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ROYAL AIRCRAFT ESTABLISHMENT
FARNBOROUGH, HANTS

TECHNICAL NOTE: No. G.W.300

A HIGH SPEED ELECTRO-MECHANICAL MULTIPLIER

by

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A High Speed Electro-Mechanical Multiplier

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SUMMARY

Requirements exist in simulator work for a simple high speed squaring and multiplying unit of moderate accuracy.

This note describes a simple electro-mechanical multiplier using a type E.4 relay as a position servo driving a potentiometer.

The unit will operate on frequencies up to 15 c.p.s. without introducing any appreciable phase shift. Accuracy depends primarily on the quality of the potentiometers used but maximum errors of 1% of the maximum output appear possible.

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1 Introduction

In analogue computors of the electronic type it is often required to produce a voltage that is equal to, or proportional to, the product of two given voltages. A number of electronic circuits for multipliers have been devised[1] but these are generally fairly complex or else their accuracy is poor. Electro-mechanical multipliers have also been made but these, usually operated by motors or velodynes, introduce time lags which are too long for many purposes.

It is the purpose of this note to describe an electro-mechanical multiplier which is capable of moderate accuracy and has a time lag of the order of ten milli-seconds only.

2 The Method

It is well known that analogue multiplication can be achieved by the arrangement shown in Fig.1. When V_x is zero the motor turns until the feedback voltage V_f is zero, i.e. until the slider of the potentiometer P_1 is central. When V_x is changed to some other value the motor will turn until $V_f = -V_x$ so that the potentiometer slider will have turned through an angle θ which is proportional to V_x; i.e. $\theta = k'V_x$, similarly, the slider of potentiometer P_2 will have turned through the same angle θ. Hence, if the ends of the winding of P_2 are at potentials $+V_y$ and $-V_y$, the potential V_o at the slider of P_2 will be proportional to V_y and also to θ. Thus $V_o = k'' \theta V_y = k'' k' V_x V_y = k V_x V_y$. If both V_y and $-V_y$ are not available a reversing amplifier or alternatively a push-pull amplifier must be used.

3 The Multiplier

The device to be described resembles Fig.1 in principle, but instead of the motor an efficient form of polarised relay[2] is used. This relay, a rotary type, has a spindle which turns through an angle proportional to the current flowing through the coils over the range of angles $\pm 6^{o}$. An arm attached to the spindle carries two light potentiometer sliders. The two high-grade wire-wound linear potentiometers are supported on an adjustable mount fitted to the base. The general arrangement of one of these devices, mounted in a standard Tridac brick unit is shown in Fig.2.

In order to obtain a suitably damped response such as that shown in Fig.3, some form of damping is required and one possible method, used in the prototype instrument, is the air dash-pot. The one in the illustration was obtained from an aircraft rate-of-turn indicator, but the accuracy is adversely affected by the total friction in the system and it is believed that eddy current damping would be superior.

A schematic diagram of the unit is given in Fig.4 and a circuit diagram of the Relay amplifier in Fig.5.

4 Accuracy

The accuracy of the instrument depends upon the performance of the amplifier-relay-feedback potentiometer servo system and the matching accuracy of the two potentiometers. It is not necessary that the potentiometers be linear but they must be matched. Currently available linear potentiometers of a suitable size[3] may be obtained with maximum errors from linearity of the order of 0.1% and therefore matching to 0.2%. The steady state accuracy of the servo system, assuming it is stable, depends on the torque-current characteristic of the relay, the effective slope of the amplifier and the torque necessary to move the slider arm. The torque-current characteristic of the relay is nearly linear and of the order of 50 gm. cm/ma. and the effective slope of the amplifier is 30 ma./volt. The static friction of the prototype unit was rather high and consequently a torque of 70 gm. cm was necessary to move the slider arm and under these conditions steady state errors of the order of one or two percent would be expected.

At the time when the results given in Fig. 6 were obtained high accuracy potentiometers were not available and the potentiometers used were only matched to within about 5%, and this accounts for the large error quoted for the multiplier potentiometer output.

5 Speed of response

The speed of response of the multiplier depends on the torque-inertia ratio of the relay and associated wiper arm. In order to use the full length of a 1" potentiometer a $4\frac{1}{2}$" wiper arm is needed and its weight should be kept as low as possible while maintaining a high degree of mechanical stiffness. The arm used on the experimental instrument was made of solid bakelised fibre and therefore rather heavy, but even so operating frequencies of 15 cycles per second are possible with negligible phase shift (Fig. 7a).

