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Space Shuttle Pogo Pressure Measuring System A Progress Report

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National Bureau of Standards
Washington, D. C. 20234

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Progress Report Covering Period
December 15, 1973 to June 15, 1974

Prepared for
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This is a progress report. The work is incomplete and is continuing. Results and conclusions are not necessarily those that will be included in the final report. Performance Test Data were obtained from one or two samples of several transducer types, and do not necessarily represent the characteristics of all transducers of a given type.

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

ABSTRACT

This progress report describes two methods for the dynamic calibration of pogo pressure transducers used to measure oscillatory pressures generated in the propulsion system of the space shuttle. The requirements are for the generation of a known (5% or better) sinusoidal pressure perturbation of 140 kPa (approximately 20 psi) peak-to-peak at bias pressures up to 55 MPa (approximately 8000 psi) over a frequency range of from 1 Hz to 100 Hz. Rotating a mercury-filled column in a vertical plane at frequencies below 10 Hz generates peak-to-peak pressures of 48 kPa (7.0 psi); vibrating the same mercury-filled column in a vertical plane continues the frequency response from 10 Hz to 200 Hz at peak-to-peak pressures ranging from 21 kPa to 145 kPa (approximately 3 psi to 21 psi). A method for vacuum filling of the column is described.

KEY WORDS

Calibration; differential pressure; dynamic; high pressure; orbiter vehicle; pogo; pressure; sinusoidal space shuttle; transducer.

Space Shuttle Pogo Pressure Measuring System

Progress Report for the Period
from December 15, 1973 to June 15, 1974

to the

George C. Marshall Space Flight Center
NASA Order #H-92100A
NBS Project 4253448

Prepared by

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and
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1. Introduction

The objectives of this project include (1) the development of a dynamic pressure calibration method for pogo pressure transducers used to measure oscillatory pressures generated in the propulsion system of the space shuttle and (2) the procurement and evaluation of several commercial transducers to determine their suitability for the measurement of such pogo pressure perturbations. Specified is a full-scale range of 140 kPa peak-to-peak at bias pressures up to 55 MPa over a frequency range of from 1 Hz to 100 Hz*. Transducers used for shuttle pogo measurements will be required to operate in vibration environments ranging from 5 Hz (0.8-cm double-amplitude displacement) to 3 kHz (140 g_n peak-to-peak acceleration) and in the shuttle propulsion system temperature range of from -253°C to about 480°C. Vibration levels and temperatures to be experienced by each transducer will be determined by its site in the system; sites have not yet been selected. Since exact information on the temperature environment for pogo transducers is not available, transducers have been procured with a major consideration being performance over as wide a portion possible of the temperature range given above, and efforts have been directed toward developing calibration methods suitable for use at the most convenient temperature, laboratory ambient (the NBS Laboratories at Boulder, under a separate contract, have developed some preliminary techniques for determining transducer suitability at cryogenic temperatures).

As methods for transducer calibration using liquid-filled calibration tubes were available, these methods were chosen as starting points for the present work. The use of a liquid-filled tube as opposed to a gas-filled tube does not affect the performance of flush-diaphragm

* 1 kPa = 0.145 psi; 1 MPa = 145 psi.

type pressure transducers; the performance of differential types may be different for gaseous than for liquid media. Whether a given transducer in the shuttle propulsion system is responding to gas pressure, to liquid pressure, or to the pressure of a mixture of phases will depend on both its detailed location in the oxidizer or propellant flow stream and on the flow conditions at any given moment of time.

2. Dynamic Calibration of a Piezoelectric Pressure Transducer Using the Liquid-Filled Calibration Tube on the Windmill Apparatus and on the Vibration Generator

A test was described in the previous report [1]** in which the windmill tube (a liquid-filled calibration tube mounted on the windmill apparatus) was first partially filled with mercury; filling was completed with oil to prevent mercury contamination of the oil piston-gage system connected to the tube during the pressurization cycle. The use of two liquids with significantly different compressibilities resulted in a calibration tube that behaved in part as an open tube and in part as a closed tube. A conclusion was that the tube should be filled with mercury only.

