NBS TECHNICAL NOTE 1110

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

NBS Interagency Transducer Project 1951-1979 — An Overview

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[1]Headquarters and Laboratories at Gaithersburg, MD, unless otherwise noted; mailing address Washington, DC 20234.
[2]Some divisions within the center are located at Boulder, CO 80303.

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Abstract

Between 1951 and 1979, the National Bureau of Standards was engaged in a continuing project to study the performance of sensory transducers, primarily those used in telemetry. This project has been supported by agencies of the Defense Department and NASA. This report provides a brief description of the background and history of the project, of its objectives, of some of the techniques and specialized facilities developed and used, and of some of the publications that have been issued from the project.

Key Words: Transducer, telemetry, Interagency Transducer Project, dynamic calibration, evaluation, performance characteristics.

Introduction

As a result of the 1978-79 reorganization of the National Bureau of Standards, the NBS Interagency Transducer Project was terminated. In view of the substantial impact which this project has had on the transducer community, it seems proper to summarize its background and history, briefly describe its accomplishments, and list its publications.

Background

In missile, rocket, and aircraft flight test instrumentation, the weakest link in the telemetering system is often the sensory transducer, either because of its limiting performance or because of limited knowledge concerning its performance. This situation results in part from the fact that in the design of transducers, adequate information has not been available to manufacturers as to the performance needed by users, and in part from the fact that adequate information on the performance of transducers has not been available to guide the selection of transducers by missile, rocket, and aircraft instrumentation designers. To supplement the often meager information supplied by manufacturers, as well as to check the manufacturer's claims on performance, users frequently have been forced to devise and carry out laboratory tests of their own. Techniques and equipment for such tests, particularly for determining performance under dynamic conditions, have often not been available. Such methods as have been available have not been standardized adequately and have often produced different results when used in different laboratories.

History

Recognition of these problems led in 1951 to the establishment of a "Transducer Project" at the National Bureau of Standards under the sponsorship of the Bureau of Aeronautics, U.S. Navy. The objectives were threefold: to obtain additional performance data on sensing instruments for use with telemetering systems in guided missiles, to establish a standard report form for evaluation tests, and to evaluate and recommend standard testing procedures for these instruments.

This work was undertaken by NBS because the development of new and improved measurement techniques, both as applied to the measurement of transducer performance and to the development of improved transducers, falls within NBS' central continuing mission of providing national leadership in the development and use of accurate and uniform techniques of physical measurement. At the same time, the ongoing program of NBS on measurement, calibration, and instrument development, particularly of such quantities as force, strain, temperature, mass, acceleration, pressure, etc., provides knowledge, experience, and facilities complementary to the telemetering transducer project. This expertise has contributed directly to the development of some of the techniques used and developed by this project.

The first performance test report resulting from this project was issued in March 1952. Beginning in 1953, the Ballistic Research Laboratories, Aberdeen Proving Ground, U.S. Army joined the Bureau of Aeronautics in providing project support. In 1955, White Sands Proving Ground took over from the Ballistic Research Laboratories its share of project support. It became a Tri-Service project in 1956, when the Wright Air Development Center, U.S. Air Force added its support. This arrangement continued until 1963, when the National Aeronautics and Space Administration joined as a sponsor. Shortly after that, however, the Army (White Sands Proving Ground) discontinued its support. NASA supported the work for four years, and Air Force funding continued until 1968. Navy funding was continuous from 1952 through 1976 (except for 1973 and 1974). Member ranges of the Range Commanders Council also put up shares of support for the work between 1974 and 1978, as did the National Bureau of Standards from 1974 to 1979. It should be noted that all of the funding referred to so far was for "generic" work, i.e., broad based, fundamental studies leading to better understanding of transducer performance and the development of transducer calibration and evaluation methods.

To make up funding deficiencies without losing project staff with valuable expertise, specific tasks were accepted from other government agencies starting in 1968. In all cases, these were mission-oriented tasks relating to transducer calibration and evaluation and thus fitting within the major objectives of the project. The major reorganization of the National Bureau of Standards in 1978 and resulting reprogramming of certain activities led to the decision to terminate the NBS Interagency Transducer Project at the end of Fiscal Year 1979.

The project itself, which was started in the Office of Basic Instrumentation of the National Bureau of Standards, was transferred to the Mechanical Instruments Section in 1954, and to the Engineering Electronics Section in 1964. In 1965, the project came home again to the Basic Instrumentation Section. The Section became the Instrumentation Applications Section in 1970, Components and Applications Section in 1973 and, finally, Sensory Transducer Section in 1977.

The staff of the project varied from two to eight professionals during its existence, averaging four during most of its existence. About 115 publications originated from the work of the project (not counting voluntary standards which staff members helped write), with a total professional effort of roughly 120 man years.

Funding received during the project duration was approximately the following (records are not complete) in order of size: U.S. Navy $ 1093 k, Mission-Related Tasks $ 719 k, U.S. Air Force $ 656 k, NBS $ 535 k, U.S. Army $ 371 k, NASA $ 120 k, for a grand total of $ 3494 k or about $ 3.5 million during the 28-year duration of the project.

Objectives

The original objectives of the project as stated in the history were somewhat modified circa 1959, thus: to obtain performance data on selected telemetering transducers, and to develop and evaluate testing procedures for transducers. The modifications resulted from the realization that resources of staff and facilities were, and would remain inadequate, for performance testing of all types of transducers, and that optimum benefits would accrue to sponsors from tests only on certain transducers to be selected on the basis of potentially superior performance or potential weakness; verification of either characteristic being of great practical importance to users. Recognition of inadequacy or non-existence of testing procedures in some areas led to efforts to develop adequate procedures.

Since 1959 there have been some further slight modifications and the final objectives of the Interagency Transducer Project may be stated as:

> "Investigation of the performance characteristics of electro-mechanical telemetering transducers required for making meaningful measurements of physical quantities."

"Development of techniques and apparatus for the determination of these characteristics."

"Effective dissemination of the knowledge obtained."

Work Areas

To achieve these objectives, project work was conducted in six areas.

The first area encompassed the precise measurement of changing physical quantities. This necessitated the development of techniques and apparatus for evaluating the dynamic measurement capabilities of transducers in areas where such techniques did not exist or were inadequate.

The second area was concerned with the effects on transducers of the environments in which they are used or stored. The environment in which a transducer operates while performing measurements may have a detrimental effect on the quality of the measurements. Rapidly changing environments may pose particularly severe problems. This required the development of techniques and apparatus for simulating environments and evaluating their effects on the measurement capabilities of transducers.

The third area dealt with "durability" of transducers and sensors in service. This is of particular importance in industrial service, where sensors are expected to perform properly over extended periods of time. Equipment and procedures for "life testing" of transducers and sensors were developed.

The fourth area dealt with the study and investigation of principles and materials which may lead to improved evaluation techniques and apparatus.

The fifth area included participation in efforts of professional societies and other organizations to develop standards and recommended practices for transducers and sensors.

Finally, sixth, transducers, especially those with novel operating principles or employing newly developed materials, may exhibit unexpected shortcomings and, therefore, require thorough evaluation to establish their performance characteristics reliably. Such evaluations also provide a means for establishing the validity of existing evaluation procedures and equipment, including those developed as part of the work in the areas listed above. This was also to help to identify areas in which additional work is required.

Needs and Feedback

Selection of the tasks to be undertaken to fulfill the objectives of the project was based on the needs of the sponsoring agencies and the capabilities of the project staff. Needs were established by consultation with representatives of the sponsors and their contractors. Information as to needs in areas of measurement and calibration was also obtained by participation in professional society meetings, visits to sponsoring agencies and their laboratories, personal contacts with transducer users, careful perusal of current scientific literature, and, in particular, through the agency of the Transducer Committee of the IRIG Telemetry Working Group.

Relations With Transducer Committee, Telemetry Working Group, IRIG

Information gathered on the needs of transducer users in areas within the purview of the project had never been as comprehensive as desired. Accordingly, at the eleventh meeting of the Inter-Range Telemetry Working Group (April 1958), and at the request of the National Bureau of Standards and the Bureau of Aeronautics, a Committee on Transducers was established by the Telemetry Working Group. The purpose of this committee was to provide more effective feedback and guidance to the NBS Transducer Project by IRTWG, as well as to provide IRTWG with information of significant developments in the field of telemetry transducers. Close liaison between the NBS project and IRTWG was desirable to assure maximum usefulness to the sponsors and to telemetry users generally.

In 1959, the Transducer Committee recommended that a symposium be held, to be attended by representatives of member ranges, engineering societies and other agencies having a direct interest in transducer developments. The objectives of this symposium were to be: to publicize the goals of the Transducer Committee; to determine the usefulness of standardization of evaluation, calibration and specification procedures; to communicate with related transducer programs directed by other non-(TWG)-Agencies; and, to determine the extent of any coordinated efforts directed toward improving transducer performance to keep pace with advanced telemetry development.

The first Telemetry Transducer Symposium was held in February 1960 and it was the consensus of attendees that several areas of effort needed immediate attention. These were (1) standard telemetry transducer terminology, (2) recommended calibration procedures, and (3) establishment of a clearinghouse for transducer calibration and evaluation reports.

Subsequent Transducer Workshops were held in July 1961, June 1962, and June 1964. Participants have commented favorably on subjects covered and on the value of the free exchange of information possible in the informal atmosphere that prevailed at the meetings. A fifth Transducer Workshop held in October 1967 at the new laboratories of the National Bureau of Standards incorporated a panel session with audience participation. This format was kept during subsequent workshops which were held in October 1969, April 1972, April 1975, and April 1977. A manufacturers' panel was added and formal proceedings were published after the workshops. Attendance has averaged about 100 participants. A tenth Workshop is planned for June 1979.

Participation in Voluntary Standardization Activities

In 1960, in response to transducer needs expressed by the aerospace industry, the Instrument Society of America established a committee to identify specific instrumentation areas requiring standardization. The committee, the Survey Committee on Transducers for Aero-Space Testing (SCOTFAST), conducted a survey among transducer users throughout the country and identified some specific needs in the field of transducers. Among them were improved and uniform transducer nomenclature and specification terminology, and standardization of performance characteristic specifications, test methods, and electrical requirements for certain classes of transducers used in aerospace testing.

As a result of the survey, five subcommittees were established, each to deal with one class of transducers, and a sixth subcommittee to concern itself with nomenclature and specification terminology.

A tentative recommended practice "Nomenclature and Specification Terminology for Aero-Space Test Transducers with Electrical Output" (RP 37.1) was issued by ISA in April 1963.

One of the staff members of the NBS Transducer Project was asked to join the SCOTFAST Committee shortly after its formation and was appointed chairman of the subcommittee dealing with strain gage pressure transducers. Based on the experience gained with this class of transducers in the NBS Interagency Transducer Project and with the assistance of other subcommittee members, a tentative recommended practice was written. This document, "Guide for Specifications and Tests for Strain Gage Pressure Transducers for Aero-Space Testing," was released as ISA-RP 37.3 in April 1964.

Subsequently, additional standards documents dealing with transducers were written by the various subcommittees and, ultimately, turned into ANSI standards.

Project staff members participated in voluntary standards committees of other organizations such as ASME, ANSI, ASTM, and SAE. At the end of 1977, 42 voluntary transducer standards were identified, 16 of those (38% of the total) had been written (wholly or partially) or critically reviewed and/or revised by staff members of the NBS Interagency Transducer Project.

Information Dissemination

A variety of means was used to attempt to meet the third project objective: the effective dissemination of information.

Project publications were distributed to a mailing list of about 140 instrumentation people in government laboratories and industrial plants throughout the country. In addition, all NBS Technical Notes were also sold through the Government Printing Office, which by May 1978, had <u>sold</u> a total of 8316 copies of 17 Technical Notes.

Project staff actively participated in the transducer workshops, visited laboratories and plants, presented talks at technical society meetings, and were consulted extensively through visits and telephone calls.

As indicated earlier, project staff participated actively in voluntary standardization efforts. A listing of committee affiliations follows:

Instrument Society of America	Standards and Practices Board SP 37 "Measurement Transducers" SP 37.3 "Strain Gage Pressure Transducers" SP 37.5 "Strain Gage Accelerometers"
American National Standards Institute	MC 88 "Calibration of Instruments" MC 88 Subcommittee on Pressure
American Society of Mechanical Engineers	"Pressure Technology"
American Society of Testing and Materials	E10.07 "Reactor Instrumentation"
Society of Automotive Engineers	"Transducers" Subcommittee

Accomplishments

During the course of the project, a number of techniques and devices have been developed for the calibration and evaluation of transducers. Brief descriptions follow:

1. Earth's Field Static Calibrator for Accelerometers [9]*

This device as shown in Figure 1 consists of a precision machinist's dividing head mounted on a surface plate and a precision level. A carefully machined bracket attached to the dividing head serves as a mounting surface for the accelerometer. Calibration is accomplished by rotating the bracket in the earth's gravitational field. From a precise knowledge of the angle between the sensitive axis of the accelerometer and the vertical, the value of the component of gravity acting on the seismic mass can be computed. The system is simple, relatively inexpensive and has an estimated limit of error of ±0.004 g_n.

2. Earth's Field Dynamic Calibrator For Accelerometers [19]

This device was developed to calibrate accelerometers at frequencies from about 30 Hz down to about 0.5 Hz by rotating the transducer at uniform velocity in the earth's gravitational field, the magnitude of which is

*Figures in brackets refer to the publications listed in the Section "Publications".

well known. The electrical connections to the accelerometer are made through slip rings. An improved version of this device has been completed with improved bearing supports and more constant rotational speed and is shown in Figure 2. These changes were made to improve accuracy of calibration. This and the previous device have the limitation that the exciting force cannot exceed $\pm 1 g_n$ and the further limitation that the accelerometer under test must have negligible response to transverse excitation.

