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A TRANSDUCER FOR THE MEASUREMENT OF SMALL
PRESSURE DIFFERENTIALS ON PARACHUTE CANOPIES

HELMUT G. HEINRICH
and SHUKRY IBRAHIM

DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MINNESOTA

NOVEMBER 1959

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A TRANSDUCER FOR THE MEASUREMENT OF SMALL
PRESSURE DIFFERENTIALS ON PARACHUTE CANOPIES

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and
L. ALBERT SCIPIO

DEPARTMENT OF AERONAUTICAL ENGINEERING
UNIVERSITY OF MINNESOTA

NOVEMBER 1959

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WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by the Department of Aeronautical Engineering of the University of Minnesota in compliance with Air Force Contract No. AF 33(616)-3955.

The work being accomplished under this contract is sponsored jointly by QM Research and Engineering Command, Department of the Army; Bureau of Aeronautics and Bureau of Ordnance, Department of the Navy; and Air Research and Development Command, Department of the Air Force, and is directed by a Tri-Service Steering Committee concerned with Aerodynamic Retardation. Contract administration is conducted by Wright Air Development Center (ARDC) and Mr. Rudi J. Berndt of the Parachute Branch, Aeronautical Accessories Laboratory, Wright Air Development Center, is Project Engineer.

The earlier development and all precision mechanical work was done by Mr. Mikelis Geistauts, Senior Engineer, while the scientific guidance and analysis were performed by Mr. Shukry Ibrahim, Research Associate, in cooperation with Dr. H. G. Heinrich, Professor of Aeronautical Engineering.

Other members of the Department of Aeronautical Engineering who have contributed significantly to the project include:

Professor J. D. Akerman	Director of Rosemount Aeronautical Laboratories, U. of Minn.
Mr. Mihkel Schonberg	Research Laboratory Foreman
Mr. Miles Mock	Senior Laboratory Machinist

and a number of graduate and undergraduate students of the University of Minnesota.

ABSTRACT

→ A ~~pressure transducer~~ ^{le} for the measurement of pressure distribution on parachute canopies in subsonic flow ~~has been~~ ^{was} developed and tested in wind tunnel experiments. The transducer which has a pressure range of 0.5 psi differential is to be fastened to the canopy structure. It employs ~~SP-4~~ ^{le} strain gages ~~manufactured by Baldwin-Lima-Hamilton Corporation,~~ which are bonded to light steel beams. The beams are deflected by the differential pressure by means of a diaphragm. The strain gages are electrically connected in a 4-arm bridge arrangement providing means of compensation for temperature and inertia effects. A suitable method to lead the local pressure to the transducer is proposed.

The transducers originally developed to be used in connection with parachutes may advantageously be applied for other purposes where high sensitivity, high natural frequency, low temperature drift and low dynamic response are required. ~~It~~

PUBLICATION REVIEW

This report has been reviewed and is approved.

For the Commander:

Warren P. Shepardson
WARREN P. SHEPARDSON
Chief, Parachute Branch
Aeronautical Accessories Laboratory

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SECTION 1

INTRODUCTION

The measurement of the pressure distribution of a freely floating parachute made out of porous cloth poses certain difficulties due to the rapid motions which either the entire canopy or portions thereof may perform, and in the past, several attempts of pressure recording did not provide satisfactory information.

Since the pressure distribution is an essential information of advanced analysis of parachute performance, the Armed Forces Steering Committee asked the University of Minnesota to pursue on a promising basis another attempt for the registration of the pressure distribution of a parachute while actually retarding an airborne object or while freely floating in a wind tunnel.

The task was formulated as follows: "Establishment of Reliable Test Methods for Measuring the Pressure Distribution on the Inner and Outer Surfaces of Porous Textile Parachute Canopies."

In view of the known parachute behavior and the stated requirement, a system was chosen as shown in Fig. 1. The characteristic feature of which is that the transducers are fastened to the relatively heavy radial seams and the pressure is fed through relatively short tubes from the point of investigation to the transducer. Electric wires carry then the signal to the recorder.

By means of this arrangement, the interference between the pick up and transducer and the parachute surface is avoided as far as practically possible.

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In connection with this general arrangement, the pressure sensing element must have the following characteristics:

- a) high sensitivity for conversion of small pressure differentials,
- b) minimum weight to avoid interference with the parachute shape,
- c) high natural frequency and low dynamic response in view of the violent motion of the canopy, and
- d) simplicity.

1.1 Survey of Available Transducers

An initial study of commercially available pressure transducers revealed that most transducers are based on one of the following principles:

- a) mechanical strain, measured by electric strain gages
- b) mechanical strain, measured by electric induction
- c) mechanical strain, measured by electric capacitance
- d) mechanical strain, measured by piezo electric phenomena
- e) mechanical strain, converted to electro-osmosis effects

The commercially available transducers are described in References 1 to 13. None of them appeared to combine the required characteristics as outlined above.

Reference 14 describes an interesting application in which an array of capacitive pressure sensing elements is mounted in a flexible blanket to enable the measurement of pressure contours with a relatively high geometric resolution. Unfortunately, these elements do not have the sensitivity required for the present application.

1.2 General Design Considerations

As a result of the survey, it was decided to develop an instrument based on the use of electric strain gages, the mechanical strain to be produced by means of suitable bellows or diaphragms subjected to the pressure differential.

As indicated before, the transducer element, which converts the air pressure differential into electrical signals, shall be fastened to the radial seam carrying the suspension line, and the pressure pick-up on the inner or outer side of the canopy is lead through short flexible tubes into the transducer and the electric leads would run along the suspension lines to the recording instrument.

The first attempt at establishing a method for measuring the pressure distribution on textile parachute canopies was concerned with the operation in the subsonic regime. For possible supersonic experiments, merely some pertinent recommendations are given at the end of the report.

In order to establish the design pressure range for the transducer, the following conditions were selected:

Free Stream Velocity $V = 150$ mph at sea level

Air Density $\rho = .002378$ slugs per cu. ft.

For these conditions; $q = \frac{1}{2}\rho V^2 = .400$ psi.

Reference 15 gives the pressure distribution for a textile (silk) canopy of conventional shape, expressed in the non-dimensional form:

$$\frac{P_1 - P_2}{q} \quad \text{versus} \quad \frac{r}{a}$$

where p_1 = surface pressure on the inner side of the canopy,

p_2 = surface pressure on the outer side of the canopy,

r = radial distance from the axis of symmetry,

a = inflated radius of the canopy.

From Fig. 10 and Table 23 of Reference 15, it is apparent that the value of the differential pressure coefficient $\frac{p_1 - p_2}{q}$ is very close to 1.50 over the full range of $\frac{r}{a}$ values.

Let p_s be the free stream static pressure and let

$\Delta p_1 = p_1 - p_s$ = difference between pressure on inner side
and free stream static pressure

$\Delta p_2 = p_2 - p_s$ = difference between pressure on outer side
and free stream static pressure

Assuming that the pressure on the inner side equals the stagnation pressure then $\Delta p_1 = q$. Therefore: $\frac{p_1 - p_2}{q} = \frac{\Delta p_1 - \Delta p_2}{q} = \frac{q - \Delta p_2}{q} = 1.5$.
Hence $\Delta p_2 = -0.5q$.

Therefore, if the pressure transducer is used to measure the differential pressure between inner and outer sides, the required pressure range would be given by $p_1 - p_2 = 1.5q = 0.60$ psi.

For convenience, the design pressure range was taken as 0.50 psi. The transducer itself is capable of withstanding, without damage, considerably larger pressure differentials.

By using the free stream static pressure instead of the pressure on the inner side as datum pressure, the maximum pressure differences to be sensed by the transducer are reduced by 50%, i.e., $\Delta p_1 = q = 0.4$ psi.

This arrangement would be desirable for speeds greater than 150 mph; the specified pressure range of 0.50 psi would correspond to a speed of nearly 170 mph.

SECTION 2

EARLY DESIGNS AND TEST RESULTS

2.1 Bellows or Diaphragms

In the early stages of this study, it was not known whether bellows or diaphragms would have the best over-all characteristics for the present application. It was, therefore, decided to experiment with both types.

The first design for a pressure transducer with bellows is shown in Fig. 2, and is referred to as type 1. It consists of two chambers, one leading to atmospheric or total pressure and the other to the local pressure. The differential pressure of the two chambers causes, by means of a rubber bellow and a small rod, the deflection of a flat beam to which is cemented a strain gage. The beam is supported at each end between two knife edges. The strain gage deflection is then electrically converted to an indication of the pressure differential.

The first design of a diaphragm type sensing element is also shown in Fig. 2 as type 2. It consists of two chambers, one leading to atmospheric or total pressure and the other vented to the test pressure. The pressure differential across the diaphragm creates a force which is transmitted to a beam with attached strain gage and the electric signal is a measure of the pressure difference.

2.2 Sensitivity and Linearity Tests

Two models of bellow type sensing elements were made and tested.

The results are presented in Fig. 3 which indicates that both models did not have the desired linearity of strain versus differential pressure. Special bellows made of .004 in. thick playtex rubber were used on these models after the available metal bellows were tried and found to lack the desired sensitivity.

Three versions of the diaphragm type transducers were originally made each with a different diaphragm material. The first diaphragm consisted of a fine stainless steel mesh disc coated with latex rubber, the second was a .001" thick brass disc while the third was a plain rubber disc. The test results are given in Fig. 3. These tests showed that the plain rubber diaphragm (diaphragm design No. 3) was the only type with satisfactory linearity.

For these tests a Baldwin SR-4 Type L Strain Indicator was used for indicating the transducer output.

2.3 Vibration Tests

In order to check the response to external vibration both types of pressure transducers were subjected to vibration tests in such a way that the amplitude of the vibrations were either parallel or perpendicular to the surface of the membrane. These initial tests showed the superiority of the diaphragm type of sensing element and this type was then selected for further development in view of its good linearity and adequate sensitivity.

The results of vibration tests carried on the transducer shown in Figs. 4 and 5 are given in Fig. 6 (A to F) for parallel vibration in the

frequency range 0 - 700 cycles per second and in Fig. 7 (A and B) for perpendicular vibration in the frequency range 0 - 100 cycles per second.

2.4. Drift Tests

So far all pressure calibrations had been carried out by means of simple water column, at constant ambient temperature and without exposing the transducer to any airflow. For further development it was decided to test the transducers under more realistic conditions, and four transducers, type 3, illustrated in Fig. 5, were mounted to a metal parachute model as shown in Fig. 8 and tested in the subsonic wind tunnel of the University of Minnesota.

These tests indicated that the relatively thin plexiglass cases were not rigid enough and as the most significant result it was found that all instruments had a marked drift of the zero position with respect to time when exposed to constant or varying air velocity.

The drift was traced to several causes, the most important being the change of ambient temperature, the changed rate of heat exchange between the transducer and the airflow, and the changed pressure distribution on the transducer casing.

After stopping the flow, the instrument returned to zero very slowly and the time lag before a return to zero was of the order of 10 minutes or longer.

Attempts were made to reduce the drift by using stiff metal cases, by modifying the pressure connections and by employing different materials for the case and strain gage beam. Invar and magnesium were tried for

the transducer case while stainless steel and invar were used for the strained beam. The use of invar with its extremely low expansion coefficient was aimed at reducing temperature expansion problems while magnesium was tried for the case because of its very favorable strength/weight ratio and thermal conductivity properties.

Five gages were made as follows:

- a) Three had magnesium cases and stainless steel beams
- b) One had a magnesium case and an invar beam
- c) One had an invar case and an invar beam

All five gages were provided with light magnesium holders for mounting on parachutes. Fig. 9 illustrates this version of the transducer type 4 and mounting bracket.

The five transducers were mounted on the same parachute model and tested in the wind tunnel with speeds of up to 100 feet per second. In addition, one of the transducers was fastened to a panel of parachute cloth and that panel was placed in the wind tunnel test section. The instruments appeared to withstand the flapping and flutter satisfactorily but all transducers showed again the undesirable zero drift. The order of magnitude of this drift was the same as the deflection due to the full pressure range and therefore completely unacceptable.

SECTION 3

LATER DESIGNS

When all attempts to reduce the drift by changing the heat capacity or the heat transfer characteristics of the transducer by introducing dimensional or material changes or by thermal insulation of the case resulted in only very minor improvements, a complete redesign of the transducer was undertaken with special emphasis on the drift problem.

3.1 Compensation for Temperature Effects

In order to achieve temperature compensation, two identical strain gage beams (one active and one compensating) were used. Both beams were mounted in identical fashion and subjected to the same temperature conditions, thereby neutralizing any temperature effects in the bridge circuit. Fig. 9-A illustrates the mechanical arrangement and Fig. 9-B the corresponding wiring diagram.

3.2 Compensation For Inertia Effects

In order to obtain compensation for inertia effects, an additional or "dummy" diaphragm was incorporated in the design as shown in Fig. 9-A. The dummy diaphragm acts on the compensating beam while the main diaphragm operates on the active beam. The compensating beam plus dummy diaphragm tends to duplicate the inertia and damping characteristics of the active beam plus main diaphragm and the two effects are in opposition in the

bridge circuit. Of course the dummy diaphragm is provided with holes to prevent pressure differentials across it. Fig. 10 gives the dimensions and general arrangement of the main and dummy diaphragms.

3.3 Isolation of Pressure Sensing Element From the Casing

In order to ensure relatively good isolation (both thermal and mechanical) of the pressure sensitive elements from the case, the active and compensating beams and the dummy diaphragm were mounted in a system of tapered rings out of invar material with flexible rubber rings and tightening screws (Fig. 10-A) to provide the desired fixity for the beam ends. This adjustment is carried out in the initial calibration and the screw heads are then permanently sealed off.

Since the pressure measuring elements were now relatively isolated from the case, the material used for the case did not appear to be as critical a feature as before. Flexiglass was used again at this stage because of its light weight, electrical insulation and transparency advantages.

Two identical transducers incorporating the principles mentioned above were made. Tests conclusively showed the effectiveness of the principles of separate compensation and of mechanical and thermal isolation. However, for a given size of beam and diaphragm, the sensitivity was reduced to about one half the value in the earlier design; a relatively small drift persisted and this drift appeared to be associated with the inherent unsymmetry of the two-arm bridge arrangement.

3.4 4-Arm Bridge Arrangement

In order to double the sensitivity and reduce the residual drift, a four-arm bridge arrangement was tried with the two active beams operating first in unison and then in opposition. It was found that the unison beam arrangement resulted in more effective compensation of the residual drifts, and this configuration has been retained for future designs.

3.5 Improved Diaphragm

Efforts were then directed toward the improvement of the diaphragm. A circular rubber diaphragm had been used but tests proved that using an annular rubber ring type of diaphragm would be more advantageous. The final result consists of a circular aluminum plate which is cemented to a rubber disc (dimensions may be seen in Fig. 11).

The use of the four-arm bridge circuit occasioned a need for either small strain gages or larger beams. Consequently, type A-18 strain gages were used. Fig. 12-A shows the internal arrangement of the transducer employing four type A-18 strain gages and Fig. 12-B gives the corresponding wiring diagram.

3.6 General Design Parameters

Referring to Fig. 13, the force F due to the differential pressure on the main diaphragm is applied at the mid-point of the strain gage beam of effective length l , width w and height h .

Assuming the beam to be simply supported, the stress at the mid-point due to P is given by:

$$\sigma = \frac{My}{I}$$

Where M is the bending moment, y is the distance from the Neutral Axis and I is the Moment of Inertia.

The maximum stress is given by: $\sigma_{\max} = \frac{Pl}{2} \cdot \frac{h}{2} \cdot \frac{12}{wh^3} = \frac{3Pl}{wh^2}$

Therefore, the maximum strain and hence the resistance change of the strain gage will be proportional to the differential pressure, and to the effective length of the beam and inversely proportional to the beam width and the square of its thickness.

The diaphragm area, beam length and width are determined by the physical dimensions of the transducer and of the smallest available strain gages. The desired sensitivity may be obtained by varying the beam thickness. Very thin beams (0.003 in. thick) show relatively greater tendency to drift and a stainless steel beam 0.009 in. thick was found to give a good compromise between sensitivity and drift.

TEST EQUIPMENT AND TEST RESULTS

4.1 Recording Equipment

A Century carrier amplifier and recording system comprising the following components was used for these tests:

- a) Century Model 408 Recording Oscillograph
- b) Century Model 507 Amplifier
- c) Century Model 808 Power Supply
- d) Century Type 850 Galvanometer

The following settings were used for all tests:

Bridge Excitation: 5 volts

Gain Multiplier Setting: 1

4.2 Pressure Measuring Equipment

A micromanometer (Meriam Model A-750) was used for all further pressure calibrations. This micromanometer uses Silicone 200 (Sp-Grav = 0.82 at 20°C) as the liquid column and has a maximum range of 10 inches. It is designed to read pressures to 0.001 in. of the liquid column.

4.3 Test Results4.3.1 Sensitivity and Linearity Tests

The sensitivity will be defined as the galvanometer deflection for a specified pressure differential.

The linearity is defined here as the maximum difference

between the experimental calibration curve taken on increasing readings and the most favorable straight line. Fig. 16 shows the results obtained. The sensitivity was 0.221 in/in of water. The maximum linearity error in the range 0 - 10 inches of H₂O pressure was 0.02 in. of galvanometer deflection.

4.3.2. Slipstream Drift Test

The transducer, with its two chambers interconnected to equalize the pressure on both sides of the diaphragm, was placed in a wind tunnel test section and its response was noted for different flow conditions such as starting and stopping of the flow, change of air speed, etc. The results for this test are given in Fig. 17 A and B. The maximum zero drift for the airspeed range 0 - 120 mph was 0.05 in. in the recording with settings described above.

4.3.3 Ambient Temperature Drift Test

The transducer was placed in a small thermostatically controlled electric oven with its two chambers interconnected as before and the drift was recorded over the desired temperature range from 80°F to 120°F.

The results of temperature drift tests showed a relatively wide scatter among transducers of the same configuration. For the gage described, the best value for the average temperature drift was 0.0018 in/°F in the specified range, and this drift appears to be acceptable.

4.3.4 Response to External Vibration

The transducers were fastened to a mechanical vibrator and

given both transverse and axial vibrations in a range of 0 - 630 cps. Results of a series of vibration tests on this sensing element may be seen in Fig. 18 for transverse vibrations and Fig. 19 for axial vibrations. Both responses appear to be acceptable.

