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# A THREE - CHANNEL PIEZO - ELECTRIC PRESSURE RECORDER

By

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# A Three-Channel Piezo-Electric Pressure Recorder

- by -

P.J. Fletcher.

SUMMARY

To speed up operation of a low speed cascade tunnel, an apparatus has been constructed to record the pressures needed for "loss coefficients". The pressures are, upstream total head, downstream total head, and downstream static pressure. An electrical method of recording has been chosen on account of the ease with which the sensitivity can be varied to accommodate a large tunnel speed range. A diaphragm-loaded quartz crystal is used as the pressure sensitive element.

The signal from the crystal is indicated on a cathode ray oscilloscope and recorded by a 35 mm. moving film camera. To record the three pressures concurrently, they are connected in sequence by a rotary valve to the quartz crystal pick-up, and the potential produced amplified by long time-constant circuits.

Linearity of indication is satisfactory, but there is a slight air leakage due to the air capacity of the pick-up and care must be taken to ensure that the error due to this is within desired limits.

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## 1.0 Introduction

In measuring the performance of cascades of aerofoils, the normal method of obtaining the drag coefficient is a pitot traverse of the loss wakes of the blades[1]. This involves at least 100 manometer readings for a 4-blade traverse at a given cascade setting, and on a projected series of tests on a low speed wind-tunnel, the total number of readings is of the order of 100,000. Much time can therefore be saved by recording the pressures automatically. The tunnel is required to operate over a 10:1 Reynolds No. range (from $3 \times 10^4$ to $3 \times 10^5$), so a loss recorder whose sensitivity can be varied 100-fold (.04" water to 4" water for full-scale deflection) is required. In addition to recording the traversing pitot pressure, it has to be capable of recording upstream total head and atmospheric pressures concurrently. In view of the wide pressure range required, an electrical method has been chosen because of the ease with which sensitivity can be varied in electrical amplifiers.

## 2.0 Description of Recorder

The three pressures to be recorded are led to the inlet ports of a motor-driven rotary valve, which applies them in sequence to the diaphragm of the quartz crystal pick-up. The signals from this are amplified and indicated on a cathode ray oscilloscope. Fig. 1 shows the arrangement of the apparatus.

The rotary valve shown in Fig. 2 runs at 300 r.p.m. and has a steel tapered plug running in an "Oilite" seating, the included taper angle of 60° giving satisfactory sealing and freedom from binding. It has been found that running the valve at rotational speeds greater than 400 r.p.m. gives rise to excessive air leakage due to break-down of the oil-film between the plug and seating, and above about 600 r.p.m., accuracy of indication is reduced owing to insufficient "open" period to accommodate pressure changes. Chambers of about 40 cu.ins. volume are placed in each pressure line immediately before the valve to act as reservoirs for the small air-flow necessary to change the pressure in the pick-up (.0002 cu.ins. for 1" $H_2O$ pressure change).

The quartz crystal is X-cut, size 25 x 25 x 2 m.m. and loaded as in the pick-up has a sensitivity of approximately 37 Mv/in.water pressure. It is silver-plated on the two faces normal to the X-axis, and mounted as shown in Fig. 3. This method of mounting eliminates electrical leakage except across the crystal itself, and in the first amplifying valve. A theoretical sensitivity of about 100 Mv./in. water has been calculated[2] and the discrepancy between actual and theoretical values appears to be due to the difficulty of determining the input capacity of the crystal and its amplifier, and to imperfect silver-plating of the crystal.

The open period of any one valve port is approximately 1/15 secs., and negligible leakage of the charge on the crystal must be apparent during this time. To achieve this, an enormous insulation resistance in the circuit connected to the crystal is required. By thorough and continuous drying, the insulation resistance of the crystal can be maintained at about $10^{12}$ ohms but to obtain a similar figure for the resistance of the 1st stage of voltage amplification it has been found necessary to use an electrometer valve. The G.E.C. Type E.T.1 Electrometer Triode used has, under dry conditions, an input impedance of the order of $10^{17}$ ohms. Fig. 1 shows the circuit of the R/C coupled amplifier, which is battery operated for simplicity and stability. The R.C. value of the crystal/electrometer circuit is about 25. Further amplification of up to 7,000 times is obtained in the Mullard E.800 oscilloscope used as indicator. It has an interstage coupling of R.C. value 4.65 and is satisfactorily linear at the low frequencies used in the recorder.

### 2.1 Indication of the pressure cycle

*If the sweep frequency of the oscilloscope is synchronised to the* R.P.M. of the rotary valve and the three pressures applied to their respective ports, indication is in the form of a square wave, shown in Fig. 4 (a). The vertical portions of this wave are suppressed by a cam-operated contact-breaker connected to the "beam suppressor" terminals of the oscilloscope (Fig. 4(b)) and the sweep amplitude of the oscilloscope reduced to zero, giving the final form of indication (Fig. 4(c)). This is then recorded by a 35 mm. moving film camera.

## 3.0 Performance

The recorder in the form described above is capable of giving full scale deflection at pressures between 0.3" and 4.0" water, and a separate single-valve battery-operated R/C. coupled amplifier has been built to provide sufficient amplification to indicate pressures down to 0.04" water (full-scale deflection). Careful sound proofing is required, however, as sound-waves reaching the crystal produce signals comparable in magnitude to the pressure being recorded.

Linearity of indication is satisfactory at all pressures used: a representative selection of curves is shown in Fig. 5.

