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NBS InterAgency Transducer Project Progress Report No. 3

P. S. Lederer and J. S. Hilten

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

April 1976

Progress Report Covering Period January 1, 1975 to June 30, 1975

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

U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***

James A. Baker, III, ***Under Secretary***
Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

ABSTRACT

Concluding efforts related to the development of a test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure-transducer response are described. The method consists of monitoring pressure-transducer output (zero shift with the transducer at atmospheric pressure) as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. Thermal energy pulses as great as 0.1 J/cm^2, with durations of about 6 ms, have been generated using an electronic flash; pulses of up to 2.2 J/cm^2, with durations of about 37 ms, have been generated using No. 22 flashbulbs. Flood-flash FF-33 lamps were also investigated, but their use is not recommended. In tests with No. 22 bulbs, 25 commercial pressure transducers have shown zero shifts ranging from 0.4% to about 400% of the full-scale output. Transducer-related tasks being performed for other agencies are also described briefly, and other recent NBS publications of interest to the transducer community are identified.

Key words: Calibration; dynamic; electronic flash; photoflash bulb; pressure; pressure measurement; pressure transducer; pressure transducer response; response; thermal transient; transducer; zero shift.

NBS InterAgency Transducer Project

Progress Report No. 3, for the Period
From January 1 to June 30, 1975

to the

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

NBS Cost Center 4253434

Prepared by

Paul S. Lederer
and
John S. Hilten

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Transducer-related tasks being performed for other agencies are also described briefly, and other recent NBS publications of interest to the transducer community are identified.

Key words: Calibration; dynamic; electronic flash; photoflash bulb; pressure; pressure measurement; pressure transducer; pressure transducer response; response; thermal transient; transducer; zero shift.

1. INTRODUCTION

A brief background for the NBS InterAgency Transducer Project, its recent history, and current objectives were given in a previous progress report [1]*. The current task assigned to the Project by the Transducer Committee** calls for the development of a test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure-transducer response. The method is intended to serve as an initial screening test.

Specific requirements set by the Transducer Committee and the Naval Air Systems Command include: the method should be inexpensive to implement and simple to operate; the equipment should be readily replicable; and the method should be capable of applying thermal transients with durations of 1 ms and longer with controlled heat-flux inputs to the test transducers.

Work continued on the test method developed during earlier reporting periods [1,2]. The method consists of monitoring pressure-transducer output (zero shift with the transducer at atmospheric pressure) as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash.

The sponsors further intend that the method be used for evaluating the effectiveness of various schemes that have been proposed to reduce the effect of thermal radiant-energy transients on pressure-transducer response. Experimental work for this new task will begin following the completion of experimental development of the method. Preliminary work, including a survey of protective schemes now in use, is discussed in section 4.

2. EXPERIMENTAL DEVELOPMENT

Experimental work carried out during this reporting period consisted of investigations of the effect of various parameters on the method and evaluation of the flood-flash FF-33 lamps as a potential source for the method.

The investigations include studies of such effects as: (1) the supply-voltage variation on electronic-flash output, (2) the aperture size on energy-meter reading, (3) the angle of incidence on transducer response, (4) the presence of reflectors on transducer response, (5) the energy loss in the glass window, (6) the increased air pressure from heating, and (7) the exposure of the transducer to full-scale pressure.

2.1 Effect of Supply-Voltage Variation on Electronic-Flash Output

Evaluation of the electronic-flash system as a source for the method included investigation of the dependence of flash-system performance on supply voltage when the unit was operated from either the a-c line or from a battery supply.

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*Figures in brackets indicate literature references, section 7.
**Transducer Committee, Telemetry Group, Range Commanders Council.

To measure the effect of a-c line voltage variations on electronic-flash energy output, a variable transformer was inserted into the line ahead of the internal flash power supply, and the radiant-energy output was measured at selected a-c supply voltages ranging from 110 V to 120 V in 2-V steps. The a-c supply voltage was set with the variable transformer and measured on a digital multimeter. The flash energy output was measured with the energy meter and the photodiode; the corresponding zero shift of transducer Z was also measured. Table 1 shows that the radiant energy available at an a-c supply voltage of 110 V is about 20% less than that at 120 V. The percentage change in radiant energy is on the order of double the percentage change in supply voltage causing it. This observation corroborates the recommendation that some type of voltage regulation be used in the supply line to the flash system to ensure consistent flash performance.