4.3.5 Response to Fluctuating Pressure

In order to examine the frequency response characteristics of the transducer when subjected to a fluctuating pressure, a special apparatus was set up consisting of a variable speed motor driving a cam over a flexible tube connected to one of the transducer chambers. This produced pressure pulsations which could be varied between 15 and 4000 cycles per minute. The transducer response was recorded on the Century oscillograph. A record of a series of dynamic pressure tests is given in Fig. 20.

By subjecting the transducer simultaneously to an external vibration and an internal pressure fluctuation, conditions closely resembling those of flutter or flapping of the parachute canopy could also be simulated and studied. Results of these tests are given in Fig. 21 (pressure fluctuation combined with transverse vibration) and Fig. 22 (pressure fluctuation combined with axial vibration). Summarizing the results of the temperature drift, the mechanical vibration and the combined vibration and pressure fluctuation tests, it may be stated that none of these environmental conditions induced an effect which would invalidate the usefulness of the transducer.

SECTION 5

FURTHER MODIFICATIONS AND IMPROVEMENTS

Attention was then directed to the problem of mounting the pressure transducer on the parachute canopy, providing convenient and rugged electrical connection between the transducer and the recording equipment and finding an effective method of pick up of the pressure from the inner and outer surface of the canopy to the transducer.

5.1 Electrical Terminal Connections

Soldered connections to the four transducer terminals had been adopted in the experimental models. These were discarded in favor of a four-pin socket and plug arrangement which provides a quicker and better electrical connection capable of withstanding severe vibration and flutter.

5.2 Transducer Case Material

The Plexiglass transducer case was replaced by a laminated phenolic base material available under the trade name of "Consoweld." This material has better dimensional stability, greater mechanical strength, good machining properties and temperature resistance. Fig. 23 illustrates the general arrangement and detailed dimensions of the final version of the transducer incorporating the four-pin terminals and Consoweld case. Fig. 24 is an exploded view of the transducer listing the main parts.

5.3 Mounting Bracket

For mounting the transducer on the radial seam of the parachute canopy close to the desired pick-up point, a simple mounting bracket made of a plexiglass base and light metal clamp was designed; its dimensions are given in Fig. 25.

Figs. 26 and 27 are two photographs of the transducer and mounting bracket.

The pressure transducer with its bracket was mounted on a parachute model and tested in the subsonic wind tunnel.

It successfully withstood repeated opening shock loads and accelerations without apparent damage to the internal mechanism or external connections.

5.4 Method of Pressure Pick-up

An effective method of pressure pick-up was devised and tested. As indicated in Section 1, it consists in attaching the mounting bracket on a radial seam of the canopy close to the desired pick-up point and using a short piece of flexible plastic tubing connected at one end to one of the pressure leads of the transducer and cemented at the other to the textile canopy at the pressure pick-up point by means of a two component, rubber base cement known as Fuller Resiweld Adhesive Number 2. This cement is described in the Fuller Technical Bulletin RTB-13A. After the tubing has been cemented to the back face of the canopy, a pressure pick-up hole is pricked on the other face of the textile surface by means of a heated needle point.

(wing to the low airspeeds obtainable in the return circuit of the tunnel where tests on textile parachute models are possible, the maximum pressure range is only about 1/10 the specified range of the transducer; under such severe limitations, the sensitivity is too low for quantitative pressure distribution tests on parachute canopies, and more extensive experimental work is recommended.

SECTION 6

FINAL CALIBRATIONS AND TYPICAL CALIBRATION RESULTS

Five pressure transducers of the type illustrated in Fig. 26 were built and calibrated prior to delivery to the Procuring Agency. They were subjected to the different types of tests described earlier. In the course of this calibration, considerable difficulties were experienced, which, however, were not due to the transducers themselves but to the calibrating equipment.

After eliminating instrument errors and inaccuracies, reliable calibrations for all transducers were established. They provided the transducer output in microvolts per psi differential pressure per volt. A sample and summary table is given below.

6.1 Final Calibration Equipment

In order to avoid calibration errors resulting from incorrect amplification factors or fluctuations of the power supply, a Leeds & Northrup Precision Millivoltmeter was substituted for the Century Amplifier system for measurement of the transducer output. Bridge excitation was provided by a battery and the DC excitation voltage was accurately adjusted to 5 volts.

The use of this system made it also possible to determine the initial bridge unbalance.

6.2. Typical Calibration Results


Fig. 28 illustrates a typical Transducer Calibration Curve. From the experimental points a best fitting straight line was obtained from which the following characteristics could be calculated:

Sensitivity in microvolts full scale

Calibration Factor in microvolts per psi per volt excitation

Maximum deviation in per cent of full scale

The temperature drift, measured as a zero shift with changes of the ambient temperature between 80° and 120° F. was measured; this drift depends to a certain extent on the rate of change of the ambient temperature and the tests correspond to a rate of 3° to 4° F. per minute. For tests of short duration, i.e., one or two minutes, the zero shift is considerably smaller.

Fig. 29 illustrates the standard arrangement of the transducer terminals and the corresponding  diagram.

Appendix I is a typical Pressure Transducer Data Sheet.

A Calibration Curve, Data Sheet and Circuit Diagram as shown in Figs. 28, 29 and Appendix I were attached to each one of the five transducers submitted to the procuring agency.

The following table summarizes their performance characteristics:

Transducer No.	1	2	3	4	5
Sensitivity (microvolts full scale)	1263	1155	1268	1268	1202
Calibration Factor (microvolts per psi per volt)	498.5	460.0	507.3	499.9	483.2
Maximum Deviation (% full scale)	+ 2.375 - 1.818	1.731 .866	.630 .945	.394 1.261	.250 .750
Temperature Drift (% full scale/°F)	.082	.033	.131	.112	.036

Wind tunnel experiments indicated satisfactory over-all operation but owing to the low airspeeds obtainable, the maximum pressure range was only about 1/10 the specified range of the transducer and consequently the sensitivity was too low for quantitative pressure distribution tests. Therefore, after evaluation of the five pressure transducers by the Procuring Agency under the full pressure range, it will be possible to determine whether or not further modifications need be introduced to the transducer, its mounting or the method of pressure pick-up.

SECTION 7

RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Originally, the application of pressure transducers for the study of pressure distribution on parachute canopies was arranged into one study concerned with an instrument for:

- a) Subsonic parachutes, and
- b) Supersonic parachutes.

The present transducer is designed for use at subsonic speeds. It may also provide the basis of the design to be used in the supersonic regime but a number of design modifications and further development might be required. In particular it would be necessary to increase the natural frequency, attempt to reduce the size and weight, modify the method of fastening, and review the required sensitivity.

It is also felt that the temperature drift may be greatly reduced and the operating temperature range very sensibly extended by introducing constant input voltage type of span compensation with a temperature sensitive resistor placed in series with each input lead.

A development along these lines appears to be promising but it would exceed the scope of the original task.

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1. Hathaway Instrument Company, 1315 South Clarkson Street, Denver 10, Colorado
2. Statham Scientific Instruments, Los Angeles, California
3. Sierra Pressure-Cell Instruments, 778 El Camino Real, San Carlos, California
4. Dynamic Instrument Company, Inc., 28 Carleton Street, Cambridge 42, Massachusetts
5. Byron Jacksons Company, Los Angeles 54, California
6. Bourns Laboratories, 6135 Magnolia Avenue, Los Angeles, California
7. Consolidated Electrodynamics Corporation, 300 North Sierra Villa, Pasadena, California
8. Trans-Sonic, Inc., Bedford, Massachusetts
9. Superior Tube Company, Morristown, Pennsylvania
10. F. D. Werner, R. L. Geronime and R. E. Keppel, Development of an accurate, rugged miniaturized pressure gage readily adapted to digital output, University of Minnesota Research Report No. 108
11. The Beta Corporation, Instruments and Control Devices, Forest Avenue, Richmond 26, Virginia
12. John L. Matterson, A Miniature Electrical Pressure Gage Utilizing A Stretched Flat Diaphragm, NACA TN 2659, 1952
13. Y. T. Li, High Frequency Pressure Indicators for Aerodynamics Problems, NACA TN 3042, 1953
14. W. E. Frank and R. J. Gibson, Development of an Apparatus for Measuring Load Patterns of a Soldier on the Ground, The Franklin Institute, Final Report F-2321
15. R. Jones, On the Aerodynamic Characteristics of Parachutes, Aeronautical Research Committee, Reports and Memoranda, No. 862 (Ae 101), published by Her Majesty's Stationary Office, London

APPENDIX I

PRESSURE TRANSDUCER DATA SHEET

Serial Number: 5Model: Special design for pressure measurements on parachute canopies
(Project No. 3, WADC Contract No. AF 33(616)-3955)Pressure Range: + .5 psidElectrical Configuration: 4-arm Wheatstone Bridge
Each arm consists of an A-18, 120 ohms, SR -4 strain gage elementTerminals: Input : 1 & 4 Green & Red
(Fig. 1) Output : 2 & 3 Black & WhiteExcitation: 5 volts D.C. or A.C. RMSSensitivity:* 1,202 Microvolts full scaleCalibration Factor:* 483.2 microvolts per psi per volt excitationLinearity:* maximum deviation: + .250% full scale
- .760% full scaleZero Shift with Temperature:** .036% full scale/°F
(Temp. Range: 80-120°F)

* The Sensitivity, Calibration Factor and Linearity were calculated from the experimental calibration curves (Fig. 2). Two curves were plotted for each transducer and a mean value was calculated.

** The zero shift depends on the rate of change of the ambient temperature. The values given correspond to a rate of 3 to 4°F per minute. For tests of short duration i.e. one or two minutes the zero shift is considerably smaller.