Owing to slight air leakage through the rotary valve, the recorder must be used with air leads of low flow resistance. Fig. 6 shows the flow through the valve per inch of water pressure applied. The leakage is not mainly due to non-perfect sealing of the valve and its seating, but to "blow-down" from the pick-up as it is connected from a high pressure to a low pressure lead.

Air capacity between the valve and the pick-up diaphragm has been kept to a minimum to lower this blow-down volume and also to raise the resonant frequency of the air in the pick-up and connecting tube. The effect of resonance is shown in Fig. 4(f). To eliminate this completely, a screw restrictor is provided in the lead. The effect of excessive restriction is also shown.

By motorising the traversing pitot tube, a continuously recorded traverse of the blade wakes can be made; Fig. 8 shows typical recordings. The notation of this illustration indicates the respective pressures, and by measuring the upstream total head pressure of the tunnel at any time during the traverse, no absolute calibration of the recorder is necessary, only proof of linearity. A curve of % loss variation with stagger for a typical compressor cascade, together with wake traverse recordings is given in Fig.7.

## 4.0 Difficulties encountered during Development

The major difficulty has been electrical leakage in the input circuit, and its effect is shown in Fig. 4(e). The leakage path is through water adsorbed on the faces of the crystal from the atmosphere. Both crystal and electrometer valve are therefore isolated in an almost airtight compartment, and continuously dried by a Silica Gel absorber. A pressure balance tube has to be provided to compensate for changes in atmospheric pressure, and due to slight infiltration of moist air through this, it is necessary to renew the absorber occasionally.

Vibration of the electrometer valve filament due to mechanically conducted impulses occurred, but has been overcome by using a heavy-gauge metal container mounted on sorbo-rubber, the electrometer being suspended by light springs inside this.

A more subtle vibration effect has been encountered due to impulses conducted axially from the motor to the valve, causing the latter to move within the limits of the thickness of the oil film. This has been eliminated by lubrication with very low viscosity oil (watch-oil) and the use of axial-flexible couplings (Fig. 3).

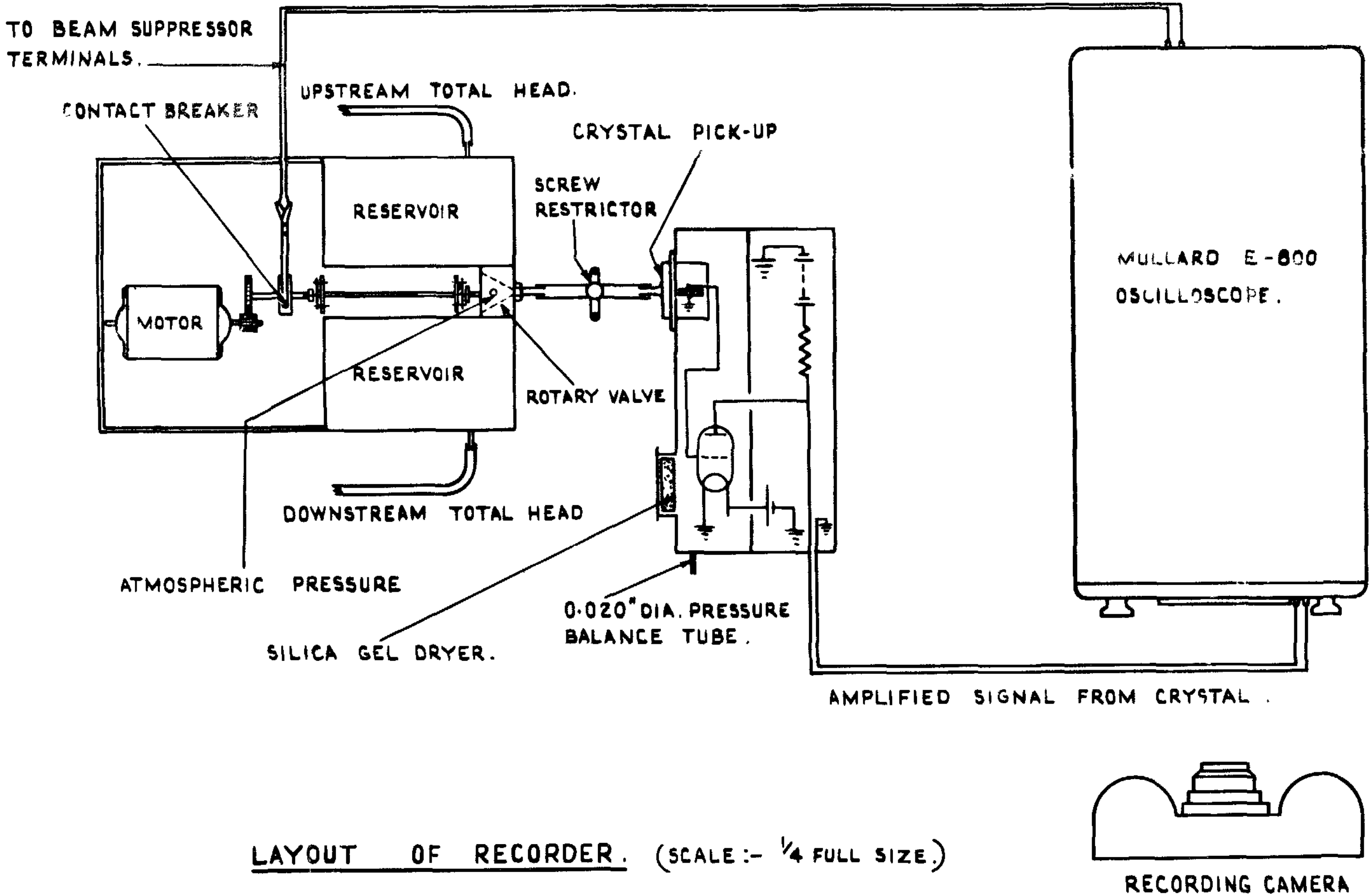
## 5.0 Conclusions

A three-channel pressure recorder has been developed with the object of reducing the time required for cascade wake traversing. On a current series of low speed tests, a typical manual traverse required of the order of 100 separate pressure readings, traversing time being about 10 minutes. Using the recorder, this time is reduced to 1.1/2 minutes for the same traverse, and the necessity for plotting manometer readings avoided.

