A STUDY OF OSCILLOGRAPHS AND TRANSFORMER CURRENT WAVE SHAPES

by

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INTRODUCTION

This thesis is a study of oscillographs and the current wave shapes of a transformer with a capacity load. It is an effort to explain the curves obtained on the basis of the hysteresis loop of the transformer. It was written for J.G. Tarboux, Professor of Electrical Engineering, for the degree of Bachelor of Science in Electrical Engineering.

It is known that the exciting current of a transformer is a non-sinusoidal wave, containing a third, a fifth, a seventh, and sometimes, a small ninth harmonic. The seventh harmonic is usually so small that it can sometimes be neglected, and the ninth harmonic is never large enough to be objectional.

In power work, where the load is constantly changing, the presence of large harmonics is objectionable because eddy current losses increase as the square of the frequency. These losses are manifested in the form of heat. Consequently, if the larger harmonics could be eliminated or reduced in value, the transformer would operate at a higher efficiency.

The presence of harmonics in the current waves of a transformer are admitted, and methods of analysis of the wave shapes are given in various text-books on alternating currents; but so far as the writer has found, there has been no attempt to explain the peculiar current wave shapes which

may be obtained by various combinations of capacitous and inductive loads. Under different conditions of load, a transmission line may take either a leading or a lagging current. This is equivalent to placing either a capacitance or an inductance in series with the primary of a transformer. These conditions produce very peculiar current wave shapes.

The study of the oscillographs was secondary to the study of the current wave shapes, but had to precede the wave shape study because the oscillographs furnished the method of obtaining photographs of the waves. While holding a secondary place in relation to the wave study, the oscillograph study is of importance in itself. With the perfection of the oscillograph to its present point, it is being used more extensively in the engineering field.

CHAPTER I

THEORY OF OSCILLOGRAPHS AND THE CONSTRUCTION OF WAVES FROM THE HYSTERESIS LOOP

The oscillographs employed in this study were of the galvanometer or vibrator type. The vibrator consists essentially of a fine ribbon of some conductive material, usually silver alloy, suspended in a magnetic field. The magnetic field may be produced either by an electro-magnet or by a permanent magnet. All of the more recent oscillographs employ the permanent magnet for simplicity and ease of operation due to the fact that no D.C. supply is then necessary. The ribbons vary in size for the sensitivity desired. For the standard element, a ribbon 0.007" by 0.00075" is employed, while for high sensitivity, a ribbon 0.006" by 0.00055" is used.[1] The size of material will vary with the various manufacturers.

On this vibrator ribbon is fastened a small mirror against which a light beam is directed. As the vibrator moves, the beam of light reflected from the mirror moves back and forth in a fixed plane. Before the light reflected from the mirror can assume a wave form, another motion must be provided. This motion is usually produced by means of a "rocking" mirror. A shutter is provided to interrupt the light beam when the beam reaches the edge of the viewing screen and to keep the screen dark until the mirror has

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1. General Electric Company, Bulletin H-624, p.18.

returned to its original position. This shutter is necessary to keep the wave from running back over itself. A typical optical layout of a thru-element oscillograph is shown in Fig. 1.[2] In some oscillographs, the rocking mirror and the shutter are driven by a small, salient pole, synchronous motor; while in others, a small single phase motor is used to give speed control. For the wave to appear to stand still, the rocking mirror and the shutter must be in synchronism with the vibrator element.

The vibrator elements may be connected to show either the current wave or the voltage wave. This is accomplished by the addition of resistance in the vibrator circuit. Then taking a voltage wave, a resistance of 1000 ohms per volt is about the proper amount. The various methods for connecting the vibrator to give either a current wave or voltage wave are shown in Figs. 2, 3, 4, and 5. Figs. 2 and 3 show the connections for current measurement, while Figs. 4 and 5 are those for voltage measurements.

To determine the magnetizing current of a transformer, it is necessary to have the hysteresis loop. A sine wave of voltage is assumed, and consequently a sine wave of flux. To each value of B correspond two values of i_u, the one given by the ascending, and the other the descending branch of the curve. The graphic construction of the curve is

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2. Optical arrangement was taken from the General Electric Company's Bulletin H-624, p.10.

shown in Fig. 6.[3] The hysteresis loop on the left gives B as a function of i_u, the sine curve gives B as a function of time. For a particular value of B, to which corresponds the current i_1 and i_2, occurs at the times t_1 and t_2. Then plot $_oi_1$ over t_1 and $_oi_2$ over t_2, giving i_1 and i_2 as two points on the required curve. The whole curve may be drawn in this way. The curve i_h is simply a sine curve in quadrature with B. The idle current i_o is the resultant of these two components.

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3. Kapp, Gisbert, Transformers, p.106.

