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NBS InterAgency Transducer Project

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Paul S. Lederer

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

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For a number of years, the National Bureau of Standards has been engaged in a continuing project to study the performance of 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 specialized facilities developed and used, and of some of the publications that have issued from the project.

KEY WORDS: Transducer, telemetry, InterAgency Transducer Project, dynamic calibration, evaluation, performance characteristics.

Introduction

In missile, rocket, and aircraft flight test instrumentation, the weakest link in the telemetering system is often the 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, fall 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 in 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. Since then sponsorship has been retained by the three remaining organizations; U. S. Navy (Naval Air Systems Command), U. S. Air Force (Electronic Systems Division), and NASA (Office of Advanced Research and Technology).

The project itself, which was started in the Office of Basic Instrumentation of the National Bureau of Standards, was transferred to the Mechanical Instrumentation Section in 1954, and to the Engineering Electronics Section in 1964. In 1965 the project came home again to the Basic Instrumentation Section. During the life of the project its staff has grown in number from two to the present level of six full time professionals.

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 present objectives of the InterAgency Transducer Project may be stated as:

"Investigation of the performance characteristics of electromechanical 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."

Current and Future Work

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

The first area encompasses the precise measurement of changing physical quantities. This necessitates the development of techniques and apparatus for evaluating the dynamic measurement capabilities of transducers in areas where such techniques do not exist or are inadequate.

The second area is 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 requires the development of techniques and apparatus for simulating environments and evaluating their effects on the measurement capabilities of transducers.

The third area deals 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 period of time. Equipment and procedures for "life testing" of transducers and sensors are under development.

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

The fifth area includes 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 work will also 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 projects is based on the needs of the sponsoring agencies and the capabilities of the project staff. Needs are established by consultation with representatives of the sponsors and their contractors. Information as to needs in areas of measurement and calibration is 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 has 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 is desirable to assist the project to achieve 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 co-ordinated 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 clearing house 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.

Participation in SCOTFAST Committee, Instrument Society of America

In 1960, in response to transducer needs expressed by the Aero-Space 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 aero-space 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.

Another staff member of the NBS Transducer Project is currently active on a subcommittee writing a recommended practice on strain gage accelerometers.

In August 1965, the Transducer Committee TWG-IRIG was asked to help in the revision of the "Glossary of Range Terminology" by reviewing the terms pertaining to transducers. This was done on the basis of the ISA RP 37.1 referred to above.

The ISA Tentative Recommended Practices dealing with transducers have been repeatedly called to the attention of the Telemetry Working Group, IRIG, by the Transducer Committee with the recommendation that transducer personnel on the range take advantage of these documents.

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[1]

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 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*.

2. Earth's Field Dynamic Calibrator[2]

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 whose magnitude is well known. The electrical connections to the accelerometer are made through slip rings.

A new version of this device has been completed with improved bearing supports and more constant rotational speed and is shown in Figure 2. These changes are expected to improve accuracy of calibration. This and the previous device have the limitation that the exciting force cannot exceed ± 1*g* and the further limitation that the accelerometer under test must have negligible response to transverse excitation.

3. Dual Centrifuge[3]

The dual centrifuge was developed to generate large amplitudes of acceleration in the frequency range from 0.5 cps 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 ± 1*g* at 1 Hz, increasing to ± 100*g*'s 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[4, 5]

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 rise time 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 section 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[6]

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 rise time 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 conical valve with 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 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 stem 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 rise time 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 rise time 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[5]

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 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, using 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 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 system. All their resonances were found and their amplitudes determined.

9. Thermal Gradient Testing Method[8]

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. Modification of technique and equipment to enable the investigation of the effect of thermal transients on sensitivity is under study.

10. "Life Cycling" Technique for Pressure Transducers[9]

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

Consultation and Visitors

At various times project staff members at NBS have been asked by the Transducer Committee to review critically technical proposals received by TWG members. A number of visitors from TWG member agencies and their contractors have visited the laboratory of the Inter-Agency Transducer Project at the National Bureau of Standards. A much larger number of people have contacted project personnel by telephone to discuss instrumentation problems.

Professional Society and Committee Activities

Project personnel are active in the following organizations:

1.	Transducer Committee	TWG-IRIG
2.	SCOTFAST Committee	Instrument Society of America
3.	Primary Elements Committee	Instrument Society of America
4.	Research Committee on Pressure Technology	American Society of Mechanical Engineers

References and Publications

The following formal publications have resulted from project activities:

1. Lederer, P. S. and Hilten, J. S., "Earth's Field Static Calibrator for Accelerometers." NBS Technical Note #269 (February 1966).

2. Wildhack, W. A. and Smith, R. O., "A Basic Method of Determining the Dynamic Characteristics of Accelerometers by Rotation." Instrument Society of America Paper #54-40-3 (September 1954).

3. Smith, R. O., Willis, E. A., and Hilten, J. S., "A Dual Centrifuge for Generating Low-Frequency Sinusoidal Accelerations." NBS Journal of Research, Vol. 66D, No. 4 (October - December 1962).

4. Schweppe, J. L., et al., "Methods for the Dynamic Calibration of Pressure Transducers." NBS Monograph #67 (December 1963).

5. Lederer, P. S., "Methods for Performance-Testing of Electromechanical Pressure Transducers." NBS Technical Note #411 (February 1967).

