RECORD COPY

SNPO-C

Astronuclear

WANL-TME-1199

June 18, 1965

SUBMITTED BY

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh 36, Pennsylvania

MASTER

NON-NUCLEAR QUALIFICATION TESTING
OF THE PHYSICAL SCIENCES MODEL AT-302-2 ACCELEROMETER

PREPARED BY:

W. D. Loftus

T. A. Pappas

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

APPROVED BY:

H. P. Kalapaca

H. P. Kalapaca, Supervisor
Reactor Component Sensor Development
Instrumentation and Control

R. L. Ramp

R. L. Ramp, Manager
Instrumentation Development
Instrumentation and Control

INFORMATION CATEGORY

UNCLASSIFIED

R. L. Ramp 6/23/65
Authorized Classifier Date

RECORD COPY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SUMMARY

This report presents the results of the non-nuclear qualification testing performed on two Physical Sciences Type AT-302-2 variable reluctance accelerometers (WANL Part No. 978D193H02). One unit developed an intermittent short in the coil windings, and hence could not be tested. The other unit exhibited a wide deviation from the performance requirements of the accelerometer Equipment Specification and is not acceptable in its present state. The specific performance characteristics of this unit are as follows:

1. Linearity and Hysteresis: The combined error resulting from the effects of non-linearity and hysteresis was more than ± 14 per cent of full scale output over the temperature range of -320°F to $+600^{\circ}\text{F}$.
2. Thermal Sensitivity Shift: The thermal sensitivity shift was found to be dependent on the acceleration levels. At 10 g's, it was approximately ± 30 per cent of the room temperature value over the temperature range of -320°F to $+600^{\circ}\text{F}$. At 2 g's, however, the sensitivity decreased by 60 per cent at -320°F and increased by 40 per cent at $+600^{\circ}\text{F}$.
3. Frequency Response: The frequency response from 15 cps to 200 cps was flat to within ± 7 per cent over the temperature range of -320°F to $+600^{\circ}\text{F}$.
4. Thermal Shock: The unit behaved erratically during the thermal shock test to liquid nitrogen temperature indicating mechanical instability of the core, the core windings, or binding of the sliding member inherent to the transducer design.

The operable unit is scheduled for irradiation testing at the Plum Brook reactor during July 1965 in order to determine its performance characteristics in a high level nuclear environment.

NON-NUCLEAR QUALIFICATION TESTING OF THE PHYSICAL SCIENCES MODEL AT-302-2 ACCELEROMETER

1.0 INTRODUCTION

This report describes non-nuclear qualification testing of the Physical Sciences Corporation Model AT-302-2 variable reluctance accelerometer which has been conducted by the WANL Reactor Component Sensor Development Group. The work was requested by Sensor Application Engineering and authorized by project task V-6 of project NE 2460A. The purpose of the work was to determine the non-nuclear performance characteristics of the accelerometer prior to nuclear testing and evaluation at the Plum Brook Reactor Facility.

2.0 BACKGROUND HISTORY

These transducers were purchased as a deliverable hardware backup for the Wiancko AX-44 accelerometer. Purchase Order 45071 was awarded to the Physical Sciences Corporation on the basis of a technically satisfactory proposal and the low bid. The accelerometers were specified by Equipment Specification E-675453-B. Two units were accepted by WANL after minimal testing by PSC in order to obtain first hand knowledge of the device performance through in-house qualification testing, and to receive the units in time for inclusion in the Plum Brook accelerometer radiation test.

3.0 SYSTEMS DESCRIPTIONS

3.1 Accelerometers

Two + 10 g accelerometers, having serial numbers A30944 and A30945, were received by WANL in late March 1965. Unit A30945 developed an intermittent short in the coil windings, and hence could not be tested.

3.1.1 Purchase Details: The accelerometers discussed below were purchased under Purchase Order 59 NW 45071 and made to WANL drawing 978D193H02. They were specified by Equipment Specification WANL-E-675453-B. The IDB code number is Gr-34.