Three high-natural-frequency servo accelerometers were calibrated from 2 Hz to 24 Hz. The agreement between the sinusoidal excitation responses and the static response was within ±0.1% from 10 Hz to 20 Hz, ±0.2% from 22 Hz to 24 Hz, and ±0.5% from 2 Hz to 8 Hz (the deviations from perfect agreement are attributed largely to accuracy limitations of the voltmeter used).

The carefully confirmed discrepancies between experimentally determined values of natural frequencies and damping ratios for linear and rotational dynamic calibrations of low-natural-frequency accelerometers indicate that the rotational technique should be avoided or used only with great caution for accelerometers of that type.

3. Dual Centrifuge [4]

The dual centrifuge was developed to generate large amplitudes of acceleration in the frequency range from 0.5 Hz to about 30 Hz. As shown in Figure 3, it consists essentially of a small turntable mounted on a large one, each turning in a horizontal plane. The accelerometer is mounted on the small table with its sensitive axis in a horizontal plane. When the turntables are rotating with constant angular velocities, the seismic mass in the accelerometer responds to a sinusoidally varying component of the centrifugal force field generated by the rotation of the large table. A system of pulleys and timing belts is arranged so that the small turntable has zero absolute angular velocity in inertial space at all times (its motion is like that of the connecting rods for the drivewheels of a steam locomotive). The equation of motion of the seismic mass of the accelerometer is the same as for sinusoidal linear motion. Due to the character of the motion, the accelerometer is also subjected to transverse acceleration during each cycle and the output will reflect this in its departure from the ideal. The magnitude of the generated acceleration can be varied by locating the small turntable at various distances from the center of the large one.

The dual centrifuge can generate accelerations of $\pm 1 g_n$ at 1 Hz, increasing to $\pm 100 g_n$ at from 10 Hz to about 25 Hz.

4. Torsional Vibration Calibrator

This device, shown in Figure 4, was built as a generator of sinusoidal angular motion for the calibration of angular motion sensing instruments, such as angular accelerometers and rate gyros. Based on a similar device used by a transducer manufacturer, it is essentially an electrically driven torsion pendulum with its shaft vertical and two tangential springs supplying the restoring torque. The calibrator is useful over a frequency range from 0.57 Hz to 30 Hz, generating angular accelerations up to 40 rad/s^2 over most of the frequency range, depending on the inertia of the instrument under test.

5. Shock Tube [5, 10]

Since it is extremely difficult to generate sinusoidal pressures of known amplitude in gases, the dynamic characteristics of a pressure transducer are generally obtained from its transient response. To provide excitation for observation of transient response, a shock tube has been developed that generates a pressure step function with a risetime of less than 10^{-8} seconds. The shock tube, shown in Figure 5, is 20 ft. long and is divided into two chambers, 12 ft. long and 8 ft. long, by a cellulose acetate diaphragm. The 12 ft. section is filled with helium and the 8 ft. section with dry air, the ratio of respective absolute pressures in these sections is set to be 2.7 to 1 over the entire range of operation of the shock tube. The pressure of the helium is set to a value approximately equal to the desired pressure amplitude of the step function. Upon rupture of the diaphragm, helium pushing into the air chamber generates a shockwave in the air which travels the length of the 8 ft. section, and is then reflected from the rigid end wall at an increased pressure. The amplitude of the step function pressure to which a pickup in the end wall is exposed can be estimated by means of ideal gas theory from the velocity of the shockwave, and the temperature and pressure of the air before the diaphragm is burst. The range of step pressures that can be generated by this shock tube is 6 psi to 1000 psi and the duration of the pressure at these values is about 4.5 milliseconds.

6. Pneumatic Step Function Calibrator [1]

The step function generated by the shock tube is not accurately known because computation of the amplitude of the step is based on ideal gas theory. A device, shown in Figure 6, that generates a known step function of gas pressure (for use where the extremely rapid excitation obtainable with the shock tube is not necessary) has been developed. The amplitude of the step generated by this device can be measured statically.

The risetime of the generated pressure is about 0.9 milliseconds (much longer than that of the shock tube) and the initial oscillation superimposed on the step decreases to less than 2% of the step amplitude within 15 milliseconds. The range of pressures of this pneumatic calibrator is 2 psi to 100 psi. The heart of the calibrator is a pneumatically operated quick opening valve which applies air pressure from a large storage tank to the transducer under test. The tank pressure is set to the desired value by a pressure regulator and measured by a precision dial pressure gage. Since the volume of the storage tank is more than 100 times that of the combined internal volumes of the quick opening valve and the fixture holding the transducer, gas flow and temperature change are held to a minimum. The pressure in the storage tank after the step is applied to the transducer, as indicated on the dial gage, is then the same as the amplitude of the pressure step within about ±1%. This calibrator is most useful for the inspection of transducers for dynamic errors at low frequency such as those due to hysteresis.

7. Liquid Medium Step Function Calibrator [7]

A liquid medium step function calibrator (based on a design by Dr. Daniel Johnson of NBS) has been procured. The calibrator, Figure 7, consists of a conical valve with a long stem in a large pressure vessel. The transducer to be tested is mounted to face a small cavity in front of the conical valve. Application of pressure to a piston at the end of the long stem of the conical valve causes the latter to close. Pressure of the desired amplitude is built up in the large pressure vessel. The transducer cavity is brought to zero psig by a bleeder valve which is thereafter kept closed. A fast release of the pressure on the valve step piston relieves compressive stress in the valve stem and the conical valve begins to open. As the pressure in the transducer cavity builds up, opening of the valve accelerates, so that a pressure step of short risetime is applied to the transducer. As in the pneumatic step function calibrator, the ratio of the volume of the large pressure vessel to that of the transducer cavity is very large. In this case, also, static measurement of the amplitude of the pressure step within about ±0.2% is possible using a precision dial gage. By selection of cavity size, oil viscosity and the diameter of the valve stem, a nearly optimum step function of pressure with a risetime of less than 3 milliseconds can be obtained at most pressures from 500 psi to 3000 psi.

This device also is most useful for the inspection of transducers for dynamic errors at low frequency such as those caused by hysteresis.

8. Transient Recorder and Frequency Analysis Scheme [10]

If pressure transducers were linear single degree of freedom systems, simple calculations from their responses to step pressures would yield the frequency response characteristics. Most pressure transducers are multiple degree of freedom systems and some are nonlinear. The analysis of such systems, even when they are perfectly linear, is not simple. A simple scheme was devised for the wave analysis of the step function pressure response. This scheme involves the recording of the step pressure response of the transducer on a magnetic recorder and subsequent repetitive playback of this transient into an electronic frequency analyzer. In this manner the resonant frequencies of multiple degree of freedom systems may be identified. A recorder was procured, meeting these requirements, with an oxide-coated drum rotating at 3000 rpm. The system has a flat response from about 1.5 kHz to 80 kHz and is capable of recording transients with durations of 1 to 6 milliseconds and amplitudes from about 1 mV to 10 V. A multiple head arrangement makes possible recording and storing of four transients. Playback occurs at a rate of 60 transients per second.

The frequency analyzer, a commercial item, covers the frequency range from below 1 kHz to 300 kHz and throughout most of the range is capable of identifying frequencies of equal amplitudes less than 1 kHz apart as well as frequencies with amplitude ratios of 100:1, but at least one octave apart. The recorder and the frequency analyzer are shown in Figure 8.

To test the operation of the system, the recorder analyzer was used to analyze the transient response of electrical analogs of multiple degree of freedom systems. All the resonances were found and their amplitudes determined.

9. Thermal Gradient Testing Method [8, 17]

A technique was developed to assess the effects of thermal shock applied to the sensing elements of pressure transducers. Zero shifts observed were found to be related to the thermal gradient developed across the body of the transducer when its sensing end was suddenly dipped into a pool of molten Wood's metal. This relatively simple and repeatable technique makes it possible to compare the thermal transient responses of flush diaphragm transducers. This test set-up is shown in Figure 9. Thirteen different flush mounted pressure transducers of seven manufacturers were tested by creating a thermal gradient in them and recording the resultant zero shifts. A typical recording shows these general characteristics: (1) a very rapid change in output reaching a peak in a second or less, (2) a more gradual shift which reaches a peak in a time which may range from a few seconds to more than a minute, and (3) a shift in reading which remains as long as the gradient is maintained. Examples were found in which each of these were positive or negative. The magnitude in a few cases was small, in many was a large fraction of the transducer's range, and in one case well in excess of the full scale range.

10. "Life Cycling" Technique for Pressure Transducers [12, 22]

Apparatus was assembled to study the effects of the repeated application of pressure stimuli on the performance characteristics of pressure transducers. The equipment consisted essentially of a quick-operating solenoid three-way valve which was energized by a cam-operated switch. A timing motor drove the cam, which energized the valve 3000 times per hour. A pressure stimulus of selected amplitude was thereby applied to the transducer and then relieved, 3000 times per hour. The equipment, shown in Figure 10, ran continuously, a totalizing counter keeping track of the number of elapsed cycles. At prescribed intervals, cycling was interrupted and the transducer was statically calibrated to establish its performance characteristics. Each transducer under test was subjected to one million pressure cycles in order to assess any deterioration in its performance characteristics.

Subsequently, another durability investigation was conducted on a group of eighteen bonded-wire strain gage pressure transducers with ranges of 0 to 15 psig (0 to 103 kPa) and 0 to 100 psig (0 to 689 kPa) using an improved version of a previously developed technique as shown in Figure 11. Some of the transducers were subjected to 40 x 10^6 pressure cycles at a 5-Hz rate at laboratory ambient conditions, others were cycled at a temperature of 150 °F (65.6 °C). The largest change in sensitivity observed was 0.22% for a 100-psig transducer subjected to 40 x 10^6 pressure cycles at 150 °F. The largest change in zero pressure output observed was 0.91% FS for the same transducer. None of the transducers failed completely as a result of cycling at or below full scale pressure.

11. Computation of Useful Frequency Range of Piezoelectric Accelerometers [16]

A study was conducted into a method for computing the useful frequency range of piezoelectric accelerometers and a paper published. This paper analyzes two lumped-parameter models for computing the usable frequency range of piezoelectric accelerometers. The analyses indicate why application of an electrical excitation to the piezoelectric element of a mounted pickup does not, in general, give the same result as application of a mechanical acceleration to the structure on which the pickup is mounted. Tabular results of the computations for various sets of parameters indicate those cases for which the electrical drive will give resonant frequency values within 2% of those for the pickup mounted on a vibrating structure. For these parameter sets, the electrical drive can be used as a reliable substitute.

12. Effects of High-Temperature Storage on Strain Gage Pressure Transducers [18]

An experimental investigation was conducted into the effects of extended high-temperature storage on the performance characteristics of several strain gage pressure transducers. Using the equipment shown in Figure 12, the results of this 5-week test program indicate that changes in the sensitivity and zero characteristics of electromechanical pressure transducers can occur as a result of storage at temperature above ambient laboratory conditions. In some cases these performance changes are permanent. High-temperature soaking of some transducers before putting them into service at elevated temperature may reduce performance changes during their operation since some transducers were observed to have their most drastic changes during the early portion of this temperature-storage test.

To assure reliable performance of pressure transducers operated at elevated temperatures for extended periods of time, the effects of the environment on the particular transducer must be investigated, since zero shifts up to 4.5% FS were observed in this program in which the pressure transducers were subjected to the elevated temperatures for only 5 weeks. Some applications of transducers require that the transducer operate reliably in elevated temperature environments for much longer periods.

13. Hydraulic Sinusoidal Pressure Calibrator [20]

Figure 13 shows a simple, accurate device for the sinusoidal calibration of pressure transducers. Calibration is achieved by vibrating a liquid-filled tube on an electrodynamic vibration exciter; the pressure transducer mounted at the base of the tube senses the sinusoidally varying pressure in the tube. The frequency range is 15 Hz to 2000 Hz with a maximum obtainable amplitude of 19.5 psi (134 kPa) peak to peak. The transducer can easily be calibrated statically in the same device, thus permitting precise correlation between static and dynamic calibrations. Agreement between static and dynamic calibrations to within 0.1% has been achieved.

14. Thermal Transient Tests Using Laser [21]

A simple and repeatable testing technique was developed which makes it practical to obtain information on the zero shift and change in sensitivity of a pressure transducer while it is subjected to a thermal transient generated by a mechanically chopped cw laser beam. The test setup is shown in Figures 14 and 15. Several commercial, flush diaphragm, pressure transducers with ranges up to 50 psi (345 kPa) were tested and showed zero shifts and changes in sensitivity of the order of 20% FS due to thermal transients with power densities up to 10 W/cm^2. The transducer under test can be pressure cycled while it is irradiated. In this way, zero shifts and sensitivity changes may be directly displayed in a procedure which requires a testing time of only about one minute.

15. Thermal Transient Test for Piezoelectric Accelerometers [23, 27]

A simple, inexpensive method was developed for determining the effects of thermal transients on the zero output and sensitivity of piezoelectric accelerometers. Thermal transient stimuli are generated by an incandescent lamp and can be made to heat the top or side of the test accelerometer. The test setup is shown in Figure 16. 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.

16. Vibratory Phenomena in Liquid-Filled Cylinder [28]

A theoretical study was conducted in support of a dynamic pressure calibration technique involving liquid media. By making appropriate physical approximations and idealizations, a theoretical explanation was found for a vibratory phenomenon observed in calibrating pressure transducers inside thin liquid-filled cylinders. The theoretical explanation required proving the equivalence of two initial-boundary problems which define the vibratory phenomenon. A short, general and complete proof of this equivalence is given.

