FAILURE ANALYSIS OF XE-P FLUSH MOUNT
THIN FILM-VAPOR DEPOSITED-STRAIN GAGE BRIDGE
PRESSURE TRANSDUCER-STATHAM MODEL
PA812-750 AGC PN50390-1 SN66

RN-TM-0595

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MASTER

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FAILURE ANALYSIS OF XE FLUSH MOUNT

THIN FILM - VAPOR DEPOSITED - STRAIN GAGE BRIDGE

PRESSURE TRANSDUCER STATHAM MODEL

PA812-70 AGC PN 50390-1, SN66

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TABLE OF CONTENTS

	<u>Page</u>
I. Introduction	1
II. Conclusions and Recommendations	1
III. Technical Discussion	2
A. Description of Transducer	2
B. XE Test Data	3
1. EP's 1-7	3
2. EP 8-10	7
3. Post Test Data	7
C. Post Mortem Results	8
1. Electrical Checks	8
2. Dissection Findings	9
D. Failure Analysis	18

Figures

1. Crossection of Vapor-Deposited Thin Film Pressure Transducer	4
2. Diaphragm Layout and Hookup	5
3. Bridge Resistance	6
4. EP-5C Full Power Test - Transducer Drift	9
5. Photomicrograph Gage 1	11
6. Photomicrograph Gage 2	12
7. Photomicrograph Gage 3	13
8. Photomicrograph Gage 4	14
9. Photomicrograph Trimmer Tab	15
10. Overall Photograph of Diaphragm	16

	Page
11. Enlarged Photomicrograph of Gage #4	17
12. Photomicrograph of Statham Failed Strain Element	19
Tables	
A. Summary of Bridge Resistance Measurements	8
B. Individual Legs Resistance Measurements	10
References	21

I. Introduction

A Statham Instruments, Inc. Model PA812-750 (AGC P/N 50390-1, SN66) vapor-deposited thin-film strain gage pressure transducer was used during the XE series of tests to monitor the turbine inlet gas pressure. The transducer was installed on the engine and located on the turbine inlet line in the vicinity of the nozzle hot bleed port and was identified as parameter PT810...A.

The transducer performed satisfactorily during EP 1 through 7 of the XE test series. However, during the cooldown period of EP 8, the transducer output exhibited an erratic drift and finally drifted negatively off scale. Efforts to rebalance the transducer before EP 9 were unsuccessful and the parameter was identified as inoperative throughout the remainder of the test series.

The purpose of this report is to present the results of the post mortem examination and failure analysis of PT810 pressure transducer.

II. Conclusions and Recommendations

All the evidence indicates that the mode of failure was caused by a high voltage transient of unknown origin. This high voltage transient produced insulation failure between the bridge element and the transducer case. Once the failure to ground had been established, extensive damage resulted from subsequent electro-chemical action. Normal bridge excitation voltage (10 VDC) provided the electrical source of energy and the electrolyte is produced from within the insulating material. It was just a matter of time until the transducer failure occurred.

Recommendations were made to thicken the substrate material to prevent insulation breakdown. An increase in the thickness of the substrate would improve the electrical properties at the expense of reducing the mechanical overload capability of the transducer. However, in view of the extensive damage encountered by PT810, even doubling the substrate thickness would not have helped.

Protective circuitry in front of the transducer is a practical solution if the protective device is radiation tolerant or can be placed in a non-radiation environment. For non-nuclear type transducers, the manufacturer installs a Zener diode internally to the transducer as a means to protect the bridge from this kind of failure. However the Zener diode is only good for low voltage transients and the manufacturer was doubtful it could sustain a high voltage transient for any length of time. There are several overvoltage and over-current protective devices available on the market that will provide adequate protection against transients by sensing the transient and switching the circuit open before the high voltage reaches the vulnerable portion of the transducer. However, extensive tests and qualification will have to be performed on these protective devices before adapting them for NERVA use.

Preparing tight operational specifications and maintaining strict quality control will also aid in preventing this mode of failure. High voltage transients can be man caused especially if improper or defective instruments or equipment are used.

Future use of this type of transducer will incorporate qualified protective devices in front of the transducer to eliminate high voltage transients from reaching the vulnerable vapor deposited strain elements on the diaphragm. Also, tight calibration, installation and operational procedures will be written and followed by Q. C. to assure successful operation of this transducer on future NERVA tests.

