Fire Research Note

No 985

GAS EXPLOSIONS IN BUILDINGS

PART 2. THE MEASUREMENT OF GAS EXPLOSION PRESSURES

by

S A AMES

December 1973

FIRE
RESEARCH
STATION

50306

Fire Research Station
BOREHAMWOOD
Hertfordshire
WD6 2BL

Tel 01.953.6177

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FOREWORD

Following the Ronan Point disaster and the report of the Investigating Tribunal it was decided that the Fire Research Station of the Building Research Establishment would undertake a study of gas explosions in large compartments. In particular, the study would cover the factors affecting the development and severity of the explosions and the extent to which the pressures obtained could be relieved by venting.

In the context of the problem as a whole, the study is intended to provide the basic data on the form and magnitude of the transient stresses likely to be experienced by buildings, in the event of gas explosions involving one or more compartments. This information is required as a guide for safe structural design and for any re-appraisal of the relevant parts of Building Regulations 1972, Part D, England, or Building Standards (Scotland) (Consolidation) Regulations 1971.

The study has begun with explosions in a single compartment of realistic dimensions (1000 ft^3, 28 m^3) provided with a single opening of simple configuration, the size of which can be varied and which can be closed with panels having a range of bursting pressures.

/In view ..

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

In view of the progressive change to natural gas, which is lighter than air, and the probable circumstances of the Ronan Point explosion, special emphasis is placed on the explosion of layered gas/air mixtures and the effects of layer depth, composition and point of ignition.

The principal measurements consist of high-resolution pressure-time records at points both inside and outside the compartment. In general, these pressure records are complex, including both positive and negative pressures, and attention is given to the exclusion of spurious effects due to mechanical vibration and transient heat pulses accompanying the explosion.

The study is to be extended to gas explosions in multiple compartments communicating by door openings and corridors. Here, particular attention will be given to the effects of turbulence generated at openings, bends and obstacles and the possibility of increasing pressures as explosion propagates from one compartment to another.

This series of notes comprises detailed accounts of phases of the work as it proceeds. A project of this magnitude necessarily involves a considerable amount of preliminary work in the development of equipment and procedures all of which needs to be placed on record, but, in isolation, may sometimes appear somewhat remote from the objectives. This foreword is intended to facilitate the presentation of the detailed material with a minimum of introductory matter - no more than is needed to indicate the place of the particular work reported in the project as a whole. Reports of results and conclusions from this study will be included in the series at appropriate stages as the work proceeds and, correspondingly, these will need to contain a minimum of experimental detail.

Reports preceding the present one in the series are:

FR Note 984. Part I - Experimental explosion chamber by P S Tonkin and C F J Berlemont.

SUMMARY

A critical study has been made of the system used to measure explosion pressures developed in a 28 m^3 steel compartment. The pressure measuring equipment used is based on a quartz piezo transducer and a charge amplifier. The interfering effects of vibration and radiation have been examined; a transducer mounting technique has been devised and a diaphragm coating material found to eliminate these unwanted effects. A portable apparatus has been devised for the calibration of the system using a pressure cycling technique.

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INTRODUCTION

(i) General

In order to examine the effects of venting of gas explosions in large compartments[1] it was necessary to examine, critically, methods of measuring the transient pressures developed. The explosions themselves were generated in a 28 m^3 steel compartment using natural gas/air mixtures[1]. The pressure measuring equipment used for this work consisted of quartz piezo electric transducers with appropriate charge amplifiers. In this application the transducers are subjected to high levels of heat radiation and vibration, both of which effects can produce spurious signals. It was necessary to examine the levels of these effects during actual explosions and devise means of eliminating or attenuating them.

Since this and subsequent work was to be carried out at a remote field site, a portable calibration apparatus was devised.

This Note describes the preliminary work; certain conclusions are drawn and certain areas of further investigation are suggested.

(ii) Types of interference examined

Quartz piezo-electric type pressure transducers were used having a very high frequency response (80 k Hz) coupled with an ability to record quasistatic pressures of many seconds duration. Transducers of this type can suffer from the disadvantages of being sensitive to interference by mechanical shock, vibration and thermal radiation.

The effects of mechanical shock and vibration are clearly exhibited when the object in which the transducer is mounted is struck with a heavy object. The high frequency signals produced in this manner are broadly symmetrical (as seen in Fig.1). The effects of vibration are particularly marked in the application under discussion due to the resilience of the steel walls of the test compartment.

When the transducer diaphragm is exposed to thermal radiation the expansion of the diaphragm and other parts of the transducer can give rise to an output signal which would indicate that a negative-going pressure change had occurred. When recording actual explosion pressures this phenomenon can be seen as a transient baseline drift, as shown in Fig.2 where the drift reached maximum value of about 1 psi after 0.8 sec. This problem can sometimes be overcome by measuring the pressures superimposed on the estimated baseline drift when the latter is obvious. This does not take into account, however, any change in sensitivity which may have accompanied the baseline change. The effects of radiation are particularly acute when examining large scale gas explosions; since the radiation levels are higher and of longer duration than those experienced with smaller scale explosions.

Electrical interference in the form of 50 Hz mains pick up, also responsible for spurious signals, can usually be overcome by careful attention to the earthing of the whole system. In this case it was found necessary to reduce the amplifier input lead to 0.5 m to eliminate it completely. Other causes of slow, continuous baseline drift sometimes observed with this type of equipment are the presence of moisture, dirt and grease or other electrically conducting material at the transducer terminal. This can be remedied by cleaning with a solvent or aerosol electrical cleaner and drying in air, or in an oven in severe cases. These, however, are well known precautions and as such are not the subject of experimentation here.

PRESSURE MEASURING EQUIPMENT AND CALIBRATION

The pressure transducers used in this work were a commercial product of the quartz piezo-electric type having an output of approximately 150 pico coulombs per atmosphere. The output from a transducer is fed to a charge amplifier (see Fig.3). This amplifier consists of a high input impedance (10^{14} ohms) DC amplifier with capacitive negative feed-back. This effectively converts the electrostatic charge developed by the transducer under pressure into a proportional DC voltage output.

The output from the amplifier was monitored using a cathode ray oscilloscope from which images could be recorded using a camera with polaroid film. In order to obtain a record of the pressure developed during a gas explosion the oscilloscope was used in the single sweep mode giving a sweep duration of 2 sec, a triggering pulse being supplied by a synchoronizing unit which switched a 4 volt signal to the oscilloscope at the same time that the gas in the test chamber was ignited. The basic arrangement is shown in Fig.4 and includes a remote reset switch necessitated by the close proximity of the amplifier to the explosion cell.

In order to carry out regular checks on the sensitivity (and to a limited extent the dynamic response) a portable calibrating apparatus was devised the details of which are shown in Fig.5. A small electric pump delivers air to a reservoir of 10 l capacity. The pressure inside the reservoir is controlled by the setting of a bleed valve and is measured by a bourdon type gauge which was calibrated using a dead weight tester. A three way solenoid valve permits application of the test pressure to the transducer either manually by the use of a push button or automatically by the use of a pulse generator (the circuit of which is shown in Fig.6) which enables the pressure to be applied and removed alternately at regular intervals. In the prototype the frequency of the pressure pulses was adjustable from 1 to 10 Hz.

When using the pulse generator, the rapidity of the solenoid opening and shutting caused some oscillation within the transducer mount. With the fast cycling speed, the transducer signal did not come to rest at the calibration pressure. Fig.7(a) shows a pressure record where these unwanted oscillations (100 Hz) can be seen superimposed upon the test pressure pulses (10 Hz).

This phenomenon was suppressed by restricting the flow of gas to the transducer by means of a pinch valve on the rubber tubing between the solenoid valve and the transducer mount. Results from the effectively suppressed system are shown in Fig.7(b). Care was taken not to restrict the flow so much that the calibration pressure was never achieved, as shown in Fig.7(c). The problem of resonance was improved by making the cavity in the mount as small as possible and the connecting tube as short as possible.

Throughout the period of the preliminary explosion tests (3 months) the calibration apparatus was used frequently to keep a constant check on the performance of several transducers at calibration pressures up to 70 kN/m^2 (10 psi). Throughout this time no measurable change in performance was observed.

