C.P. No. 177

C.P. No. 177
(15,421)
A R C Technical Report

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The M.A.E.E. Recording Accelerometer

By

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LONDON HER MAJESTY'S STATIONERY OFFICE
1954

TWO SHILLING; NET

C.P. No. 177

Report No. F/Res/226

September 1952

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT

THE M.A.E.E. RECORDING ACCELEROMETER

by

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and

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SUMMARY

The M.A.E.E. recording accelerometer is basically the accelerometer unit of a desynn accelerometer, adapted to make a continuous and immediate presentation of accurate, calibrated accelerations on a half second time base.

The recording medium is metallised paper, having a speed of half an inch per second, and the instrument can be operated continuously for twenty minutes on one loading. It can record with full scale deflections, from 1 to 10g when the natural frequencies will be about 7 and 22 c.p.s. respectively.

The instrument is simple, it has been proved reliable and accurate and it is most convenient in use.

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/1. INTRODUCTION

1. INTRODUCTION

An accelerometer for the measurement of vertical impact accelerations occurring in flying boat landings was needed at M.A.E.E. An Instrument, named for reference the M.A.E.E. Recording Accelerometer, has been made to meet this requirement and. is discussed in this report.

2. GENERAL CONSIDERATIONS

The Instrument is basically the accelerometer unit of a desynn accelerometer, together with a recording unit designed to present an acceleration record, as a continuous trace on metallised paper.

The desynn transmitting accelerometer Type IT. 2-2 (R.A.E. Specification No. IT. 101) was used as a starting point because,

(a) it was generally suitable,

(b) it has been fully developed,

(c) replacements and spares are available at R.A.E. and

(d) all normal desynn accelerometer adjustments still apply.

The final form of the Instrument and magazine is the result of detailed discussion with the following aims in view,

(a) to make a continuous and immediate presentation of accurate, calibrated results,

(b) simplicity,

(c) ease of adjustment, including loading, with the minimum expenditure of time and

(d) to cover as wide a range of accelerations and frequencies as possible.

At the start of a series of tests an initial setting up and calibration is necessary, but time spent on any subsequent adjustments is negligible.

3. DESCRIPTION

The Instrument is 8 inches long, $7\frac{3}{4}$ inches wide, 6 inches deep and weighs 12 lb. (Figure 3). Those are overall dimensions and include clearance for plugs, etc. The remote control lend weighs an additional 1 lb. and the master contactor (to provide the time base) weighs $5\frac{1}{2}$ lb. Figure 1 shows the complete aircraft installation and Figure 2 is an exploded view of the instrument.

It consists of two main parts, the accelerometer mechanism and the magazine. A removable end plate (on which is inscribed a circuit diagram), located by two spring loaded latches and a groove in the instrument base, allows the top cover to be removed and the magazine slid out. Removal of the other end plate, positioned by nine 6 B.A. screws, gives access to the accelerometer mass, spring and damping mechanism. The 24 volt D.C. supply, timing and remote control are connected by three plugs on the front face of the instrument.

/3.1. Accelerometer

3.1. Accelerometer mechanism

This can be seen in Figure 2. The normal case and miniature desynn transmitter have been removed from the desynn accelerometer and a bridge has been built onto the frame, level with the top surface of the mass, to carry an adjustable end pivot for the writing arm. One of the tapped holes in the accelerometer mass has been used to take the central pivot round which the arm turns and slides. The arm, of straight tapered channel sectioned phospor bronze, has a 4:1 movement ratio, and carries at its narrow end the scriber. This is adjustable, on a normal screw thread, and is locked with shellac.

3.2. Magazine

The magazine frame is of aluminium alloy plate. It is slid into the instrument along two guides and is located by two dowels. The assembly is kept rigid and free from chatter by means of a strong leaf spring on the lower end of the removable end plate.

The recording medium is metallised paper which is taken over a table and fed out between two rollers, through a slot aligned with a similar slot in the end plate. A simple clutch is provided on the driven roller for loading and provision is made for timing, event and calibration marks. A general view of the magazine is given in Figure 5.

3.2.1. Paper and loading

The recording medium, metallised paper, is paper impregnated on one surface so that with minimum pressure, commoner non-ferrous alloys (brass, German silver and beryllium copper) will make a pencil-like mark. In trying to obtain longer wearing scribers, zirconium, tungsten and tungsten carbide were found unsatisfactory. The paper is used in 50 feet rolls 2 inches wide, with $\frac{1}{2}$ inch bore and metallic surface outside. The magazine is shown loaded in Figure 5 and unloaded in Figure 6.

To load, the sleeve (Figure 6) is pushed into the paper and the whole positioned to take the pin which is locked as in Figure 5. Timing and event scribers (Figure 7) are lifted by means of their springs, the paper is pushed underneath, fed past the calibration comb (Figure 8) which has been rotated on its axis by means of the cam and finally wound out of a slot in the casing using the clutch (Figure 9).

Throughout its travel the paper is guided by the inner faces of the main frame members which are 2 inches (paper width) plus 0.01 inches apart, and frictional resistance is sufficient to keep the paper taut in operation.

Paper speed is approximately $\frac{1}{2}$ inch per second, and the instrument can be operated continuously for 20 minutes on one loading.

3.2.2. Calibration comb

An enlarged photograph of the calibration comb is shown in Figure 8. The teeth are positioned along their axis by set screws at suitable acceleration increments determined during calibration. A series of parallel lines comes out on the record and the magnitude of any impact can be seen with fair accuracy immediately. Further accuracy may be obtained by measuring between the lines. The whole assembly is turned through 90 degrees for loading. It is held in the loading or operating position by means of a spring-loaded cam.

Beryllium copper was found most suitable for the scribers, each one of which is individually spring-loaded with an adjustment for spring tension.

/3.2.3. Timing

3.2.3. Timing and events

In each case the principle is the same, the basic difference being that the timing is operated by a ½ second Cambridge master contactor and the event mechanism by a manually operated button. The systems are clearly visible in Figure 6 and a detailed view of the scribers is given in Figure 7.

The solenoids are of 30 S.W.G. enamelled copper wire with 1,800 turns giving 20.5 ohm resistance. Both core and screening are of Swedish iron.

The cores are pivoted to channel section spring loaded levers with adjustable stops, so that the timing scriber has a movement ratio of 1:2 and the event 1:3.

As shown in Figure 7, the scriber arrangement is similar to that of the calibration comb, with an additional screw for locking the spring tensioning system. 'This allows for the up and down movement of the scribers in overcoming the angular movement of the levers.

