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NON-NUCLEAR QUALIFICATION TESTING OF
IMPROVED DESIGN OF PHYSICAL SCIENCES PRESSURE TRANSDUCERS

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NON-NUCLEAR QUALIFICATION TESTING OF
IMPROVED DESIGN OF PHYSICAL SCIENCES PRESSURE TRANSDUCERS

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SUMMARY

This report presents the results of the non-nuclear testing performed on improved models of Physical Sciences variable reluctance type pressure transducers. Analysis of the data from the tests reveal that:

1. Model PT1015 absolute pressure transducer has greatly improved temperature characteristics as compared to the earlier Models PT1001 and PT1007. However, the change in zero output due to a thermal shock is greater than the 10% F.R. WANL specification.
2. The changes made to Model PT1015 to produce PT1008 have not improved the thermal shock characteristics of the transducers.
3. The design of the transducers appears good, but better controlled inspection and manufacturing processes are required.
4. These transducers are unacceptable for NERVA application as they are.
5. Design changes should not be made until Physical Sciences has obtained reasonable performance from the present design.

INTRODUCTION

Pressure transducers are required to monitor pressure in the flow path during NERVA tests. Flow instabilities must be measured to better understand vibration problems. Frequency response is reduced by long pressure tubes, making it necessary to place pressure transducers inside the pressure vessel. Transducers mounted on the core side of the shield can be used to make high frequency measurements in the core inlet plenum.

The purpose of this report is to present the results of the non-nuclear testing performed on an improved design of Physical Sciences pressure transducers for application on the core side of the shield within the pressure vessel. The transducers tested include Model PT1015, absolute pressure, and Model PT1008, bi-directional, differential pressure transducers for acoustic pressure measurement applications. The purpose of this effort was to establish the adequacy and possible improvements in this type transducer for NERVA applications internal to the pressure vessel.

GENERAL DESCRIPTION

The Physical Sciences pressure transducer is a variable reluctance type transducer. A convoluted, single diaphragm welded to the end pressure port fitting serves as the pressure sensing element or force summing device. A rod is welded to the center of the diaphragm with a paramagnetic material core slug welded to the opposite end of the rod. Pressure applied to the diaphragm displaces the core proportionately to the applied pressure. The displacement of the core changes the inductance of the two coils surrounding the core. This change in inductance is detected and is proportional to the applied pressure. The coils are excited with a 5 KC, 5 volt signal.

BACKGROUND

The first Physical Sciences pressure transducers tested were Model PT1001, 0-70 psid. These units were tested in the General Dynamics reactor, Fort Worth, Texas

in August, 1963. This was a combined effects test that included vibration, cryogenic temperature (LN_2) and radiation. These same transducers were exposed to the same environment in an October, 1963 test.¹

It was pointed out in this report that these pressure transducers were knowingly accepted without temperature compensation. This resulted in a big change in zero output voltage when going from ambient to cryogenic temperatures. Comparison of the pre-and post-irradiation LN_2 curves from the August test indicated no change in output due to radiation up to 5×10^{16} nvt. Again in March, 1964 the Physical Sciences unit was irradiated and temperature cycled from $+250^\circ\text{F}$ to -320°F . Large zero shifts occurred with change in temperature, but no radiation damage was evident.

Two Physical Sciences, Model PT1001, 0-250 psia absolute pressure transducers were tested in the NASA, Plum Brook reactor in April, 1964 primarily to observe gamma heating effects.² These transducers were not temperature compensated and displayed very large zero shifts as the coil temperature increased due to gamma heating. The coil temperature of both transducers approached 1000°F , but no permanent damage was incurred. The integrated fast flux exposure during this test was 2.7×10^{17} nvt and the gamma heating was approximately 2.7 watts/gram. These tests indicated that the Physical Sciences pressure transducers with temperature compensation would be good candidates for NERVA applications.

DESIGN IMPROVEMENTS IN MODEL PT1015

Physical Sciences Model PT1015 is a second generation transducer to be used in an environment of high nuclear radiation and extreme temperatures. Design changes in the Model PT1015 resulted in a greatly improved pressure transducer. These changes

include:

1. Improvements in welding techniques allows heat to be concentrated without risk of damage to the heat-treated diaphragm, aluminum windings, ^{*}Durock wire insulation and insulating beads, and the elimination of distortion and high stress build-ups in the various welded members.
2. The coils are wound with a high inductance to resistance ratio in order to provide little change in sensitivity over a large temperature range.
3. The materials selected for use in close proximity of the coils' magnetic field are high electrical resistance alloys with low temperature coefficients of resistance. These materials with high electrical resistance reduce eddy current losses, thereby allowing a higher electrical output.