III. Technical Discussion

A. Description of Transducer

The Statham Model PA812-750 pressure transducer is a flush mounted absolute type with a range of 0-750 psia, 30 millivolt full scale output and an excitation of 10V dc. The sensing element is a four active arm strain gage

bridge vapor deposited directly onto the diaphragm. Figure 1 is a cross-section of the transducer. A ceramic sub-strate is vapor deposited on the diaphragm and metallic strain elements are vapor deposited onto the substrate. Lead wire connection tabs and a long thin trimmer tab are then vapor deposited on. This trimmer tab is used to initially balance the bridge. Thin gold foil wire is spot welded to the connecting tabs and to the header pins to complete the bridge. One gage is connected to a dummy header pin then to the trimmer tab for balancing the bridge. Figure 2 is a diagram of the deposited gages, tabs, trimmer tabs and header pin arrangement on the diaphragm.

The initial input and output bridge resistance was 665 ohms with an insulation resistance to ground of 1.5 K megohms.

B. XE Test Data

1. EP 1-7

PT810..A performed satisfactorily during the first seven EP's of the XE test series. During the full power run, EP-5C there was an indicated pressure drift noted during the hold period at the various power levels. This indicated pressure drift was predicted and was due to Gamma heating of the transducer.

The drift values noted during the test were similar in magnitude to the drift recorded during the evaluation test of four similar transducers at the ASTR test facility in Fort Worth, Texas. (Reference RN-S-0529 Final Report - Evaluation of Test Results for Thin Film Pressure Transducers, September 1969). Figure 3 is a plot of PT810 and PT814 pressure vs time for EP-5C. PT814 is another transducer measuring turbine inlet gas pressure, however, the transducer was located in the Upper Thrust Structure (UTS) and a pneumatic line connected the transducer with the point of measurement. PT814 was not subjected to gamma heating and serves as a good comparison for the operational performance of PT810.

CROSSECTION OF VAPOR DEPOSITED
THIN FILM PRESSURE TRANSDUCER

FIGURE 1

FIGURE 2
DIAPHRAGM LAYOUT
AND HOOKUP

The indicated pressure drift is a function of gamma heating and is not evidence of transducer failure since the transducer recovers completely after reactor power is turned off. By knowing the temperature coefficient of resistance (TCR) of the bridge material and the gamma heating rate, the indicated pressure drift can be calculated for any point in time during the test. This was proven with data from the ASTR test and served as an aid to minimize errors due to nuclear heating.

2. EP 8-10

The post calibration data for EP 8 indicated that PT810..A output was saturated at the negative full scale reading of -9999. The Digital Acquisition System was checked and found to be operating satisfactorily. The transducer was then checked by measuring the bridge resistances from the Test Cell Building at ETS-1. The input resistance measured 923 ohms, and the output resistance measured 931 ohms. This large increase in resistance from the nominal value of 665 ohms indicated that some change in the transducer had taken place. At this time in the test series the bridge of the transducer was still intact with some or all of the strain elements changed in value. The resistance measurements indicated that the bridge unbalance was only 8 ohms even though a significant increase in resistance had occurred in both the input and output values. The transducer was left on-line throughout EP-9 and EP-10 for the purpose of monitoring further changes, if any. However, no changes were recorded and the output of the bridge remained at -9999 reading.

3. Post Test Data

After completion of the XE series of tests, a post operational electrical check was performed on all instrumentation before removing the engine from ETS-1. From the Instrument Data Log Sheet for PT810, the following resistance

measurements were obtained; input resistance 1644 ohms, output resistance 2760 ohms and insulation resistance to ground 10 megohms. The post test electrical check indicated that the bridge deterioration had continued throughout EP-9 and EP-10.

After the post test operational electrical check the VE engine was removed from ETS-1 and sent to E-MAD building for more post test operations and disassembly. The PT810 transducer was removed and shipped to AGC Sacramento for post mortem tests and examination.

C. Post Mortem Results

1. Electrical Check

After the transducer was decontaminated, the sheath cable was stripped back and electrical leads attached for post test calibration. Resistance measurements of the bridge were made after the leads were attached. The input leads were color coded green and white and the output leads were color coded red and black. Table A is a summary of the resistance measurements.

