psid transducers were tested with air and with helium as the pressure media. The transducers were purged when the change was made from air to helium. The results are given below.

Transducer	Zero Unbalance with Air (mv)	Zero Unbalance with Helium (mv)	Full Scale Sensitivity	Zero Shift % F.R.
1	+0.4	+0.6	40.0	+0.5
2	-0.5	-0.9	42.8	-0.93
3	+0.2	-1.4	41.2	-3.88

It can be seen that each transducer had its own characteristics. During preparation of the pressure panels for the NRX-A4 test, twenty-eight (28) CEC pressure transducers had zero shifts due to a change in pressure media ranging from 0% FR to 5% FR.

An additional test was performed on transducer No. 2 to observe the change in zero balance, when changing pressure media from helium to hydrogen.

The system was purged before the application of each gas and the zero balance recorded. There was no change in zero balance, when changing the pressure media from helium to hydrogen.

11. Temperature Characteristics

CEC pressure transducers mounted in the pressure panel for the NRX-A3 and A4 tests were calibrated at 77°F and 300°F. Figure 9 is a typical calibration of a 50 psid transducer. The difference between the two curves is less than 1 per cent full scale.

D. CEC Model 4-351-0002

This pressure transducer is a dual-diaphragm, bi-directional, ± 50 psid, differential pressure transducer. The transducers are designed for the measurement of small bi-directional pressures with high line pressure. The unbonded strain gage principle is used with a four-active-arm spring-type sensing element and a force-summing diaphragm. With this sensing element attached to the diaphragms, pressure against either diaphragm produces a displacement which changes the resistance of the active arms. This in turn causes an electrical output proportional to the applied pressure. The cavity containing the bridge is filled with an oil damping fluid.

1. Materials

The mounting of the transducer in a flux region of 3.6×10^{11} n/cm²sec and 2.0×10^9 ergs/gm (c) hr does not create any difficult materials problems. The materials in this transducer that limit its rise in radiation are teflon, neoprene and Dow Corning 210 Silicone damping fluid. The damping fluid freezes at -100°F and begins to get at 1.7×10^{10} ergs/gm with no off-gas, making it acceptable for the shielded application.

FIGURE 9

2. Test Results

The CEC transducer was tested for high line pressure effects on zero unbalance. The results are given in Table II. Equal pressure was applied to both diaphragms of the transducer in 100 psi steps up to 800 psi at -80°F , $+80^{\circ}\text{F}$ and $+250^{\circ}\text{F}$. No change from atmospheric zero unbalance occurred. The transducer was insensitive to line pressure over the range indicated.

Additional tests were performed at the temperatures indicated above to determine zero and sensitivity shifts due to temperature. The negative pressure port, negative electrical output with pressure applied to that port, did not have a zero or sensitivity change due to temperature. However, the positive pressure port did have a 0.016% F.R. Amb/ $^{\circ}\text{F}$ sensitivity shift but no zero shift.

Mechanical shock tests were conducted to determine the transducers' sensitivity to shock on its most sensitive axis. The transducer was tested with the positive port mounted downward and then the negative port mounted downward. The first test was conducted at approximately 35 g's, Figure 10. The second test was conducted at approximately 22 g's, Figure 11. The transducer output was 4 millivolts and 2.5 millivolts respectively, or 0.28% F.R./g. The transducers were calibrated after this test with the results showing no change in zero unbalance or transducer performance.

TOP TRACE - ACCELEROMETER OUTPUT, 10 G/CM
BOTTOM TRACE - PRESSURE TRANSDUCER OUTPUT, 5 MV/CM
SWEEP SPEED, 5 MSEC/CM

POSITIVE PRESSURE PORT DOWN

NEGATIVE PRESSURE PORT DOWN

MECHANICAL SHOCK TESTS 35 G'S
CEC MODEL 4-351

FIGURE 10

CONCLUSIONS AND RECOMMENDATIONS

The Statham Model PL 749 and CEC Model 172550 pressure transducers satisfy NERVA requirements for remote application during NERVA tests. The transducers show individual characteristics, and although some units are well within specification others are marginal. This is particularly true for CEC units during high line pressure and pressure media tests. This should not cause concern, since selective transducers can be used where higher accuracy is required.

The results of the tests conducted show that:

1. The error band for differential pressure transducers, Statham Model PL 749 and CEC Model 172550 is a nominal ± 2.0 per cent full range. This error band includes non-linearity, hysteresis, repeatability and temperature effects from 77°F to 300°F. As stated above, some transducers fall well within this error band and some transducers are marginal. When line pressure effects are considered, only the Statham units remain within the $\pm 2.0\%$ range.

Typical results of testing (based on 10 of each type tested) are given below.

	Statham PL 749	CEC 172550
Linearity and Hysteresis	0.75% F.R.	0.72% F. R.
Repeatability	0.07% F. R.	0.1% F. R.
Thermal Zero Shift	0.0024% F.R./°F	0.0021% F. R./°F
Thermal Sensitivity Shift	0.0012% F. R.	0.0025% F. R./°F
Line Pressure Zero Shift	0 to .035% F. R./100 psi	0.1 to 0.25% F.R./100 psi
Pressure Media Zero Shift	Zero	Zero to 5% F. R.

TOP TRACE - ACCELEROMETER OUTPUT, 10 G/CM
BOTTOM TRACE - PRESSURE TRANSDUCER OUTPUT, 2 MV/CM
SWEEP SPEED - 5 MSEC/CM

POSITIVE PRESSURE PORT DOWN

NEGATIVE PRESSURE PORT DOWN
MECHANICAL SHOCK TESTS, 22 G'S
CEC MODEL 4-351

FIGURE 11

If the above errors are analyzed for NERVA conditions of 700 psia line pressure and 225°F change in temperature, the maximum accumulative error band for Satham transducers as tested was 1.92% and 3.8% for CEC transducers. If accuracy only is considered the Satham Model PL 749 is the best choice for differential pressure measurements.

2. Satham transducers are insensitive to line pressure and to pressure media. CEC transducers are, in some cases, sensitive to both pressure media and line pressure. For this reason, application of transducers will have to be selective and helium gas used for zero adjustment on installation.

3. The Satham transducers do not meet the 700°F ambient temperature test. This, however, does not impair its performance since the temperature in the pressure panel is not expected to exceed 300°F. The highest temperature recorded in the pressure panel during EP-V run of the NRX-A3 test was 228°F with the reactor at full power for approximately 13 minutes. The specification should be modified to eliminate the 700°F test.

4. The transducers should always be tested with helium as the pressure media at the vendors', at WANL and at NRDS. The system should be purged before zero unbalance recording is made.

5. All transducers do not show the same characteristics due to line pressure or pressure media. Therefore, all transducers should be tested for high line pressure effects. This should be included in the procurement specification as an acceptance test. All differential pressure transducers should be calibrated up to 700 psi line pressure as part of the transducer calibration. Improved performance can result from more rigid control of manufacturing and/or selective screening for NERVA applications.

6. More work should be performed to better understand the reason for the zero shifts due to line pressure and pressure media. Improved design and compensating techniques can evolve from this effort.

7. The Statham and CEC oil filled units should not be considered for NERVA application. The temperature error and material limitations overcome the advantage of insensitivity to high line pressure.

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