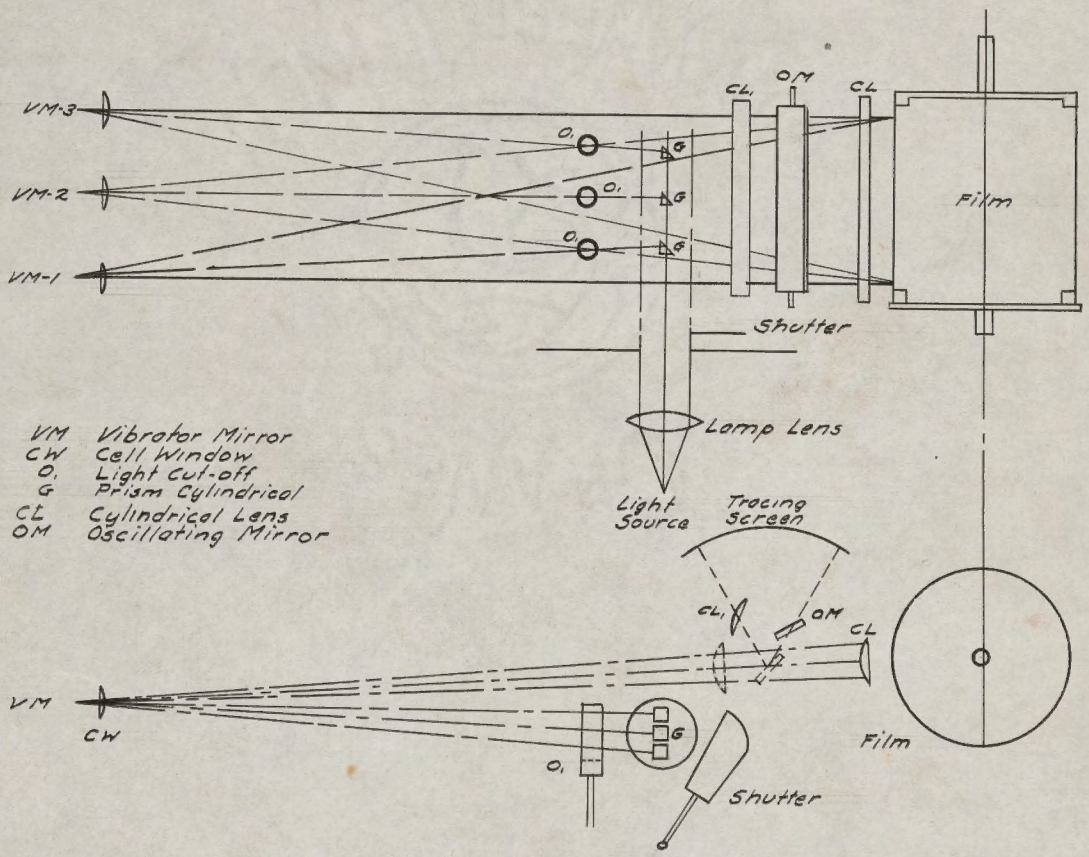


FIG. 1
Diagram of Optical System

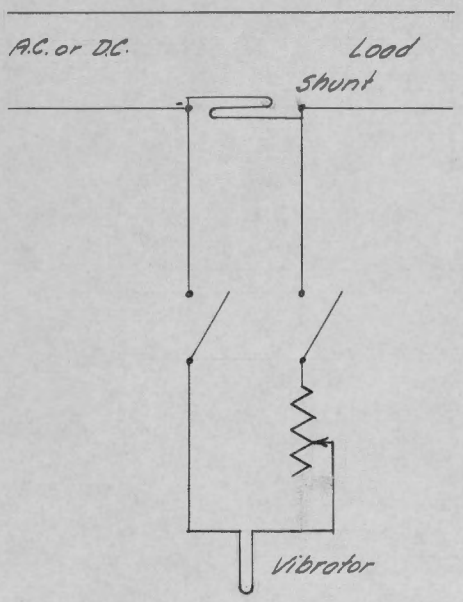


FIG. 2

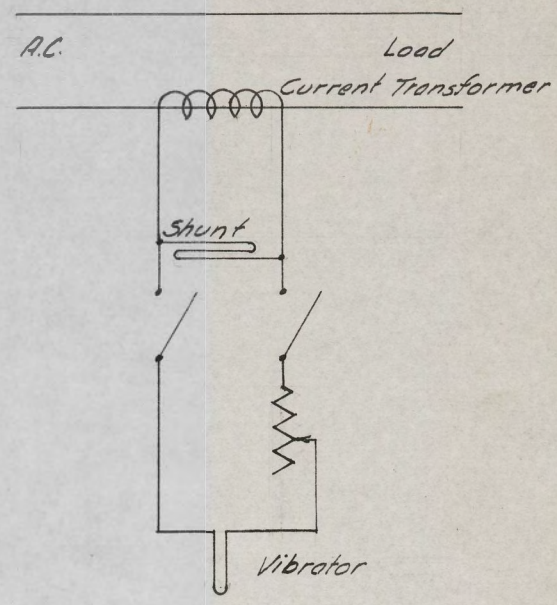


FIG. 3

Diagrams for Current Measurements

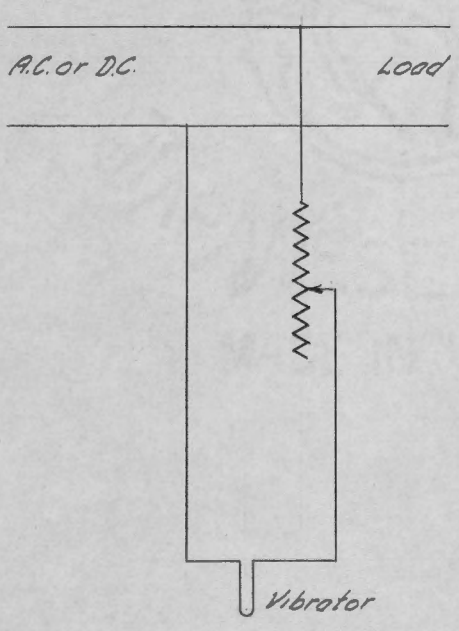


FIG. 4

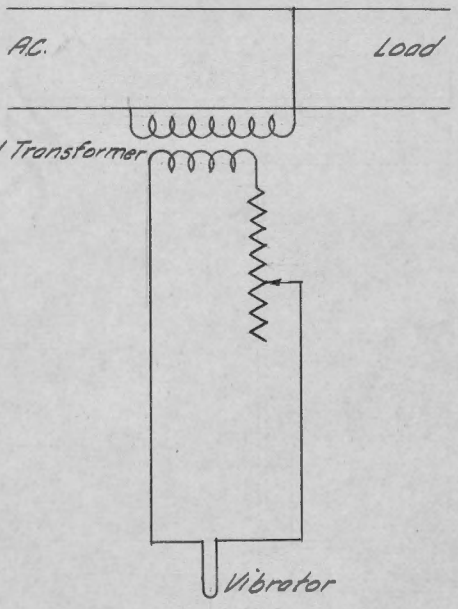


FIG. 5

Diagrams for Voltage Measurements

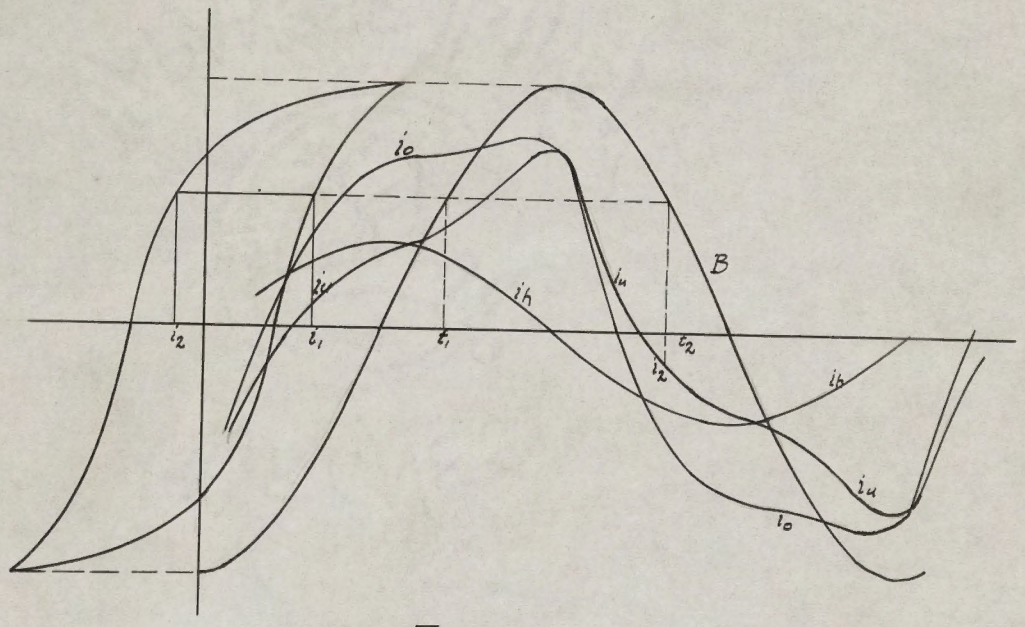


FIG. 6
Curve of Exciting Current

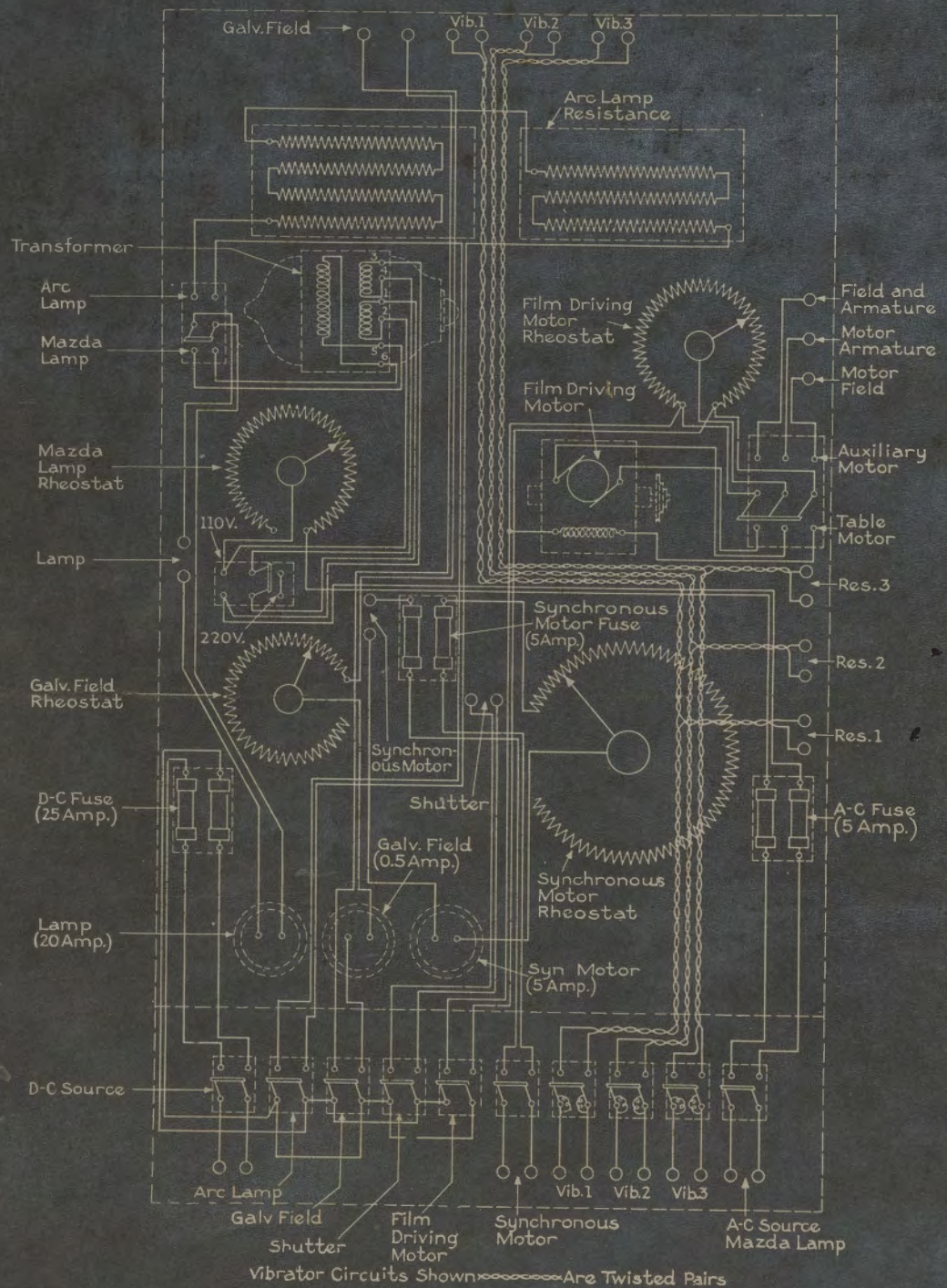


Fig. 7 Connections for Portable Table for Use with Arc or Mazda Lamp

CHAPTER II

DESCRIPTION OF APPARATUS AND METHOD OF PERFORMING TESTS

In preparing for the laboratory work to be done, it was first necessary to study the operation of the oscillographs. The first one studied was the General Electric H-624, portable oscillograph. An excellent picture of this instrument is shown on page 2 of the General Electric Company's Bulletin incorporated in the appendix. A complete wiring diagram is shown in Fig. 7. The oscillograph with the arc lamp, meters for the lamp, galvanometer fields, and synchronous motor, and the resistances for current and voltage measurements are mounted on top of the table, while all the auxiliary equipment is mounted underneath the table in the relative position shown in Fig. 7. The complete instructions for the operation of the instrument are given in the General Electric Company's Bulletin, H-624.

There were two disadvantages to the use of this oscillograph. The source of light was an arc lamp. It required constant observation to keep the carbons adjusted correctly, as they burned away rapidly; and if not watched closely, the arc would blow out. An attempt was made to overcome this disadvantage by the construction of a Mazda lamp stand. The lamp gave excellent light but the cover for the bulb was so poor that the whole stand got too hot, hot enough in fact, to melt the solder in the base of the bulb.

The other outstanding disadvantage was that the ball joints supporting the prisms which reflected the light into the cell windows had become so worn that the vibration of the synchronous or a slight jar of the table would cause the prisms to move out of position. They required constant adjustment, and sometimes it was hard to keep them focused long enough to get a picture.

The other oscillograph studied, and the one which was used to make all the oscillograms was the General Electric portable instrument. It was more compact than the old oscillograph and had many distinct advantages. It embodied the permanent magnet in the galvanometer and, consequently, needed no d.c. supply. The shutter and the whole photographic mechanism was much easier to operate. The complete instructions for the operation of the instruments, together with pictures of the whole and of the various parts, and the wiring diagram, are given in the General Electric Company's Bulletin which may be found in the appendix.

At first, some difficulty was had in getting the shutter to work properly. It would hang open for several revolutions of the motor, and give a picture of the wave running back over itself as shown in Fig. 8. It was found that as long as the instrument was out of its case, the shutter worked properly. The conclusion reached was that the screws which fastened the instrument in its case warped the panel and thus

caused the shutter mechanism to bind. Working with this idea in mind, the oscillograph was placed back in its case with the screws just tight enough to hold the panel in place, and not tight enough to bind. The shutter then worked perfectly.

In getting the oscillograms, it was necessary to show the axis. This required two exposures on the same film, since the voltage wave was also shown in order that the beginning of each current circle could be found. The exposure was accomplished in the following manner. The film was exposed to the wave forms and then the lamp was cut off until the shutter could be reset. The circuit of each galvanometer was then broken so that the light reflected from the vibrator would be a straight line, and another exposure was made. This procedure was necessary due to the fact that the film holder fit too loosely in the opening provided for it. If the light beam is adjusted so that it is about 1/32 of an inch wide when no current is flowing in the galvanometer circuit, the waves will show up much better on the developed film.

A list of the instruments used in the final tests are as follows:

1 G.E. a.c. ammeter 0-5 amperes

1 G.E. portable oscillograph 0-5 amperes

1 G.E. a.c. voltmeter 0-150 volts

1 G.E. frequency

1 G.E. a.c. ammeter 0-2 amperes

1 G.E. KVP transformer 110-220 volts

1 G.E. sine wave generator

1 Westinghouse condenser

1 inductance bank (knife switch type)

1 resistance (knife switch type)

The above list of equipment, with the exception of the portable oscillograph, which has already been described, is the standard laboratory equipment.

The equipment was connected as shown in Fig. 9. The sine wave set was used because it would furnish a sine wave of voltage and, consequently, a sine wave of flux. Figs. 10 and 11 show the complete set-up. In Fig. 10, a part of the transformer, condenser, and inductance can be seen in the background.

Since the transformer was too heavy to move, the output of the sine wave set was carried back through the switchboard to the transformer which was situated a little way from the rest of the equipment.

The generator was started and the voltage was adjusted so that the current was 0.8 of an ampere with only the transformer in the circuit. (The value of current of 0.8 amperes was used in all tests with the generator running at 61 cycles). An oscillogram of the resulting wave was taken,

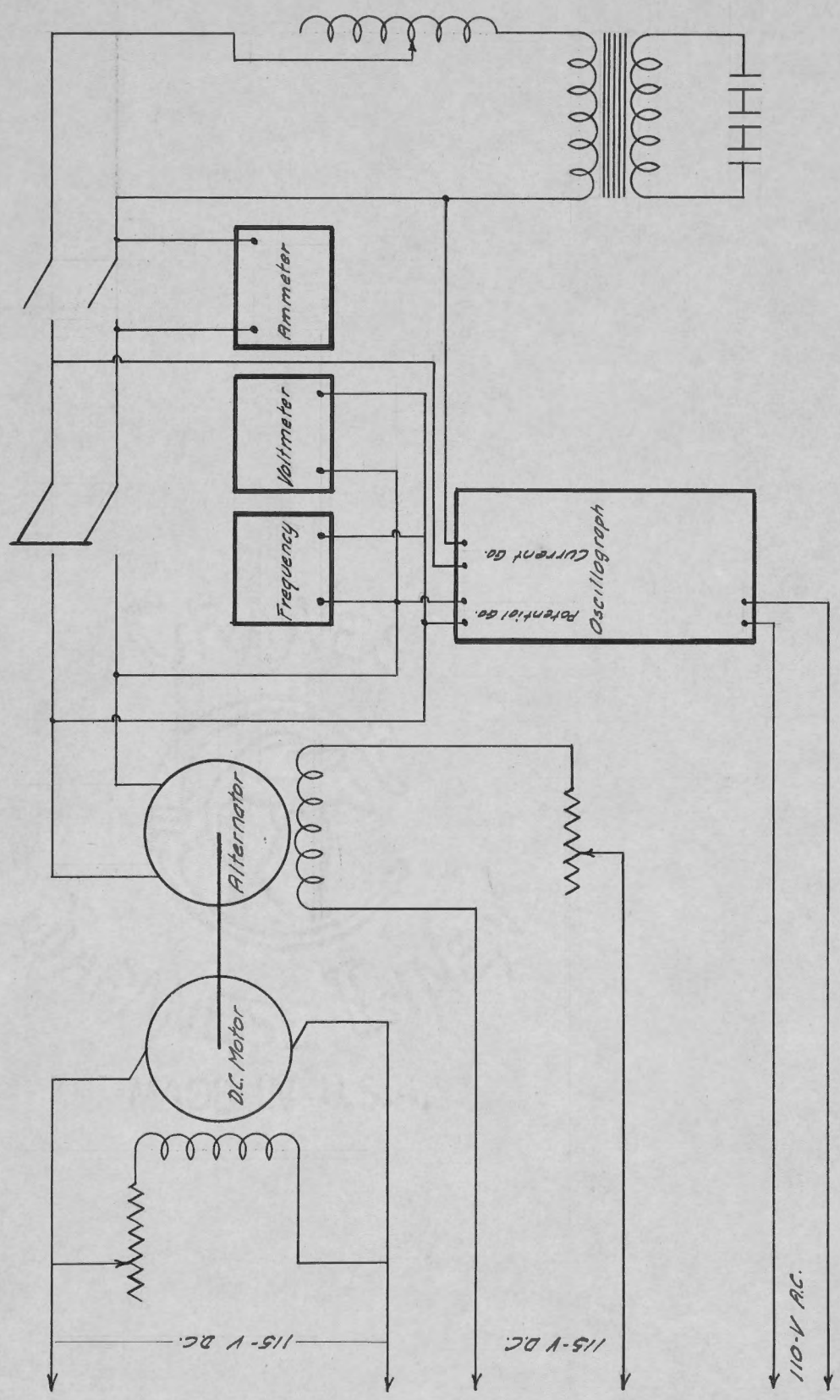


FIG 9
Diagram of Connections

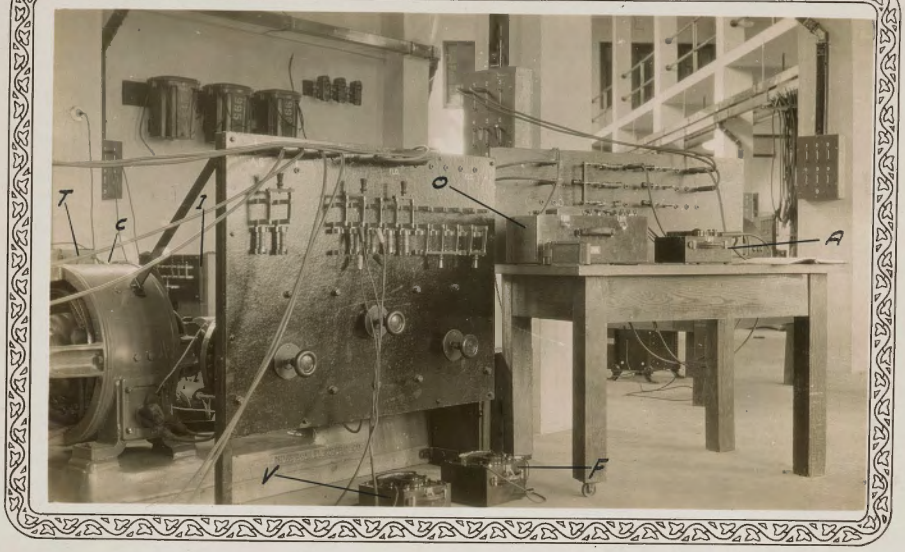


FIG. 10

O- Oscillograph
A- Ammeter
V- Voltmeter
F- Frequency Meter
T- Transformer
C- Condenser
I- Inductance

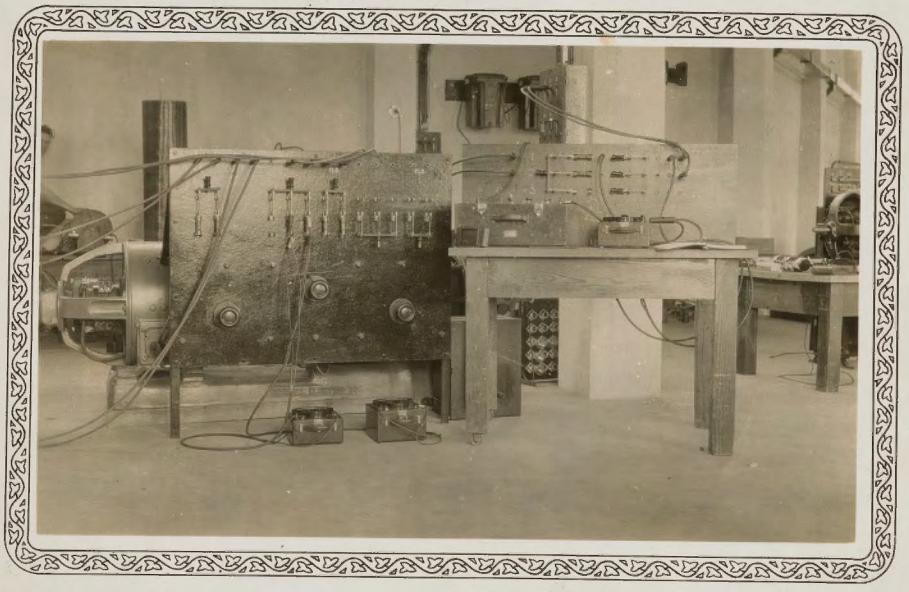


FIG. 11

and is shown in Fig. 12. Fig. 13 is the wave obtained when the secondary of the transformer was loaded with a condenser. Figs. 14, 15, and 16 are the results of putting varying amounts of inductance in the primary circuit. The arrangement of switches for these waves are shown in Figs. 17, 18, and 19 respectively. They show the arrangement of the arrangement of the knife switches on the inductance in each of the tests.