The apparatus is at present suitable for recording pressures from tappings where slight leakage can be permitted.

## REFERENCES

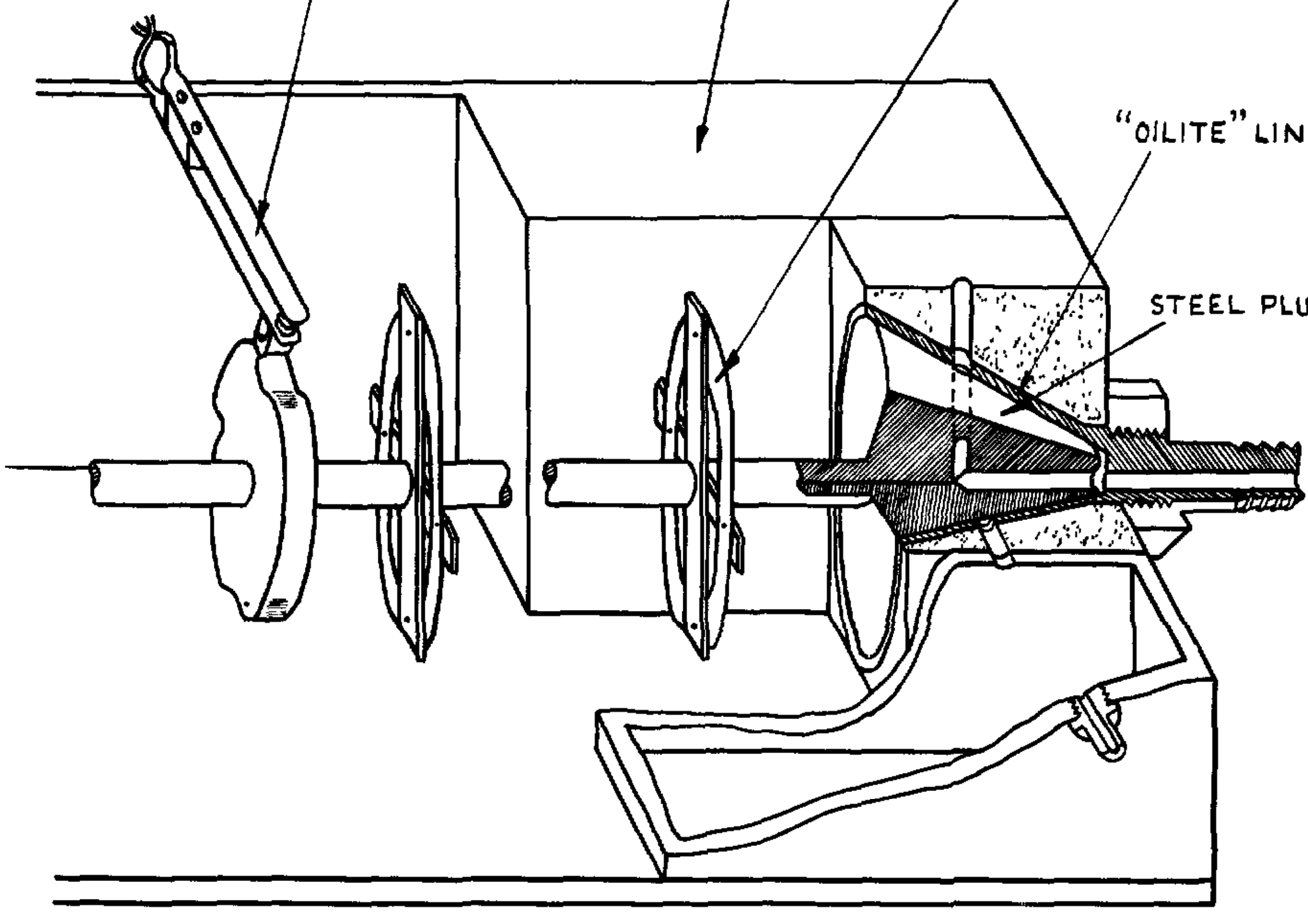

| No. | Author | Title |
|---|---|---|
| 1 | A.R. Howell | Fluid Dynamics of Axial Compressors. Proc. Inst. Mech. Engrs. Vol.153. W.E.I. No.12. |
| 2 | W.G. Cady | Piezo-Electricity (McGraw-Hill). |




LAYOUT OF RECORDER. (SCALE:- ¼ FULL SIZE.)