By the use of a properly designed wiper arm and possibly a shorter potentiometer, the maximum operating frequency could be raised considerably and it is of interest to note the frequency response of the E.4 relay driving a piston valve given in Fig. 8.

6 Conclusions

It would seem quite possible to construct a multiplier of the type described to have maximum steady state errors of the order of 1% of full scale and a time lag of 10 milliseconds. Such an instrument could also be arranged to produce an output voltage proportional to non-linear functions of the input voltage by the substitution of a suitably shaped or loaded potentiometer for the linear multiplier potentiometer.

REFERENCES

No.	Author	Title, etc.
1	Thomas and Squires	Electronic Analogue Methods of Multiplication. R.A.E. Tech. Note No. G.W.53.
2	Laws	An Electro-Mechanical Transducer with Permanent Magnet Polarisation. R.A.E. Tech. Note No. G.W.202.
3	-	Prov. Spec. for Straight Wirewound Potentiometers. R.A.E. Prov. Spec. No. G.W.72.

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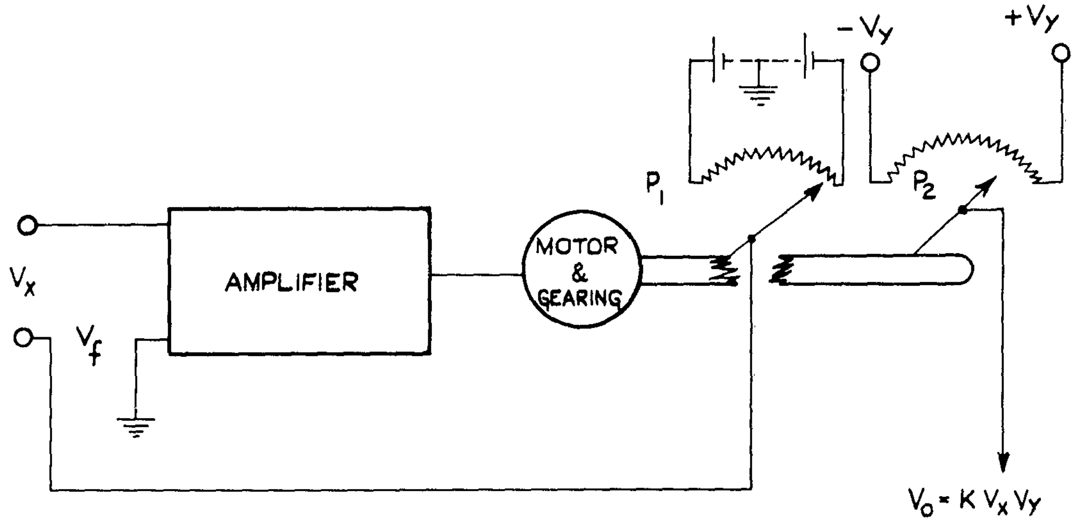

FIG. 1. THE MULTIPLYING METHOD.

