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A STUDY OF MEANS FOR ADAPTING THE OSCILLOGRAPH
TO THE RECORDING OF MOTION
THESIS FOR DEGREE OF B. S.

C. C. NOECKER

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A STUDY OF MEANS FOR ADAPTING THE OSCILLOGRAPH
TO THE RECORDING
OF MOTION

A
THESIS SUBMITTED TO THE FACULTY
OF MICHIGAN STATE COLLEGE OF
AGRICULTURE AND APPLIED SCIENCE

BY

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OF BACHELOR OF SCIENCE

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A STUDY OF MEANS FOR ADAPTING THE OSCILLOGRAPH TO THE RECORDING OF MOTION

A considerable amount of work has been done in connection with the measurement of mechanical motion by use of mechanical methods alone*. Some of these methods seem to be sufficiently accurate and satisfactory. The mechanical methods have the advantage of requiring no complicated electrical circuits and, of course, no oscillograph which is a very expensive instrument. But owing to the fact that the oscillograph is an exceedingly sensitive recording device it was considered wise to develop the project of designing a suitable method of motion measurement employing it.

There are a great number of important uses to which such a device could be applied. Vibrations of machines, ships, structures and air could be studied. It is possible to take oscillograms of the human voice and sounds from musical instruments and study

* The Use of Vibration Instruments on Electrical Machines, by J. Ormondroyd. Journal of A.I.E.E. Apr. 1926, page 330.

their properties. By observing oscillograms taken from a genuine Stradivarius violin one might be able to determine what number of overtones were present, and what their relative intensities were-- for it is upon these two that the quality of music depends.

By analyzing vibrations of the human voice recorded on oscillograms it is possible to determine the harmonic characteristics of a given voice.

Swaying of buildings and towers could be studied under different conditions of disturbance. The effect of acceleration and deceleration of heavy traffic on such structures is sometimes very pronounced and destructive.*

Lately, due to the collapse of bridges, roofs and other structures, engineers have begun to more fully realize the necessity for studying the vibration of mechanical structures.** From an investigation

* Apparatus for Studying the Vibration produced in Buildings by Traffic. Bul. de la Socié'té l'Encouragement pour l'Industrie Nationale. Vol. 134, no. 3, March 1922. pp 177-186

** Field for Research Work. By Prof. Foltz M.S.C. Record, May 3, 1926, page 452.

of vibration it might be possible to obtain records of the deterioration in structures and prevent disastrous failure. Analysis of periodic shocks and their resultant vibrations will reveal conditions jeopardizing the safety of structures before material damage results.

In a good many electrical machines due to an unbalanced condition of the rotor there arises certain speeds, termed critical speeds, where the period of the rotor vibration is equal to the natural period of the stator and foundation or some multiple thereof. By taking an oscillogram of the natural period of the latter it should be possible to predetermine the critical speeds of the rotor.

" In any vibration problem there are five things which should be known: *

1. Frequency of vibration.
2. Amplitude of vibration .
3. Type of vibration — simple-harmonic or complex.
4. The elastic properties and mass distribution of the vibrating body .

* The use of Vibration Instruments on Electrical Machines. By J. Ormondroyd. Journal of A.I.E.E., Apr. 1926, page 330.

5. A general knowledge of the possible mechanical and electrical forces acting on the body.

The first three must be gotten by quantitative measurement. Observations of these without measurement is usually valueless. The fourth is gotten from a knowledge of the material and dimensions of the body. The fifth involves a clear understanding of the mechanical and electrical functioning of the body. No instrument can supply the fourth and fifth. Trained human intelligence is necessary here".

In the problem of measuring the magnitude, period and direction of vibration or motion by means of an oscillograph one is immediately confronted with the determination of a suitable of a suitable means for transforming small and delicate mechanical motions into electrical impulses of sufficient magnitude. The magnitude of the electrical impulse must be great enough to give a good deflection on the oscillograph. The mass of the moving part of the device that will absorb energy directly from the moving body should be as small as possible in order that the inertia of it will be relatively small. If the inertia of it is too large there is apt to be a change in the phase positions of the reaction to the true vibrations. Therefore, in this problem it is of

prime importance to evolve a device that will have but a small value of inertia compared to that of the moving body.

Another characteristic which this device must possess is that for a small motion there will be a comparatively large change of current in the oscillograph.

Bearing these points in mind numerous experiments were performed which are listed and explained a little later. Some of the experiments seemed to be theoretically sound yet they failed to work out in practice.

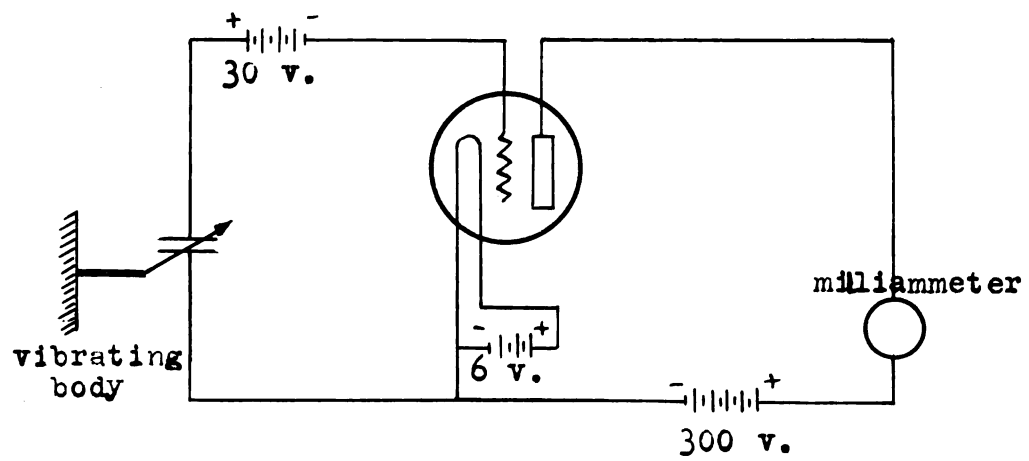


Figure 1.

One of the first experiments was that of having a moving body change the capacity of the variable condenser in Fig. 1. Theoretically when the capacity of the condenser is changed there should accompany it a change of potential of the grid. The grid and filament form a condenser by virtue of the fact that they are separated by a layer of air or gas. The equivalent circuit can be represented as shown in Fig. 2.

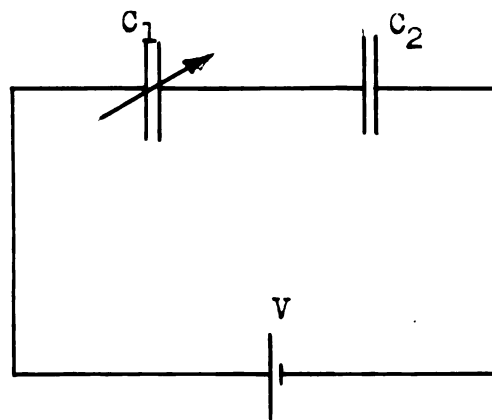


Figure 2.

In Fig. 2 we know that q_1 the charge in condenser C_1 is equal to q_2 the charge in condenser C_2 . This is true because the condensers are connected in series.