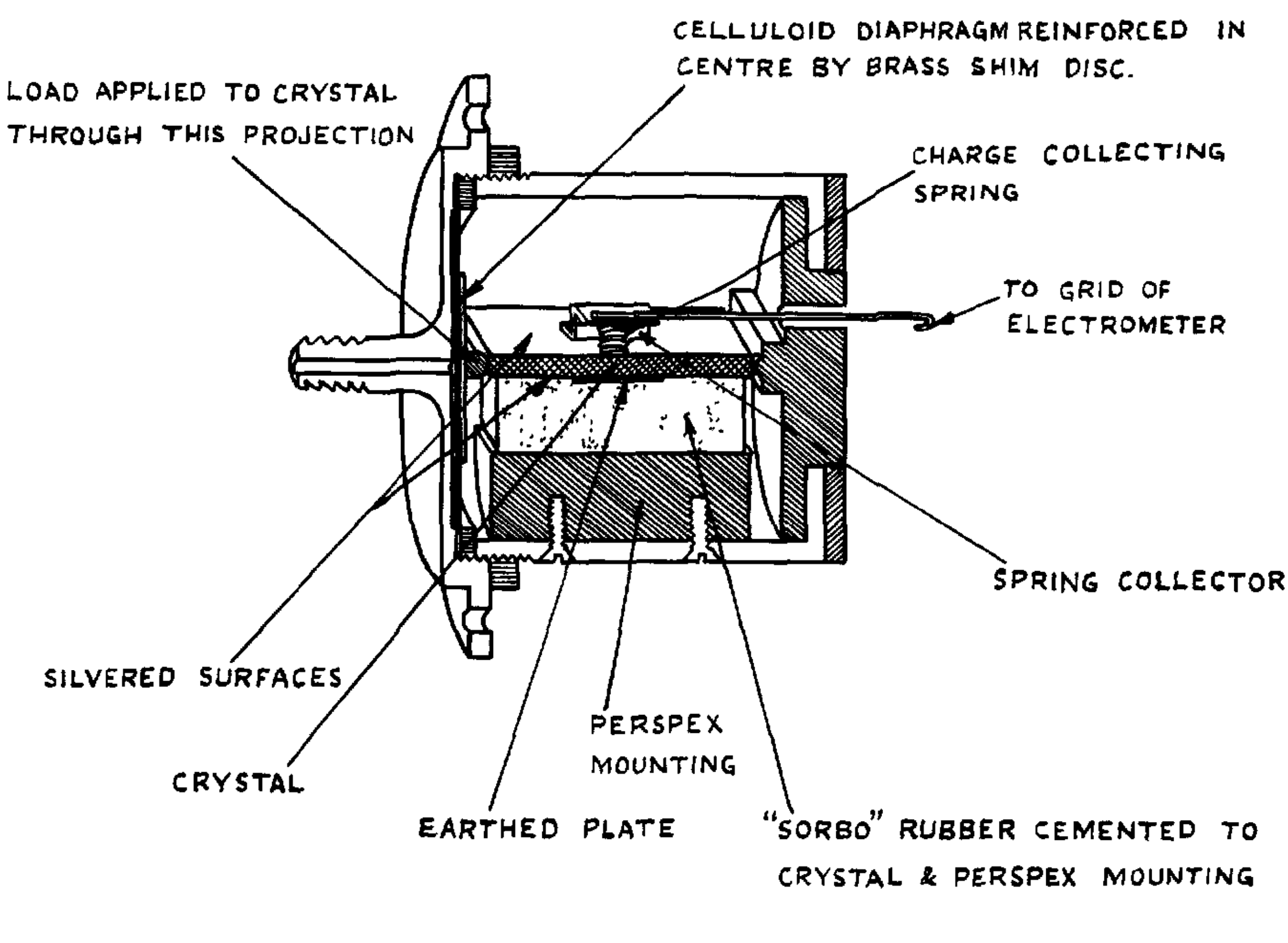
FIG. 1.

FIG. 2.



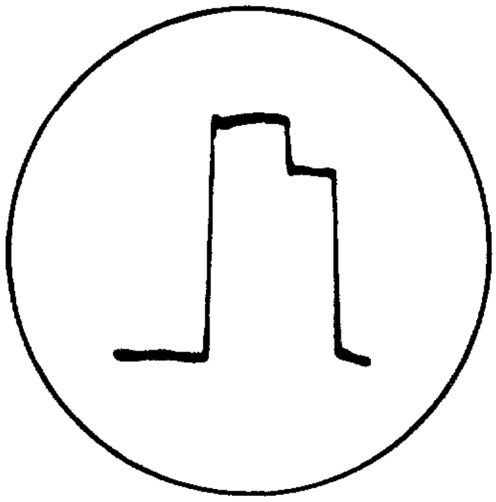

ROTARY VALVE (SCALE - ¾ FULL SIZE)

FIG. 3

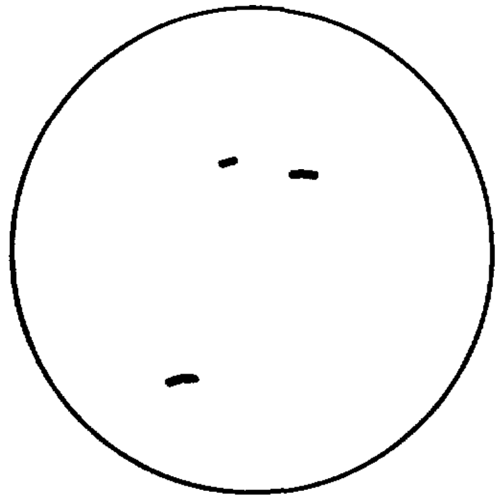



PRESSURE PICK-UP (SCALE - FULL SIZE)

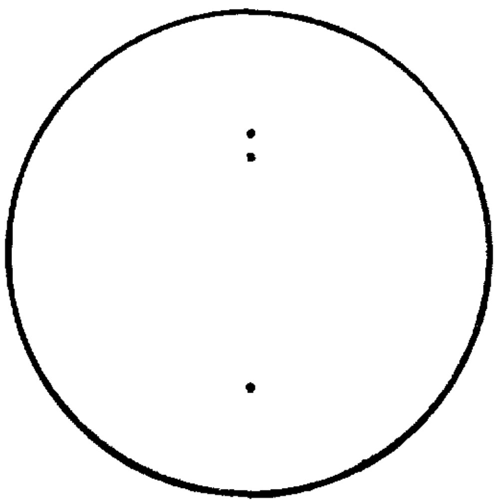
FIG. 4.