3.2.4. Clutch

The paper feed is through two rollers, one of which is driven by means of a 24 volt D.C. motor through a 400:1 worm reduction gearing. To facilitate loading a simple dog clutch (shown disengaged in Figure 9) was built on to an extension of the driven roller shaft. For loading it is pressed in against the spring thereby disengaging the drive, and wound clockwise until the paper is through the slot, It can then be left and will automatically engage when the instrument is running.

Power necessary to drive the magazine motor and operate'the solenoids is picked up on four knife edge contacts on the side of the magazine. The wiring diagram is reproduced in Figure 4.

4. OPERATING CONSIDERATIONS

Prior to any series of tests the user will generally have a fair idea of the maximum anticipated acceleration and the highest working frequency it is desired to record. For optimum performance the lowest rate accelerometer spring compatible with these requirements should be used. Otherwise a high rate spring can be used initially and from those results the correct one can be decided. The required clearance of 0.001 inch must then be made between the mass and spring (a normal Desynn accelerometer adjustment).

By turning the instrument so that the rollers go from horizontal to vertical while running, the deflection may be noted and the undamped natural frequency calculated from

$$n = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} = \frac{3.13}{\sqrt{\delta}} \text{ c.p.s.}$$

where g = acceleration due to gravity = 386.4 in./sec.^{2}.

and δ = static deflection of mass in inches.

The main tracing point is set and locked to give the lightest trace than can be conveniently seen.

The damping is then set, the spring positioned and the instrument calibrated.

/4.1. Damping

4.1. Damping

With rollers vertical and spring offset to give a good deflection and the mass suddenly released, the ratio of the first overshoot to the initial deflection can be measured with sufficient accuracy to give a damping ratio of 0.7 ± 0.02. This involves measuring to 0.005 inches on the record. The response is therefore true up to a frequency of 40% of the natural frequency. At the natural frequency, accelerations will still be recorded, but amplitudes will be about 30% underestimated. Alternatively, measurements within ± 4% may be made up to 80% of the natural frequency by adjusting the damping ratio to 0.6. This is illustrated in Figure 10.

When the damping has been satisfactorily adjusted by means of the damping screws on the accelerometer mass, the spring position is set, i.e. if only positive acceleration is anticipated the mass and recording stylus should be offset to one side of the paper. The instrument is then calibrated.

4.2. Calibration

This can be done by means of,

(a) a tilting table,

(b) a whirling arm,

(c) addition of weights bearing a given ratio ($\frac{1}{4}$, $\frac{1}{2}$, 1, 2 etc.) to the effective weight of the mass.

The three methods are well known and it is not proposed to detail them.

The tilting table method is the most convenient and the calibration can be safely extrapolated to cover a range of say 3g.

To find the effective weight of the mass, the mass and pivots are weighed. The arm only is then pivoted externally at its larger end and suspended from the arm of a delicate balance by its central pivot hole. A short piece of thread can be used. The arm should be kept horizontal. A weight, equalling the sum of the two previous weights, suspended from the mass in line with its C.G. will then give the same deflection as an acceleration of 1g.

It has been generally found advisable to draw the calibration curve in the normal way with distances from a datum (mark of timing scriber) as abscissae, when any backlash or friction will be evident. The teeth of the calibration comb are then set by measurement using the calibration. This method provides an additional check in case the teeth on the comb should slip.

Owing to the displacement along the paper of the timing, event and tracing scribers, a simple graticule is necessary to relate them in time. The three points are manually moved over their full range with the instrument switched off. A perspex graticule made to the pattern so formed will relate records, events and time and correct for the radius action of the main tracing point.

The instrument is now ready for use and should need no adjustment during tests.

/4.3. Operation

4.3. Operation

The instrument is positioned by means of two wedge plates for either longitudinal or vertical acceleration measurement.

The remote control (Figure 1) is hand held with a switch on the side and a button on top. Both can be easily operated by the thumb.

Switching on starts the accelerometer roller drive, the paper feed and the timing solenoid. (The master contactor must be wound up and on).

The button operates the event solenoid only.

The paper, coming out of the slot, can be torn off as required or collected in any convenient receptacle.

When the instrument is running it takes, without timing or event 0.6 amperes, with timing (normal operation) an average of 1.2 amperes and with the event button pressed 2.1 amperes.

5. COMPARISON WITH MILLER ACCELEROMETER

To prove the instrument, landing impacts were recorded by both the M.A.E.E. accelerometer and a 12-channel galvo camera recorder, using a Miller Inductance type pick-up and. McMichael amplifiers. Photographs of the two traces, showing a typical Impact, are given in Figure 11

The Miller record. is shown approximately half scale, with the acceleration calibration at one end. The M.A.E.E. record is full size, but the trace and calibration marks have been pencilled in for ease of reading. The timing marks are untouched. For these checks, a range A spring (-0.3 to +1g) was fitted to the M.A.E.E. accelerometer, giving it a natural frequency of 7, and the damping ratio was set to 0.65. Accepting a maximum damping error of 2%, cutting off would start at about 4 c.p.s.

The two sets of peak acceleration values and the times between them agree well within the 2% limit. The 4 c.p.s. oscillation (the first mode of vibration of the wing) between the peaks is recorded accurately, while the higher frequency vibration preceding the first impact is almost damped out.

The Miller inductance type pick-up was under-damped, having a ratio not better than 0.3. It has a natural frequency of about 120 c.p.s. and the amplifiers start cutting off above 80 c.p.s.

6. DISCUSSION

The instrument is very convenient in use. It is simple, robust and reliable. The accuracy and sensitivity depend to a large extent on the acceleration range to be covered and the setting up. The percentage error obtained in the choice of damping ratio is fundamental, but the relative ease and accuracy with which the damping can be set allow this to be a pre-determined factor. The other basic causes of error in this accelerometer are friction, backlash and whipping of the writing arm.

Friction can occur only at the two pivots and the scriber. If this is adjusted to give a trace that can be just seen, the friction is negligible when the paper is moving.

/Backlash

Backlash can occur at the two pivots and also at the spring-mass connection. The latter has the normal desynn clearance of 0.001 inch, and this comes out at mid-range as 0.006 inch at the scriber, while backlash at the pivots comes out at not more than 0.002 inch, so the nett effect, 0.008 inch is little more than the line thickness.

As the writing arm is made out of tapered channel section, whipping, at the normal working frequencies, is negligible.

When Bitted with a -0.3 to +1.0g spring (as during the comparison with the Miller accelerometer), 1g was equivalent to 0.64 inch at the pointer. In recording the peak acceleration of about 1.2g, the error due to backlash was less than 1.0%, as the 0.001 inch spring clearance is taken up at the ends of the mass travel. Together with the accepted 2% damping error, this gives a maximum possible error of 3%.

