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NBS InterAgency Transducer Project
A Project Report

P. S. Lederer and J. S. Hilten

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

February 20, 1975

Progress Report Covering Period July 1, 1974 to Semptember 30, 1974

Prepared for
Naval Air Systems Command
U.S. Navy and Transducer Committee
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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 a 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.

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

NBS InterAgency Transducer Project

A method is being developed to apply short-duration thermal transients to pressure transducers and to observe the effects of these transients on transducer performance. The method consists of monitoring pressure transducer output as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. During this reporting period, the work has been exploratory in nature to determine values for method parameters. Thermal energy pulses as high as 0.4 J lasting 4 ms have been generated using an electronic flash; pulses as high as 1 J lasting 18 ms have been generated using #22 flashublbs.

Work being performed for other agencies is also described briefly.

Key words: Calibration; dynamic; photo flashbulb; pressure; pressure measurement; pressure transducer; thermal transient; transducer.

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Progress Report for the Period
From July 1, 1974 to September 30, 1974

to the

Naval Air Systems Command,
U.S. Navy Transducer Committee,
Telemetry Group,
Range Commanders Council
NBS Project 4253434

Prepared by

Paul S. Lederer
and
John S. Hilten

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1. Introduction

1.1 Background

The NBS InterAgency Transducer Project has been supported by various agencies of the Department of Defense and NASA between 1951 and 1972. Agency budget restrictions in FY 1973 forced the discontinuance of the project during that year. The Transducer Committee of the Range Commanders Council Telemetry Group (TG/RCC) obtained some support from national test ranges for the resumption of this project in FY 1974, and the Naval Air Systems Command resumed its support in FY 1975.

Current objectives of this project are the following (the first four objectives have been pursued since the inception of the original project in 1951):

1.1.1 Investigation of the Performance Characteristics of Telemetering Transducers

1.1.2 Development of Calibration and Evaluation Techniques and Apparatus for Telemetering Transducers

1.1.3 Evaluation of New Transducer Technologies for Telemetry

1.1.4 Consultation to Navy Research, Test, and Evaluation Facilities and Test Ranges

1.1.5 Support of Range Commanders Council, Telemetry Group, in Investigations and Development of Transducer Standards for Telemetry

1.2 NBS InterAgency Transducer Project

In order to supplement the variable funding made available specifically for the NBS InterAgency Transducer Project, support has been sought from other agencies to fund certain mission-oriented tasks. These tasks have generally met one or more of the objectives of the InterAgency Project as well. Therefore, reports describing the mission-oriented work have been made available to the Naval Air Systems Command, to national test ranges, and to other interested agencies and their contractors. Plans are to continue this policy.

1.3 Current Assignment

The Transducer Committee of TG/RCC has assigned the following task to the NBS InterAgency Transducer Project: "Develop a test device and generate a test procedure to impinge thermal transient inputs on pressure transducers. The requirements of the test device should include:

1. Inexpensive to build;
2. Simple to operate;
3. Easily reproducible by transducer manufacturers, test ranges, or range users;
4. Capable of impinging thermal transients of any duration greater than 1 millisecond;
5. Controlled heat flux inputs capable of being quantized.

Documentation of this test procedure and the devices constructed should be formalized in report form. In addition, this report should relate the heat flux capabilities of the test device to actual thermal transient environments. Quarterly progress reports should be submitted to the TG Transducer Committee."

2. Experimental Development

2.1 Introduction

A method for generating and applying thermal transients to pressure transducers was described in an oral presentation to the Task Group Executive Committee and to the Transducer Committee at the July 1974 TG/RCC meeting. The method, in brief, consists of monitoring transducer output as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. Experimental work began when the energy meter and electronic flash were received in September 1974. Most of the work has been exploratory in nature to determine values for method parameters.

2.2 Method and Arrangement of Apparatus

The experimental arrangement is as follows: The flashbulb or flashtube is mounted in a vertical position at the center of an optical bench; mounted on the bench on opposite sides are an energy meter and the transducer mounting fixture. The diaphragm of the mounted pressure transducer and the sensing element of the energy meter are aligned with, and equidistant from, the center of the flash unit. The energy meter and transducer may be moved along the bench to vary the respective distances between them and the flash unit, which is held fixed. Also fixed in position is a photodiode mounted at right angles 15 cm from the bench center and used as a flash output monitor to check the operation of the energy meter. The output for a given flash is assumed to be constant in azimuth to with 5%. All four elements are adjusted in position vertically to be coplanar.