The effect of battery-voltage variations on electronic-flash energy output was measured by monitoring the voltage drop across the battery supply and the radiant-energy output of the flash system during a series of 15 consecutive shots. The voltage decreased from 419 V to 397 V during the series. The resultant energy output as measured with the energy meter decreased linearly by approximately 11%, as shown in table 1. The percentage change in radiant energy is again on the order of double the percentage change in voltage. The interval between flashes was two minutes or longer to allow the flash unit to recharge. Nevertheless, the battery voltage dropped gradually during the test, indicating that the flash-system performance would be more consistent if the system were operated from a regulated a-c line. It should be noted that the batteries used in these tests had been used for several hundred shots previously. New batteries would probably produce more repeatable flash energies.

2.2 Effect of Various-Sized Apertures on Energy-Meter Readings

Geometrical relationships between the energy-meter sensor, the source, and the paths followed by radiant energy from source to sensor vary considerably for the various source-sensor distances and sources used in the method. Extensions of the method have been proposed using narrow-angle, high-energy sources. For these reasons, the response of the energy meter was investigated with various-sized apertures placed at the front end of the sensor collimating tube. Apertures with diameters of 0.38, 0.53, 0.75, 1.06, 1.50, 2.12, and 3.00 cm were used. These diameters were chosen so that each aperture has twice the area of the next smaller aperture. Three tests with each aperture were run with a No. 5 flashbulb as source 7 cm from the energy-meter sensor. The results as shown in table 2 indicate that the energy approximately doubles with doubling of the area until a diameter approximately equal to that of the energy-meter sensor (1.15 cm)* is reached. For the apertures with diameters of 1.50, 2.12, and 3.00 cm, the energy increases by less than a factor of two with each doubling of aperture area, with the relative increase becoming progressively smaller as the aperture size becomes larger.

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*The sensor diameter is also comparable to the diameter of the diaphragm of the largest transducer tested.

2.3 Effect of Angle of Incidence on Transducer Response

The response of transducer Z to thermal radiant-energy transients impinging on the diaphragm in directions 30, 60, and 90° from the normal to the diaphragm was investigated.

It was necessary to remove the transducer mounting plug from the fixture housing to perform these tests, as the housing would otherwise shield the transducer from radiation entering the fixture at more than a few degrees from the normal. A simple mounting pedestal was fabricated on which the plug and transducer could be rotated about a vertical axis through the center of the transducer diaphragm surface.

The tests were conducted with the center of the transducer diaphragm 7 cm from the center plane of the No. 5 flashbulb source. Five runs were made at normal incidence and three runs each at 30, 60, and 90° from the normal. The results are given in table 2.

At 30° from the normal, the zero shift of test transducer Z was 89% of the zero shift at normal incidence. At 60° from the normal, the zero shift was 56% of that at normal incidence, and at 90°, it was 4%. These figures correspond closely with the projected area of the transducer diaphragm as seen by the beam of radiation at each angle. The areas would be 87% of the normal area at 30°, 50% at 60°, and 0 at 90°.

Comparison of the data of table 3 with data given in tables 4 or 5 shows that the zero shift of transducer Z resulting from ignition of a No. 5 flashbulb at a source-transducer distance of 7 cm is approximately 20% smaller when the transducer is mounted on the pedestal described above than when it is mounted in the fixture used in the method. A probable explanation is that internal reflections in the mounting fixture increase the total amount of energy incident on the diaphragm.

2.4 Effect of Reflectors on Transducer Response

A brief investigation to determine the gain in energy level that could be achieved with the use of reflectors behind the energy source showed that by using reflectors designed for photographic purposes, an increase of about 18% was achieved with the No. 5 and No. 22 flashbulbs, and about 340% with the electronic flash at 150 J, at a transducer-source distance of 7 cm, as shown by the data in table 3.

Energy levels impinging upon transducer Z with and without the reflectors behind the sources were compared by measuring the resultant zero shift of the transducer. In the tests with No. 5 and No. 22 flashbulbs mounted vertically as sources, a reflector from a photoflash gun was positioned behind the bulbs. This reflector has a mirror finish, a diameter of 14.2 cm, and a depth of 3.4 cm. With the reflector in place, the distance from the center of the bulb to the reflector surface is approximately 3.7 cm.

The reflector supplied with the electronic flash unit was used with the electronic flash. This reflector has a satin finish, a diameter of 13.5 cm, and a depth of 6.8 cm. In use, the flashtube base passes through the center of the reflector, and the center of the tube is approximately 2.6 cm from the reflector surface.