Let the capacity of $C_1 = c_1$ and $C_2 = c_2$.
 Also let the voltage drop across $C_2 = v_2$ at first,
 and after C_1 has been changed let the voltage drop
 across $C_2 = v_2'$.

V = total impressed voltage,

q = charge in the circuit at first, and

q' = charge in circuit after C_1 has been changed

In a series circuit

$$(1) \quad q = \left(\frac{c_1 c_2}{c_1 + c_2} \right) V = c_2 v_2$$

Now change the capacity of C_1 to $c_1 + \Delta c$. Now

$$(2) \quad q' = \frac{(c_1 + \Delta c) c_2}{c_1 + \Delta c + c_2} V = c_2 v_2'$$

Solving for v_2 in (1) yields

$$(3) \quad v_2 = \frac{c_1}{c_1 + c_2} .$$

Solving for v_2' in (2) yields

$$(4) \quad v_2' = \frac{c_1 + \Delta c}{c_1 + \Delta c + c_2}$$

Now dividing (3) by (4) to obtain the ratio of the
 voltage drops across C_2 we have

$$(5) \quad \frac{v_2}{v_2'} = \frac{\frac{c_1}{c_1 + c_2}}{\frac{c_1 + \Delta c}{c_1 + \Delta c + c_2}} .$$

Equation (5) shows that v_2^1 is larger than v_2 . In other words the potential drop across the grid and filament must have been increased. If the capacity of C_1 had been decreased then from similar reasoning we would find that the voltage drop across C_2 would decrease. Practically, however, there seemed to be no change of current in the plate circuit, Fig.1, so probably there was not a sufficient change in grid potential as the variable condenser was moved.

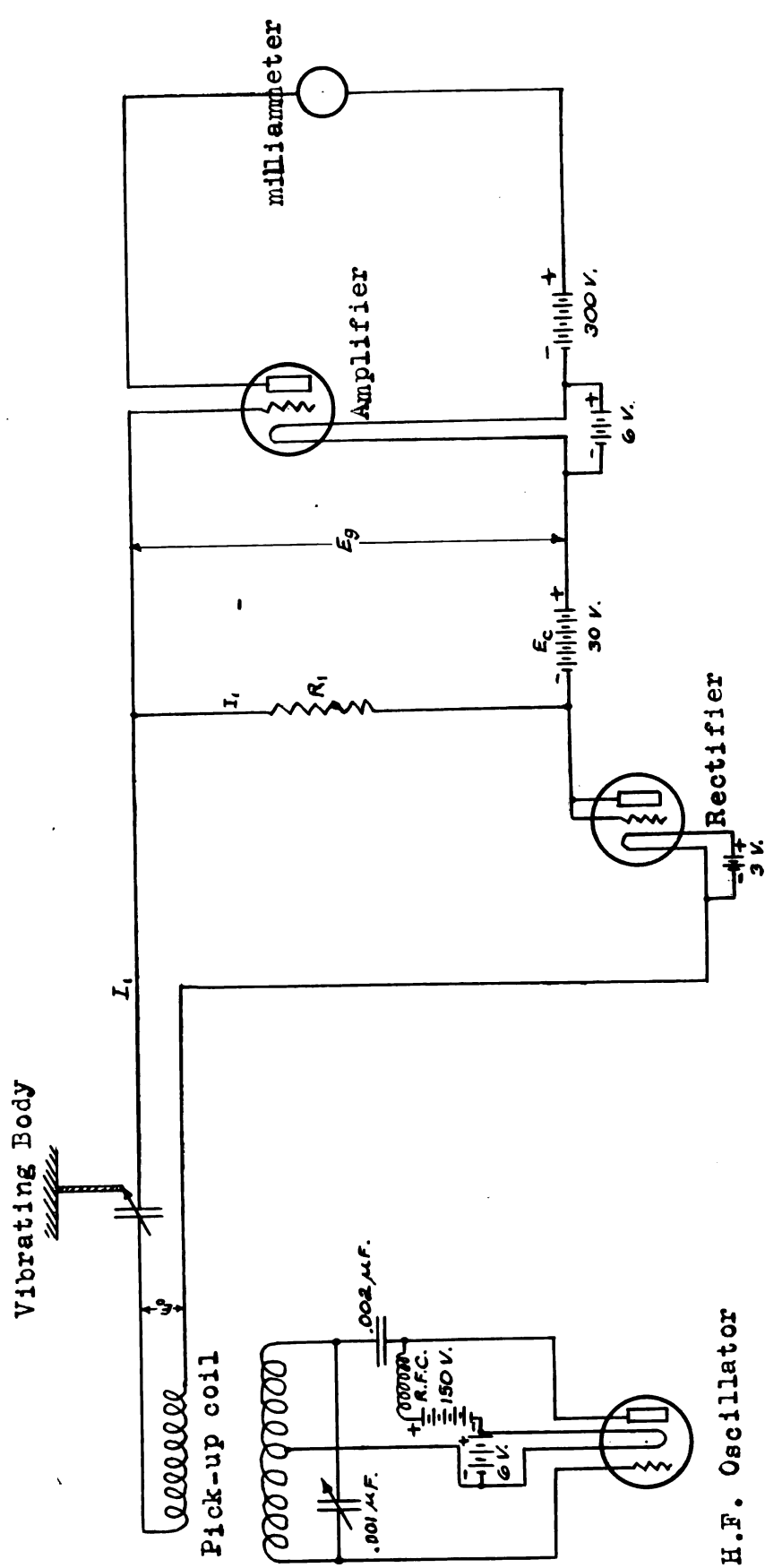
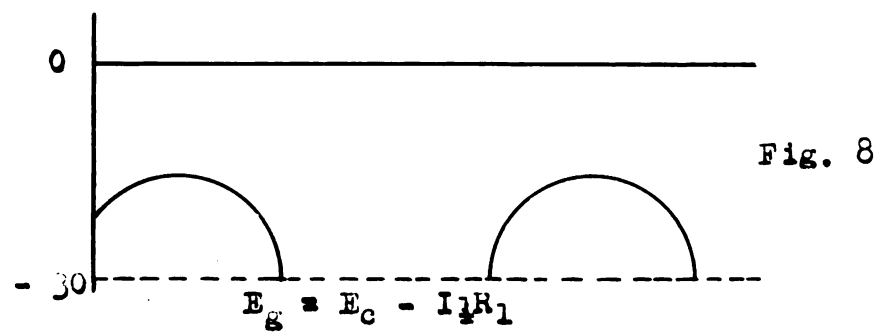
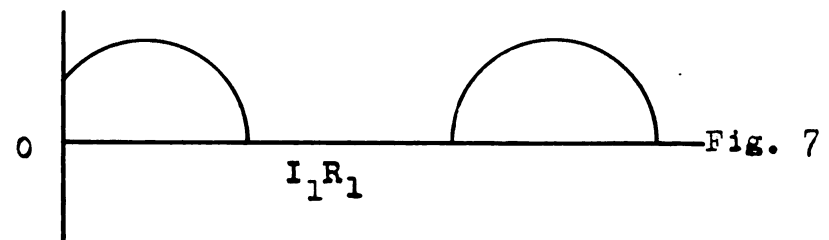
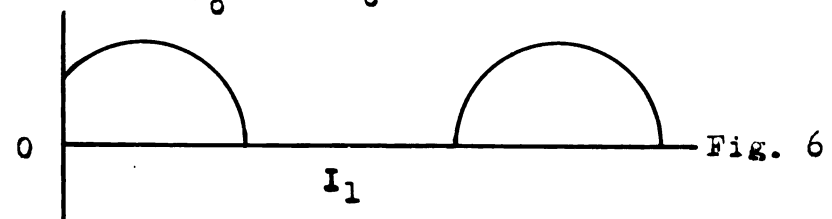
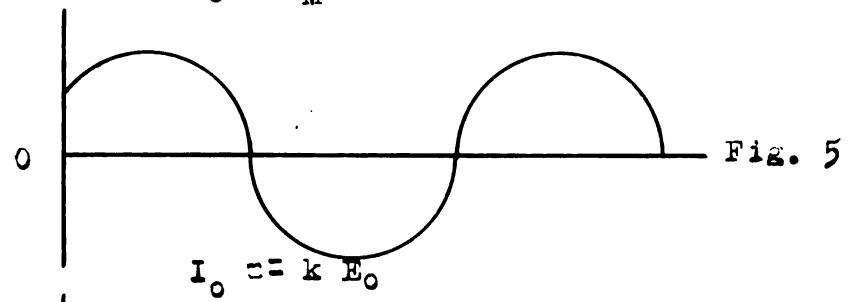
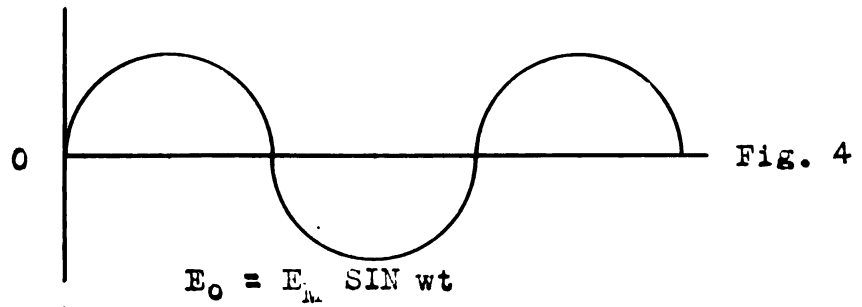