3.1.2 Specification: Reference is made to Equipment Specification WANL-E-675453-B. The specified performance characteristics are listed below for easy reference.

Range: The nominal range shall be ± 10 g, unless otherwise specified on the purchase order or specification control drawing.

Sensitivity: Minimum 5 millivolts rms, maximum 1 volt, preferred nominal 100 millivolts; for rated peak to peak g level at rated excitation of 5 volts at 5 kc.

Linearity and Hysteresis: The combined error resulting from the effects of nonlinearity and hysteresis shall not exceed ± 1 per cent of peak to peak output over the operating temperature range. Linearity and hysteresis shall be demonstrated at 40 ± 5 cps and at 100 ± 5 cps during acceptance testing.

Repeatability: The output shall be repeatable within 0.5 per cent for three consecutive full range excursions performed under identical conditions at the 100 ± 5 cps test condition over the operating temperature range.

Operating Temperature Range: The accelerometer shall be operable within the limits of accuracy specified herein from -320°F to $+600^{\circ}\text{F}$. (Test temperatures shall be $\pm 25^{\circ}$ from the preceding temperatures.)

Thermal Zero Shift: Shall not exceed ± 1 per cent per 100 degrees of the full range output at $75^{\circ} \pm 10^{\circ}\text{F}$. Upon return to room temperature from any point within the operating temperature range, the permanent shift shall not exceed ± 0.25 per cent per 100 degrees of the temperature change from which the accelerometer has recovered.

Residual Unbalance: The residual unbalance shall not exceed ± 10 per cent of the full range output at rest with the base down.

Frequency Response: The output shall be flat within 5 per cent with input frequencies from 5 to 200 cps at ± 5 g's, limited to 0.5 inch double amplitude, at $75 \pm 10^{\circ}\text{F}$.

Transverse Sensitivity: The change in indicated acceleration due to vibration in the transverse direction shall not exceed 5 per cent. Preference will be given to accelerometer design not exceeding 2 per cent for this parameter.

Acoustic Noise: The performance of the accelerometer shall be within the limits of this specification at a noise level of 150 db when tested in accordance with MIL-STD-810 (or MIL-STD-446 at vendor's option). Sound level may be applied broadband with a random gaussian distribution.

Ambient Pressure: The accelerometer shall be operable within the limits of this specification when subjected to an external pressure of 0 to 1000 psia.

Shock: A 25 g shock pulse of seven milliseconds total duration shall not cause a shift in performance outside the limits of this specification.

Humidity: Subjection to an external 0 to 100 per cent relative humidity shall not cause a shift in performance outside the limits of this specification. This shall be tested by immersion in water pressurized to 200 psi.

Natural Frequency: The natural frequency of the accelerometer shall be at least 1000 cps.

Ambient Temperature Range: The performance of the accelerometer shall be within the limits of this specification when tested at $75 \pm 10^{\circ}\text{F}$ after it is held at -423°F for one hour and also after it is held at $+750^{\circ}\text{F}$ for one hour.

Resolution: A change in measurand as small as 0.1 per cent of the full range measurand shall produce a recognizable change in output.

3.1.3 Mechanical Details: The transducer sensing unit consists of two masses which move under inertial forces between the transducer coils within an H core structure. The reluctances of each magnetic circuit is related to the position of its associated mass which forms a part of the circuit. The masses are attached to a rod which is joined to a diaphragm at one end and which slides in a bushing at the other end. The case is inconel. Integral MgO insulated cables are provided.

3.1.4 Electrical Details: The transducer is compatible for operation with the Crescent-East demodulator amplifier. Excitation at 5 volts rms, 5 kcs, is required. Durock insulated, aluminum wire is used in the coils. The magnetic circuits are fabricated from a proprietary alloy referred to as TI-15.