Figure 1 is a schematic of the apparatus used to fill an evacuated calibration tube with mercury; valve sequencing is indicated in the valve position chart. Following the mercury fill, the tube was pressurized to 55 MPa by means of the oil piston gage. The closed liquid-filled calibration tube was mounted on the windmill apparatus and measurements of transducer output were made at 17 rotational speeds corresponding to frequencies ranging from 1.93 Hz to 6.25 Hz; the dynamic pressure level for all tests was 48 kPa peak-to-peak. The liquid-filled calibration tube was then removed from the windmill apparatus and attached to the vibration exciter with the transducer under test at the upper end of the tube. Calibrations were carried out from 10 Hz to 200 Hz at dynamic pressure levels ranging from 21 kPa to 145 kPa peak-to-peak. For the tube used, an acceleration of $\pm 3\ g_n$ produces pressure pulses of 134 kPa peak-to-peak. Extrapolations to the region of 8 Hz of the two calibration curves obtained from these tests agreed to within 1%. The tube was then mounted on the vibration exciter in an inverted position with the transducer at the lower end of the tube, and a set of 10-200 Hz frequency-response measurements was performed as described above. These two sets of 10-200 Hz measurements were then averaged, as described in the previous report [1], to determine a geometry correction factor of 6% for the data shown in figure 2. With the factor of 6% applied, the manufacturer's calibration was within 2% of the NBS dynamic calibration. Some uncertainty in this comparison is created by the fact that in the manufacturer's calibration and in the NBS calibration different combination power supply-amplifiers were used; as reported previously, choice of power supply may affect the calibration significantly (up to 5%) [1]. Figure 2 shows the frequency response for transducer A-1 in terms of response ratio, defined as the ratio of (1) transducer output at the

** Figures in brackets refer to references, section 7.

given frequency to (2) the average transducer output over that portion of the frequency range in which the output is considered to be flat, for A-1, 20-50 Hz. At the low-frequency end of the range, response is down about 15% at 2 Hz from unity response ratio.

3. Construction of New Windmill Calibrator

As reported, the present windmill calibrator was modified from the prototype Earth's field dynamic calibrator for acceleroemters [2] by removing the turntable and replacing it with a 76-cm tube and mount. The new apparatus is intended to extend the frequency range downward to below 1 Hz and upward to approximately 15 Hz. The new design incorporates two variable-speed motors; the slower of these rotates the tube at frequencies from below 1 Hz to about 4 Hz; the other, at frequencies from about 2 Hz to as much as 15 Hz. Chief factors limiting maximum rotational speed are the degree of balance achieved and the amount of friction present. Mercury slip rings are used to reduce friction and noise. Completion of the calibrator is subject to component delivery. As of July 1, 1974 the air bearings, two motors, and drive belts have been received; shaft and shaft-support housing have been fabricated. Pulleys for the drive system and mercury slip rings have not been received although the orders for these items were placed over 5 months ago. The manufacturers have been contacted repeatedly; delivery is now scheduled within 40 days.

4. Transducer Repair and Procurement

Two piezoelectric pressure transducers F-1 and F-2 have been procured with a range of from 0 MPa to 69 MPa, a sensitivity of about 0.65 mV/kPa, and a time constant of 2500 s. Two power supply-amplifiers for use with these transducers (one line powered, S-4, and one battery powered, S-5) have also been received.

As previously reported, transducer A-4 has been returned to the manufacturer for warranty repair. To provide improved low-frequency response the manufacturer was instructed to modify the instrument increase the time constant to 0.5 s. The new designation for the modified A-4 is G-1. This change also reduces the sensitivity of the instrument from 4.4 mV/kPa to 1.5 mV/kPa.