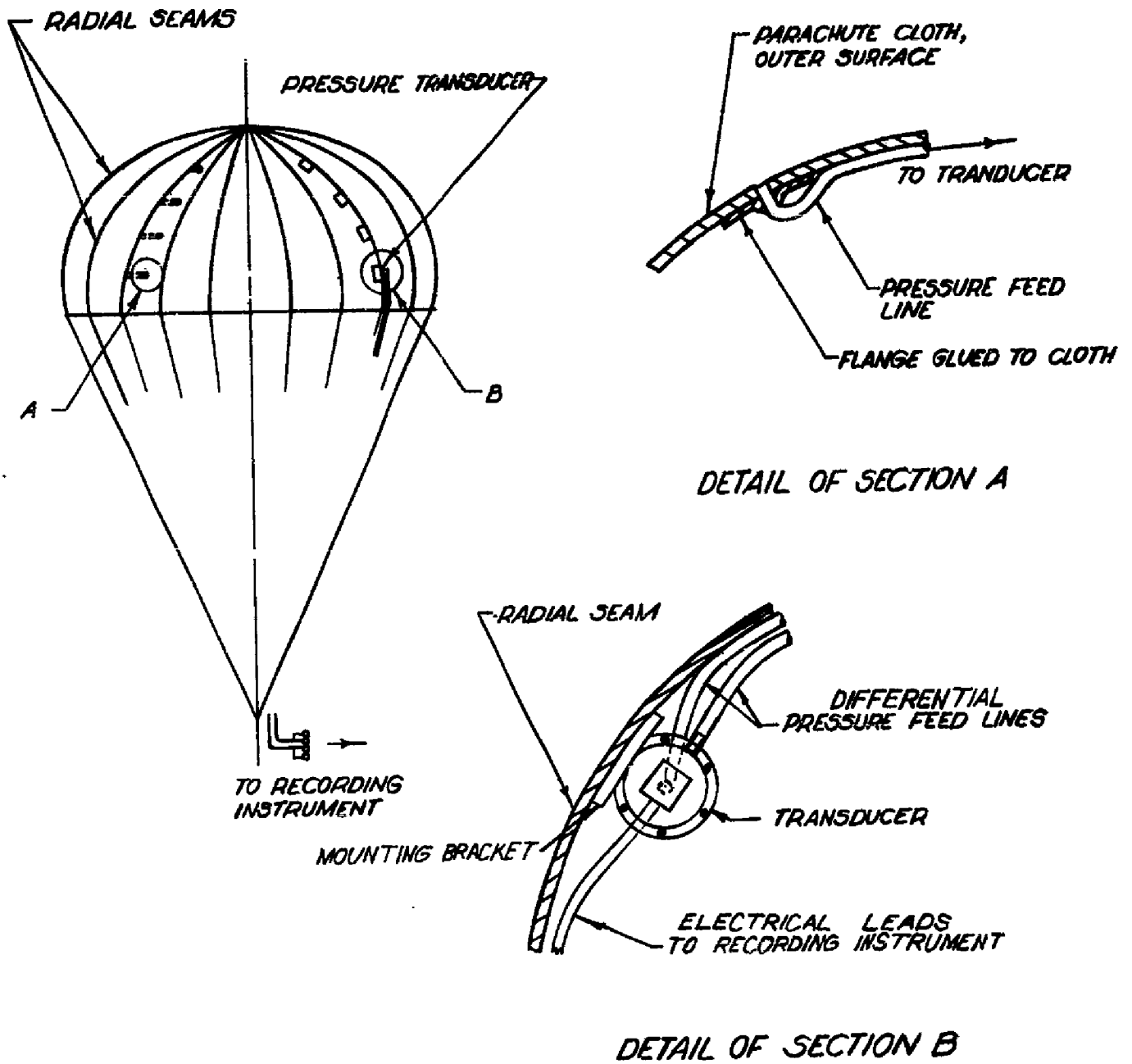


FIG. 1 SCHEME OF PRESSURE PICK-UP AND TRANSFORMATION TO ELECTRICAL SIGNAL

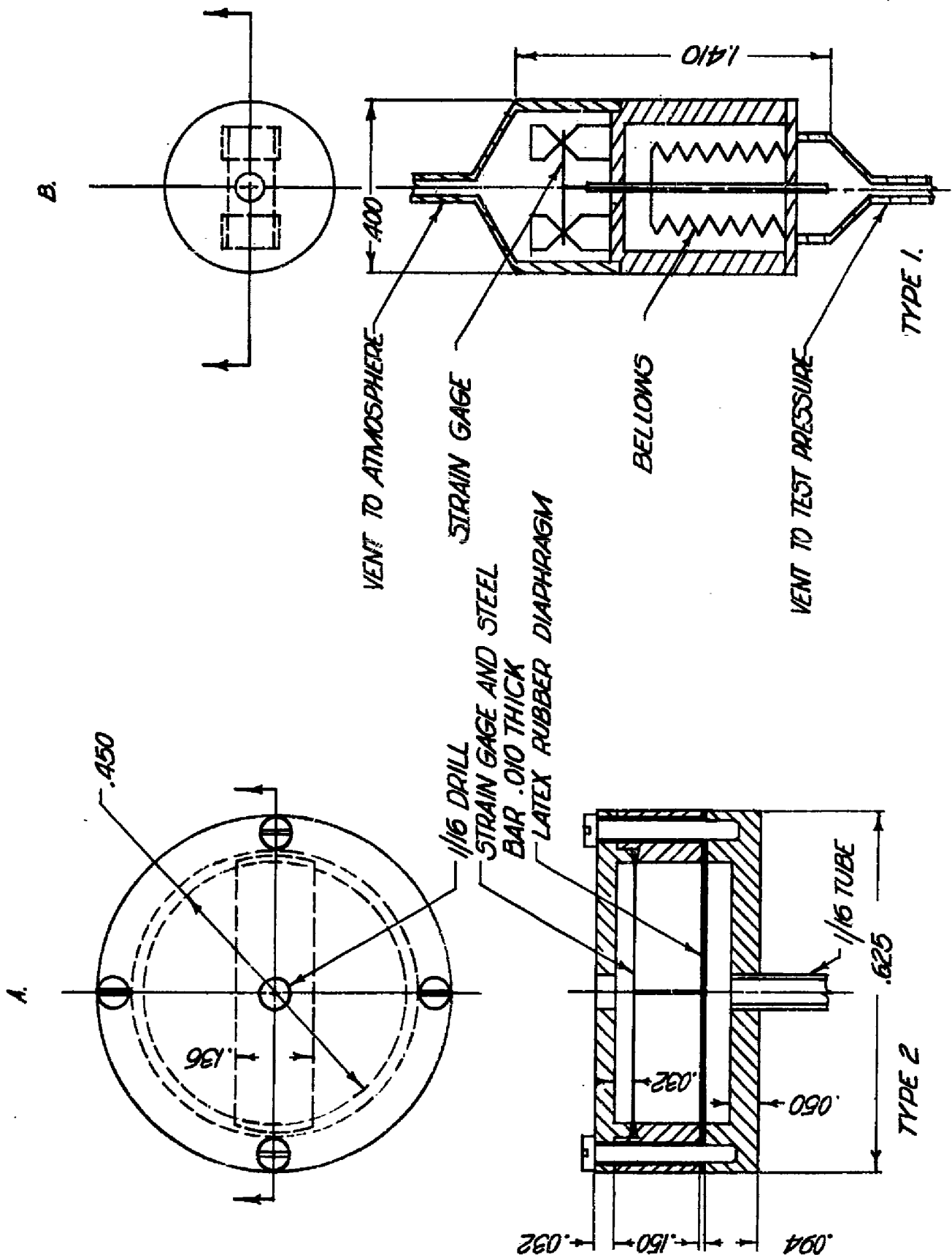


FIG. 2 PRESSURE TRANSDUCER

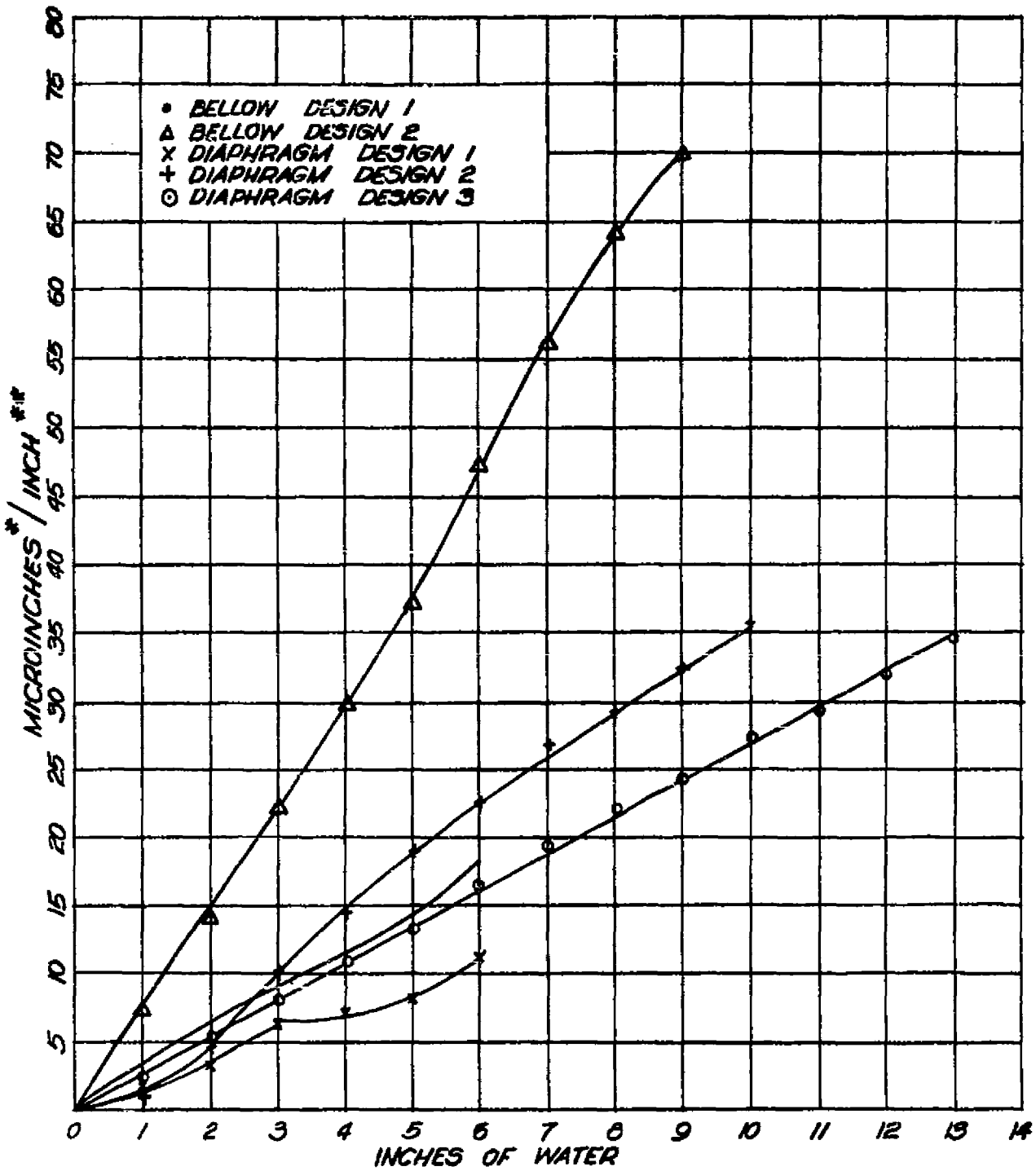
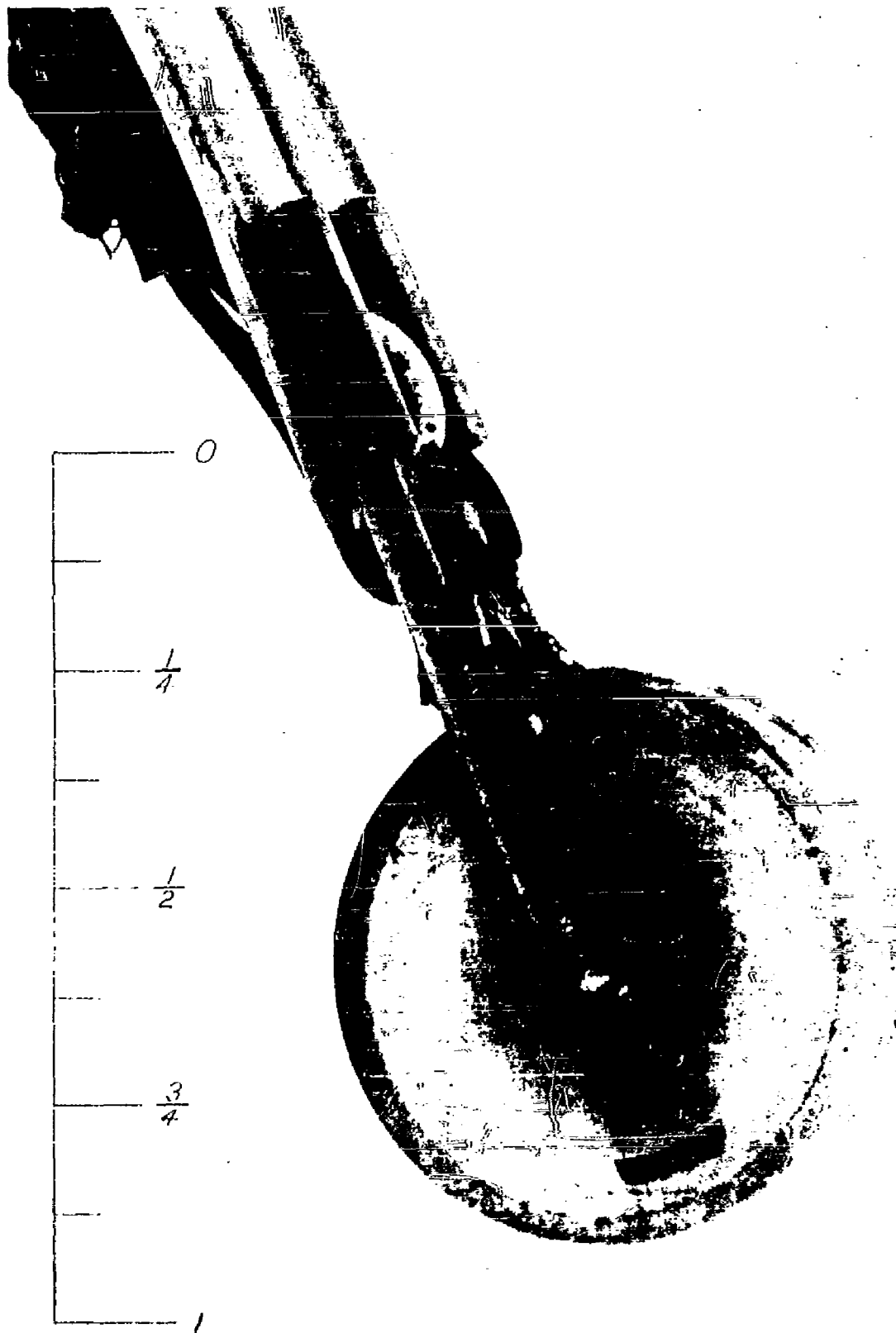


FIG. 3 DEFLECTION VERSUS DIFFERENTIAL PRESSURE OF VARIOUS DESIGNS

* BEAM DEFLECTION
 ** BEAM LENGTH



SCALE - INCHES

FIG. 4 DIAPHRAGM PRESSURE TRANSDUCER (TYPE 3)

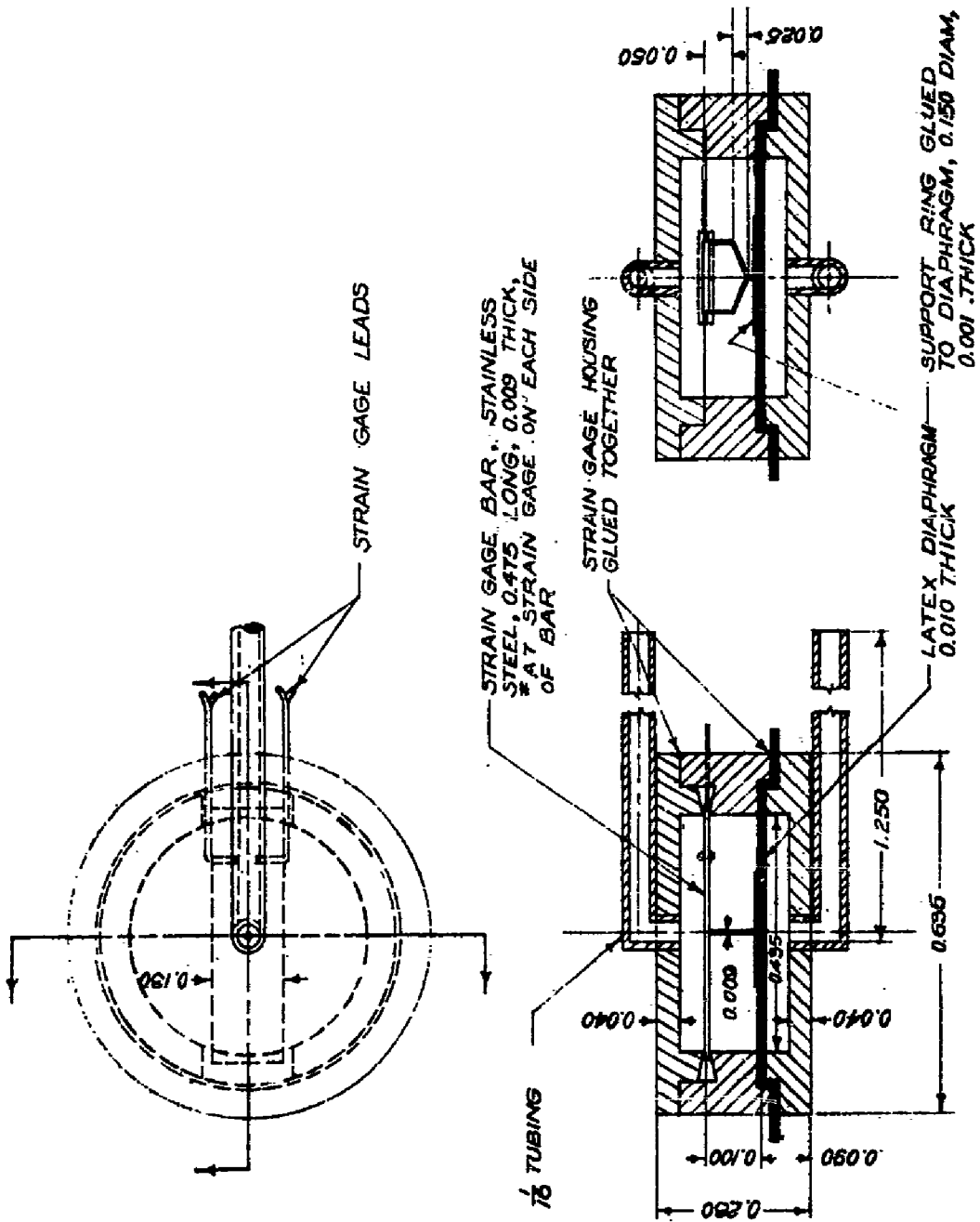
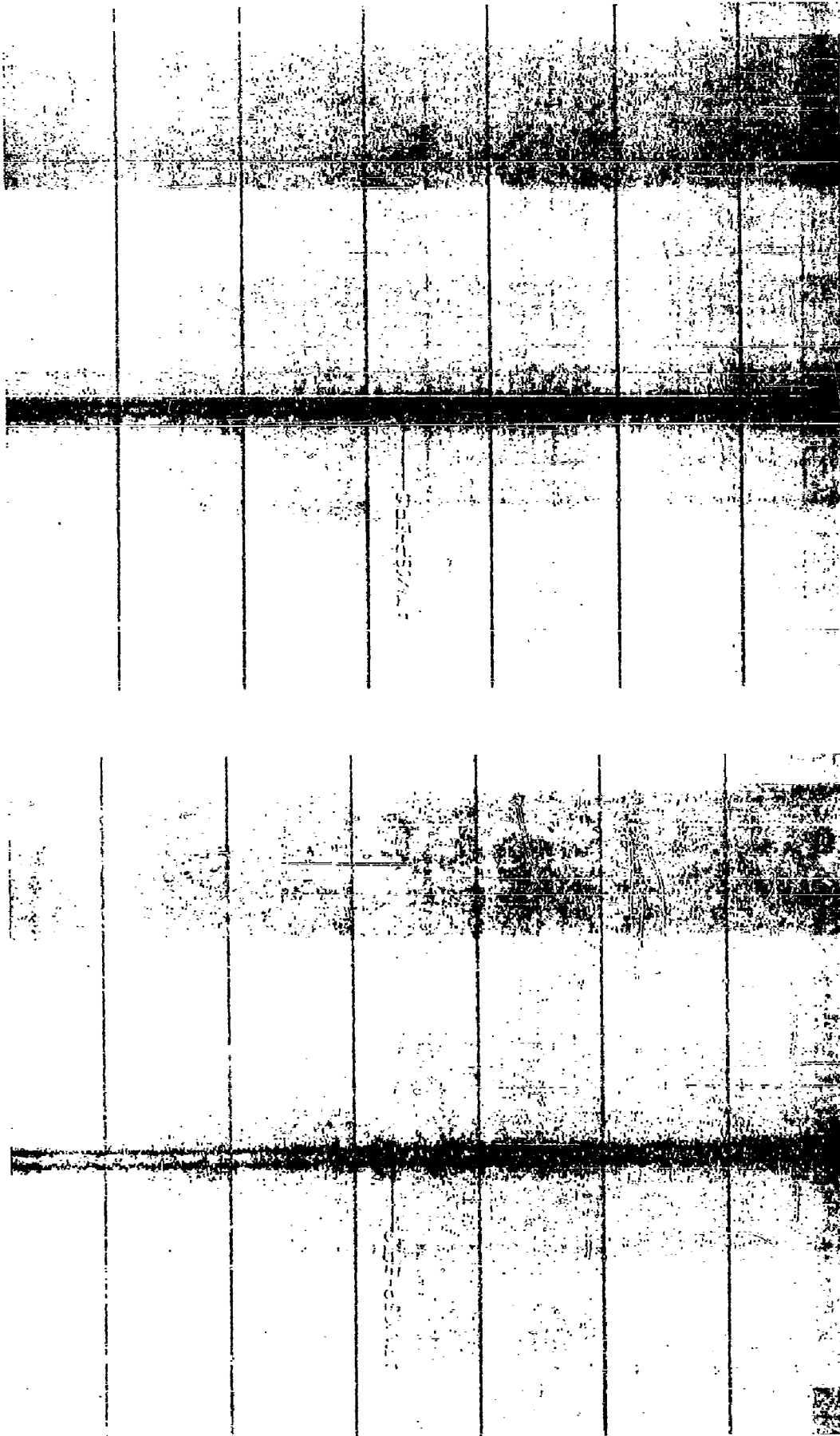


FIG. 5 PRESSURE TRANSDUCER (TYPE 3)

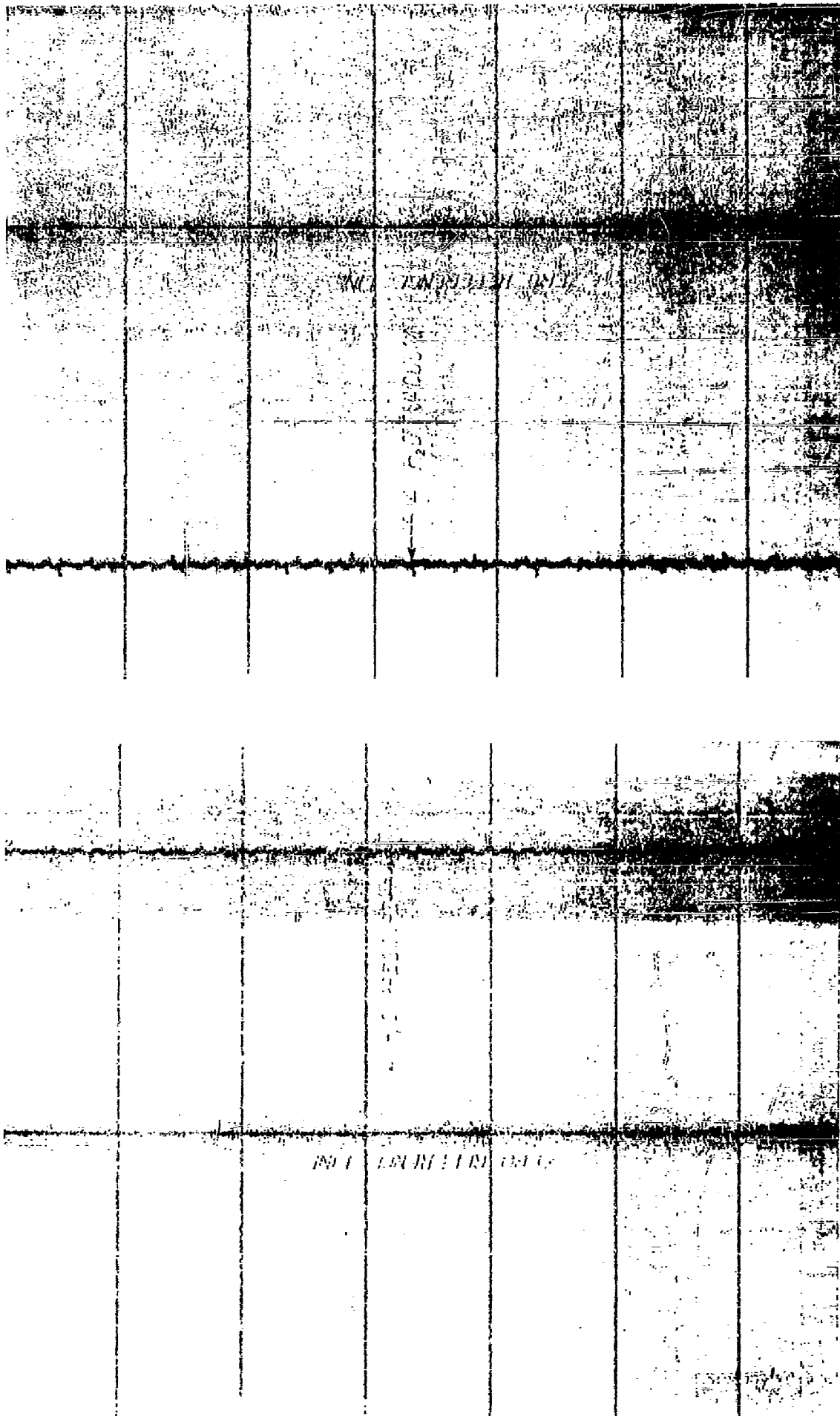


A. Pressure - Atmospheric
Frequency - 10

B. Pressure - Atmospheric
Frequency - 100 cycles per second

Vibration - Amplitude parallel to plane of diaphragm
Recording Velocity - 10" per second

