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by

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A NOTE ON THE DESIGN AND CONSTRUCTION OF A LOW-PRESSURE CALIBRATOR AND A COMPARISON WITH SHOCK-TUBE AND STATIC CALIBRATION METHODS

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SUMMARY

This Report describes the design and construction of a semi-dynamic calibrator for use with transducers at sub-atmospheric pressures.

Pressure rise times of 500 μs have been achieved with pressure steps of the order of 5 mm Hg absolute. The results of calibration checks on three piezo-electric transducers are compared with shock-tube and static calibrations.

*Replaces R.A.E. Tech. Report 66110 - A.R.C.28318

CONTENTS

1 REQUIREMENT AND SPECIFICATION FOR A LOW-PRESSURE CALIBRATOR

Because of the very short running times and low densities in the 6" shock-tunnel experiments to measure pitot and surface pressures on models require transducers with a fast rise-time and the ability to measure pressures of the order of 0.1 psi absolute.

The only existing method of dynamic calibration of transducers employs a small shock-tube in which the pressure step of the shock wave is calculated from the known initial conditions in the tube, i.e. driver and channel pressures and the measured shock velocity. This method presents certain difficulties; in particular the measurement of shock velocity at very low channel pressures.

It was felt that an alternative calibrating device in which a known pressure could be so rapidly applied as to produce an impulse was essential to obtain meaningful results from shock tunnel experiments. It was also considered desirable to investigate the possibility of deviations between static and dynamic calibration constants.

The problem resolved itself into applying to a transducer a known pressure step with a minimum rise-time.

2 PRINCIPLE AND DESIGN OF CALIBRATOR

The method used was to couple a large vessel in which the pressure could be accurately measured to a transducer via a quick-acting valve. To keep the pressure rise-time to a minimum, pipework volume between the vessel and the transducer must also be a minimum. The transducer cavity must be very small in comparison to the vessel so that there is no measurable pressure drop when the valve is opened.

The scheme for this rig is illustrated in Fig. 1(a). The valve and its actuating solenoid are enclosed in a pressure vessel $13\frac{1}{2}$" I.D. and 19" long. The valve abutts onto an end plate into which the transducer is fitted. Fig. 1(b) is a photograph of the end plate and valve assembly. The valve seat is a standard "O" ring and the valve is held against the seal by a spring incorporated in the solenoid.

The vessel is connected to a vacuum pump and the pressure is measured with a Wallace and Tiernan vacuum dial gauge. There is also a vacuum connection to the transducer cavity. This design eliminates any pipework between the transducer and the vessel and keeps the volume of the transducer cavity to a minimum. The type of valve chosen ensures a relatively large valve orifice for a small valve movement. To use a lightweight valve was no advantage as the valve weight is negligible compared with the weight of the solenoid core, The calibrating rig was installed adjacent to the 3" x $1\frac{1}{2}$" calibrating shock tube and utilised a common vacuum system: Transducers could be readily transferred from the calibrating rig to the shock tube using the same cable and associated electronic recording equipment, Fig.7 is a photograph of the test rig with its associated vacuum equipment and recording instrumantntion.

3 DEVELOPMENT TESTS

The solenoid was designed to operate on 11 volts D.C. and using a 12 volt D.C. supply the pressure rise-time was in excess of 2 m sec. The voltage was increased in steps to 72 volts and the rise time was reduced to approximately 500 µsec (Fig.2). Fig.3 is a curve showing the effect of solenoid actuating voltage upon the pressure rise-time. 72 volts D.C. was chosen as the actuating voltage as this level was easily achieved using 12 v batteries. Repeated actuation of the solenoid at the high operating voltage throughout the series of tests did not appear to affect its working life.

The pressure in the cavity immediately ahead of and around tho transducer was reduced to at least 1 micron Hg before the solsnoid valve was actuated. Any slight leakage across the valve face was readily apparent in that the pressure rise-time increased by a factor of ten.

An attempt to reduce the valve opening time by reducing the core weight by machining out $\frac{1}{3}$ of the centre of the core (by weight) showed only a marginal improvement.

The first tests showed that the opening of the solenoid valve caused considerable mechanical noise on the pressure record. This was overcome by fitting a rubber buffer sleeve over the valve stem to act as a shock absorber. This can be seen in Fig.1(b).

Valve heads manufactured from steel, aluminium and nylon were tried in the tests but no one head was superior and tha steel head was finally used in all the calibration tests.

4 INSTRUMENTATION

Response time requirements demand that the transducers be mounted within the model and therefore the transducers must be small in size, Those in current use have quartz as their sensing clement and are available commercially. These transducers are normally used to measure pressures in the region of 2500 psi and arc being used at the extremely low end of their pressure range as no other suitable gauges are available at present.

Experience of other users of this type of transducer shows that a variation in calibration constant may exist between the gauge under static and dynamic calibration[1]. Static calibration is usually done on a dead-weight tester and dynamic calibration in a shock-tube.

The transducers used in the present work were the Kistler type 601A and 701A piezo-electric gauges and a similar type of gauge obtained from a research laboratory in the U.S.A. The Kistler 601A gauge has a natural frequency of 125 Kc/s and a rise-time of 4 microseconds. Its overall dimensions are 6 millimetres diameter by 15 millimetres long.