The use of a reflector, while increasing the level of energy available, renders energy monitoring difficult, since an energy sensor detector cannot be located in the normal position on the optical bench. Therefore, the use of a reflector as part of the method is not recommended unless the greater amount of energy available for a given test is an overriding consideration.

2.5 Effect on Method of Energy Lost in Glass Window

The transducer mounting fixture was designed to permit the transducer to be subjected to pressures above or below atmospheric pressure during exposure to thermal radiant energy entering the fixture through a glass window. The significance of the effect of this glass window on transducer response was investigated by measuring the zero shift of transducer Z with and without the window in place. No. 5 flashbulbs, 7 cm from the transducer, were used in these tests. Table 5 shows that for the ten shots without the window, the average transducer zero shift was 93.7 mV, and the average energy-meter reading 586.4 $mJ \cdot cm^{-2}$, corresponding to a radiation sensitivity of 0.160 $V \cdot cm^2 \cdot J^{-1}$. With the window in place in the transducer fixture, the average zero shift was 89.8 mV and the average energy-meter reading 568.3 $mJ \cdot cm^{-2}$, corresponding to a radiation sensitivity of 0.158 $V \cdot cm^2 \cdot J^{-1}$. Adjusting the data for the differences in energy levels shows that the zero shift with the window is only 1.1% less than that without for transducer Z. Unless a given transducer diaphragm material were especially sensitive to the effects of radiation of wavelengths absorbed by the window, this result may be taken to indicate that the presence of the window will, in general, have no significant effect on the results of the method.

2.6 Effect on Method of Increased Air Pressure from Heating

The possibility existed that the air in the closed volume of the mounting fixture would itself be heated by energy from the source to a significant degree. This heating would result in an instantaneous change in air pressure which in turn would be sensed by the test transducer. To investigate the significance of this effect, three tests were run with transducers M and Z with the fixture at a vacuum pressure of 3.4 Pa absolute (25 μm Hg absolute). The results were compared with results from tests under the same conditions of distance and source, but with the fixture at atmospheric ambient pressure. The data are given in table 6. No significant difference between the results of the two sets of tests is seen. The conclusion may be drawn that any "pressurizing" effect resulting from the heating of air in the mounting fixture can be ignored for the purpose of the method.

2.7 Effect on Transducer of Exposure to Full-Scale Pressure

A series of 9 tests was run to investigate how transducer response to a thermal transient was affected when the transducer was exposed to pressure above ambient atmospheric in the mounting fixture. The pressure chosen was the full-scale pressure for the two transducers used (M and Z), 345 kPa.

Transducer Z is a semiconductor strain-gage type and was chosen for this investigation because its zero shift at atmospheric ambient was well characterized and positive in direction. Transducer M is a semiconductor strain-gage type with a metal diaphragm and was also known to have a positive zero shift. Three tests were made with each transducer at atmospheric ambient and at 345 kPa, with the tests at 345 kPa first. Tests were run with the transducer diaphragm 7 cm from the center plane of the No. 5 flashbulb source. The data are given in table 6.

As might be expected, the results show that the shift in the response measured when the transducer is exposed to full-scale pressure is larger than the zero shift. The differences, however, are small. For transducer M, the shift at 345 kPa is approximately 38% of the full-scale output (38% FS), and the zero shift measured immediately following the test at full-scale pressure is approximately 34% FS. The corresponding figures for transducer Z are 19% FS and 16% FS, respectively. These results suggest that for the intended screening purposes, ambient atmospheric pressure may be specified for the method with no significant loss in screening capability compared to tests run at pressures higher than ambient. Special circumstances, such as application of the method to transducers known to have a strongly enhanced, non-linear pressure response over some part of their rated range, may require *ad hoc* treatment.

2.8 Evaluation of Flood-Flash FF-33 Lamps

Measurements of (1) the variation in intensity with distance from flood-flash FF-33 lamps as source and (2) the repeatability of the method with this source were delayed until this reporting period because the FF-33 lamps were not previously available. These long-duration flashlamps (2.3 s compared to approximately 0.03 s for No. 5 and No. 22 flashbulbs) were designed for use in automobile crash photography and, according to the manufacturer, the amplitude-time waveform of the radiation output is roughly triangular in shape. However, oscilloscope traces of photodiode output for these lamps were found to be characterized by a number of high-amplitude spikes, as well as longer duration fluctuations of considerable amplitude (on the order of the 25% of the maximum). These phenomena are presumed to result from erratic burning of the FF-33 lamps and were seen in all photodiode traces for these lamps.