FIG. 6. A.B. TRANSDUCER RESPONSE TO EXTERNAL VIBRATION

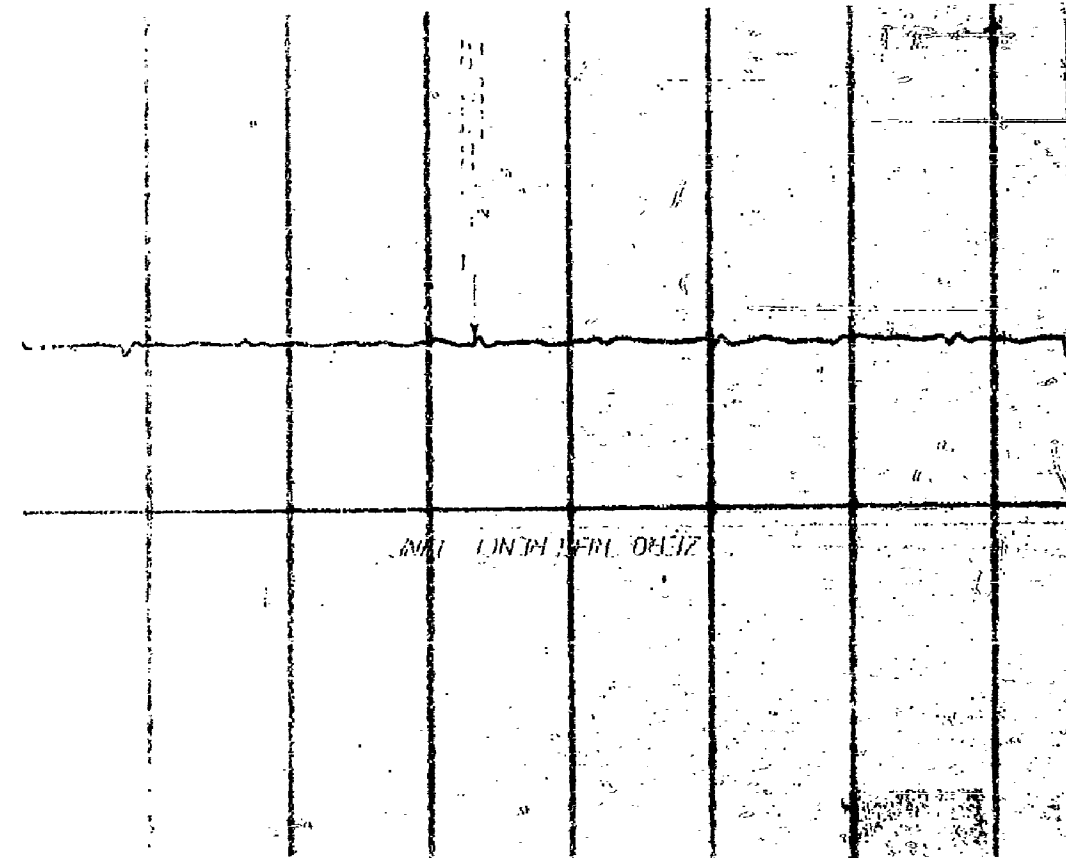


C. Pressure - 14" H₂O, Positive
 Frequency - 100 cycles per second

D. Pressure - 14" H₂O, Vacuum
 Frequency - 200 cycles per second

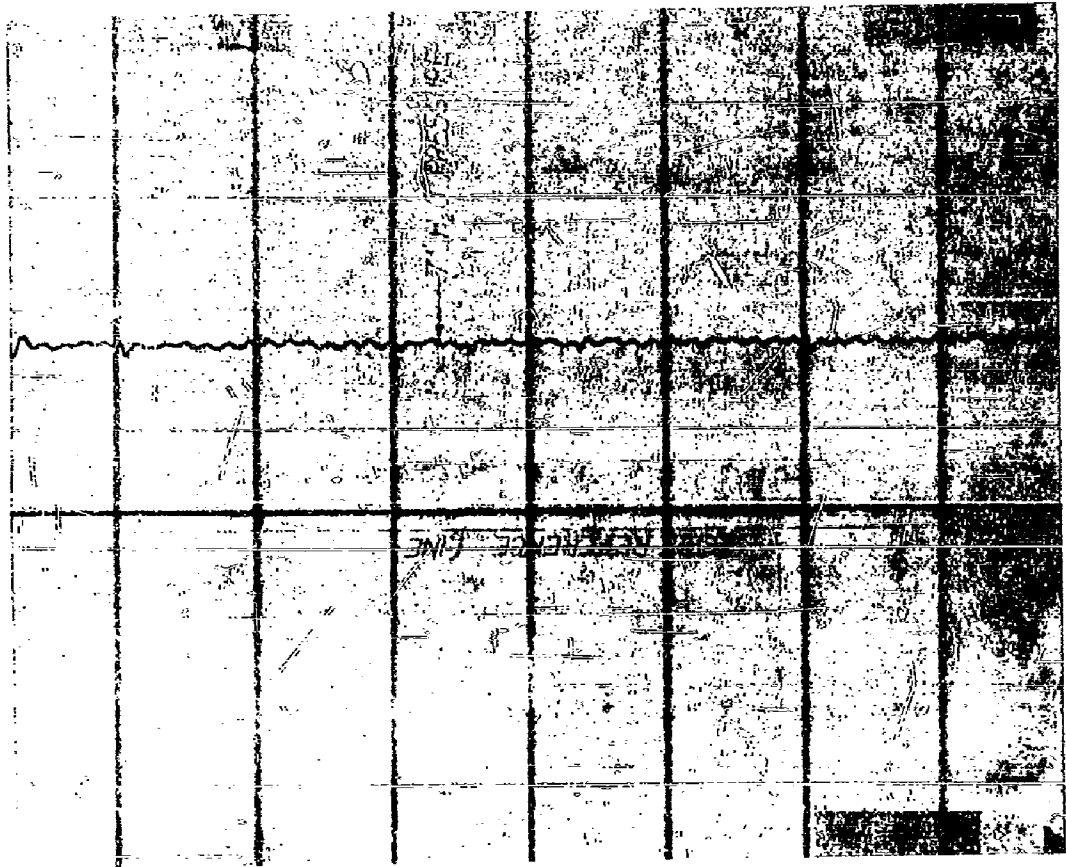
Vibration - Amplitude parallel to plane of diaphragm
 Recording Velocity - 10" per second

FIG. 6. C.D. TRANSDUCER RESPONSE TO EXTERNAL VIBRATION



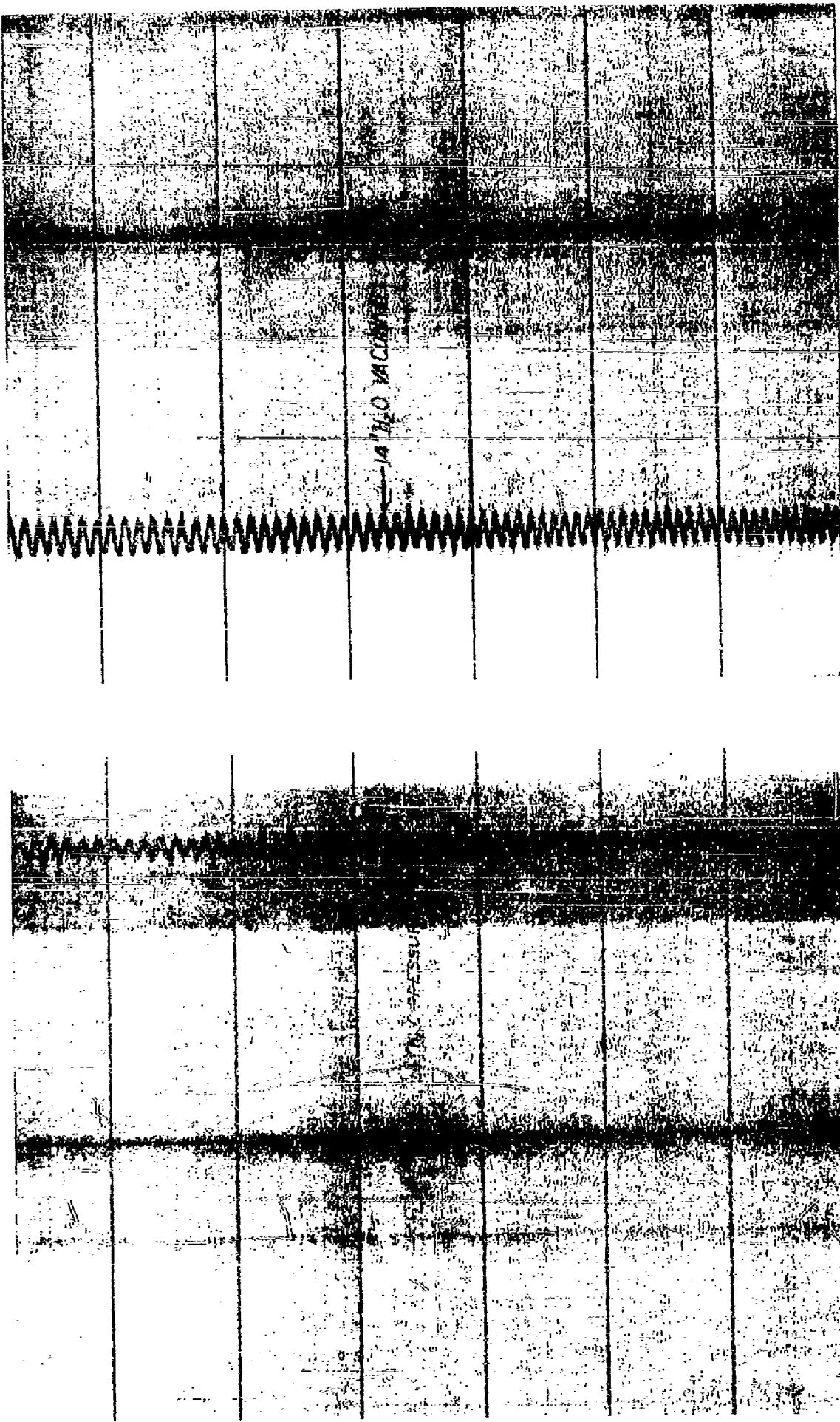
E. Pressure - 7th H₂C, Positive
Frequency - 400 cycles per second

Vibration - Amplitude parallel to plane of diaphragm
Recording Velocity - 100^m per second



F. Pressure - 7th H₂C, Positive
Frequency - 700 cycles per second

FIG. 6. E.F. TRANSDUCER RESPONSE TO EXTERNAL VIBRATION



A. Pressure - 11" H₂O, Positive
 Frequency - 100 cycles per second

B. Pressure - 11" H₂O, Vacuum
 Frequency - 100 cycles per second

Vibration - Amplitude perpendicular to plane of diaphragm
 Recording Velocity - 10" per second

FIG. 7. A.B. TRANSDUCER RESPONSE TO EXTERNAL VIBRATION

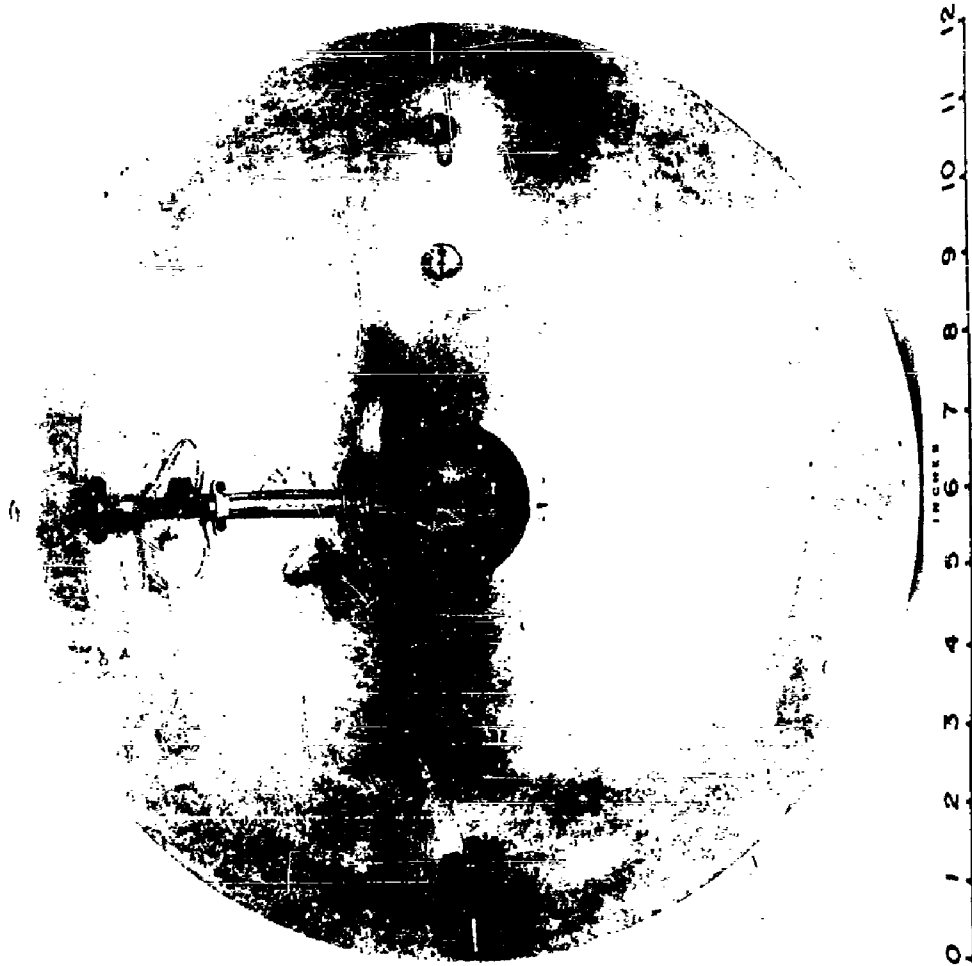
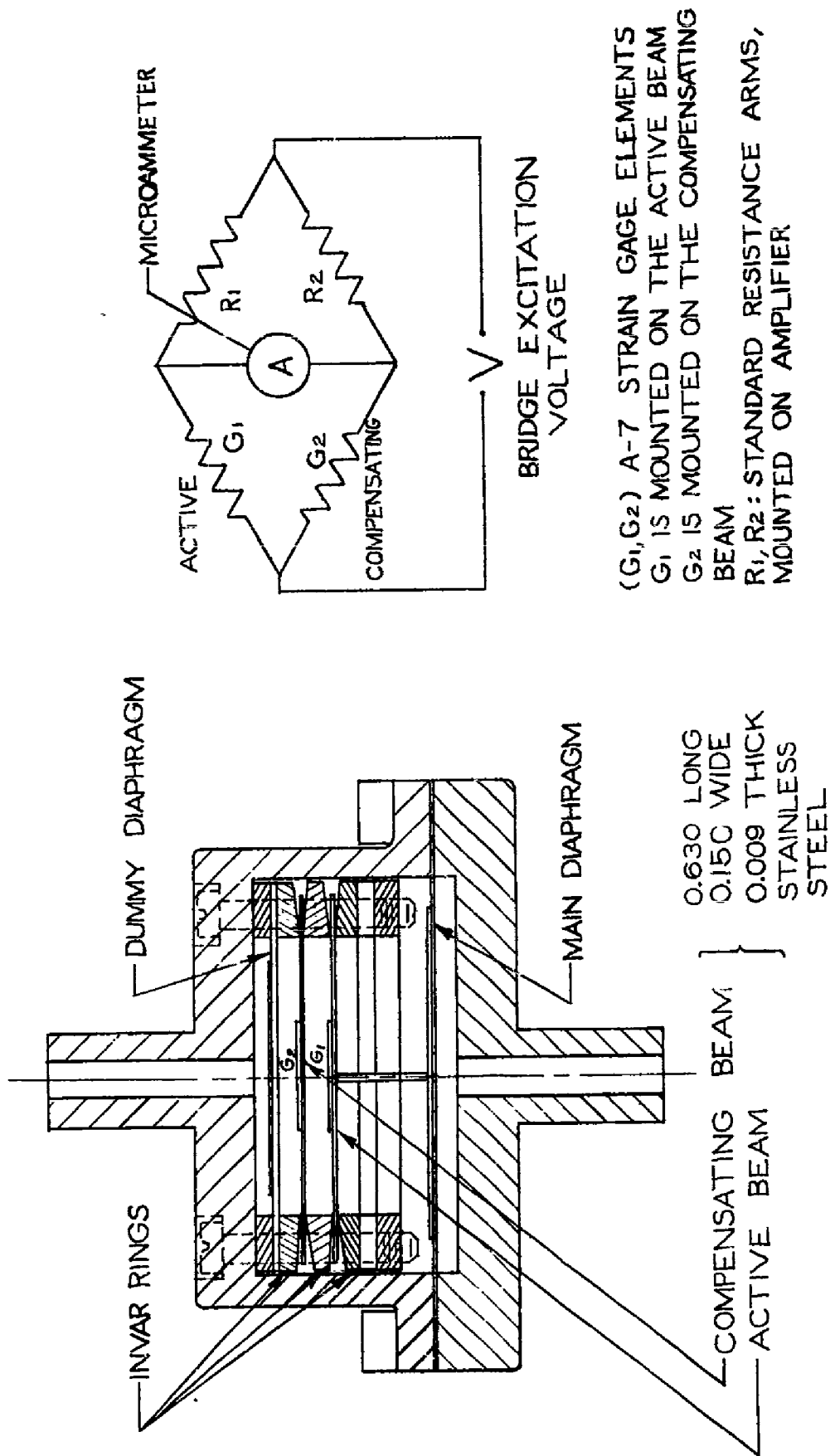


FIG. 8 DIAPHRAGM PRESSURE TRANSDUCER MOUNTED FOR TESTING
ON SOLID PARACHUTE MODEL



FIG. 9. DIAPHRAGM PRESSURE TRANSDUCER (TYPE 4)
WITH MOUNTING BRACKET



(G_1, G_2) A-7 STRAIN GAGE ELEMENTS
 G_1 IS MOUNTED ON THE ACTIVE BEAM
 G_2 IS MOUNTED ON THE COMPENSATING BEAM
 R_1, R_2 : STANDARD RESISTANCE ARMS, MOUNTED ON AMPLIFIER