The apparatus was found to be reliable and convenient and using the pressure cycling technique, calibration results could be kept as a permanent record as an oscilloscope photograph as shown in Fig.8. It might be possible to improve the ease of calibration still further by the use of a special transducer mount with an integral valve (available commercially) to permit calibration whilst the transducer is still mounted on the test chamber.

SUPPRESSION OF UNWANTED EFFECTS

VIBRATION

In the initial experiments the transducer was fixed with its diaphragm flush with the inside surface of the mount (see Fig.9(a). In order to measure the effects of vibration, a dual mount was constructed to accommodate two similar pressure transducers, one being normally 'flush' mounted the other being mounted in a blind hole. The flush mounted transducer recorded pressure plus vibration and the blind transducer recorded only vibration as a reference, see Fig.9(b). Using this mount attached to the wall of the compartment a series of experimental explosions were monitored to measure the effect of vibration. A typical record is shown in Fig.10, of which trace b shows signals due to vibration at a level equivalent to ± 1.4 kN m^2 (± 0.2 psi).

In order to reduce the level of interference by vibration the duel mount was attached to the end of a short length, 100 mm (4 in) of 50 mm dia (2 in) convoluted rubber tube (see Fig.9c and 11). The mount was supported by a 75 mm thick slab of polyurethane foam. This arrangement was to act as a shock absorber to prevent wall vibrations being transmitted to the mount and the transducers. A typical result obtained using this system is shown in Fig.12. By using the convoluted tube mount the signals due to vibration were suppressed to a very low level, viz 0.14 kN/m^2 (0.02 psi) compared with an explosion pressure of 3.5 kN/m^2 (0.5 psi).

RADIATION

During large-scale experiments with the convoluted rubber tube to reduce vibration effects it was observed that the depression of the baseline due to radiation was also reduced presumably due to the shading afforded by the tube. Although the baseline drift was attenuated in this way, any influence that the radiation might have upon the sensitivity of the system could not be observed under operational conditions.

The levels of radiation occurring during several explosions were monitored using a fast response infra-red radiometer[2] calibrated by comparison with standard thermopile radiometer and a premixed methane/air flame.

In order to calibrate the radiometer it was fixed in a frame next to the thermopile facing a premixed methane/air burner in such a way that each detector could be swung into position alternately. The frame was fixed on rails so that the distance between the flame and the radiometer could be varied. The output of each detector was measured using a digital voltmeter with an accuracy of 0.01 mV. The results of this calibration are shown in Fig.13.

In order to monitor the radiation level reached at the transducer diaphragm during the large scale explosion tests the calibrated radiometer was placed in the position normally occupied by the transducer and measurements taken during several explosion tests. The output of the radiometer was recorded photographically from an oscilloscope and a typical result is shown in Fig.14 where it can be seen that the maximum radiometer output of 4.5 volts occurred 0.6 seconds after ignition corresponding to about 4 kW/m^2.

In order to examine the effects of radiation on the sensitivity of the pressure transducer, a special mount was made with a window to facilitate calibration of the transducer whilst being exposed to radiation. (See Fig.15). The attenuation of the radiation due to the mount window was first measured and found to be less than 5%.

Several calibration tests were carried out using the pressure cycling technique previously described, during which the transducer was exposed to radiation from a pre-mixed methane/air flame of a similar level and duration to that experienced during the explosion tests (kW/m^2 for 2-5 sec), the length of exposure being controlled by an interleaf camera shutter. The warming up and cooling effects were both examined using a cyclic calibration pressure of 15 kN/m^2 (2 psi) see Fig.16. It can be seen that this level of radiation produces no measurable change in response to the applied pressure ($<$ 2%), although the baseline was depressed by an amount equivalent to 1 psi (7 kN/m^2).

The effects of a protective coating on the transducer diaphragm, to absorb the radiation, were examined by carrying out calibration tests similar to the radiation test above using pressure cycling but with the transducer diaphragm coated with (a) a 3 mm layer of silicone grease and (b) a 3 mm layer of a commercial silastomer.

Coating the transducer with a 3 mm layer of silicone grease reduced the baseline depression, but only by 20%. The use of a 3 mm layer of silastomer, however, eliminated the baseline depression almost completely at the radiation level of 5 kW/m^2 and a switched calibration pressure of 15 kN/m^2. See Fig.17.

Finally, if it becomes necessary to pursue the subject of interference further, it may be noted that acceleration compensated transducers are available and their use might eliminate the need of an anti-vibration mount. A considerable reduction in interference might be afforded by mounting the transducer at right angles to the normal so that the vibration is not applied to its most sensitive axis and the diaphragm is not facing the source of radiation. It may be possible to make quick sensitivity checks on the transducers whilst they are still attached to the explosion chamber with the use of a special mount equipped with a two way gas valve.

CONCLUSIONS

Preliminary work with large scale gas explosions has shown that a type of quartz piezo-electric pressure transducer is subject to interference by both radiation and vibration. Both types of interference can be suppressed by the use of a special mount and by coating the transducer diaphragm with a commercial silastomer. Although the levels of radiation experienced in the explosion tests (4 kW/m^2) tended to displace the pressure record baseline, it has been shown that the sensitivity is not measurably affected.

A portable calibration apparatus was devised to facilitate 'on site' testing and was also used to examine the effects of interference on the sensitivity of the pressure measuring system.

REFERENCES

1. TONKIN, P S and BERLEMONT, C F J. Gas explosions in buildings. Part I. Experimental explosion chamber. FR Note No.984. In preparation.

2. TUCKER, D M. A new radiometer for monitoring fire extinction experiments. FR Note No.968, 1973.

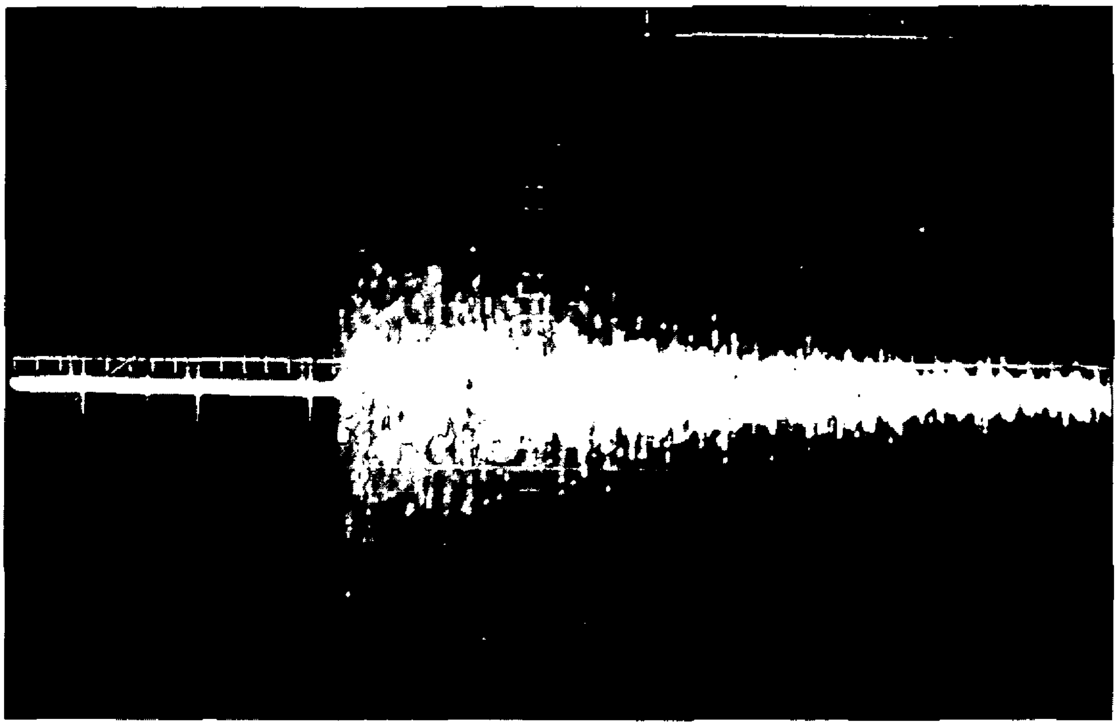
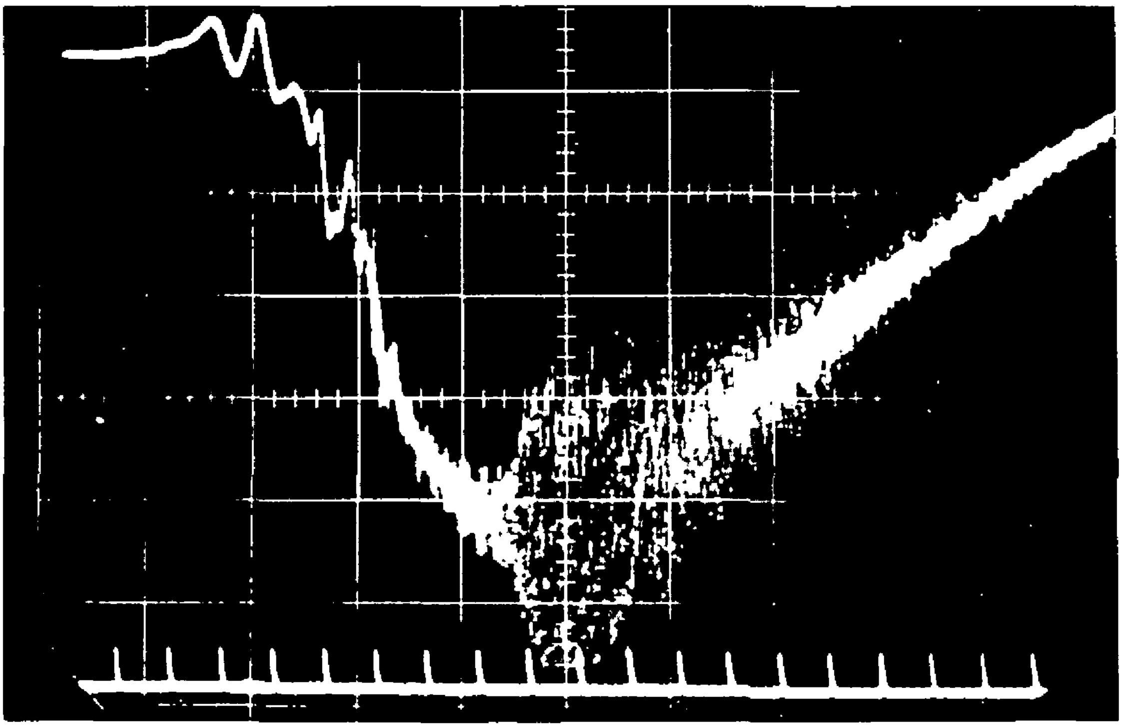