Investigation of available energy as a function of FF-33 source-transducer distance was carried out in a similar fashion to that described in previous reports for the short-duration sources, with the following exceptions: (1) A power meter, calibrated in watts, was substituted for the energy meter, because the energy meter is not capable of reading energy pulses with a duration greater than 50 ms. The maximum output of the power meter was read visually on a panel meter "on the fly." That is, the operator was required to estimate the maximum upward excursion of the (relatively slowly moving) meter pointer. Output from the power meter was also displayed on an oscilloscope. (2) Tests were run in 1-cm increments from 8 cm to 15 cm; the size of the FF-33 bulbs prevented tests at source-sensor distances less than 8 cm, and the low energy level (as determined by transducer response) suggested 15 cm as a good termination point as was the case for measurements with the electronic flash at 150 J. The data are given in table 7.

Repeatability tests with the flood-flash FF-33 bulbs as the method source were carried out at a source-sensor and source-transducer distance of 12 cm and consisted of 10 consecutive shots. Transducer Z was the test transducer. The effects of the long duration (about 2 s) of the FF-33 flash, of the use of a power meter instead of an energy meter, and especially of the observed erratic burning complicate the reporting of results. Peak-power levels as determined from the analog output of the power meter, displayed and photographed on an oscilloscope, show variations of up to 12% below and 18% above the ten-shot average; the data are given in table 8. Peak-power levels determined by reading the maximum excursion of the panel meter show variations of similar magnitude. Peak transducer zero shifts, as determined from a photographed oscilloscope display, show variations of up to 24% below and up to 21% above the ten-shot average. Comparison of transducer Z zero shift with the power-meter output from one shot to another shows little or no correlation between the two quantities. An explanation may be that the energy output from the FF-33 bulbs varies greatly in azimuth, as is suggested by the erratic burning. As was the case to a much lesser extent with the short-duration sources, the transducer under test and the sensing meter would "see" different power levels for the same test run. As described earlier, the photodiode response to FF-33 bulbs was characterized by the presence of spikes and other fluctuations, and average levels could not be determined with any reasonable precision. Photodiode measurements were therefore not useful in repeatability tests with FF-33 bulbs.

Following these tests no further work was carried out with FF-33 bulbs as the method source. This type is not recommended for this application because it exhibits erratic burning and apparent large variations in output from one bulb to another, and because it has lower output and larger size relative to other sources available.

3. RESULTS OF TESTING TRANSDUCERS USING THE METHOD

The work carried out to date has been primarily concerned with the development of the method. In the course of this work, the zero shift of transducer Z as determined by the method has been well characterized. It is of interest to investigate by the method the zero shifts of other models of the same type as transducer Z and of other transducer types and to compare these results.

Accordingly, 25 transducers, including Z as a control, were selected and tested by the method with a distance of 7 cm* between the transducer diaphragm and the center plane of the No. 22 flashbulb source. All measurements were made with the transducer exposed to ambient atmospheric pressure. Each transducer was tested three times, and an average zero shift computed. These average zero shifts were expressed as a percentage of the transducer full-scale output and are given in table 9, along with a brief indication of transducer type, range, pressure equivalent to the zero shift, and percent full-scale radiation sensitivity. The average zero shifts ranged from about 0.4% of full-scale output for transducer S to 430% of full-scale output for transducer N. The semiconductor strain-gage transducers as a class exhibited the greatest vulnerability of any transducer type to the thermal radiant-energy transients produced in the method.

4. PRELIMINARY WORK FOR NEW TASK

Planning was initiated for a new task with experimental work scheduled to begin in FY 1976. The task is to evaluate the effectiveness of schemes in use or proposed to reduce the effects produced by thermal radiant-energy transients and other thermal inputs on pressure transducer response. The intent is to use the test method discussed in the other sections of this report for evaluating protection from thermal radiant-energy transients and to modify this method as required for generating other thermal inputs to the test transducer and protection scheme. The task assignment lists these considerations: "(a) protection from radiated and/or convected transients of various amplitudes and durations; (b) effects of any protection scheme on transducer performance such as increased acceleration sensitivity, degradation in dynamic performance, etc.; (c) ability of the protection scheme to survive the adverse environments associated with the real physical processes generating these transients." Goals of the work include development, for users, of guidelines and protective schemes for the use of existing pressure transducers in applications in which thermal inputs are present and, for manufacturers, recommendations relating to pressure transducer design and construction.