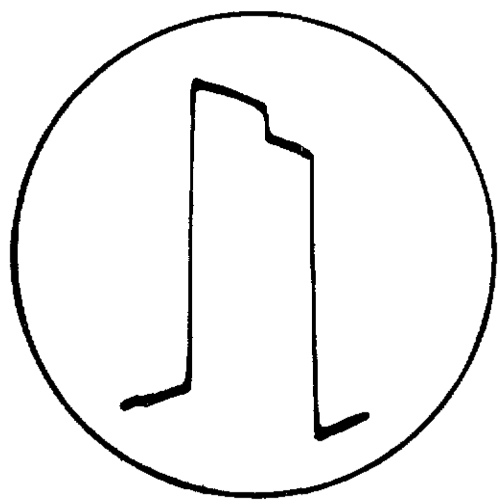
(a) BASIC SQUARE WAVE.



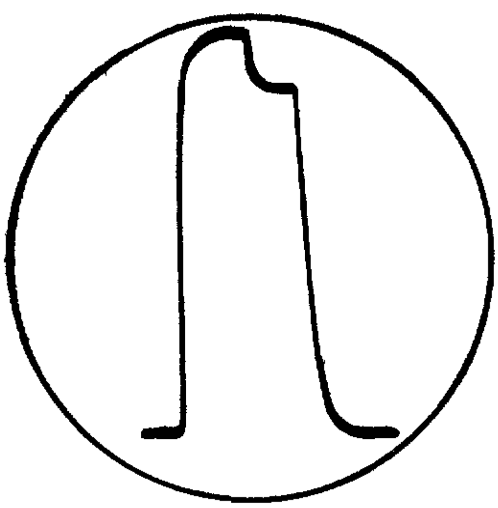
(b) SQUARE WAVE SUPPRESSED.



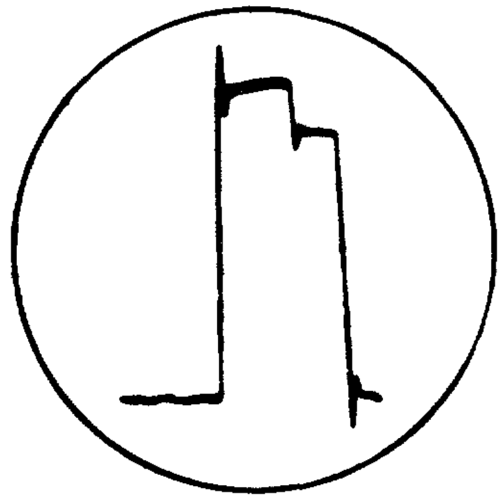
(c) SWEEP REDUCED TO ZERO. (FINAL FORM OF INDICATION.)



(d) ELECTRICAL LEAKAGE IN INPUT CIRCUIT CAUSING SIGNAL DECAY.

