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WANL-TME-1032

November 13, 1964

QUALIFICATION TEST REPORT
WIANCKO PRESSURE TRANSDUCERS
(Title Unclassified)

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TABLE OF CONTENTS

	<u>Page</u>
1.0 Introduction	1
1.1 General	1
2.0 Nuclear Testing	1
2.1 Test History	1
2.2 PBRF Nuclear Test	2
2.2.1 Description of Test Specimens	2
2.3 Test Results	7
2.3.1 Transducer S/N 70639, 0-800 psia	12
2.3.2 Transducer S/N 69952, 0-150 psid	16
2.3.3 Transducer S/N 69955, 0-800 psia	22
2.3.4 Transducer S/N 69953, 0-150 psid	22
2.3.5 Estimated Internal Temperatures During Irradiation Testing	31
2.3.6 Ohmic Heating Studies	31
3.0 Conclusions	33
4.0 Non-Nuclear Testing	34
4.1 General	34
4.2 Temperature Tests	34
4.2.1 Transducer Characteristics at Soak Temperatures	34
4.2.3 Conclusions	46
5.0 Vibration Tests	46
5.1 Test History	46
5.2 Vendor Vibration Tests	47
5.3 Conclusions	47
6.0 Other Qualification Tests	47

QUALIFICATION TEST REPORT
WIANCKO PRESSURE TRANSDUCERS

1.0 INTRODUCTION

1.1 General

This report describes the Westinghouse Astronuclear Laboratory (WANL) environmental tests and test results of Wiancko Engineering, variable reluctance, absolute and differential pressure transducers, Model No. 54726 and 54727. The purpose of these tests was to obtain operational data on diagnostic pressure transducers in a high radiation environment, at cryogenic and elevated temperatures and under vibration.

This report is divided into two sections; nuclear and non-nuclear testing. The nuclear testing was conducted at the NASA Plum Brook Reactor Facility (PBRF). The non-nuclear testing was conducted at WANL and at Wiancko.

2.0 NUCLEAR TESTING

2.1 Test History

Forerunners of the Wiancko Models 54726 and 54727 were tested in the General Dynamics test reactor at Fort Worth, Texas and were designated as Models PX-100 and PX-102A. These transducers were tested in a combined environment of radiation, cryogenic temperature and vibration and reported in WANL-TNR-145, WANL-TME-700 and WANL-TME-786. Testing of Models 54726 and 54727 was conducted at PBRF to obtain high flux levels equal to those for NRX applications.

2.2 PBRF Nuclear Test

This test was designated as experiment 23/W506, and was conducted July 29 and 30, 1964. Design and hazards information is described in WANL-TNR-119 and, for this experiment, in WANL-REP-2012. Final test specifications for this experiment are described in WANL-TME-800.

The experiment was designed to observe the effects of radiation on the four transducers. To obtain comparable data, the transducers were pressure cycled before, during, and after irradiation.

2.2.1 Description of Test Specimens

The four pressure transducers irradiated in this experiment are listed in Table 1. These transducers were clamped to the inside edge of the test fixture cage at 90° intervals. During irradiation, the transducers were directly actuated from a helium gas supply incorporated in the system.

TABLE 1

Variable Reluctance Pressure Transducers Irradiated in Experiment 23/W506

<u>Quantity</u>	<u>Manufacturers</u>	<u>Model No.</u>	<u>Type</u>	<u>Range</u>	<u>Instrumentation Data Book Code Number</u>
2	Wiancko	54726	Absolute	0 to 800 psia	Pr-18
2	Wiancko	54727	Differential	0 to 150 psid	DPr-16

The test fixture for experiment 23/W506 was designed with an aluminum cage into which four Wiancko pressure transducers were clamped and welded, (Figure 1 and 2). This cage also contained a manifold and tubing system which permitted transfer of gas from the pressurized helium supply to each transducer (Figure 3). During irradiation the applied gas pressure to the transducers was manually regulated from a pneumatic system positioned near the helium bottle supply. The cage of the test fixture was enclosed with an aluminum shroud to direct flow of coolant water and the entire fixture was attached to the unitrace holder as described in WANL-TNR-119.⁽¹⁾