After the oscillograms were obtained, they were enlarged four times, and analyzed. The method used in analyzing these wave shapes is outlined by Ralph R. Lawrence in his Principles of Alternating Currents, p.89-92. The tables of angles, sines, and cosines were taken from Electric Current Analysis by M.G. Malti. Figs. 20, 21, 22, 23, and 24 show the enlarged oscillograms with the principal harmonics of Figs. 12, 13, 14, 15, and 16 respectively. All the tabulated data, together with the values of each of the harmonics, are embodied in the appendix to this paper.



FIG. 12

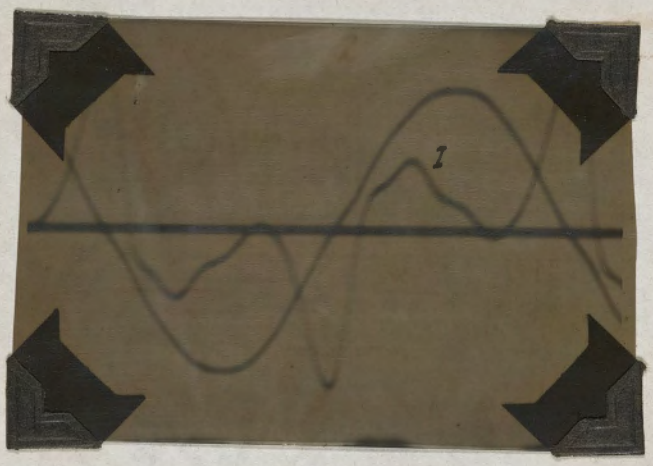


FIG. 13

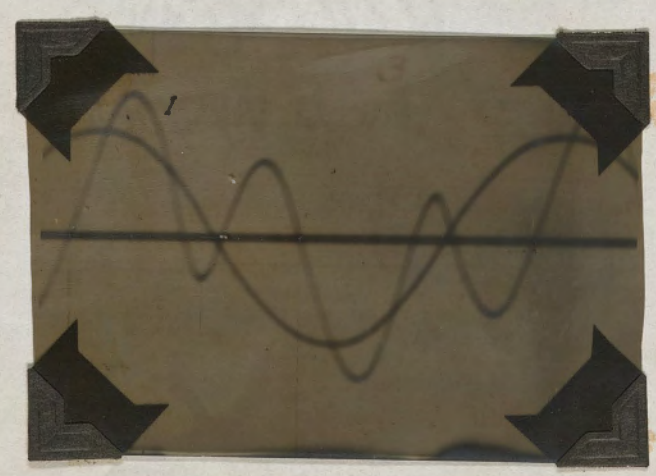


FIG. 14

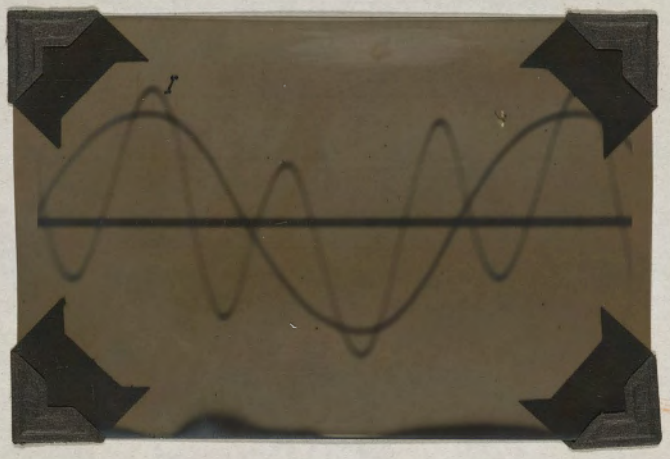


FIG. 15

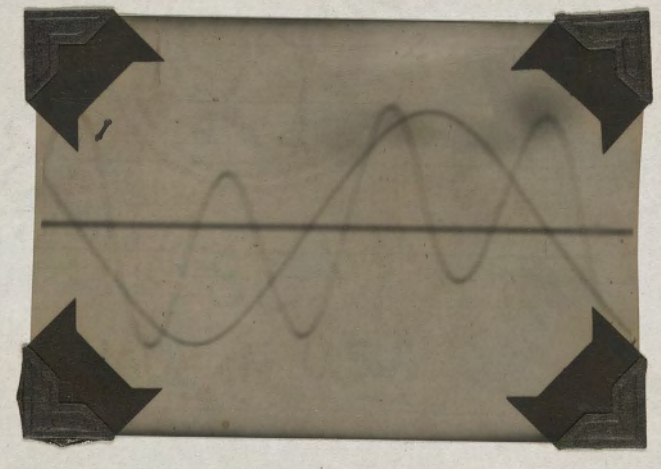


FIG. 16

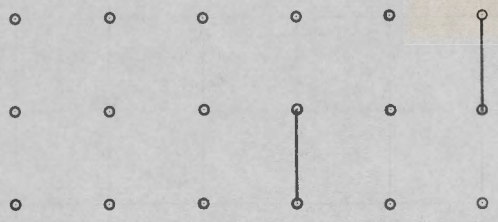


FIG. 17
Position of switches on inductance for Fig. 14

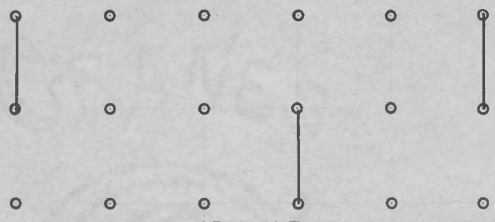


FIG. 18
Position of switches on inductance for Fig. 15

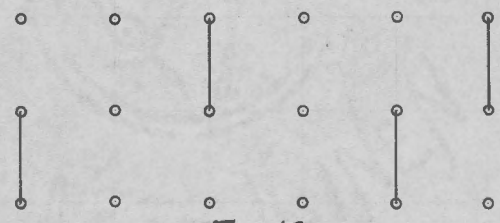


FIG. 19
Position of switches on inductance for Fig. 16

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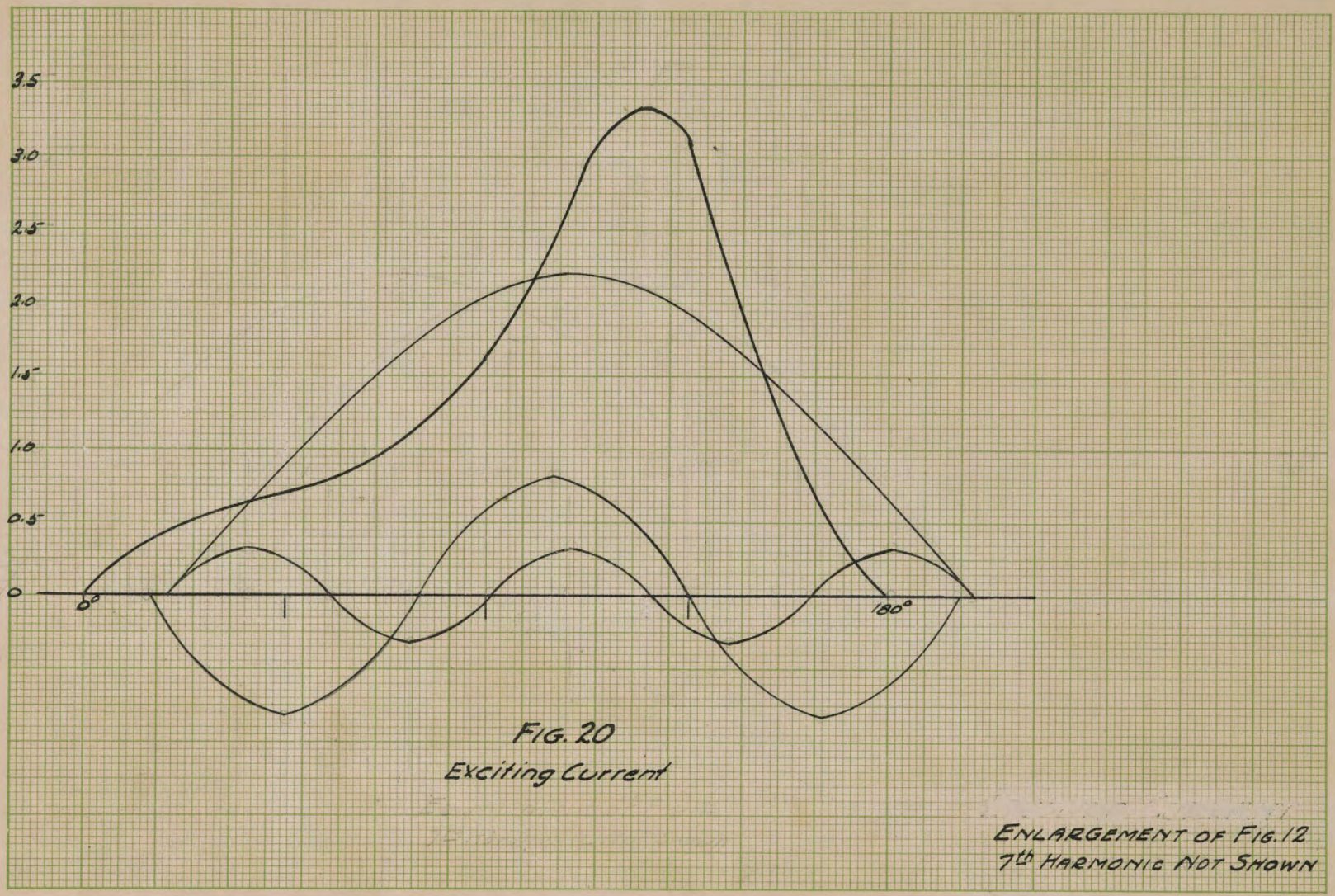


FIG. 20
Exciting Current

ENLARGEMENT OF FIG. 12
7th HARMONIC NOT SHOWN

Published by The H. Cole Co., Columbus, Ohio, No. 290 G.