FIGURE 3.



In Fig. 3 the pick-up coil receives energy from the high-frequency oscillator and has a voltage

$$E_0 = E_m \sin t$$

induced in it, Fig. 4. The current I_0 which tends to flow in the circuit is leading the voltage E_0 , and may be represented by Fig. 5. Since E_0 is changed into a pulsating direct current by means of the rectifier the resultant current has a shape similar to Fig. 6, and is termed I_1 . The average value of I_1 is equal to one half the value of I_0 or

$$I_1 = \frac{.637}{2} I_0 .$$

With the current I_1 flowing through the resistance R_1 there is a voltage drop of $I_1 R_1$ across the resistance, Fig. 7, which effects the potential of the grid. The absolute potential of the grid for a given position of the variable condenser is equal to

$$E_g = E_c - I_1 R_1$$

and is represented by Fig. 8. Thus, as the condenser capacity is varied by the vibrating body, various values of I_1 result and by virtue of the fact that this will cause a varying voltage drop across the resistance there will be a changing grid potential.

The changing potential of the grid, E_g , will change the value of current in the plate circuit. A milliammeter was connected in series with the plate circuit and an extremely small variation of plate current was noticed as the condenser capacity was varied. There was not enough variation to justify connecting the oscillograph in place of the milliammeter. Perhaps the variation in current could be increased by two or three stages of resistance coupled amplification to a proper value. Due to the fact that for low frequencies the impedance of the condensers used in the amplifying would be relatively high it would be necessary to use very large condensers to eliminate distortion of the low period vibrations.

This device will not give a straight line function because the relation of a given movement of the condenser to another value of movement is not directly proportional to the values of their respective plate currents.

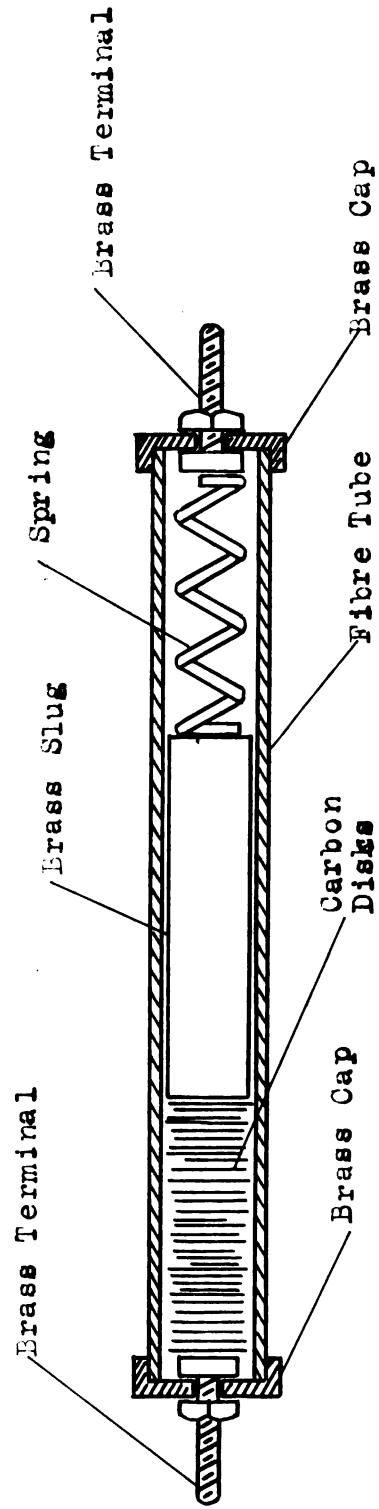


FIGURE 9

The inertia recorder, Fig. 9, gave very poor results. Theoretically when this device is attached to a machine which is vibrating in the horizontal plane the inertia of the brass slug will cause a varying pressure on the carbon pile thus varying the resistance. Practically, with the simple series circuit of recorder, milliammeter and battery, the sensitivity was extremely low. This sensitivity might be increased with two or three stages of resistance coupled amplification with the added danger of distortion of the lower frequencies. This device does not give a straight line relation between pressure and resistance but a curve similar to a hyperbole.