Four stainless steel sheathed copper-constantan thermocouples were pressure fitted between each of the pressure transducers and the aluminum cage. In this manner the outer surface temperature of each transducer was continually monitored during irradiation. The radiation exposure of each transducer was monitored by a dosimeter package mounted on the test fixture near to each transducer. Each dosimeter package contained aluminum-cobalt wires, bare and cadmium covered for thermal and epi-thermal flux measurements, and sulfur for fast flux measurements. On .090-inch diameter, 13-foot long, stainless steel-sheathed cable with MgO insulation was provided from each transducer to the conax fittings in the back plate of the sample holder to provide read-out capabilities. Extension wires from the test holder back plate to the read-out instrumentation were enclosed in Tygon tubing to prevent exposure to moisture.

FIGURE 1

FIXTURE FOR RADIATION TESTING
OF WIANCKO PRESSURE TRANSDUCER AT PBRF, END VIEW

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FIGURE 2

TRANSDUCER TEST FIXTURE, OBLIQUE VIEW

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The data read-out equipment for this experiment, Table 2, was part of an instrument control panel from which the test was regulated. The instrumentation was selected to provide capabilities for measuring insulation resistance, coil resistance, excitation voltage, output voltage and applied pressure.

TABLE 2

Data Acquisition Equipment for Experiment 23/W506

1. Two digital voltmeters, Kintel, Model 473 A.
2. Two Crescent Demodulators, Model 9105 (one spare).
3. One Hewlett-Packard Oscillator, Model 650 A.
4. One McIntosh Amplifier, Model M 175.
5. One AC to DC converter.
6. One Megohmmeter, General Radio.
7. One Wheatstone Bridge.
8. One AC Voltage Regulator.
9. Two Heise Pressure Gages, 0-50 psi and 0-200 psi.

During irradiation a gas pressure of 100 spig was continually maintained on the pressure transducers except during the periods of data acquisition.

The gas pressure was released, the zero unbalance recorded, and the voltage output recorded at 30 psig increments up to 150 psig and back to 0 psig. The electrical resistance of the coils of each transducer was measured and recorded indicating coil temperature. The insulation resistance was also measured and recorded. These operations were repeated at each reactor power level. The reactor power was increased to levels of 1 MW, 5 MW and increasing 5 MW increments to 40 MW. Each of these levels was held for approximately two hours to allow for temperature stabilization (Figure 4). Due to indications of malfunction in two transducers, one absolute and one differential, the test was terminated at 40 MW. Because of the transducers position in relationship to the the reactor core, the flux levels across the test fixture varied considerably. Table 3 gives the approximate gamma heating rate for each transducer at different reactor power levels.

TABLE 3

Reactor Power MW	1	5	10	15	20	25	30	25	40
Gamma Heating watts/gm S/N 70639	.07	0.35	0.70	1.05	1.40	1.75	2.10	2.45	2.80
S/N 69952									
Gamma Heating watts/gm S/N 69953	.03	0.14	0.26	0.42	0.57	0.71	0.85	0.99	1.13
S/N 69955									

2.3 Test Results

Because all of the transducers were not exposed to the same flux intensity, each transducer will be discussed individually. Four dosimeter packages were attached to the sample fixture at positions adjacent to each transducer, as seen in Figure 3, to measure neutron flux distribution. The thermal, epi-thermal and fast neutron flux values are given in Table 4.

FIGURE 3

DESIGN OF THE TEST FIXTURE FOR EXPERIMENT 23/W506

FIGURE 4
REACTOR POWER PROFILE

TABLE 4

Dosimeter	Transducer	Cd Ratio	Φ_f	Φ_{epi}	Φ_{th}
9	S/N 69953	10.2	8.4×10^{11}	1.2×10^{12}	1.3×10^{13}
11	S/N 69952	17.8	2.1×10^{12}	1.7×10^{12}	3.4×10^{13}
10	S/N 69955	21.9	*	2.2×10^{12}	5.4×10^{13}
12	S/N 70639	21.0	*	4.3×10^{12}	1.0×10^{14}

* Capsule broken; sulfur not retrievable.