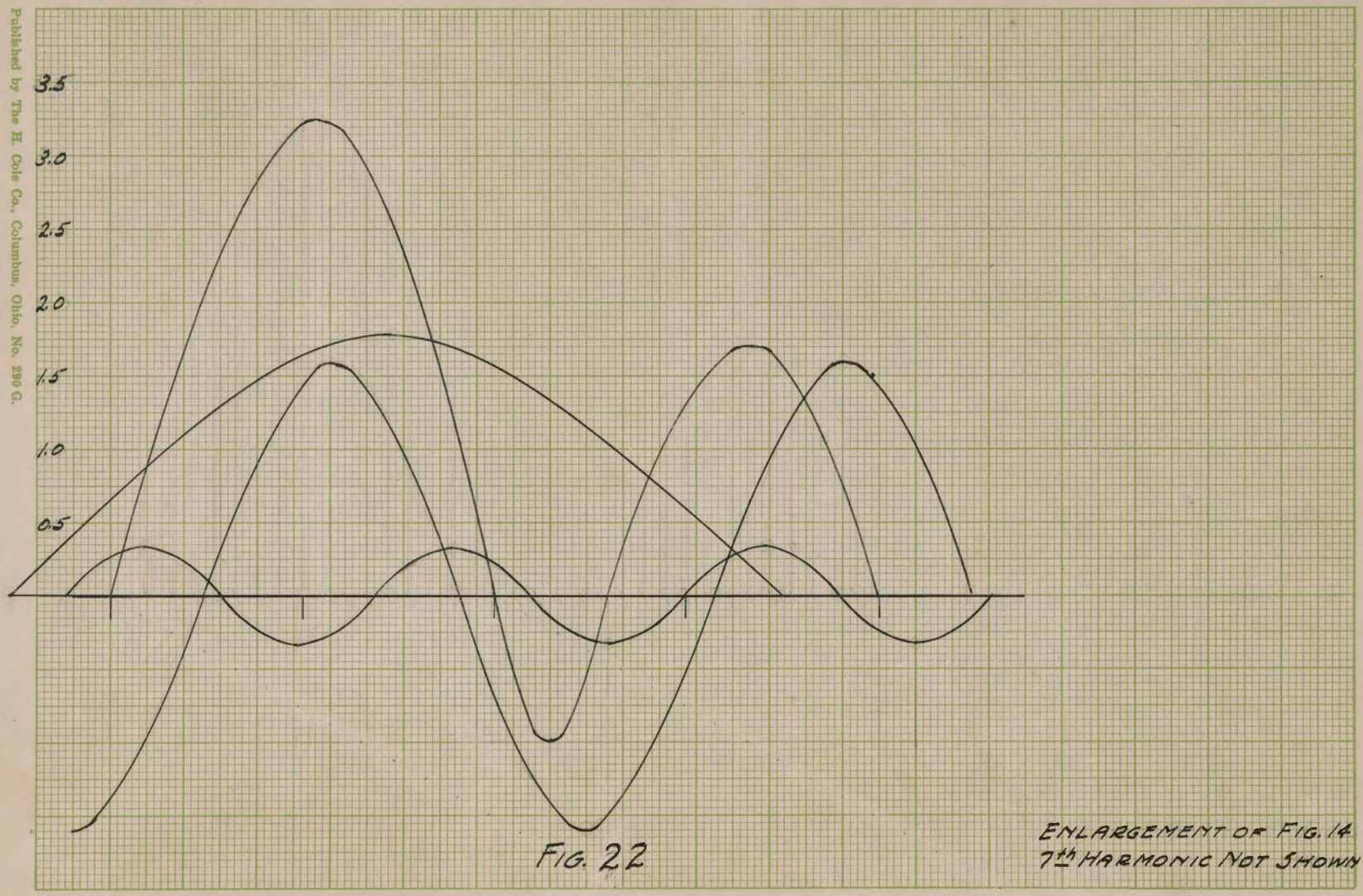


FIG. 22

ENLARGEMENT OF FIG. 14
7th HARMONIC NOT SHOWN

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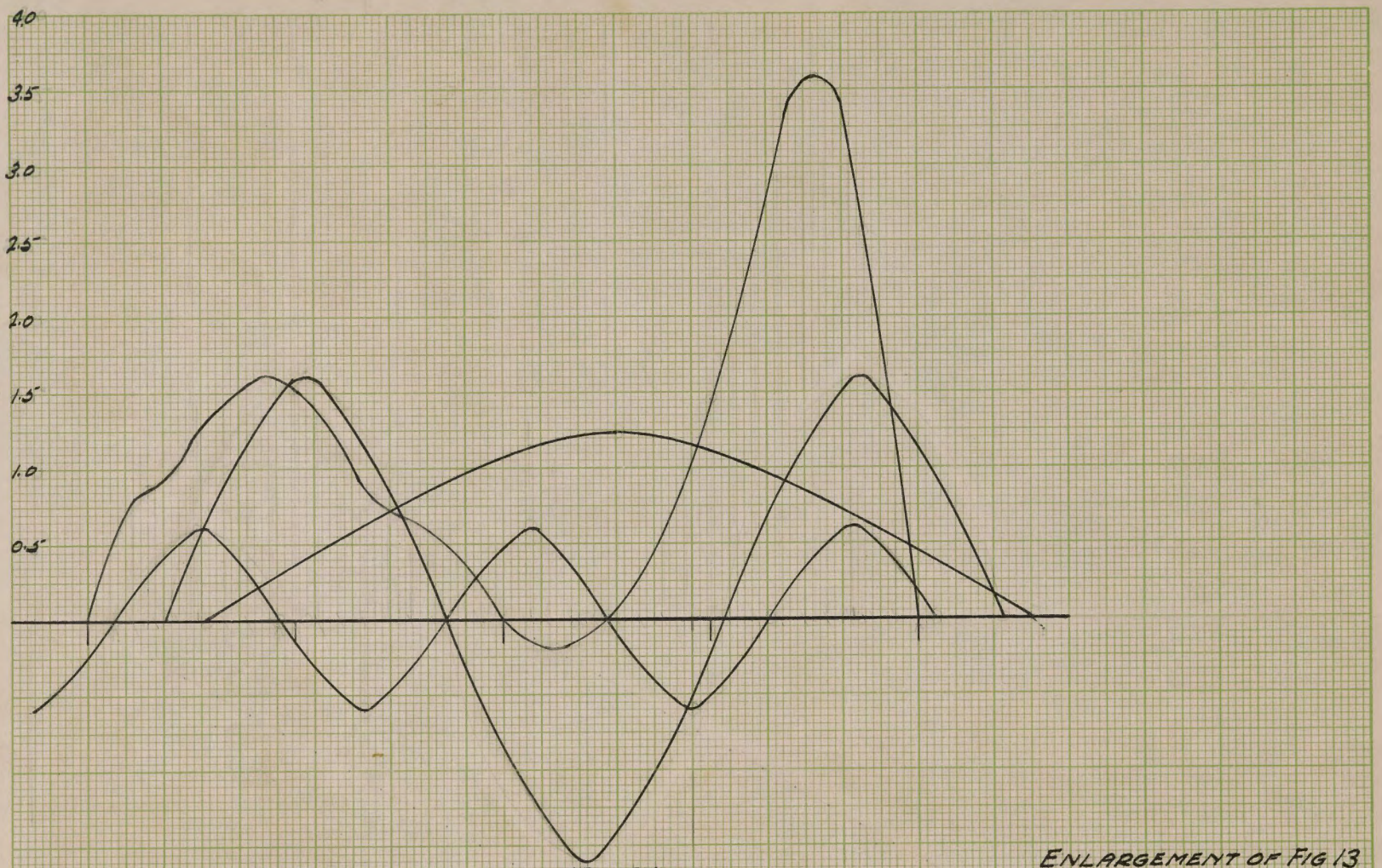


FIG. 21
Condenser in Secondary

ENLARGEMENT OF FIG 13
7th HARMONIC NOT SHOWN

Published by The H. Cole Co., Columbus, Ohio. No. 290 G.

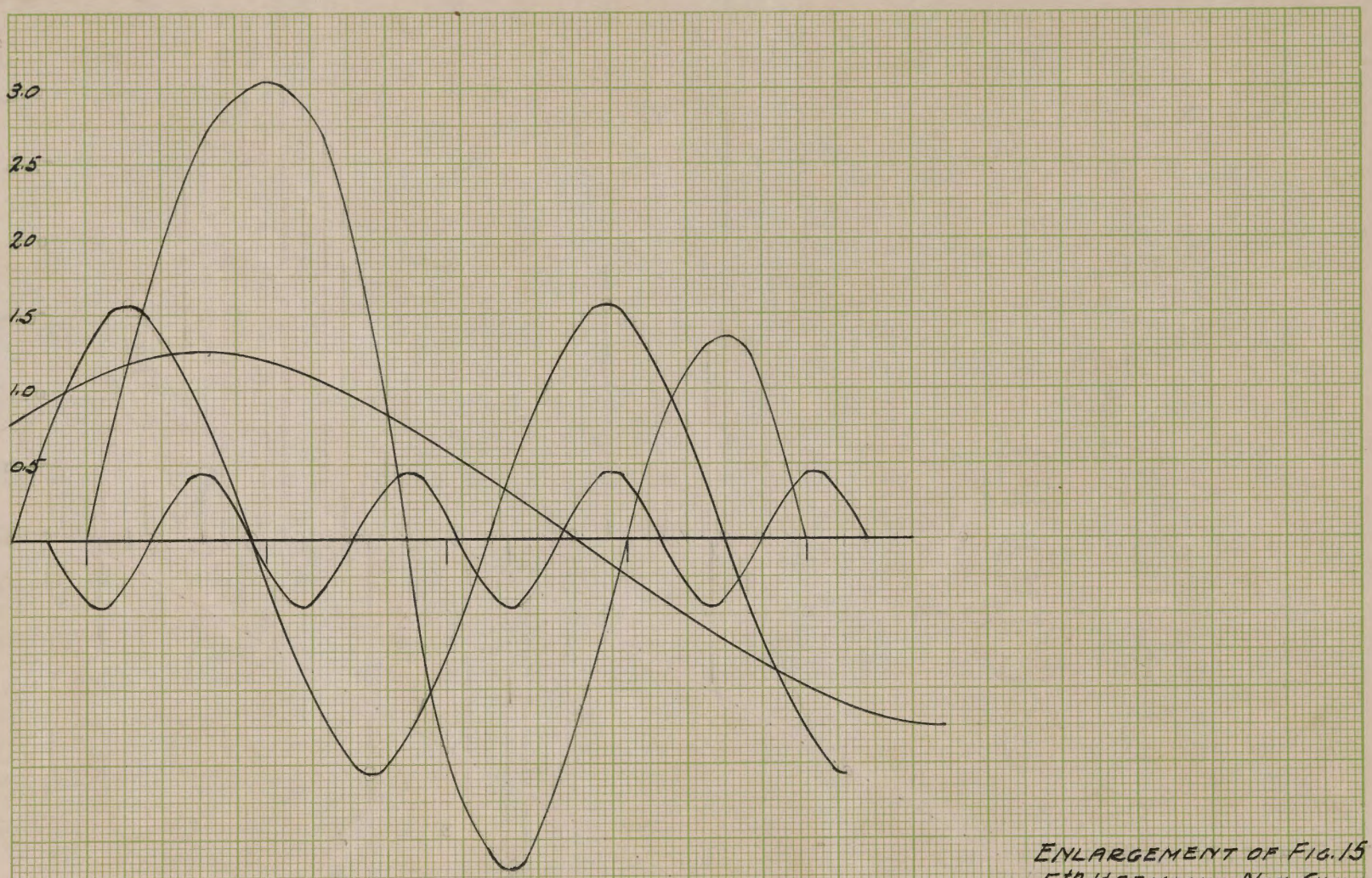


FIG. 23

ENLARGEMENT OF FIG. 15
5TH HARMONIC NOT SHOWN

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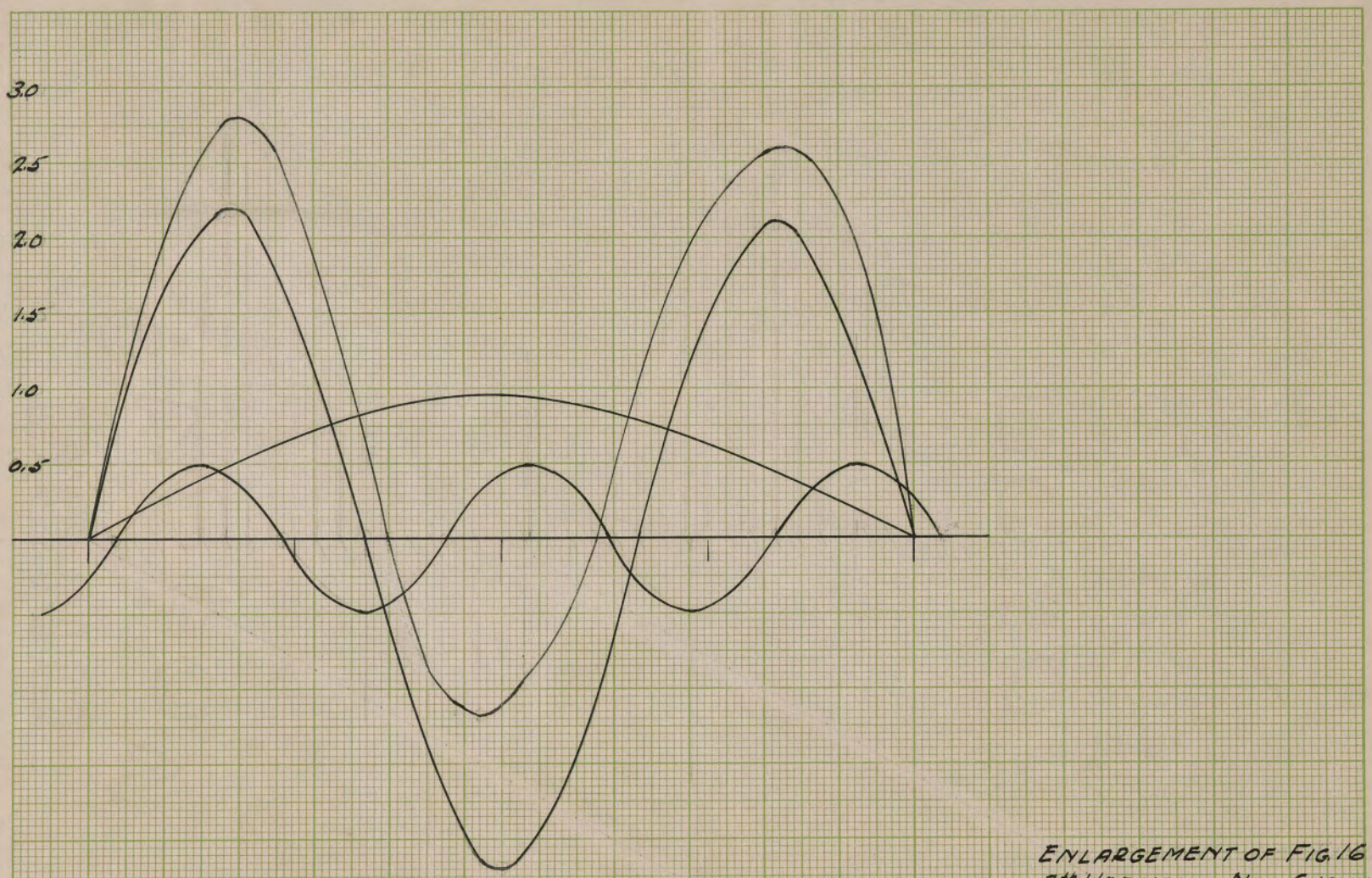


FIG. 24

ENLARGEMENT OF FIG. 16
7th HARMONIC NOT SHOWN

CONCLUSION

Several combinations of resistance, capacitance, and inductance were tried in making the experiments which have been mentioned. It was found that inserting resistance in series with the primary of the transformer did not alter the general shape of the wave, but merely limited the value of the current flowing in the circuit. By raising the voltage high enough to cause the test current of 0.8 of an ampere to flow, the wave assumed the exact proportions it had before the resistance was placed in the circuit. This fact was established by making measurements of the wave as it appeared on the viewing screen of the oscillograph.

Combinations of inductance and capacitance were also tried in series with the primary of the transformer. In this case, it was found that any wave shape produced by any combination of capacitance and inductance, could be reproduced by adjusting the amount of inductance in the circuit with the capacitance removed, as long as the load did not draw a leading power factor. When this condition is reached, the wave shape changes radically. The waves which could be obtained under these conditions were not investigated.

In order for a transformer to deliver a sine wave of voltage at the secondary, the exciting current must be of the general shape as shown in Fig. 12. The voltage wave

produced by such an exciting current as shown in Figs. 13, 14, 15, and 16, were not investigated; but they may be constructed by reference to the hysteresis loop discussed in Chapter I.

In the wave analysis, it was found in the case of Figs. 23 and 24, that the third harmonic currents were larger than the fundamental, and also in Fig. 23, that the seventh harmonic current was larger than the fifth. These conditions represent something unusual. At first, it was thought some error had been made in the analysis; but the calculations were checked and re-checked and no error could be found. The waves themselves bear out the fact that the calculations are correct; for in every case, when the ordinates are added, the result closely approximates the original wave.