3.2 Measurement Systems

3.2.1 Dynamic Test Set: Details of the dynamic test set are shown in single line by Figure 2. The data indicated by the figure were monitored and recorded at each data run. A computer program was written and the acquired data were machine plotted at the East Pittsburgh Division of Westinghouse. About 25 curves on the one operable unit were so prepared; selected typical curves will be presented in the following sections. The remaining curves are available to interested persons. Selected hand plotted curves are also presented. It will be observed that point-to-point plotting (no smoothing) was employed. The accuracy of the dynamic test set is estimated to be 4.3 per cent, worst case.

Shaker Calibration	3.0 per cent
Effect of Mounting Extension	3.0 per cent
Instrumentation, Other	1.0 per cent
	<hr/>
Accuracy, Worst Case	4.3 per cent

3.2.2 Static Test Set: Resistance, inductance, and capacity measurements were made by use of the General Radio Type 1650A impedance bridge. The accuracies of these measurements are essentially that of the bridge, 1.5 per cent.

4.0 THERMAL CHARACTERISTICS

4.1 Computed: A heat transfer analysis of the accelerometer was made by the WANL Radiation Effects Program Department using the TOSS (Transient Or Steady State) computer code. The result of this work is shown by Figure 1 and Graph 1. The computed internal temperatures, generated by 3 watts per gram radiation heating with the transducer case held to +150°F, are shown on the model of Figure 1. In the graph, the computed maximum internal temperature is shown as a function of heat generation rate for 150°F transducer case temperature.

4.2 Measured: Measured thermal characteristics will be discussed under the individual test descriptions.

5.0 NON-NUCLEAR QUALIFICATION TESTS

The static tests to be described consisted of a check of hermetic seal and measurement of coil resistance, inductance, insulation resistance and coil to case capacity at -320°, 75°, 200°, 400°, and 600°F. The dynamic tests consisted of measurement of linearity and

frequency response at the above temperatures. Sensitivity as a function of temperature was measured and recorded during change of test temperature. In addition, sensitivity was measured as a function of time and of temperature during temperature shock from 75° to -320°F. Transverse response was measured at room temperature.

6.0 STATIC TEST RESULTS

6.1 Hermetic Seal: The unit was mounted inside a pressure chamber and pressurized with helium at 200 psi for 30 minutes. The unit was then removed and probed for helium leakage. No leakage was observed during this test.

6.2 Coil Resistance: Coil resistance was measured at several temperatures within the -320° to +600°F temperature range. The end-to-end coil resistance, within the above temperature range is described by equation (1).

$$R = 2.11 \times 10^{-2} T + 13.04 \text{ (ohms)} \quad (1)$$

where R = end-to-end coil resistance in ohms

T = temperature in °F.

The center conductor of the sheathed cable employed is nickel clad copper, while the outer conductors are copper. This configuration prevents the measurement of individual coil parameters since an active cu-ni thermocouple is introduced in series with the center tap. The thermocouple does not exist in the outer leads, therefore, end-to-end coil parameters were measured.

6.3 Coil Inductance: Coil inductance was measured at several temperatures. The nominal 3.34 millihenries increased by 10 per cent at 600°F.

6.4 Insulation Resistance: The insulation resistance observed at 50 volt d-c, at 400°F was 500 megohms.

6.5 Coil to Case Capacity: The typical coil to case capacity was 10,000 pf (Included was 15 feet of sheathed lead). This value changed by less than 2 per cent over the -320° to +600°F temperature range.

6.6 Residual Unbalance: The measured residual unbalance voltages are shown below as per cent full scale.

Unit	Residual Unbalance Voltage - per cent FR		
	<u>75°F</u>	<u>-320°F</u>	<u>600°F</u>
A30944	2,600	2,300	3,800

While the data acquisition equipment following the demodulator can be AC coupled, thus discarding the unbalance voltage, the unbalance is undesirable since the demodulator must be scaled to accept the high level quadrature voltage. It was necessary to scale the demodulator to 100 millivolts for the above unit.