As the recorded acceleration decreases, the effect of backlash will increase and, as this is mainly due to the spring clearance of 0.001 inch, a direct spring connection to the mass will greatly reduce this in subsequent instruments. Again, at the end of the range, the spring clearance is taken up by the obliquity of the spring, the loading changes from that of a simple cantilever to an encastre beam and the calibration loses its linearity. This is evident only at the outer edges of the paper, and will be rectified with the modification of the connection.

After 3-4 hours running time, all writing points will need sharpening. The substitution of knife edges instead of cylindrical scribers in the calibration comb will greatly increase this time, leaving only the main point to be sharpened occasionally.

Subsequent to its check, the instrument has been used for the following purposes.

(a) It was mounted on the main spar near the C.G. of the aircraft, remotely controlled and recorded vertical accelerations in flying boat landing impacts up to 2.5g (Figure 11).

(b) Fitted with a -3 to +8g spring in airborne lifeboat drops, it was automatically started on release from the aircraft and used to record parachute snatch and landing impact. There was no access to the instrument after the lifeboat was offered up to the aircraft and, in the subsequent trials, it was subjected to violent irregular accelerations. The accelerometer functioned satisfactorily and recorded up to approximately 6g.

(c) It was mounted on the carriage frame members of the M.A.E.E. hull launching tank to assess component accelerations. Considerable high frequency accelerations were present, but these were effectively damped out leaving a clear record of the fundamental accelerations.

(d) Fitted with a very low rate spring, it was used by A. & A.E.E. to record vibrations in helicopters.

It could be used, where the weight and size are acceptable, on almost any job to measure up to 10g, when the natural frequency would be 22 c.p.s.

/7. CONCLUSIONS

7. CONCLUSIONS

The M.A.E.E. recording accelerometer is a simple self-contained instrument which gives a continuous and immediate presentation of accurate, calibrated accelerations on a half second time base.

It can be used over ranges of 1 to 10g, when the zero can be set at any convenient position and the corresponding natural frequencies will be 7 to 22 c.p.s.

The damping can be simply set to thi optimum value so that accurate measurements can be made over the desired range and response falls off rapidly with frequencies above this, giving a clear record of the fundamental acceleration.

8. ACKNOWLEDGMENTS

The authors wish to acknowledge the many useful ideas submitted by Mr T. H. Balls, who is in charge of the M.A.E.E. Light Engineering Shop, and by Mr E. Pearce, who made the prototype accelerometers to verbal requirements only. Their full co-operation and considerable skills interpreted the ideas into a sound practical instrument.

FIGS. 1 & 2.

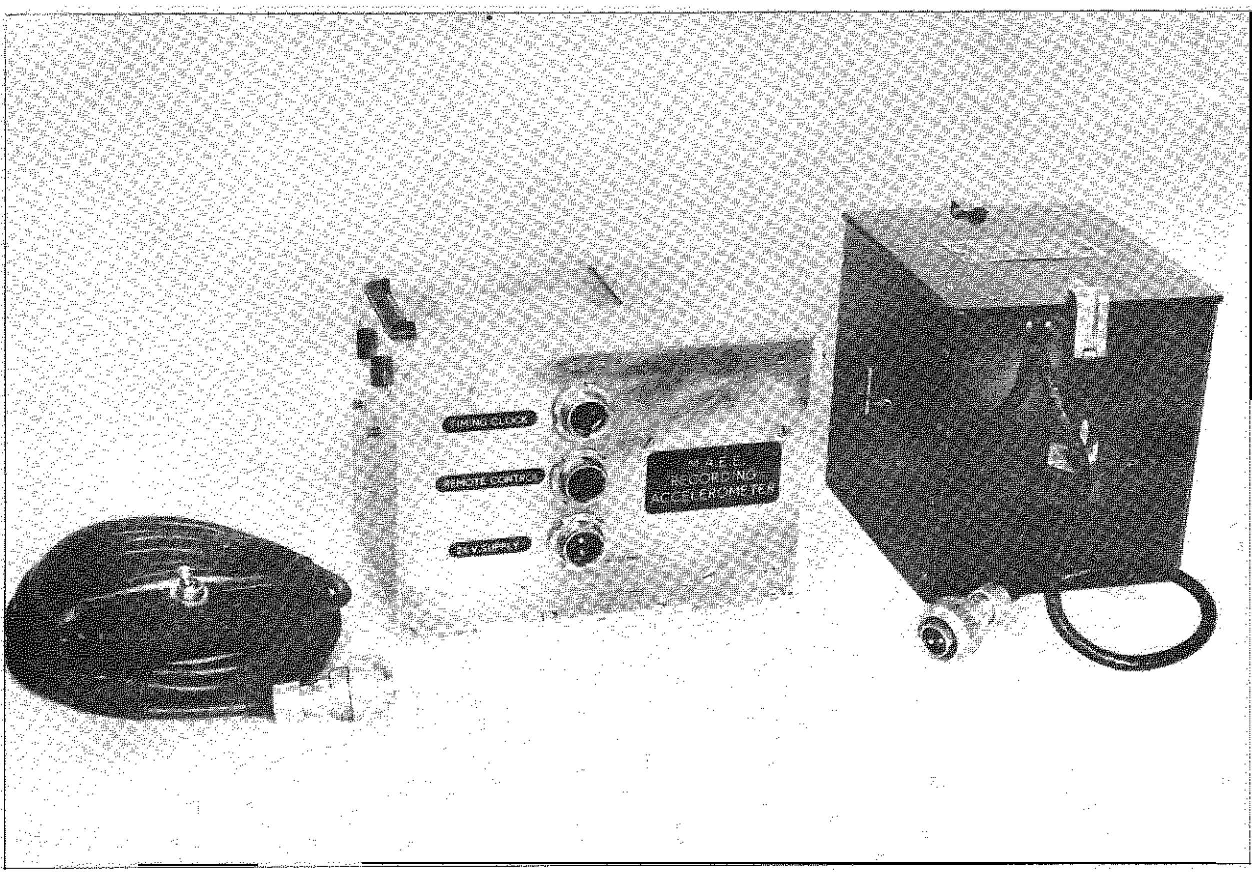


FIG. 1. COMPLETE AIRCRAFT INSTALLATION.