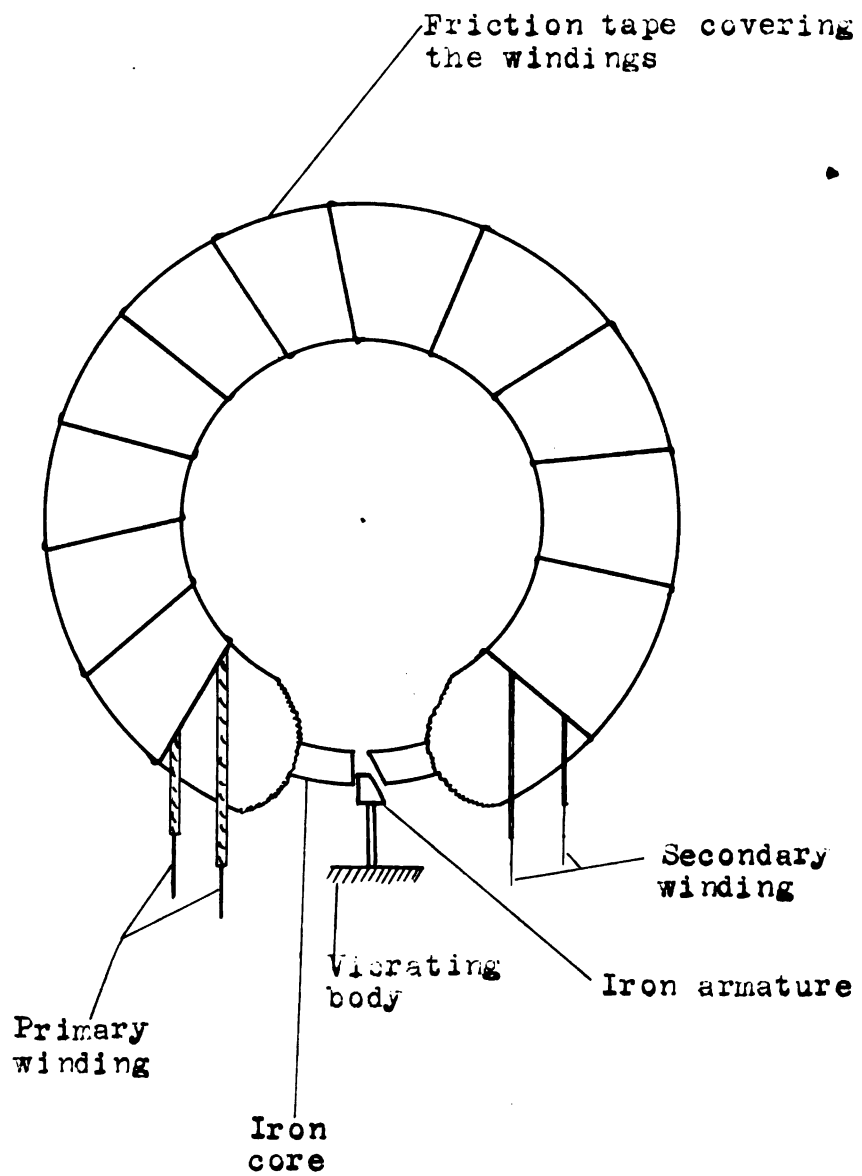


FIGURE 10

This device, Fig. 10, operates directly by the change in reluctance of the magnetic circuit by movement of the armature in the air-gap. Since

$$\phi = \frac{MMF}{R}$$

it is evident that a change in the reluctance causes a change of flux when the MMF is constant.

Because $e = k \frac{d\phi}{dt}$, there is generated in the secondary winding a voltage e .

By quickly inserting the armature the voltage induced in the secondary coil was only about two or three millivolts. This could be amplified. The relation here between movement of the armature and the induced e.m.f. will not be a straight line.

The curve taken from a device of this type would be a first derivative of the true vibration.

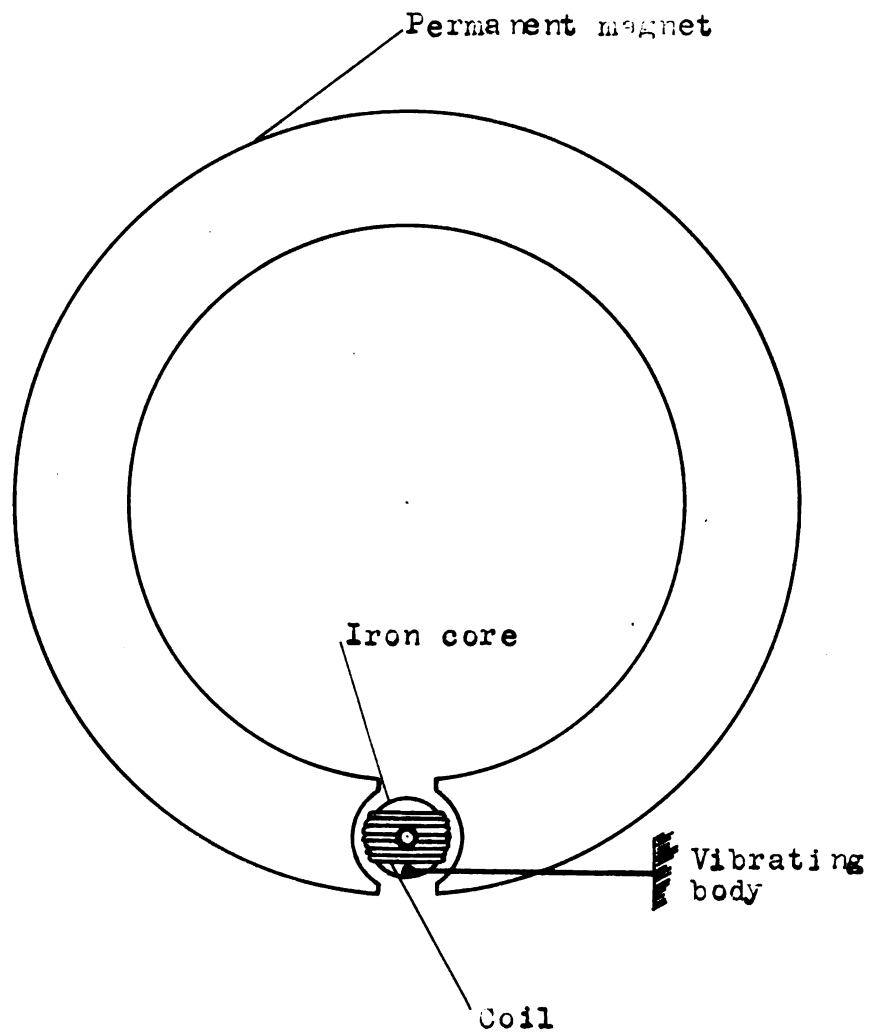


Figure 11

The meter-movement, Fig. 11, also gave rather poor results. The ends of the coil were connected to a millivoltmeter. When the coil was moved through the field of the permanent magnet there was a small e.m.f. generated in it and this caused a small deflection on the millivoltmeter. This device will not produce a straight line for the relation of coil-movement and induced voltage. The curve in this case will also represent the first derivative of the true vibration.