It must be noted that the dosimeter report lists only representative figures of what the transducers experienced. It can be seen that although dosimeter No. 24 indicated a higher flux than dosimeter No. 23, S/N 69952 was in a higher flux field than S/N 69955 (Figure 1). Reference will be made primarily to Table 3.

During the radiation period, the outer surface of the transducer experienced water temperatures from 85°F to 125°F and was exposed to an average water pressure of 132 psig. A pre-irradiation test to determine the coil resistance versus temperature was conducted, with this data then used to determine coil temperature during the test (Figure 5). The two coils were connected in series, while making these measurements. Although the temperature characteristics of the transducers during these tests did not simulate those experienced during irradiation, a saturated temperature versus differential heating, it was considered the most accurate method of determining coil temperature.

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FIGURE 5

WIANCKO PRESSURE TRANSDUCER COIL RESISTANCE VERSUS TEMPERATURE

-11-

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2.3.1 Transducer S/N 70639, 0 to 800 psia

This transducer was the first one to show signs of malfunction.

This is explained by its location in the test fixture at a position closest to the reactor core and, therefore, experienced the highest radiation exposure of the absolute transducers tested. The coil resistance increased linearly until the reactor power reached 25 MW (Figure 6). At this point, the coil temperature was indicated to be approximately 830°F. The coil resistance then decreased until reactor shutdown, and the postirradiation value was lower than those measured prior to the test. This was an indication of insulation breakdown between the coil turns causing a short circuit between turns. The shorted turns appeared to be in one coil, which created an unbalanced bridge network resulting in a large zero shift and loss of sensitivity.

The insulation resistance to ground decreased rapidly as the reactor power was increased, but remained greater than one megohm at 40 MW reactor power (Figure 7). After reactor shutdown the insulation resistance increased to a very high value, indicating no permanent insulation damage.

It can be seen in Figure 8 that the zero unbalance shifted negatively as the reactor power was increased. This is characteristic of the Wiancko pressure transducers with increasing temperature. The maximum zero shift before the transducer began to malfunction was -7.9 % full scale, pre-irradiation. At this point the coil temperature was, as previously mentioned, 830°F. The transducer zero shift due to temperature is specified to be within .01% F.R./°F; so the transducer was close to specification, even with the large coil to case temperature gradient.

FIGURE 6

COIL RESISTANCE VERSUS REACTOR POWER

WIANCKO MODEL 54726, S/N 70639, 0-800 PSIA

FIGURE 7

INSULATION RESISTANCE VERSUS REACTOR POWER

WIANCKO MODEL 54726, S/N 70639, 0-800 PSIA

-14-

FIGURE 8

REACTOR SHIFT VERSUS REACTOR POWER

WIANCKO MODEL 54726, S/N 70639, 0-800 PSIA

Figure 9 shows the maximum sensitivity shift to be 0.5% full scale, pre-irradiation until the sensitivity began to increase rapidly at 20 MW reactor power. The transducer full scale sensitivity was 1.46 volts at 25 MW reactor power, and lost sensitivity beyond that point as the zero unbalanced shifted excessively. There was no recovery of sensitivity after the test. The case of this transducer was removed in the hot cell with no internal physical damage evident.

2.3.2 Transducer S/N 69952, 0 to 150 psid

Of the two differential pressure transducers tested, this transducer was exposed to the higher flux. This was the second transducer to show signs of malfunction. The coil resistance increased as the reactor power was increased up to 40 MW (Figure 10). The coil temperature at this point was close to 800°F. Again, as in transducer S/N 70639, the resistance in one coil began to decrease, indicating insulation breakdown between the turns. This resulted in a large zero unbalance and sensitivity loss, which in turn resulted in the termination of the test. The test plan included a provision that the test would be terminated after the absolute and differential pressure transducers in the high flux field failed. The zero unbalance increased as high as 2 volts at one point during the test (Figure 11) and lost sensitivity at 40 MW (Figure 12).

The insulation resistance, as seen in Figure 13, increased slightly at the start of the test. This may have been caused by moisture being driven out of the insulation as the temperature increased. The resistance then decreased, but never dropped below 7.6 megohms.