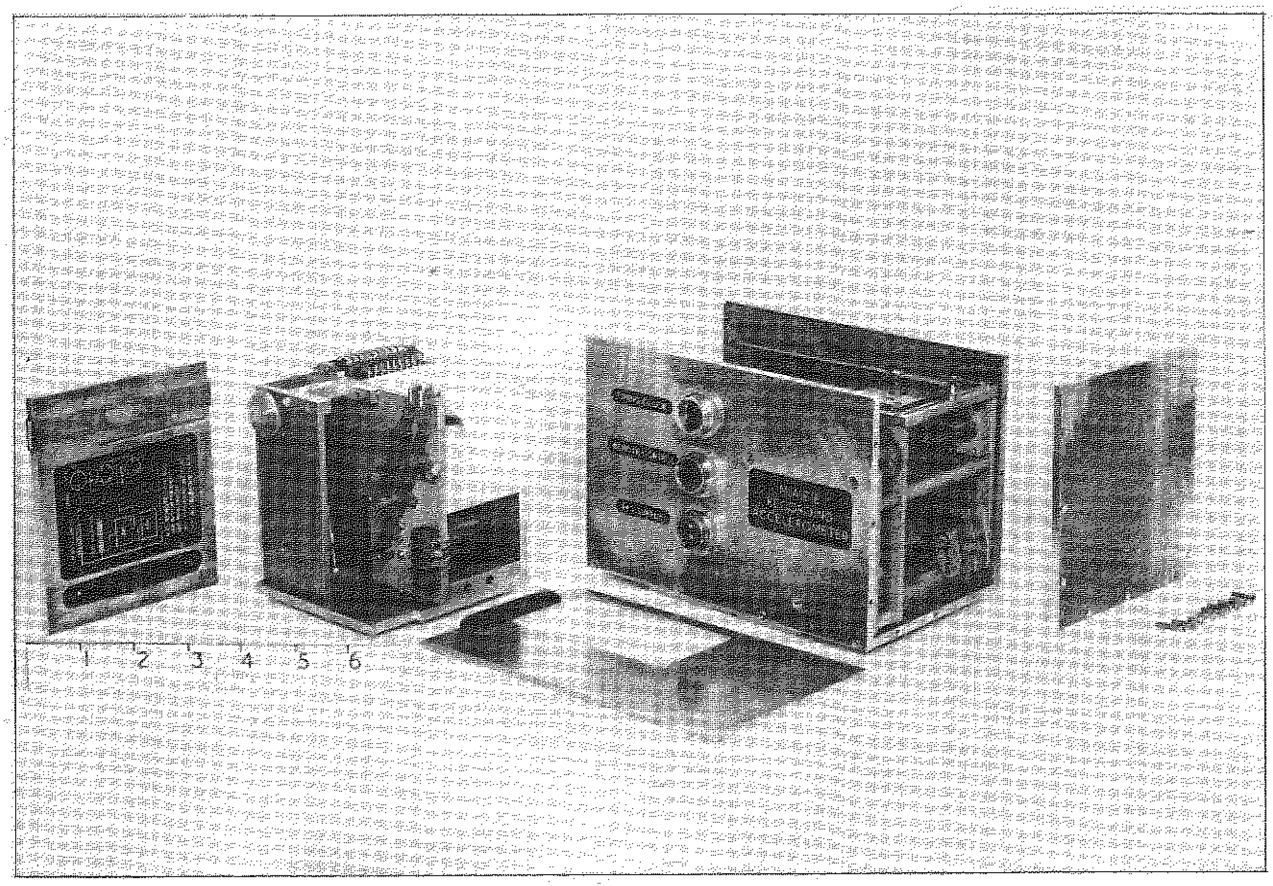
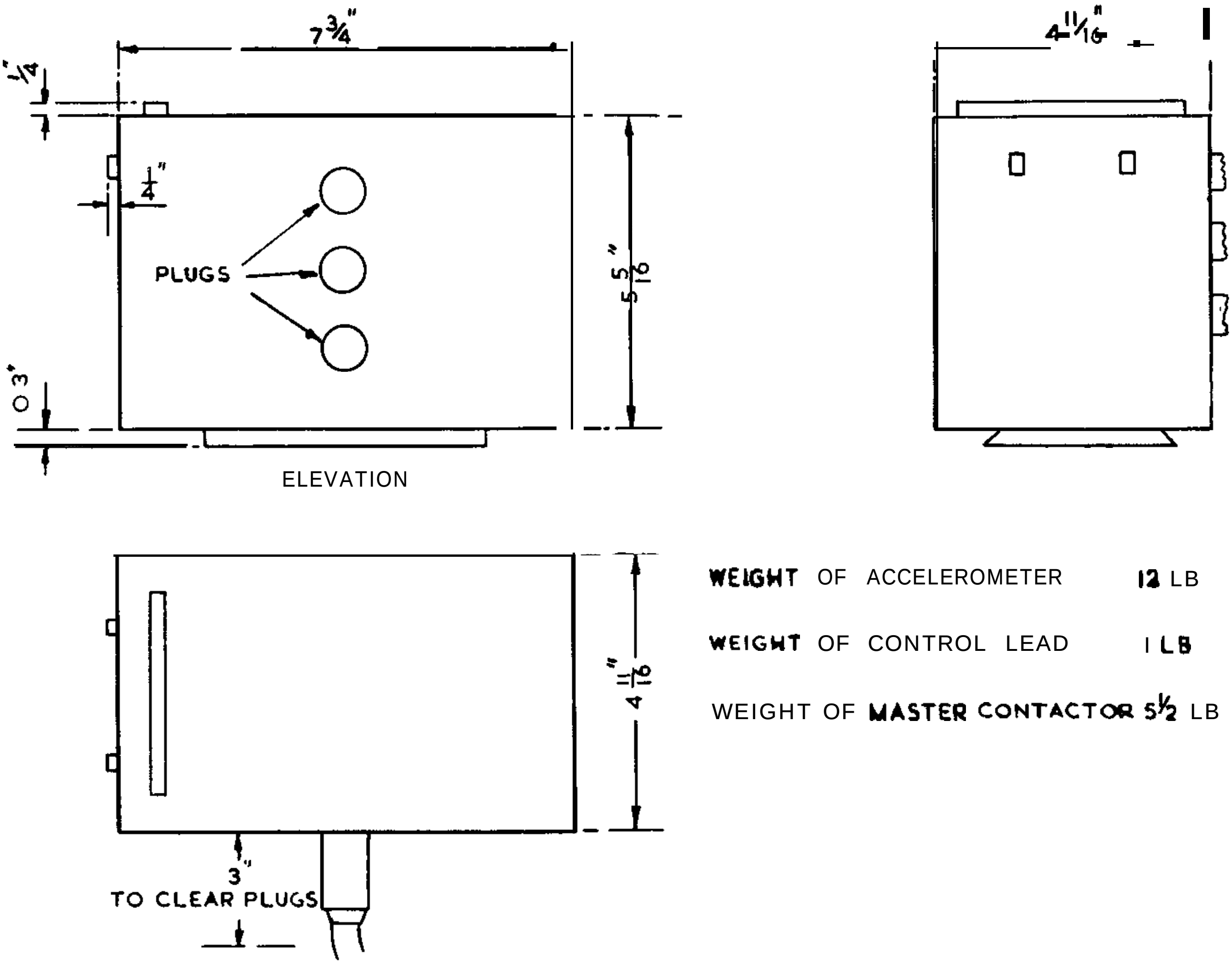