B. WIRING DIAGRAM

A. INTERNAL ARRANGEMENT OF TRANSDUCER
 2 ARM BRIDGE

FIG. 10 2-ARM BRIDGE ARRANGEMENT

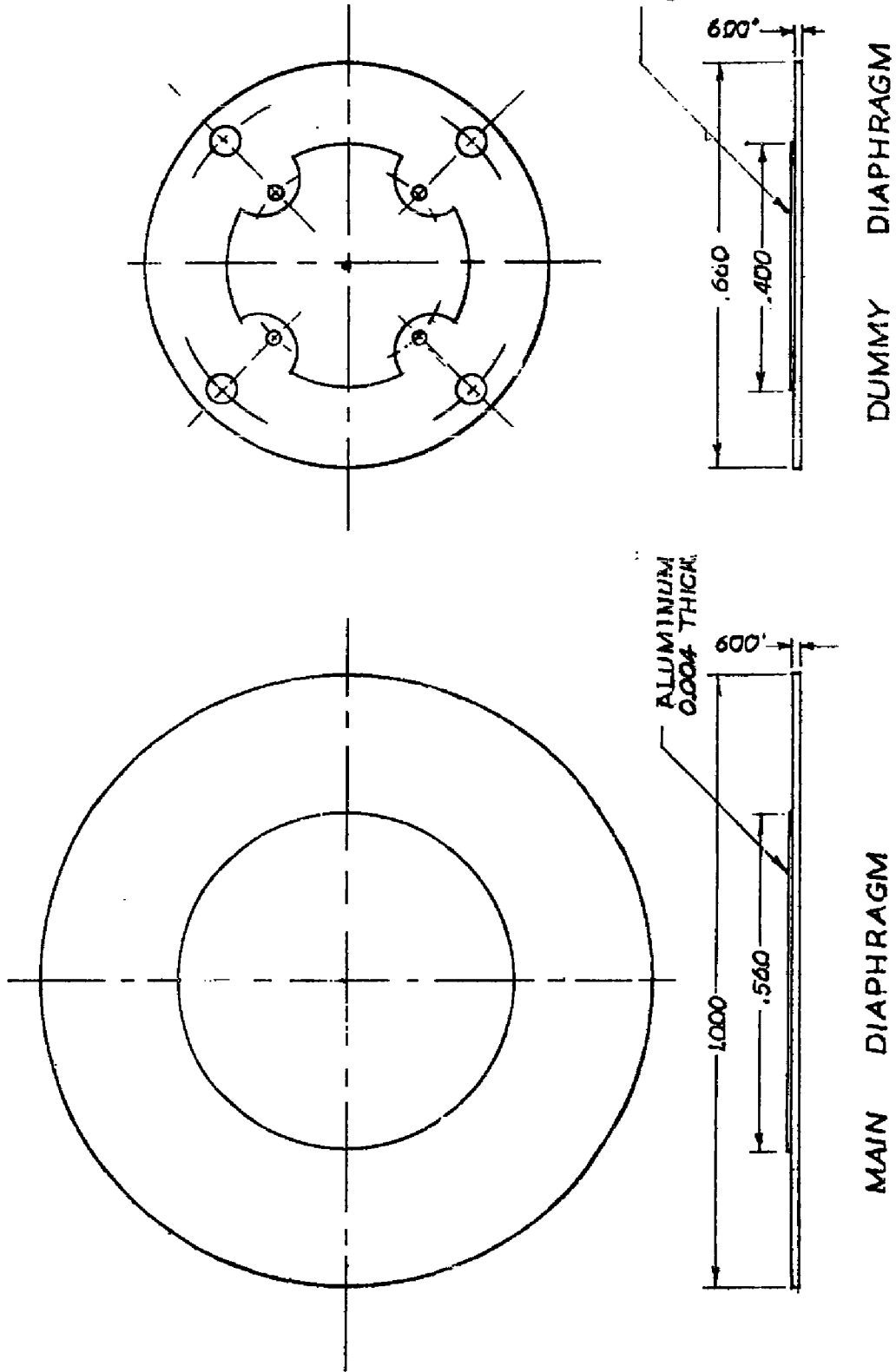
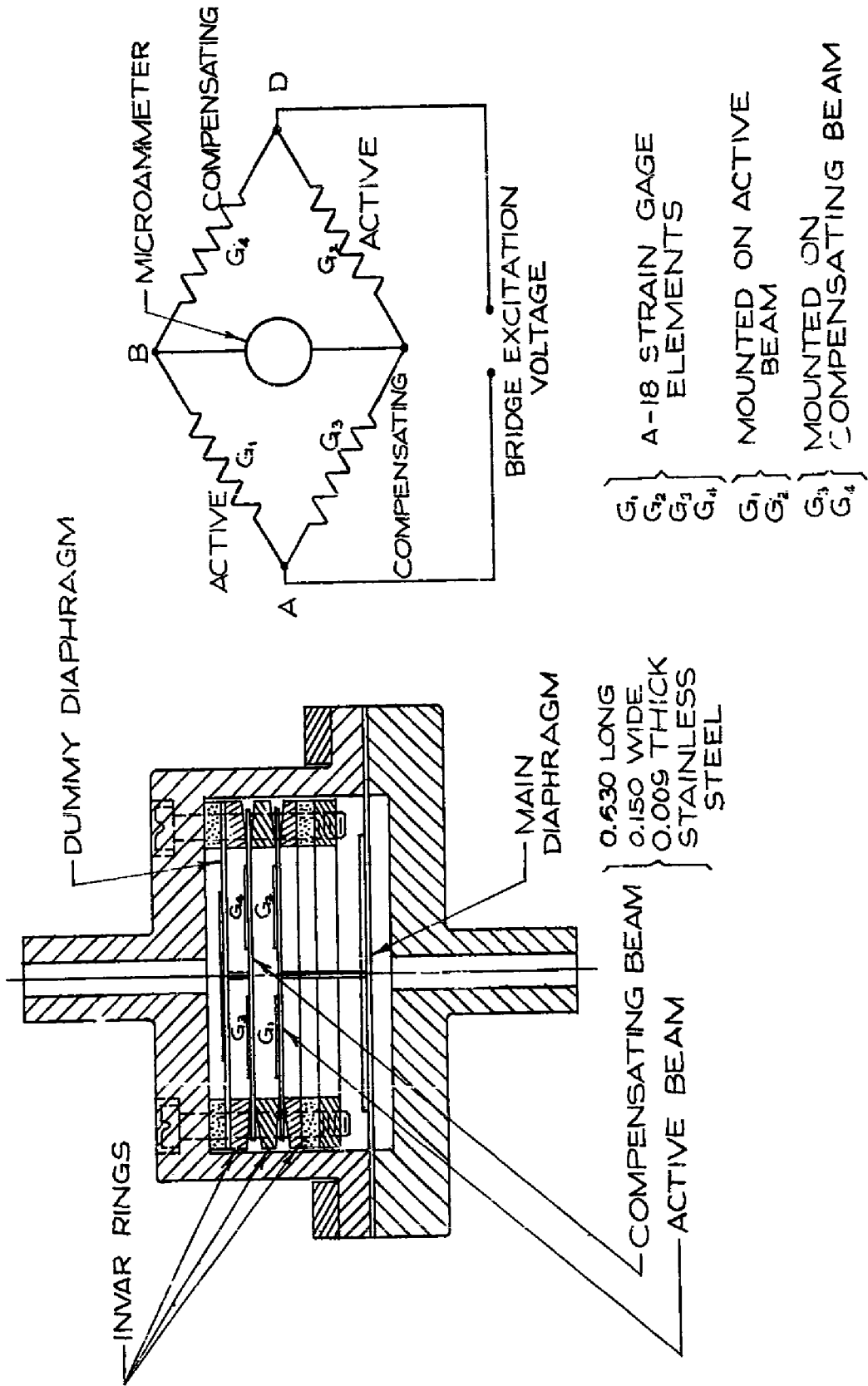


FIG 11
 MAIN AND DUMMY DIA PHRAGMS



A. INTERNAL ARRANGEMENT OF TRANSDUCER

B. WIRING DIAGRAM

FIG. 12 4-ARM BRIDGE ARRANGEMENT

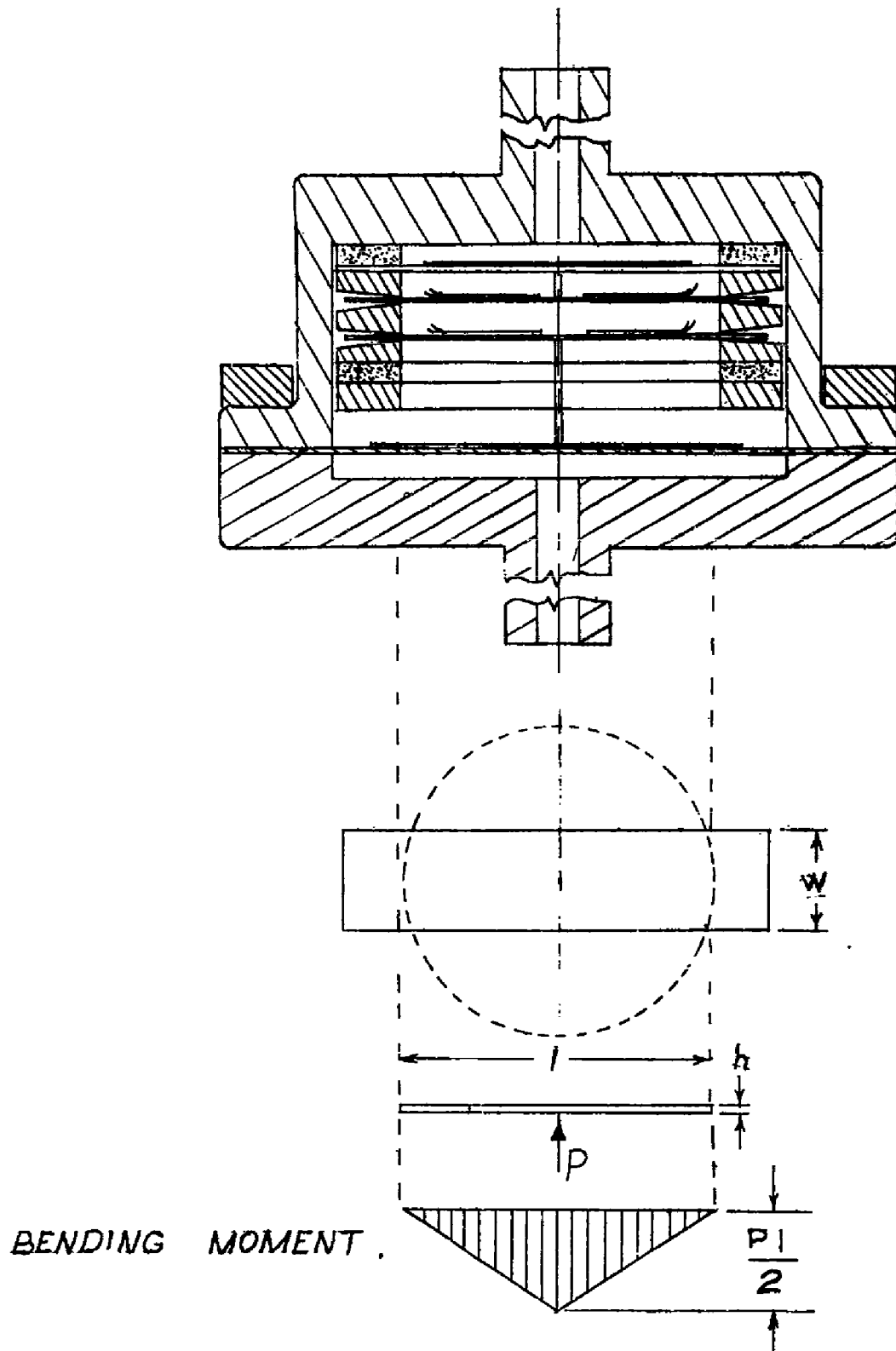


FIG. 13
 STRAIN GAGE BEAM LOADING

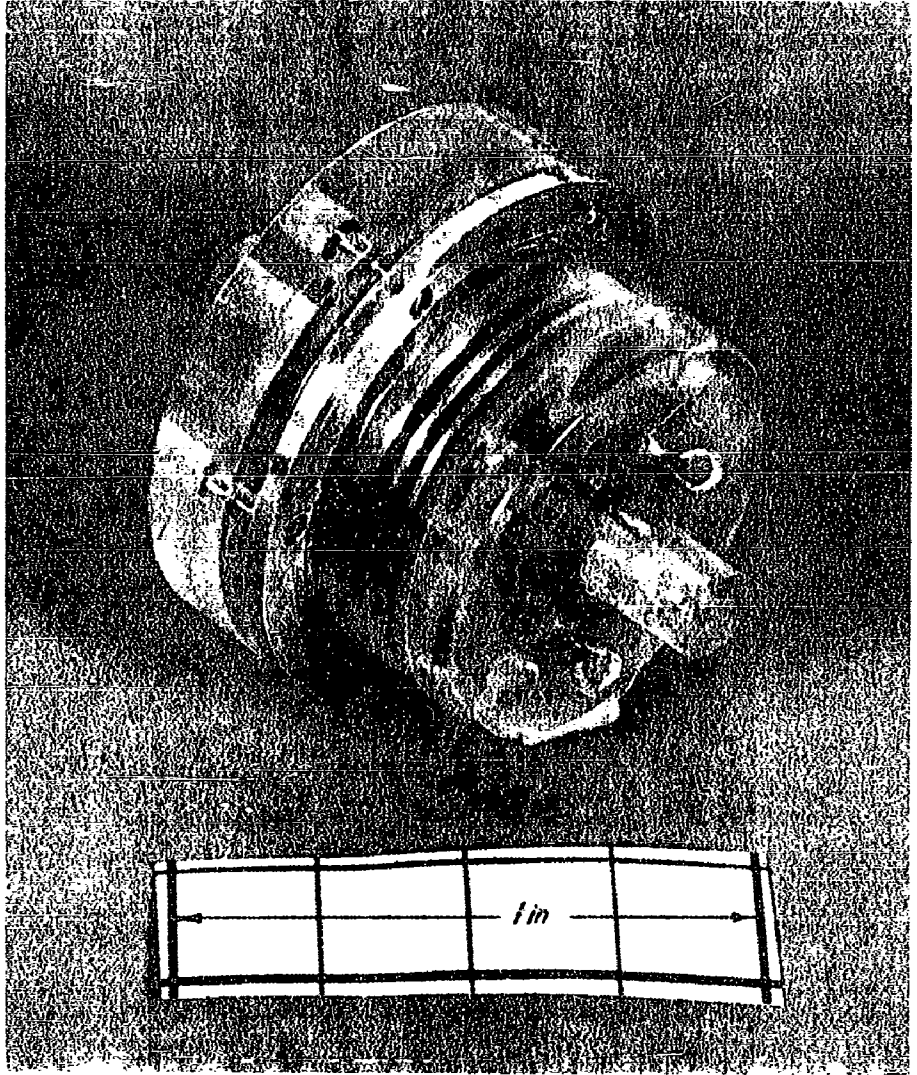


Fig. 11A Three-Quarter View of Pressure Transducer (TYPE 5)

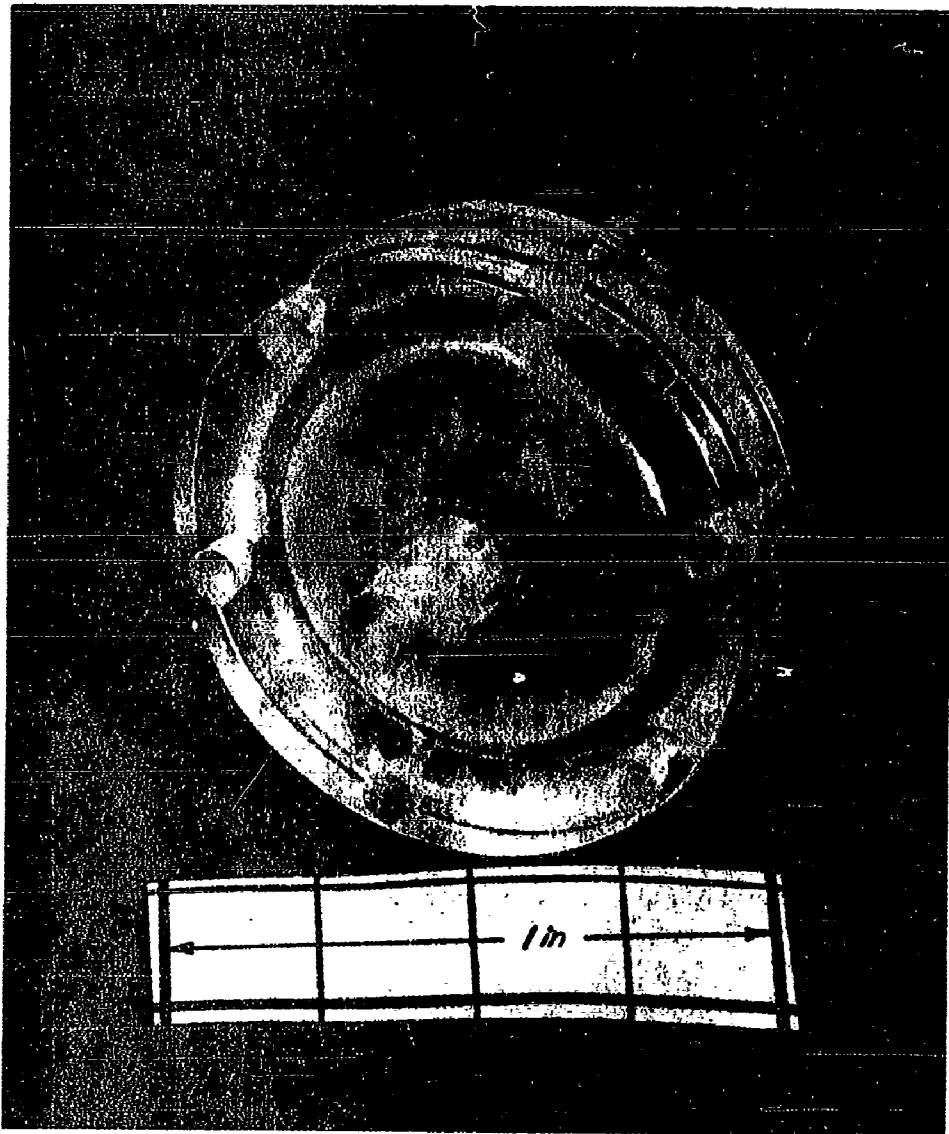


FIG 1A2 END VIEW OF PRESSURE TRANSDUCER (MAIN DIAPHRAGM SIDE)
(TYPE 5)