FIGURE 9

FULL SCALE SENSITIVITY SHIFT

WIANCKO MODEL 54726, 0-800 PSIA

FIGURE 10

COIL RESISTANCE VERSUS REACTOR POWER

WIANCKO MODEL 54727, S/N 69952, 0-150 PSID

FIGURE 11

ZERO SHIFTS VERSUS REACTOR POWER

WIANCKO MODEL 54727, S/N 69952, 0-150 PSID

FIGURE 12

FULL SCALE SENSITIVITY SHIFTS

WIANCKO MODEL 54727, S/N 69952, 0-150 PSID

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-20-

FIGURE 13

INSULATION RESISTANCE VERSUS REACTOR POWER

WIANCKO MODEL 54727, S/N 69952, 0-150 PSID

2.3.3 Transducer S/N 69955, 0-800 psia

This transducer was in a region of low flux during the test. The output of this transducer can be compared closely to S/N 70639 at the same gamma heating rates (Table 3). The sensitivity shifts with the same gamma heating are both within 0.5 % full scale.

The coil resistance increased with reactor power, but did not experience shorted turns. The highest indicated temperature was 650°F. The post-irradiation resistance was very close to the pre-irradiation value (Figure 14). The zero unbalance decreased and then increased as did S/N 70639, but was not extreme. The postirradiation zero was shifted from the original value, but may have been caused by electronic equipment drift (Figure 15). The maximum change in full scale sensitivity was + 0.5% during the test. The abrupt change with reactor shutdown could not be determined (Figure 16). The insulation, as seen in Figure 17, did not decrease below 7.6 megohms, and recovered after reactor shutdown.

2.3.4 Transducer S/N 69953, 0-150 psid

The discussion of this transducer will again be brief, because of its similarity to S/N 69952. Figure 18, 19, 20, and 21 tell the story as to how the transducer responded during the test. The indicated average coil temperature did not exceed 525°F. This transducer also showed an abrupt change in zero unbalance and full scale sensitivity at shutdown which was unexplainable. Water got into the reference side of this transducer while moving it to the hot cell, and this caused the transducer to be inoperative.

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FIGURE 14

COIL RESISTANCE VERSUS REACTOR POWER

WANL-KO MODEL 54726, S/N 69955, 0-800 PSIA

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-23-

FIGURE 15

ZERO SHIFT VERSUS REACTOR POWER

WIANCKO MODEL 54726, S/N 69955, 0-800 PSIA

24-

FIGURE 16

FULL SCALE SENSITIVITY SHIFT

WIANKO MODEL 54726, S/N 69955, 0-800 PSIA

-25-

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FIGURE 17

INSULATION RESISTANCE VERSUS REACTOR POWER

WANLCO MODEL 54726, S/N 69955, 0-800 PSIA

-26-

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FIGURE 18

COIL RESISTANCE VERSUS REACTOR POWER

WIANCKO MODEL 54727, S/N 69953, 0-150 PSID

FIGURE 19

ZERO SHIFTS VERSUS REACTOR POWER

WANLCO MODEL 54727, S/N 69953, 0-150 PSID

FIGURE 20

FULL SCALE SENSITIVITY SHIFTS

WIANCKO MODEL 54727, S/N 69953, 0-150 PSID

FIGURE 21

INSULATION RESISTANCE VERSUS REACTOR POWER

WANLCO MODEL 54727, S/N 69953, 0-150 PSID

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-30-

2.3.5 Estimated Internal Temperatures During Irradiation Testing

A heat transfer analysis of the Wiancko pressure transducer was performed in order to determine the internal temperatures during irradiation testing. The results shown in Figure 22 were calculated. Errors may exist where the exact thermal conductivity of some compounds was not known, but the results should be within $\pm 50^{\circ}\text{F}$. The results are lower than those calculated to exist during the test, and it has not been determined why this is so. The helium is shown as the pressure media for a differential transducer as existed at PBRF during the irradiation test. The highest temperature is shown to exist inside the coil. This verifies the reasoning that hot spot temperatures broke down the insulation within the coil.