During tests, transducer C-2 was damaged in an unknown way; it was also returned to the manufacturer for repair and conversion to a 0.5-s time constant. The new designation for the modified C-2 is G-2.

5. Calibration of Strain Gage Differential Pressure Transducer

The sponsor requested that a specific manufacturer be given the opportunity to supply a differential-type transducer for evaluation. On being contacted, this manufacturer indicated that considerations of time and cost precluded the development of a special design for pogo evaluation, but that he would modify an existing industrial high line-pressure, low differential-pressure transducer constructed with two diaphragms separated by an oil-filled cavity. Accordingly, the manufacturer supplied a metallic strain gage transducer consisting of "two pressure chambers, connected through an adjustable leak-rate valve and separated by a diaphragm which responds to the pressure difference between chambers."

A 25.4-cm brass pipe was screwed into the pressure fitting of the transducer to form a vertical calibration tube; both pressure chambers as well as the 25.4-cm pipe were filled with oil using a vacuum filling technique and the transducer-calibrator was mounted on the vibration exciter in a vertical position. A hose was attached to the top of the pipe, and a bellows was used to apply a pneumatic pressure of first +10 kPa and then -10 kPa for a static calibration. The static calibration resulted in only about 4% of the output predicted by the manufacturer's calibration sheet. An explanation may be that when the chambers of the pressure transducer are filled with oil and when the transducer by-pass valve connecting the two chambers is closed, the presence of the nearly incompressible oil in the bottom chamber of the transducer changes the effective spring constant of the pressure-sensing diaphragm to result in a stiffer system. When the oil was removed from the transducer and the static calibration again performed, the sensitivity observed was approximately that given by the manufacturer; this observation tends to confirm the explanation given above.

A few dynamic calibration measurements of the response of the transducer were performed using the vibration exciter. These measurements also showed a greatly reduced sensitivity factor from that claimed by the manufacturer.

It should be noted that the manufacturer supplied a transducer more suitable for gaseous than for liquid media. The test results indicate in themselves only the unsuitability of the design for liquid-media pogo measurements. However, experience with pressure transducer evaluation, including analysis of design principles, suggests that behavior of the acoustic filter -- the by-pass line and adjustable leak-rate valve -- will vary with changes in the ambient temperature and media density and render this design unsuitable for flight rating. No further testing of transducers with acoustic filters is planned.

6. Future Plans

Tasks for the Reporting Period June 15, 1974 to December 15, 1974 are the following:

(1) Completion and testing of windmill apparatus.
(2) Calibration of transducers F-1, F-2, G-1, and G-2. These transducers will first be calibrated using the windmill apparatus and then calibrated using the vibration exciter. Calibration will

be at full bias pressure and with a dynamic component varying from 48 kPa to 145 kPa peak-to-peak. The data will cover the frequency range of from 0.5 Hz to 100 Hz.

(3) Two-plane vibration sensitivity tests of transducers F-1, F-2, G-1, and G-2 over the frequency range of from 5 Hz to 3 kHz.

(4) A mathematical analysis of the closed tube amplitude-halving and frequency-doubling phenomena will be developed and included in the final report.

7. References

[1] Hilten, J.S., and Lederer, P.S., Space Shuttle Pogo Pressure Measuring System, Progress Report for the period September 15, 1973 to December 15, 1973, NBSIR.

[2] Hilten, J.S., Accelerometer Calibration with the Earth's Field Dynamic Calibrator, NBS Tech. Note 517 (March 1970).

VALVE POSITION CHART

VALVE	A	B	C	D *	E
Step					
Evacuate System	closed	closed	open	open	open
Fill System	closed	open [2]	closed [1]	open	open
Pressurize System	open [2]	closed [1]	closed	open	open
Close Calibrator Valve	open	closed	closed	open	closed
Oil Piston Gage to Atmospheric Pressure	open	closed	closed	open	closed
Close Down System	closed	closed	closed	closed	closed
Invert; Empty Mercury Reservoir	closed	closed	closed	closed	closed

*Valve D prevents oil from contaminating the rest of the system when system is inverted.
1,2 Numbers refer to the sequence of valve operation within the step.