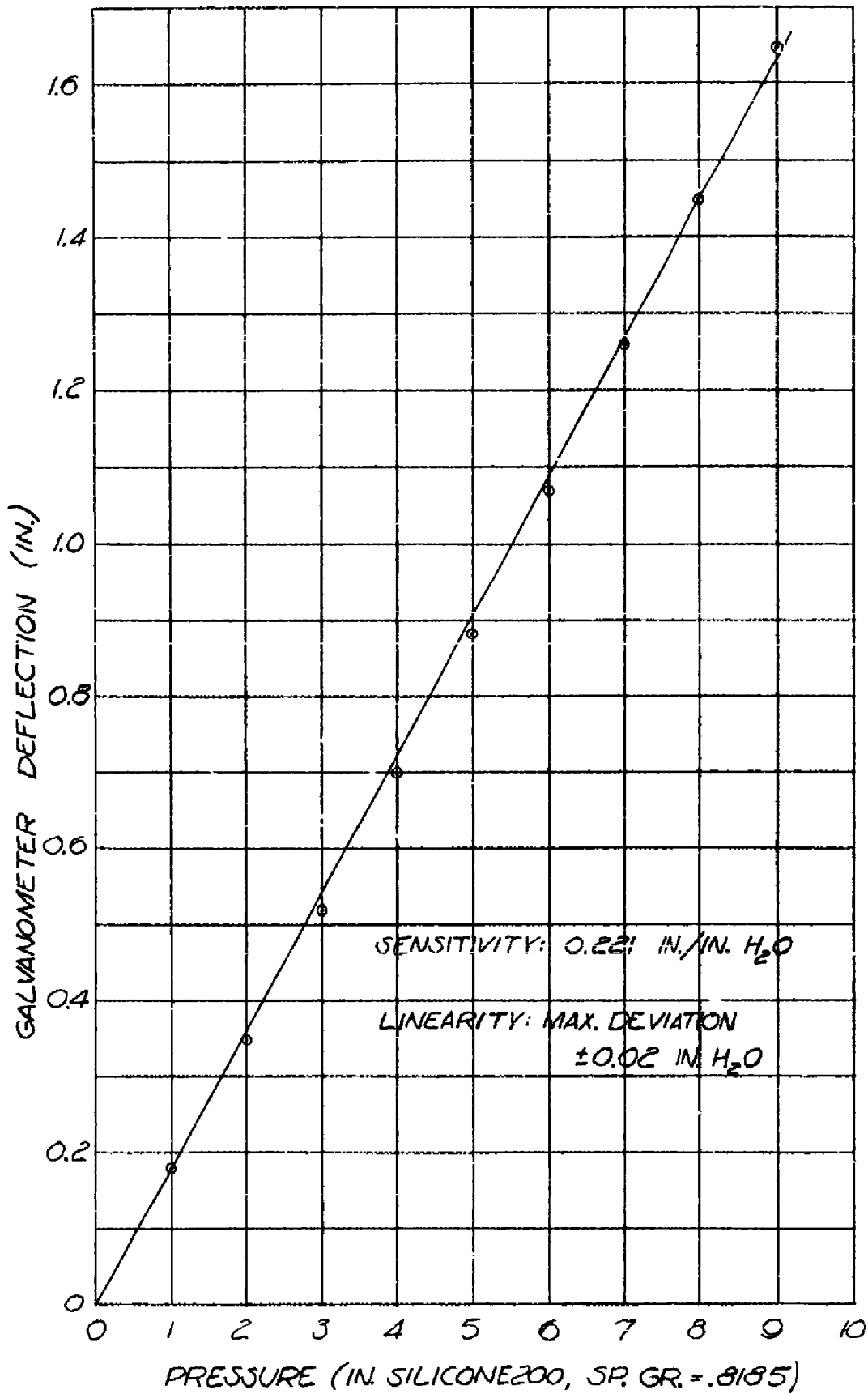


FIG. 16 CALIBRATION CURVE

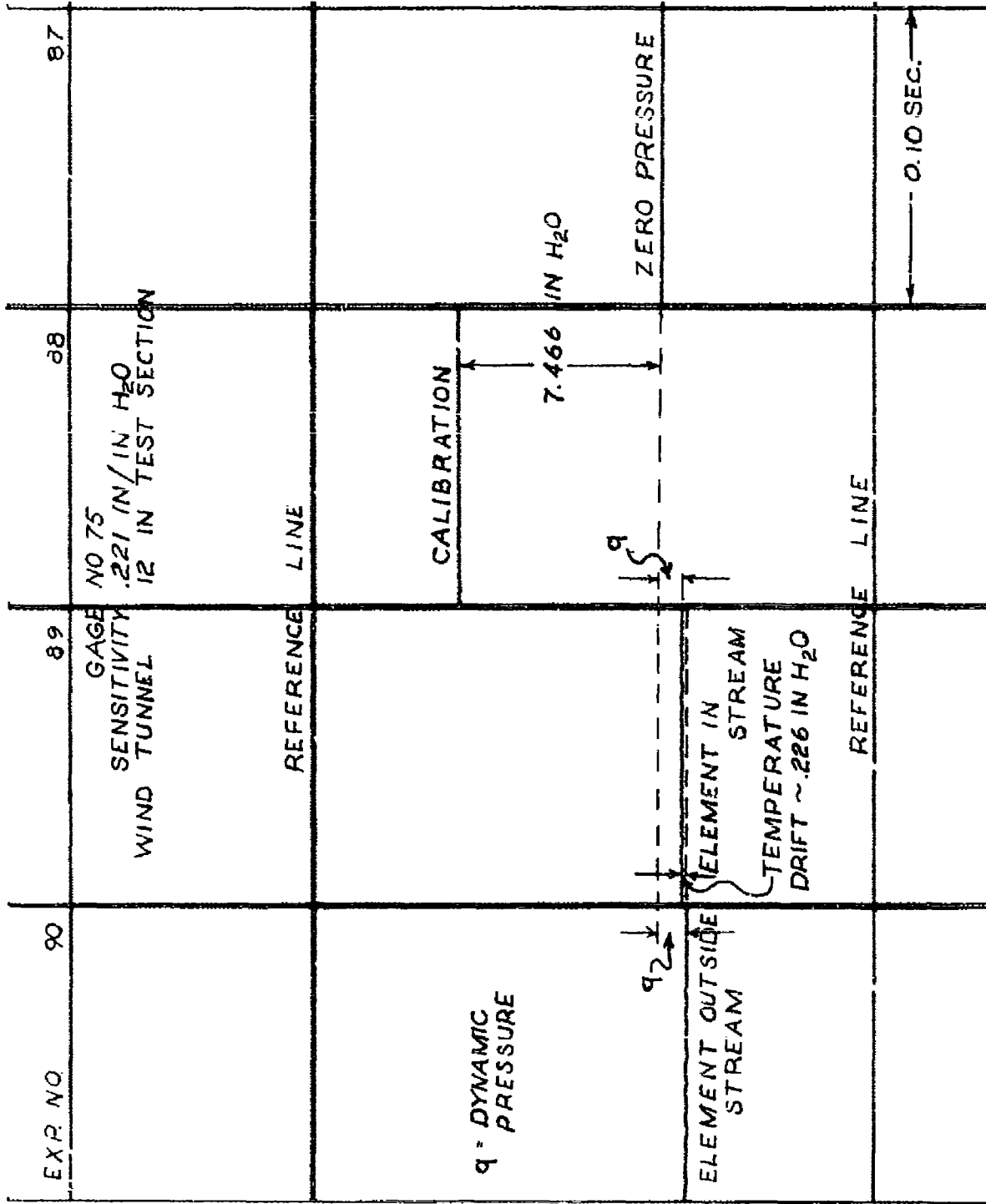


Fig. 17-A Slipstream Drift Tests (Transducer Element Inside and Outside Test Section)

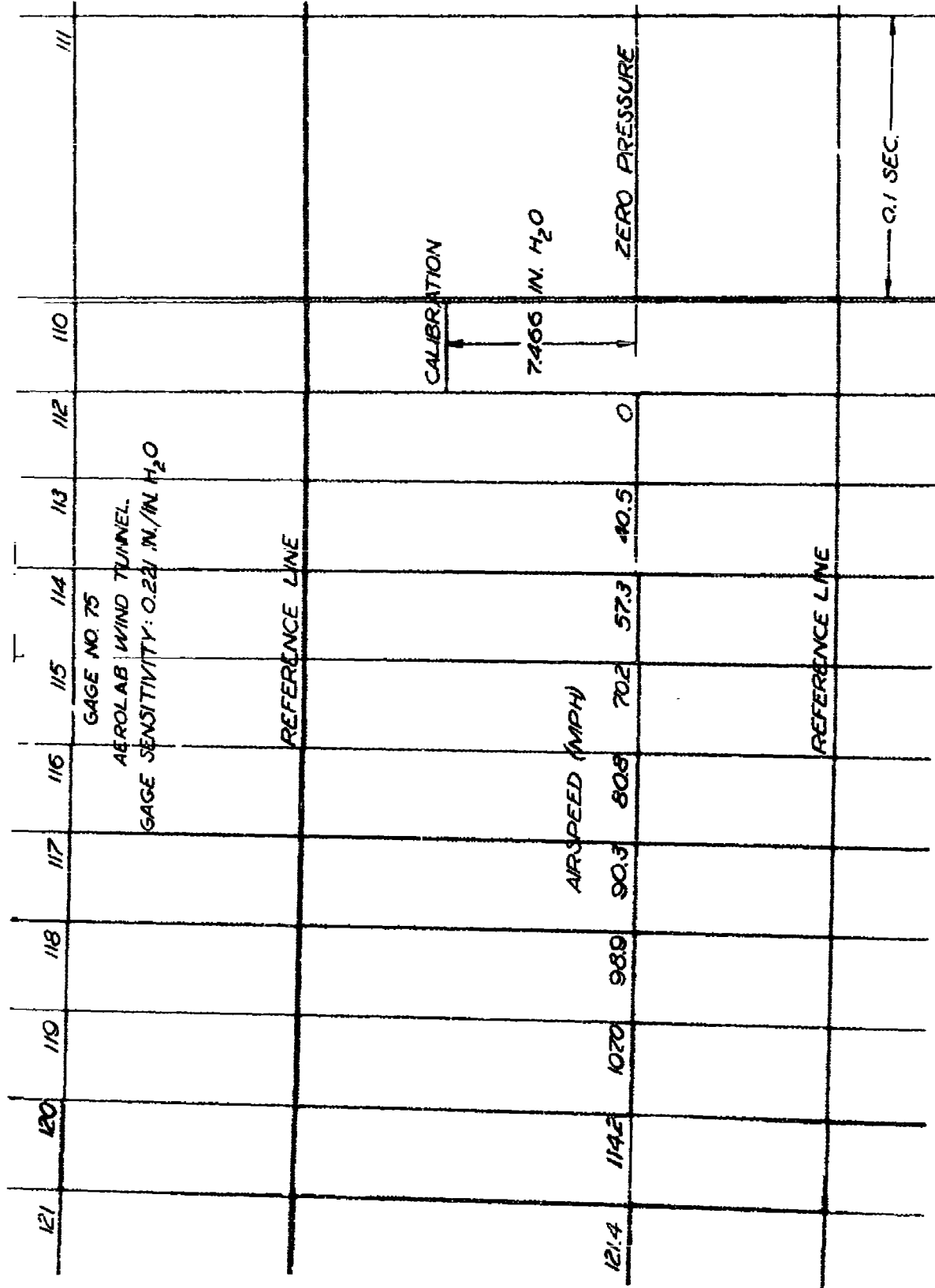


Fig. 17-B. Slipstream Drift Tests of the Transducer Subjected to Different Flow Velocities