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

7. Smith, R. O., "A Liquid Medium Step-Function Pressure Calibrator." ASME, Journal of Basic Engineering Transactions, pp. 723-728 (December 1964).

8. Horn, L., "The Response of Flush Diaphragm Pressure Transducer to Thermal Gradients." Instrument Society of America Paper #13.3-3-65 (October 1965).

9. Lederer, P. S., "'Life Cycling' Test on Several Strain Gage Pressure Transducers." NBS Technical Note #434 (October 1967).

Lederer, P. S., "General Characteristics of Linear Strain Gage Accelerometers used in Telemetry." NBS Technical Note #150 (June 1962).

In addition to the formal publication listed above, results obtained during the course of the project have been reported in detail to the sponsoring agencies. Included among these are 51 descriptions of performance characteristics of a variety of commercially available telemetering transducers.

Future Plans

Within the availability of funds, personnel and time, and subject to revisions based on sponsors' needs, some of the future tasks planned to meet the objectives of the NBS InterAgency Transducer Project are listed below.

1. Improved dynamic calibration for accelerometers.

2. Methods for generating and measuring low level accelerations.

3. Improved pneumatic step function pressure calibrator.

4. Improved liquid medium step function pressure calibrator.

5. Evaluation of differential pressure transducers at various system pressures.