The Kistler 701A gauge has a natural frequency of 6.5 Kc/s and a rise-time of 7 microseconds. Its overall dimensions are 11 millimetres diameter by 26 millimetres long.

The American gauge has a rise-time of 3 microseconds. The natural frequency is not quoted. Its overall dimensions are 13 millimetres diameter by 11 millimetres long. Each transducer was calibrated in three modes, i.e. static, semi-dynamic and dynamic, using a Tektronix 535 oscilloscope with a Type D pre-amplifier and a Kistler Type 566 charge amplifier.

The triggering of the oscilloscope trace was synchronised with the switching of the solenoid valve in tho calibrating rig so that the rise-time of the pressure step could be observed.

5 TEST PROCEDURE

Each gauge was calibrated statically, (by steadily increasing the pressure in the transducer cavity to a series of fixed values,) semi-dynamically, (in the calibrating rig described in this Report), and dynamically in a shock-tube.

The tube used in these tests was the 3" x $1\frac{1}{2}$" shock-tube as described in a note by Stevens[2]. Preliminary calibrating runs in the shock-tube showed considerable mechanical noiso to be present on the pressure records before the arrival of the pressure-step, due to diaphragm rupture noise being transmitted along the length of the tube. This was reduced to an acceptable level by lagging the entire length of the shock-tuba with thick felt.

The gauges under test are also acceleration sensitive and the original brass transducer mounts were finally replaced by nylon mounts to rcduco the acceleration response to a minimum. These nylon mounts were also used in the semi-dynamic tests, The shock speed across the transducer was obtained by timing the transit of the shock-wave across two resistance thermometer detectors in the shock-tube wall, a known distance apart. The gauge under test was mounted centrally between these detectors.

The pressure step applied to the transducer was then calculated knowing the shock speed and the initial pressure in the channel. An atmospheric pressure driver was used in all the tests.

Figs. 4, 5 and 6, show the calibration curves for the three gauges for each method of calibration.

6 RESULTS

Examination of the points from the static and semi-dynamic calibrations for the Kistler 601A gauge shows a slight difference in output for a given pressure step throughout the pressure range tested, the output being less in the semi-dynamic mode. In each case the calibration curve is a straight line through the origin. Prom the shock-tube calibration however the points are randomly spaced about a straight line which does not appear to extrapolate linearly through the origin.

The Kistler 701A gauge shows similar properties although the static and semi-dynamic points lie on sensibly the same straight line calibration

The American gauge, while exhibiting the same tendencies as the Kistler gauges, shows a much wider variation in output when comparing the static and semi-dynamic calibrations. In these two modes the calibrations are linear except at pressures very close to zero where some deviation from linearity occurs. The dynamic calibration points are random about a straight line which does not extrapolate linearly through the origin.

It is not understood why the shock-tube calibrations for all the gauges do not pass through the origin, The intercept in each case, although not significant in terms of the range of the transducer, indicates a possible source of error if these gauges are used for low pressure measurement on the manufacturers calibration alone.

7 CONCLUSIONS

The semi-dynamic calibrator described above does not reproduce the same conditions as are generated in a shock-tube. It does however show a marked improvement on the present static method of calibration and is considered adequate for calibrating transducers to be used for surface pressure measurement on models in the working-section of a shock tunnel where steady flow times between 5 and 8 milliseconds are expected. For measuring the exact duration and steadiness of useful running times, where rise-times of the order of 200 microseconds or less are expected, the shock-tube method of calibration must be used,

The calibrator is simple to use and has the advantage that very low absolute pressure steps can be applied to any transducer. Existing dead-weight calibrators do not have this capability.

To avoid errors in pressure level measurement transducers should be calibrated in the mounting to be used in the shock-tunnel where possible, together with the associated cables and recording instrumentation.

It is intended to extend the range of this investigation to compare calibrations by the three methods outlined herein at higher pressure levels where it is believed tnc calibration discrepancies described may become much less evident.

REFERENCES

No.	Author	Title, etc.
1	L. Pennelegion	Uncertainties in pressure measurements using commercial transducers in short duration facilities, A.R.C. 26737, March 1965
2	D. R. Stevens	The evaluation of some commercial and development pressure gauges in a laboratory shock tube with a view to their suitability for use in shook tunnels. A.R.C. C.P. 677, March 1962