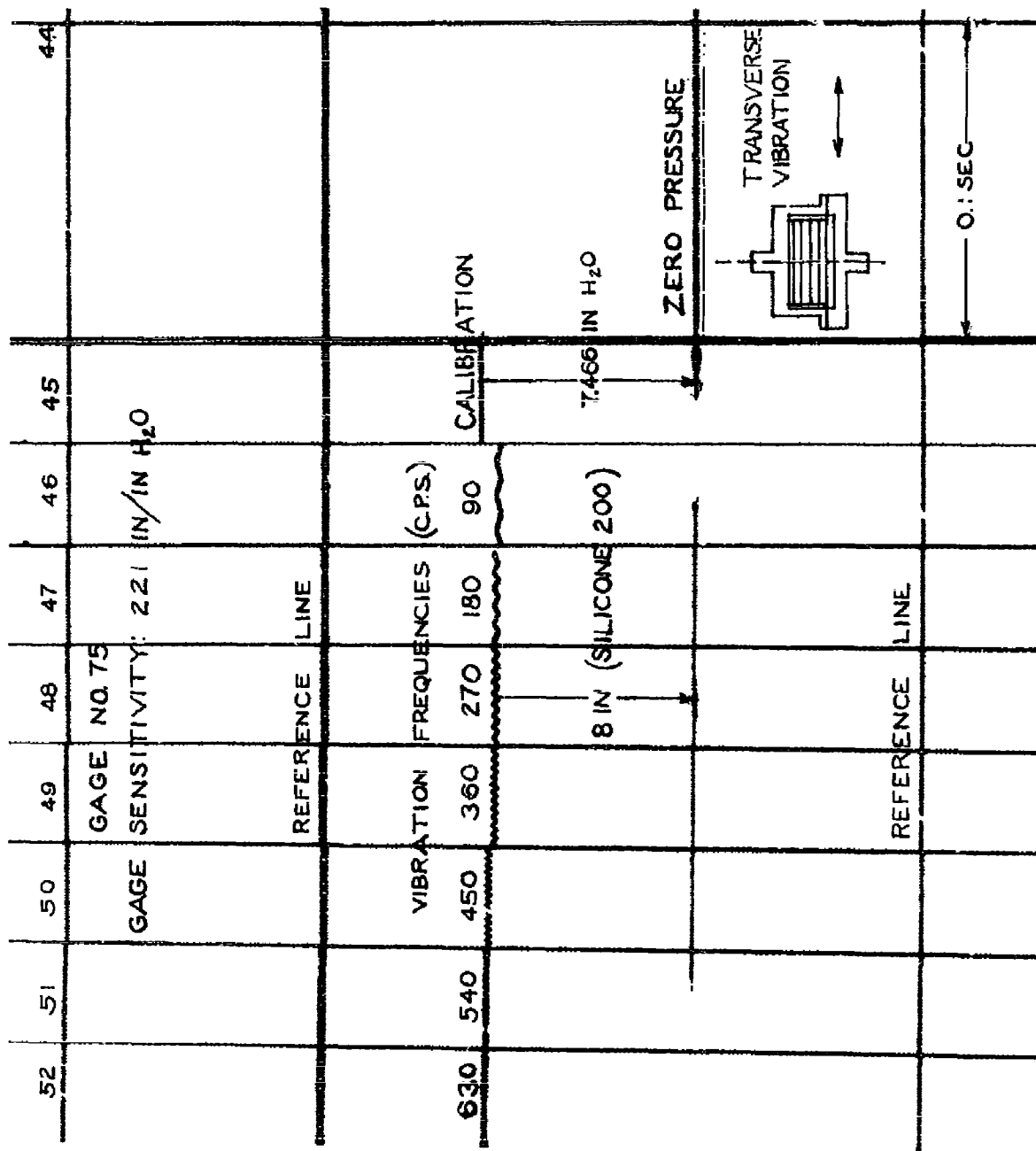


Fig. 18 Response to Transverse Vibration of the Casing

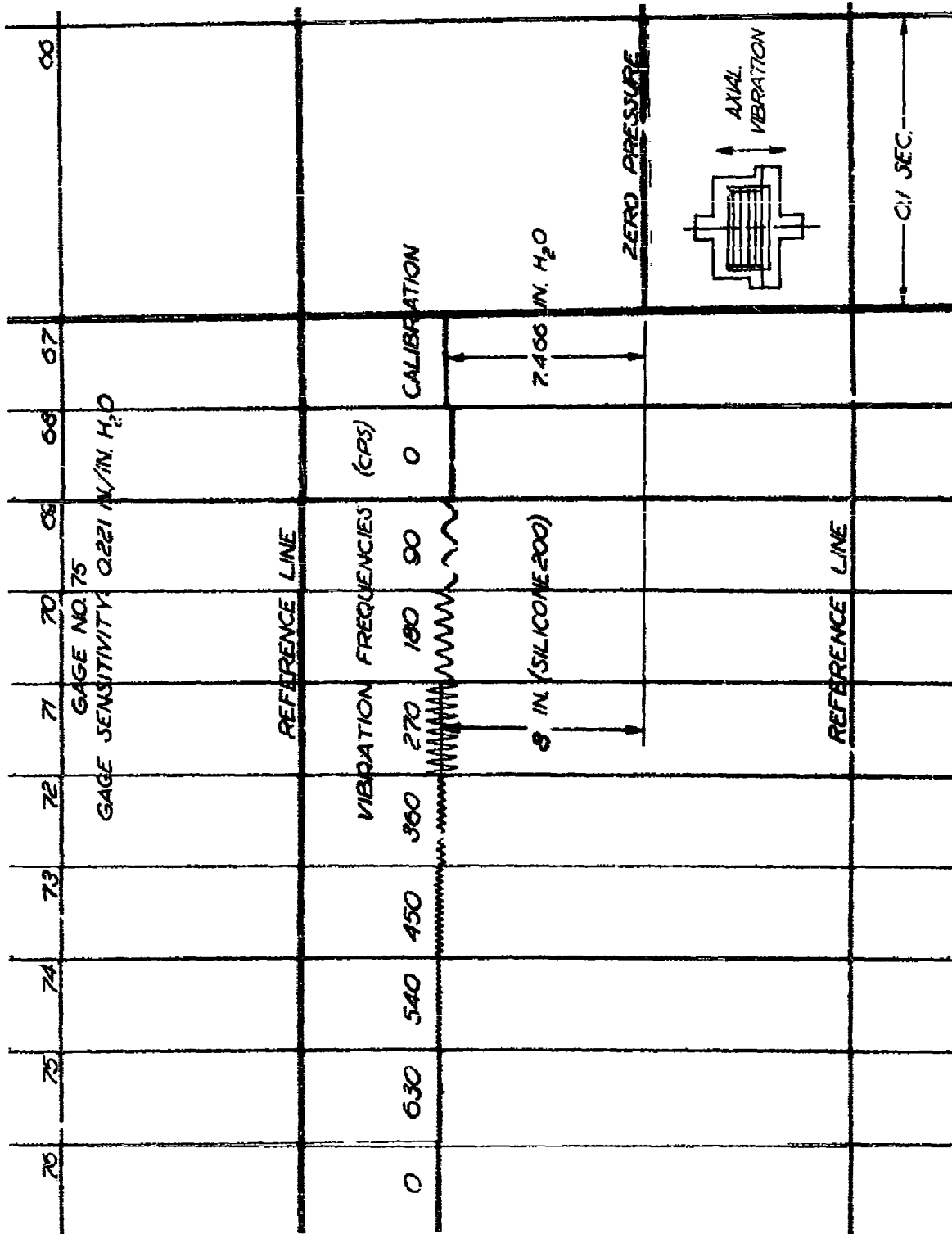


Fig. 19 Response to Axial Vibration of the Casing

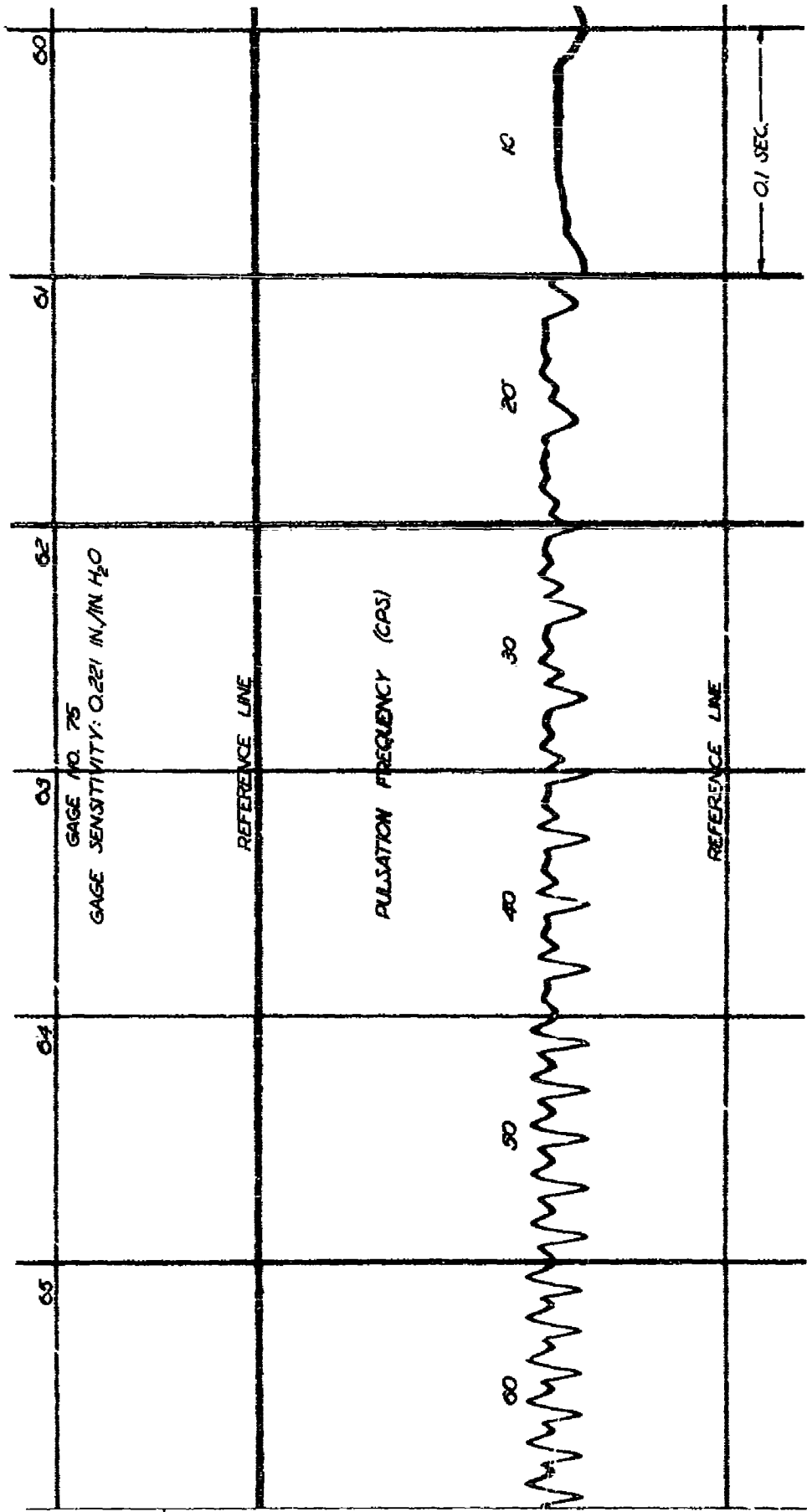


Fig. 20 Response to Fluctuating Pressure

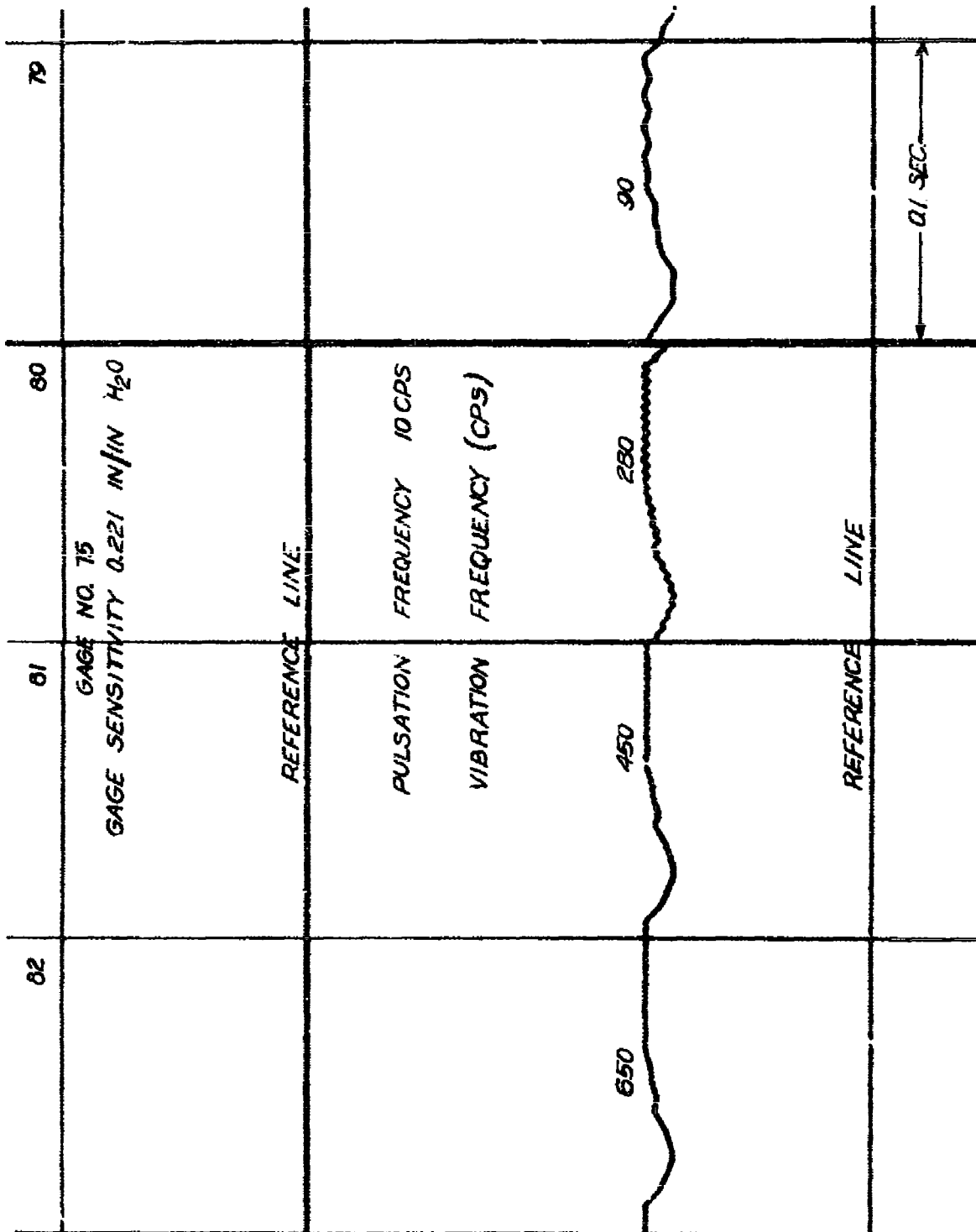


Fig. 21 Response to Fluctuating Pressure Combined with Transverse
Vibration of the Casing

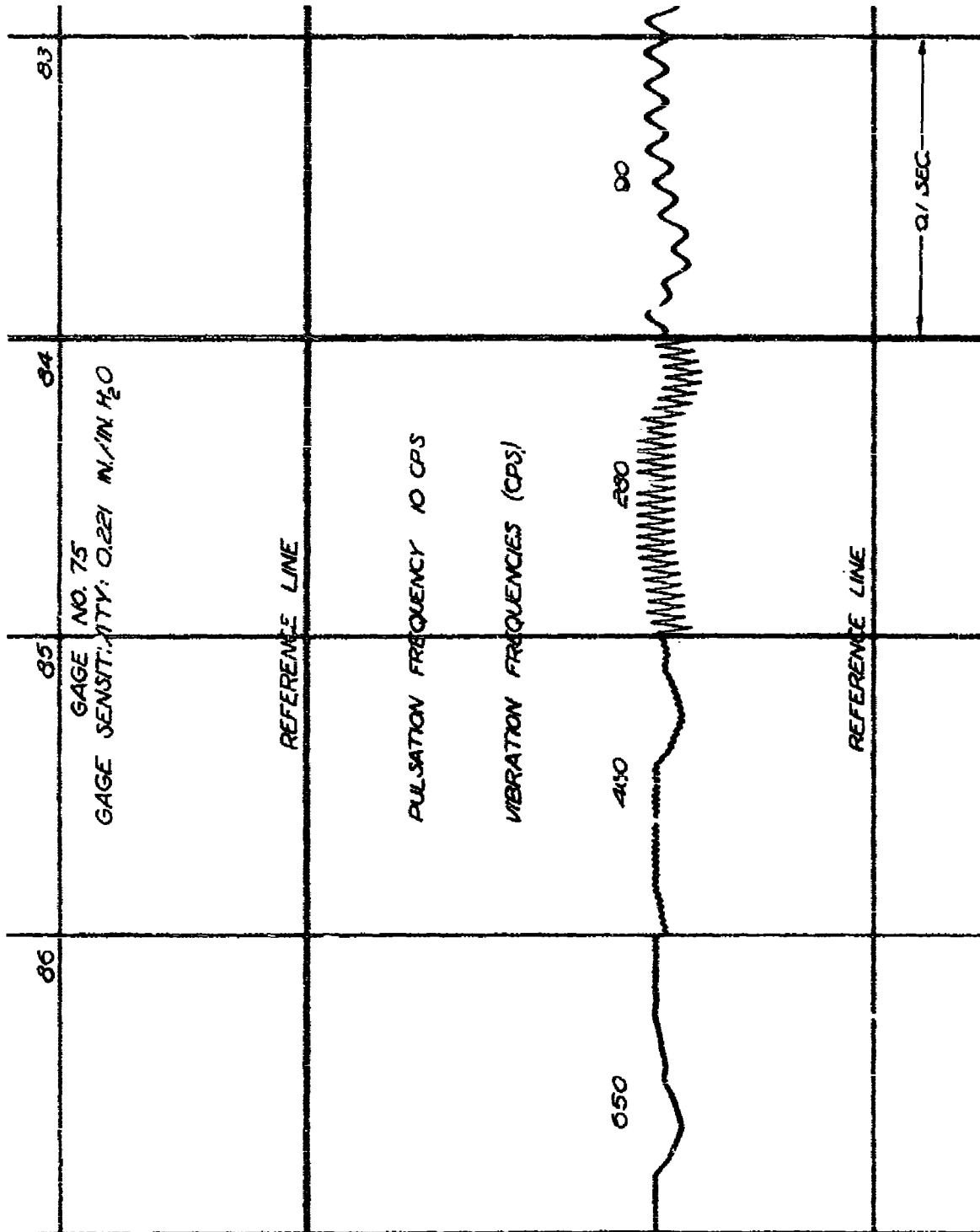


Fig. 22 Response to Fluctuating Pressure Combined with Axial Vibration of the Casing