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A P P E N D I X

D A T A F O R F I G. 20

y	x°	nx°	Sine nx	Cos. nx	y Sine nx		Cos. nx	
					+	-	+	-
0.15	5	5	0.0872	0.9962	0.0131		0.1495	
0.40	15	15	0.2588	0.9659	0.1035		0.3880	
0.50	25	25	0.4226	0.9063	0.2115		0.4530	
0.60	35	35	0.5736	0.8192	0.3440		0.4920	
0.65	45	45	0.7071	0.7071	0.4580		0.4580	
0.75	55	55	0.8192	0.5736	0.6150		0.4150	
0.85	65	65	0.9063	0.4226	0.7700		0.5620	
1.15	75	75	0.9659	0.2588	1.1000		0.2980	
1.45	85	85	0.9962	0.0872	1.4450		0.1263	
1.85	95	95	0.9962	-0.0872	1.8400			0.1610
2.45	105	105	0.9659	-0.2588	2.3700			0.6350
3.10	115	115	0.9063	-0.4226	2.8100			1.3100
3.40	125	125	0.8192	-0.5736	2.7800			1.9500
3.05	135	135	0.7071	-0.7071	2.1560			2.1560
2.10	145	145	0.5736	-0.8192	1.2070			1.7200
1.25	155	155	0.4226	-0.9063	0.5280			1.1340
0.70	165	165	0.2588	-0.9659	0.1810			0.671
0.15	175	175	0.0872	-0.9962	0.0131			0.1495
					18.9452		3.3418	-9.8865

y	x°	zx	Sine zx	Cos. zx	y Sine zx +	y Sine zx -	y cos. zx +	y cos. zx -
0.15	5	15	0.2588	0.9659	0.0388		0.1450	
0.40	15	45	0.7071	0.7071	0.2830		0.2830	
0.50	25	75	0.9659	0.2588	0.4840		0.1295	
0.60	35	105	0.9659	-0.2588	0.5800			0.1553
0.65	45	135	0.7071	-0.7071	0.4600			0.4600
0.75	55	165	0.2588	-0.9659	0.1940			0.7250
0.85	65	195	-0.2588	-0.9659		0.2200		0.8220
1.15	75	225	-0.7071	-0.7071		0.8130		0.8130
1.45	85	255	-0.9659	-o.2588		1.4000		0.3750
1.85	95	285	-0.9659	+0.2588		1.7850	0.4780	
2.45	105	315	-0.7071	0.7071		1.7300	1.7300	
3.10	115	345	-0.2588	0.9659		0.7700	2.9900	
3.40	125	15	+0.2588	0.9659	0.8800		3.2900	
3.05	135	45	0 .7071	0.7071	2.1500		2.1500	
2.10	145	75	0.9659	0.2588	2.0300		0.5450	
1.25	155	105	0.9659	-0.2588	1.2100			0.3240
0.70	165	135	0.7071	-0.7071	0.4950			0.4950
0.15	175	165	0.2588	-0.9659	0.0388			0.1420
					8.8436	6.7180	11.7405	4.3143

Y	x^{o}	5x	Sin 5x	Cos. 5x	Y Sin 5x		Cos. 5x	
					+	-	+	-
0.15	5	25	0.4236	0.9063	0.0640		0.1355	
0.40	15	75	0.9659	0.2588	0.3860		0.1035	
0.50	25	125	0.8192	-0.5736	0.3280			0.2880
0.60	35	175	0.0872	-0.9962	0.0523			0.5980
0.65	45	225	-0.7071	-0.7071		0.4600		0.4600
0.75	55	275	-0.9962	0.0872		0.7480	0.0655	
0.85	65	325	-0.5736	0.8192		0.4900	0.6960	
1.15	75	15	+0.2588	0.9659	0.2980		0.1010	
1.45	85	65	0.9063	0.4226	1.3150		0.6125	
1.85	95	115	0.9063	-0.4226	1.6800			0.7820
2.45	105	165	0.2588	-0.9659	0.6350			2.3700
3.10	115	215	-0.5736	-0.8192		1.7900		2.6400
3.40	125	265	-0.9962	-0.0872		3.9500		0.2960
3.05	135	315	-0.7071	+0.7071		2.1600	2.1600	
2.10	145	5	+0.0872	0.7962	0.1830		3.0900	
1.25	155	55	0.8192	1.0250	1.0250		0.7200	
0.70	165	105	0.9659	-0.2588	0.6760			0.1810
0.15	175	155	0.4226	-0.9063	0.0640			0.1355
					6.7083	-9.5980	6.7540	-7.7605

Y	x°	7x	Sin 7x	Cos. 7x	& Sin. 7x		Cos. 7x	
					+	-	+	-
0.15	5	35	0.5736	0.8192	0.0870		0.1230	
0.40	15	105	0.9659	-0.2588	0.3880			0.1035
0.50	25	175	0.0872	-0.9962	0.0436			0.4980
0.60	35	245	-0.9063	-0.4276		0.5450		0.2540
0.65	45	315	-0.7071	+0.7071		0.4600	0.4600	
0.75	55	25	+0.4226	0.9063	0.3170		1.0400	
0.85	65	95	0.9962	-0.0872	0.8450			0.0740
1.15	75	165	0.2588	-0.9659	0.2980			1.1110
1.45	85	235	-0.8192	-0.5736		1.1900		0.8330
1.85	95	305	-0.8192	+0.5736		1.5150	1.0630	
2.45	105	15	+0.2588	0.9659	0.6350		3.3700	
3.10	115	85	0.9962	0.0872	3.0900		0.2700	
3.40	125	155	0.4226	-0.9063	1.4380			3.0800
3.05	135	225	-0.7071	-0.7071		2.0600		2.0600
2.10	145	295	-0.9063	+0.4226		1.9000	0.8880	
1.25	155	5	+0.0873	0.9962	0.1090		1.2450	
0.70	165	75	0.9659	0.2588	0.6770		0.1810	
0.15	175	145	0.5736	-0.8192	0.0870			0.1230
					8.0136	-7.6700	7.8400	-8.1355

$$A = \frac{2}{M} \sum Y \sin x = 2/18(18.9452) = 2.105$$

$$B = \frac{2}{M} \sum Y \cos x = 2/18(-6.5447) = -0.727$$

$$\theta = \tan^{-1} \frac{3/}{B} = \tan^{-1} \frac{-0.727}{2.105} = \tan^{-1} -0.345 = -19 \leftarrow$$

$$I = \sqrt{A^2 + B^2} = \sqrt{2.105^2 + 0.727^2} = 2.21 \leftarrow$$

$$A_3 = 2/18(8.8436 - 6.7180) = 2/18(2.1256) = 0.236$$

$$B_3 = 2/18(11.7405 - 4.3143) = 2/18(7.4262) = 0.824$$

$$\theta_3 = \tan^{-1} \frac{B_3}{A3} = \tan^{-1} \frac{0.824}{0.236} = \tan^{-1} 3.5 = 74^{o}5 \leftarrow$$

$$I_3 = \sqrt{A_3^2 + B_3^2} = \sqrt{0.236^2 + 0.824^2} = 0.846 \leftarrow$$

$$A_5 = 2/18(6.7093 - 9.5980 = 2/18(-2.8897) = -0.321$$

$$B_5 = 2/18(6.7540 - 7.7605) = 2/18(-1.0065) = 0.112$$

$$\theta_5 = \tan^{-1} \frac{B_5}{A_5} = \tan^{-1} 0.3490 = 19^{o}20^{1}$$

$$I_5 = \sqrt{A_5^2 - B_5^2} = \sqrt{0.321^2 - 0.112^2} = 0.326 \leftarrow$$

$$A_7 = 2/18(8.0136 - 7.6700) = 2.18(0.3436) = 0.0382$$

$$B_7 = 2/18(7.8400 - 8.1355) = 2/18(-0.2955) = -0.0328$$

$$\theta_7 = \tan^{-1} \frac{B_7}{A_7} = \tan^{-1} = -0.858 = -40^{o}40^{1} \leftarrow$$

$$I = \sqrt{A^2 - B^2} = \sqrt{0.0382^2 - 0.0328^2} = 0.0554 \leftarrow$$

DATA FOR FIG. 21

Y	x°	x	Sin x	Cos x	Y xin x		Y cos. x	
					+	-	+	-
0.45	5	5	0.0373	0.9962	0.0393		0.4480	
0.90	15	15	0.2588	0.9659	0.2330		0.8700	
1.30	25	25	0.4226	0.9063	0.5500		1.1800	
1.55	35	35	0.5737	0.8192	0.8900		1.2700	
1.50	45	45	0.7071	0.7071	1.0600		1.0600	
1.15	55	55	0.8192	0.5736	0.9425		0.6610	
0.70	65	65	0.9063	0.4226	0.6350		0.2960	
0.55	75	75	0.9659	0.2588	0.5315		0.1420	
0.25	85	85	0.9962	0.0872	0.2490		0.0218	
- 0.15	95	95	0.9962	-0.0872		0.1495	0.0131	
- 0.15	105	105	0.9659	-0.3588		0.1450	0.0388	
+ 0.05	115	115	0.9063	-0.4226	0.0453			0.0211
0.60	125	125	0.8192	-0.5736	0.4920			0.3440
1.45	135	135	0.7071	-0.7071	1.0250			1.0250
2.45	145	145	0.5736	-0.8192	1.4080			2.0100
3.55	155	155	0.4226	-0.9063	1.5000			3.2200
3.15	165	165	0.2588	-0.9659	0.8150			3.0400
1.15	175	175	0.0872	-0.9962	0.1050			1.1450
					10.3306	0.2945	6.0007	10.8051

Y	x°	3x°	sin 3x	cos. 3x	Y sin 3x		Cos 3x	
					+	-	+	-
0.45	5	15	0.2588	0.9659	0.1165		0.4350	
0.90	15	45	0.7071	0.7071	0.6360		0.6360	
1.30	25	75	0.9659	0.2588	1.2550		0.3370	
1.55	35	105	0.9659	-0.2588	1.5000			0.4020
1.50	45	135	0.7071	-0.7071	1.0600			1.0600
1.15	55	165	0.2588	-0.9659	0.2980			1.0550
0.70	65	195	-0.2588	-0.9659		0.1810		0.6760
0.55	75	225	-0.7071	-0.7071		0.3890		0.3890
0.25	85	255	-0.9659	-0.2588		0.2415		0.0647
- 0.15	95	285	-0.9659	+0.2588	0.1450			0.0388
- 0.15	105	315	-0.7071	0.7071	0.1060			0.1060
+ 0.05	115	345	-0.2588	0.9659		0.0129	0.0483	
0.60	125	15	+0.2588	0.9659	0.1550		0.5800	
1.45	135	45	0.7071	0.707	1.0250		1.0250	
2.45	145	75	0.9659	0.2588	2.3700		0.6350	
3.55	155	105	0.9659	-0.2588	3.4300			0.9200
3.15	165	135	0.7071	-0.7071	2.2250			2.2250
1.15	175	165	0.2588	-0.9659	0.2980			1.1100
					14.6195	0.8244	3.6983	8.0665

Y	x^{o}	$5x^{o}$	Sine 5x	Cox 5x	Y Sin 5x		Y Cos 5x	
					+	-	+	-
0.45	5	25	0.4226	0.9063	0.1900		0.4075	
0.90	15	75	0.9659	0.2588	0.8700		0.2330	
1.30	25	125	0.8192	-0.5736	1.0650			0.7450
1.55	35	175	0.0872	-0.9962	-0.1350			1.5450
150	45	225	-0.7071	-0.7071		1.0600		1.0600
1.15	55	275	-0.9962	+0.0872		1.1450	0.1000	
0.70	65	325	-0.5736	0.8192		0.4020	0.5730	
0.55	75	15	+0.2588	0.9659	0.1425		0.5310	
0.25	85	65	0.9063	0.4226	0.2270		0.1060	
- 0.15	95	115	0.9063	-0.4226		0.1360	0.0634	
- 0.15	105	165	0.2588	-0.9659		0.0388	0.1450	
+ 0.05	115	215	-0.5736	-0.8192		0.0287		0.0410
0.60	125	265	-0.9962	-0.0872		0.5975		0.0523
1.45	135	315	-0.7071	+0.7071		1.0250	1.0250	
2.45	145	5.	+0.0872	0.9962	0.2130		2.4400	
3.55	155	55	0.8192	0.5736	2.9100		2.0400	
3.15	165	105	0.9659	-0.2588	3.0400			0.9200
1.15	175	155	0.4226	-0.9063	0.4860			1.0420
					9.2785	4.4336	7.6639	5.4053

Y	x	7x	Sin 7x	Cos 7x	Y Sin 7x		Y Cos 7x	
					+	-	+	-
0.45	5	35	0.5736	0.8192	0.2580		0.3690	
0.90	15	105	0.9659	-0.2588	0.8700			0.2330
1.30	25	175	0.0872	-0.9962	0.1135			1.2950
1.55	35	245	-0.9063	-0.4226		1.4050		0.6550
1.50	45	315	-0.7071	+0.7071		1.0600	1.0600	
1.15	55	25	+0.4226	0.9063	0.4860		1.0400	
0.70	65	95	0.9962	-0.0872	0.6970			0.6100
0.55	75	165	0.2588	-0.9659	0.1425			0.5031
0.25	85	235	-0.8192	-0.5736		0.2050		0.1430
- 0.15	95	305	-0.8192	+0.5736	0.1230			0.0860
- 0.15	105	15	+0.2588	0.9659		0.0389		0.1450
+ 0.05	115	85	0.9962	0.0872	0.0498		0.0044	
0.60	125	155	-0.4226	-0.9063	0.2530			0.5440
1.45	135	225	-0.7071	-0.7071		1.0250		1.0250
2.45	145	295	-0.9063	+0.4226		2.2200	1.0350	
3.55	155	5	+0.0872	0.9962	0.3100		3.5400	
3.15	165	75	0.9659	0.2588	3.0400		0.8150	
1.15	175	145	0.5736	-0.8192	0.6600			0.9420
					7.0028	5.9539	7.8634	6.1731

$A = 2/18 \Sigma\ Y \sin x = 2/18(10.3306 - 0.2945) = 1.115$

$B = 2/18 \Sigma\ Y \cos x = 2/18(6.007 - 10.8051) = -0.534$

$\theta = \tan \frac{B}{A} = \tan^{-1} \frac{-0.534}{1.115} = -25^{\circ}30^{1}$

$I = \sqrt{A^2 - B^2} = \sqrt{1.175^2 + 0.534^2} = 1.235$

$A_3 = 2/18 \Sigma\ Y \sin 3x = 2/18(14.6193 - 0.8244) = 1.53$

$B_3 = 2/18 \Sigma\ Y \cos 3x = 2/18(3.6983 - 8.0665) = -0.485$

$\theta_3 = \tan^{-1} \frac{-0.485}{1.53} = -17^{\circ}\ 40^{1}$

$I_3 = \sqrt{1.53^2 + 0.485^2} = 1.61$

$A_5 = 1/9(9.2785 - 4.4336) = 0.538$

$B_5 = 1/9(7.6639 - 5.4053) = 0.251$

$\theta_5 = \tan^{-1} \frac{0.251}{0.538} = 25^{\circ}$

$I_5 = \sqrt{0.538^2 + 0.251^2} = 0.595$

$A_7 = 1/9(7.0028 - 5.9539) = 0.117$

$B_7 = 1/9(7.8634 - 6.1731) = 0.188$

$\theta_7 = \tan^{-1} \frac{0.188}{0.117} = 48^{\circ}10^{1}$

DATA FOR FIG. 22

Y	x^o	x^o	Sin x	Cos x	Y Sin x		Cos x	
					:	:	:	:
0.50	5	5	0.0872	0.9962	0.0437		0.4980	
1.50	15	15	0.2588	0.9659	0.3890		1.4500	
2.25	25	25	0.4226	0.9063	0.9500		2.0200	
2.85	35	35	0.5736	0.8192	1.6700		2.3300	
3.20	45	45	0.7071	0.7071	2.2600		2.2600	
3.15	55	55	0.8192	0.5736	2.5800		1.8050	
2.60	65	65	0.9063	0.4226	2.3400		1.0940	
1.80	75	75	0.9659	0.2588	1.7400		0.4675	
0.55	85	85	0.9962	0.0872	0.5480		0.0478	
- 0.50	95	95	0.9962	-0.072		0.4980	0.0436	
- 0.95	105	105	0.9659	-0.2588		0.9180	0.2460	
- 0.15	115	115	0.9063	-0.4226		0.1360	0.0635	
0.70	125	125	0.8192	-0.5736	0.5740			0.4020
1.35	135	135	0.7071	-0.7071	0.9550			0.9550
1.65	145	145	0.5736	-0.8192	0.9450			1.3540
1.65	155	155	0.4226	-0.9063	0.6970			1.4950
1.25	165	165	0.2588	-0.9659	0.3240			1.2100
0.50	175	175	0.0872	-0.9962	0.0437			0.4980
					16.0594	1.5520	12.3254	5.9140