17. Flashbulb Thermal Transient Test Method [33]

A test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure-transducer response is 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. The original setup is shown in Figure 17, and an improved version in Figure 18. The method is intended to serve as an initial screening test. 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. 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.

18. Dynamic Pressure Calibration Source [35]

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. Figure 19 shows the test setup. 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-Stoke dimethyl siloxane working fluid in order to extend the useful frequency range to higher frequencies than would be provided by an undamped system.

19. Dynamic Pressure Calibrations at High Static Pressures [37]

Two dynamic pressure sources were developed for the calibration of "pogo" pressure transducers used to measure oscillatory pressures generated in the propulsion system of the space shuttle. Rotation of a mercury-filled tube in a vertical plane at frequencies below 5 Hz generates sinusoidal pressures up to 48 kPa, peak-to-peak; vibrating the same mercury-filled tube sinusoidally in the vertical plane extends the frequency response from 5 Hz to 100 Hz at pressures up to 140 kPa, peak-to-peak. The sinusoidal pressure fluctuations can be generated by both methods in the presence of high (static) pressures (bias) up to 55 MPa. The sources are shown in Figures 20 and 21.

Calibration procedures are given in detail for the use of both sources. The dynamic performance of selected transducers was evaluated using these procedures; the results of these calibrations are presented. Calibrations made with the two sources near 5 Hz agree to within 3% of each other.

20. Thermal Transient Protection for Pressure Transducers [41, 33]

An experimental investigation was conducted to evaluate protective diaphragm coatings as a means to reduce the effects produced by thermal radiant-energy transients on pressure-transducer response.

A series of tests was carried out to investigate the effects of a variety of protective coatings on the amount and rate of thermal energy transmission through thin metal disks (used to simulate transducer diaphragms) as revealed by measurements of the disk back-side temperature. The temperature histories of both bare and protected disks were measured with thermocouples during and after exposure of the disks to thermal radiant-energy transients (of approximately 2 J/cm^2 at the disk) generated by No. 22 photographic flashbulbs. Protective coatings investigated include various tapes, greases, and room-temperature-vulcanizing rubbers (RTVs).

Based on the results from these tests, the effectiveness of nine selected coatings in reducing thermally-induced zero shifts of four types of pressure transducers was investigated. In these tests, a pair of transducers -- one protected and the other unprotected, but otherwise nominally identical -- were exposed to a thermal radiant-energy transient as described above. The resulting zero shift was measured and taken as an index of coating effectiveness.

The effect of the mass of the coatings on transducer dynamic response was investigated by means of a shock tube in which a protected and unprotected pair were simultaneously exposed to a pressure step of approximately 280 kPa (40 psi). Also, the effect of selected coatings on transducer acceleration sensitivity was investigated by monitoring the outputs of pairs of transducers mounted on a vibration exciter.

Test results indicate the validity of the simulated diaphragm test as a predictor of protection effectiveness. Results from both disk and transducer tests show that some coating combinations appear to be an order of magnitude more effective than others in delaying and reducing zero shift. Coatings of multi-layer black tape, red RTV silicone rubber, and "heat sink" compound appear most effective. Silicone grease is found least effective, while single-layer black tape appears to produce results ranging from very limited protection to actual degradation of response, based on the limited sampling carried out in this investigation.

Applications of Project Results

At the time of this report, the following users of transducer test methods originating from the NBS Interagency Transducer Project have been reported:

Earth's Field Dynamic Calibrator for Accelerometers	Naval Air Test Center Navy Metrology Engineering Center Sandia Laboratories Bendix Corporation

Dual Centrifuge for Accelerometers	Available Commercially from Genisco Schaevitz Engineering
Shock Tube for Pressure Transducer Evaluation	Naval Proving Ground NASA Marshall Space Flight Center Naval Ship Research & Development Center
Pneumatic Step Function Pressure Calibrator	Naval Air Test Center NASA Langley Research Center Sandia Laboratories Air Force Armament Development and Test Center General Motors Research Laboratory
Thermal Transient Tester for Pressure Transducers	Wright Air Development Center Sandia Laboratories Naval Weapons Center Lawrence Livermore Laboratory Air Force Armament Development and Test Center
Dynamic Pressure Calibrator	NASA Langley Research Center
Dynamic Pressure Calibrator at High Static Pressures	NASA Marshall Space Flight Center Servonic Division, Gulton Rockwell Corporation

Publications

The following formal publications have resulted from NBS Interagency Project activities since 1962.

1. Lederer, P. S., Step Function Pressure Calibrator, U.S. Patent #3,034,332 (May 15, 1962).

2. Lederer, P. S., General Characteristics of Linear Strain Gage Accelerometers Used in Telemetry, NBS Tech. Note 150 (June 1962) [out of print].

3. Smith, R. O. and Hilten, J. S., Low Frequency Calibration of Spring-Mass Accelerometers, 3rd Transducer Workshop, Telemetry Working Group, National Bureau of Standards, Gaithersburg, Md. (June 1962).

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5. Schweppe, J. L., et al., Methods for the Dynamic Calibration of Pressure Transducers, NBS Mono. 67 (December 1964) [out of print].

6. Lederer, P. S., Some Aspects of Transducer Calibration Techniques, 4th Transducer Workshop, Telemetry Working Group, Wright Air Development Center, Ohio (June 1964).

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8. Horn, L., The Response of Flush Diaphragm Pressure Transducers to Thermal Gradients, 20th Annual ISA Conference, Los Angeles, Calif., Paper 13.3-4-65 (October 1965).

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16. Newman, N., Considerations in Computing the Useful Frequency Range of Piezoelectric Accelerometers, NBS Tech. Note 487 (July 1969) [NTIS: TN 487].

17. Horn, L., Thermal Gradient Effects on Thirteen Flush Mounted Pressure Transducers, NBS Tech. Note 490 (August 1969) [NTIS: TN 490].

18. Williams, R., The Effects of Extended High-Temperature Storage on the Performance Characteristics of Several Strain Gage Pressure Transducers, NBS Tech. Note 497 (October 1969) [NTIS: AD 695821].

19. Hilten, J. S., Accelerometer Calibration with the Earth's Field Dynamic Calibrator, NBS Tech. Note 517 (March 1970) [NTIS: PB 190072].

20. Hilten, J. S., Lederer, P. S., and Sethian, J. D., A Simple Hydraulic Sinusoidal Pressure Calibrator, NBS Tech. Note 720 (April 1972) [GPO: SN003-003-00989-0, $0.65].

21. Lederer, P. S. and Hilten, J. S., A Laser Technique for Investigating the Effects of Thermal Transients on Pressure Transducer Performance Characteristics, NBS Tech. Note 723 (May 1972) [NTIS: COM-72-50535].

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23. Lederer, P. S., Experimental Study of the Effects of Thermal Transients on the Performance Characteristics of the Piezoelectric Accelerometers -- Progress Report September 15, 1972 to April 15, 1973, NBSIR 73-230 (July 15, 1973) [out of print].

24. Lederer, P. S., Development of a Dynamic Pressure Calibration Technique -- Progress Report June 15, 1973 to September 15, 1973, NBSIR 73-290 (October 15, 1973) [NTIS: COM-74-10974].

25. Hilten, J. S. and Lederer, P. S., Space Shuttle Pogo Pressure Measuring System -- Progress Report January 15, 1973 to September 15, 1973, NBSIR 74-562 (July 15, 1974).

26. Lederer, P. S., Transducers in the Real World, Joint Measurement Conference, National Bureau of Standards, Gaithersburg, Md. (November 1974).

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28. Kraft, Richard, Note on a Vibratory Phenomenon Arising in Transducer Calibration, NBS Tech. Note 856 (February 1975) [GPO: SN003-003-01371-4, $0.65]. (A theoretical analysis referring to work reported in Items 35 and 37).

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42. Hilten, J. S., Vezzetti, C. F., Mayo-Wells, J. F., and Lederer, P. S., Experimental Investigation of Drill-Bit Wear, NBSIR 78-1423 (February 1978) [NTIS: PB-278618].

43. Vezzetti, C. F., Mayo-Wells, J. F., Hilten, J. S., and Lederer, P. S., Bibliography and Brief Review of Literature on Machine-Tool Measurements for Automatic Control, NBSIR 78-1424 (April 1978).

44. Hilten, J. S., Lederer, P. S., Mayo-Wells, J. F., and Vezzetti, C. F., Loose-Particle Detection in Microelectronic Devices, NBSIR 78-1590 (NASA) (January 1979).

In addition, from 1952 to 1969, 71 NBS reports were published, dealing with evaluations of selected commercial transducers (53 publications) or with preliminary accounts of test methods (18 publications). All of these publications are obsolete. Most are out of print or were superseded by the formal publications listed above.

Acknowledgment

The NBS Interagency Transducer Project and its accomplishment resulted from the dedication, inspiration and hard work of a number of people through the years. It would not be fair to try to list them all lest someone is overlooked. It is fitting, however, to recognize the efforts of Raymond O. Smith, who led the project from its inception until his retirement in 1964.

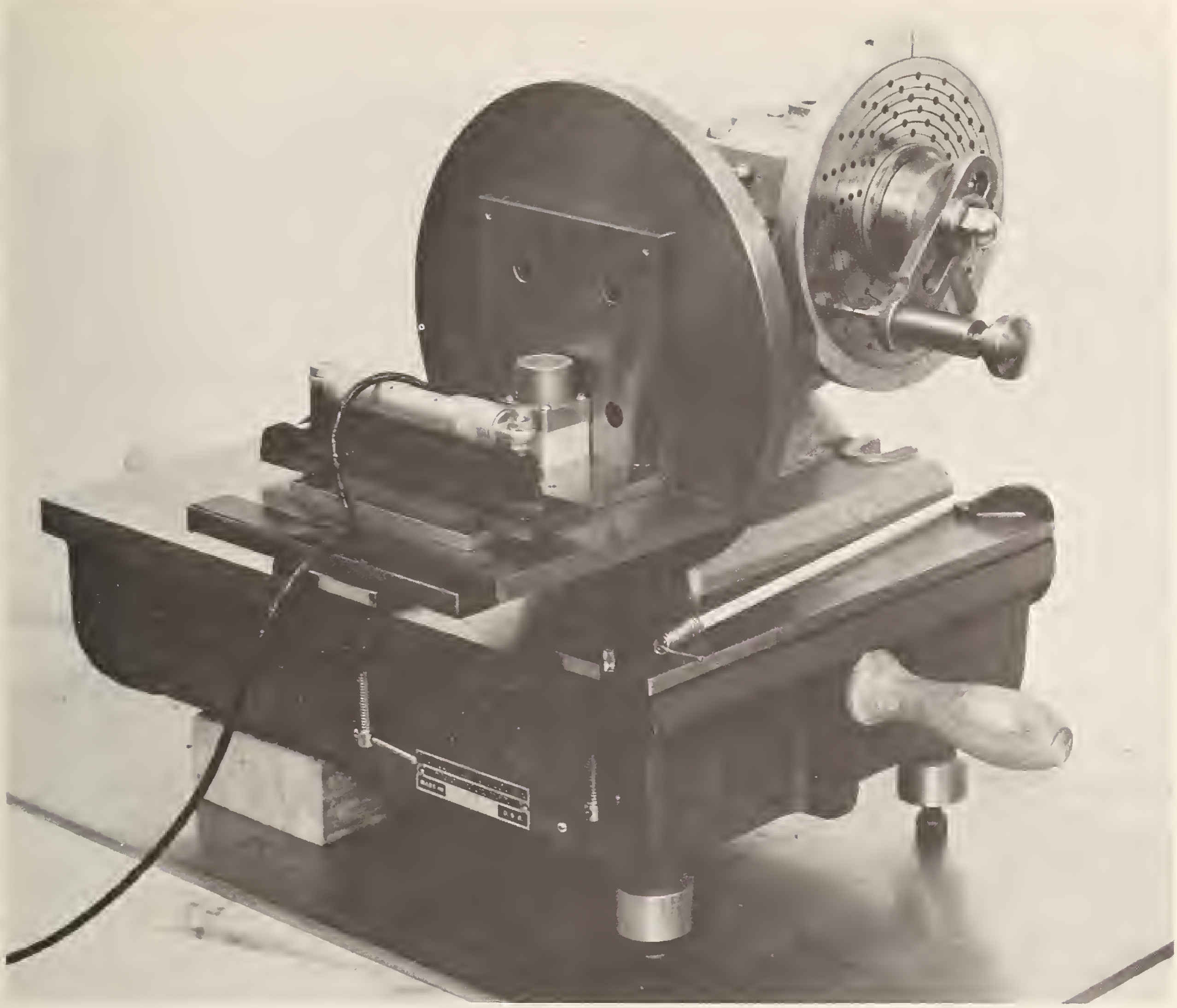

Figure 1. Earth's field static calibrator for accelerometers. Shown are the dividing head, surface plate, and reference level, as well as the precision right-angle bracket on which the accelerometer is mounted.