6. Investigation of storage life of transducers.

7. Application of "Fluidics" components to instrumentation.

8. Investigation of thermal gradient effects on sensitivity of pressure transducers.

9. Dynamic calibration of flow meters.

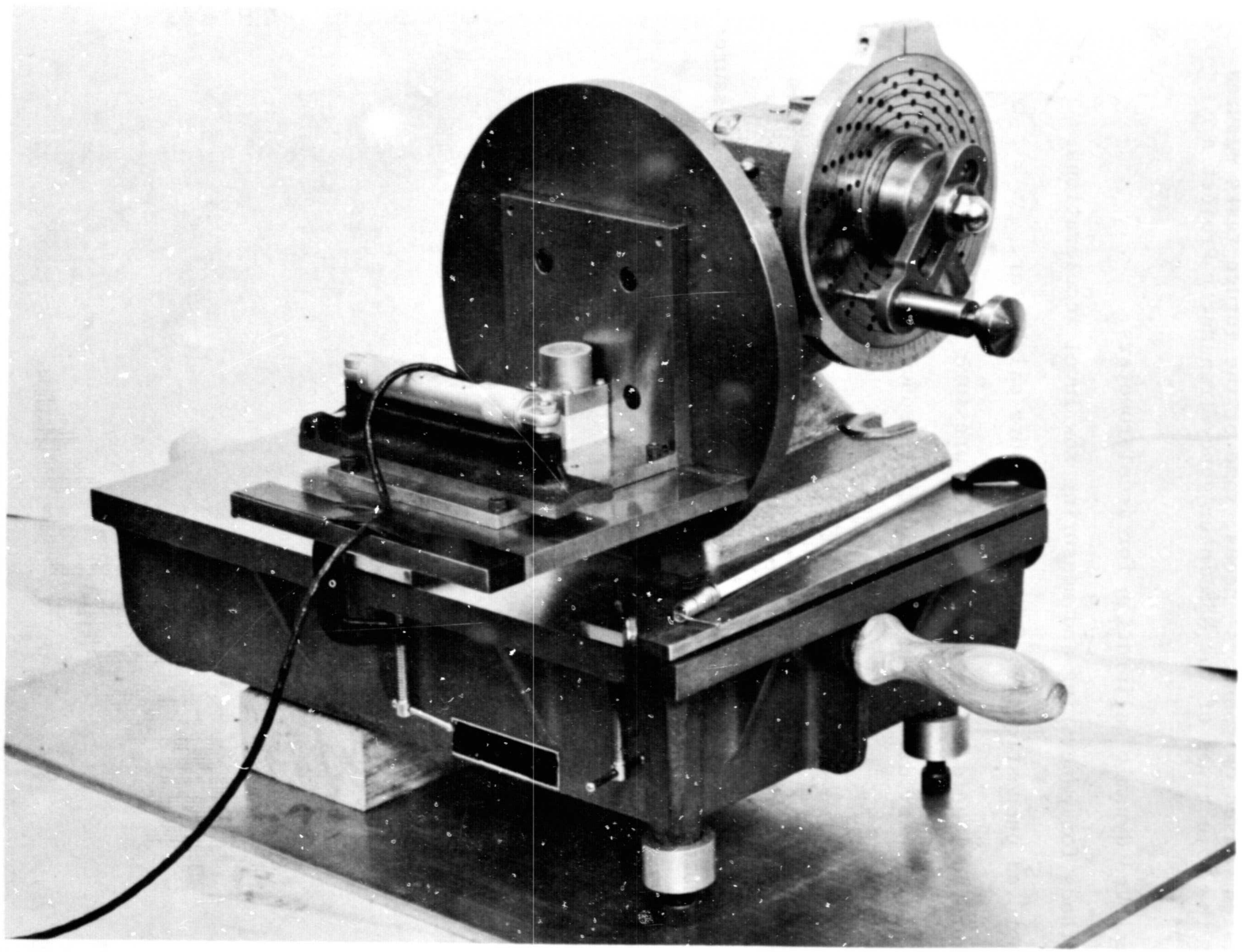

FIG. I EARTH'S FIELD STATIC CALIBRATOR FOR ACCELEROMETERS

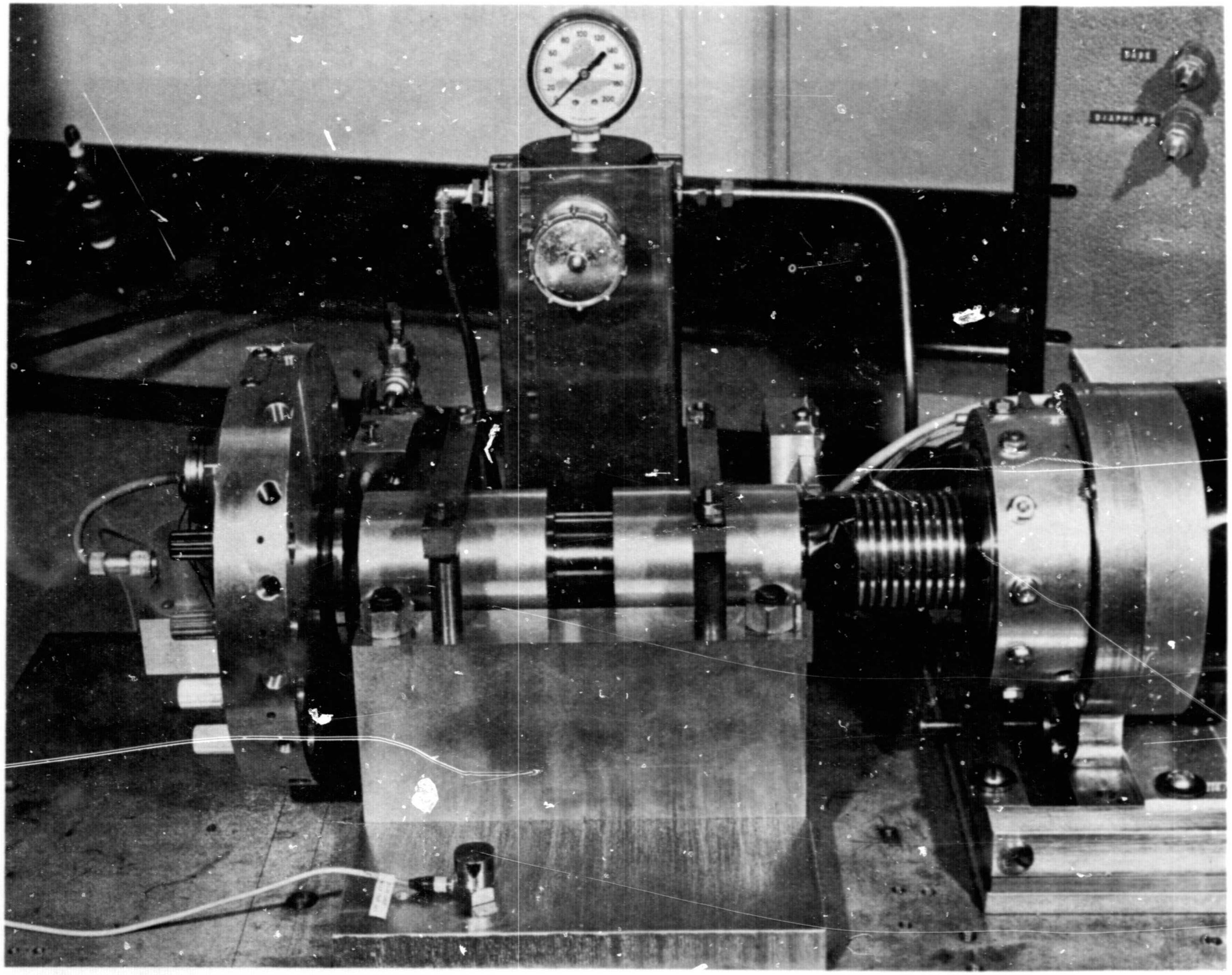