As a starting point, information concerning types of pressure transducers used, pressure ranges, nature of thermal inputs, nature of applications, protection schemes, nature of any initial screening tests, and the like was sought from a sampling of transducer users at test ranges and other agencies. The responses indicated such a wide variety of applications, transducers, and measurement conditions that it was not possible to select representative pressure ranges and test conditions. With the concurrence of NAVAIR and the Transducer Committee, it was proposed that work would begin (1) using the test method with No. 22 flashbulbs as source, (2) with flush-diaphragm transducers having full-scale ranges of 0.35 and 6.9 MPa and either strain-gage or piezoelectric sensing

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*This distance is convenient for the No. 22 flashbulb. The energy levels available at the transducer diaphragm are considerable (approximately 1.7 $J \cdot cm^{-2}$) and there is good access to flashbulb and mounting fixture.

elements, and (3) with thermal protection either provided by diaphragm coatings applied in-house or based on path geometry. Based on the results of these investigations, further work covering a broader range of conditions may be proposed.

5. OTHER AGENCY WORK

Two tasks are nearly completed for other Government agencies outside the NBS InterAgency Transducer Project. Since the objectives of those tasks fall within the area of the NBS InterAgency Project, brief reports on these tasks are presented:

5.1 Development of a Dynamic Pressure Calibration Method (For NASA Langley Research Center)

A draft of the final report has been written, with authors, title, and abstract as follows:

Vezzetti, C. F., Hilten, J. S., Mayo-Wells, J. F., and Lederer, P. S., A New Dynamic Pressure Source for the Calibration of Pressure Transducers (to be published as NBS Tech Note)

> A dynamic pressure source is described for producing sinusoidally varying pressures of up to 34 kPa zero-to-peak, over the frequency range of approximately 50 Hz to 2 kHz. The source is intended for the dynamic calibration of pressure transducers and consists of a liquid-filled cylindrical vessel, 11-cm in height, mounted upright on the armature of a vibration exciter which is driven by an amplified sinusoidally varying voltage. The transducer to be calibrated is mounted near the base of the thick-walled aluminum tube forming the vessel so that the pressure-sensitive element is in contact with the liquid in the tube. A section of the tube is filled with small steel balls to damp the motion of the 10-St dimethyl siloxane working fluid in order to extend the useful frequency range to higher frequencies than would be provided by an undamped system.
>
> The dynamic response of six transducers provided by the sponsor was evaluated using the pressure source; the results of these calibrations are given.

5.2 Pogo Pressure-Measuring System for Space Shuttle (for NASA Marshall Space Flight Center)

The windmill calibrator was assembled in late December 1974. When tested, the device did not operate properly because of excessive friction in the air bearings. This condition was traced to improper machining of the bearing journals and faulty installation of the bearings. Furthermore, the bearing manufacturer's specification of the proper shaft diameter was found to be incorrect. The journal assembly and shaft were therefore remachined. These operations were completed in early March 1975, and the calibrator was reassembled. As soon as the air supply was turned on, the rotating structure vibrated severely. After examination, the air bearings themselves were found to be poorly machined, and questions were raised about the basic design. As a result, the calibrator was redesigned to accept previously used air bearings of smaller diameter. The redesign also required a new shaft. This new version of the calibrator was put into operation in early June 1975 and appeared to function well. A number of pogo pressure transducers were successfully calibrated using the windmill apparatus and the liquid-filled tube on the vibration exciter.

Two organizations within Rockwell Corporation, the prime contractor for the space shuttle, have indicated that they plan to copy the windmill calibrator and to use it in the dynamic calibration of pressure transducers for pogo and similar applications.

6. TRANSDUCER-RELATED NBS PUBLICATIONS

Abstracts are presented below of work completed in other parts of the National Bureau of Standards which is applicable to transducers:

6.1 Pontius, P. E., Notes on the Fundamentals of Measurement and Measurements as a Production Process, September 1974, NBSIR 74-545

The concept of a measurement process as a production process is relatively new, having evolved in the last ten years. There have been significant contributions from many sources which have served to refine the initial ideas. The generalized concept of a measurement process is discussed together with techniques and examples for verifying the validity of the result. While some of the techniques may not be appropriate for certain highly specialized measurement processes, it is felt that the concepts are applicable to practically all measurement processes. For certain types of general measurement processes, which must operate in a variety of environments, and which must accommodate a variety of materials and properties, the techniques have been invaluable in understanding the manner in which measurement processes operate in a "real" world.