FIG.1. EFFECTS OF VIBRATION INDUCED BY
STRIKING TRANSDUCER MOUNT



1.4 kN/m^2 (0.2 psi) PER DIVISION

0.1 Second Marker

FIG.2 TYPICAL PRESSURE RECORD SHOWING BASELINE DRIFT DUE TO RADIATION AND VIBRATION INTERFERENCE DURING A LARGE GAS EXPLOSION

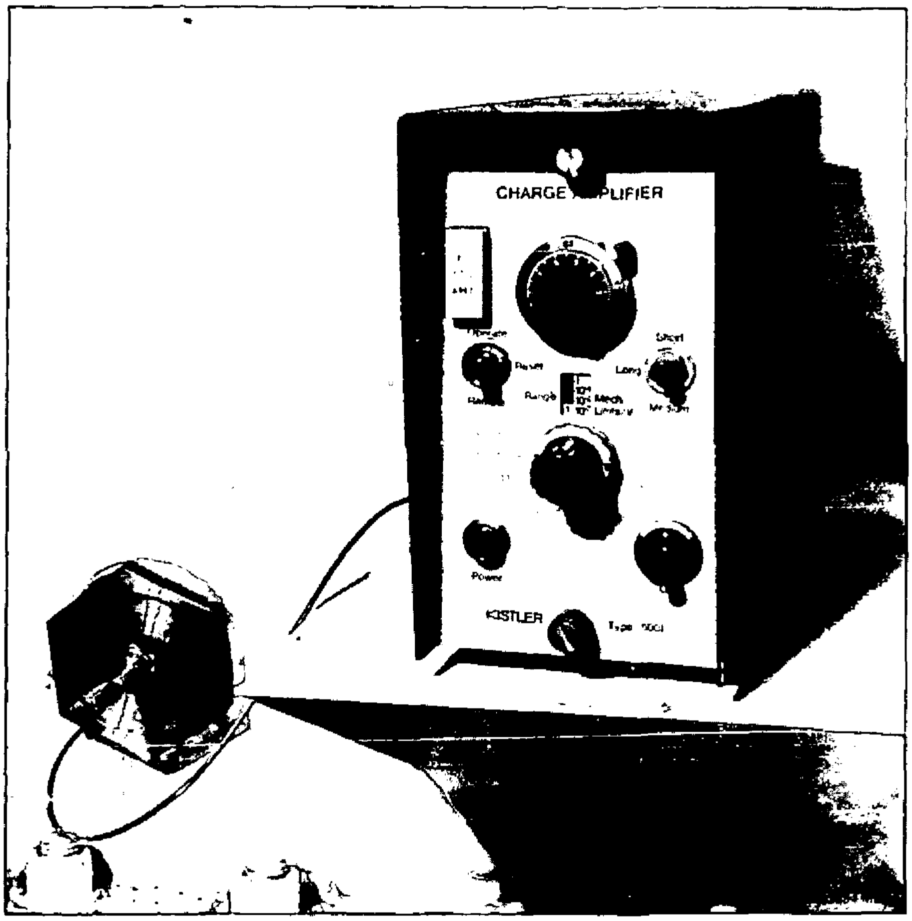


FIG.3 TRANSDUCER AND AMPLIFIER

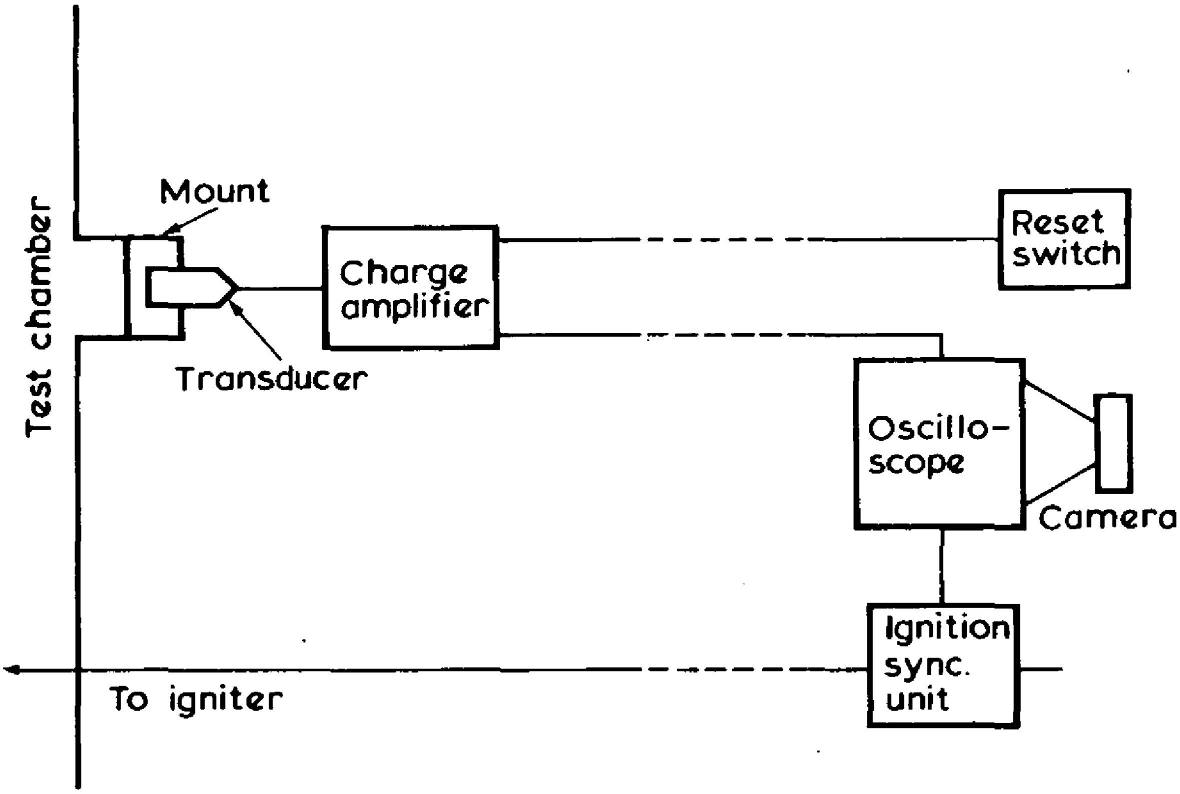


Figure 4 Basic pressure measurement system