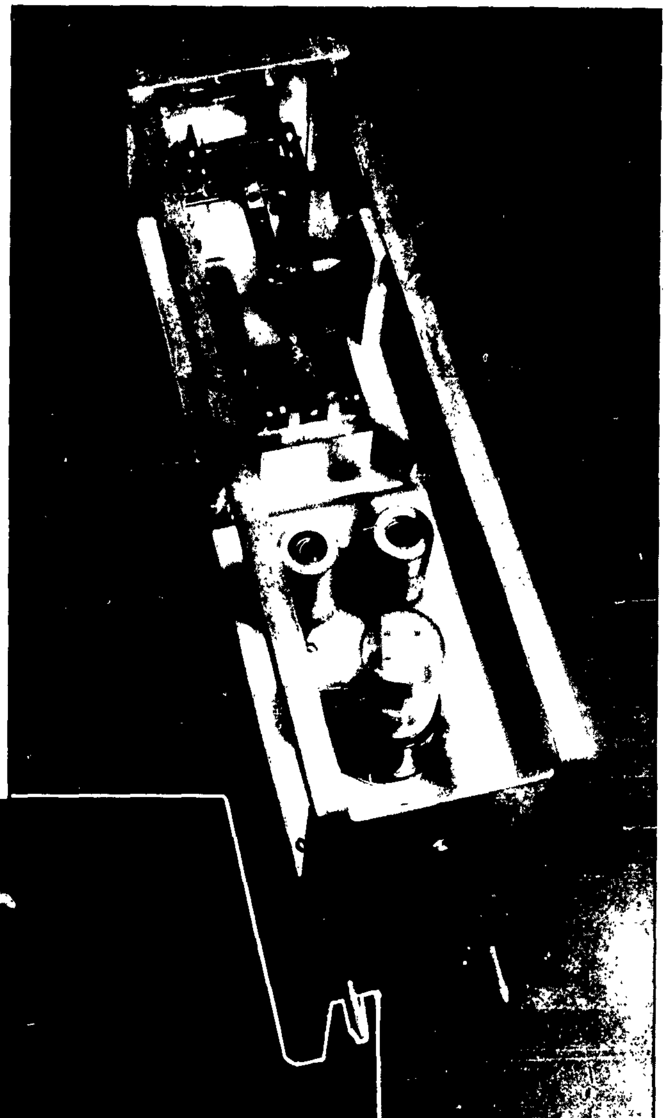

FIG.2. HIGH SPEED ELECTRO-MECHANICAL MULTIPLIER ASSEMBLED IN A "TRIDAC" BRICK UNIT

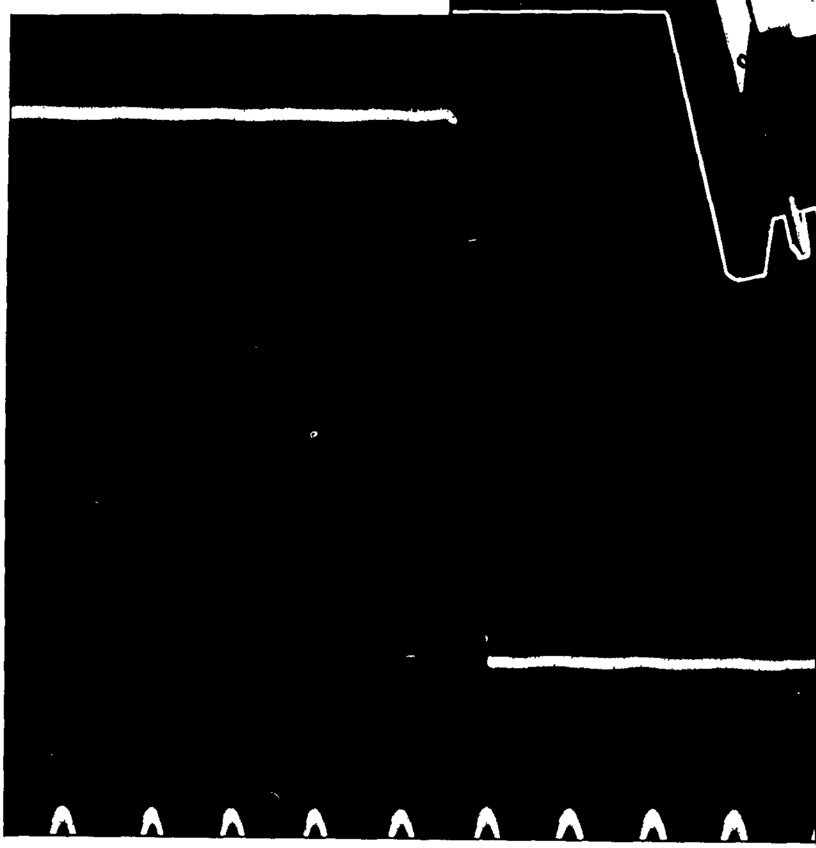

FIG.3. CLOSED LOOP RESPONSE TO STEP INPUT

[step 90% of full pot travel, time 10 milli-seconds. (Timing marks as 50 c.p.s. sine wave peaks)]