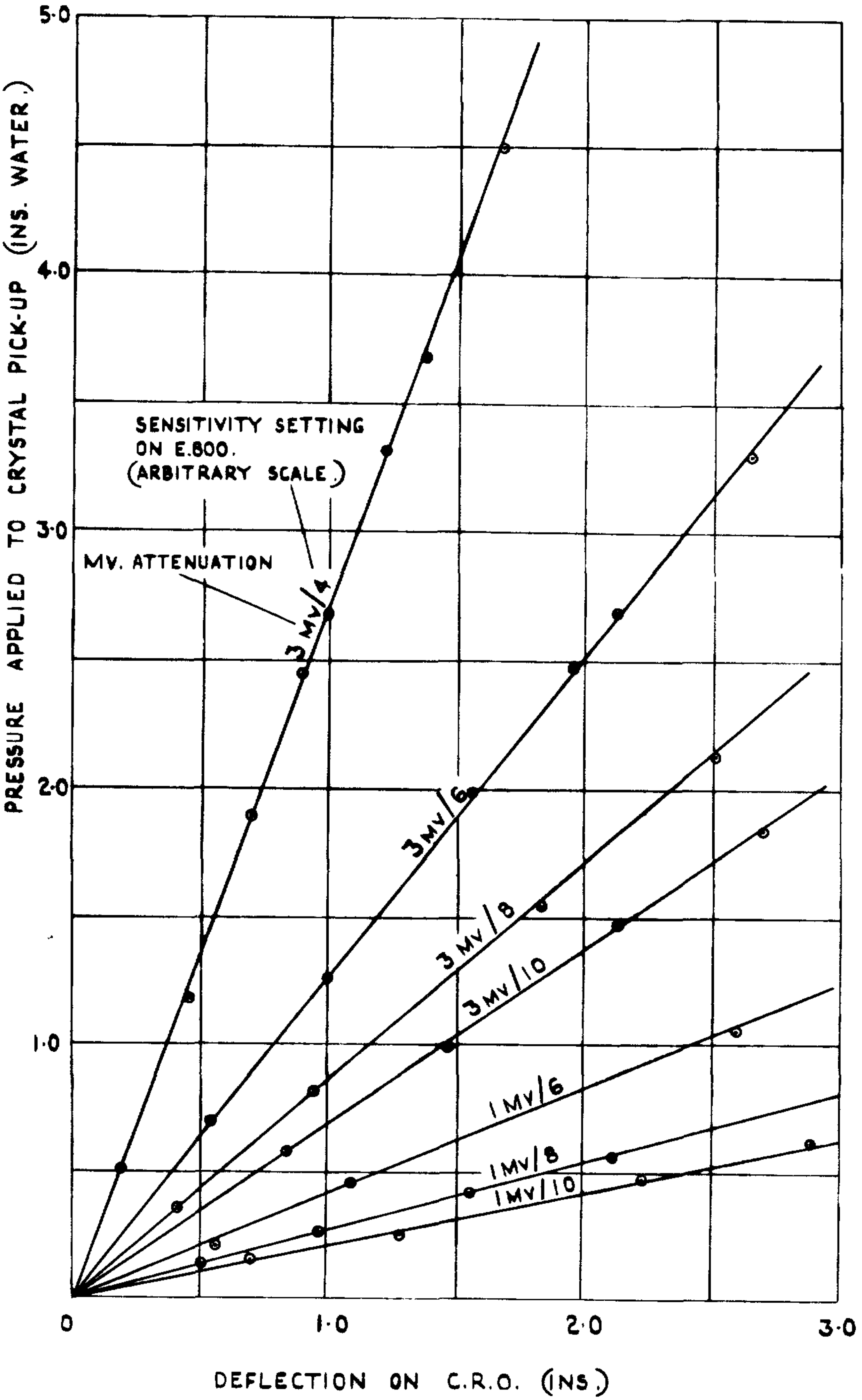


(e) EXCESSIVE RESTRICTION BETWEEN ROTARY VALVE. AND PICK-UP



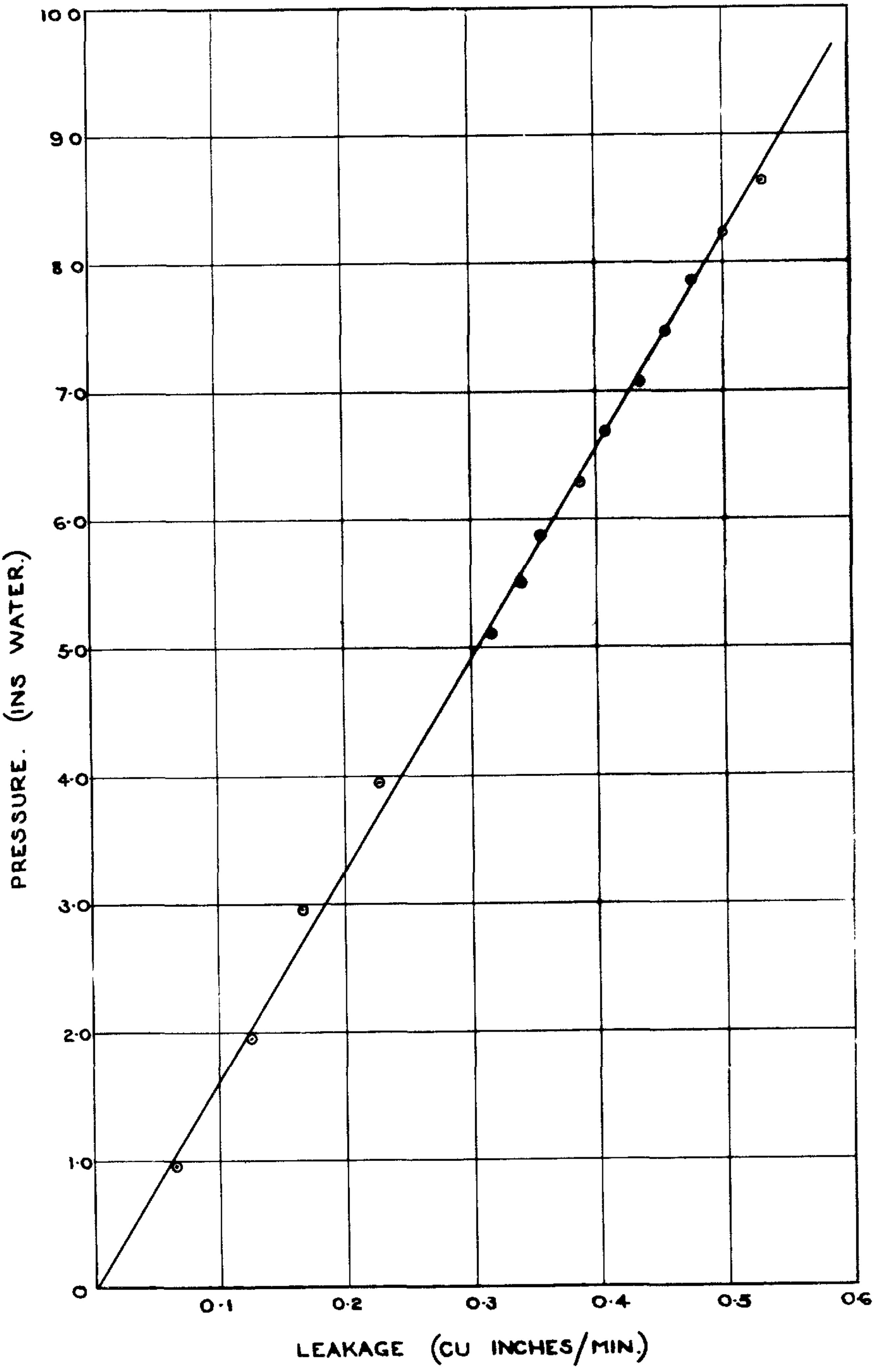
(f) RESONANCE BETWEEN ROTARY VALVE AND PICK-UP.