7.0 DYNAMIC TEST RESULTS

7.1 Transverse Sensitivity: The transverse response, at room temperature, was 3.4 per cent FR.

7.2 Linearity: Graphs 2 through 9 are computer plots of SN A30944 linearity data, measured at 40 and 100 cps, within the -320°F to +600°F temperature range. Output voltages which are labeled DC volts on the curves were obtained from an AC-DC converter. They were inadvertently marked DC volts rather than RMS volts. The linearity curves show large deviations from the best straight line. This is attributed to binding of the sliding member discussed in paragraph 3.1.3.

7.3 Hysteresis: Reference to the linearity plots indicates large, random type, hysteresis effects.

7.4 Frequency Response: Graphs 10 through 13 are computer plots of SN A30944 frequency responses at temperatures within the -320°F to +600°F range. The curves were plotted with the 100 cps output as the reference point. The specified upper frequency of the accelerometer is 200 cps; however, the unit was tested to 500 cps for comparison with the Wiancko AX-44.

7.5 Relative Output versus Temperature: Graph 14 is a plot of percent full scale output versus temperature for SN A30944. The graphs for 50, 100 and 200 cycles per second were plotted utilizing the output at 100 cycles per second and 75°F as the 100% reference point.

As can be seen from the graph, the sensitivity of the transducer increases with increasing temperature. This phenomenon can be explained by analyzing the four transducer parameters that are being affected.

7.5.1 Coil Winding Resistance: A rise in coil winding temperature results in an increase in the resistance of the copper wires with a consequent decrease in primary current. This, in turn, decreases the output and sensitivity level.

7.5.2 Permeability of Materials: The permeability of the transducer material increases with temperature up to 700°F. This tends to increase the sensitivity with increasing temperature.

7.5.3 Modulus of Elasticity of Materials: The modulus of elasticity of materials will decrease with increasing temperature. This will tend to soften the material and consequently increase the sensitivity of the transducer.

7.5.4 Eddy Current Losses: If a solid block of metal is traversed by a varying magnetic flux, there will be eddy currents induced in the metal. All of these stray currents entail losses, and are proportional to I^2R . An increase in material temperature will increase the electrical resistance of the unit with a consequent decrease in the currents induced in the material of the circuit itself. Therefore, the eddy current losses will decrease and the sensitivity of the transducer will increase.

Evidently, the last three parameters override the first since the sensitivity was observed to increase with temperature. The above analysis indicates that the output versus temperature performance of the transducer can be improved by increasing the resistance of the coil windings.

7.6 Percent Deviation versus Temperature: Graph 15 is a plot of percent deviation versus temperature for a family of "g" curves at a constant frequency of 100 cycles per second. The curves were plotted utilizing the output at 75°F and the corresponding g level as the reference point. As can be seen from the curves, the percent deviation becomes progressively worse at the lower g levels.

7.7 Temperature Gradient Test: The unit was vibrated at half range (5 g's) at 100 cps at room temperature, and then suddenly immersed in liquid nitrogen. The vibration was held constant and the outputs were monitored. Graph 16 is a computer plot of sensitivity versus time in the LN₂; Graph 17 is a plot of sensitivity versus case temperature. During the first part of the test a temperature gradient approaching 400°F was generated between the accelerometer case and the internal components. Operation in a cold gas with radiation heating was thus simulated. It is difficult to postulate what is taking place during the stabilization time because of non-linearity, threshold, and sliding friction inherent to the transducer design. However, it can be predicted that when operated in a cold ambient environment with radiation heating, the transducer sensitivity will decrease sharply.

7.8 Additional Non-Nuclear Tests Required: The following tests, not yet performed in order to avoid possible damage to the only sample available for radiation testing, would be required if it were desired to complete non-nuclear qualification testing on this particular model: Acoustic Noise; Ambient Pressure to 1000 psia; Shock; and storage at -423°F and $+750^{\circ}\text{F}$.

7.9 Nuclear Tests: Nuclear evaluation will be made in Test 23/W006 during July 1965 at Plum Brook.

8.0 COMPLIANCE TO SPECIFICATION

A recap of Unit A30944 test results is shown by Table I.