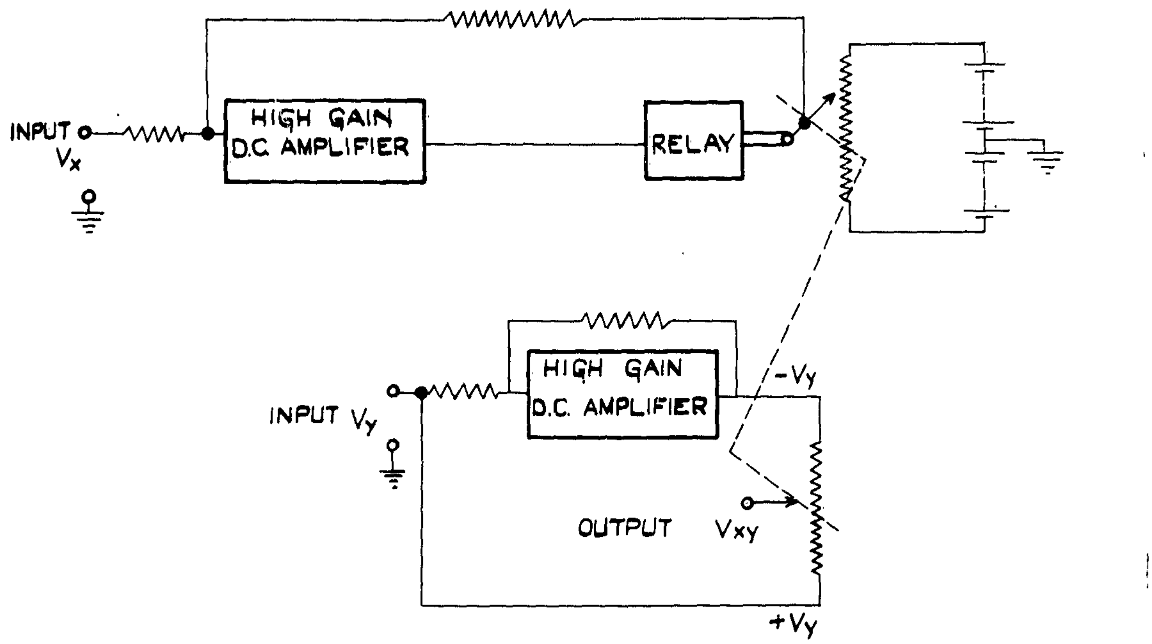

FIG. 4. SCHEMATIC DIAGRAM OF THE MULTIPLIER.