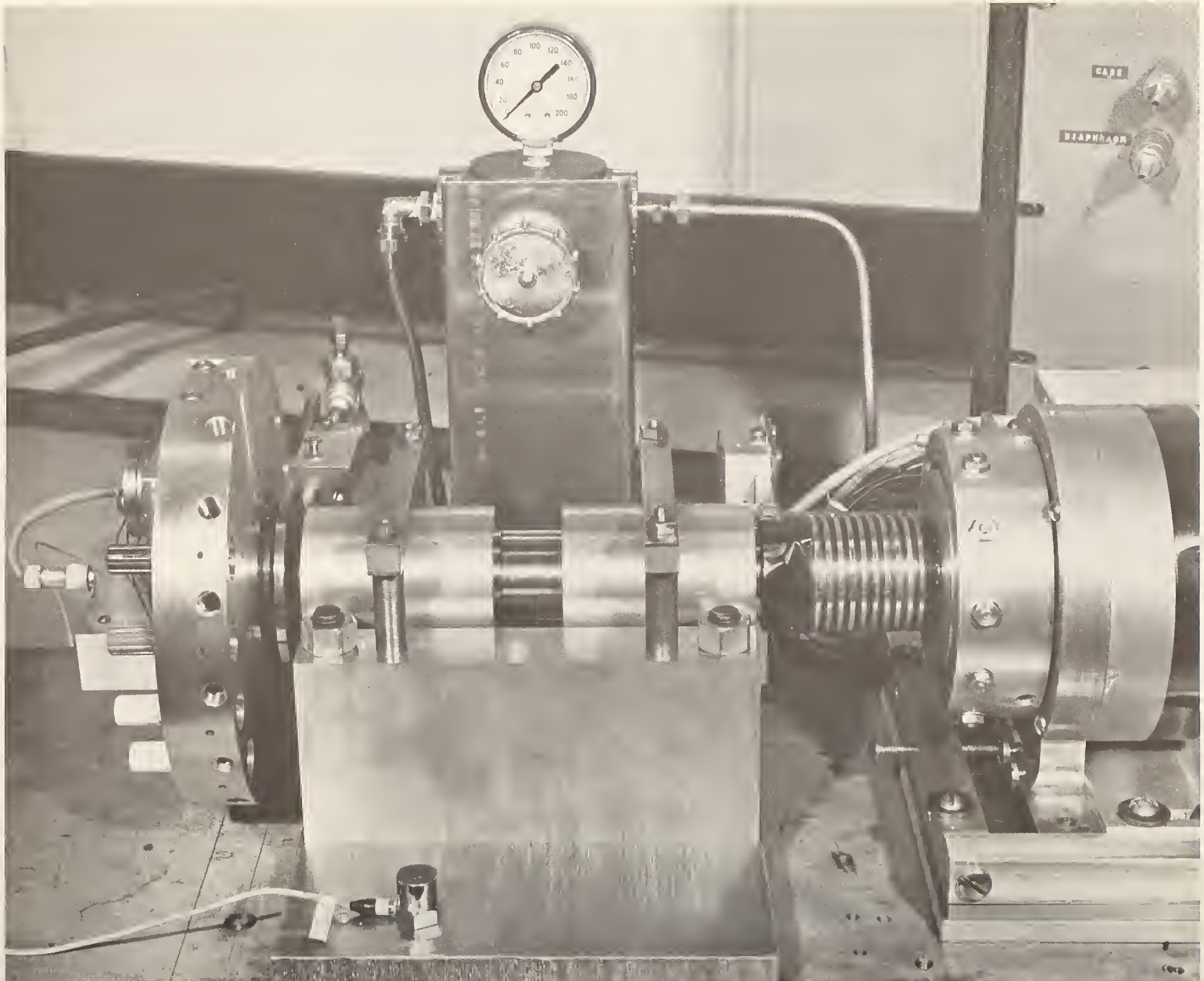

Figure 2. Earth's field dynamic calibrator for accelerometers showing air-bearing system, slip rings, and magnetic-clutch system. The regulator which controls the operating pneumatic pressure for the air bearings can be seen also.

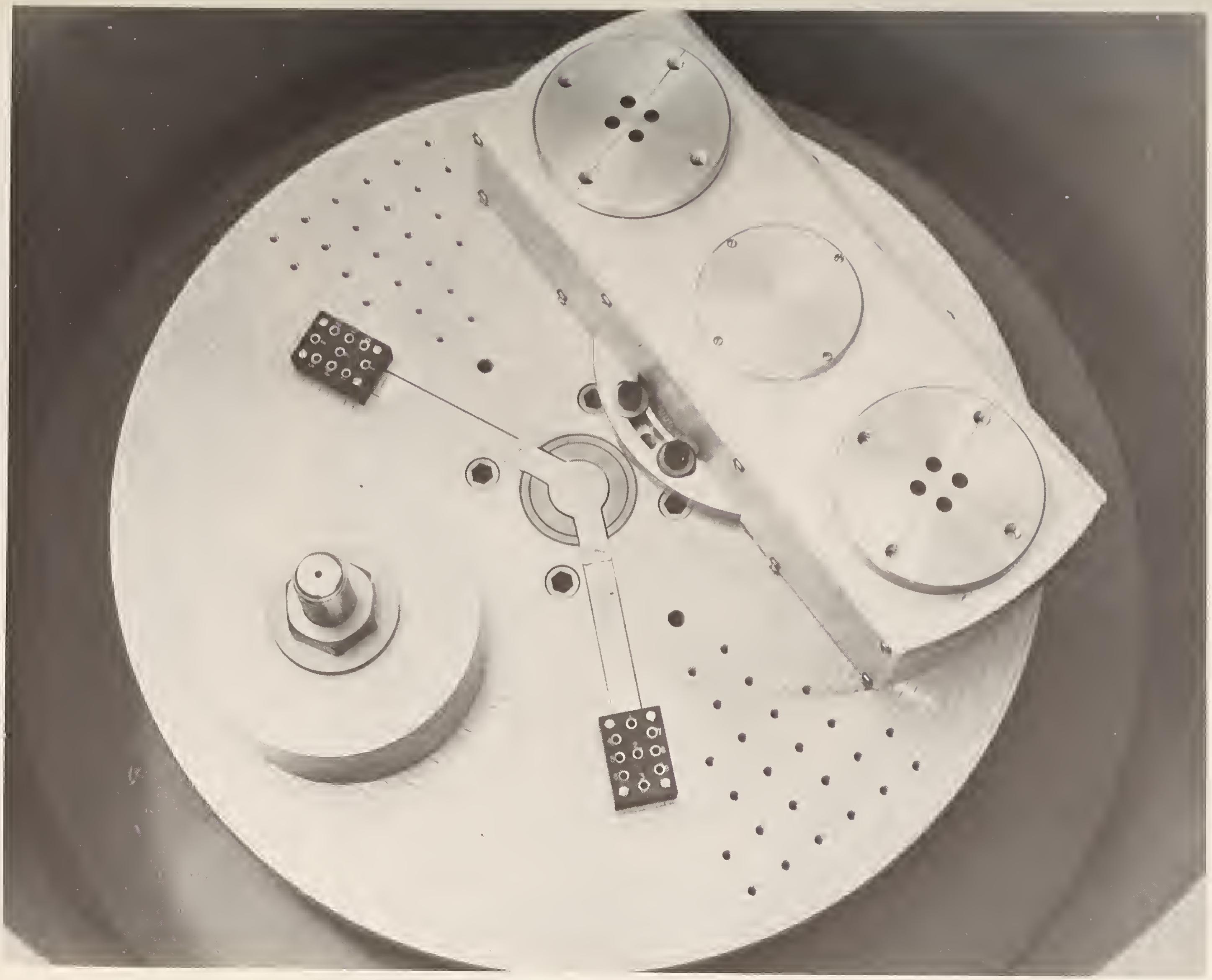

Figure 3. Top view of dual centrifuge showing main rotating table (used for steady-state acceleration calibration) and satellite tables for generation of sinusoidal accelerations. The counterweight necessary for balancing the mass of the satellite-table assembly is also shown.

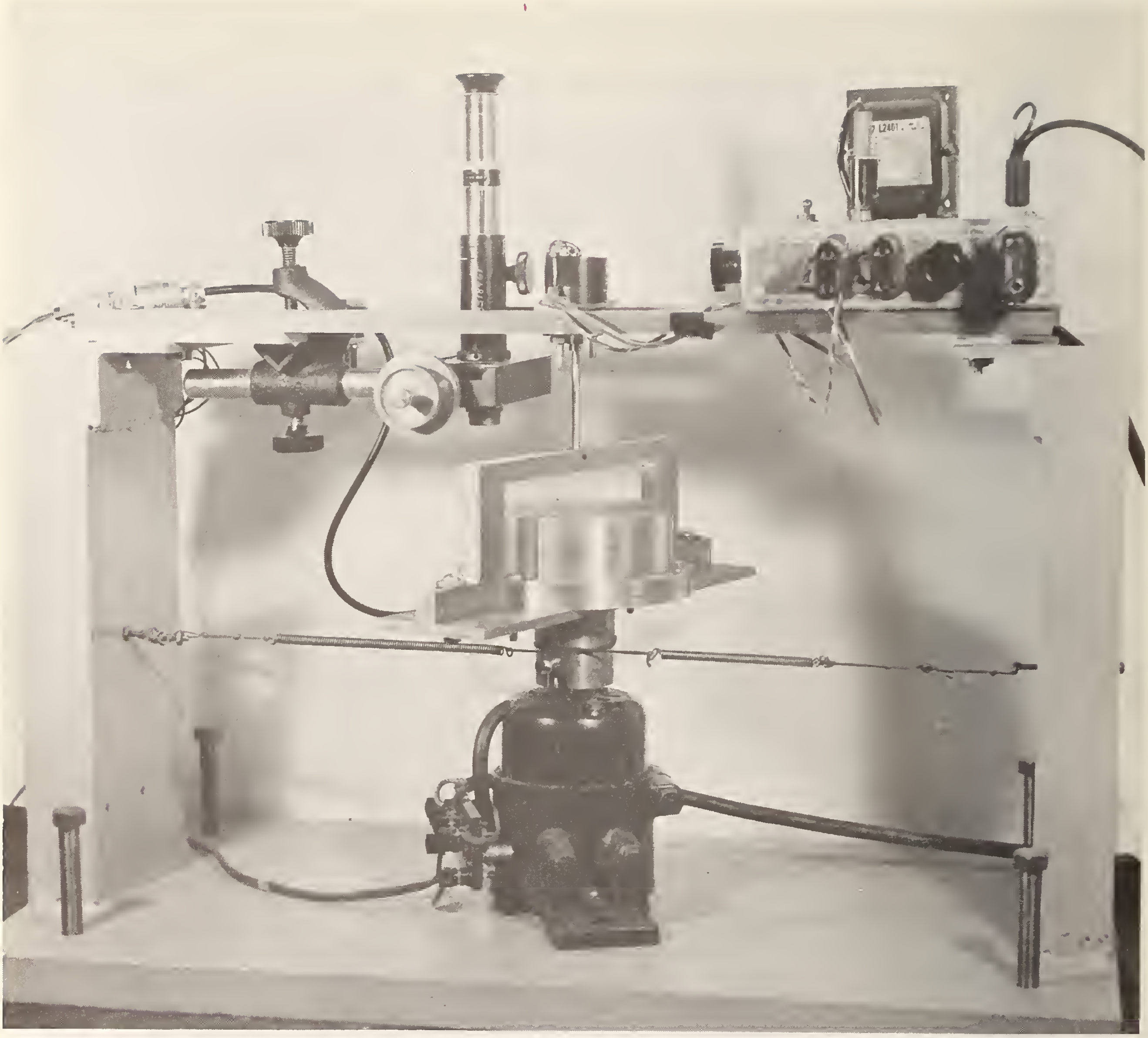

Figure 4. View of torsional vibration calibrator, including rotary displacement transducer (mounted on horizontal boom), measuring microscope (for static calibration of displacement transducer). An angular accelerometer (to be calibrated) is mounted on the oscillating table of the calibrator.

Figure 5. View of shock tube with gas supply, pressure measurement and control system (in relay rack adjacent to shock tube) and transient recording and analysis system (in rack on bench on the left).

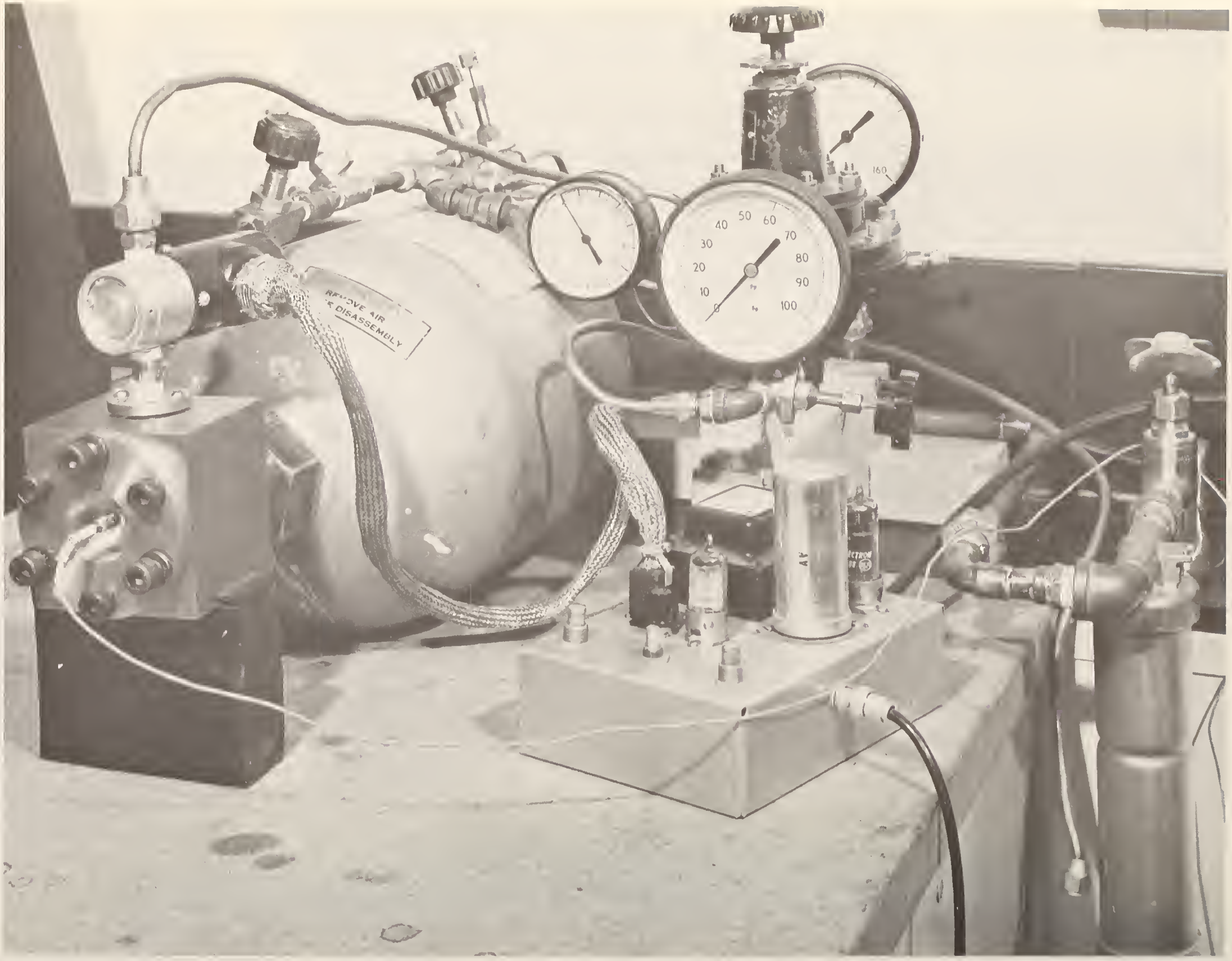

Figure 6. View of prototype pneumatic step-function pressure calibrator. The transducer to be calibrated is mounted in the square valve block on the left.