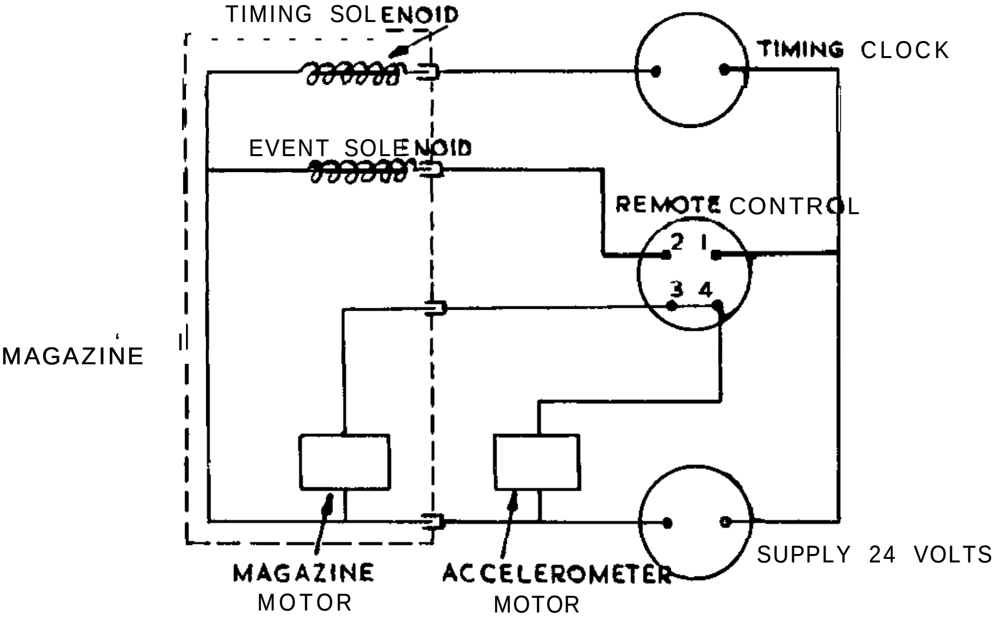
FIG. 2. EXPLODED VIEW OF ACCELEROMETER.

FIGS. 3 & 4



WEIGHT OF ACCELEROMETER	12 LB
WEIGHT OF CONTROL LEAD	1 LB
WEIGHT OF MASTER CONTACTOR	5½ LB

FIG. 3 MAIN EXTERNAL DIMENSIONS OF M.A.E.E. ACCELEROMETER



REMOTE CONTROL PIN CONNECTIONS

1 AND 2 – BUTTON FOR EVENTS

1 AND 3 – MAIN SWITCH

FIG. 4 WIRING DIAGRAM OF M.A.E.E. ACCELEROMETER

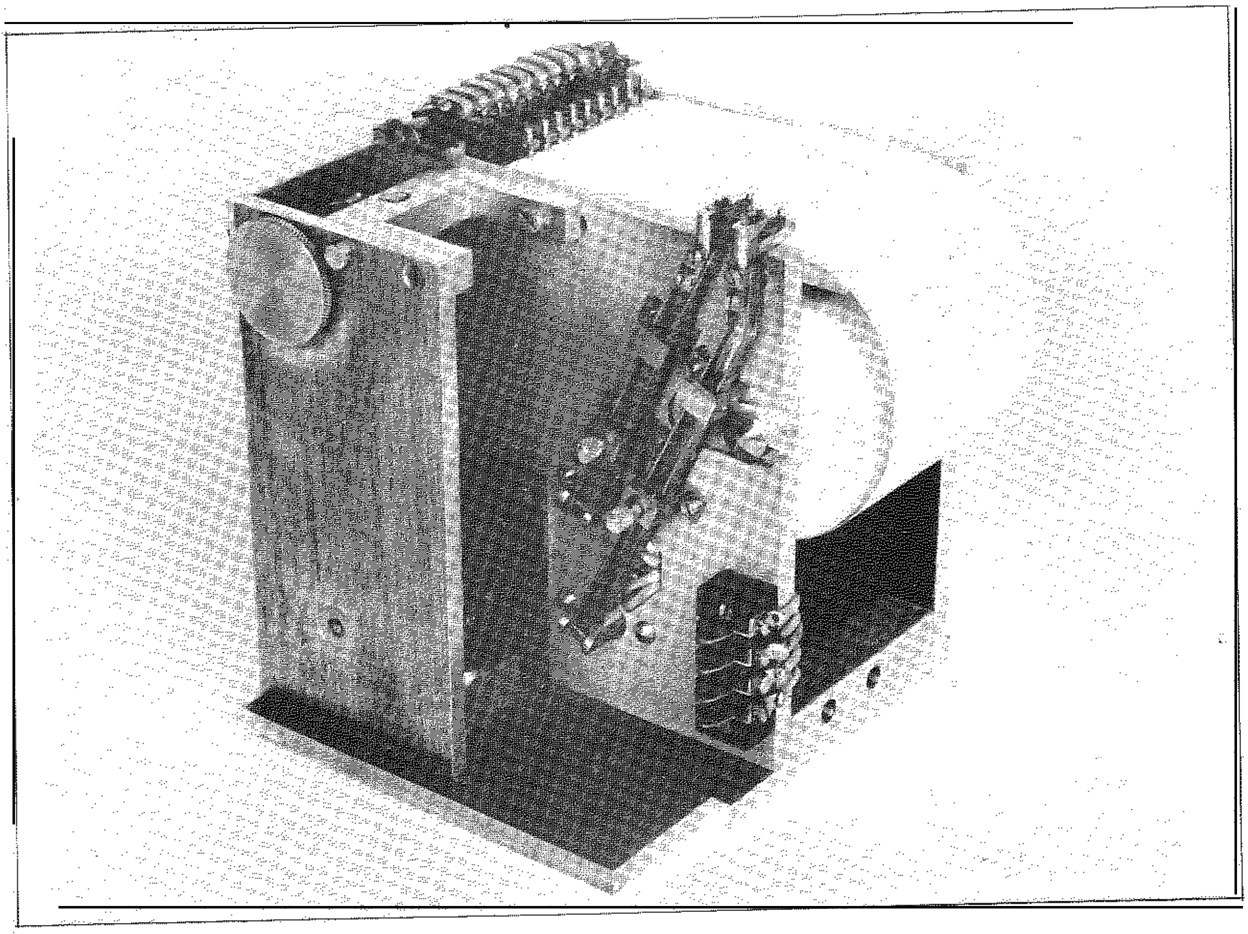


FIG.5. LOADED MAGAZINE.