The specifications were upgraded from 0.05% F.S./°F to 0.01% F.S./°F for thermal zero shift and from 0.04% F.S./°F to 0.01% F.S./°F for thermal sensitivity shift.

COMPARISON TEST RESULTS

A series of temperature tests were conducted to compare Model PT1001 with Model PT1015. In some cases, Model PT1007 was used in place of PT1001. These units are similar in all respects except for the pressure fittings.

The change in the coils to provide a high inductance to resistance ratio to provide a minimum sensitivity change with temperature is graphically displayed in Figure 1. It can be seen that coil impedance of Model PT1001 changed 0.126 ohms/°F, whereas Model PT1015 changed only 0.024 ohms/°F. This has made Model PT1015 much

*Trade name of Physical Sciences inorganic insulating material.

less sensitive to temperature than Model PT1001. Figure 2 represents the output curves of both models at 78°F and at +475°F. Note the large zero shift due to temperature for Model PT1001.

Temperature shock tests were performed to study the zero outputs due to thermal gradients in the transducers caused by rapidly changing temperatures. The curves shown in Figure 3 were obtained by immersing transducers, at room temperature with rated excitation, in liquid nitrogen. The diaphragms were exposed to the liquid nitrogen. Note the good temperature compensation of the PT1015 at cryogenic temperatures. After soak temperature is reached, the zero unbalance at -320°F is the same as that at room temperature. Similar tests were performed by heating the transducers to +475°F and then immersing them in water at +75°F. The results are shown in Figure 4. It should be noted that this test approaches operating conditions under nuclear heating conditions.

The curves in Figures 3 and 4 are representative of several immersion tests conducted and were reproduced from oscillographic recordings.

DESIGN CHANGES IN MODEL PT1008

The design changes incorporated into Model PT1015 were used in Model PT1008. The units purchased for testing are ± 25 psid pressure transducers. Some of the changes made in these units include a longer bobbin made of Inconel 702 instead of Inconel X. Inconel 702 is easier to weld and does not oxidize as readily. To maintain the same outer dimensions, the inner connections at the stand-off assembly were eliminated. These changes are used to improve the temperature characteristics of the transducers.

TEMPERATURE SHOCK TEST,
LIQUID NITROGEN IMMERSION

FIGURE 3

FIGURE 4
TEMPERATURE SHOCK TEST, +475°F TO +75°F

TRANSDUCER TEST RESULTS, MODEL PT1008

1. Thermal Shock Tests

Liquid nitrogen immersion tests performed on several transducers indicates irregularities in production and quality control. The thermal zero shift of one transducer was as low as 14.5% F. R. and another as high as 40% F. R. with the majority falling near 25% F.R. shift. In all cases, it took approximately 9.5 minutes to reach steady state conditions. Again, as in the earlier models, the temperature compensation at liquid nitrogen temperature was very good. The zero unbalance was nearly the same at a soak LN_2 temperature as it was at room temperature.

2. Ambient Temperature

Ambient temperature tests were conducted at room temperature and at $+600^{\circ}F$. The positive and negative sides of the transducers were calibrated independently with the results given in terms of full scale positive or full scale negative. The full scale sensitivity of the negative side of the two transducers tested was approximately one per cent greater than that of the positive side. It can be seen in Figure 5 that the sensitivity decreased due to temperature, with the greater change in the negative half cycle. The change in the positive cycle was 1% F.R. and the change in the negative cycle was 5% F.R.

3. Thermal Impedance Tests

Both Models PT1015 and PT1008 were tested to determine the temperature gradient that is maintained between the coil and the case of the pressure transducers due to insulation materials and air gaps. The problem of thermal impedance is important inside the pressure vessel, where the internal components of the transducers are heated

FIGURE 5

by gamma radiation and the case is cooled by a cryogenic gas. A desirable design is one in which a maximum amount of heat is conducted from the coils to the case.

The transducers were tested in air in a closed chamber. The coil temperature was controlled by placing a DC voltage across the coil and monitoring the current. Using Ohm's Law, the coil resistance was calculated. Using the temperature versus coil resistance curves developed for these transducers (see Irradiation Testing), the coil temperature was determined. The transducer case temperature was monitored with a thermocouple. The curves in Figure 6 show that Model PT1008 maintains a larger temperature gradient between coil and case, but the difference is not significant.

IRRADIATION TESTING

An irradiation test is scheduled for the PT1015 and PT1008 pressure transducers at the NASA, Plum Brook reactor in October 1965. The test plan³ specifies two of each type transducer to be tested. However, one PT1015 and both PT1008 have malfunctioned. This problem will be discussed later.