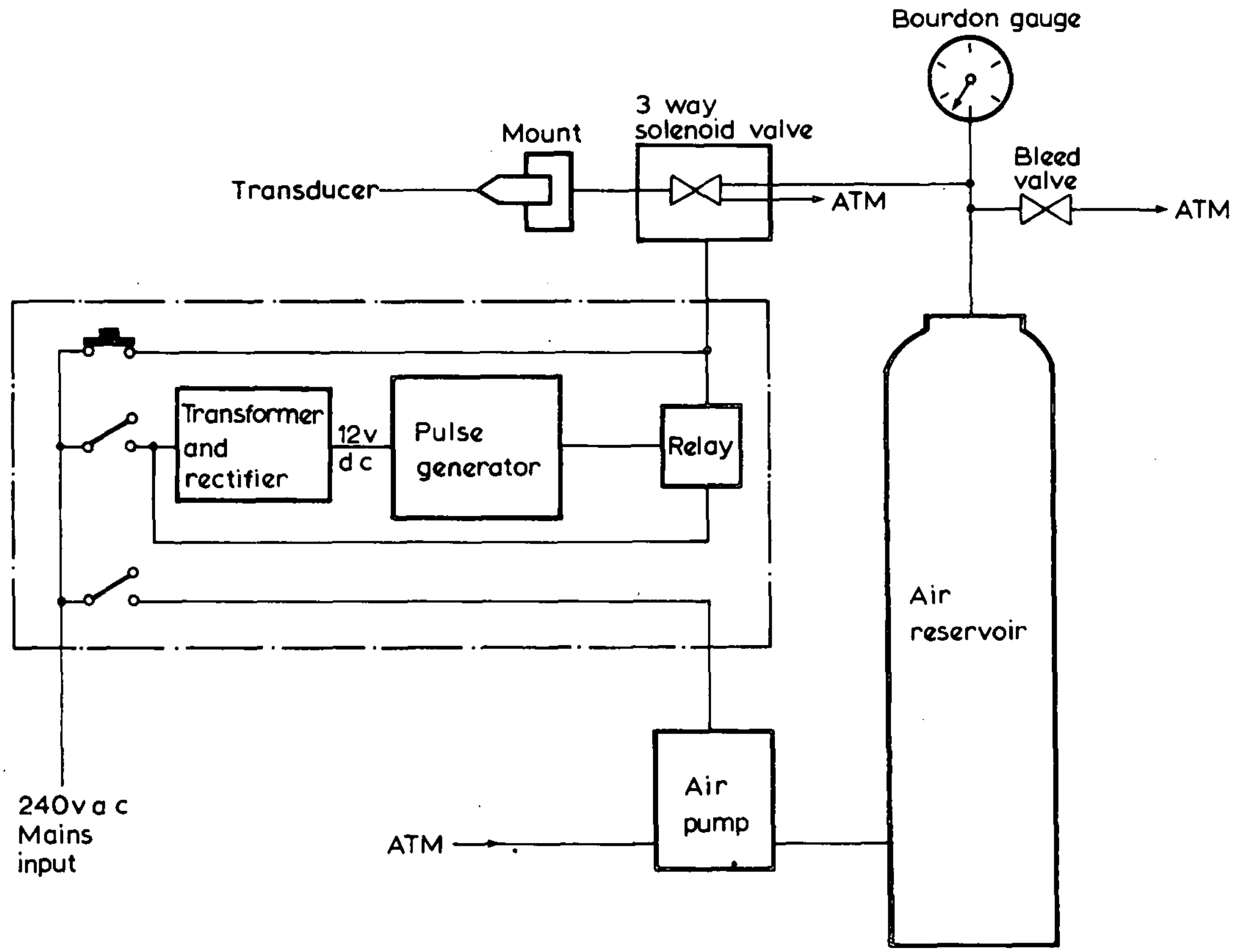


Figure 5 Calibration apparatus

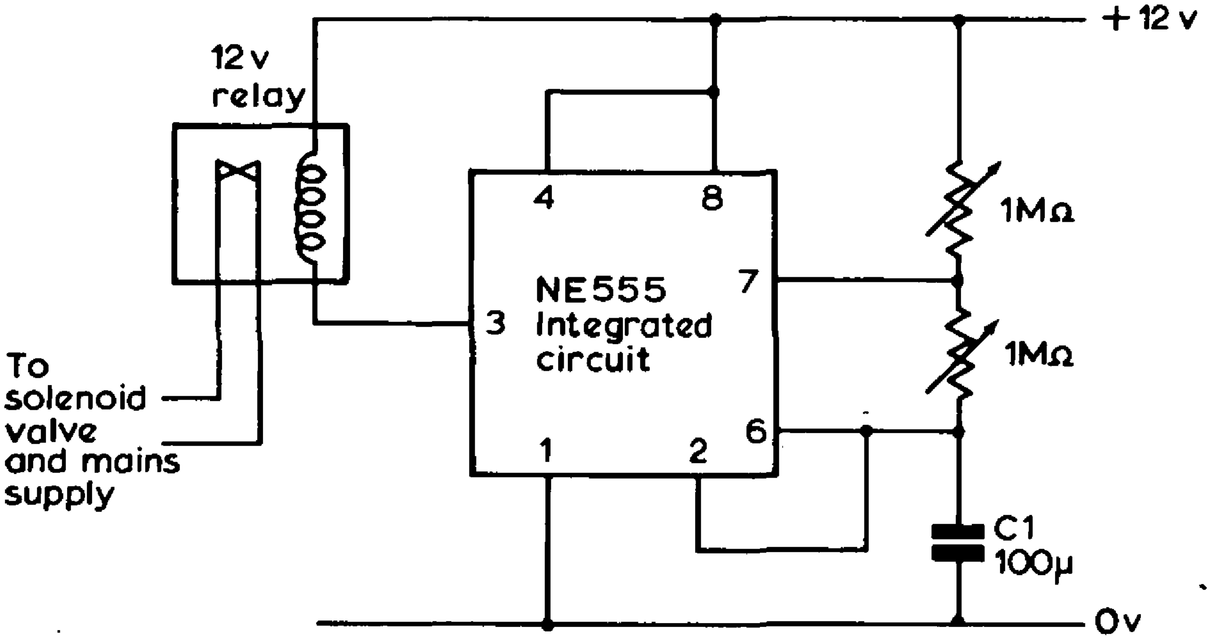


Figure 6 Circuit of pulse generator

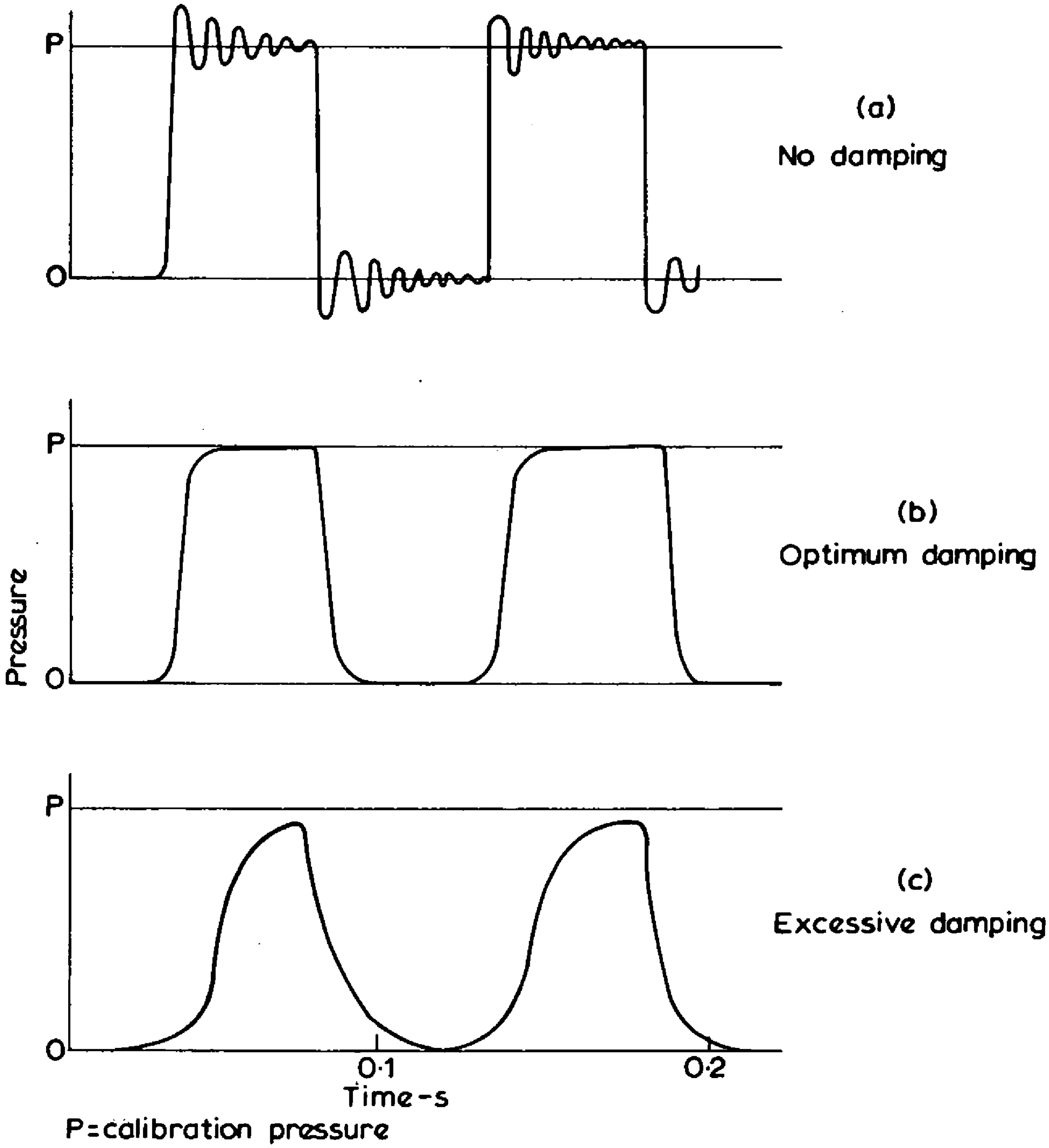


Figure 7 Pressure cycling, effects of damping

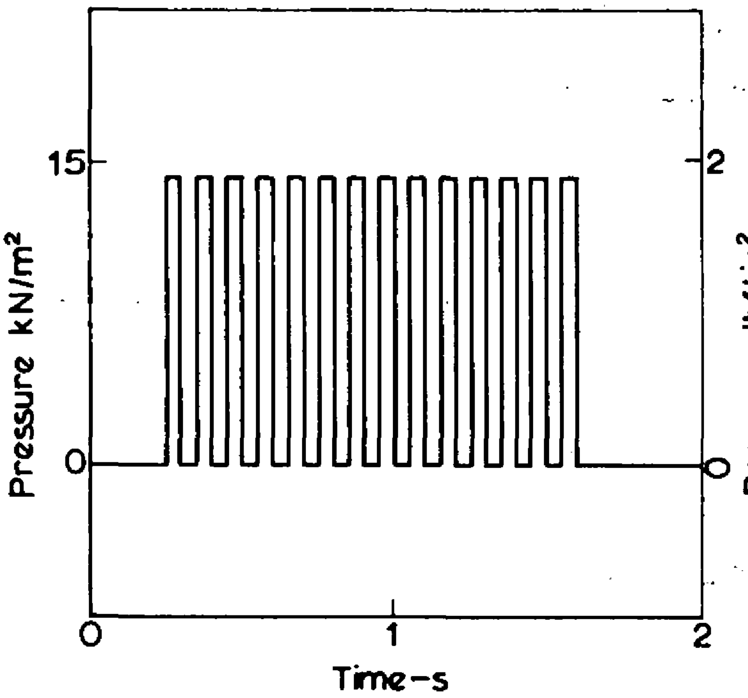
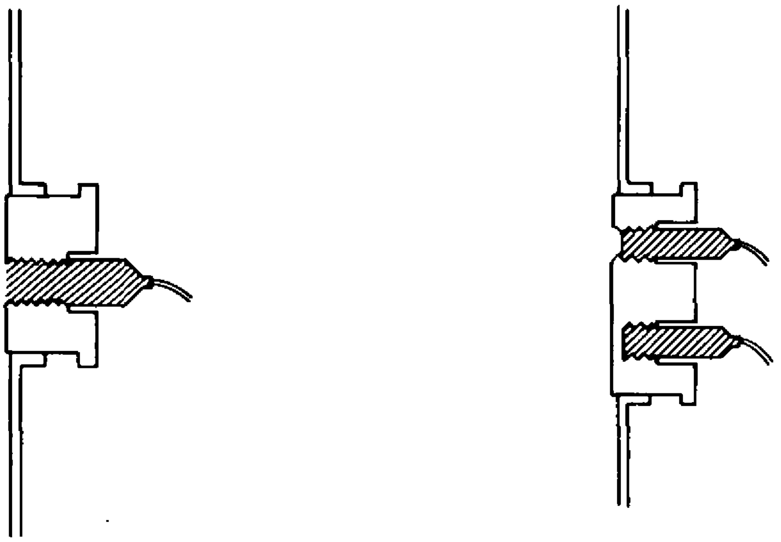
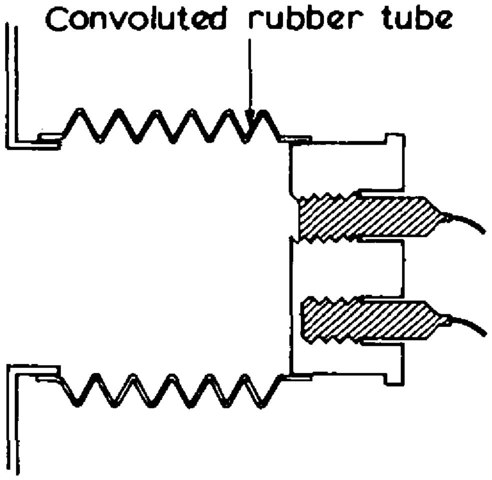