2.3.6 Ohmic Heating Studies

To simulate gamma heating voltage was applied to the coils of a transducer. The current and applied voltage were recorded, and the coil resistance and power dissipated were calculated. These tests were conducted with the unit in air and again in water at room temperature. Preliminary tests were conducted on Model PX 105 with the results reported in WANL-TME-706.

Similar tests were conducted with Model 54726 in liquid nitrogen and in air. Results showed that with the transducer in air and 3 w/gm electrical heating, the coil temperature was approximately 850°F . In liquid nitrogen with a 3 w/gm heating, the coil temperature was approximately 550°F . These figures would be approximately the same as those calculated in Figure 22. However, the indicated temperatures in the PBRF test were higher than would be predicted at the given gamma heat rates. A dosimeter test is scheduled at PBRF for December 1964 to recheck flux levels. Gamma heating cannot be read because of the lack of instrumentation. The figures given in Table 3 may be somewhat low.

FIGURE 22
 ESTIMATED INTERNAL TEMPERATURES DURING IRRADIATION TESTING
 HEAT GENERATION RATE 4 WATTS/GRAM
 WIANCKO PRESSURE TRANSDUCER - P/N 54727

3.0 CONCLUSIONS

As reported earlier this test did not simulate NRX conditions, because of the coolant temperature being at 125°F and not at cryogenic temperatures. The basic problem is for the transducers' coils to withstand high temperatures due to gamma heating. Above 750°F the insulation between turns broke down and the turns shorted causing large zero shifts. The differential unit operated a little cooler than the absolute because of the helium surrounding the coils instead of a vacuum. This aided in conducting the heat away from the coils. The disassembly of S/N 70639 in the hot cell area did not show signs of damage. The exact place of the shorted turns could not be determined.

The results of this test indicated that the Wiancko Model 54727 differential pressure transducers can be used in the shield region inside the NRX test vehicles. They could operate in the region of 4 watts/gram of gamma heating, where cryogenic coolant is in contact with both the outside of the transducer and with the coils. Their application at cryogenic temperatures will be discussed in another section of this report.

The Wiancko Model 54726 absolute pressure transducers may not operate as well in the 4 watts/gram region because the cryogenic coolant is not in contact with the coils. However, preliminary results of the NRX-A2 tests showed that the Wiancko transducers survived in that region. An analysis of the NRX-A2 data and the data obtained from NRX-A3 will clearly show the Wiancko capabilities in the NRX engine tests.

4.0 NON-NUCLEAR TESTING

4.1 General

The non-nuclear tests conducted at WANL and Wiancko Engineering were conducted to observe operational characteristics at cryogenic and elevated temperatures and under vibration conditions. The cryogenic temperature tests simulate the cryogenic coolant in the NRX, and the elevated temperature tests simulate temperatures expected due to gamma heating. These tests, combined with the nuclear tests, define the capabilities of the Wiancko Models 54726 and 54727 pressure transducers for NRX use.

4.2 Temperature Tests

4.2.1 Transducer Characteristics at Soak Temperatures

The first temperature tests conducted were to observe the electrical characteristic of the transducers at soak temperatures of 75°F, +475°F and -320°F. It is specified in WANL-E-675440-B that the zero unbalance and sensitivity will not change more than .01% F.R./°F with temperature. Figures 23 and 24 show that both models stay within this specification. Both the zero unbalance and the sensitivity shifted inversely with temperature. The linearity and the hysteresis stayed within specification over this temperature span.

4.2.2 Temperature Shock Tests

Temperature shock tests were performed to study the effects of thermal gradients throughout the transducer and to study the electrical characteristics of the transducer, when it rapidly changes temperature, as it will in the NRX tests.

FIGURE 23

OUTPUT CHANGE DUE TO TEMPERATURE

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FIGURE 24

OUTPUT CHANGE DUE TO TEMPERATURE

-36-

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The shock tests were conducted in two phases; from 75°F into liquid nitrogen (-320°F) and from +475°F into water at room temperature (+75°F). The curves showing the zero shifts were reproduced from oscillographic recordings. In both tests it took several minutes for the transducer to stabilize (Figures 25, 26, 27, 28). It is important to note that there were no high peaks or excursions out of the specified limits during rapid cool-down. The curves for both the absolute and differential pressure transducers followed similar curves for identical tests. Several transducers were tested in this manner, and all followed the same patterns.