The transducers to be tested at Plum Brook are mounted on a test fixture as shown in Figure 7. The point of highest flux intensity will be between the two PT1008 differential pressure transducers as shown. Figures 8 and 9 are pictures of the test fixture showing the mounting methods, pneumatic tubes and stainless steel sheathed cables. The larger diameter transducer that can be seen in Figure 9 is a Wiancko pressure transducer with an integral thermocouple also included in the test.

Pneumatic and electrical control and read-out panels were designed for the Plum Brook test and are shown in Figure 10.

A heat transfer analysis of the Physical Sciences PT1015 was performed in order to determine the internal temperatures during an irradiation test at the Plum Brook Reactor Facility, Figure 11. The results shown here were calculated. The helium shown in the transducer is put there during an assembly process. The hottest point would be the slug. If cryogenic cooling were used, as would be the case in an NRX test, the transducer would be well within its temperature range. The transducer in Figure 11 is shown with a connector and not an integral cable as is the case of the transducers to be tested at Plum Brook.

THERMAL IMPEDANCE TEST, MODELS PT 1008 AND PT 1015

FIGURE 6

PRESSURE TRANSDUCER TEST FIXTURE
FOR PLUM BROOK RADIATION TEST
FIGURE 8

PRESSURE TRANSDUCER TEST FIXTURE AND
HOLDER FOR PLUM BROOK RADIATION TEST

FIGURE 9

PNEUMATIC AND ELECTRICAL CONTROL PANELS
FOR PLUM BROOK TEST

FIGURE 10

Estimated Internal Temperatures of Physical Sciences Pressure Transducer
Heat Generation Rate, 4.1 watts/gram
Coolant, Water, 150°F
Internal Temperatures in °F

FIGURE 11

Besides the tests already discussed, temperature versus coil resistance curves were plotted for each transducer. During the radiation test, these curves will be used to determine the change in coil temperature due to gamma heating and act as a control to keep the transducers from being overheated.

As previously mentioned both PT1008 and one PT1015 transducers failed during the water loop test. This test simulates the Plum Brook reactor water coolant flow, temperature and pressure. Insulation resistance to ground shorted in the case of the PT1015 and became very low in the other two transducers. It was first assumed that moisture got into the transducers, although such precautionary measures as welding, helium leak checking and chrome plating were used to insure against moisture entering the transducers. The transducers were removed from the fixture and placed in a vacuum oven for approximately 48 hours. During this time the insulation resistance varied considerably but did not improve significantly. Also, during this period the coil resistances became erratic and even open circuited. Because the insulation resistance was not improved, it was decided that moisture was not the problem.

In an effort to determine the cause of these failures, one absolute pressure transducer was disassembled. It was found that a pressure connection was used to make the transition from the aluminum coil windings to the stainless steel pins on the header. Figure 12. It appeared that during temperature cycling, oxidation and/or thermal expansion caused open circuiting at this connection point.

No good explanation can be given for the erratic behavior of these transducers with respect to insulation to ground. Foreign material found in the transducer may have caused the breakdown. The source of this material is unknown. A darkened area in the

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HEADER SHOWING PRESSURE CONNECTIONS OF
ALUMINUM WINDINGS WITH STAINLESS STEEL PINS

FIGURE 12

quartz fiber and a coil wire may have caused shorting to the case. These can be seen in Figure 13. Cracks in the ceramic insulation surrounding the header pins were also observed.

More transducers will have to be tested to determine if temperature cycling is the cause of failure.

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BOBBIN WITH WINDINGS AND QUARTZ FIBER FROM
PHYSICAL SCIENCES MODEL PT1015 PRESSURE TRANSDUCER

FIGURE 13

CONCLUSIONS AND RECOMMENDATIONS

The Physical Sciences Models PT1015 and PT1008 pressure transducers are not suitable for NERVA application as presently manufactured. The transducers are too sensitive to thermal shock. This is particularly true for the Model PT1008 pressure transducers. The results of the tests conducted show that:

1. The zero shift due to thermal shock for Model PT1015 is approximately 15% full scale with six minutes stabilization time.
2. The zero shift due to thermal shock for Model PT1008 ranges from 14% full scale to 40% full scale.
3. The temperature characteristics of the PT1008 $\pm$ 25 psid pressure transducers are not equal in both the positive and negative directions.
4. Some electrical connections in Model PT1015 are pressure connected instead of being welded or brazed.
5. An improved electrical termination method for the aluminum coil wires is required.
6. Better assembly methods are required with inspections and cleaning operations or clean room techniques used in the assembly of the transducer.
7. All transducers required helium leak testing and/or water immersion testing by the manufacturer. In spite of this, leaky cases requiring repairs were delivered.

8. Vendor quality assurance and transducer testing needs improvement.
9. Further testing of these models should not be performed until Physical Sciences has shown by test history that several transducers of this design have performed satisfactorily according to WANL qualification test procedures.

REFERENCES

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