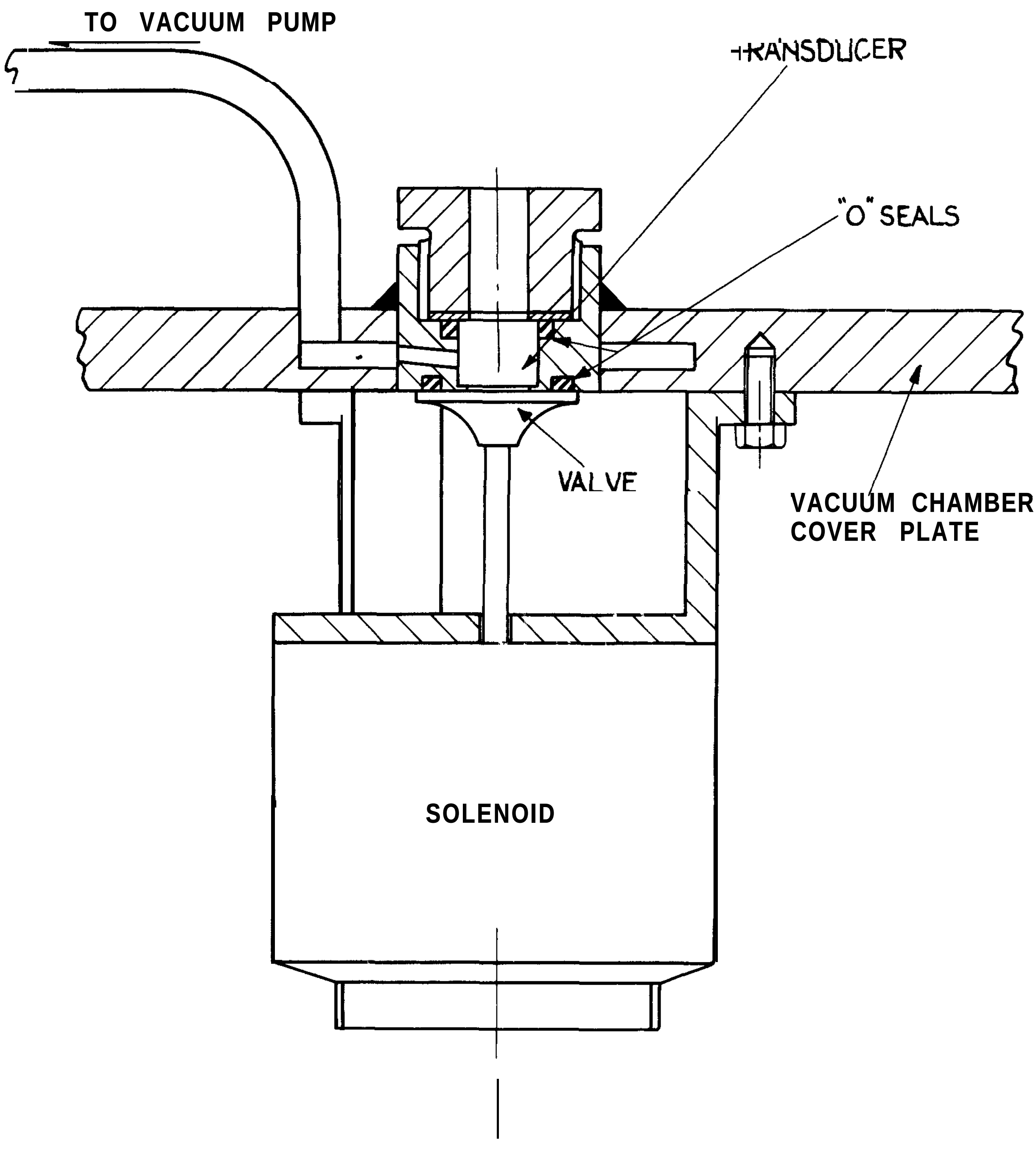


FIG. I(a) ARRANGEMENT OF SOLENOID VALVE AND TRANSDUCER IN CALIBRATION RIG