6.2 Cameron, J. M., The Use of the Method of Least Squares in Calibration, September 1974, NBSIR 74-587

This paper presents a discussion of the techniques of statistics that arise in the analysis of data from the comparative experiments used in the calibration of objects relative to a reference group of standards. In calibration one usually measures differences between nominally equal objects and uses the values assigned to the standards as the linear restraint to bring the system up to full rank. The use of the method of least squares in this situation is discussed with examples taken from the calibration work of the National Bureau of Standards.

This summary of statistical techniques is intended for metrologists and was presented at the NBS seminar on High-Efficiency Methods for Dimensional Calibrations given 10-11 June 1974.

6.3 Schoonover, R. M., and Ku, H. H., Calibration of Platinum Resistance Thermometers Using an Intercomparison Scheme, December 1974, NBSIR 74-586

In this report we describe a procedure for the calibration of capsule type platinum resistance thermometers, PRT(s), using one or more standard platinum resistance thermometers, SPRT(s), in the temperature range of 0-35°C. These PRT(s) were designed to be used in density work through hydrostatic weighing where SPRT(s) cannot be used because of space and other limitations, but the procedure is thought to be generally useful in other applications as well.

The schedule of intercomparisons was designed to eliminate possible trends in temperature variations of the constant temperature bath setup. Results of calibration can be expressed either in terms of the two constants alpha (α) and delta (δ), or in a table relating $R(t)/R(0)$ to t_{68} within the range of calibrations.

The uncertainty of the values of t_{68} calibrated by this procedure is believed to be within 2 millidegrees Celsius, not including the uncertainty of the SPRT that is used as standard.

7. REFERENCES

[1] Lederer, P. S., and Hilten, J. S., NBS InterAgency Transducer Project - Progress Report Covering Period July 1, 1974 to September 30, 1974, NBSIR 75-654 (February 1975).

[2] Lederer, P. A., Hilten, J. S., and Vezzetti, C. F., NBS Inter-Agency Transducer Project - Progress Report Covering Period October 1, 1974 to December 31, 1974, NBSIR 75-732 (June 1975).

USCOMM-NBS-DC

TABLE 1

EFFECT OF SUPPLY-VOLTAGE VARIATION ON PERFORMANCE OF THE ELECTRONIC FLASH*

Tests with Line Power Supply

Supply Voltage (a-c V)	Run	Energy Meter Reading ($mJ \cdot cm^{-2}$)
110	1	81.9
	2	80.4
	3	83.9
	av	82.1
112	1	91.1
	2	84.7
	3	92.9
	av	89.6
114	1	92.6
	2	90.0
	3	95.3
	av	92.6
116	1	98.8
	2	92.7
	3	96.5
	av	96.0
118	1	97.0
	2	94.2
	3	102.4
	av	97.9
120	1	100.5
	2	104.8
	3	103.5
	av	102.9

Tests with Battery Power Supply

Supply Voltage (d-c V)	Energy Meter Reading ($mJ \cdot cm^{-2}$)
419	73.7
414	71.9
411	70.7
409	70.0
408	69.4
406	68.5
404	67.6
403	67.2
402	66.8
401	66.3
400	66.2
399	65.9
398	65.6
398	65.4
397	64.7

*The electronic flash was operated at a setting of 150 J; the energy meter was 7.5 cm from the center of the flashtube.

TABLE 2

ENERGY-METER READINGS AS A FUNCTION OF CIRCULAR APERTURE SIZE

Aperture Diameter cm	Aperture Area cm^2	Averaged Energy-Meter Reading $mJ \cdot cm^{-2}$
0.38	0.113	46.9
0.53	0.221	104
0.75	0.442	180
1.06	0.882	306
1.50	1.77	486
2.12	3.53	536
3.00	7.07	697

*All measurements were taken with the energy-meter sensor 7 cm from the center plane of the No. 5 flashbulb source.