Y	x^{o}	$3x^{o}$	Sin 3x	Cos. 3x	Y Sin 3x		Y Cos 3x	
					+	-	+	-
0.50	5	15	0.3588	0.9659	0.2950		0.4830	
1.50	15	45	0.7071	0.7071	1.0600		1.0600	
2.25	25	75	0.9659	0.2588	2.1700		0.5820	
2.85	35	105	0.9659	-0.2588	2.7550			0.7375
3.20	45	135	0.7071	-0.7071	2.2600			2.2600
3.15	55	165	0.2588	-0.9659	0.8150			3.0400
2.60	65	195	-0.2588	-0.9659		0.6730		2.5500
1.80	75	225	-0.7071	-0.7071		1.2700		1.2700
0.55	85	255	-0.9659	-0.2588		0.5300		0.1425
- 0.50	95	285	-0.9659	+0.2588	0.4830			0.1290
- 0.95	105	315	-0.7071	0.7071	0.6720			0.6720
- 0.15	115	345	-0.2588	0.9569	0.0388			0.1450
+ 0.70	125	15	+0.2588	0.9659	0.1810		0.6770	
1.35	135	45	0.7071	0.7071	0.9550		0.9550	
1.65	145	75	0.9659	0.2588	1.5940		0.4270	
1.65	155	105	0.9659	-0.2588	1.5940			0.4270
1.25	165	135	0.7071	-0.7071	0.8830			0.8830
0.5	175	165	0.2588	-0.9659	0.2950			0.4830
					16.0508	2.4730	4.1840	12.7390

Y	x^0	5x	Sin 5x	Cos. 5x	Y sin. 5x		Y cos. 5x	
					+	: :	: :	+ : :
0.50	5	25	0.4226	0.9063	0.2115		0.4530	
1.50	15	75	0.9659	0.2588	1.4500		0.3880	
2.25	25	125	0.8192	-0.5736	1.8400			1.2900
2.85	35	175	0.0872	-0.9963	0.2580			2.8400
3.20	45	225	-0.7071	-0.7071		2.2600		2.2600
3.15	55	275	-0.9962	+0.0872		3.1400	0.2750	
2.60	65	325	-0.5736	0.8192		1.4900	2.1300	
1.80	75	15	0.2588	0.9659	0.4660		1.7400	
0.55	85	65	0.9063	0.4226	0.4980		0.2330	
- 0.50	95	115	0.9063	-0.4226		0.4530	0.2120	
- 0.95	105	165	0.2588	-0.9659		0.2460	0.9200	
- 0.15	115	215	-0.5736	-0.8192	0.8500		0.1230	
+ 0.70	125	265	-0.9962	-0.0872		0.6970		0.0610
1.35	135	315	-0.7071	+0.7071		0.9550	0.9500	
1.65	145	5	+0.0872	0.9962	0.1440		1.6450	
1.65	155	55	0.8192	0.5736	1.3500		0.9450	
1.25	165	105	0.9659	-0.2588	1.2100			0.3240
0.50	175	155	0.4226	-0.9063	0.2115			0.4530
					8.4890	9.2410	10.0140	7.2280

Y	x°	7x°	Sin. 7x	Cos. 7x	Y sin. 7x		Cos. 7x	
					+	-	+	-
0.50	5	35	0.5736	0.8192	0.2870		0.4100	
1.50	15	105	0.9659	-0.2588	1.4500			0.3890
2.25	25	175	0.0372	-0.9962	0.1960			2.2400
2.85	35	245	-0.9062	-0.4226		2.5800		1.2000
3.20	45	315	-0.7071	+0.7071		2.2600	2.2600	
3.15	55	25	+0.4226	0.9063	1.3300		2.8600	
2.60	65	95	0.9962	-0.0872	2.5900			0.2270
1.80	75	165	0.2588	-0.9659	0.4760			1.7400
0.55	85	235	-0.8192	-0.5736		0.4500		1.3150
- 0.50	95	305	-0.8192	+0.5736	0.4100			0.2870
- 0.95	105	15	+0.2588	0.9659		0.2460		0.9450
- 0.15	115	85	0.9962	0.0872		0.1450		0.0131
+ 0.70	125	155	0.4226	-0.9063	0.2960			0.6350
1.35	135	225	-0.7071	-0.7071		0.9500		0.9500
1.65	145	295	-0.9063	+0.4226		1.4500	0.6975	
1.65	155	5	+0.0872	0.9962	0.1435		1.6450	
1.25	165	95	0.9659	0.2588	1.2100		0.3240	
0.50	175	145	0.5736	-0.8192	0.2870			0.4100
					8.6755	8.0810	8.1965	9.3461

$A_0 = 1/9(16.0594 - 1.5520) = 1.61$

$B_0 = 1/9(12.3254 - 5.9140) = 0.713$

$I_0 = \sqrt{1.61^2 + 0.713^2} = 1.77$

$\theta_3 = \tan^{-1} \frac{0.713}{1.61} = 23^{\circ}50^{1}$

$P_3 = 1/9(16.0508 - 2.4730) = 1.51$

$B_3 = 1/9(4.1840 - 12.7390) = 0.6175$

$I_3 = \sqrt{1.51^2 \times 0.6175^2} = 1.63$

$\theta_3 = \tan^{-1} \frac{-0.6175}{1.51} = -22^{\circ}10^{1}$

$P_5 = 1/9(8.4890 - 9.2410) = -0.0835$

$B_5 = 1/9(10.0140 - 7.2280) = 0.31$

$I_5 = \sqrt{0.0835^2 + 0.31^2} = 0.332$

$\theta_5 = \tan^{-1} \frac{0.31}{-0.0835} = 165^{-o}$

$A_7 = 1/9(8.5955 - 8.0810) = -0.066$

$B_7 = 1/9(8.1965 - 9.3461) = -0.1275$

$I_7 = \sqrt{0.060^2 + 0.1275^2} = 0.143$

$\theta = \tan^{-1} \frac{-0.1275}{0.066} = -62^{\circ}40^{1}$

D A T A F O R FIG. 23

Y	x^0	x^0	Sin. x	Cos. x	Y Sin. x		Cos. x	
					+	-	+	-
0.50	5	5	0.0872	0.9962	0.0437		0.4980	
1.55	15	15	0.2588	0.9659	0.4020		1.5000	
2.40	25	25	0.4226	0.9063	1.0100		2.1750	
2.85	35	35	0.5736	0.8192	1.6350		2.3350	
3.05	45	45	0.7071	0.7071	2.1600		2.1600	
2.90	55	55	0.8192	0.5736	2.3800		1.6600	
2.25	65	65	0.9063	0.4226	2.0400		0.9500	
0.90	75	75	0.9659	0.2588	0.8700		0.2330	
- 0.85	85	85	0.9962	0.0872		0.8470		0.0740
- 1.80	95	95	0.9962	-0.0872		1.7920	0.1570	
- 2.20	105	105	0.9569	-0.2588		2.1270	0.5700	
- 1.80	115	115	0.9063	-0.4226		1.6300	0.7600	
- 1.00	125	125	0.8192	-0.5736		0.8192	0.5736	
0.00	135	135	0.7071	-0.7071	0.0000			0.0000
+ 0.85	145	145	0.5736	-0.8192	0.4875			0.6960
1.30	155	155	0.4226	-0.9063	0.5500			1.1800
1.30	165	165	0.2588	-0.9659	0.3370			1.2550
0.50	175	175	0.0872	-0.9962	0.0437			0.4980
					119589	6.2152	13.5716	3.7030

Y	x^0	$3x^0$	Sin. 3x	Cos. 3x	Y Sin. 3x		Y Cos. 3x	
					+	-	+	-
0.50	5	15	0.2588	0.9659	0.2950		0.4830	
1.55	15	45	0.7071	0.7071	1.0950		1.0950	
2.40	25	75	0.9659	0.2588	2.3200			0.6120
2.85	35	105	0.9659	-0.2588	2.7500			0.7375
3.05	45	135	0.7071	-0.7071	2.1500			2.1500
2.90	55	165	0.2588	-0.9659	0.7500			2.8000
2.25	65	195	-0.2588	-0.9659		0.5820		2.1700
0.90	75	225	-0.7071	-0.7071		0.6350		0.6350
- 0.85	85	255	-0.9659	-0.2588	0.8200		0.2200	
- 1.80	95	285	-0.9659	+0.2588	1.7400			0.4660
- 2.20	105	315	-0.7071	0.7071	1.5550			1.5550
- 1.80	115	345	-0.2588	0.9659	0.4650			1.7400
- 1.00	125	15	+0.2588	0.9659		0.2588		1.9659
0.00	135	45	0.7071	0.7071	0.0000		0.0000	
+ 0.85	145	75	0.9659	-0.2588	0.8200		0.2200	
1.30	155	105	0.9659	-0.2588	1.2550			0.3370
1.30	165	135	0.7071	-0.7071	0.9200			0.9200
0.50	175	165	0.2588	-0.9659	0.2950			0.4830
					17.2100	1.4758	2.0180	15.5714

Y	x^0	$5x^0$	Sin.5x	Cos. 5x	Y Sin. 5x		Y Cos. 5x	
					+	-	+	-
0.50	5	25	0.4226	0.9063	0.2115		0.4500	
1.55	15	75	0.9659	0.2588	1.4980		0.4020	
2.40	25	125	0.8192	-0.5736	1.9650			1.3750
2.85	35	175	0.0872	-0.9962	0.2490			2.8400
3.05	45	225	-0.7071	-0.7071		2.1600		2.1600
2.90	55	275	-0.9962	+0.0872		2.8900	0.2530	
2.25	65	325	-0.5736	0.8192		1.200	1.8400	
0.90	75	15	+0.2588	0.9659	0.2330		0.8700	
- 0.85	85	65	0.9063	0.4226		0.7700		0.3590
- 1.80	95	115	0.9063	-0.4226		1.6300	0.7600	
- 2.20	105	165	0.2588	-0.9659		0.5700	2.1250	
- 1.80	115	215	-0.5736	-0.8192	0.9600		1.6550	
- 1.00	125	265	-0.9962	-0.0872	0.9962		0.0872	
0.00	135	315	-0.7071	+0.7071	0.0000		0.0000	
+ 0.85	145	5	+0.0872	0.9962	0.0740		0.8450	
1.30	155	55	0.8192	0.5736	1.0640		0.7450	
1.30	165	105	0.9659	-0.2588	1.2570			0.3370
0.50	175	155	0.4226	-0.9063	0.2115			0.4500
					8,7192	8.2200	8.0322	7.5160

Y	x^0	$7x^0$	Sin. $7x^0$	Cos. $7x^0$	Y Sin. 7x		Cos. 7x	
					+	-	+	-
0.50	5	35	0.5736	0.8192	0.2870		0.4100	
1.55	15	105	0.9659	-0.2588	1.4980			0.4020
2.40	25	175	0.0872	-0.9262	0.2090			0.2390
2.85	35	245	-0.9063	-0.4226		0.2580		1.2050
3.05	45	315	-0.7071	+0.7071		2.1600	2.1600	
2.90	55	25	+0.4226	0.9063	1.2250		2.6300	
2.25	65	95	0.9963	-0.0872	2.2400			0.1960
0.90	75	165	0.2588	-0.9659	0.2330			0.8700
- 0.85	85	235	-0.8192	-0.5736	0.6950		0.4875	
- 1.80	95	305	-0.8192	+0.5736	1.4750			1.0300
- 2.20	105	15	+0.2588	0.9659		0.2700		2.1200
- 1.80	115	85	0.9962	0.0872		1.7900		0.1570
- 1.00	125	155	0.4276	-0.9063		0.4226	0.9063	
0.00	135	225	-0.7071	-0.7071		0.0000	0.0000	
+ 0.85	145	295	-0.9063	+0.4226		0.7700	0.3590	
1.30	155	5	+0.0872	0.9962	0.1135		1.2950	
1.30	165	75	0.9659	0.2588	1.2570		0.3370	
0.50	175	145	0.5736	-0.8192	0.2870			0.4100
					9.5195	5.9706	8.5848	6.6290

$A_0 = 1/9(11.9589 - 6.2152) = 0.638$

$B_0 = 1/9(1.35761 - 3.7030) = 1.09$

$I = \sqrt{0.638^2 + 1.09^2} = 1.23$

$\theta = \tan^{-1} \frac{1.09}{0.638} = 59^0 40^1$

$A_3 = 1/9(17.2100 - 1.4758) = 1.75$

$B_3 = 1/9(15.5714 - 2.0180) = 1.53$

$I_3 = \sqrt{1.75^2 + 1.53^2} = 2.32$

$\theta_3 = \tan^{-1} \frac{1.53}{1.75} = 41^0 10^1$

$A_5 = 1/9(87192 - 8.2200) = 0.0556$

$B_5 = 1/9(8.0322 - 7.5160) = 0.0574$

$I_5 = \sqrt{0.0550^2 + 0.0574^2} = 0.08$

$\theta_5 = \tan^{-1} \frac{0.0574}{0.0556} = 45^0 40^1$

$A_7 = 1/9(915195 = 5.9706) = 0.395$

$B_7 = 1/9(8.5848 - 6.6290) = 0.218$

$I_7 = \sqrt{0.375^2 - 0.218^2} = 0.428$

$\theta_7 = \tan^{-1} \frac{0.218}{0.395} = 36^0 30^1$

D A T A F O R F I G. 24

Y	x^o	xo	Sin. xo	Cos. x	Y Sin. x		Cos. x	
					+	-	+	-
0.65	5	5	0.0872	0.9962	0.0567		0.6470	
1.80	15	15	0.2588	0.9659	0.4670		1.7400	
2.55	25	25	0.4236	0.9063	1.0750		2.3100	
2.80	35	35	0.5736	0.8192	1.6600		2.3700	
2.25	45	45	0.7071	0.7071	1.5200		1.5200	
1.25	55	55	0.8192	0.5736	1.0250		0.71 0	
0.00	65	65	0.9063	0.4226	0.0000		0.0000	
- 0.90	75	75	0.9659	0.2588		0.8700		0.2330
- 1.20	85	85	0.9962	0.0872		1.1900		0.1047
- 0.95	95	95	0.9962	-0.0872		0.9460	0.8280	
- 0.50	105	105	0.9659	-0.2588		0.4830	0.1290	
+ 0.50	115	115	0.9063	-0.4226	0.4840			0.2120
1.50	125	125	0.8192	-0.5736	1.2300			0.8600
2.15	135	135	0.7071	-0.7071	1.5200			1.5200
2.50	145	145	0.5736	-0.8192	1.4300			2.0500
2.55	155	155	0.4226	-0.9063	1.0750			2.3100
2.15	165	165	0.2588	-0.9659	0.5675			2.0750
1.00	175	175	0.0872	-0.9969	0.0872			0.9969
					12.1674	3.4890	10.2610	10.3616