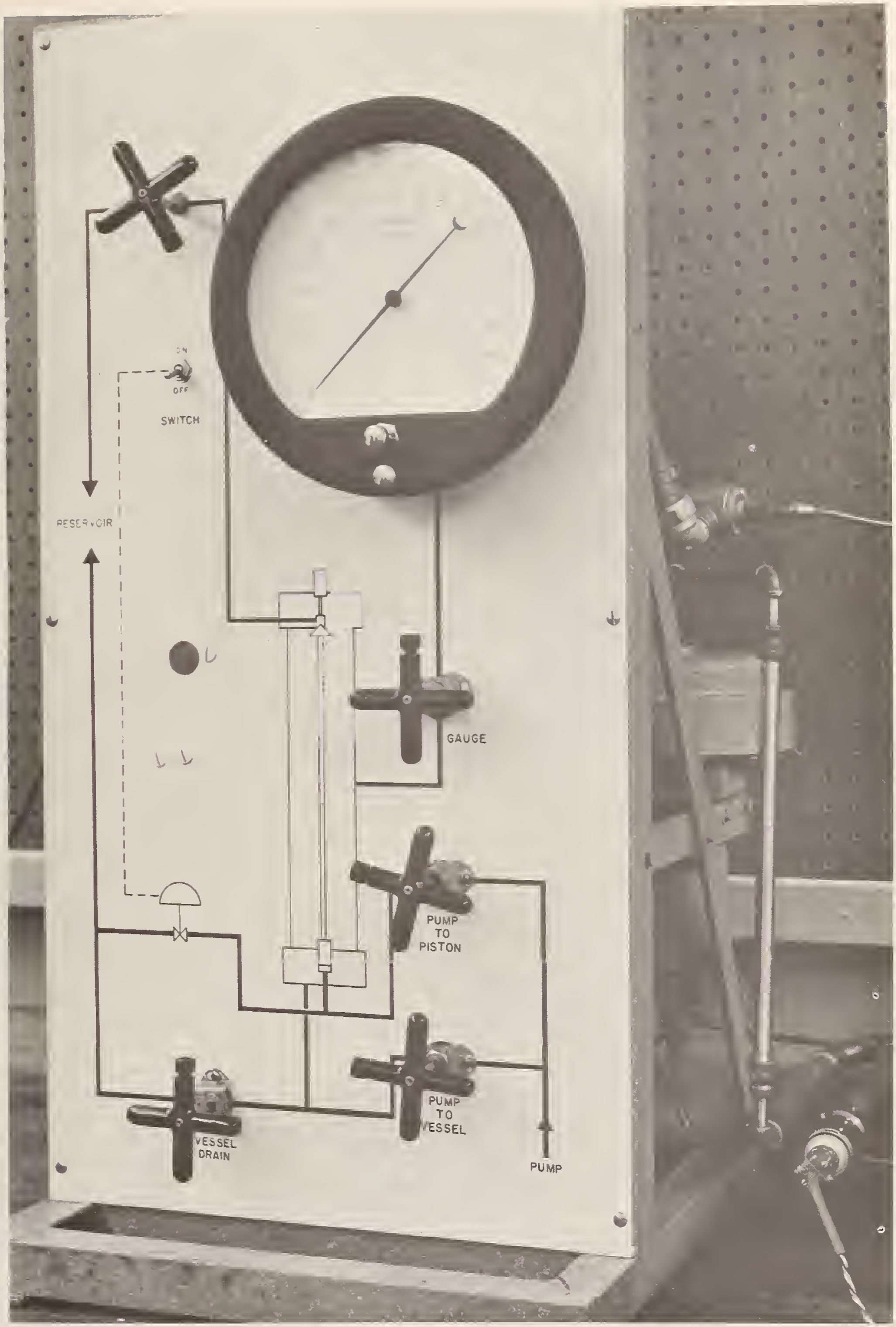

Figure 7. Liquid-medium step-function pressure calibrator. The transducer to be calibrated is mounted in the top of the valve assembly behind the panel (not visible in this photograph). The high-pressure pump used to generate the test pressure also is not shown.

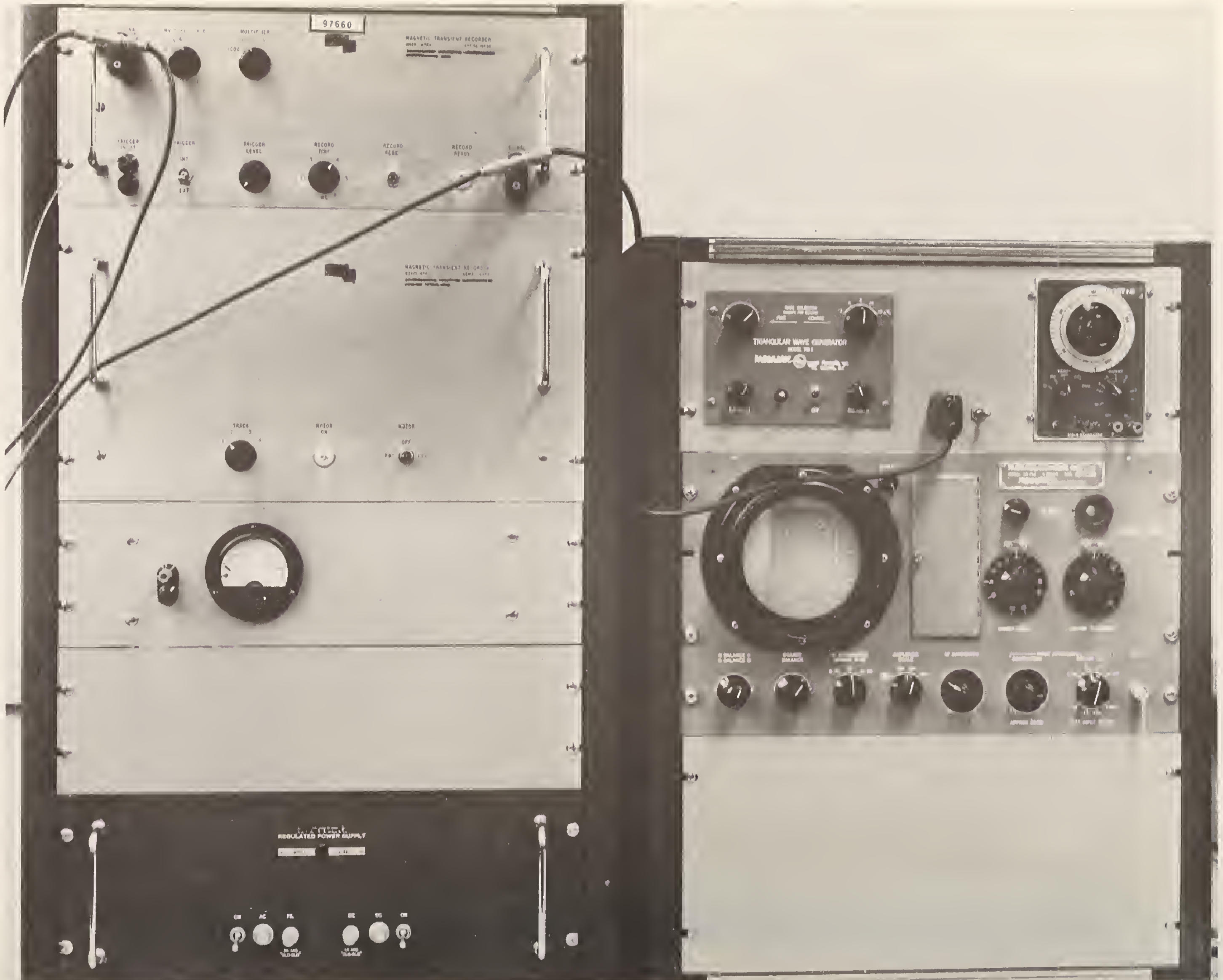

Figure 8. Transient recorder (left) and spectrum analyser (right) used in conjunction with shock tube to obtain dynamic characteristics of pressure transducers.

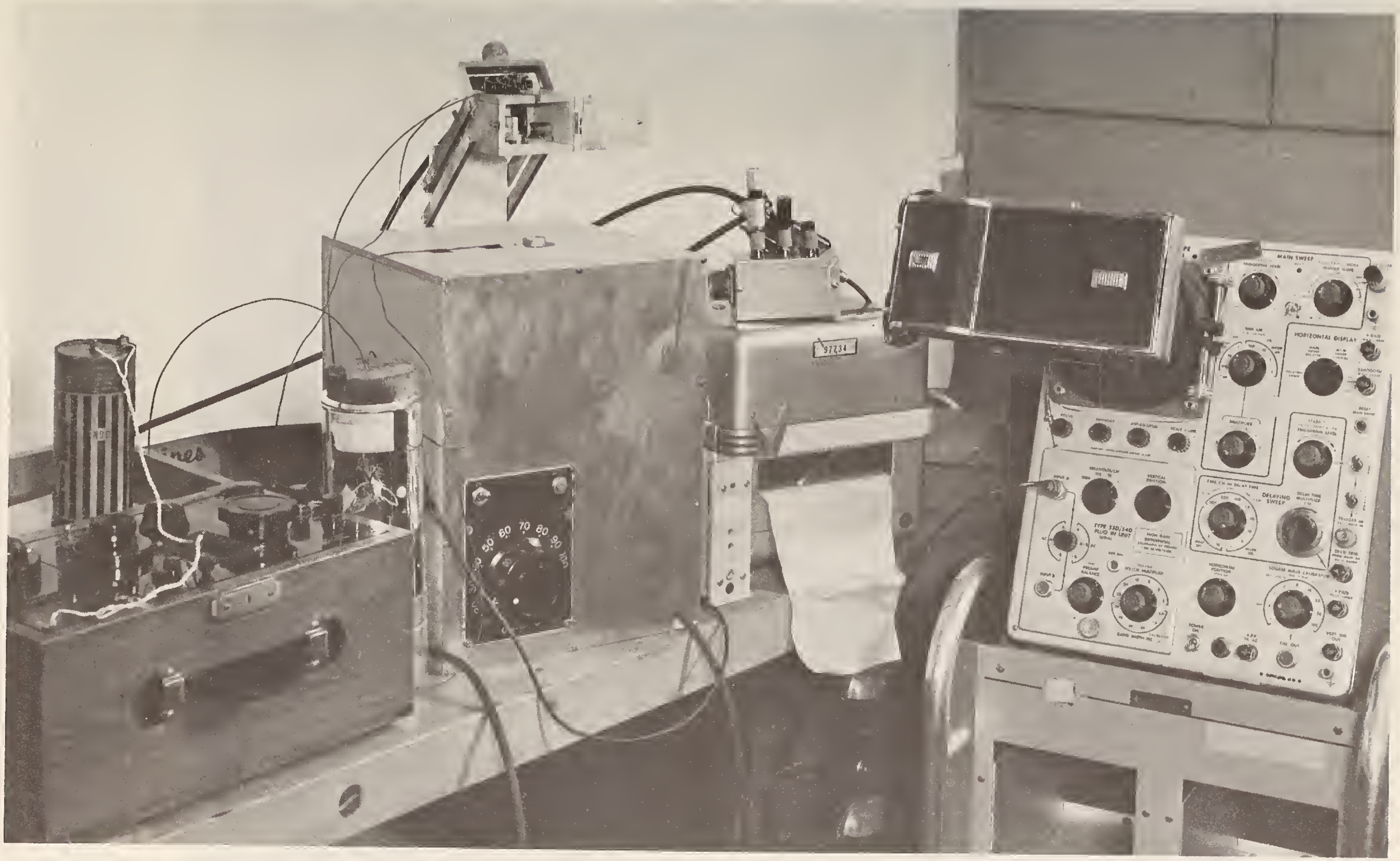

Figure 9. Apparatus for evaluating effects of thermal transients on pressure transducers. Transducer diaphragm end is dipped into pool of molten Wood's metal by means of fixture near center of picture.