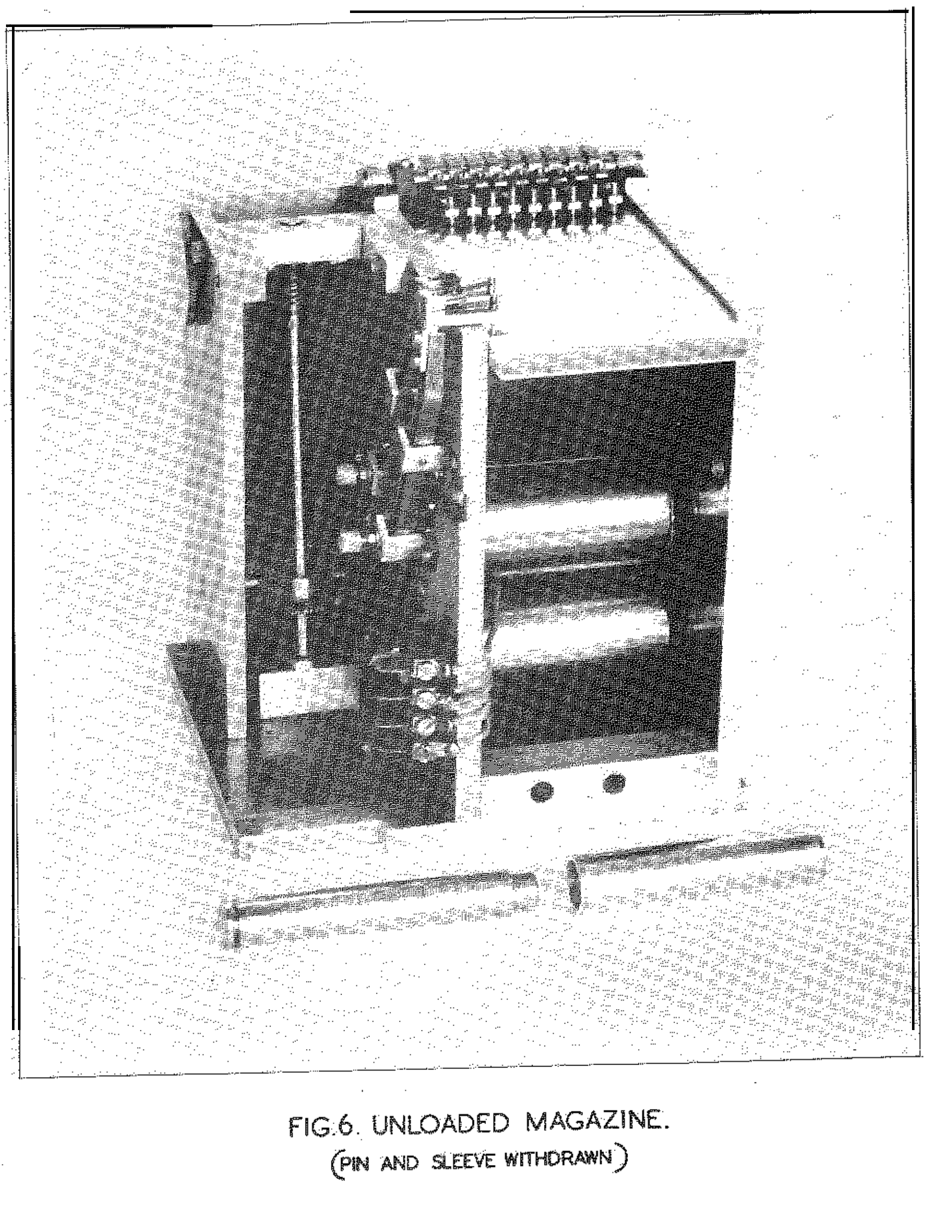


FIG.6. UNLOADED MAGAZINE.
(PIN AND SLEEVE WITHDRAWN)