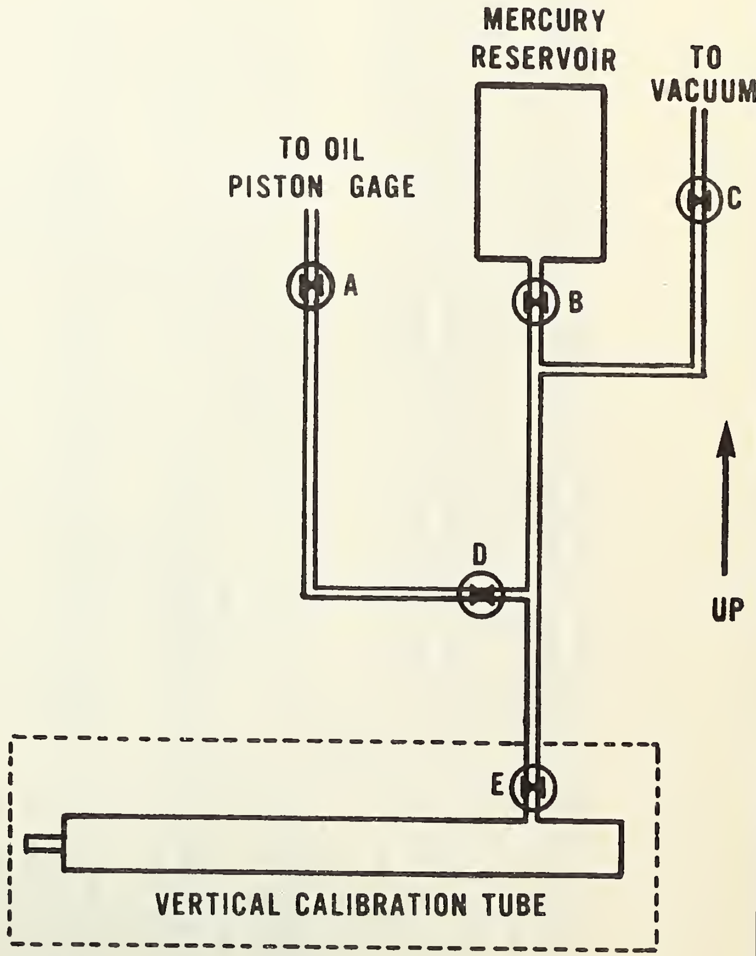

FIGURE 1: SCHEMATIC OF VACUUM FILLING OF VERTICAL CALIBRATION TUBE WITH MERCURY

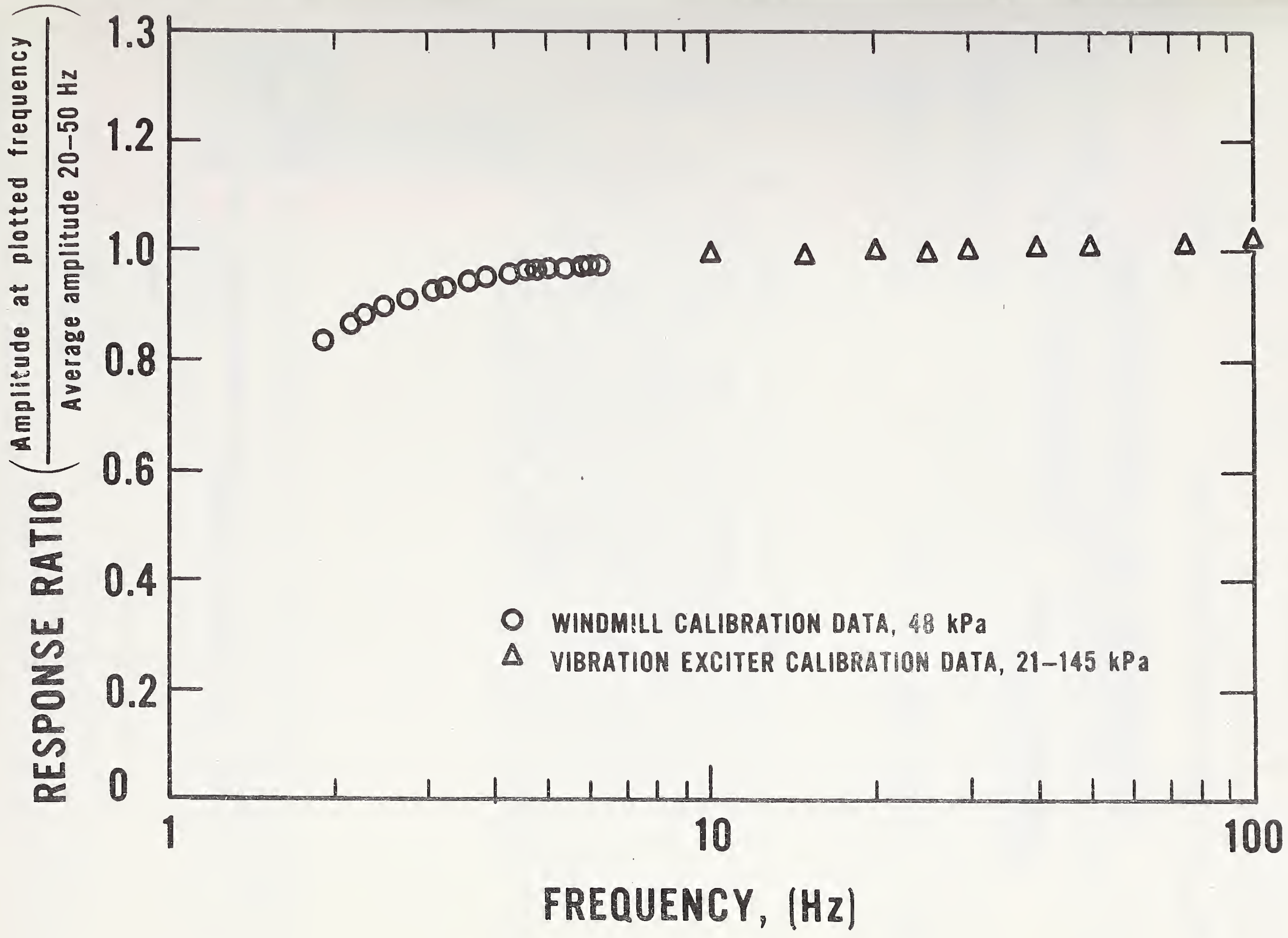

FIGURE 2: FREQUENCY RESPONSE OF PIEZOELECTRIC TRANSDUCER A-1, 55-MPa BIAS PRESSURE

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This progress report describes two methods for the dynamic calibration of pogo pressure transducers used to measure oscillatory pressures generated in the propulsion system of the space shuttle. The requirements are for the generation of a known (5% or better) sinusoidal pressure perturbation of 140 kPa (approximately 20 psi) peak-to-peak at bias pressures up to 55 mPa (approximately 8000 psi) over a frequency range of from 1 Hz to 100 Hz. Rotating a mercury-filled column in a vertical plane at frequencies below 10 Hz generates peak-to-peak pressures of 48 kPa (7.0 psi); vibrating the same mercury-filled column in a vertical plane continues the frequency response from 10 Hz to 200 Hz at peak-to-peak pressures ranging from 21 kPa to 145 kPa (approximately 3 psi to 21 psi). A method for vacuum filling of the column is described.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Calibration; differential pressure; dynamic; high pressure; orbiter vehicle; pogo; pressure; sinusoidal; space shuttle; transducer.

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