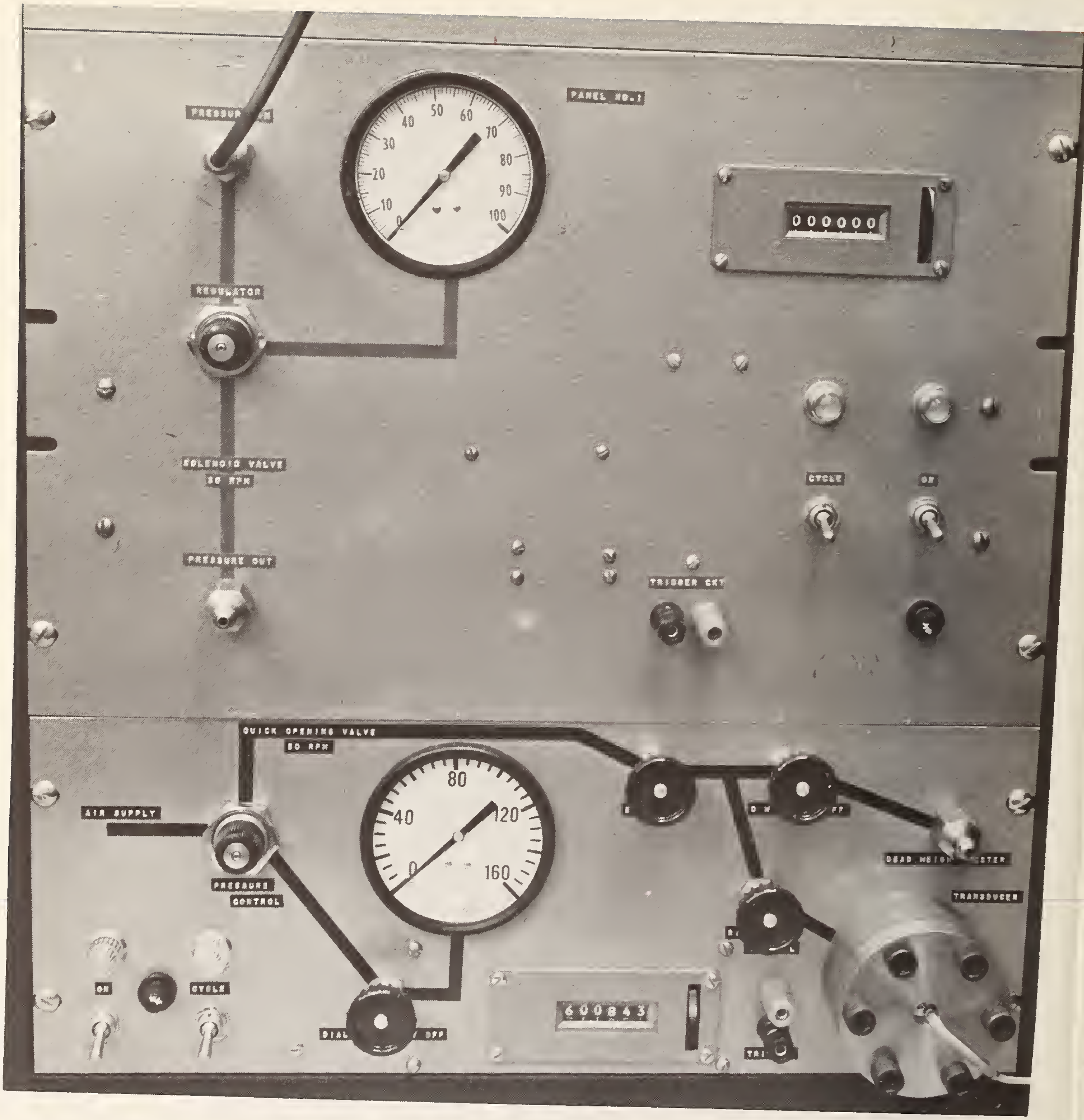

Figure 10. Equipment for cycling of pressure transducers to assess their durability. Counters indicate cumulative number of cycles of full-scale pneumatic pressure applied to test transducers.

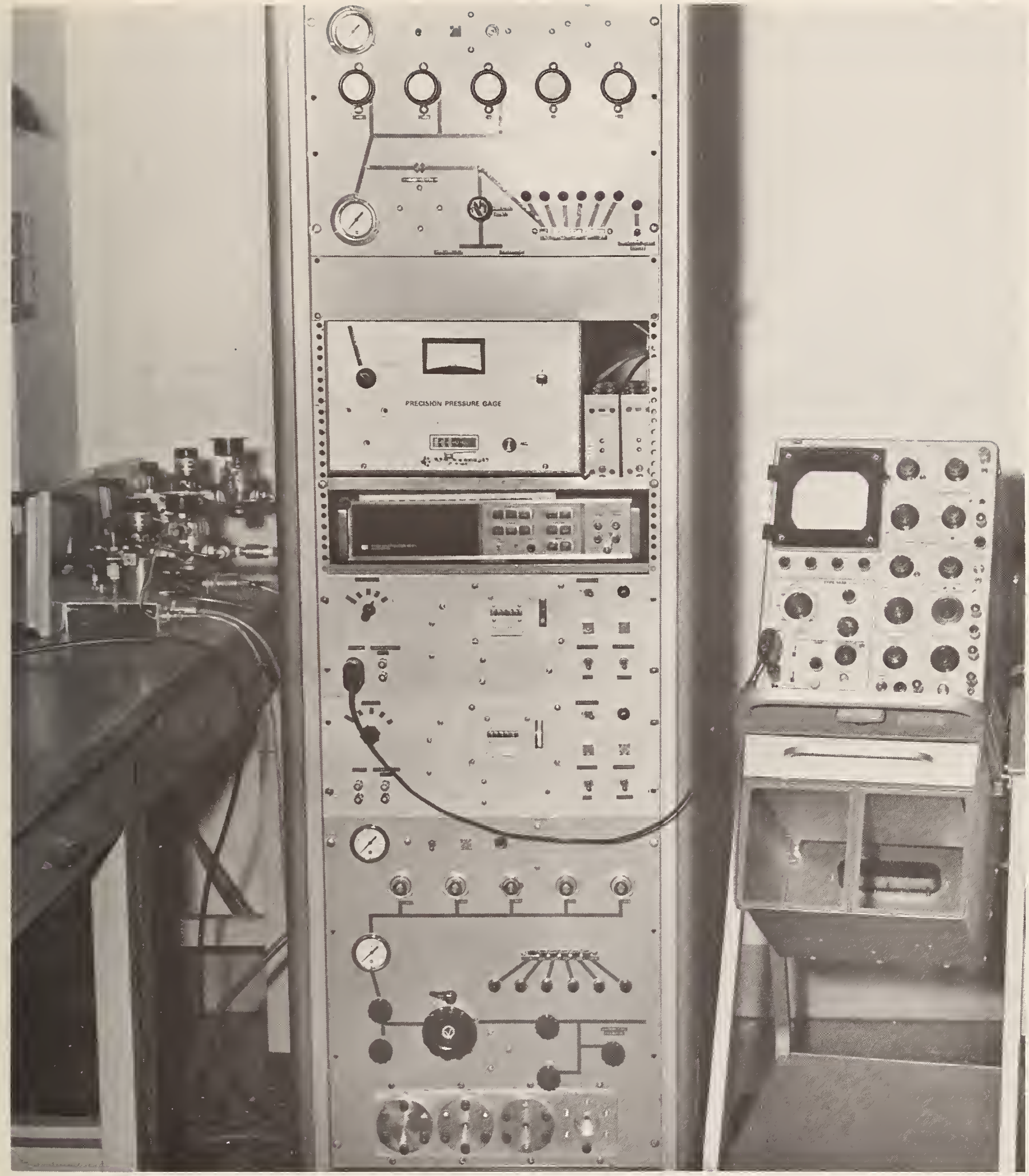

Figure 11. Improved equipment for cycling of pressure transducers. Using this equipment, the durability of a group of pressure transducers was investigated while the transducers were subjected to 40,000,000 pressure cycles.

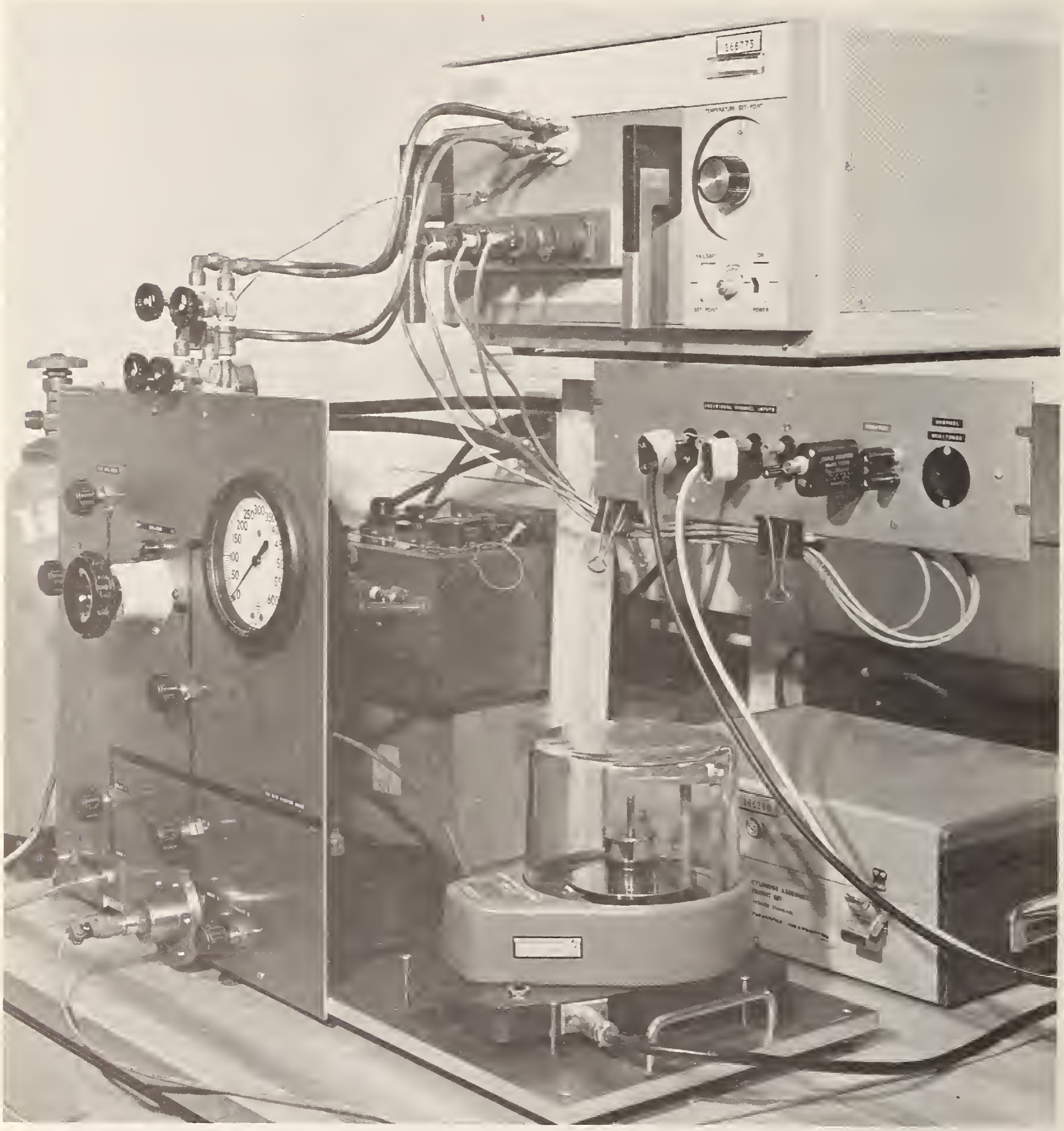

Figure 12. Experimental set-up used for an investigation of the effects of high-temperature storage on the performance characteristics of pressure transducers.

Figure 13. Liquid-medium sinusoidal pressure calibrator, with transducer to be calibrated, is shown mounted on an electrodynamic vibration exciter.