FIG. 2 EARTH'S FIELD DYNAMIC CALIBRATOR FOR ACCELEROMETERS

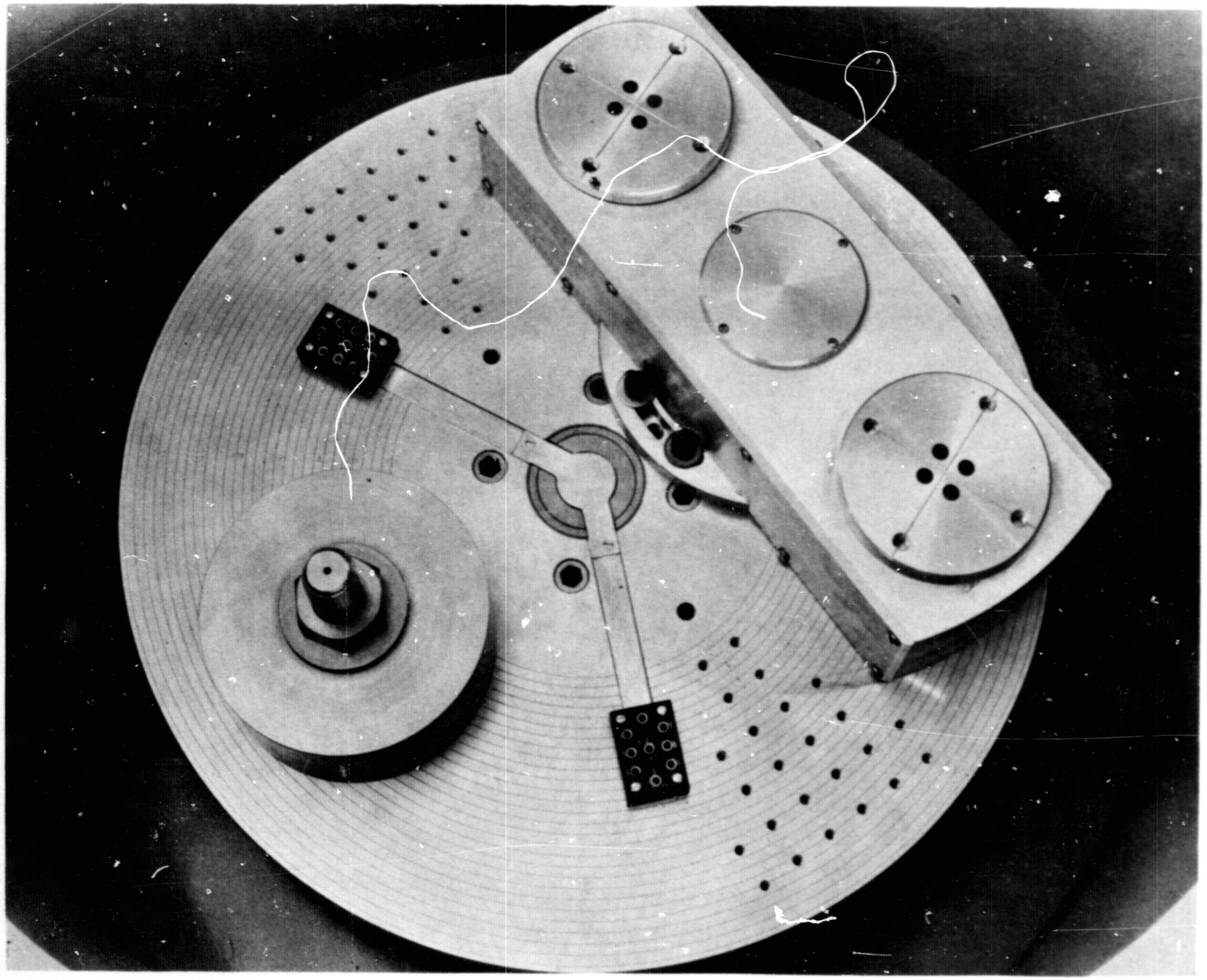

FIG. 3 DUAL CENTRIFUGE

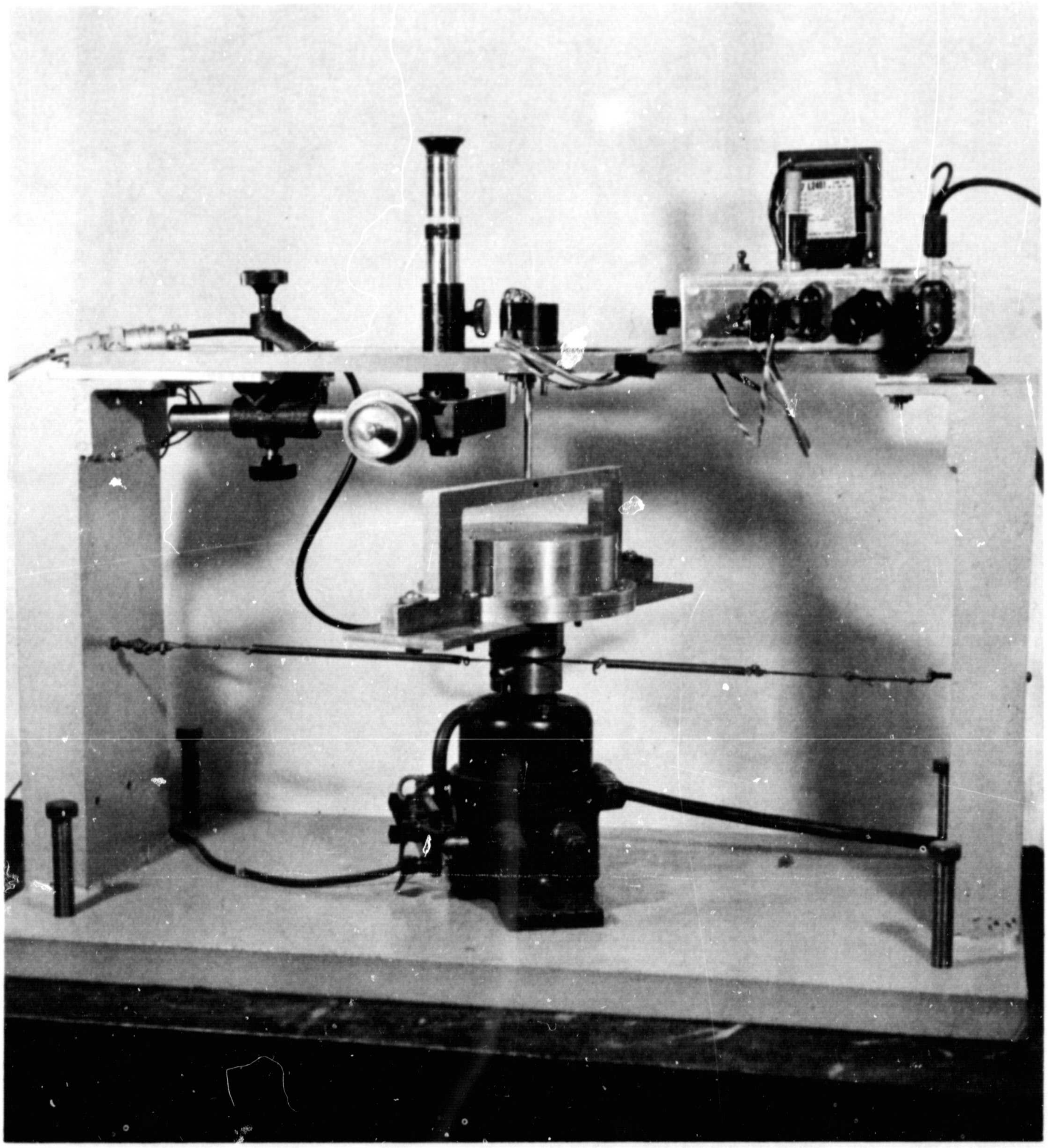

FIG. 4 TORSIONAL VIBRATION CALIBRATOR

FIG. 5 SHOCKTUBE AND ASSOCIATED EQUIPMENT

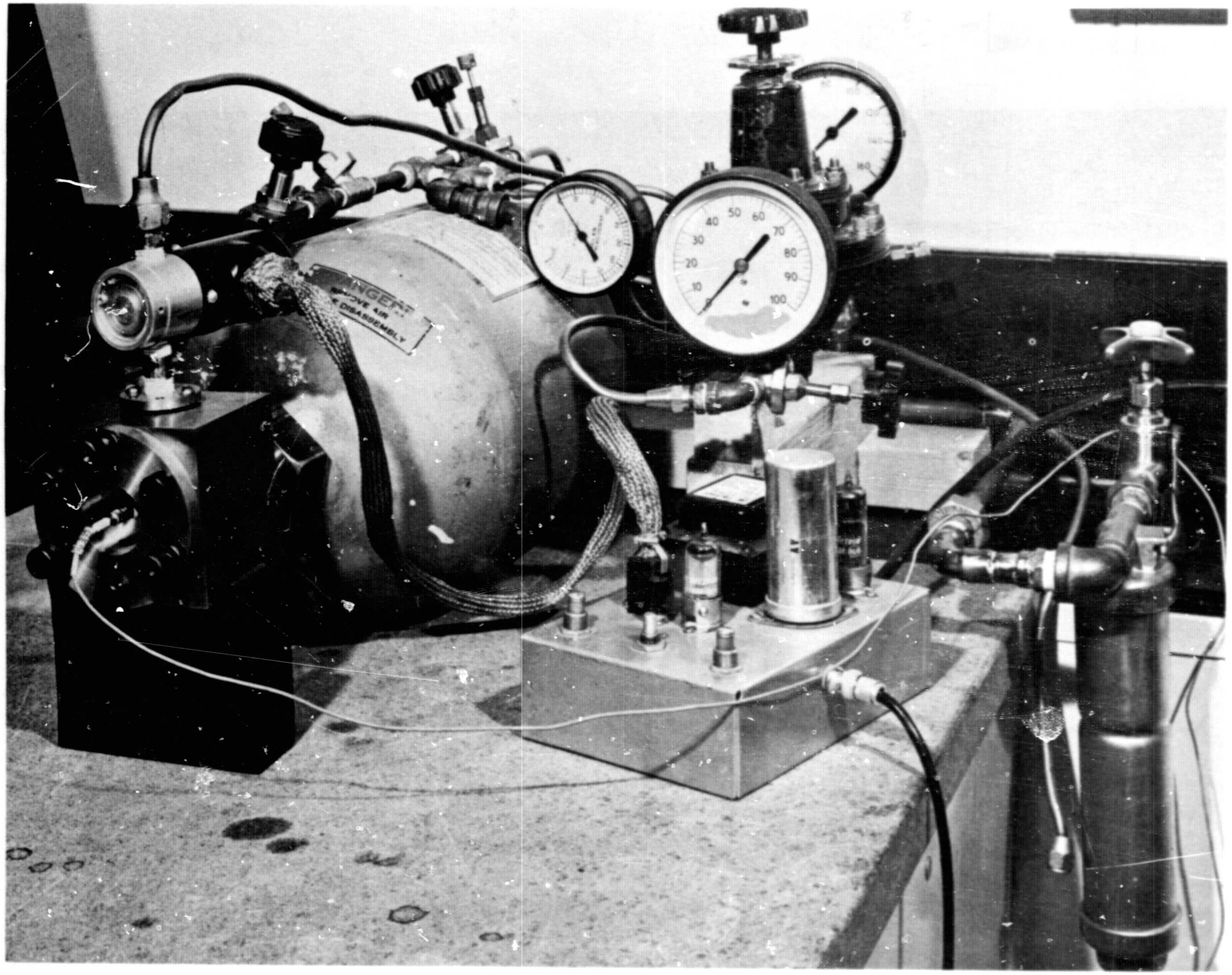

FIG. 6 PNEUMATIC STEPFUNCTION CALIBRATOR

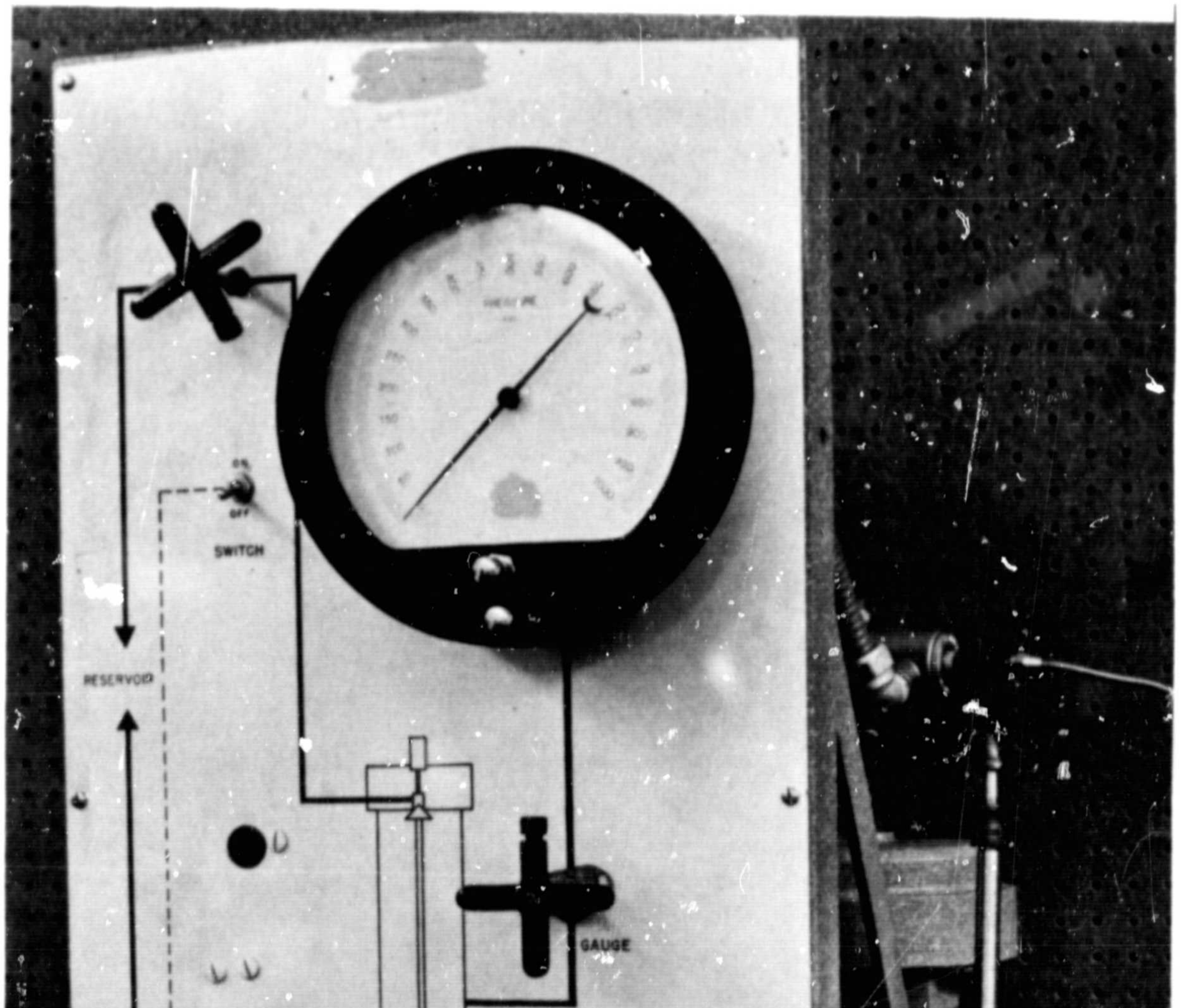