INDICATION TRACES (SCALE:- 3/4 FULL SIZE.)



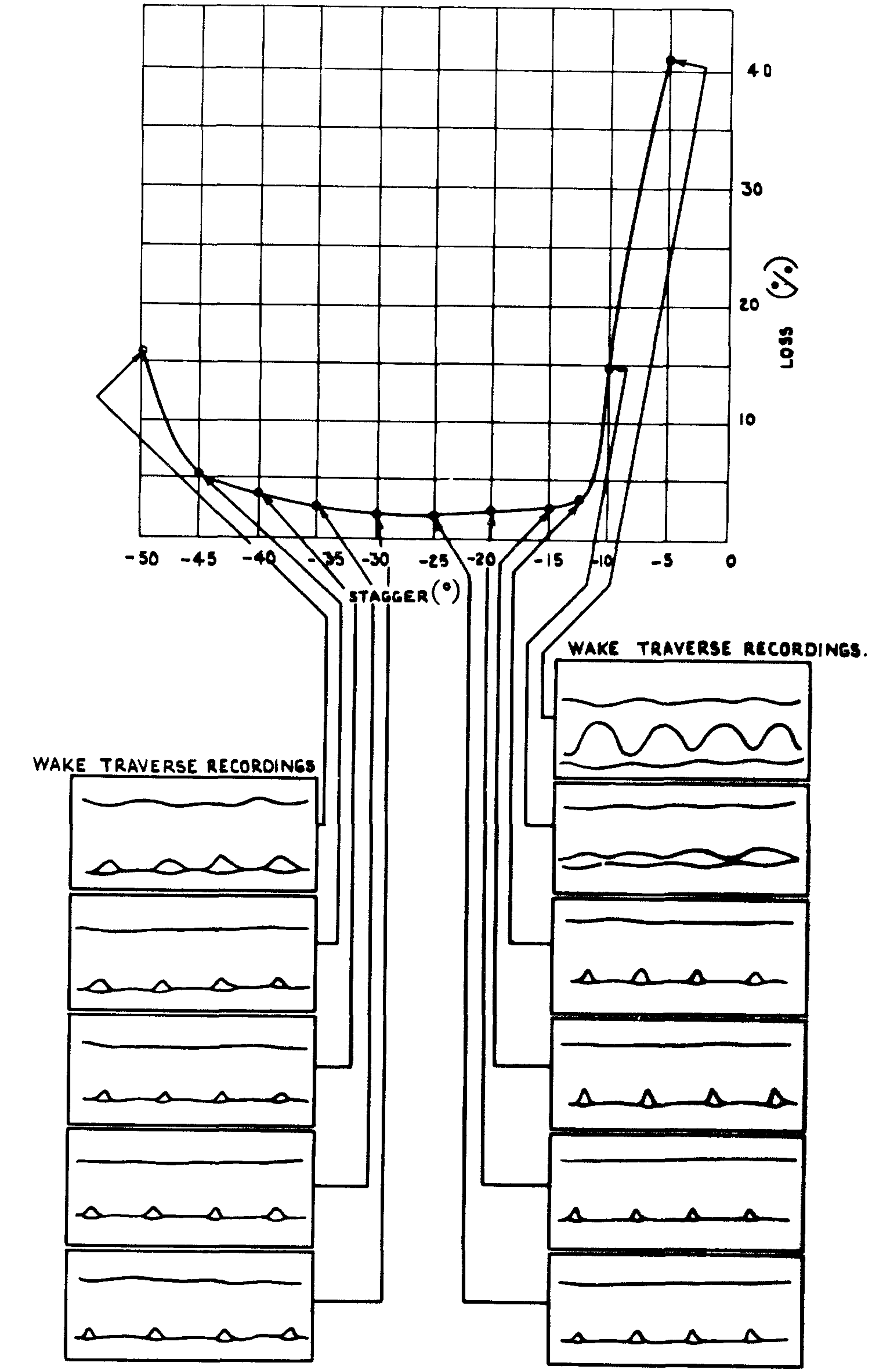

LINEARITY CURVES.

FIG. 6.




LEAKAGE THROUGH ROTARY VALVE.