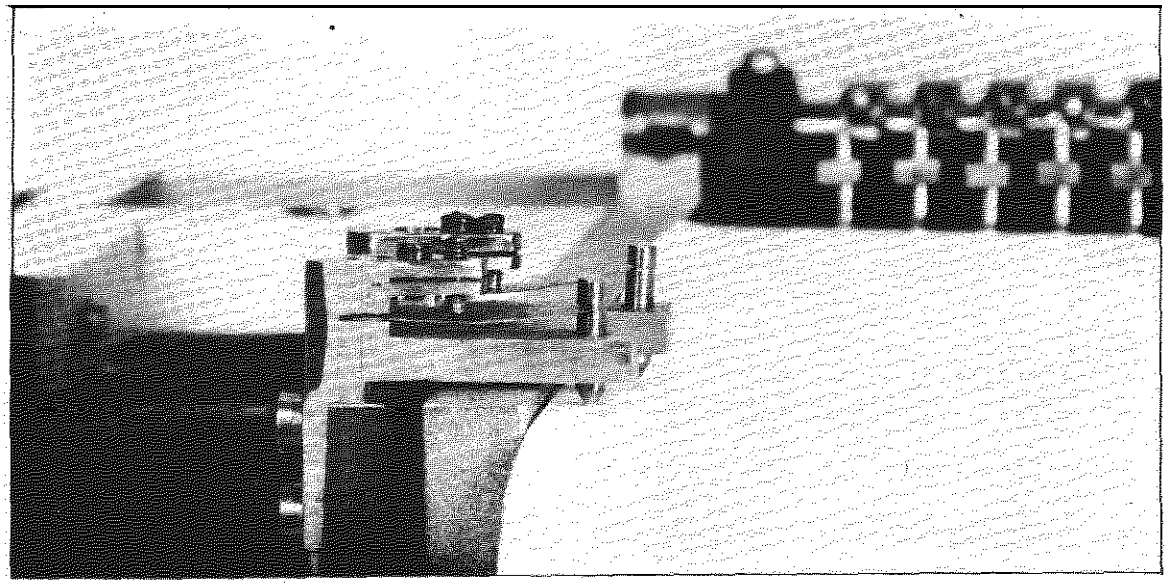


FIG.7. TIMING AND EVENT SCRIBERS

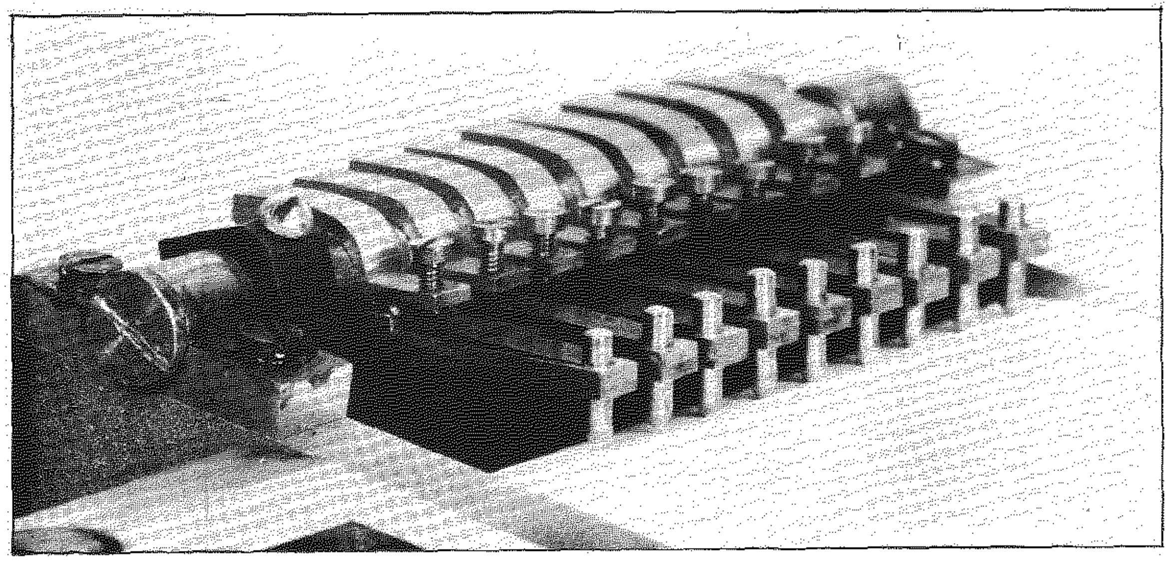


FIG.8. CALIBRATION COMB.

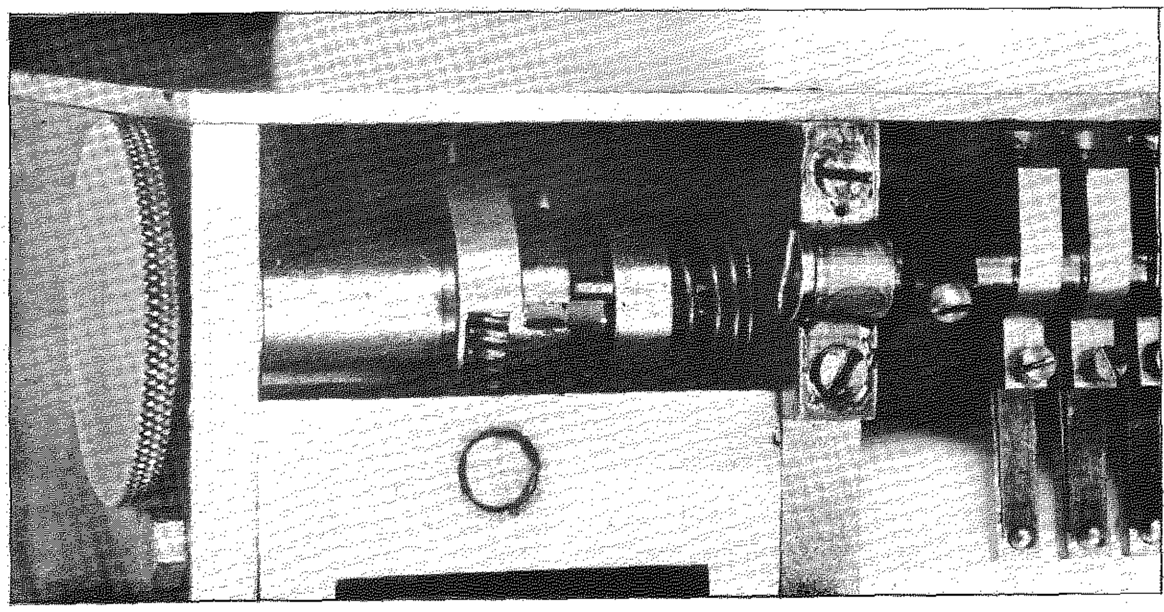


FIG.9. CLUTCH FOR LOADING.

FIG. 10

$$h = \text{DAMPING RATIO} = \frac{\text{DAMPING COEFFICIENT}}{\text{DAMPING COEFFICIENT AT CRITICAL DAMPING}}$$