Figure 8 Calibration record



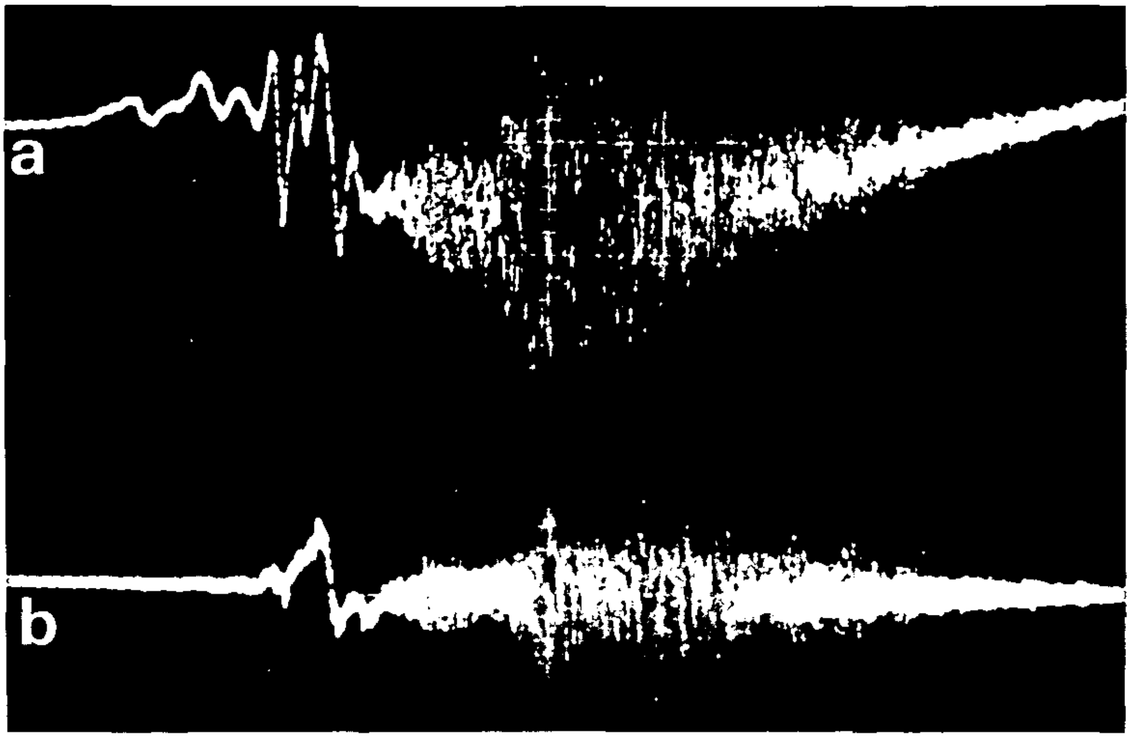
(a) Flush mount

(b) Dual mount



(c) Dual mount with antivibration tube

Figure 9 Types of transducer mount



$1.4\ kN/m^2$ (0.2 psi) PER DIVISION

0.2 seconds per division

a) pressure + vibration

b) vibration only

FIG.10 OSCILLOSCOPE RECORD SHOWING VIBRATION AND PRESSURE RECORDS OBTAINED FROM UNPROTECTED TRANSDUCERS.