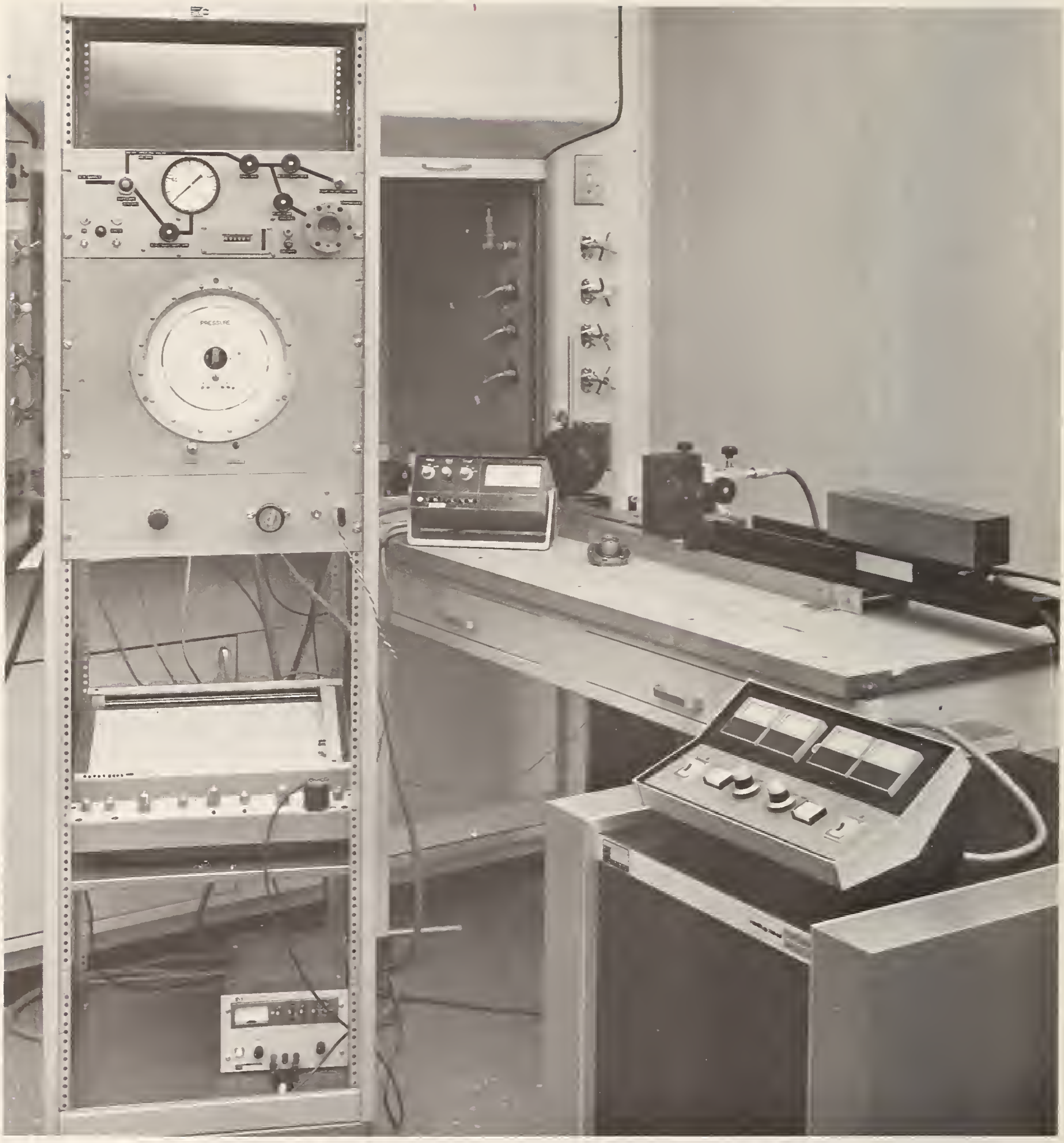

Figure 14. Experimental set-up for thermal transient tests on pressure transducers using a continuous wave laser.

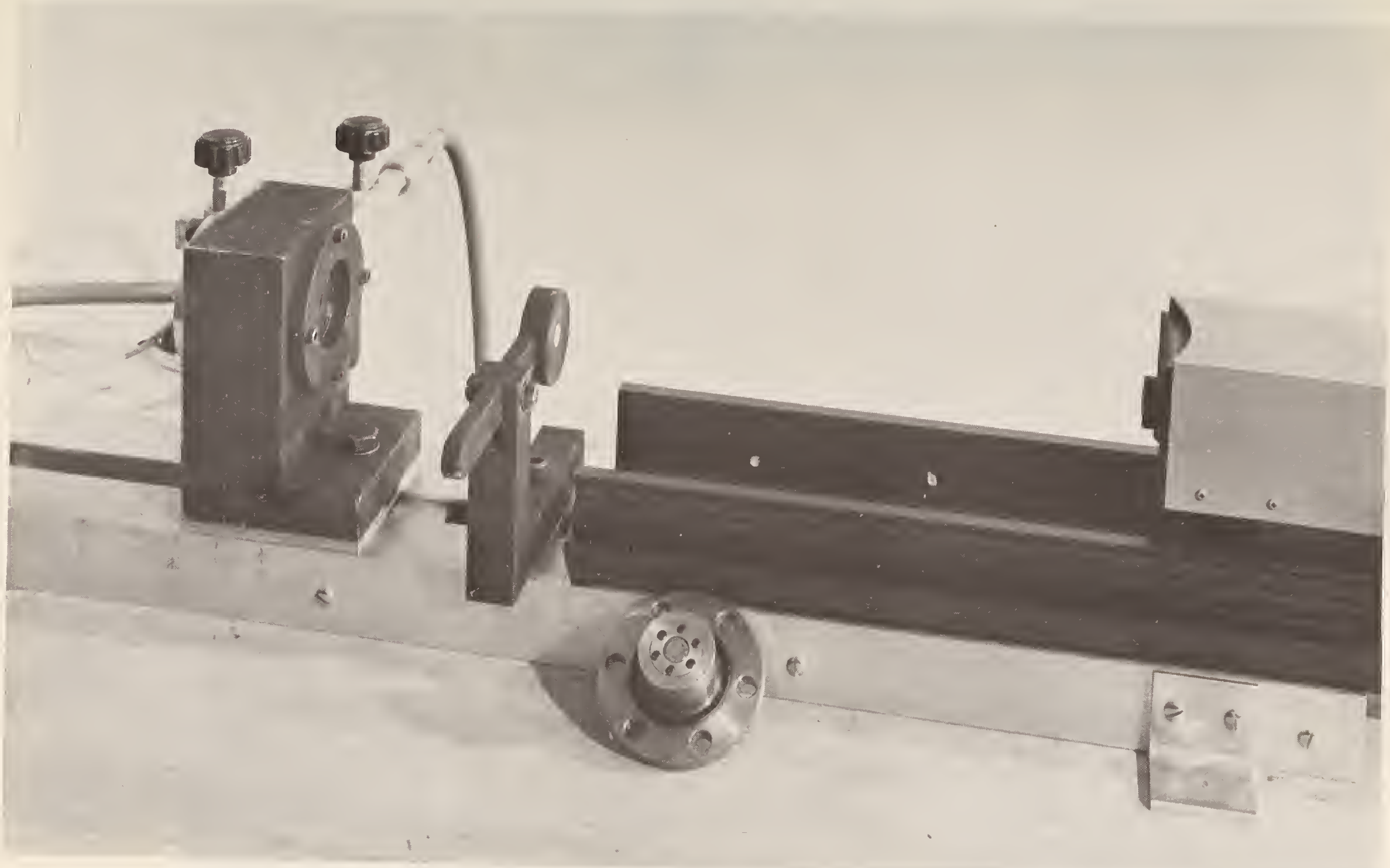

Figure 15. View of transducer test fixture, shutter assembly, and head of CW laser used for thermal transient tests on pressure transducers.

Figure 16. Experimental set-up for investigation of effects of thermal transients on performance of piezoelectric accelerometers showing radiant heat lamp and shutter with test-accelerometer side exposed to thermal transient.

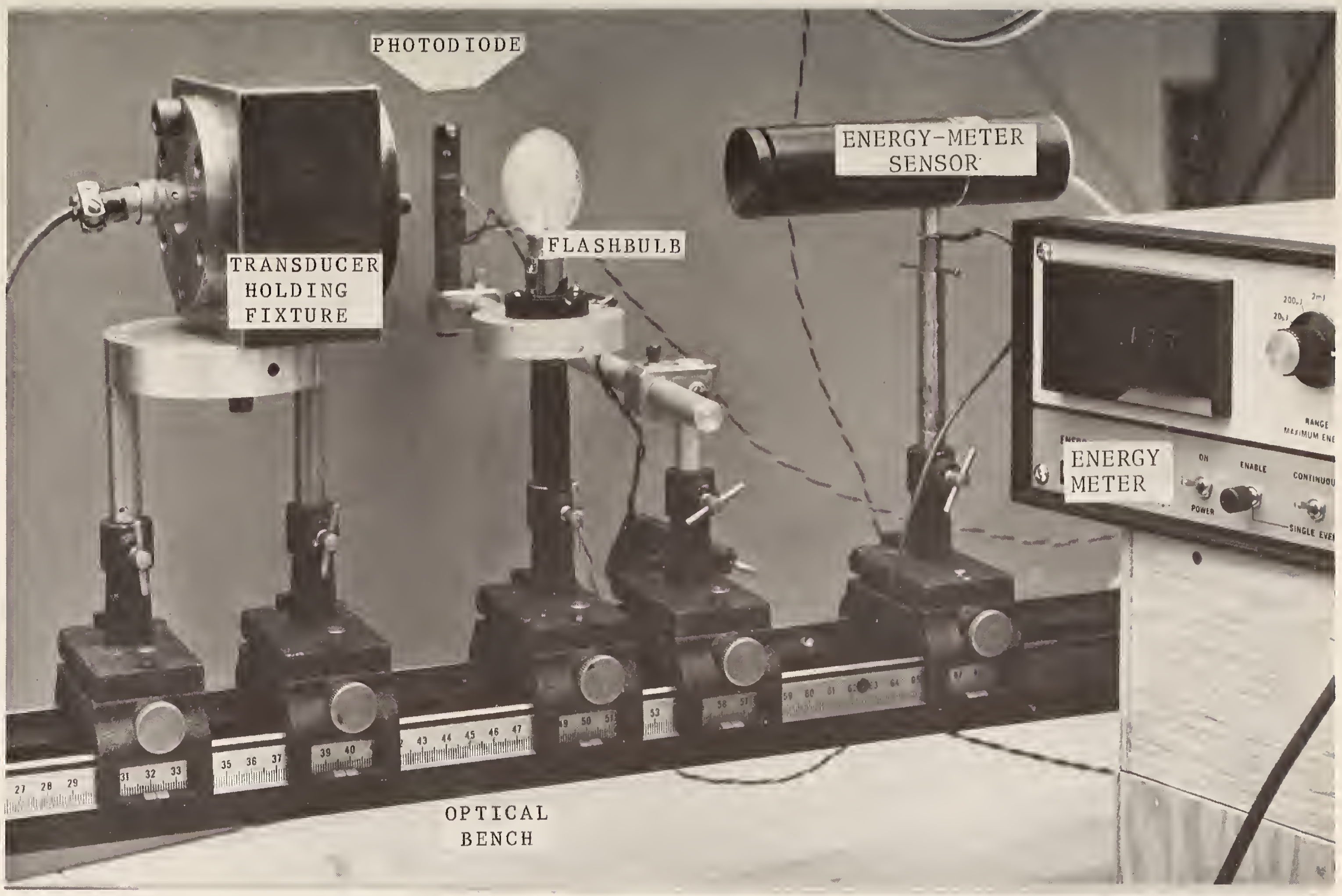

Figure 17. Overall view of experimental apparatus used to develop thermal transient tester for pressure transducers. Shown are: transducer holding fixture, flashbulb source, photodiode, and energy-meter sensor supported by holders mounted on an optical bench. The energy-meter instrument is at the right.

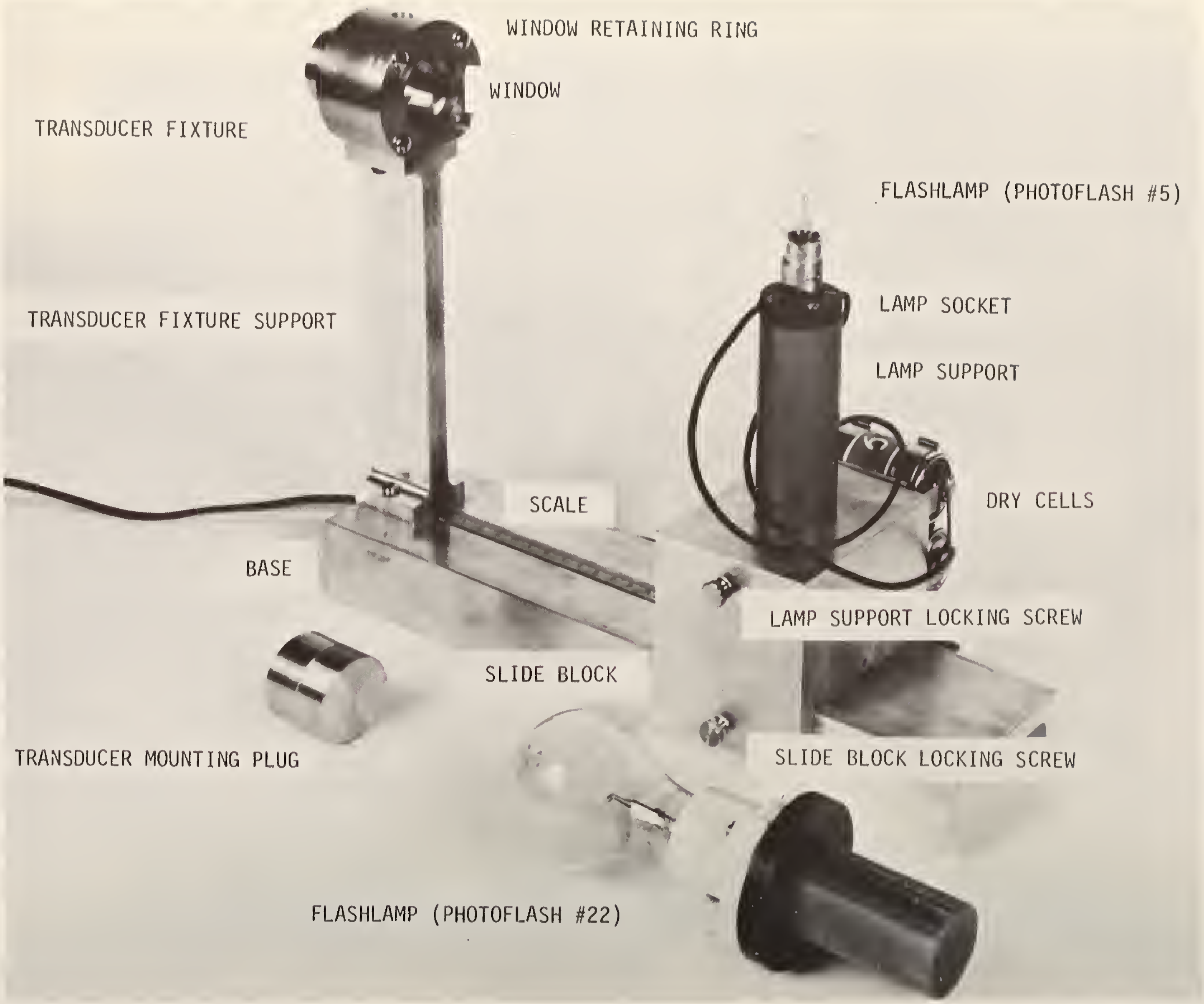

Figure 18. Refined flashbulb thermal transient tester for pressure transducers.