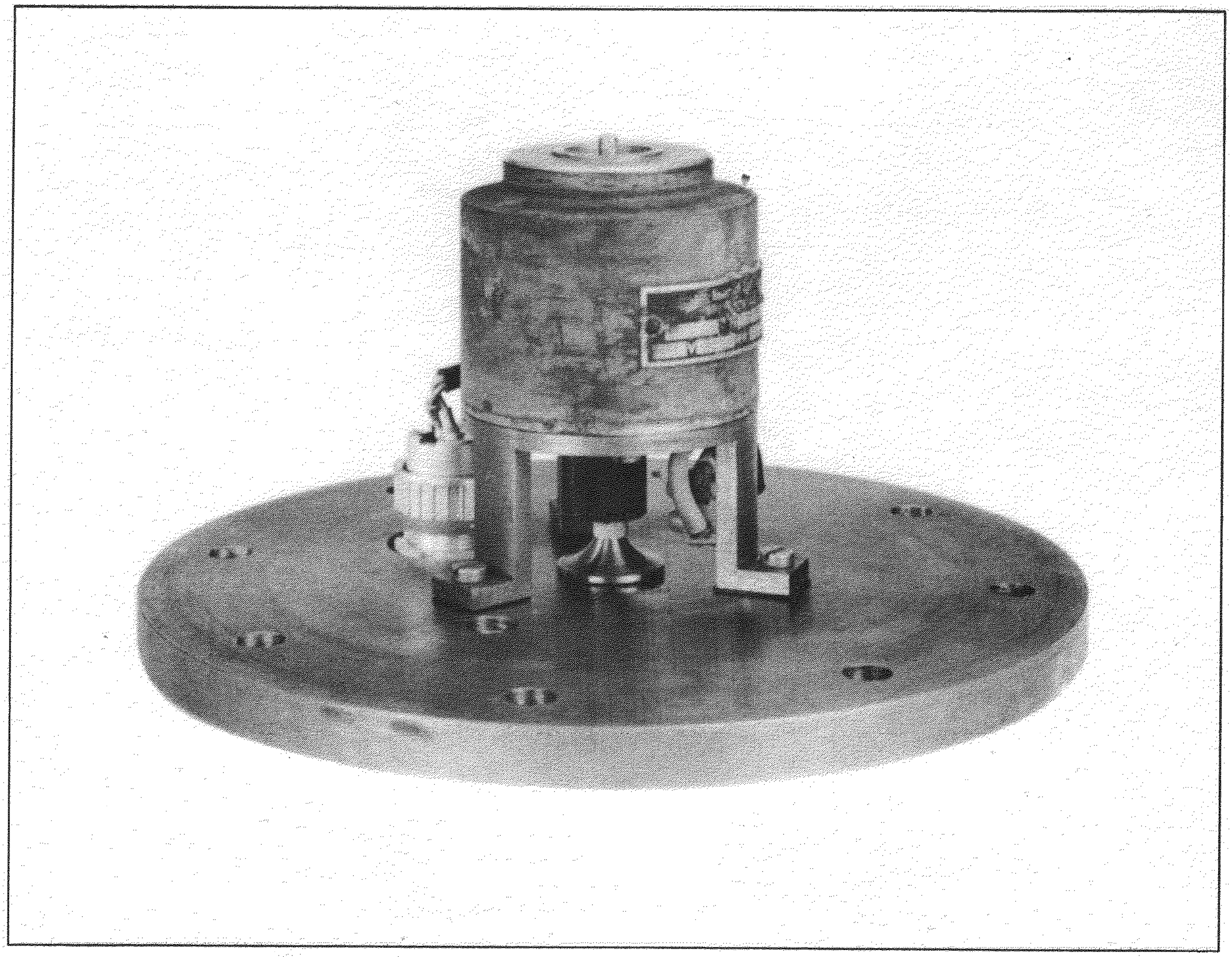
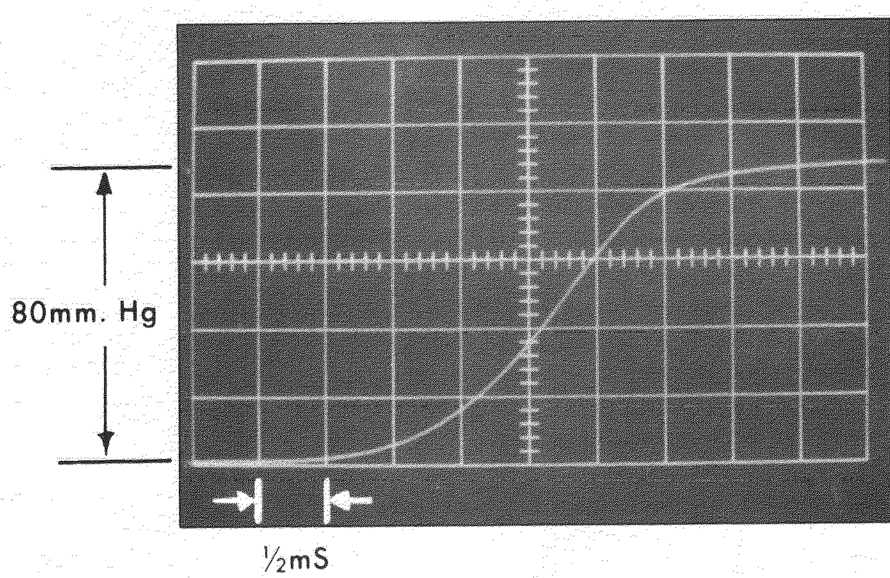
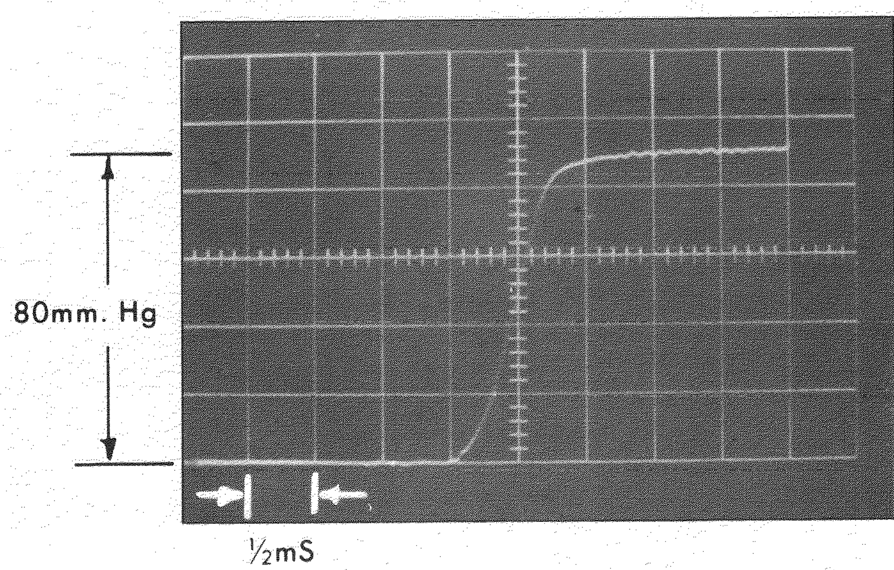