In a test the quantities monitored are as follows: (1) the output of the pressure transducer displayed on an oscilloscope, (2) the digital reading of the energy meter (which displays the total pulse energy in joules), (3) the energy meter output displayed on an oscilloscope (peak amplitude is proportional to the energy input), and (4) the photodiode output also displayed on an oscilloscope.

2.3 Equipment Description

2.3.1 Transducer Mounting Fixture

The transducer mounting fixture is a rectangular brass block approximately 10-cm high, 10-cm wide, and 6-cm deep and is purposely made massive to serve as a heat sink, with a mass of about 5 kg. A 3.8-cm bore extends through the block, centered on the front face (the face towards the flash unit). A round glass window with an aperture of 3 cm and a thickness of approximately 0.6 cm is sealed into the bore at the front face. The window glass is of a 96%-silica composition with a low coefficient of expansion. The transducer to be tested is mounted in a brass flange; an air-tight seal to the bore is made by means of an O ring between the flange and the block. The flange is mounted to the block with 6 bolts. This arrangement simulates the way a transducer is mounted in a typical application.

A hole connecting with the bore permits any desired pressure (including vacuum) to be applied to the volume between the transducer and window. Thus, the pressure the transducer sees at the beginning of a run may be preselected.

2.3.2 The Energy Meter

The following information is abstracted from the manufacturer's instruction manual: The energy meter consists of a pyroelectric detector and associated signal-processing and display electronics. The pyroelectric detector is a slice of ferroelectric material which possesses a permanent electric polarization that is highly temperature dependent. As radiant energy is absorbed by the detector coating, a current is generated that is proportional to the time-rate-of-change of the temperature of the ferroelectric material. This current is integrated by a preamplifier and produces an output that can be displayed on an oscilloscope. The peak amplitude of the preamplifier output waveform is proportional to the energy content of the radiation pulse. The readout circuitry measures the peak amplitude of the preamplifier output, computes a scale factor, and displays the result in the proper units (joules).

The meter, with four-digit readout, is intended to measure the total energy content of radiation pulses with durations ranging from less than 1 ns up to a maximum of 50 ms. This range of pulse durations represents a modification of the standard meter, which covers a 1-ns to 1-ms range.

Seven ranges are provided, which are switch selectable, with full-scale readings progressing in six decade steps from 2 μJ to 200 mJ in addition to a 1-J position.

The response of the pyroelectric detector is described as being flat to within ±2% in the wavelength range of from 0.3 μm to 20 μm. Manufacturer's literature describes the overall system accuracy as ±4% of reading ±1% of full scale with the sensing area fully illuminated. Least count is 0.1 mJ for 200 mJ full scale and 0.001 μJ for 2 μJ full scale. Maximum noise level is given as 0.3 μJ.

In the auto-trigger mode, the instrument is triggered when the energy absorbed by the detector is greater than 5% of full scale; in the external-trigger mode, a positive-going trigger pulse ranging in amplitude from 5 V to 100 V must be supplied coincident with the radiation pulse to be measured.

2.3.3 Flashbulbs

Three types of photographic flashbulbs have been or will be used in the evaluation; their characteristics, obtained from manufacturer's literature, are shown in table 1.

Table 1

Flashbulb Characteristics

Bulb Designation	Flashbulb Output (klm·s)	Peak Luminous Flux (klm)	Approximate Time to Peak (s)	Approximate Duration of Flash (s)*
# 5 clear	20	1450	0.020	0.019
#22 clear	70	4200	0.020	0.018
FF-33	not given	120	0.640	1.6

*Time measured from point when flash reaches 30% of its maximum value until it falls to 30% of its maximum value

The #5 and #22 flashbulbs are readily available from photographic supply houses; the FF-33 flashbulb, or "flood flash" as it is described by the manufacturer, is used in automotive crash-test photographic applications and can be purchased directly from the manufacturer.

The amplitude-time waveform of the radiation output from all three bulbs is roughly triangular in shape.

2.3.4 Description of Electronic Flash System

The electronic flash system consists of a xenon-filled flash tube, a capacitor bank, a power supply, and other associated electronic components including a triggering circuit. In use, the capacitor bank is charged by the power supply to approximately 450 V dc; the voltage is then discharged through the flash tube by applying a trigger pulse to the gate of a silocon controlled rectifier by means of a mechanical switch.