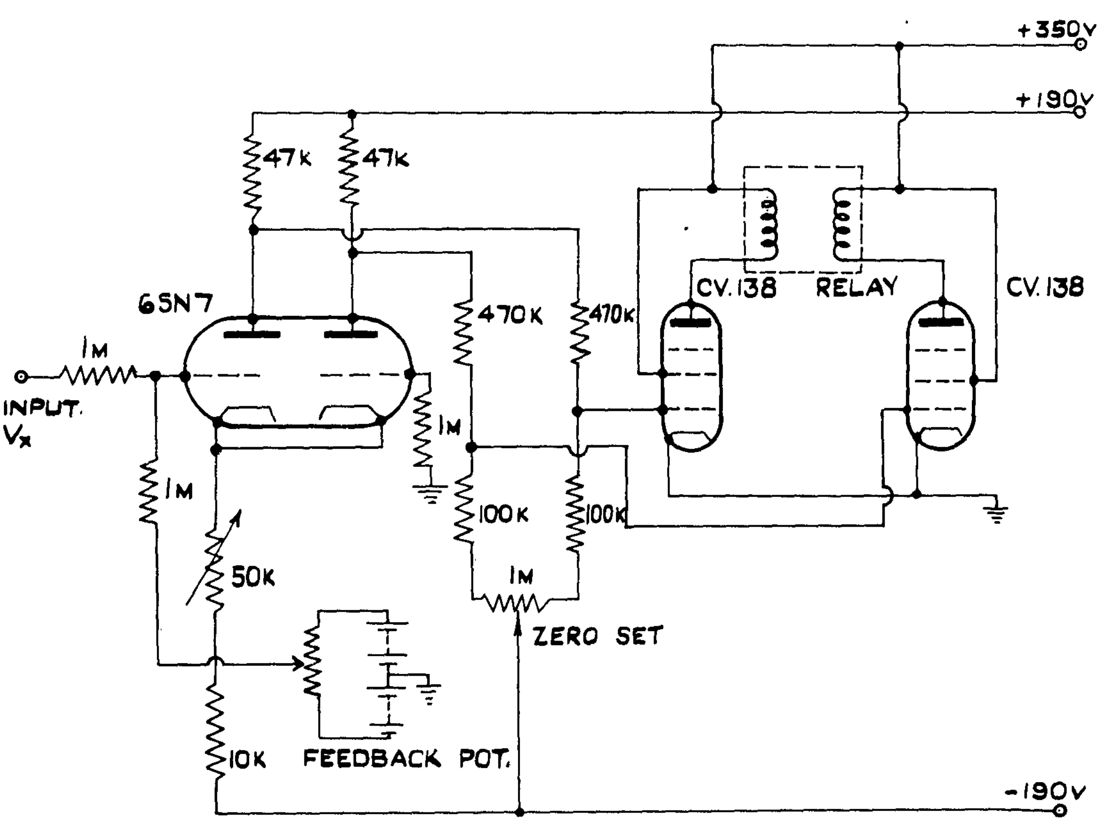

FIG. 5. CIRCUIT DIAGRAM OF THE HIGH SPEED ELECTRO-MECHANICAL SERVO.

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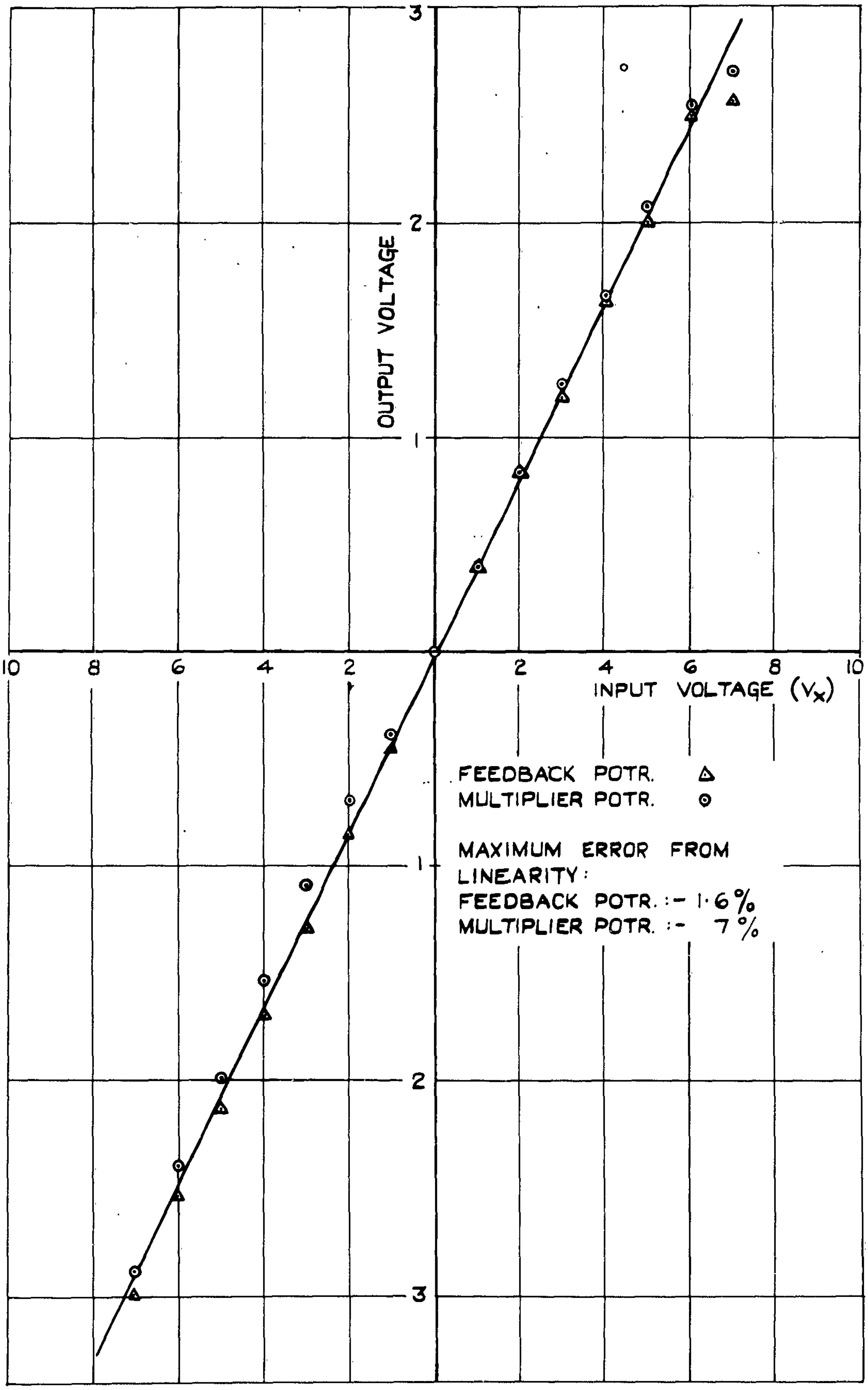