Two 300 psia transducers were assembled with a thermocouple in contact with the surface of one of the coils. The same thermal shock tests were conducted with these units, and the representative thermocouple and transducer zero outputs are shown in Figures 29 and 30. The change in slope of the zero output at the half minute point, as compared to the constant slope of the thermocouple output, indicates a mechanical change in the transducer. This is evident in the absolute units only. This can be explained by the change in pressure on the back side of the diaphragm and an oil-can effect of the diaphragm.

To determine the thermal insulation properties of the coil insulation, ohmic heating tests were performed with the thermocouple output recorded (Figures 31 and 32). The coil temperature was calculated from the resistance value of the coil. The thermocouple did not read as high a temperature as the coil indicating the thermal insulating properties of the ceramic insulation. Methods must be derived to conduct the heat from the coil to the case.

FIGURE 25

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK

(+75°F to -320°F)

FIGURE 26

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK

(+475°F to 78°F)

-39-

FIGURE 27

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK

(+75°F to -320°F)

-40-

FIGURE 28

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK

(-475°F to +75°F)

-41-

FIGURE 29

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK
THERMOCOUPLE INSTRUMENTED TRANSDUCER
(+78°F to -320°F)

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FIGURE 30

ZERO UNBALANCE DUE TO TEMPERATURE SHOCK

THERMOCOUPLE INSTRUMENTED TRANSDUCER

(+425°F to +78°F)

-43-

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FIGURE 31

COIL TEMPERATURE VERSUS THERMOCOUPLE TEMPERATURE

OHMIC HEATING IN WATER

FIGURE 32

COIL TEMPERATURE VERSUS THERMOCOUPLE TEMPERATURE
OHMIC HEATING IN AIR

4.2.3 Conclusions

The temperature tests indicate the Wiancko Models 54726 and 54727 pressure transducers operate satisfactorily at temperature levels within the specified limits. Also, the transducers operate satisfactorily while being subjected to thermal shock as will be experienced in NRX tests. These tests do not clearly answer the questions raised, when the coil is at temperatures reaching 750°F and the case is at -320°F. These questions will have to be answered in radiation tests with cryogenic cooling.

Tests conducted by Wiancko and reported in Wiancko Qualification Test Report show zero and sensitivity shifts due to temperature exposures of 750°F.

5.0 VIBRATION TESTS

5.1 Test History

Wiancko Model PX-105 pressure transducers were some of the early models vibrated. These units were similar in construction to the 54726 and 54727 models. A brief summary of these tests indicate at 10 g rms, 30 to 2000 cps vibration that:

- (1) The DC, vibration induced, unbalance was less than the resolution of the measuring equipment.
- (2) Transducer response to 10 per cent rated pressure application at 10 g rms was normal.
- (3) Maximum vibration sensitivity was less than 0.007 % FR/g.

5.2 Vendor Vibration Tests

The tests conducted by Wiancko Engineering were part of the qualification tests for the NRX-A2 pressure transducers, and the results are reported in "Qualification Test Report, Westinghouse Astronuclear Laboratories, 7-4007 and 7-4008." The output due to vibration from 5 to 2000 cps at 25 g's was negligible. However, of the three ranges of transducers tested, 100 psid, 150 psid, and 800 psia, all showed evidence of a minor resonance at 700 cps. Even with this the transducers were within specification.

5.3 Conclusions

The vibration tests conducted show the Wiancko pressure transducers Model 54726 and 54727 are not sensitive to vibration up to 25 g's.

The vibration induced error during NRX tests should be negligible.

6.0 OTHER QUALIFICATION TESTS

Other tests conducted by Wiancko and reported in 7-4007 and 7-4008 include acoustic noise, time constant, acceleration, humidity, and mechanical shock tests.

Acceptance tests conducted at WANL are reported in WANL-TME-872.

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