TABLE 3

TRANSDUCER Z ZERO SHIFT IN RESPONSE TO
THERMAL RADIANT-ENERGY TRANSIENTS
INCIDENT AT SELECTED ANGLES

Angle of Incidence (rad) [deg]	Run	Zero Shift* (mV)	Ratio of Zero Shift at Test Angle to Zero Shift at Normal Incidence
0	1	72	1.00
0	2	81	1.00
0	3	69	1.00
0	4	69	1.00
0	5	74	1.00
	av	73.0	1.00
$\frac{\pi}{6}$ [30]	1	59	0.81
$\frac{\pi}{6}$ [30]	2	68	0.93
$\frac{\pi}{6}$ [30]	3	67	0.92
	av	64.7	0.89
$\frac{\pi}{3}$ [60]	1	40	0.55
$\frac{\pi}{3}$ [60]	2	37	0.51
$\frac{\pi}{3}$ [60]	3	46	0.63
	av	41.0	0.56
$\frac{\pi}{2}$ [90]	1	2.5	0.03
$\frac{\pi}{2}$ [90]	2	2.5	0.03
$\frac{\pi}{2}$ [90]	3	4.5	0.06
	av	3.2	0.04

*All measurements were taken with constant electrical excitation supplied to the transducer and at ambient atmospheric pressure.

TABLE 4

TRANSDUCER Z ZERO SHIFT
WITH AND WITHOUT FLASH REFLECTOR

Zero Shift* (mV)

	No. 5 Flashbulb			No. 22 Flashbulb			Electronic Flash at 150 J	
Run	No Reflector	Reflector in Use	Run	No Reflector	Reflector in Use	Run	No Reflector	Reflector in Use
1		102	1		450	1		45
2	78		2	330		2		45
3		106	3		440	3		45
4	85		4	330		4		44
5		97	5		340	5		43
6	84		6	380		6	10.5	
7		107	7		450	7	10.0	
8	105		8	350		8	9.5	
9		106	9		360	9	10.5	
10	87		10	340		10	10.0	
av	87.8	103.6		346	408		10.1	44.4
sample SD	10.2	4.2		20.7	53.6		0.4	0.9

Reflector factor: ratio of av zero shift with reflector in use to av zero shift with no reflector

1.18	1.18	4.40

*All measurements were taken with constant electrical excitation supplied to the transducer and at ambient atmospheric pressure; transducer diaphragm was 7 cm from the center plane of the flash source.

TABLE 5

GLASS WINDOW ENERGY TRANSMISSION LOSS
AS SEEN IN TRANSDUCER Z ZERO SHIFT

Run	Transducer Zero Shift* (mV) with window	Transducer Zero Shift* (mV) without window	Energy Meter Reading ($mJ \cdot cm^{-2}$)
1		78	665
2		95	660
3		94	579
4		104	561
5		94	551
6		94	592
7		91	519
8		96	569
9		91	581
10		100	587
		av 93.7	av 586.4
		sample SD 6.8	sample SD 45.3
11	84		600
12	90		576
13	95		557
14	97		560
15	98		549
16	90		589
17	80		580
18	82		524
19	88		582
20	94		566
	av 89.8		av 568.3
	sample SD 6.3		sample SD 22.0

*All measurements were taken with constant electrical excitation supplied to the transducer and at ambient atmospheric pressure; the transducer diaphragm was 7 cm from the center plane of the No. 5 flashbulb source.

TABLE 6

SHIFT IN TRANSDUCER OUTPUT FROM INCIDENT THERMAL RADIANT-ENERGY TRANSIENTS WITH TRANSDUCER MEASURING ELEVATED, AMBIENT, AND VACUUM PRESSURE, FOR SELECTED TRANSDUCERS

Test Fixture Pressure		Output Shift* (mV) Transducer Z		Transducer M
345 kPa [50 psi]		97		28
		95		30
		96		28
	av	96	av	29
Ambient Atmospheric		82		25
		78		26
		80		25
	av	80	av	25
Vacuum		78		22
(3.4 Pa absolute) [25 μm Hg absolute]		92		26
		85		25
	av	85	av	24

*All measurements were taken with the transducer diaphragm 7 cm from the center plane of the No. 5 flashbulb source.

TABLE 7

TRANSDUCER Z ZERO SHIFT IN RESPONSE TO THERMAL RADIANT-ENERGY TRANSIENTS FROM FF-33 FLASHBULB SOURCE AS A FUNCTION OF SOURCE-TRANSDUCER DISTANCE

Distance from Energy Source to Transducer Diaphragm (cm)	Transducer Z Zero Shift (% of full scale)	Power-Meter Reading	
		(W)**	Corrected* to 1 cm^2 (W)
8	23.2	30.3	10.7
9	20.0	27.9	9.8
10	15.2	18.6	6.5
11	14.4	18.3	6.4
12	9.7	12.2	4.3
13	8.5	8.4	3.0
14	8.2	8.0	2.8
15	6.9	6.8	2.4

* All measurements were taken with constant electrical excitation supplied to the transducer and at ambient atmospheric pressure.