Y	x°	3x°	Sin. 3x	Cos.3x	Y Sin. 3x		Cos. 3x	
					+	-	+	-
0.65	5	15	0.2588	0.9659	0.1685		0.6280	
1.80	15	45	0.7071	0.7071	1.2720		1.2720	
2.55	25	75	0.9659	0.3588	2.4700		0.6600	
2.80	35	105	0.9659	-0.2588	2.71--			0.7250
2.25	45	135	0.7071	-0.7071	1.5900			1.5900
1.25	55	165	0.2588	-0.9659	0.3240			1.2100
0.00	65	195	-0.2588	-0.9659	0.0000			0.9659
- 0.90	75	225	-0.7071	-0.7071	0.6350		0.6350	
- 1.20	85	255	-0.9659	-0.2588	1.1700		0.3110	
- 0.95	95	285	-0.9659	+0.2588	0.9180			0.2460
- 0.50	105	315	-0.7071	0.7071	0.3540			0.3540
+0.50	115	345	-0.2588	0.9659		0.1295	0.4830	
1.50	125	15	+0.2588	0.9659	0.3890		1.4500	
2.15	135	45	0.7071	0.7071	1.5200		1.5200	
2.50	145	75	0.9659	0.2588	2.4200		0.6480	
2.55	155	105	0.9659	-0.2588	2.4700			0.6600
2.15	165	135	0.7071	-0.7071	1.5200			1.5200
1.00	175	165	0.2588	-0.9659	0.0872			0.9659
					20.0177	0.1295	7.6070	8.2368

Y	x^o	$5x^o$	Sin. 5x	Cos. 5x	Y Sin. 5x		Y Cos. 5x	
					+	-	+	-
0.65	5	25	0.4226	0.9063	0.2740		0.5890	
1.80	15	75	0.9659	0.2588	1.7400		0.4670	
2.55	25	125	0.8192	-0.5736	2.0900			1.4600
2.80	35	175	0.0872	-0.9963	0.0440			2.7900
2.25	45	225	-0.7071	-0.7071		1.5900		1.5900
1.25	55	275	-0.9962	+0.0872		1.2450		0.1090
0.00	65	325	-0.5736	0.8192		0.0000		0.0000
- 0.90	75	15	+0.2588	0.9659		0.2330		0.8700
- 1.20	85	65	0.9063	0.4226		1.0880		0.5070
- 0.95	95	115	0.9063	-0.4226		0.8600	0.4030	
- 0.50	105	165	0.2588	-0.9659		0.1290	0.4830	
+ 0.50	115	215	-0.5736	-0.8192		0.3865		0.4100
1.50	125	265	-0.9962	-0.0872		1.4950		0.1310
2.15	135	315	-0.7071	+0.7071		1.5200	1.5200	
2.50	145	5	+0.0872	0.9962	0.2180		2.4900	
2.55	155	55	0.8192	0.5736	0.2090		1.4600	
2.15	165	105	0.9659	-0.2588	0.2080			0.5570
1.00	175	155	0.4226	-0.9063	0.4226			0.9063
					5.2056	8.5465	7.4120	9.3303

Y	x°	7x°	Sin. 7x	Cos. 7x	Y Sin. 7x		Y Cos. 7x	
					+	-	+	-
0.65	5	35	0.5736	0.8192	0.3720		0.5320	
1.80	15	105	0.9659	-0.2588	1.4500			0.4660
2.55	25	175	0.0872	-0.9962	0.2230			2.5400
2.80	35	245	-0.9063	-0.4226		2.5400		1.1800
2.25	45	315	-0.7071	+0.7071		1.5900	1.5900	
1.25	55	25	+0.4226	0.9063	0.5280		1.2450	
0.00	65	95	0.9962	-0.0872	0.0000		0.0000	
- 0.90	75	165	0.2588	-0.9659		0.2330	0.8700	
- 1.20	85	235	-0.8192	-0.5736	0.9830		0.6870	
- 0.95	95	305	-0.8192	+0.5736	0.7780			0.5340
- 0.50	105	15	+0.2588	0.9659		0.1290		0.48.0
+ 0.50	115	85	0.9962	0.0872	0.4980		0.0437	
1.50	125	155	0.4226	-0.9063	0.6350			1.3600
2.15	135	225	-0.7071	-0.7071		1.5200		1.5200
2.50	145	295	-0.9063	+0.4226	2.3700		1.0550	
2.55	155	5	0.0872	0.9962	0.2220		2.5400	
2.15	165	75	0.9659	0.2588	2.0800		0.5670	
1.00	175	145	0.5736	-0.8192	0.5736			0.8192
					8.3426	8.3820	9.1297	7.9022

$A = 1/9(12.1674 - 3.42870) = 0.965$

$B = 1/9(10.2610 - 10.3610) = 0.0111$

$I = \sqrt{0.965^2 + 0.0111^2} = 0.966$

$\theta = \tan^{-1} \frac{0.0111}{0.965} = 0^{\circ}40^{1}$

$A_3 = 1/9(20.0177 - 0.1295) = 2.21$

$B_3 = 1.9(7.6070 - 8.2368) = - 0.07$

$I_3 = \sqrt{2.21^2 + 0.07^2} = 2.22$

$\theta_3 = \tan \frac{-0.07}{2.21} = - 1\ 50$

$A_5 = 1/9(5.2056 - 8.5465) = -0.371$

$B_5 = 1/9(7.4120 - 9.3303) = - 0.213$

$I_5 = \sqrt{0.371^2 + 0.213^2} = 0.485$

$\theta_5 = \tan^{-1} \frac{-0.213}{-0.371} = 210^{\circ}$

$A_7 = 1/9(8.3426 - 8.3820) = -0.0043$

$B_7 = 1/9(9.1297 - 7.9022) = 0.136$

$I_7 = \sqrt{0.0043^2 + 0.1130^2} = 0.136$

$\theta_7 = \tan^{-1} \frac{0.136}{-0.0043} = 910^{\circ}50^{1}$

INSTRUCTIONS GEH-624

OSCILLOGRAPH

TYPE EM FORM C

GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y.

May, 1927

Superseding 86111

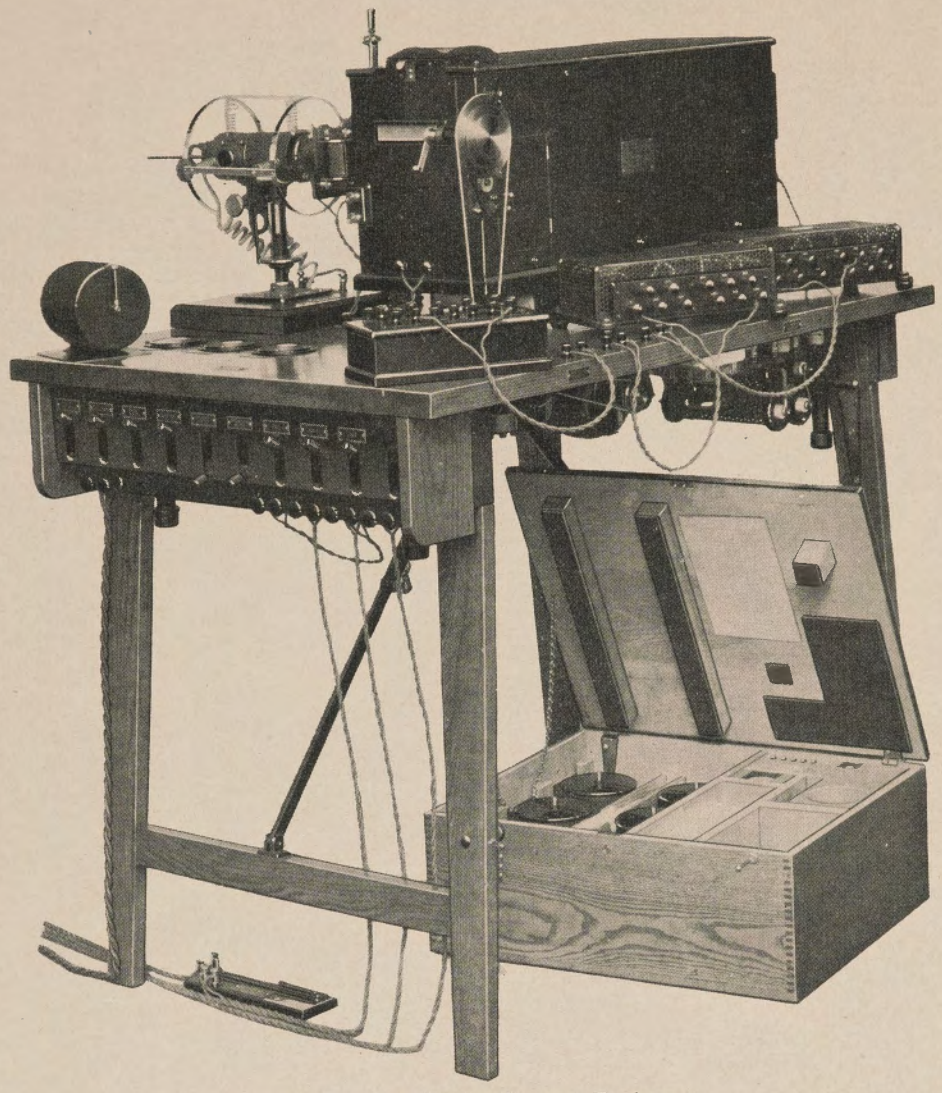


Fig. 1. Portable Oscillograph Equipment

OSCILLOGRAPH
TYPE EM FORM C

INSTALLATION

UNPACKING

The apparatus is usually shipped in several cases. The galvanometer is packed separately from the main oscillograph case. The vibrators, synchronous motor, cam, ground glass slide and step pulley, as well as film holders, supplies and some other small parts will be found in a box provided for their storage. It is well to notice the method of packing, especially that of the galvanometer, in case the apparatus is to be reshipped.

LOCATING NON-PORTABLE EQUIPMENT

The various parts of the equipment may be set up on any substantial table, approximately 36 in. by 48 in. on top and about 32 in. high. The rheostats and film-driving motor may all be mounted under the table, leaving the table top for the oscillograph, lamp, ammeters and resistors for the vibrator circuits. Ammeters of highest accuracy are not required. All switches should be located in as convenient a position as possible. Connections should be made as shown in Fig. 6.

TABLES FOR PORTABLE EQUIPMENT

The portable table shown in Fig. 1 has the necessary rheostats, instruments, control switches and film-driving motor permanently mounted on it. The connections for this table are for use with an arc lamp only and are similar to those shown in Fig. 6 except that a triple-pole double-throw switch is provided to make it convenient for using either the film-driving motor mounted on the table or an auxiliary motor, such as one with a flywheel or one with a speed reduction unit, for very slow film speeds. This motor circuit is connected as shown in Fig. 5. The table for use with either an arc or a Mazda lamp is similar to the above with the addition of a transformer and rheostat, a switch for changing transformer connections for either 110 or 220 volts and a second one for readily connecting the lamp and ammeter in either the arc lamp or Mazda lamp circuit. Connections for this table are shown in Fig. 5.

MOUNTING GALVANOMETER

After locating the oscillograph case on the table, adjust the levelling screw S, Fig. 2, until it sets firmly. Separate the group of field and vibrator leads and become familiar with the relative location of each so they will not be interchanged later. See that the vibrator cells are clean and place the galvanometer in position, as shown in Fig. 8, fastening the base down with the four screws which are in place in the wooden sub-base. It is not necessary to remove the case for this purpose.

Three leads complete the field circuit inside the case. Two of these are attached to the galvanometer winding. One has a plug terminal and should be inserted in the upper terminal board and clamped in place in the position marked F. The other which is furnished with an open end terminal and the lead marked FLD from the lower terminal board, (also furnished with an open end terminal), should be clamped together under the binding post in the back of the case.

FILLING CELLS WITH DAMPING LIQUID

Remove the packing from the galvanometer cells, Fig. 3 and Fig. 4, and see that they are clean inside. Fill each cell with sufficient damping liquid to just cover the top of the pole tips, PT, Fig. 4. If a bubble appears between the pole tips and cell window, it should be removed by means of a thin wooden tool.

INSERTING VIBRATORS

Before inserting a vibrator, clean the vibrator seat, VS, with a piece of soft cloth to remove any collection of dust or damping liquid which might prevent the vibrator from seating properly. See that the vibrator seat is set to give a maximum opening in the cell top. Lower the vibrator carefully into

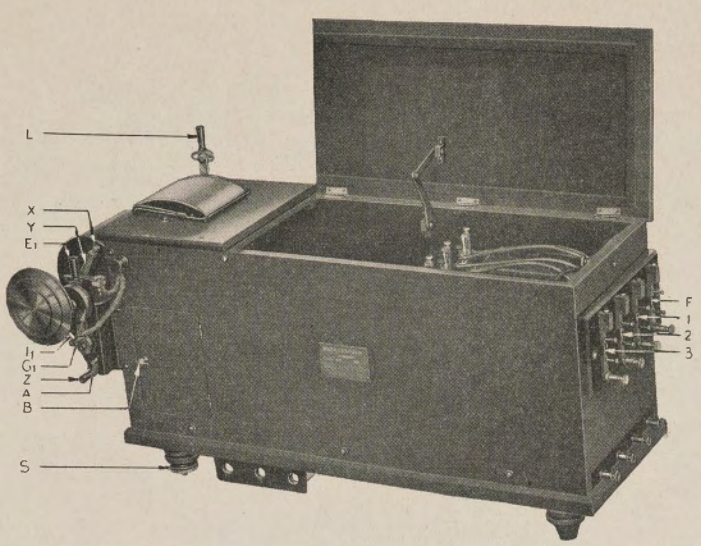


Fig. 2. Oscillograph Showing Terminal Boards

this opening, with the back of its frame resting flat against the rear cell wall, until the block A strikes the vibrator seat. Then push it straight forward as far as it will go into its seat and clamp it in this position by means of screw C.

The tension on the vibrator suspension is adjusted by means of the knurled head TS and is read on the spring balance SB, each ring representing 2 oz., the lowest one next to the lip indicating zero, the next 2 oz., the next 4 oz., etc. Standard vibrators, type V, should be adjusted to 6 oz. and high sensitivity vibrators, type SV, to 4-oz. tension.

Increased tension on a vibrator lowers its sensitivity and raises its natural frequency while decreased tension has the opposite effects.

Connect the vibrator leads to their respective vibrators, keeping the three pairs within the case free from each other and from the galvanometer field and field connections if more than 1000 volts are to be applied between vibrators.