FIG. 6. EXPERIMENTAL RESULTS FOR MULTIPLIER.

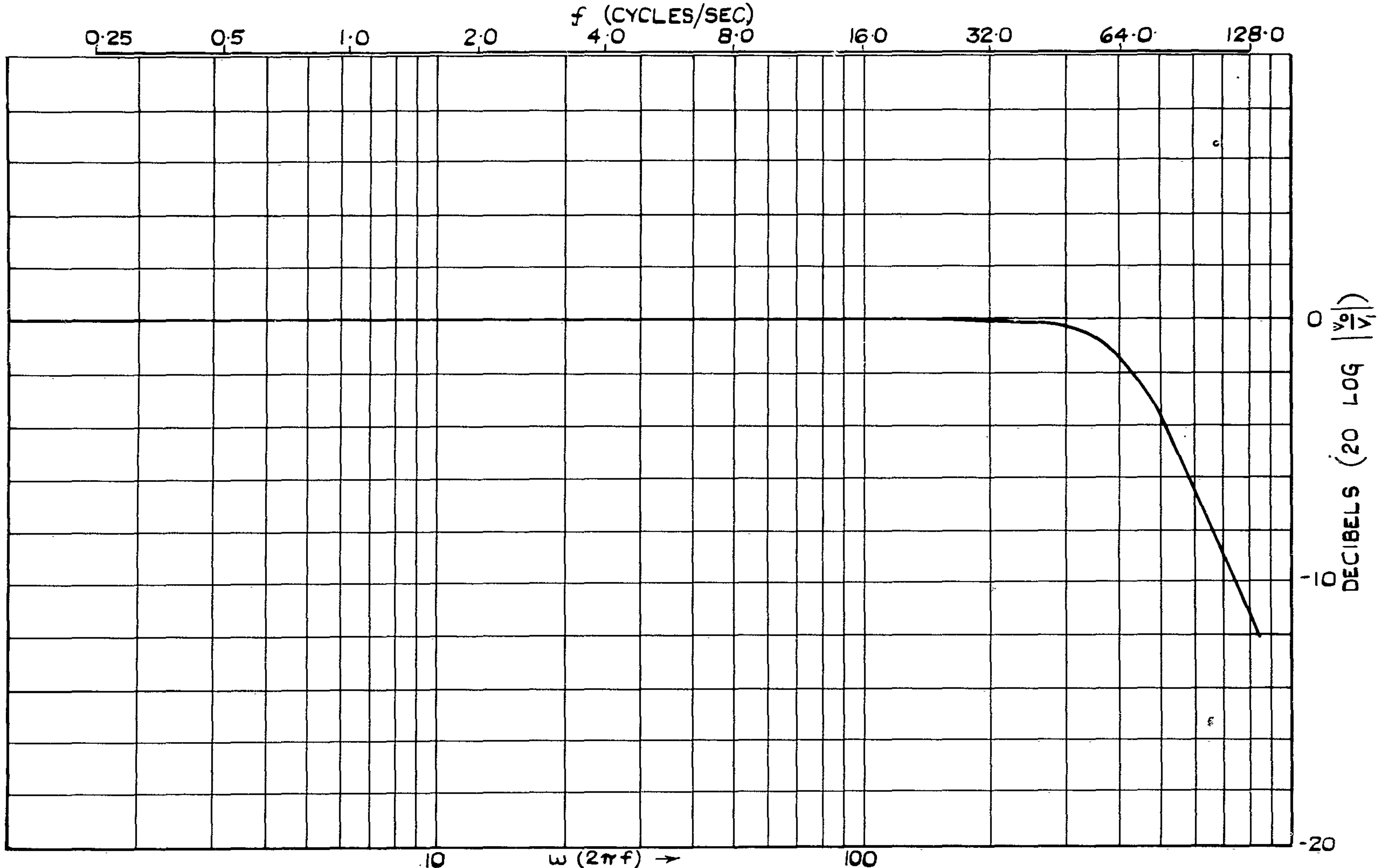

FIG. 7B. FREQUENCY RESPONSE OF THE AMPLIFIER-RELAY COMBINATION.