FIG. 7 LIQUID MEDIUM STEPFUNTION CALIBRATOR

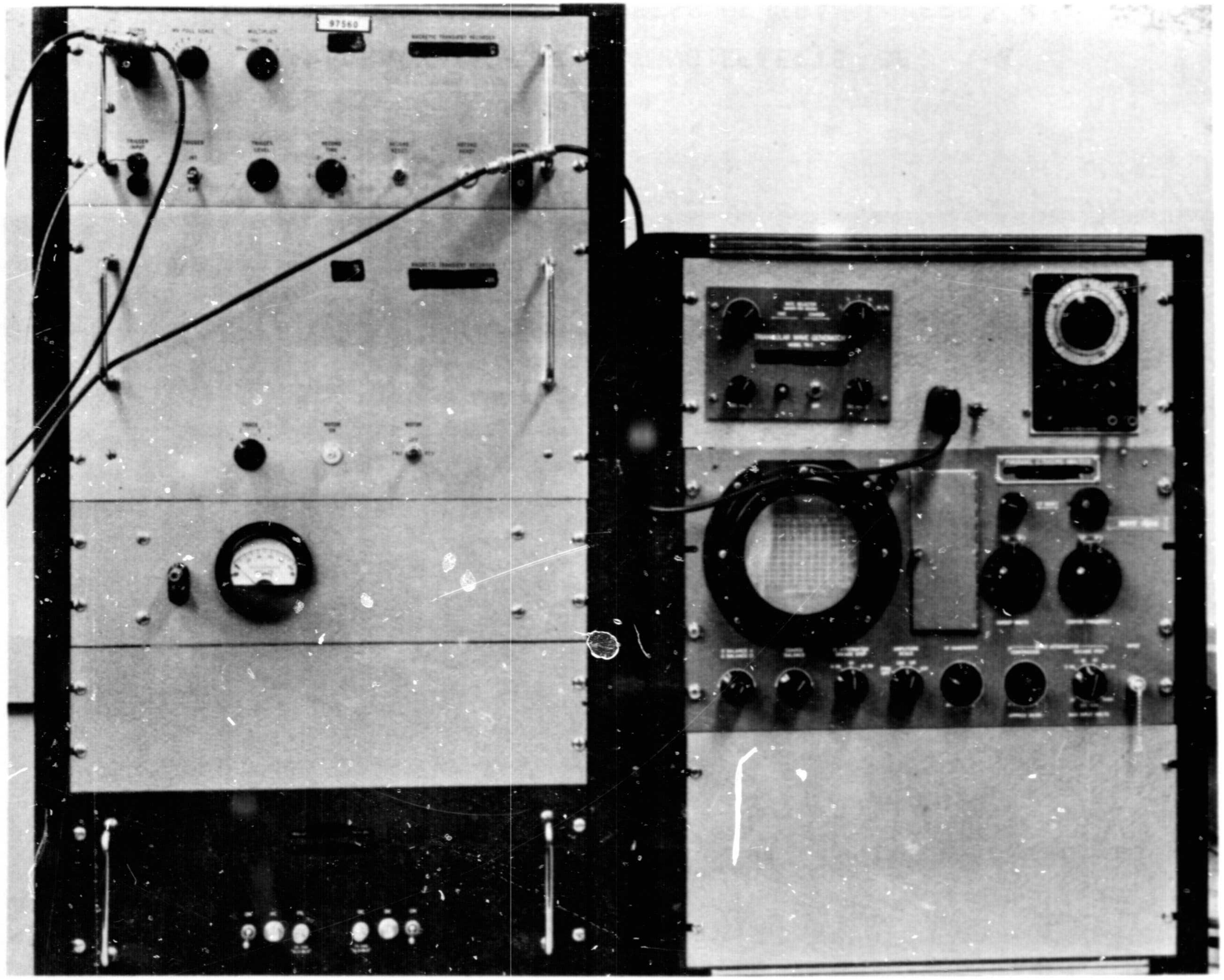

FIG. 8 TRANSIENT RECORDER AND FREQUENCY ANALYZER

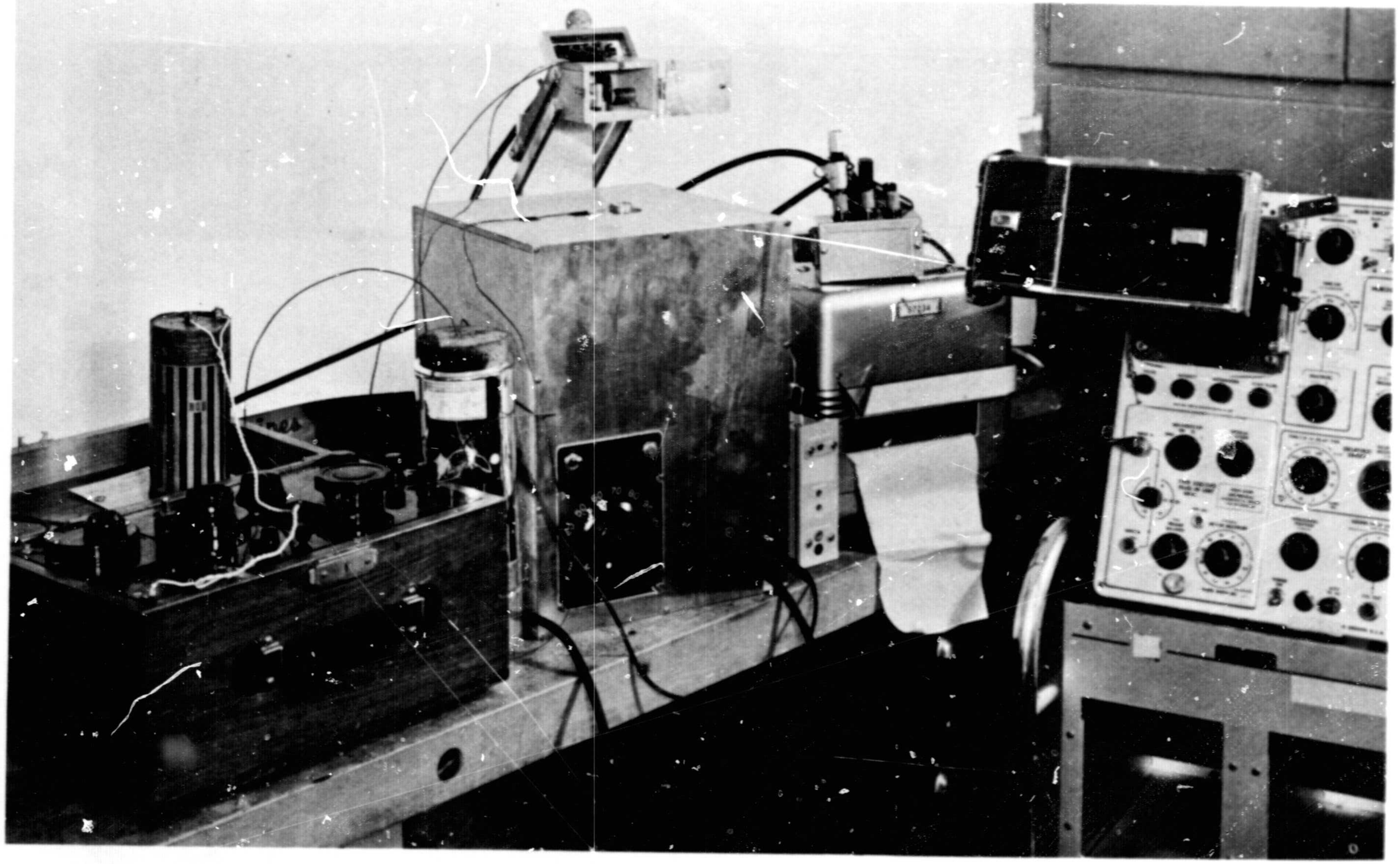

FIG.9 APPARATUS FOR EVALUATING EFFECTS OF THERMAL TRANSIENTS ON PRESSURE TRANSDUCERS

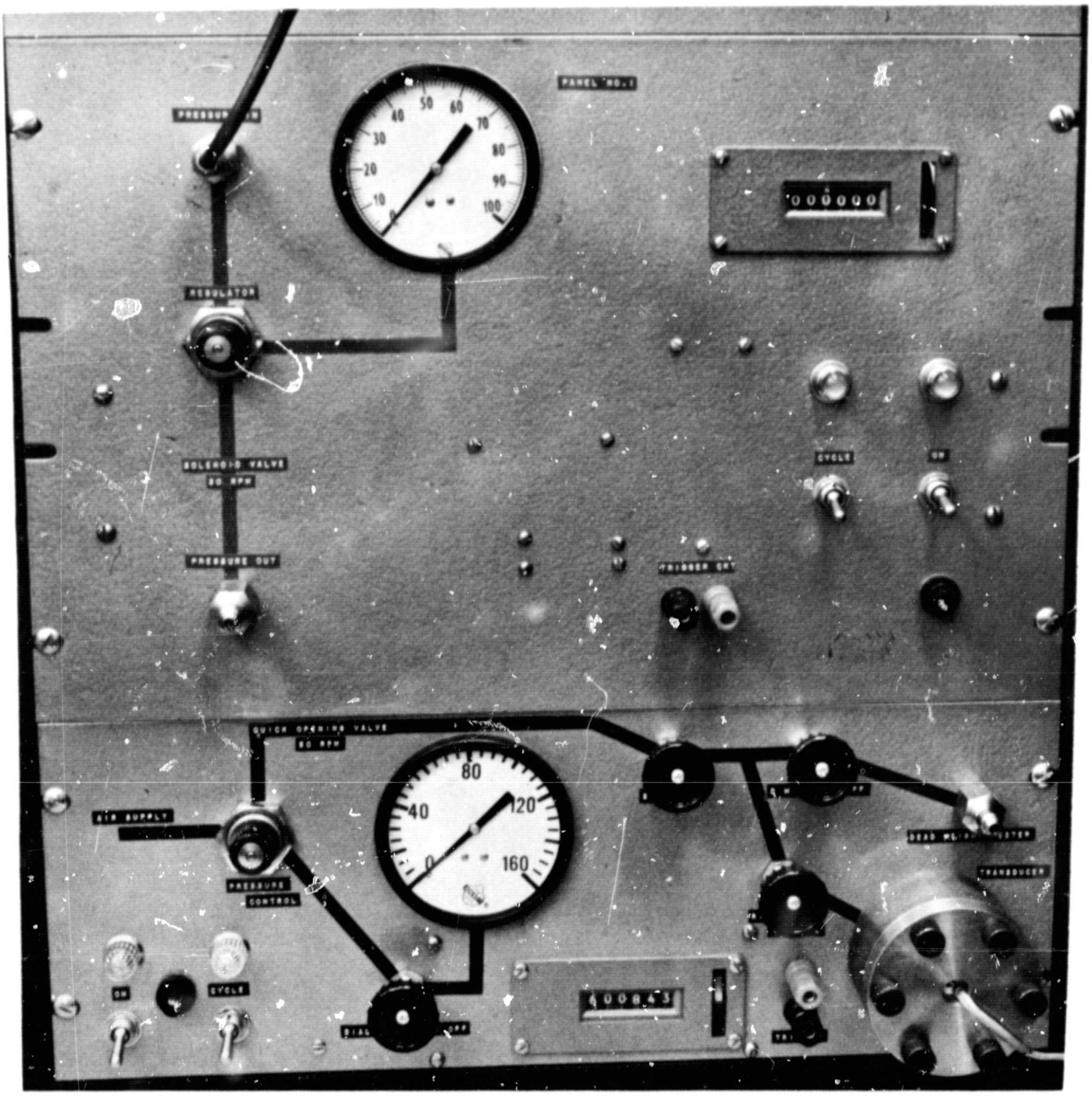

FIG.10 EQUIPMENT FOR "LIFE CYCLING" OF PRESSURE TRANSDUCERS