TABLE A
BRIDGE RESISTANCE MEASUREMENTS

Input resistance	green to white	1617 ohms
Output resistance	red to black	2716 ohms
	red to white	1836 ohms
	red to green	3441 ohms
	white to black	891 ohms
	green to black	727 ohms

Figure 4 shows the relationship of the resistance values in Table A to the bridge wiring diagram and from observation it was noted that the bridge was open at one leg. The resistance value measured between the red and green leads was approximately equal to the summation of the other three legs of the bridge. (The slight difference in the two values is due to the accuracy of the measuring instrument.) The failure of the transducer

FIGURE 4

is attributed to an open bridge, however, at the end of EP-8 the bridge measured intact within the input and output resistance values of only 923 to 931 ohms respectively. The resistance values changed from 665 ohms to approximately 930 ohms during EP-1 through EP-8 and the cause of this change was investigated by dissection of the transducer.

2. Dissection Findings

The transducer case was carefully removed to expose the back side of the diaphragm where the sensing element is located. Visual examination revealed that the two leads that were attached to the trimmer tab for bridge balancing were off and the tab was disintegrated. The two leads to the trimmer tab not being attached explains the open bridge condition noted earlier. Resistance measurements of each individual leg were made and the values obtained are listed in Table B.

TABLE B
INDIVIDUAL LEG RESISTANCE MEASUREMENTS

Gage 1	736.9 ohms	Figure 5
Gage 2	726.4 ohms	Figure 6
Gage 3	952.1 ohms	Figure 7
Gage 4	1830.6 ohms	Figure 8

All gages changed from the nominal value of 665 ohms but some more than others. Photomicrographs taken of each strain element and the trimmer tab along with an overall picture of the diaphragm are shown in Figures 5, 6, 7, 8, 9, and 10. From the photomicrographs, it was observed that there was disintegration of the strain elements also. Strain elements #3 and #4, that had the higher resistance change, also had the most disintegration, as shown in Figures 7 and 8. Figure 10 is the overall photograph of the diaphragm, and Figure 11 is a further enlargement of gage #4 showing the corroded area in detail.

Gage #1

Figure 5

Gage #2

Fig. 6

Gage #3

Fig. 7

Gage#4

Fig.8

Trimmer Tab

Fig. 9

Figure 10
Diaphragm Layout

An enlarged photomicrograph of a metal surface. The image shows a complex, irregular shape with a rough, textured interior and a smoother, more defined outer boundary. The surface is covered with numerous small, dark, circular features, likely pores or inclusions. There are also larger, darker, irregular patches scattered across the surface. The overall appearance is that of a microscopic view of a material's internal structure or surface morphology.

Enlarged Photomicrograph
Gage #4

Figure 11

D. Failure Analysis

The apparent deterioration of the strain elements was discussed with the manufacturer, Statham Instruments. Based upon verbal description of the condition of the vapor deposited strain elements, the manufacturer indicated that the most probable cause of failure was electrolytic etching of the elements caused by the application of a high voltage transient condition between the element and transducer case. The manufacturer stated that this was a common mode of failure and a persistent problem in the thin film electronic industry. The photomicrographs were sent to the manufacturer for analysis.

After reviewing the photomicrographs, the manufacturer confirmed the suspected mode of failure by performing a destructive test on a similar transducer diaphragm. One thousand volts D.C. was applied between the strain bridge and transducer case. The strain elements were examined and photomicrographed, as shown in Figure 12. The mode of failure was similar to the PT810 transducer.

Based on available data the most probable cause of the PT810 failure was the application of a very high transient voltage between the bridge and transducer case which produced numerous small insulation failures. Once these failures to ground are established, extensive damage resulting from electrochemical action takes place, with the bridge excitation voltage providing the electrical source of energy and the electrolyte is produced from within the insulating material. Comparison of Figure 12 with Gage 2, Figure 6 of PT810 shows nearly identical deterioration of the element.

The manufacturer concluded that probably a voltage was applied to PT810 and may have been in excess of 1000 V. The source of the high voltage is unknown but the insulation breakdown could have been caused by sources such

A circular micrograph showing a cross-section of a material. A bright, irregularly shaped region is visible in the upper left quadrant, possibly representing a crack or a void. The surrounding material has a granular texture. A horizontal band of lighter material runs across the lower half of the image.

Statham Instrument Inc.
Destructive Test
Strain Element Failure

Figure 12

as; static electric discharge, lightning, high voltage insulation meggers,
or transient voltage spikes induced by system operation.

REFERENCE

RN-S-0529 "Final Report - Evaluation of Test Results for Thin Film Pressure Transducer", September 1969