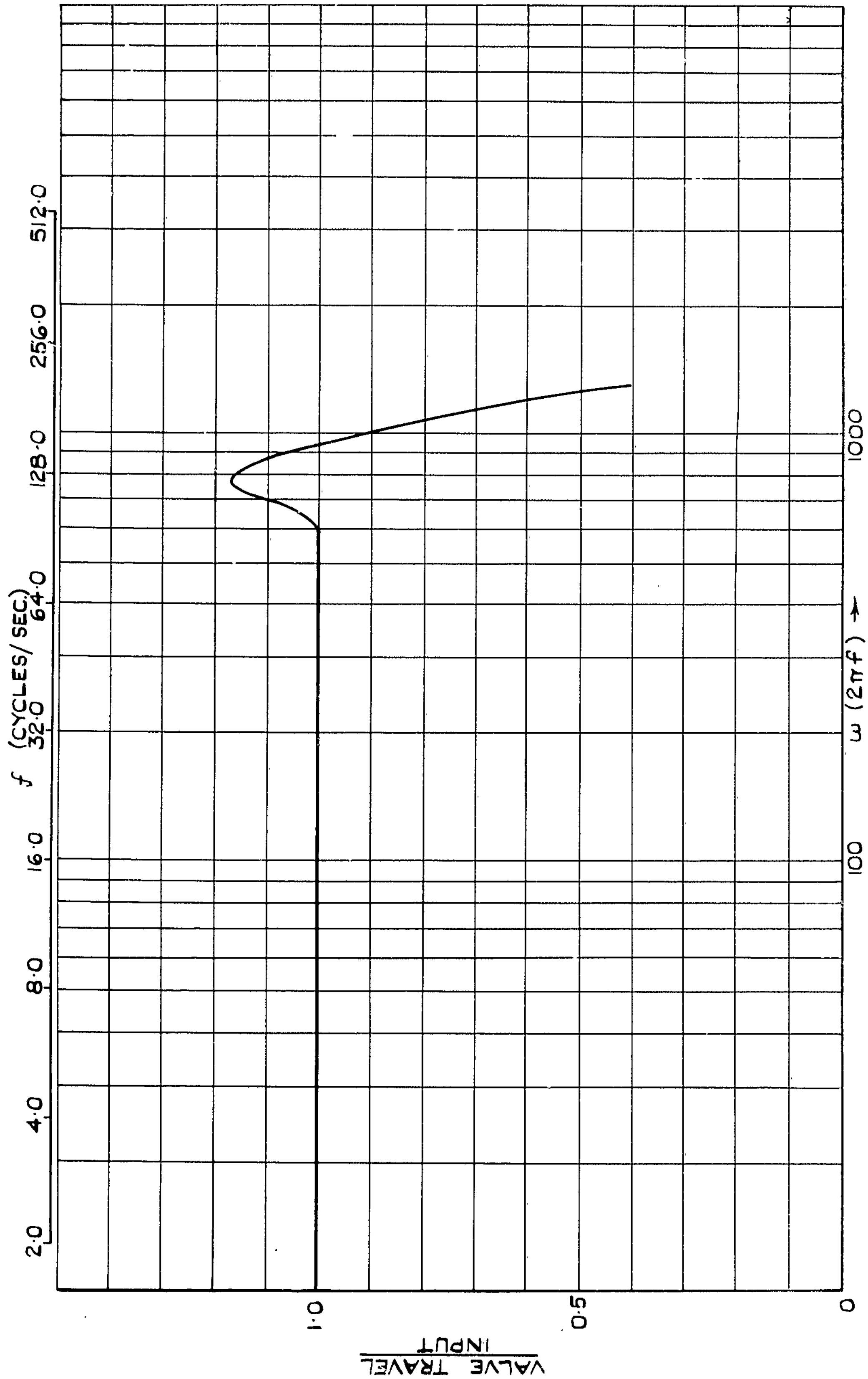

FIG. 8. FREQUENCY RESPONSE OF E.4. RELAY DRIVING A PISTON VALVE.