Fig.1b. Valve and actuating solenoid mounted on transducer plate



a. Solenoid supply 12 volts



b. Solenoid supply 72 volts

Fig.2. Effect of increasing solenoid actuating voltage on pressure rise-time

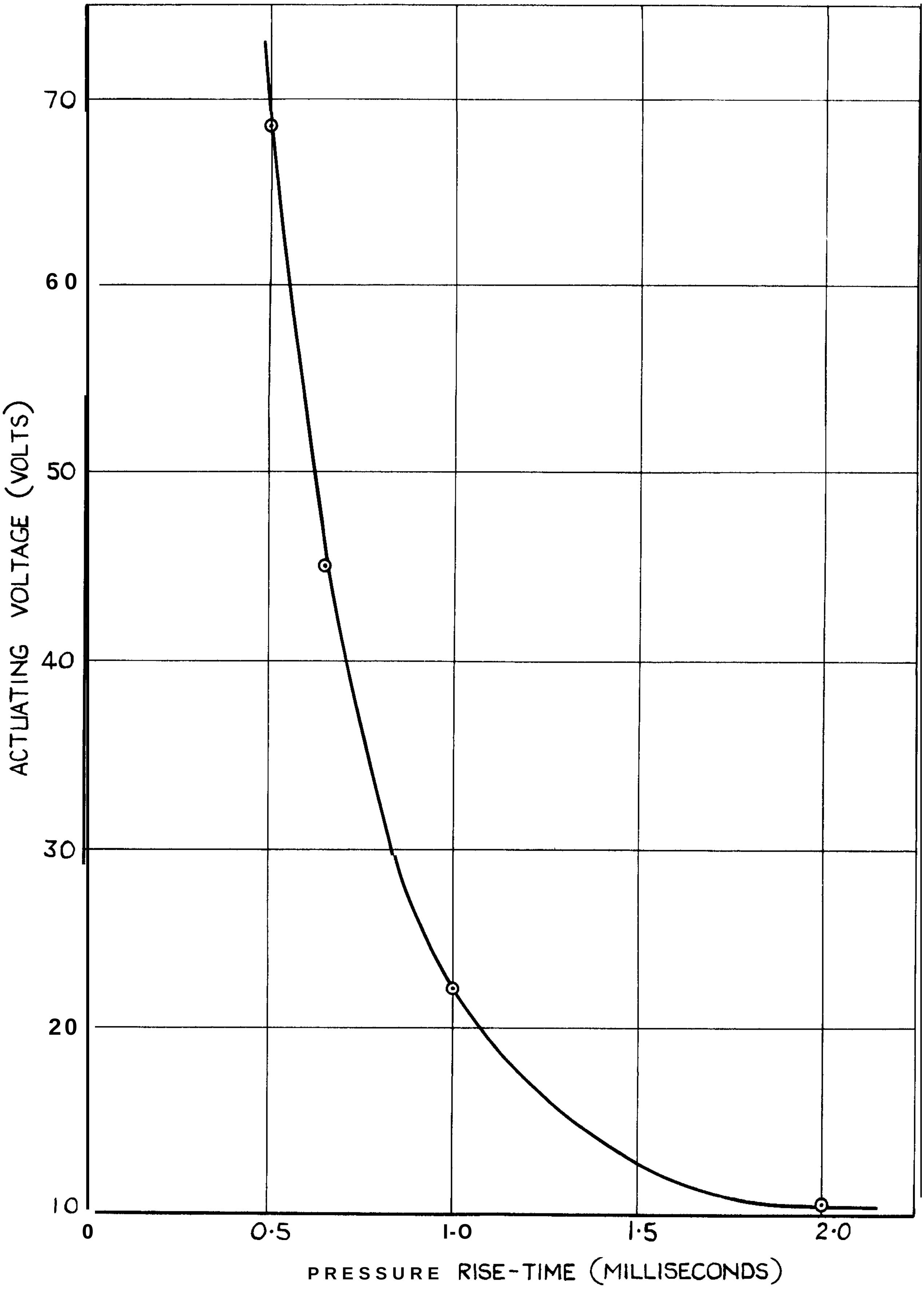


FIG. 3 EFFECT OF ACTUATING VOLTAGE ON SOLENOID ON PRESSURE RISE-TIME

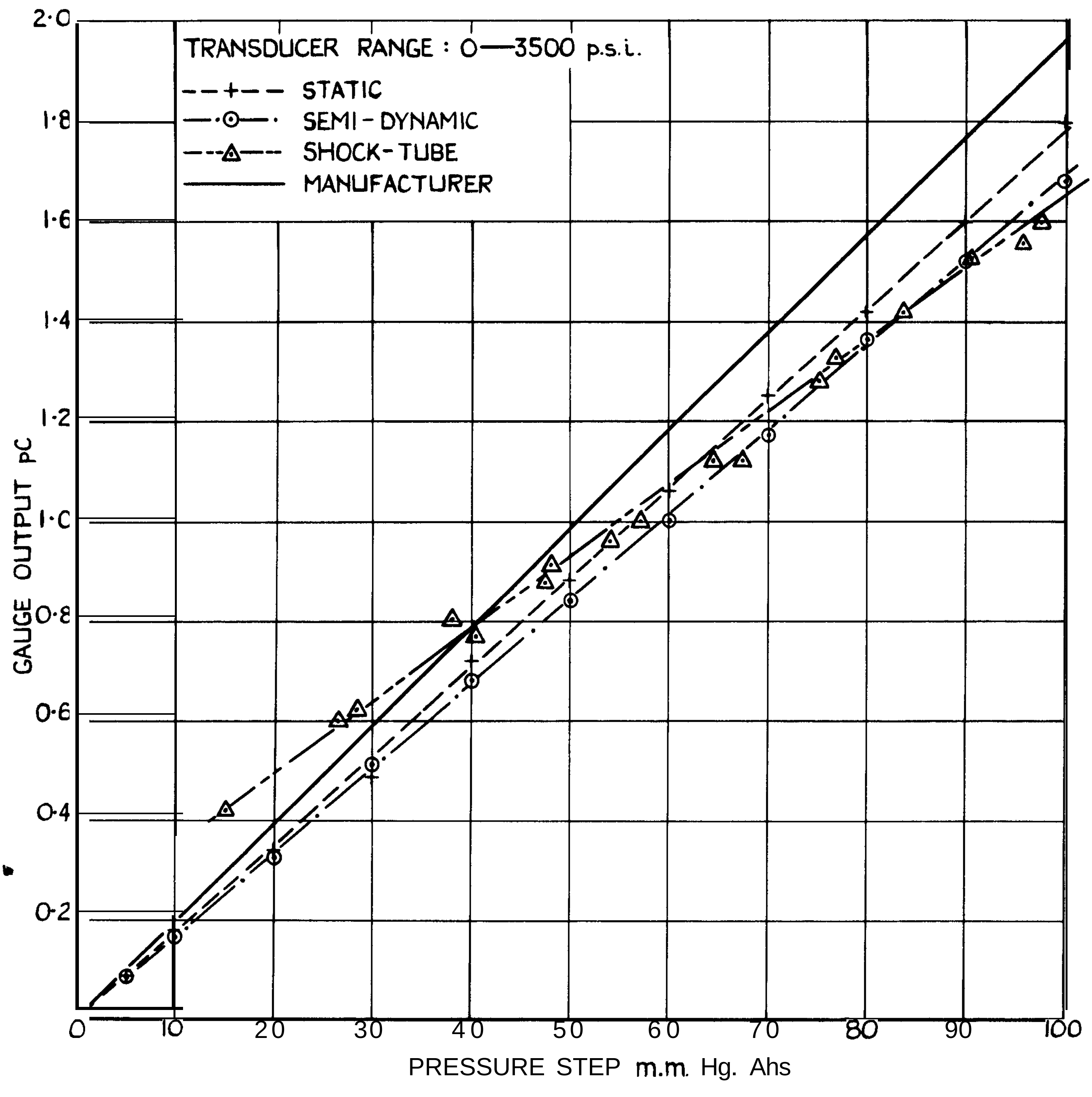