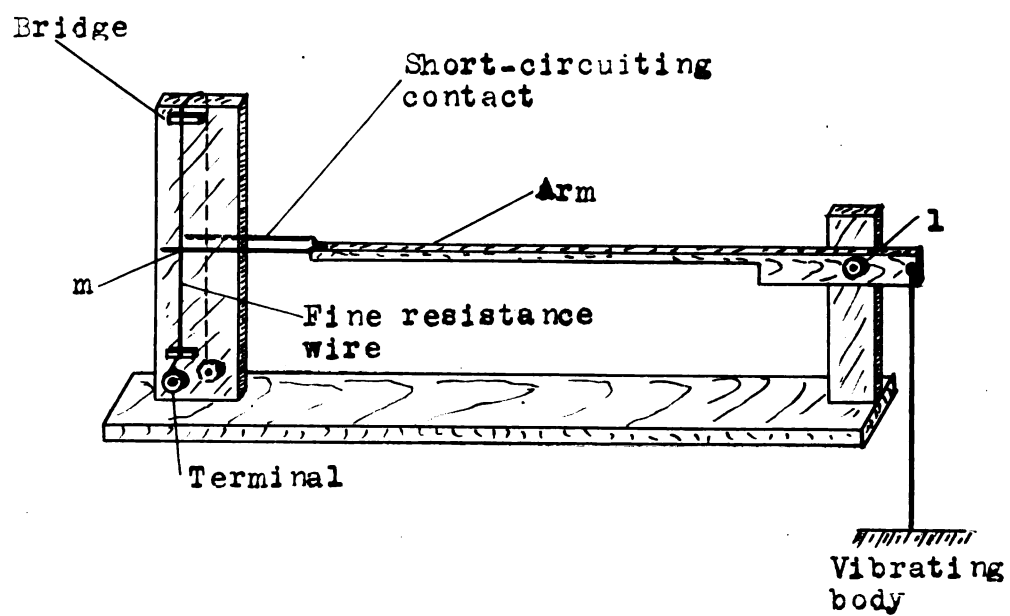
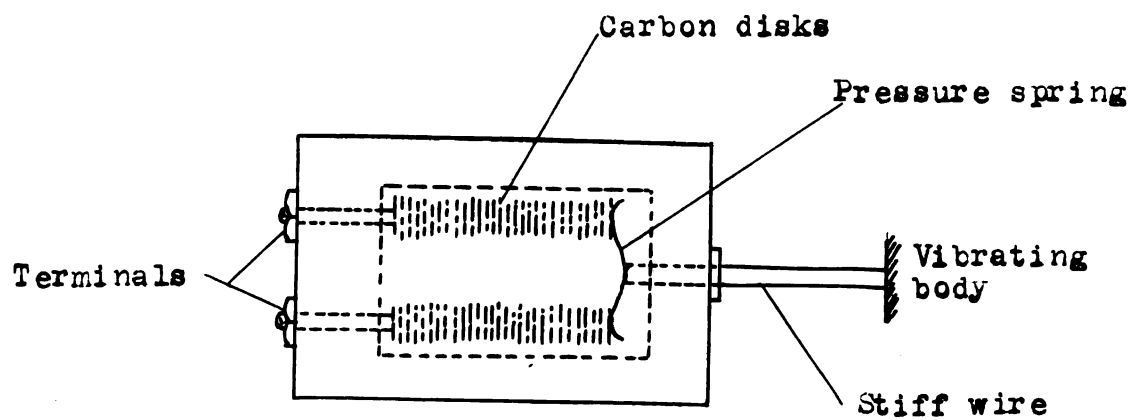


FIGURE 12

The apparatus in Fig. 12 will produce a straight line relationship between the movement of the vibrating body and the resistance between terminals. This gave a relatively large per cent variation in current for a given movement of the arm.

Practically the arm had too much inertia and there was too much lost motion at the pivot "1". There is apt to be trouble in attempting to keep a uniform contact resistance at "m" for different positions of the arm.



BRADLEYSTAT

FIGURE 13

Fig. 13 represents a Bradleystat which has the screw replaced with a stiff wire. In this device the relation between the pressure and resistance is not a straight line but has a shape similar to that of a hyperbole as illustrated in the accompanying graph.

The Bradleystat was mounted on the end of a section of rail that was clamped to a table. The table was then adjusted until the stiff wire made firm contact with the machine G_1 in the A.C. laboratory. Fig. 14 shows the set-up. As the machine vibrated the resistance of the carbon pile was varied which in turn caused a varying current to be sent through a simple series circuit of a 1.5 volt dry-cell. The oscillograph was connected in series with the Bradleystat and then some oscillograms were taken. Figures A, B, C, D, and E are oscillograms taken from this set-up. In figures A and B curves no. 1 represent the 60 cycle timing wave of voltage from the power plant and curves no. 2 show the record of the vibration of G_1 without a field. The irregularities in the vibration curves are probably due to microphonic action of the carbon pile.