**Power-meter sensor has an area of 2.84 cm^2; for comparison, calculated values are also shown for 1 cm^2, the area of the energy-meter sensor.

TABLE 8

TRANSDUCER Z ZERO SHIFT IN RESPONSE TO
THERMAL RADIANT-ENERGY TRANSIENTS FROM FF-33 FLASHBULB SOURCE

Run	Transducer Zero Shift as Percentage of 10-Run Average*	Power Meter Output as Percentage of 10-Run Average
1	96.6	87.9
2	96.6	101.1
3	92.5	102.7
4	103.8	93.7
5	107.9	105.2
6	103.8	95.3
7	102.8	93.7
8	76.1	98.6
9	121.3	103.5
10	98.7	118.3

*All measurements were taken with constant electrical excitation supplied to the transducer and at ambient atmospheric pressure.

TABLE 9

ZERO SHIFT OF SELECTED TRANSDUCERS IN RESPONSE
TO THERMAL RADIANT-ENERGY TRANSIENTS*

Transducer Code Letter	Description	Range (kPa)**	Zero Shift (% of full scale)		Equivalent Pressure (kPa)		Percent Full-Scale Output Radiation Sensitivity (% of full scale · cm^2 · mJ^{-1})	
			Positive	Negative	Positive	Negative	Positive	Negative
A		345	21	-	73	-	11.6	-
B	Semiconductor strain gage;	345	17	-	59	-	9.4	-
C	diaphragm recessed 2.2 cm	345	18	-	62	-	10.0	-
D		345	18	-	62	-	10.0	-
E		345	-	7.0	-	24	-	3.9
F	Semiconductor strain gage;	345	-	8.0	-	28	-	4.4
G	industrial transducer	345	-	6.8	-	23	-	3.8
H		345	-	6.8	-	23	-	3.8
I	Unbonded strain gage	345	-	4.8	-	17	-	2.7
J	Thin film; strain gage	345	1.0	0.27	3	1	0.6	0.2
K	vacuum deposited on beam	345	3.9	-	13	-	2.2	-
L		345	0.45	0.60	1	2	0.2	0.3
M	Semiconductor strain gage; metal diaphragm using an integrated sensor	345	113	-	390	-	62.8	-
N	Semiconductor strain gage;	345	430	-	1480	-	239	-
O	silicon diaphragm;	345	320	310	1120	1080	178	172
P	RTV coating	345	250	290	870	980	139	161
Q	Quartz crystal	68,900	-	2.2	-	1530	-	1.2
R		68,900	-	2.4	-	1650	-	1.3
S	Quartz crystal; built-	55,200	0.34	0.44	190	240	0.2	0.2
T	in integrated circuit	55,200	0.29	0.88	160	490	0.2	0.5
U		55,200	-	0.70	-	390	-	0.4
V		68,900	2.20	-	1516	-	1.2	-
W	Tourmaline crystal	68,900	2.79	-	1922	-	1.5	-
Y		68,900	2.73	-	1881	-	1.5	-
Z	Semiconductor strain gage	345	60	-	210	-	33.3	-

* All measurements were taken at ambient atmospheric pressure; the transducer diaphragm was 7 cm from the center plane of the No. 22 flashbulb source. At this distance, approximately 1.7 $J \cdot cm^{-2}$ is incident upon the diaphragm.

** 1 kPa - 0.145 psi

† The zero shift in some cases exhibits two peaks: a positive peak followed by a negative one. This double-peak response may result from the multiple-layer construction of the sensing element.

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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.)*

Concluding efforts related to the development of a test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure-transducer response are described. The method consists of monitoring pressure-transducer output (zero shift with the transducer at atmospheric pressure) as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. Thermal energy pulses as great as 0.1 J/cm^2, with durations of about 6 ms, have been generated using an electronic flash; pulses of up to 2.2 J/cm^2, with durations of about 37 ms, have been generated using No. 22 flashbulbs. Flood-flash FF-33 lamps were also investigated; their use is not recommended. In tests with No. 22 bulbs, 25 commercial pressure transducers have shown zero shifts ranging from 0.4% to about 400% of the full-scale output.

Transducer-related tasks being performed for other agencies are also described briefly, and other recent NBS publications of interest to the transducer community are identified.

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; electronic flash; photoflash bulb; pressure; pressure measurement; pressure transducer; pressure transducer response; response; thermal transient; transducer; zero shift.

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