FIG.4 CALIBRATION OF KISTLER 601 A GAUGE

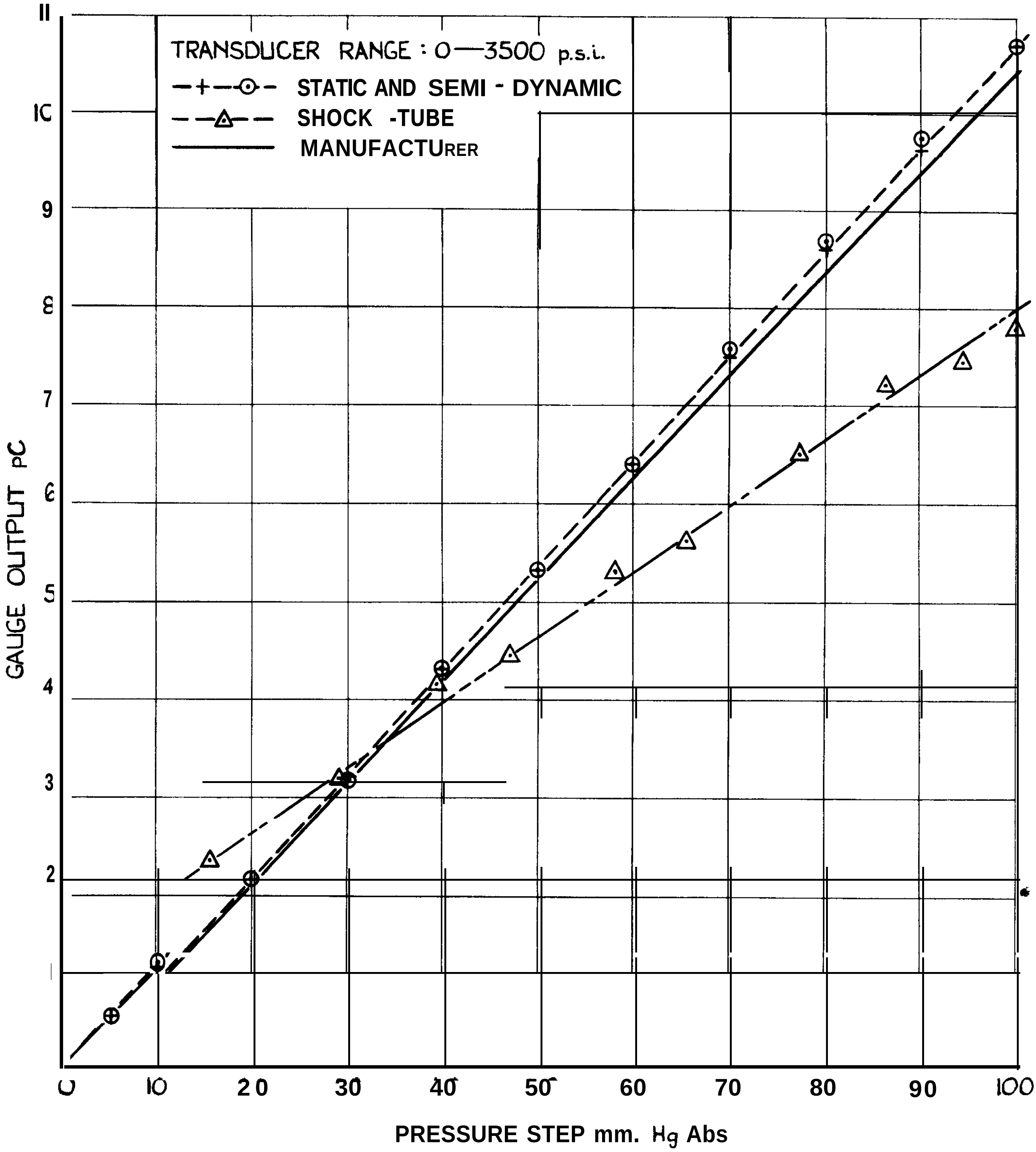


FIG. 5 CALIBRATION OF KISTLER 701 A GAUGE

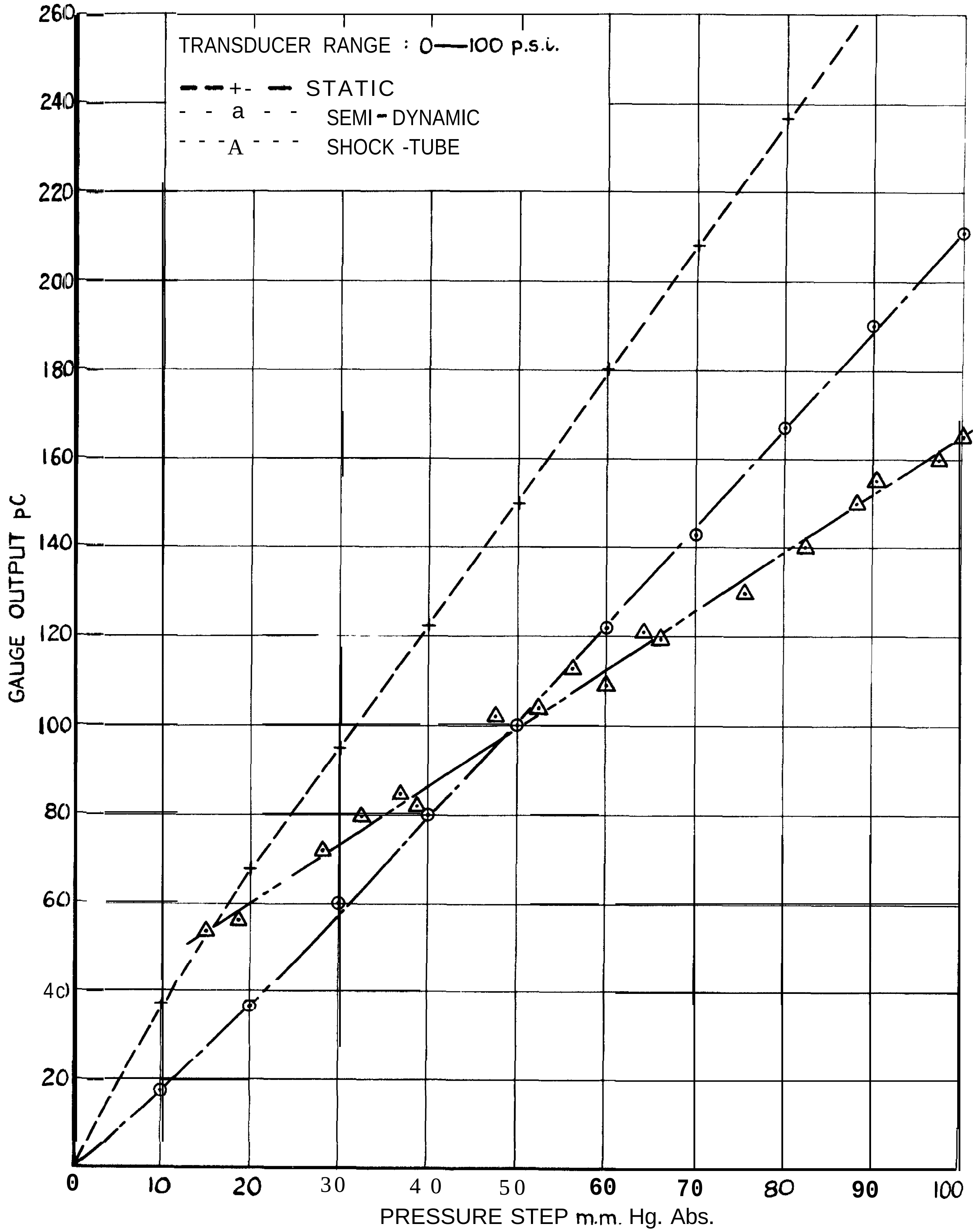