Curve no. 2, Fig. C, shows the vibration of G_1

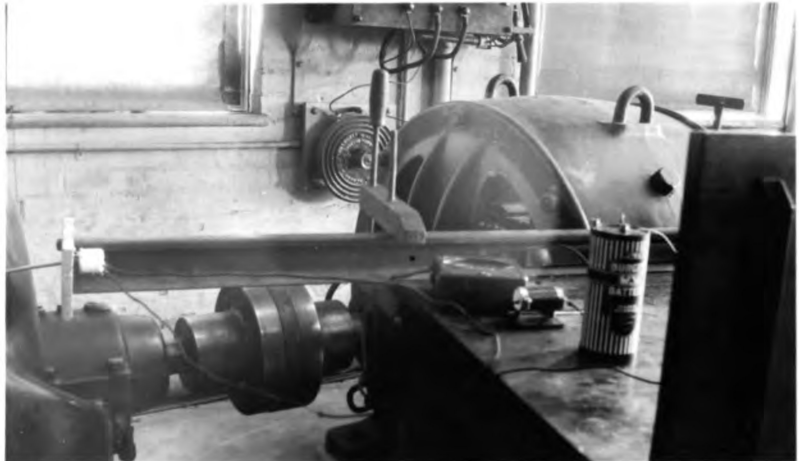


FIGURE 14

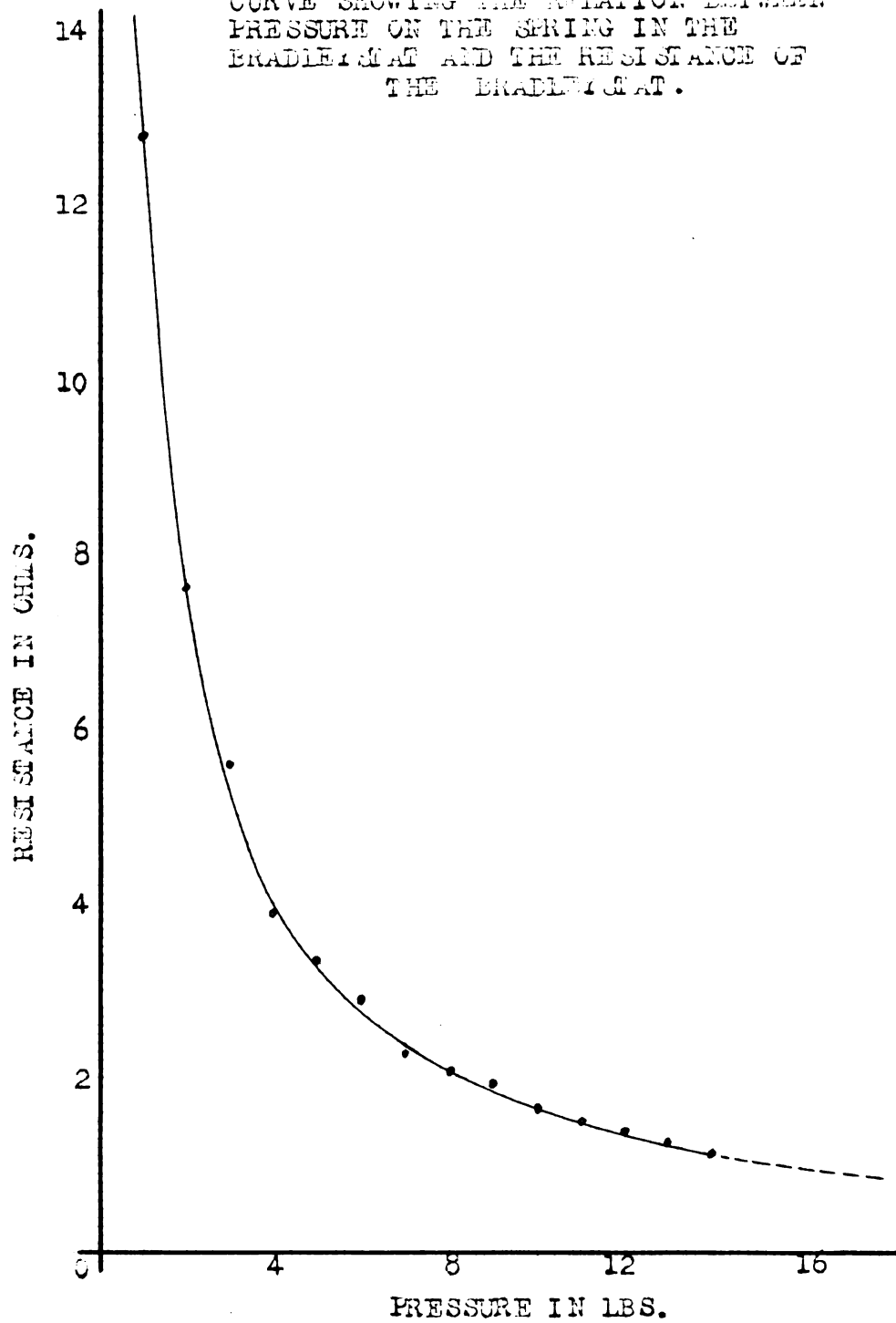
with a field. In figures D and E curves no. 1 represent the 60 cycle A.C. voltage supply from the powerhouse, curves no. 2 represent the voltage wave of G_1 and curves no. 3 show the record of the vibration of the same machine. In obtaining figures D and E the pressure between the stiff wire and G_1 was changed from the value used in taking figures A, B and C.

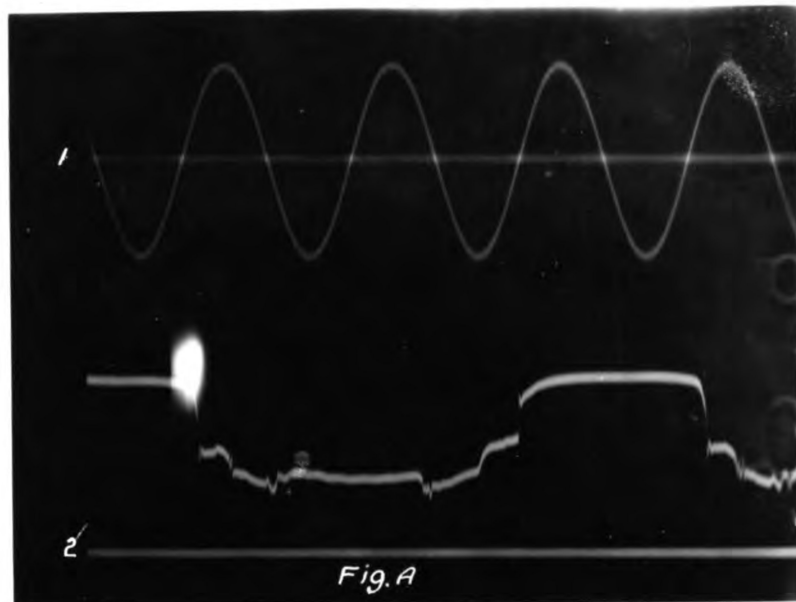
From an observation of curves no. 2 and 3 in figures D and E it can be noted that one cycle of vibration takes place in the time required to make three cycles in the voltage wave. Since G_1 is a six pole machine it is equivalent to saying that a cycle of vibration is made during every revolution of the rotor.

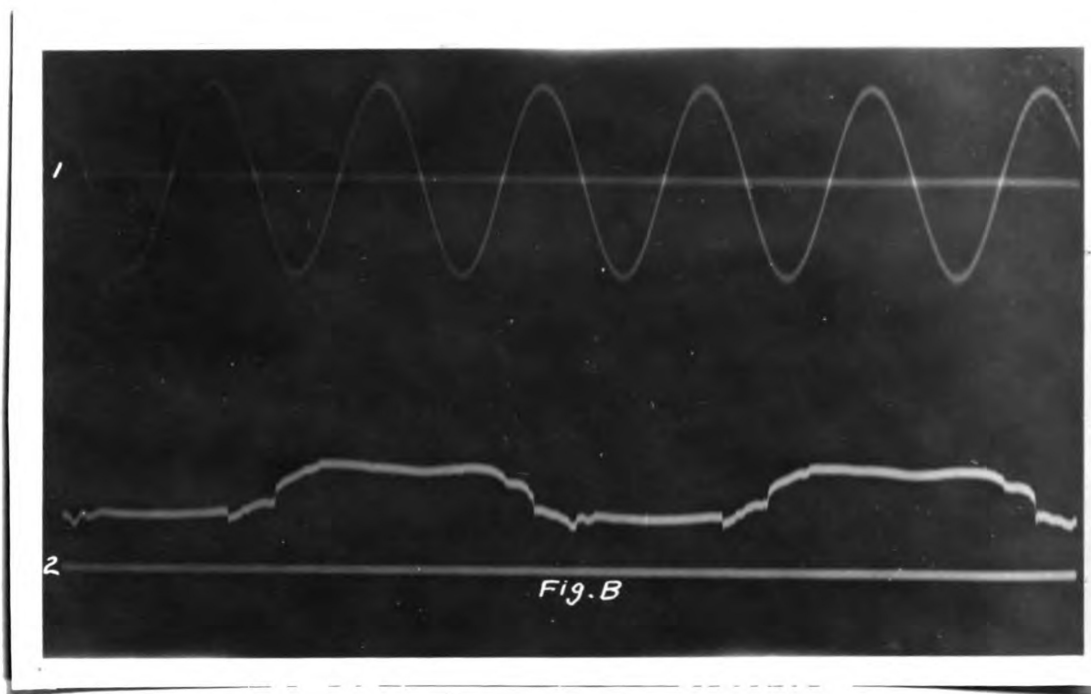
The following data and results were obtained from a test on a Bradley stat.