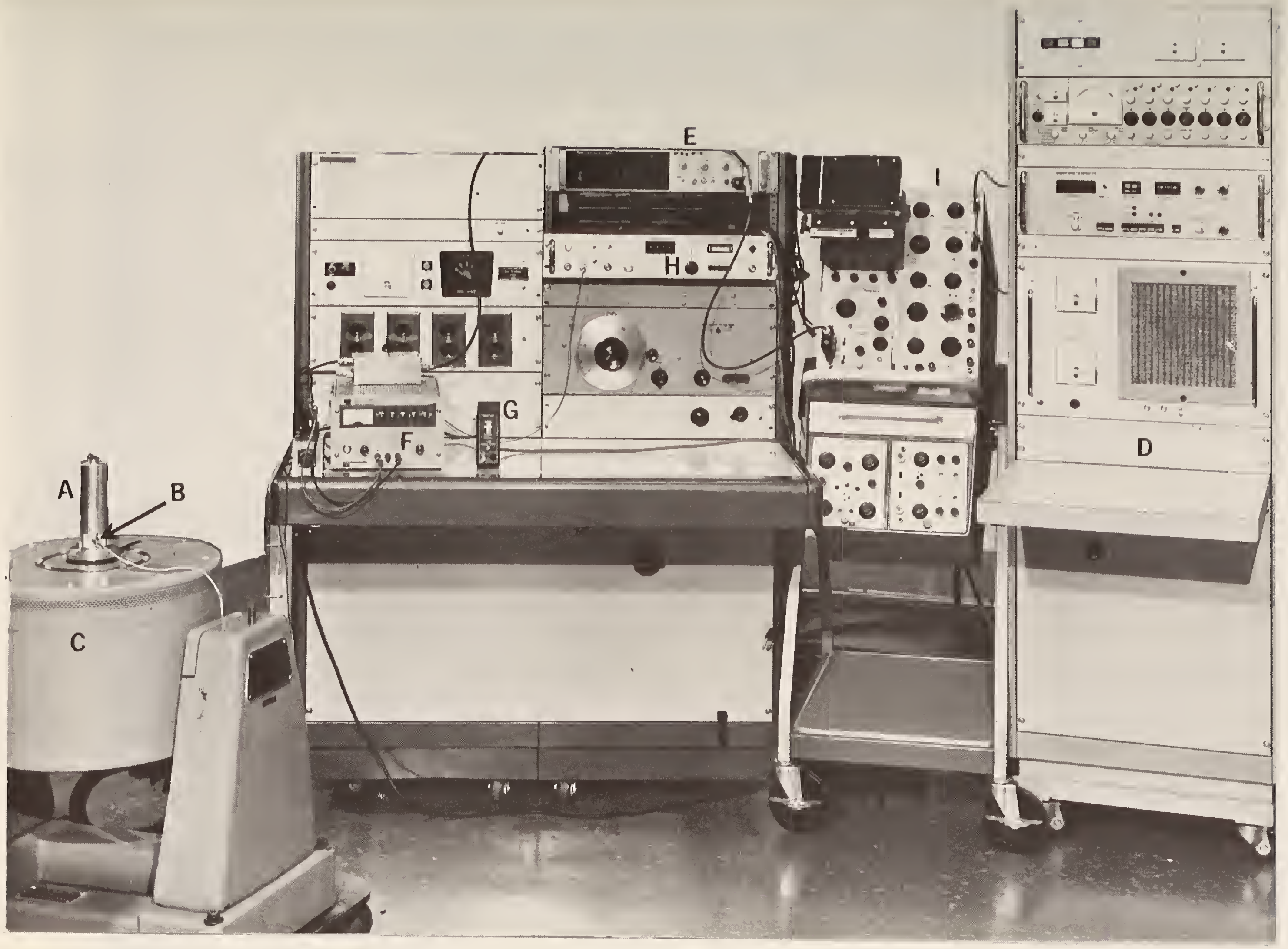

Figure 19. Improved dynamic pressure source for dynamic calibration of pressure transducers. Shown are: source (A) with reference transducer (B), vibration exciter (C), controller console (D) for vibration exciter, digital voltmeter (E), transducer power supplies (F, G), amplifier (H) for accelerometer used to monitor vibration exciter, and oscilloscope (I). The test transducer is hidden behind the source.

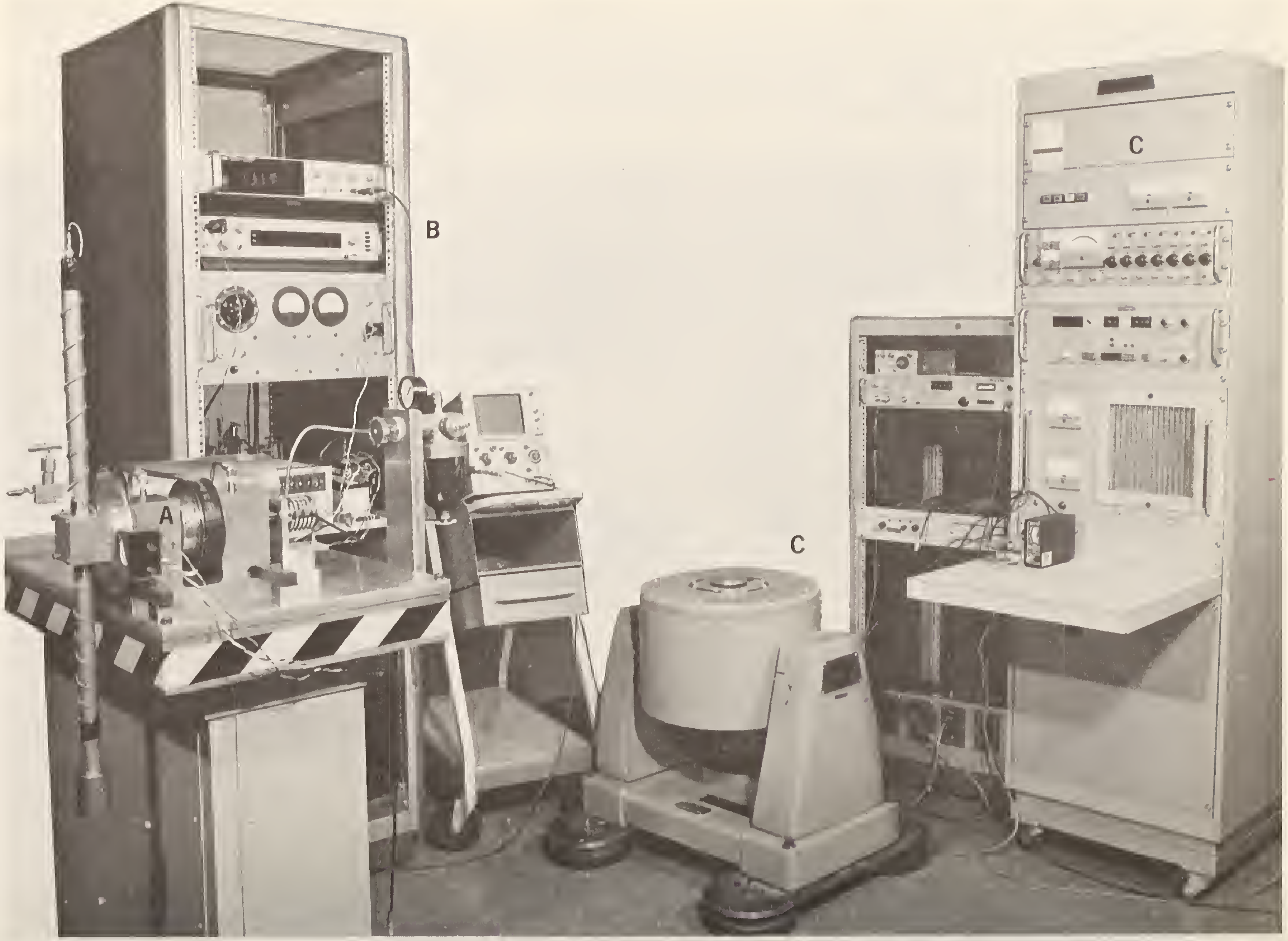

Figure 20. Apparatus used in the calibration of pressure transducers for pogo (small pressure variations at high line pressures and low frequencies) measurements. The windmill source is shown at (A) with supporting electronics in rack (B). The vibration-exciter system which forms part of the oscillating source is at (C).

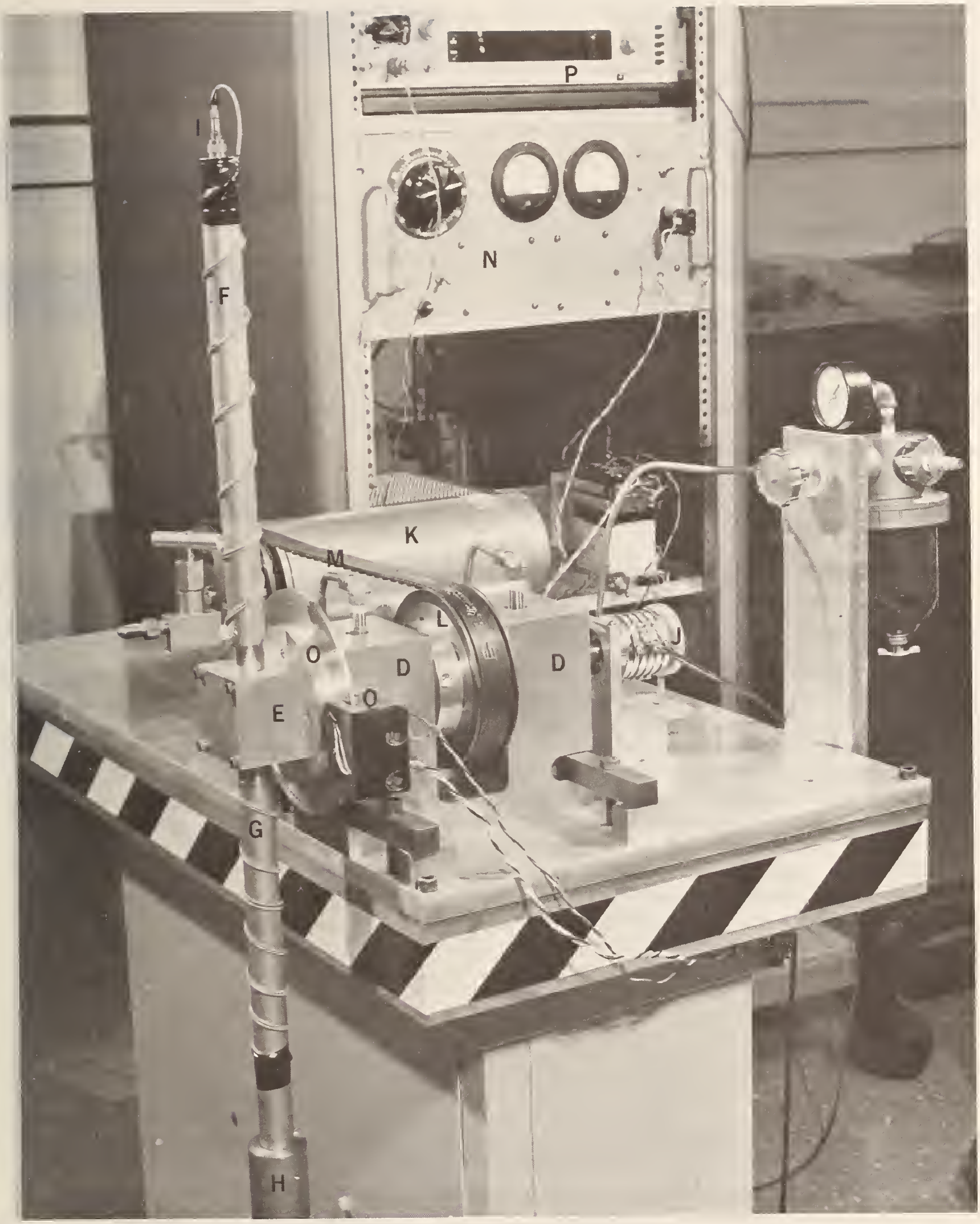

Figure 21. The windmill source for the generation of low frequency pressure variations, consisting of the closed-tube column mounted on the windmill apparatus.

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15. SUPPLEMENTARY NOTES

Supersedes NBS Technical Note 469, published October 1968.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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.*)

Between 1951 and 1979, the National Bureau of Standards was engaged in a continuing project to study the performance of sensory transducers, primarily those used in telemetry. This project has been supported by agencies of the Defense Department and NASA. This report provides a brief description of the background and history of the project, of its objectives, of some of the techniques and specialized facilities developed and used, and of some of the publications that have been issued from the project.

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*)

Dynamic calibration; evaluation; Interagency Transducer Project; performance characteristics; telemetry; transducer

18. AVAILABILITY ☒ Unlimited ☐ For Official Distribution. Do Not Release to NTIS ☒ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003- ☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED 20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	21. NO. OF PRINTED PAGES 45 22. Price

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