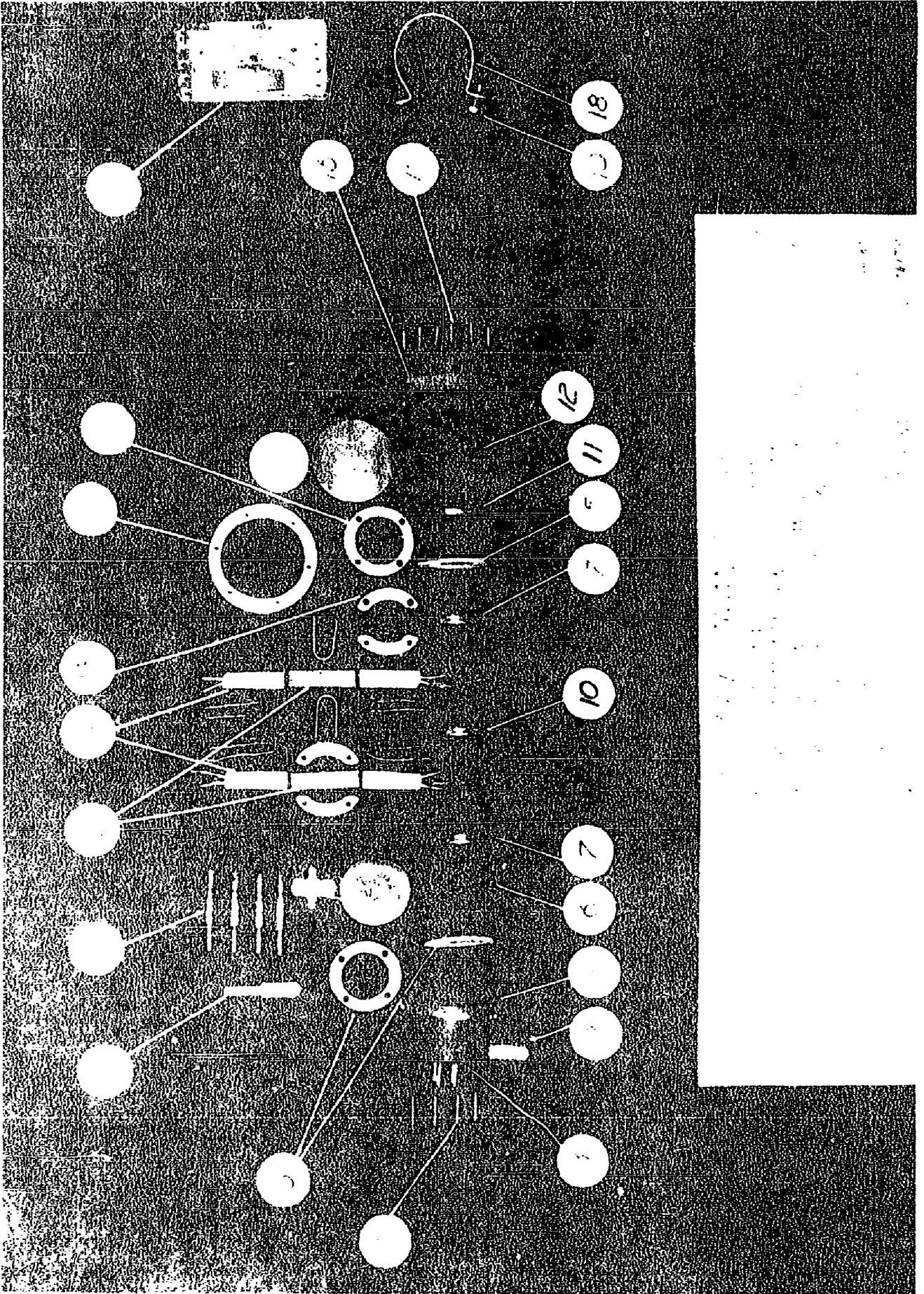


FIG. 24. EXPLODED VIEW OF PRESSURE TRANSDUCER (TYPE 6) SHOWING THE MAIN PARTS AND GENERAL ARRANGEMENT

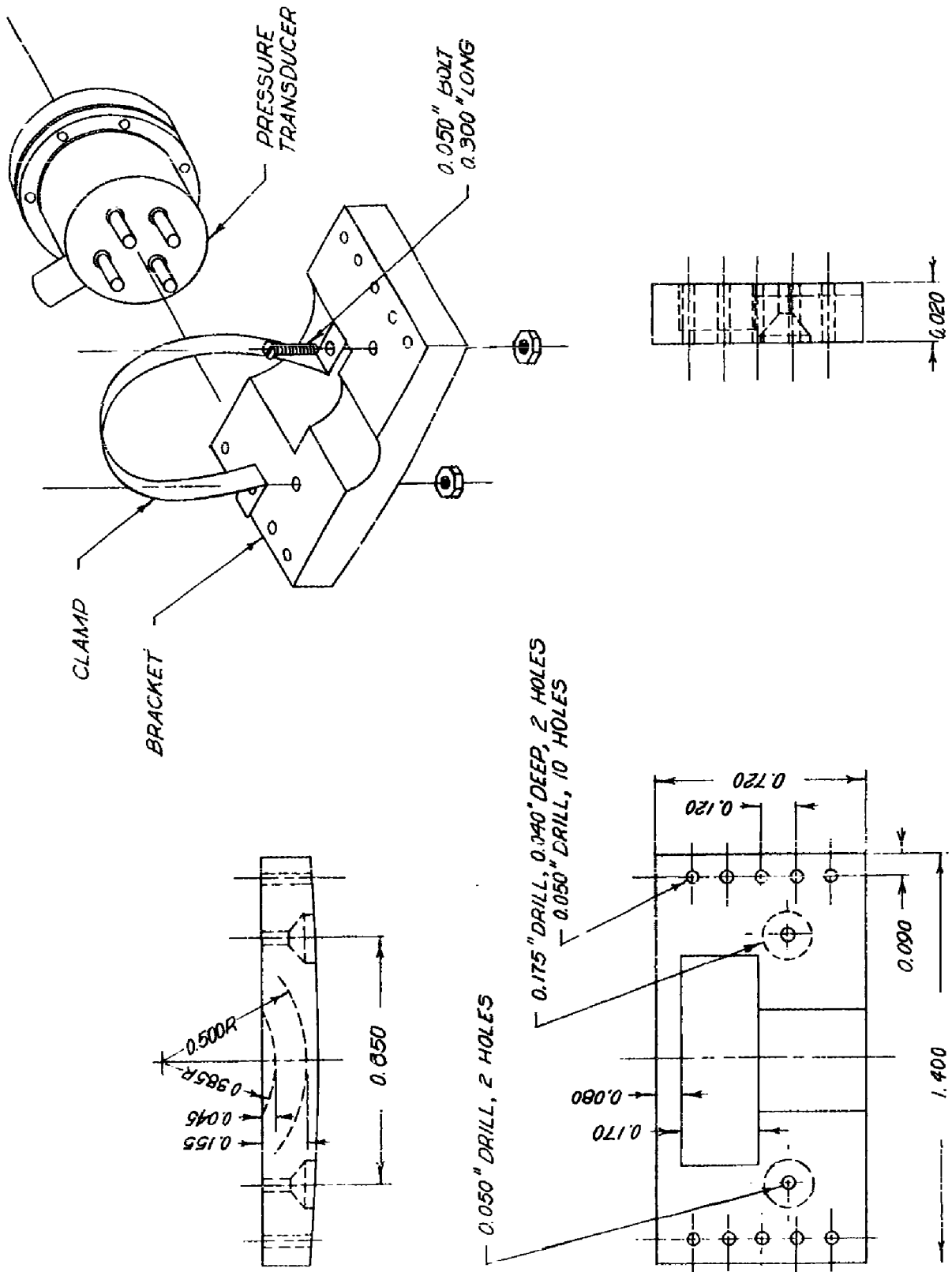


FIG.25 PRESSURE TRANSDUCER MOUNTING BRACKET

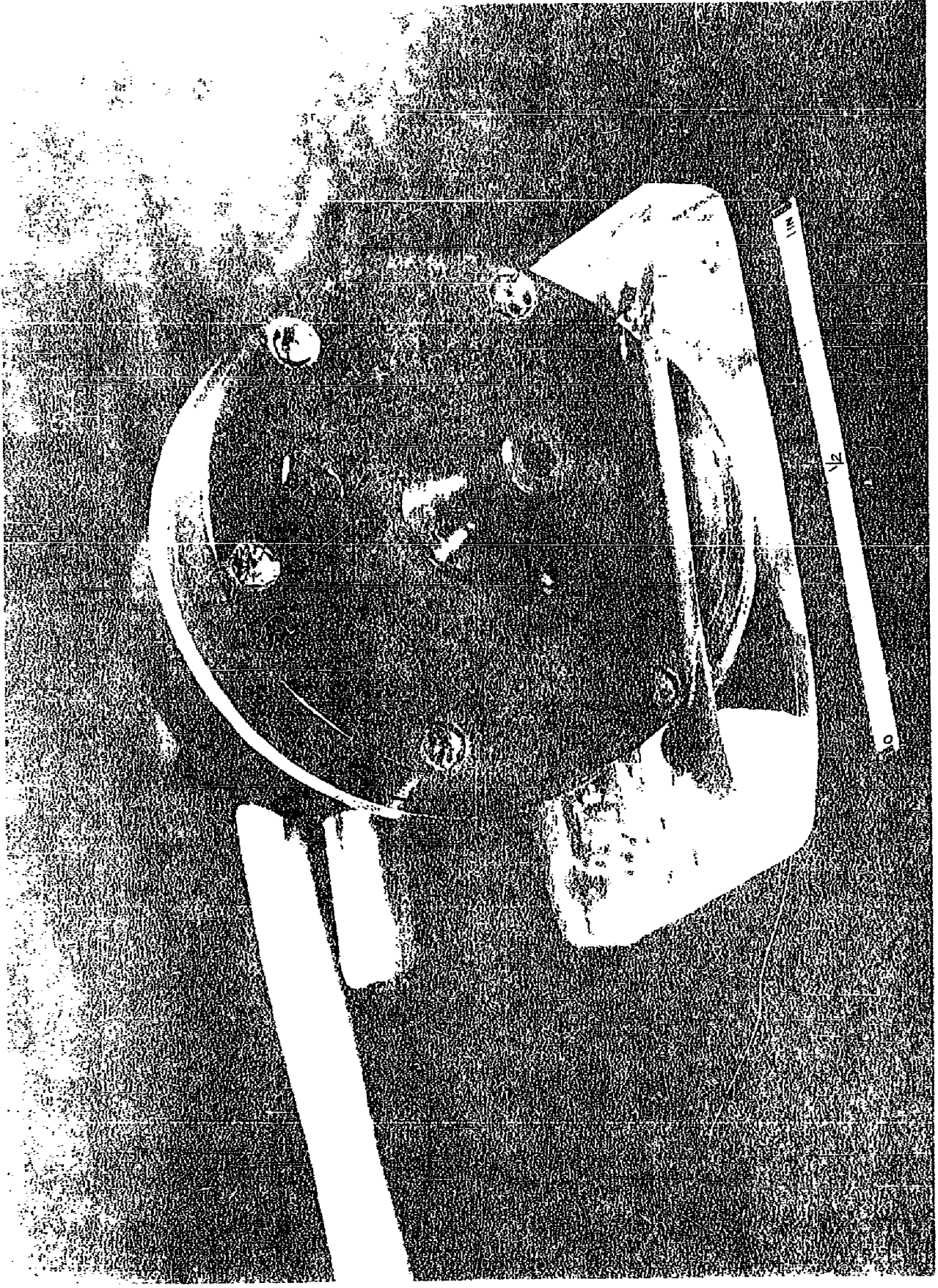


FIG. 26. PRESSURE TRANSDUCER (TYPE 6) AND MOUNTING BRACKET VIEWED FROM DIA. BRACKET SIDE

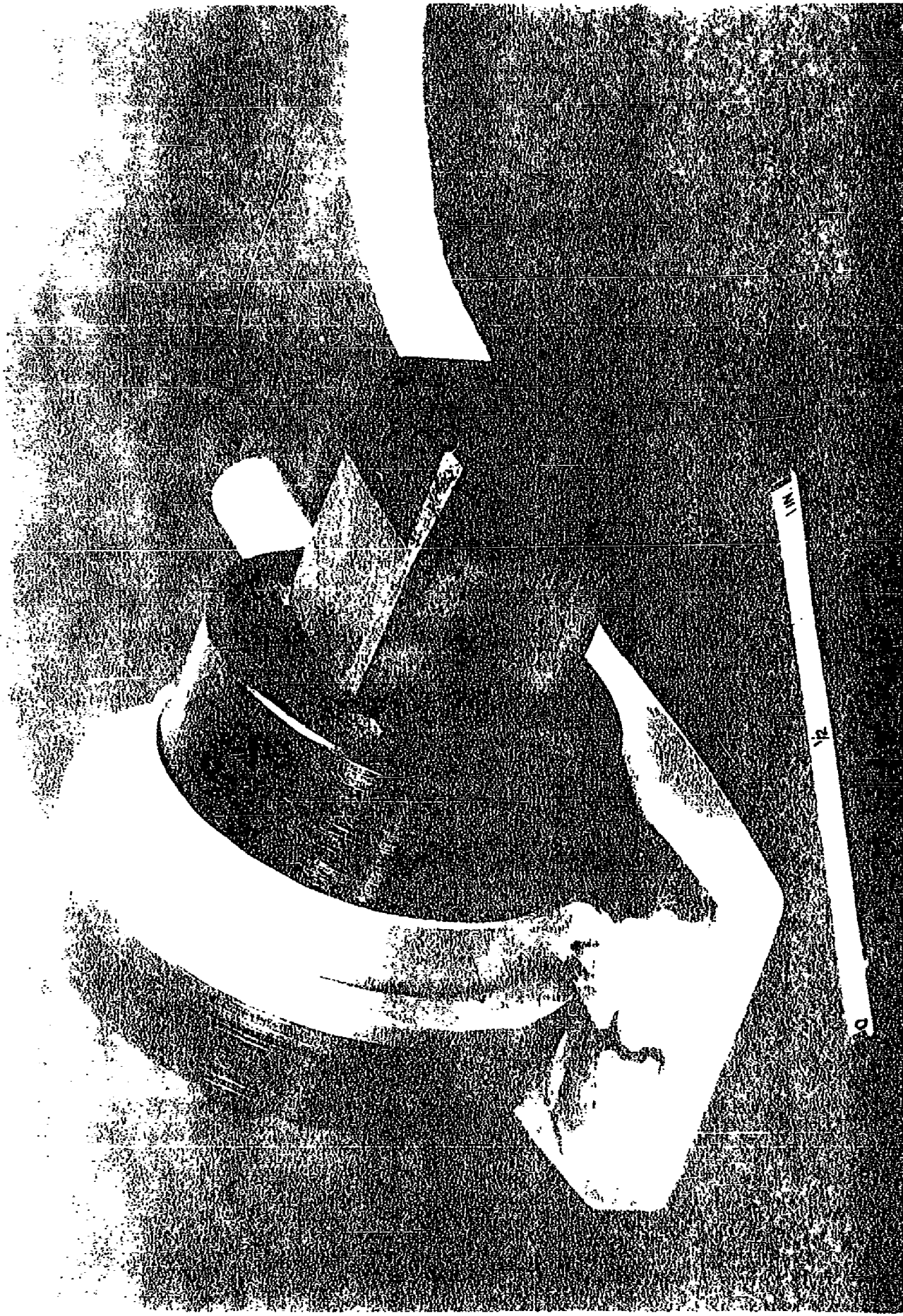
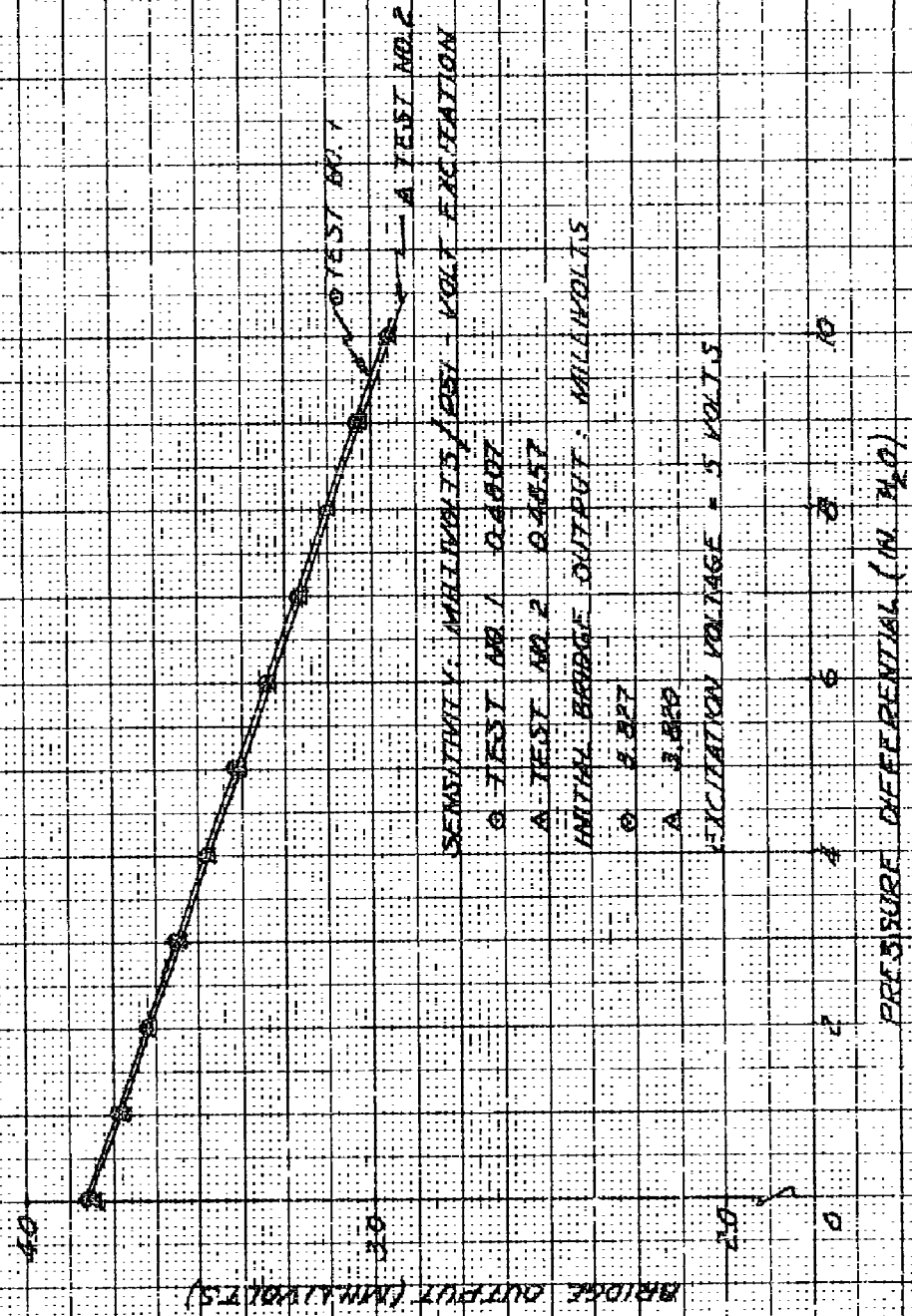


FIG. 27. THREE-QUARTER VIEW OF PRESSURE TRANSDUCER (TYPE 6) AND MOUNTING BRACKET

TRANSDUCER NO. 5



SENSITIVITY: MILLIVOLTS/PSI - VOLT EXCITATION
 O TEST NO. 1 0.4807
 A TEST NO. 2 0.4857
 INITIAL BRIDGE OUTPUT: MILLIVOLTS
 O 2.327
 A 3.849
 EXCITATION VOLTAGE = 5 VOLTS

FIG. 28 TRANSDUCER CALIBRATION CURVE

TRANSDUCER NO. 5 OF TYPE 6

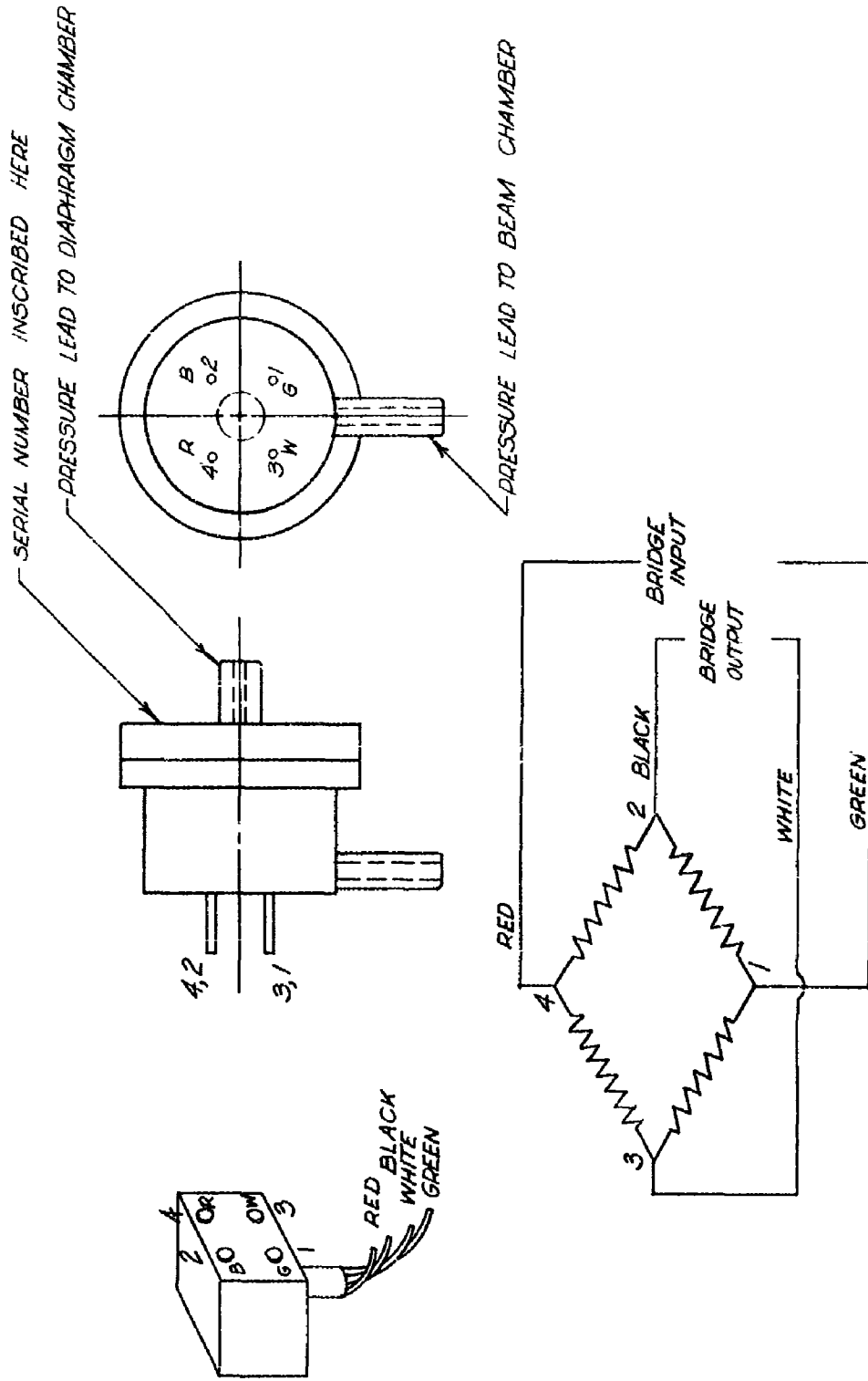


FIG. 29 TRANSDUCER TERMINALS & CIRCUIT DIAGRAM

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