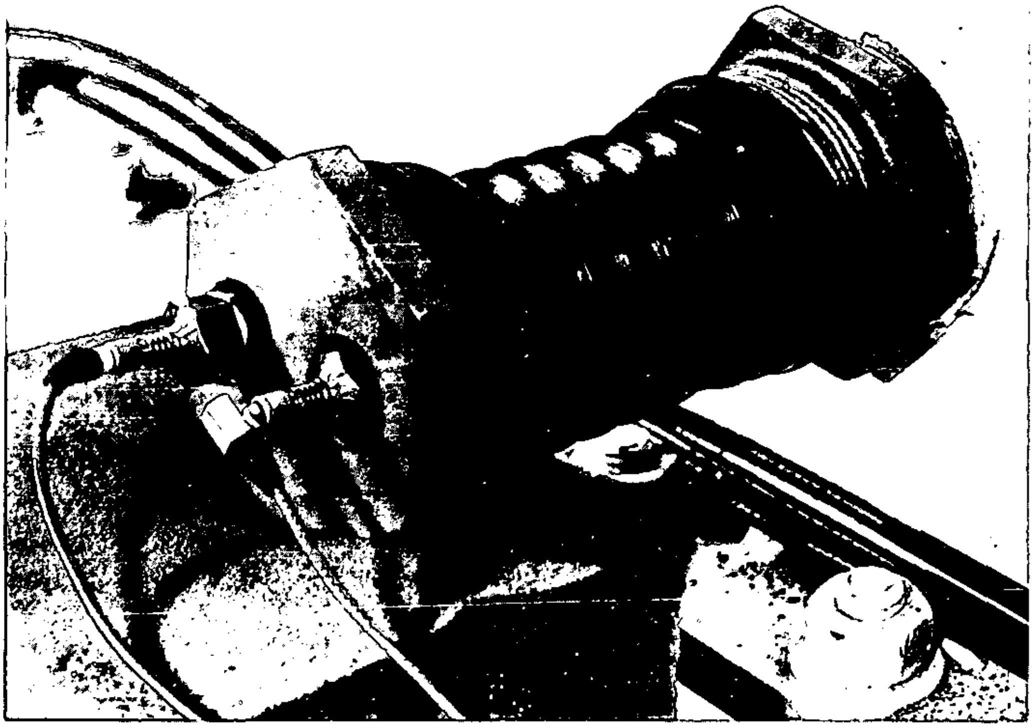


FIG.11 DUAL MOUNT AND CONVOLUTED TUBE
SHOWING METHOD OF MOUNTING

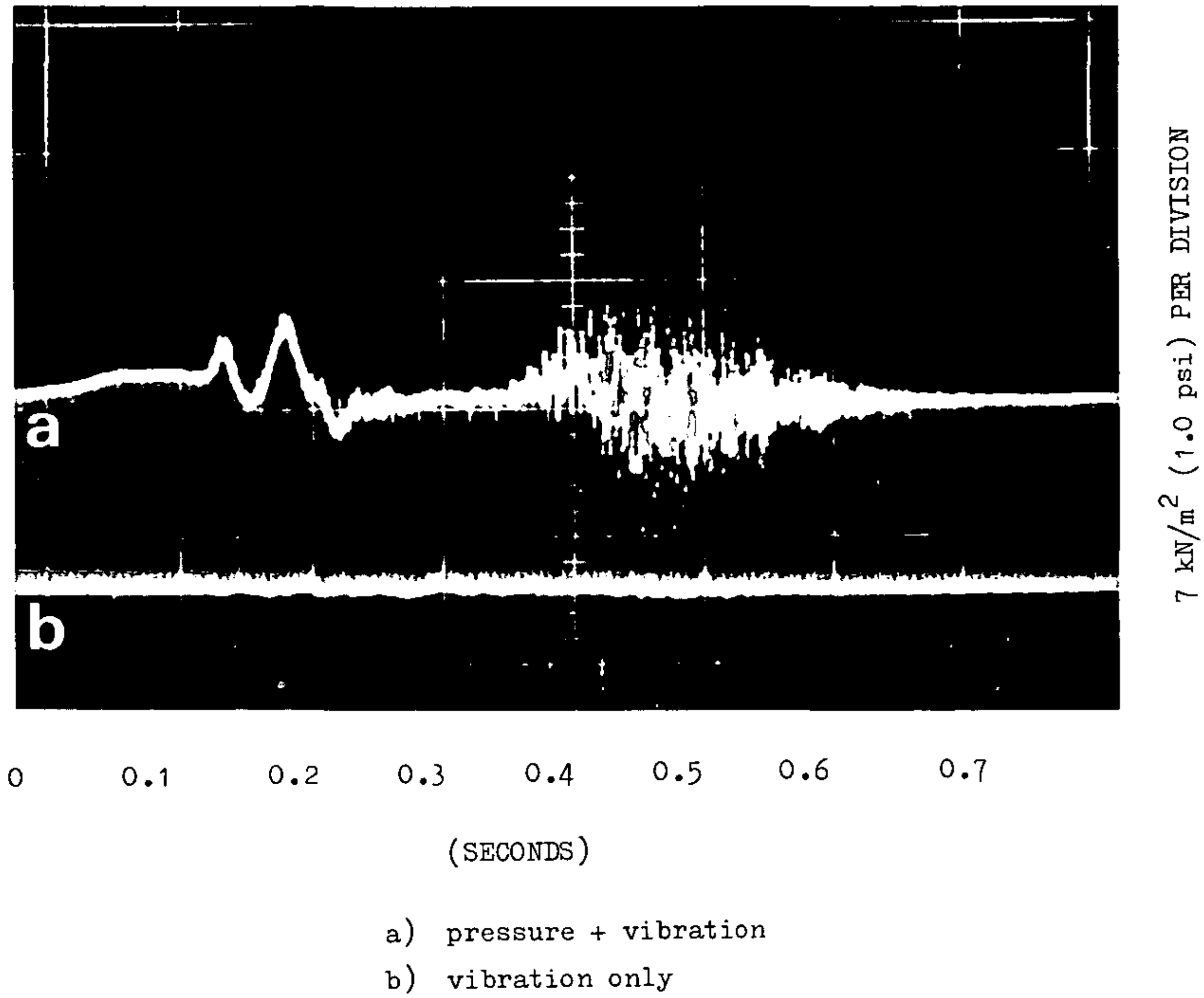


FIG.12 OSCILLOSCOPE RECORD SHOWING VIBRATION SUPPRESSION

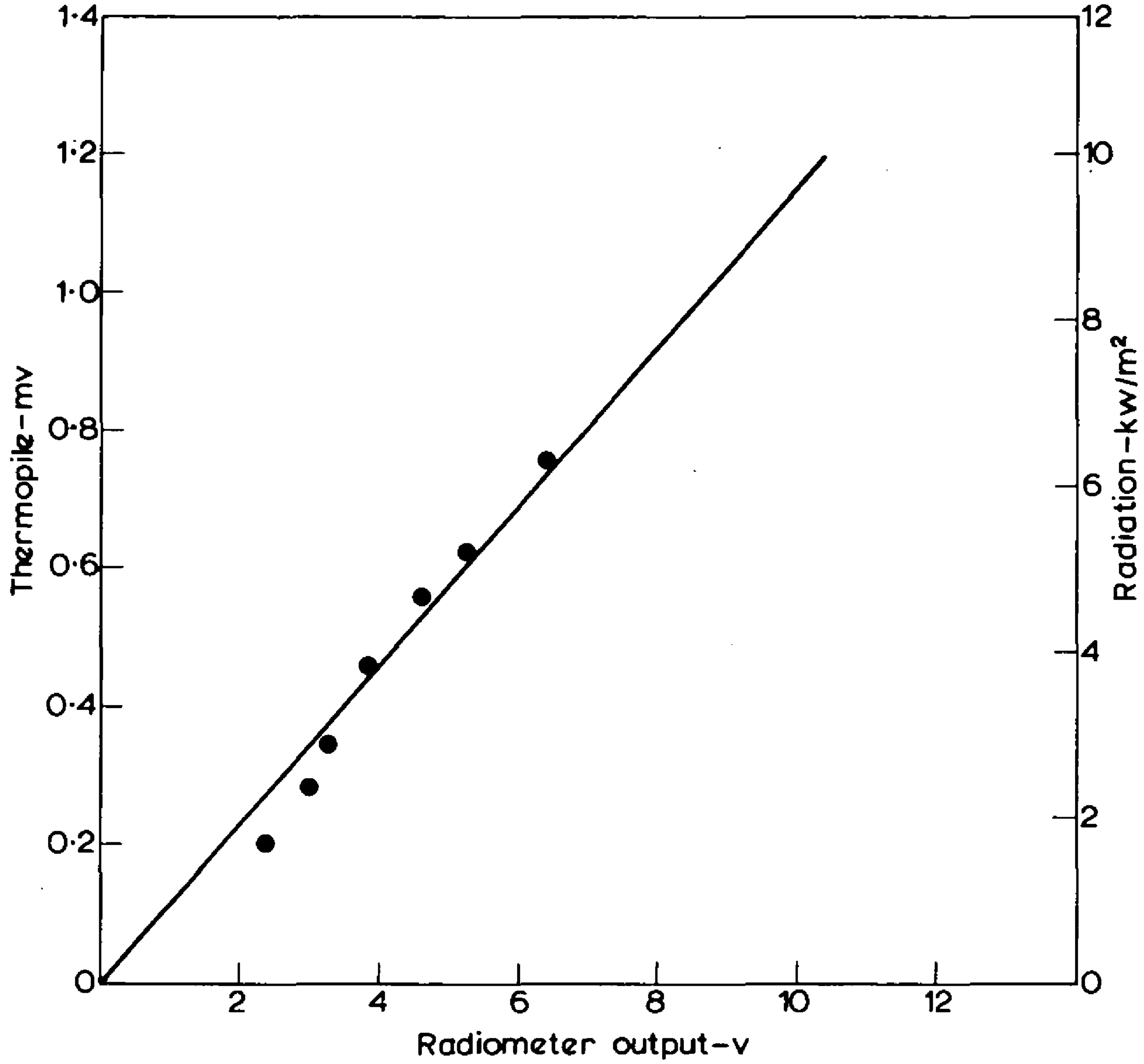