TABLE I
Test Results Summary
PSC AT-302-2 No. A30944

Insulation		Passed
Compatibility		OK
Range		OK
Sensitivity		OK
	<u>E-675453B</u>	<u>Measured</u>
Linearity	$\pm 1\%$	Up to 14% error
Hysteresis		
Repeatability	0.5%	Poor
Temperature Range	-320 to 600°F	Unstable at 600°F
Thermal Zero Shift	$1\%/100^{\circ}\text{F}$	Apparent
Thermal Sens Shift	$0.25\%/100^{\circ}\text{F}$ Permanent Set	7.7%
Residual Unbalance	$\pm 1\%/100^{\circ}\text{F}$	$5.6\%/100^{\circ}\text{F}$
Transverse	$\pm 10\%$ FR	3,800% FR
Acoustic Noise	5%	3.4%
Ambient Pressure	150 db	Not done
Shock	0 - 1000 psia	200 psia
Humidity	25 g	Not done
Natural Frequency	0 - 100	OK
Ambient Temperature	> 500	> 500 cps
	-423 $+750$	Not done

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 **Specification Requirements:** This model deviates from the specified requirements by wide margins and should not be accepted in its present state. However, it is believed that a nominal amount of development effort could result in superior performance.

9.2 **Materials:** Good material selections have been made. The curie temperature of the magnetic materials is said to be of the order of 1500°F. A very high temperature device is therefore possible. The sensitivity of the existing design increases with increasing temperature. This condition is more easily compensated than the opposite condition of decreasing sensitivity with increasing temperature.

9.3 **Mechanical Friction:** The sliding member will never be satisfactory.

9.4 **Radiation Test:** The radiation testing of one unit in test 23/W006 is justified in order to determine the magnitude of the radiation-induced heating and to establish the radiation resistance of the transducer materials.

Physical Sciences Accelerometer
Model 302

Calculated Internal Temperatures

Heat Generation Rate $-3.0 \frac{\text{watts}}{\text{gram}}$

Helium Filled

Water Coolant -150°F

All Temperatures in $^{\circ}\text{F}$

FIGURE 1

FIGURE 2
ELECTRICAL SINGLE LINE
ACCELEROMETER DYNAMIC
TEST SET

GRAPH 1

Calculated Maximum Internal Temperature
of Physical Sciences Accelerometer

Model 302

GRAPH 2

LINEARITY
AT -320°F, 40 cps
PHYSICAL SCIENCES AT302-2
SN A30944

MARCH 1965

GRAPH 3
LINEARITY
AT -320°F, 100 cps
PHYSICAL SCIENCES AT302-2
SN A30944
MARCH 1965

GRAPH 4

LINEARITY
AT 75°F, 40 cps
PHYSICAL SCIENCES AT302-2
SN A30944

MARCH 1965

GRAPH 5

LINEARITY

AT 75°F, 100 cps

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 6

LINEARITY

AT 400°F, 40 cps

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 7

LINEARITY

AT 400°F, 100 cps

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 8

LINEARITY

AT 600°F, 40 cps

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 9

LINEARITY

AT 600°F, 100 cps

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 10

FREQUENCY RESPONSE

AT -320°F , 5 g's

PHYSICAL SCIENCES AT302-2

SN A30944

MARCH 1965

GRAPH 11

FREQUENCY RESPONSE
AT 75°F, 5 g's
PHYSICAL SCIENCES AT302-2
SN A30944

MARCH 1965

GRAPH 12

FREQUENCY RESPONSE
AT 200°F, 5 g's
PHYSICAL SCIENCES AT302-2
SN A30944

MARCH 1965

GRAPH 13
FREQUENCY RESPONSE
AT 600°F, 5 g's
PHYSICAL SCIENCES AT302-2
SN A30944

MARCH 1965

GRAPH 15
PERCENT DEVIATION
vs.
TEMPERATURE
PHYSICAL SCIENCES AT-302-2
SN A30944