This unit can operate at one of two energy levels, 150 and 50 J; in the 150-J mode the peak intensity of the light is only slightly increased over the 50-J mode, but the capacitor discharge time is extended. The rise time is about 0.3 ms for both the 50- and 150-J positions, but the fall time to about 30% of the peak value is about 2 ms and 4 ms, respectively. The manufacturer describes the color content of the light as very closely resembling that of daylight.

2.3.5 Photodiodes

The *n-p-n* planar silicon phototransistor selected may be used in either the phototransistor mode or the photodiode mode of operation; in all tests described in this report the photodiode mode was used. The manufacturer gives the rise time and fall time as typically 350 ns and 500 ns, respectively. The output collector current is linear with irradiance from 0 to 80 mW/cm^2. The spectral response is near zero at 0.5 μm, rises to a maximum at about 0.9 μm, and returns to near zero at 1.1 μm. A supply voltage of up to 50 V dc may be used in the photodiode circuit.

2.4 Description of Work

The approximate amount of energy available from the electronic flash at the 150-J setting was measured with the energy meter a few cm away from the flash (within the range over which there was little variation observed with change in meter-flash distance). A level of from 0.3 J to 0.4 J was measured by the 1-cm^2 circular sensing area of the energy meter. Using the same experimental arrangement with a #22 flashbulb, approximately 1 J was measured.

Some indication of repeatability of the flash energy was obtained by firing twenty consecutive shots with the electronic flash first at the 50-J setting and then at the 150-J setting (meter-flash distance of approximately 25 cm). With 50-J, the sample standard deviation for twenty flashes was 1.51 mJ, and the sample mean 63.99 μJ; with 150 J, (excluding three shots which apparently misregistered), the sample standard deviation was 2.29 mJ, and the sample mean 109.15 mJ. Much of this variation is not scatter but a gradual decline in measured values observed as the tests proceeded.

Tests in which the flash was fired five times with the energy meter open, then fired an additional ten times with the energy meter shuttered, and finally fired five more times with the energy meter uncovered indicate that this decline results from the performance of the electronic flash. Flash output apparently drops as the internal battery voltage drops with use. A line-operated power supply has been ordered to eliminate this problem. Energy-meter malfunctions are occurring about 10% or 15% of the time, and considerable effort has been expended to determine the cause and to find a correction; faulty triggering of the energy meter is suspected.

With respect to flashbulb repeatability, the sample standard deviation for six #5 flashbulbs was 2.77 mJ (sample mean 42.12 mJ), and for six #22 bulbs, 5.47 mJ (sample mean 87.18 mJ). No FF-33 bulbs are available at this time.

Because of problems with the energy meter and with the battery-operated flash units, insufficient data is available to establish the relationship between distance and energy level. No transducers have been used in thermal transient tests in this period.

3. Plans for the Reporting Period October 1, 1974 to December 31, 1974

3.1 Energy-Distance Dependence

The change in measured energy density as a function of distance from the flash will be determined by measuring flash energy with the distance from the meter to the flash varied from 1 cm to 15 cm in 1-cm steps. Sets of measurements will be taken for five flash sources: #5 flashbulbs, #22 flashbulbs, FF-33 flood flashbulbs, electronic flash set for 50 J, and electronic flash set for 150 J. During these tests the output of a pressure transducer known to be affected by thermal transients will be measured at the time of each flash. For each position, the transducer-flash distance will be made equal to the meter-flash distance. The monitoring photodiode will also be used in these tests. The data obtained will be used to guide the selection of a convenient test distance.

3.2 Method Repeatability

Repeatability of the method will be estimated on the basis of the following experiment. The transducer used in 3.1 and the energy meter will be set at the selected distance from the flash, and ten flashes fired with a two-minute interval between flashes. Transducer response, photodiode output, and the two outputs from the energy meter will be measured and recorded. This test will be carried out for the five flash sources identified in 3.1.

3.3 Pressure Transducer Response Measurements

Response of sixteen selected pressure transducers to thermal transients will be determined at the test distance and with several of the flash sources identified in 3.1.

Six types of transducer will be represented, as follows: recessed diaphragm (four), industrial-use type semiconductor strain gage (four), unbonded strain gage (one), thin-film deposited strain gage (three), metal-diaphragm semiconductor strain gage (one), and ceramic-diaphragm semiconductor strain gage (three). The gage pressure range for these transducers is from nominal zero to 345 kPa (50 psi).