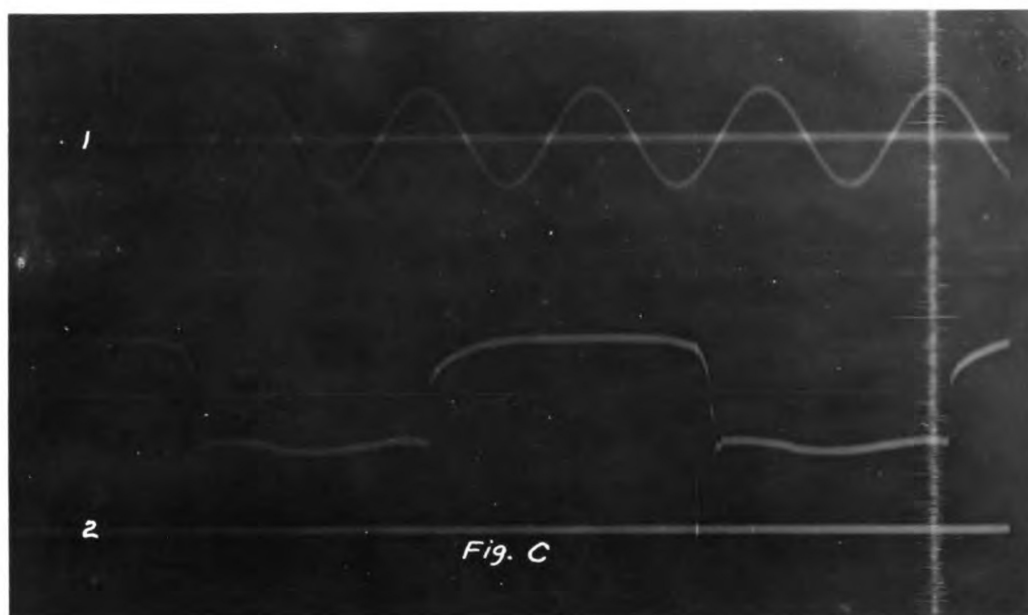
Pressure in lbs.	Volts	Amperes	Resistance in Ohms.
1	4.4	.35	12.76
2	3.8	.5	7.6
3	3.4	.61	5.58
4	2.85	.73	3.9
5	2.6	.78	3.33
6	2.35	.815	2.88
7	2.05	.9	2.28
8	1.9	.915	2.08
9	1.8	.94	1.915
10	1.6	.99	1.615
11	1.5	1.01	1.485
12	1.4	1.02	1.37
13	1.3	1.035	1.255
14	1.2	1.06	1.13

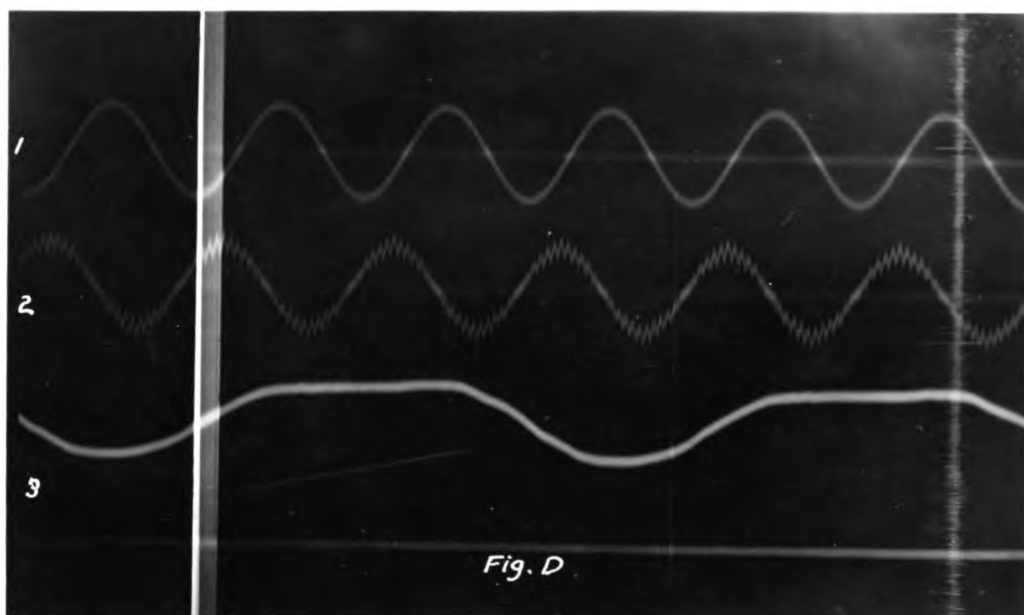
CURVE SHOWING THE RELATION BETWEEN
PRESSURE ON THE SPRING IN THE
BRADLEY STAT AND THE RESISTANCE OF
THE BRADLEY STAT.