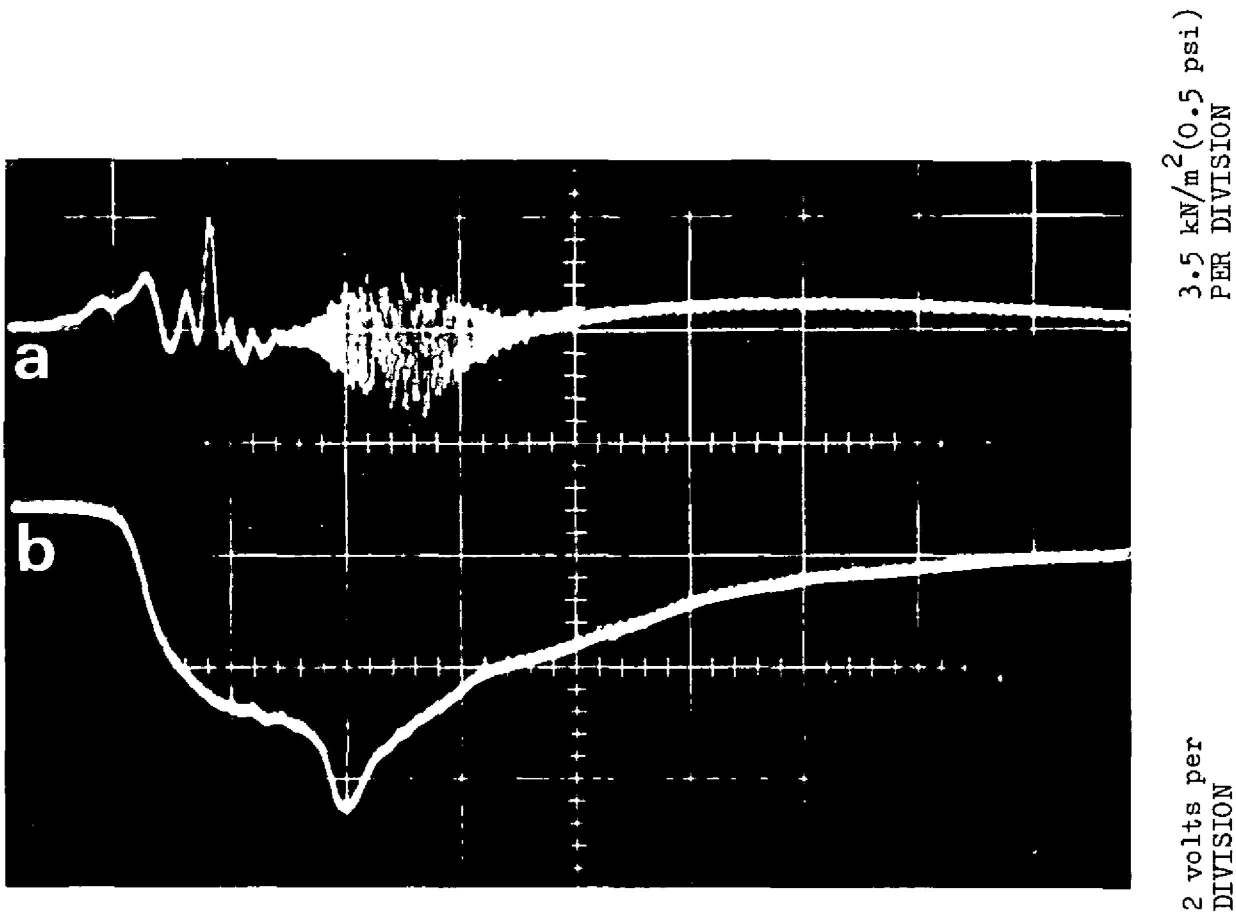


Figure 13 Calibration of infra-red radiometer



0.2 seconds per division

a) pressure

b) radiometer output

FIG.14 OSCILLOSCOPE RECORD SHOWING RADIOMETER OUTPUT AND PRESSURE LEVEL DURING EXPLOSION

(1.5 m Layer of 10% Nat.Gas/Air)