Distances other than the test distance may also be used, and tests involving FF-33 flashbulbs may be abbreviated if sufficient flashbulbs are not available. The quantities to be measured and recorded will be those of 3.2

3.4 Other Experimental Work

In addition to the work described above, the following experiments are planned:

1. Measurement of the response of selected transducers to energy incident at an angle other than normal to the exposed surface,
2. Measurement of the response of selected transducers with the transducer itself measuring full-scale pressure,
3. Measurement of the response of selected transducers with the transducer itself measuring vacuum pressure,
4. Measurement of the energy transmission loss through a glass window and window reflection coefficient,
5. Determination of the effect of aperture size on the energy measurement,
6. Measurement of the effect of line-voltage changes on electronic flash energy,
7. Measurement of the effect of battery-voltage changes on flashbulb energy, and
8. Measurement of the output of selected semiconductor strain-gage pressure transducers when exposed to thermal transients and with no transducer (electrical) excitation.

4. Other-Agency Work

During FY 1974, several tasks were in progress for other government agencies outside the NBS InterAgency Transducer Project. Since the objectives of each of these tasks fall within the area of the NBS InterAgency Transducer Project, abstracts of appropriate project reports are given:

4.1 Vezzetti, C.F., and Lederer, P.S., An Experimental Method for the Evaluation of Thermal-Transient Effects on Piezoelectric Accelerometers, NBS Tech Note 855 (November 1974)

A simple, inexpensive method was developed for determining the effects of thermal transients on the zero output and sensitivity of piezoelectric accelerometers. Thermal transients are generated by an incandescent lamp and can be made to heat the top or side of the test accelerometer. Fourteen commercial accelerometers were tested using this technique. Zero shifts with magnitudes as high as 640 g_n were observed. Zero shifts of up to 2% of full scale resulted from 1-s duration transients, and up to 7% of full scale from 15-s transients. These results were obtained at a radiation power density of 1.8 W/cm^2. No changes of accelerometer sensitivity exceeding experimental uncertainties were noted as a result of the thermal transients used.

4.2 Development of a Dynamic Pressure Calibration Method

4.2.1 Vezzetti, C.F., Lederer, P.S., and Hilten, J.S., Development of a Dynamic Pressure Calibration Technique-Progress Report for the Period September 15, 1973 to February 15, 1974, NBSIR 74-503(R) (June 1974)

The objective of this task is to develop a dynamic pressure calibration technique yielding a flat frequency response to 2000 Hz or greater and amplitude capability of at least 34 kPa (5.0 psi) zero-to-peak. Equipment was set up, a universal test fixture fabricated, and testing was initiated of various liquids and damping schemes for a hydraulic sinusoidal pressure generator consisting of a vibrating liquid column. Two liquids of density greater than water, tetrabromoethane and a fluorocarbon, were tested. As was expected from the densities and bulk moduli, improved frequency response could be accomplished only with the tetrabromoethane. Very little improvement of damping has been obtained by using tubes with large wetting surface area. Although tests using filters are only in early stages, indications are that the proper combination of liquid viscosity and filter porosity may result in improved damping.

4.2.2 Vezzetti, C.F., Hilten, J.S., and Lederer, P.S., Development of a Dynamic Pressure Calibration Technique-Progress Report for the Period February 15, 1974 to August 15, 1974, NBSIR to be published

This progress report describes continuing development of methods for the dynamic calibration of pressure transducers. The requirements are for the generation of a sinusoidally varying test pressure of at least 34 kPa zero-to-peak with a permitted variation in peak amplitude not to exceed ±5%. The pressure-generating system is to have an upper frequency capability of at least 2 kHz; no lower frequency capability requirement is specified. Vibration at ±36 g_n of a tube filled with dimethyl siloxane liquid and mounted on the armature of a vibration exciter has generated pressures of 34 kPa zero-to-peak over the frequency range of from 40 Hz to 750 Hz. A method of damping the movement of liquid in the tube by packing the larger main tube with a number of smaller tubes is described.