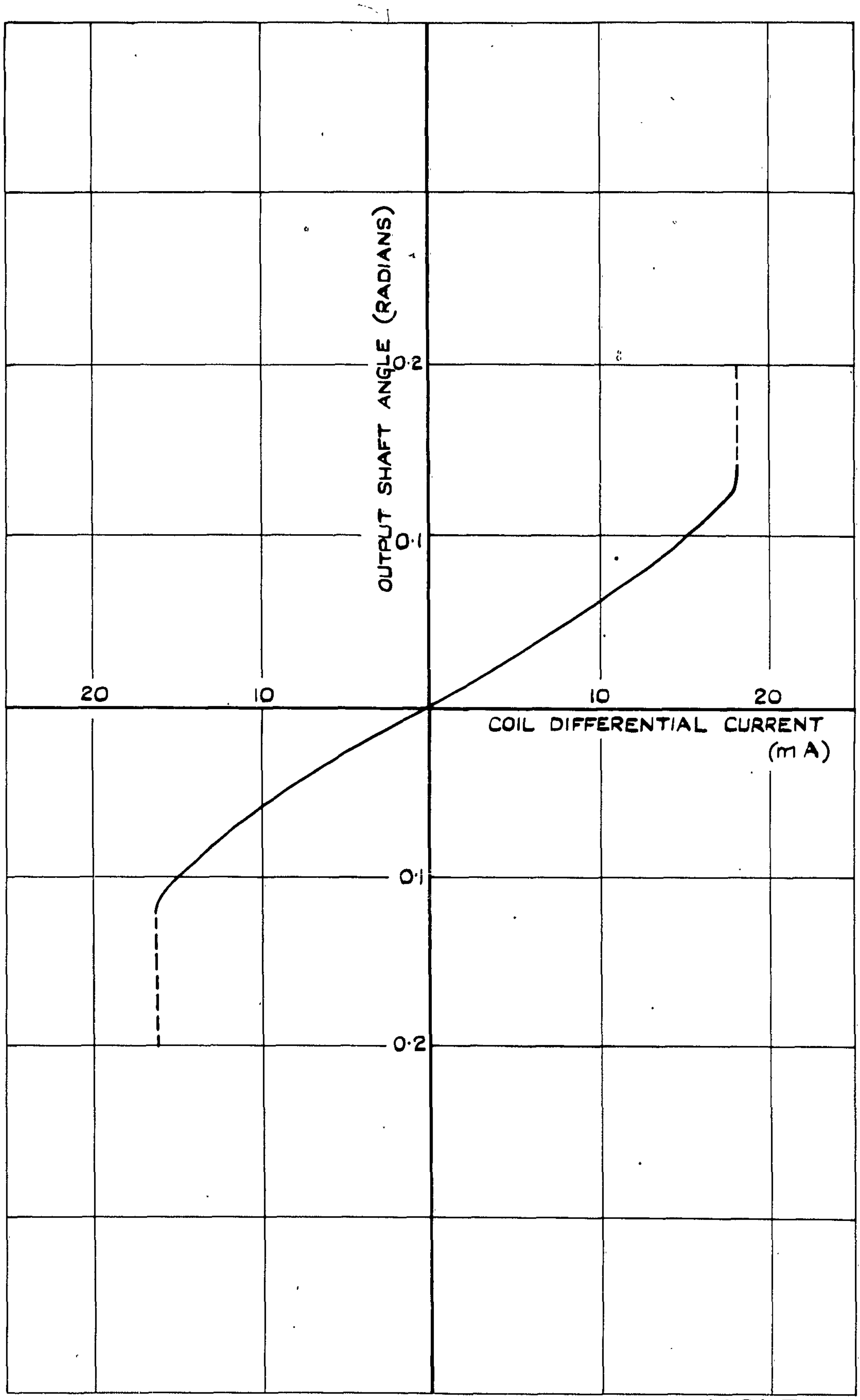

FIG. 9. TYPICAL CURRENT vs. ANGLE CURVE FOR E. 4. RELAY.

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