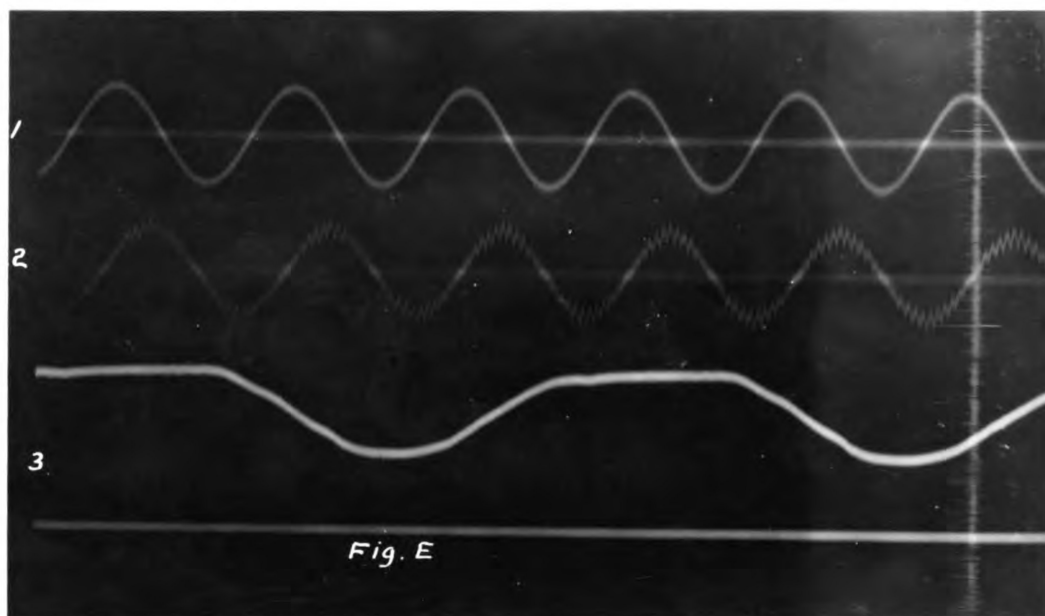


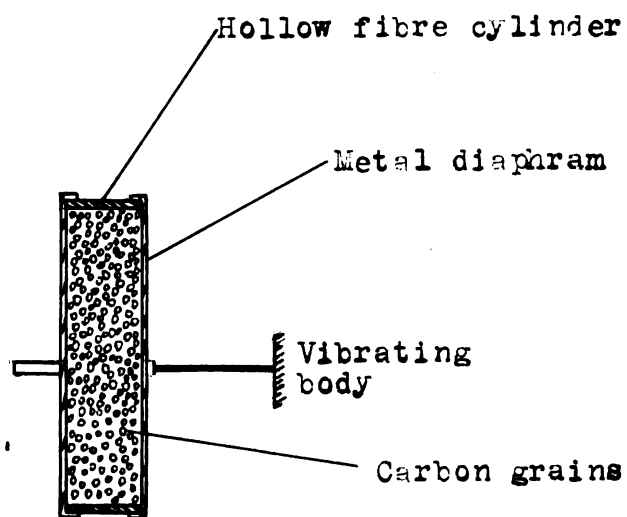












MICROPHONE BUTTON

FIGURE 15

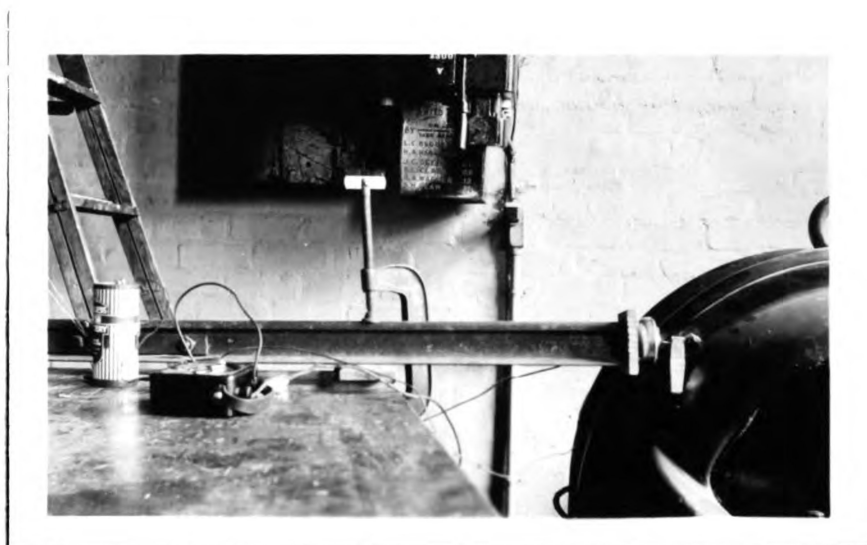
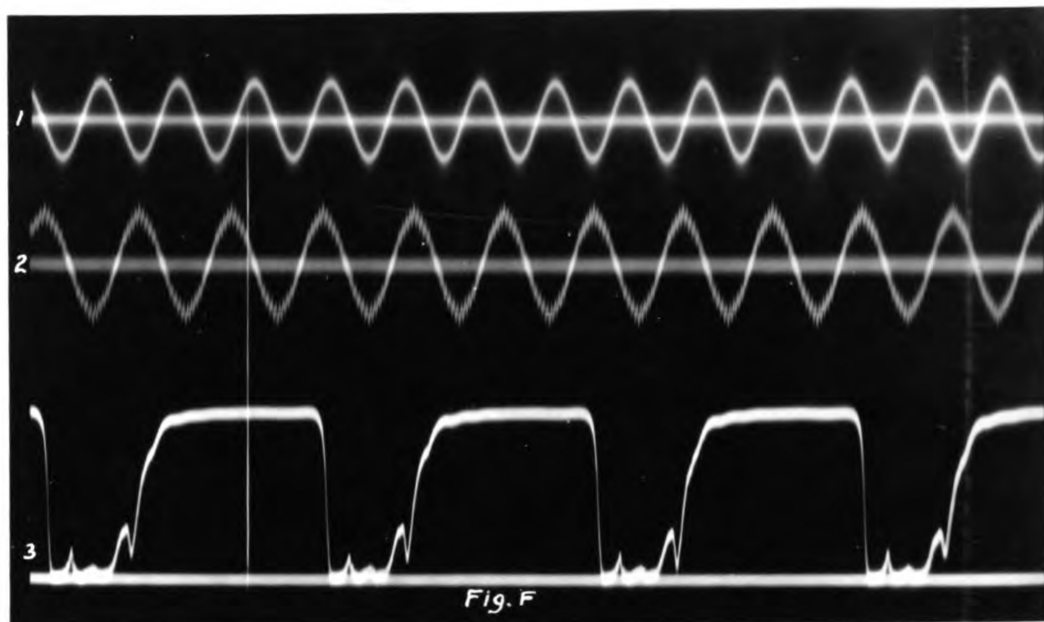
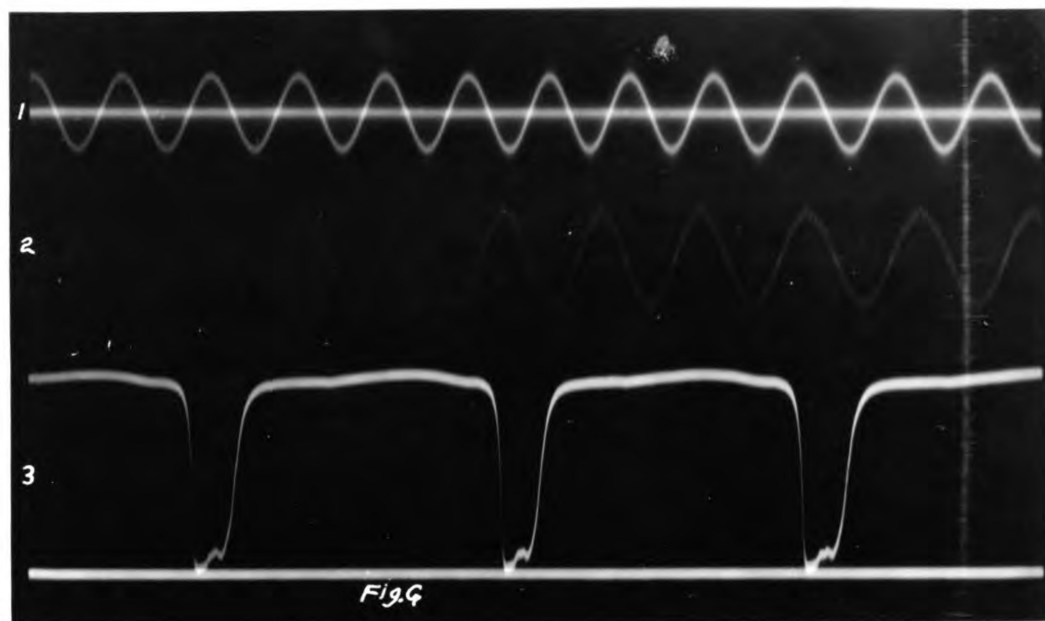


FIGURE 16





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C.R. Soderburg

The Electric Journal, Dec. 1924, page 579.

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Apparatus for Studying the Vibration Produced in
Buildings by Traffic.

Bul. de la Société l' Encouragement pour
l'Industrie Nationale. Vol. 134, March 1922,
pp 177-186, 7 figures.

Field for Research Work

Prof. Foltz

M.S.C. Record, May 3, 1926, page 452.

The use of Vibration Instruments on Electrical
Machines.

J. Ormondroyd

Journal of A.I.E.E. Apr. 1926, page 330.

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