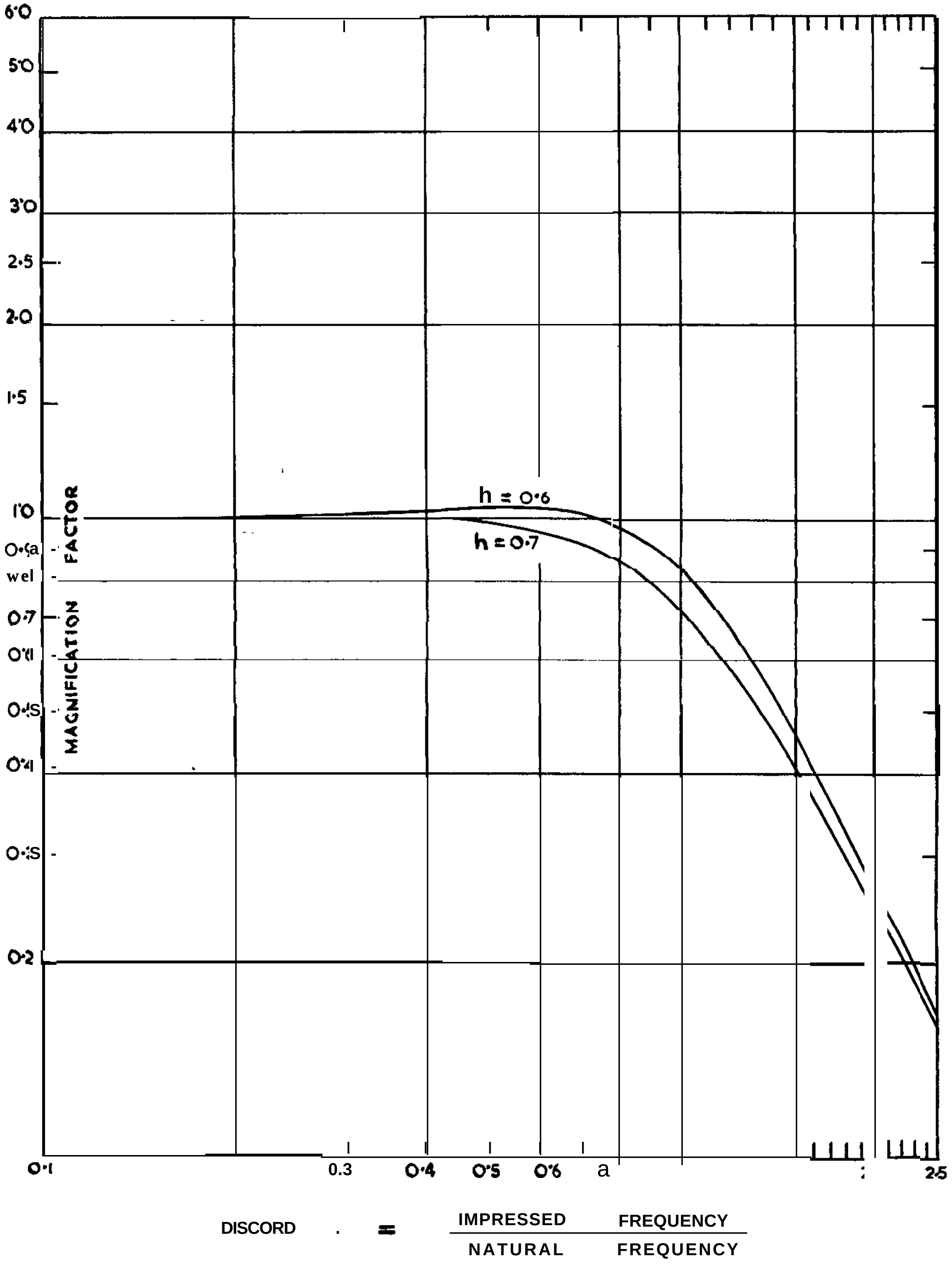
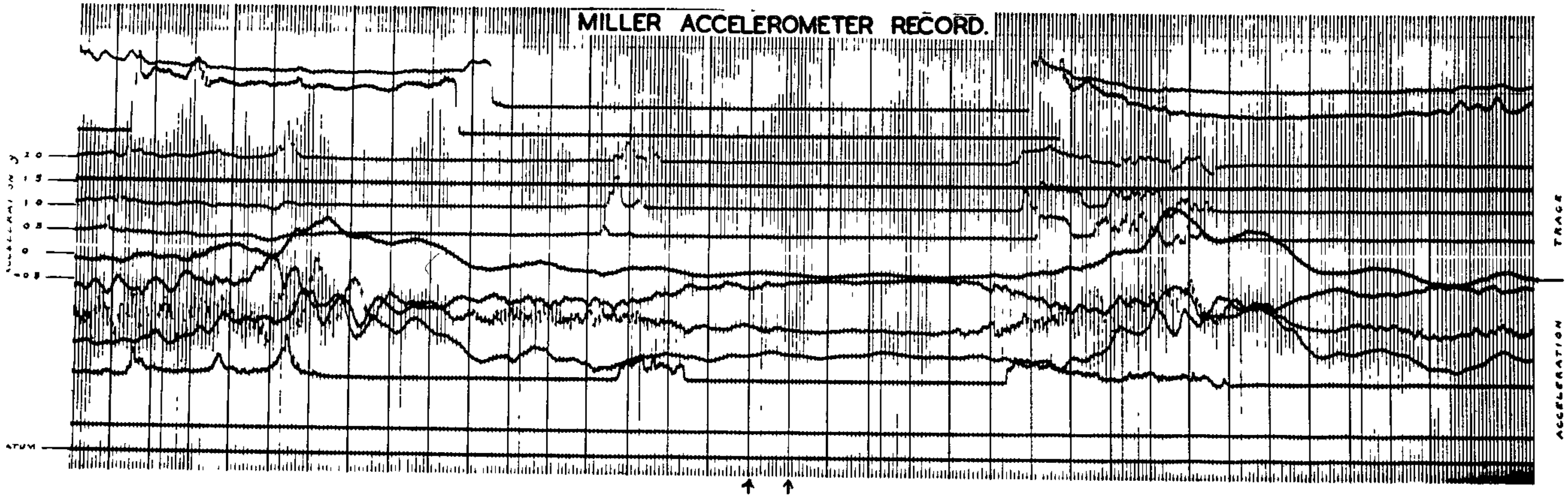
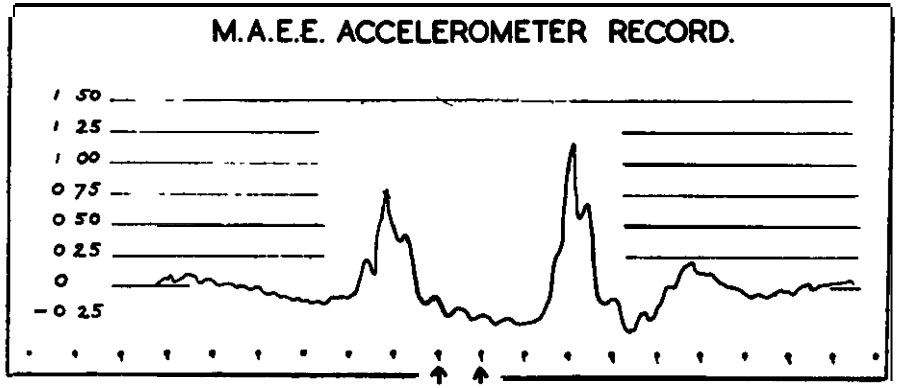


FIG. 10 RESPONSE OF ACCELEROMETER SYSTEM TO IMPRESSED ACCELERATION OF CONSTANT AMPLITUDE

FIG. 11


MILLER ACCELEROMETER RECORD.

1/10 SECOND TIMING MARKS.


M.A.E.E. ACCELEROMETER RECORD.

1/2 SECOND TIMING MARKS

FIG 11 COMPARISON OF MILLER AND M.A.E.E ACCELEROMETER TRACES.

C.P. No. 177

(15 421)

A R C Technical Report

PRINTED AND PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE
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PRINTED IN GREAT BRITAIN

S.O. Code No. 23-9007-77

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