FIG. 6 CALIBRATION OF AMERICAN GAUGE

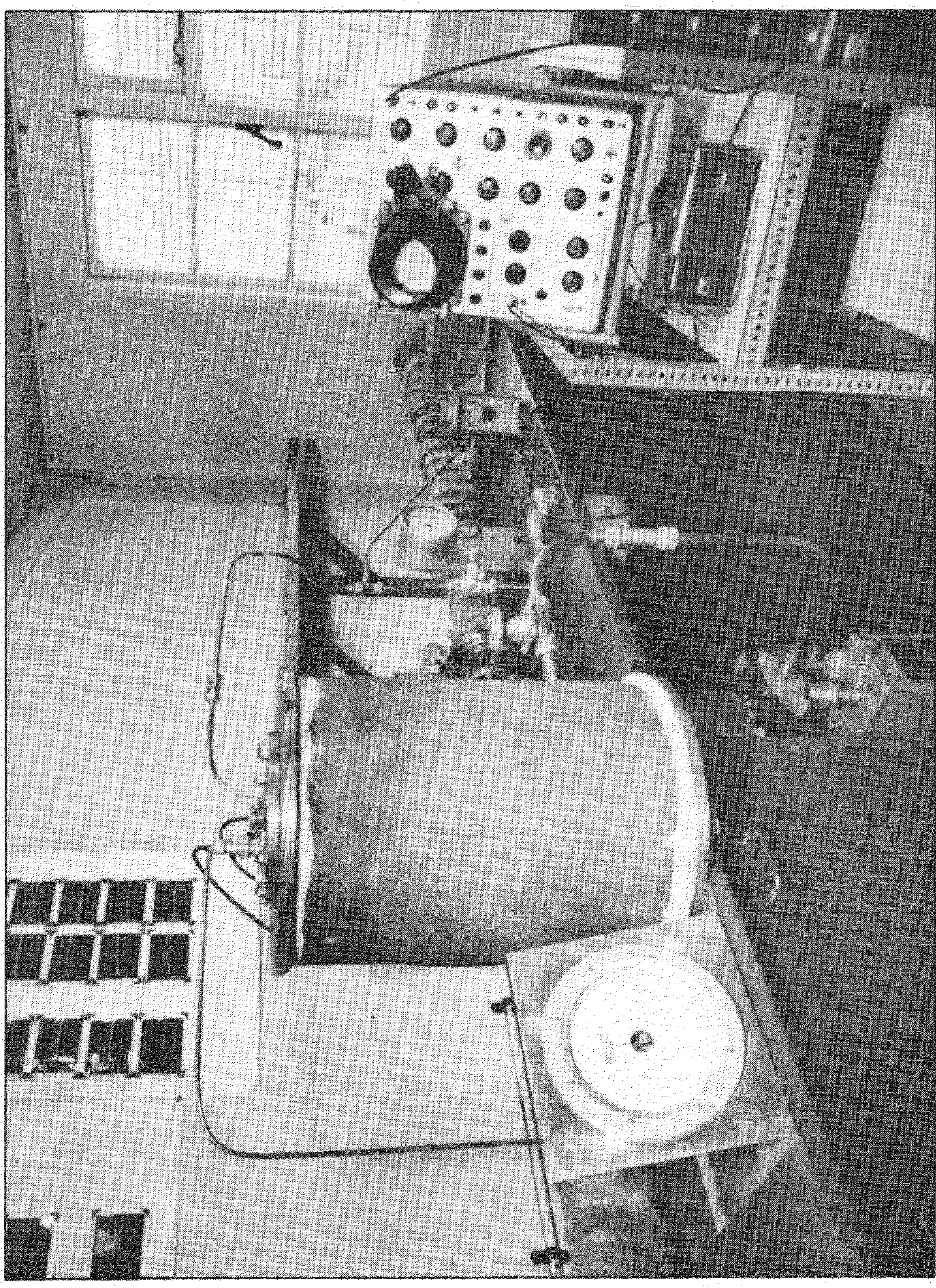


Fig.7. Calibrator rig and associated equipment

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