4.3 Space Shuttle Pogo Pressure Measuring System

4.3.1 Lederer, P.S., and Hilten, J.S., Space Shuttle Pogo Pressure Measuring System-Progress Report for the Period September 15, 1973 to December 15, 1973, NBSIR 75-560 (February 1975)

This progress report describes continuing development of 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. Rotation of a mercury-filled column in the vertical plane at frequencies of 10 Hz and below has produced peak-to-peak pressures of 39 kPa (5.7 psi) at bias pressures of up to 55.4 MPa (8030 psi). Evaluation of some variable-impedance, semiconductor strain-gage, piezoelectric, and metallic strain-gage pressure transducer systems for suitability as pogo sensors is described.

4.3.2 Hilten, J.S., and Lederer, P.S., Space Shuttle Pogo Pressure Measuring System-Progress Report for the Period December 15, 1973 to June 15, 1974, NBSIR 74-604 (December 1974)

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.

5. Transducer-Related NBS Publications

A variety of activities at NBS related to transducers and their calibration results in publications. In order to enhance the dissemination of this information, abstracts are presented below of some of the recent publications in this area.

5.1 Koyanagi, R.S., Pollard, J.D., and Ramboz, J.D., A Systematic Study of Vibration Transfer Standards — Mounting Effects, NBSIR 73-291 (September 1973)

The purpose of this study was to determine the extent of the sensitivity change of laboratory quality piezoelectric accelerometers for various mounting conditions. The mounting variables included the material upon which the accelerometer was mounted; geometry, the use of commercial insulated studs, and the use of mounting stud thread size adaptors. For the stated test conditions, the effect of different materials and geometry was insignificant below about 3000 Hz. For stainless steel, beryllium, alumina, and tungsten, the deviations were less than 0.5 percent up to 10000 Hz. The aluminum alloy base showed an increase of about 2 percent at 10000 Hz. The effect of insulated studs showed deviations beginning at about 3000 Hz. No significant deviation was found between the different stud thread size adaptors.

5.2 Ramboz, J.D., and Federman, C., Evaluation and Calibration of Mechanical Shock Accelerometers by Comparison Methods, NBSIR 74-480 (March 1974)

A means to calibrate mechanical shock accelerometers by a comparison method has been developed. Detailed procedures and equipment used to generate mechanical shock pulses, collect data, and analyze the results are discussed. Three accelerometers were subjected to haversine acceleration-time pulses of 50-, 500-, 900-, and 1500-g_n peak amplitudes and time durations of 8.5, 1.2, 1.2, and 0.7 ms, respectively. Both time- and frequency-domain calibrations were performed. The shock calibrations agreed with sinusoidal values to within a few percent. Problems encountered and future developments are discussed.

5.3 Ramboz, J.D., Absolute Calibration of Vibration Standards by the Three-Mass Reciprocity Method, NBSIR 74-481 (April 1974)

Reciprocity calibration of electrodynamic vibration exciters is reviewed. A new method is proposed. The theory for the new Three-Mass reciprocity calibration method is developed. The process requires that the electrical impedance of the exciter's drive coil be measured for three added masses separately mounted on the exciter's armature. The sensitivity of the accelerometer mounted in the armature is solved in terms of a change of electrical impedance for a change of mass, voltage ratio, electrical resistance, and frequency. A set of 38 measurements were made at 1000 Hz to experimentally verify the theory. The value of sensitivity was 2.070 pC/g_n ±1.3 percent. This agreed to within about ±0.65 percent of a transfer calibration from Bouche-Levy calibrated standards and the manufacturer's estimated value. Measurements were made to verify the theory; improvement to an uncertainty of about ±0.2 percent is ultimately possible in the absolute calibration using this method.

5.4 Olsen, L.O., Introduction to Liquid Flow Metering and Calibration of Liquid Flow Meters, NBS Tech Note 831 (June 1974)

These notes are intended to serve as an instruction manual for technicians and engineers engaged in metering liquids and calibrating liquid flowmeters. It is a condensed review of the properties of liquids and the mathematical relations required in this work. References to more complete sources of properties of liquids, theoretical relations and instructions for metering liquids are included. Separate chapters discuss liquids and their properties as they affect flow, the theory of incompressible flow of liquids and the measurements required in the metering of liquids. One chapter describes several different apparatus and their use in the calibration of liquid flowmeters. The last chapter contains brief descriptions of the many types of flowmeters such as differential pressure, positive displacement, electromagnetic and ultrasonic. It also includes a discussion of the physical principles involved in their design and use.

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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.)*

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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; dynamic; photo flashbulb; pressure; pressure measurement; pressure transducer; thermal transient; transducer.

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