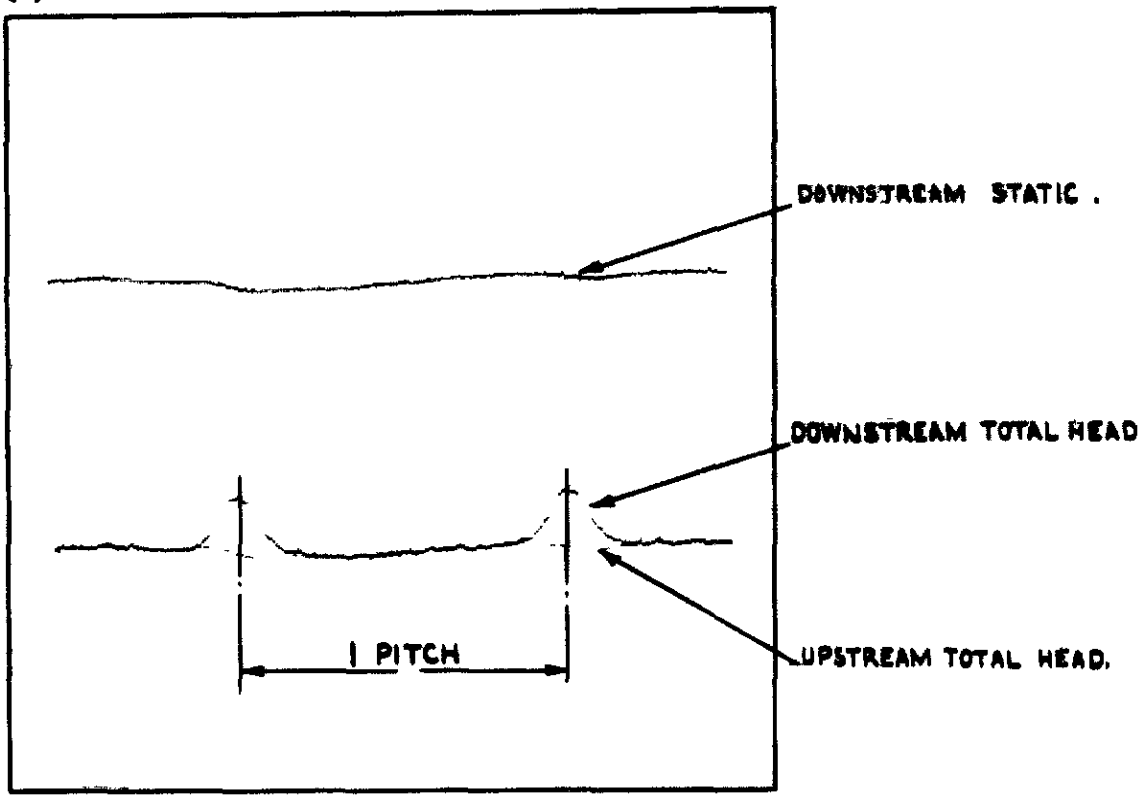
FIG. 7.



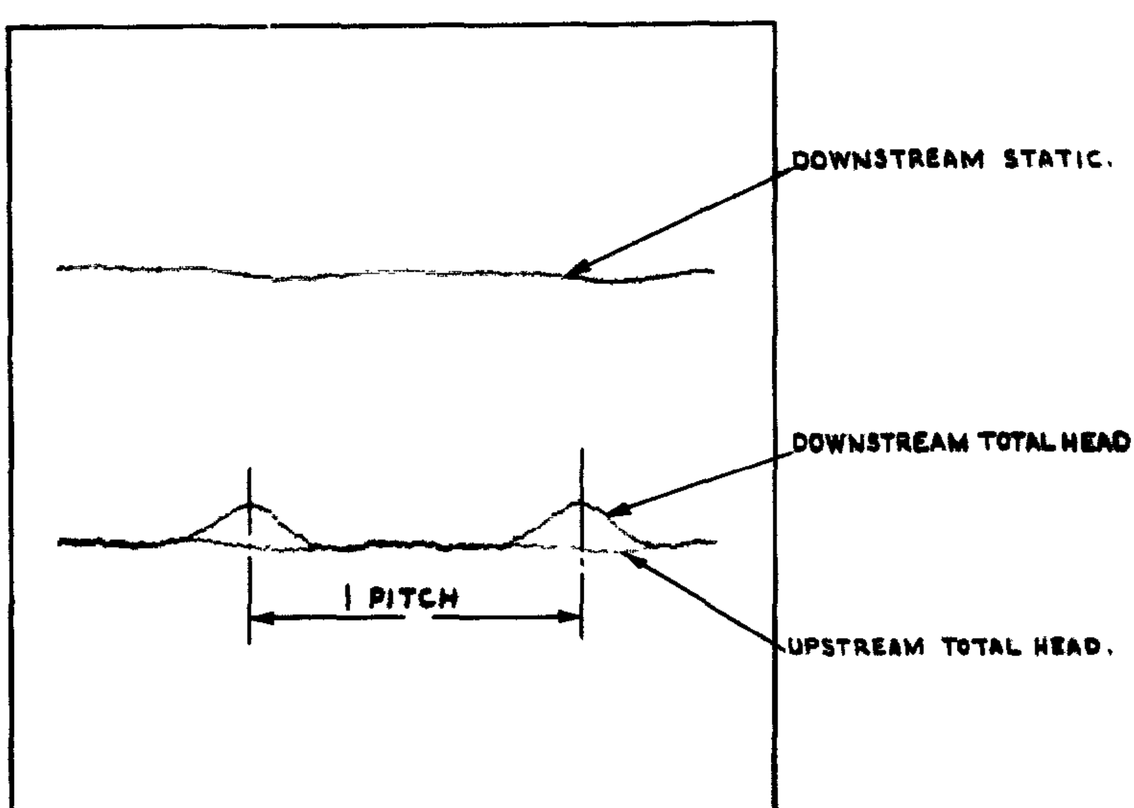

TYPICAL LOSS VARIATION WITH STAGGER FOR COMPRESSOR CASCADE.

FIG. 8.

(a) UPSTREAM TOTAL HEAD = 3·0" WATER.




(b) UPSTREAM TOTAL HEAD = 0·06" WATER




TYPICAL LOSS RECORDINGS.

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