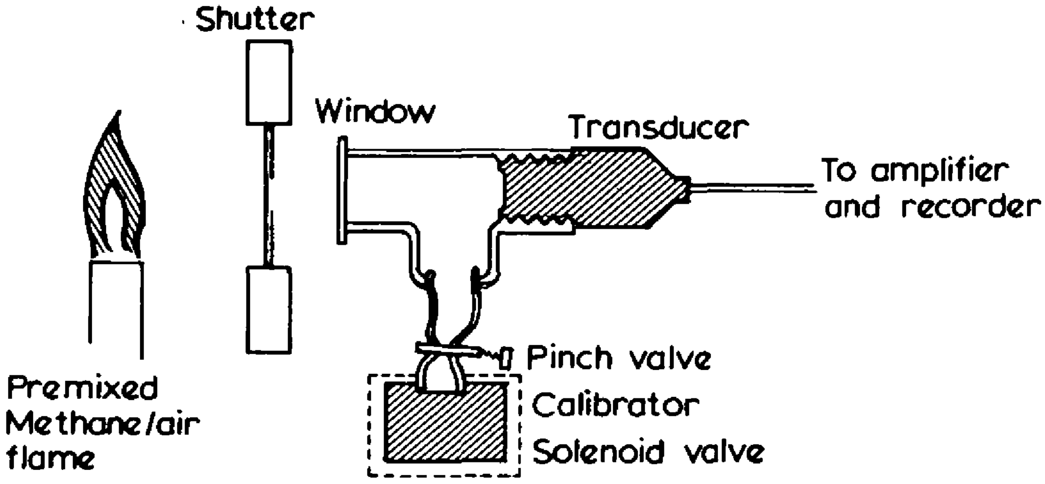


Figure 15 Apparatus for examining effects of radiation on transducers

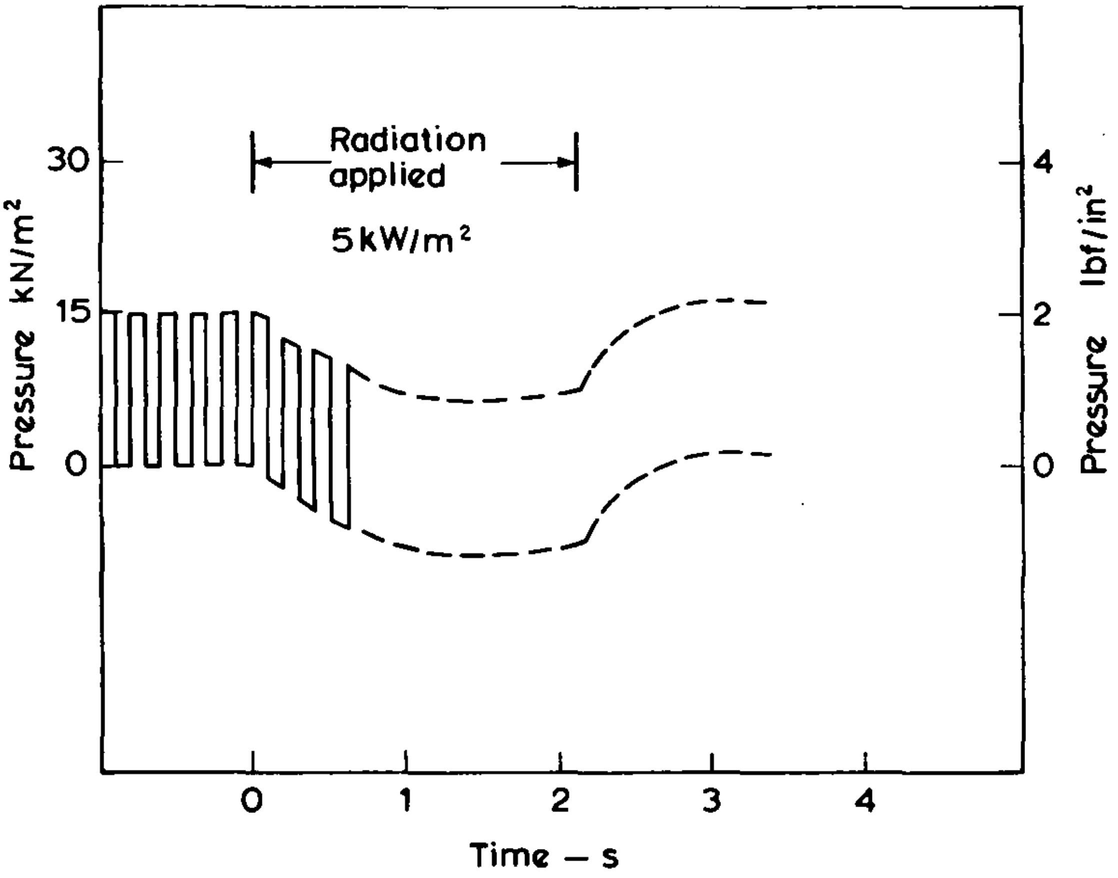


Figure 16 The effect of radiation on response

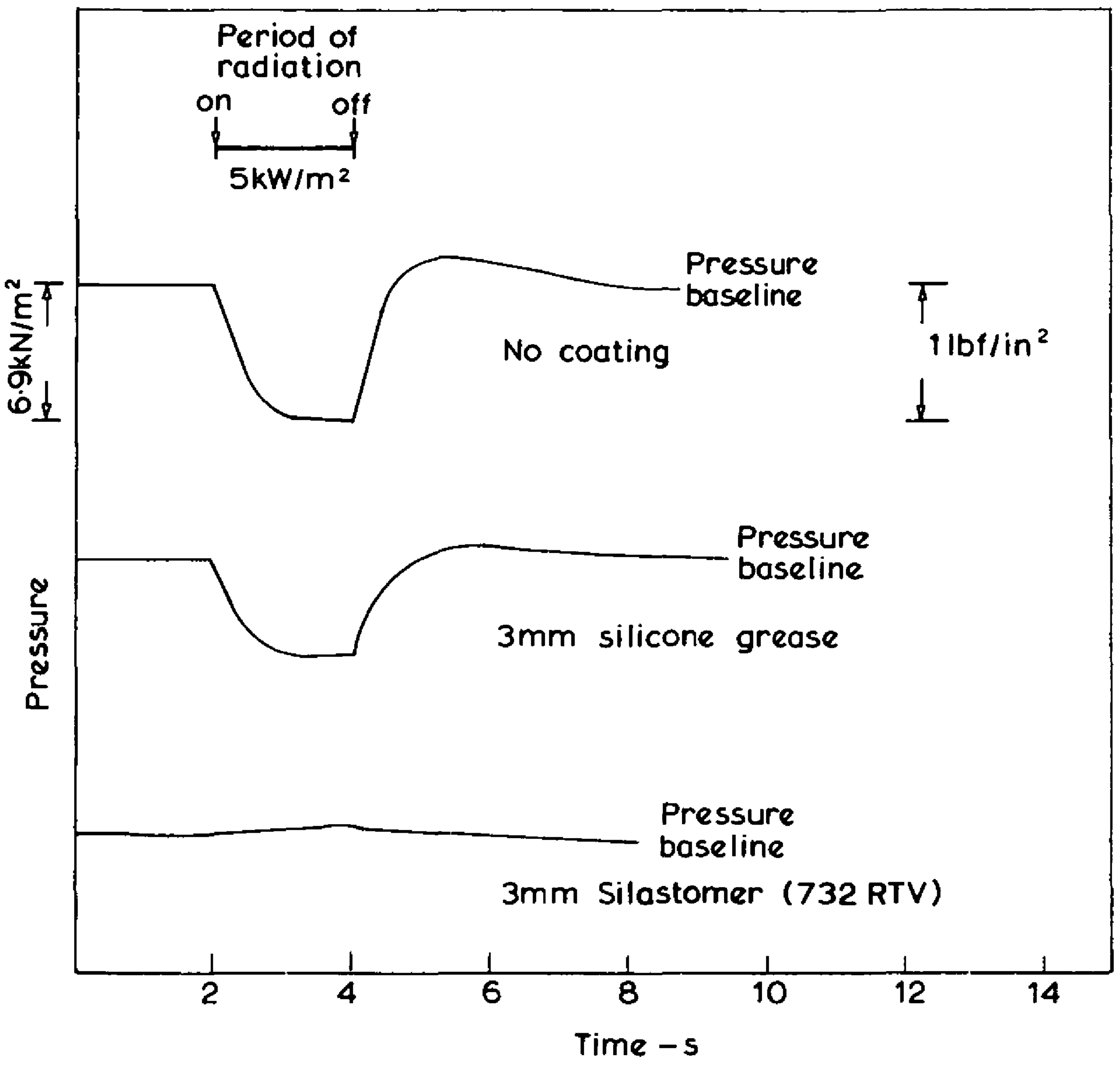


Figure 17 Effects of radiation on baseline response for coated transducers (applied pressure $15 kN/m^2$)