FUSES

The upper terminal board, Fig. 2, includes fuse holders. Suitable lengths of the fuse wire supplied should be inserted at F, 1, 2, and 3.

OPTICAL SYSTEM

ARC LAMP

This lamp, shown in Fig. 1, is intended for use on a 100-125-volt direct-current circuit and requires a resistor of 7 to 15 ohms connected in series. This is preferably adjustable to permit raising the current temporarily while making an exposure but should have 7 ohms fixed so that the current cannot be raised beyond a certain limit, say twice normal operating current. A 7-ohm fixed resistor is satisfactory if the carbons are not allowed to remain together longer than just sufficient to start an arc. The current required for slow speed photographic records or for viewing is 6 to 8 amperes and that for high-speed photography is 8 to 10 amperes.

The carbons used are ¼ in. by 8 in. solid and ¼ in. by 6 in. cored. The solid carbon must be used in the horizontal position as the positive electrode and the cored one in the vertical position as the negative electrode. The electrode which is positive can be recognized by its greater brilliancy. Do not use a cored carbon for the positive electrode as it will produce a beam with a dark center. The tip of the vertical carbon should be about on a level with the bottom of the horizontal one.

A pin-hole in the lamp housing directly

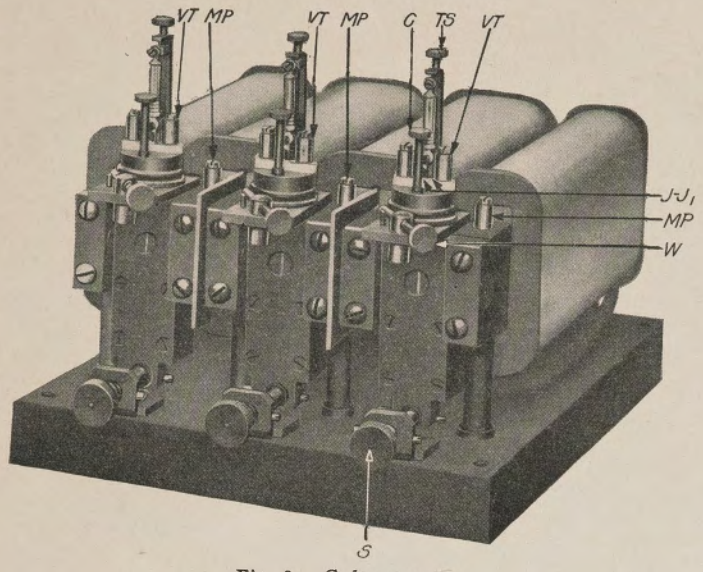


Fig. 3. Galvanometer

back of the arc throws an inverted image of the hot carbon tips on a small screen supported by the rear guard. This makes it possible to adjust the arc without looking at it through the colored glass window.

The lens will require occasional cleaning. Lack of light can usually be attributed to dirt on this lens.

MAZDA LAMP

A Mazda lamp rated 6 volts, 18 amperes, 108 watts is used in the lamp stand shown in Fig. 7. This can be connected to a large 6-volt battery or to the secondary of a small step-down transformer.

The transformer furnished for this purpose on the portable table, Fig. 5, is rated 250 watts, 110/220 volts primary, 7.5 volts secondary. A rheostat must be connected in the primary circuit to adjust the light intensity. (If it is desired to increase the intensity a definite amount while a film is being exposed, a special rheostat provided with a short-circuiting switch may be placed in either the primary or secondary circuit and short-circuited while the greater light intensity is required. No provision is made for doing this.) The lamp has normal life at 18 amperes but may be operated momentarily at 20 amperes, however, at this current value, its life is short.

The lamp stand has been adjusted for the lamp which is furnished. When replacing a lamp, it may be necessary to make readjustments because of variation in the height of the filaments. To do this, loosen the three screws A_2, Fig. 7, and remove the lamp housing. If the center of the new lamp filament is not $9\frac{1}{2}$ inches above the table, that is, at the same height as the center of the light aperture in the oscillograph case, loosen the set screw B_2 and bring the lamp to the correct height. Then tighten the set screw and

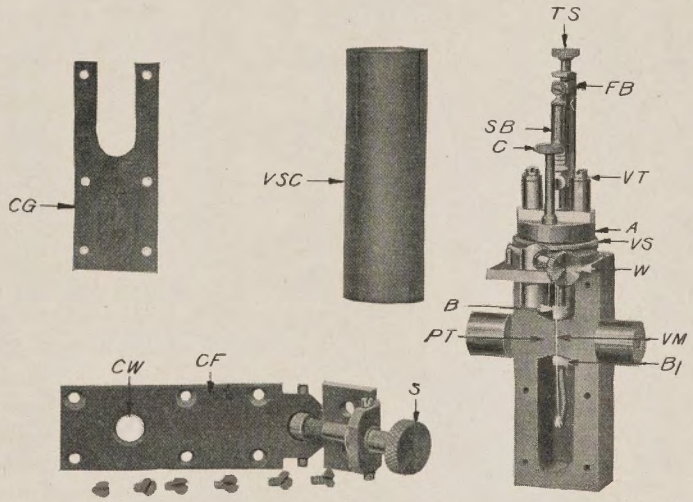


Fig. 4. Galvanometer Cell with Front Removed, Showing Vibrator in Place

The following parts, Fig. 4, are designated by letters so that the names may be known: CG, cell gasket; VSC, vibrator shipping cartridge; CW, cell window; CF, cell front; PT, pole tips; VS, vibrator seat; VM, vibrator mirror; SB, spring balance; B and B_1 bridges; TS, tension screw.

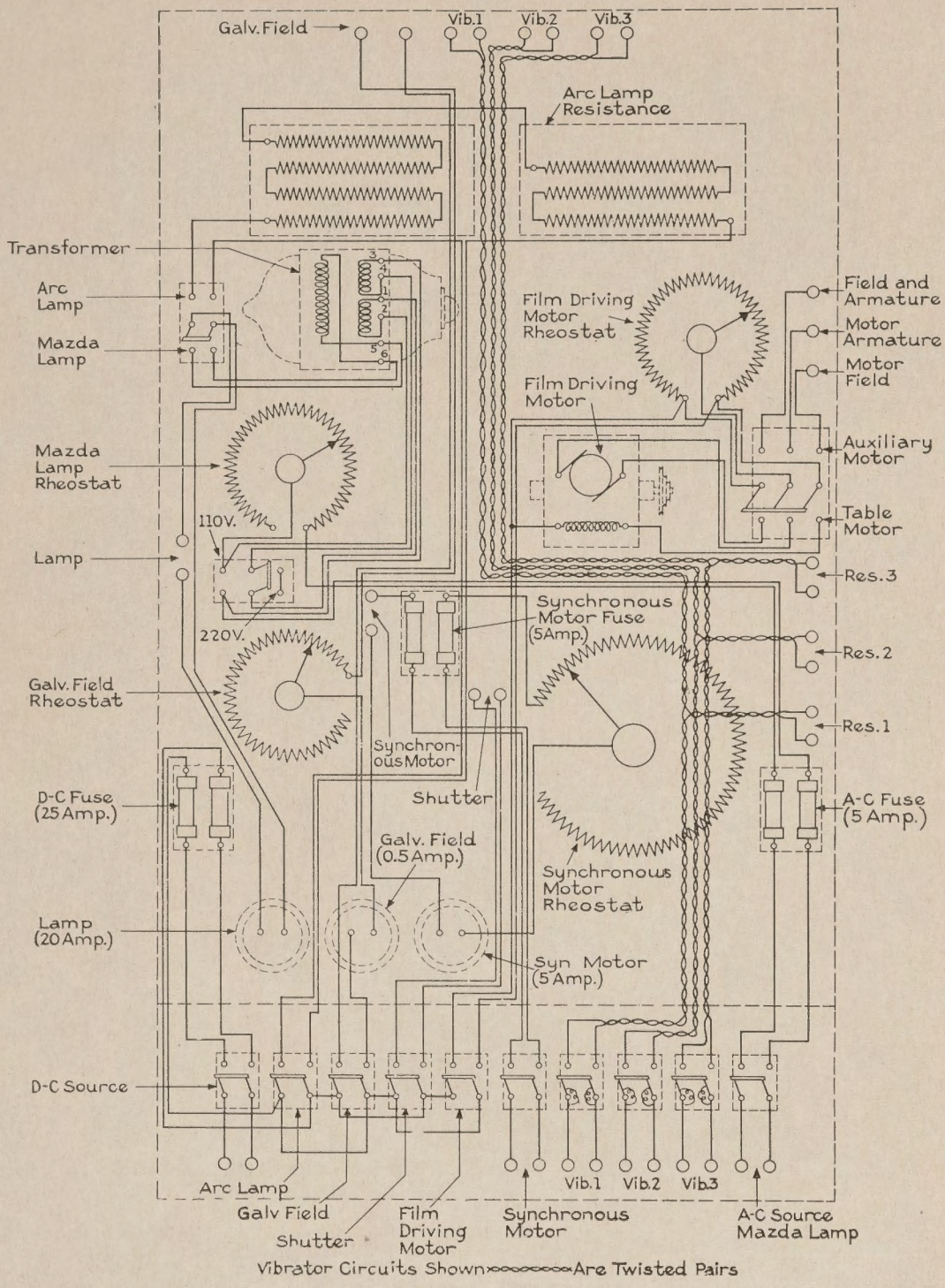


Fig. 5. Connections for Portable Table for Use with Arc or Mazda Lamp

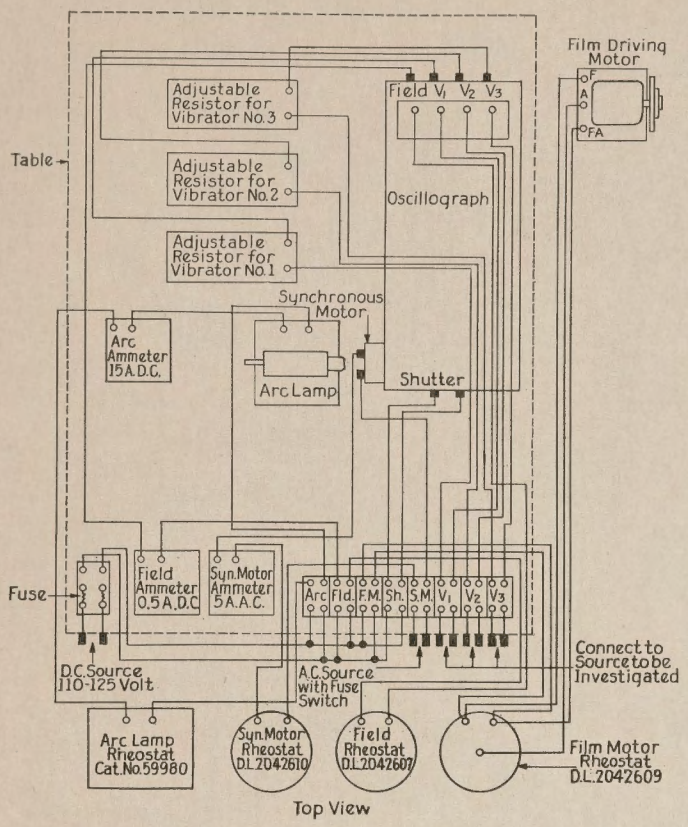


Fig. 6. Connections for Non-portable Oscillograph Equipment Using Arc Lamp

replace the housing in such a position that the wires supporting the filament do not come between the filament and the lens D_2. Loosen the screws C_2 and move the lens holder vertically until the center of the lens is at the same height as the center of the lamp filament, then retighten them to hold it in this position. The distance between the filament and the lens can be varied and should be adjusted before using, to produce the brightest spots on the cell windows.

LAMP CONNECTIONS

Either the arc or the Mazda lamp may be used while adjusting the beam, but this adjustment is easier when using an arc lamp because of the brighter light obtained. In either case the center of the lens in the lamp should be at the same height as the center of the aperture in the side of the oscillograph case.

When the arc lamp is used on a table, Fig. 5, designed for use with either type of lamp, it should be connected to the terminals marked LAMP and the double-pole double-throw switch under the table near the transformer should be thrown to the side marked ARC LAMP. The arc lamp switch on the front of the table then closes the circuit through the lamp and ammeter.

The Mazda lamp may be used by connecting it to the same LAMP terminals and throwing the switch to the end marked MAZDA LAMP. A second double-pole double-throw switch near the lamp terminals may be turned either to the end marked 110 V. or to that marked 220 V. according to the voltage available. The switch on the table front marked MAZDA LAMP A-C. SOURCE, then controls this circuit, the voltage being

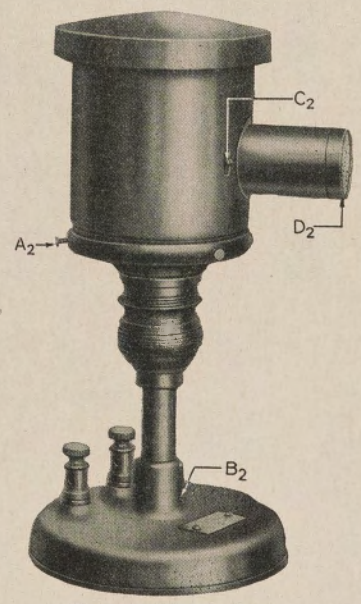


Fig. 7. Mazda Lamp

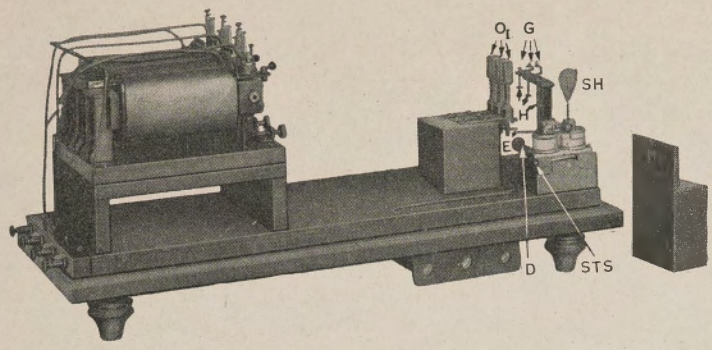


Fig. 8. Oscillograph Showing Internal Arrangement

applied to the terminals directly under this switch. The MAZDA LAMP RHEOSTAT regulates the light intensity. The ammeter marked LAMP is used for either lamp.

If it is desirable to use a Mazda lamp with a table designed for arc lamp only, it must be connected externally.

ADJUSTING LIGHT BEAM

Open door B, Fig. 2, and turn knob D, Fig. 8, counter-clockwise, opening the shutter SH. Place the lamp with the lens approximately 6 in. from the oscillograph. Light the lamp and move it, readjusting its height if necessary so that the three prisms G are in the beam of light.

The optical system has been correctly

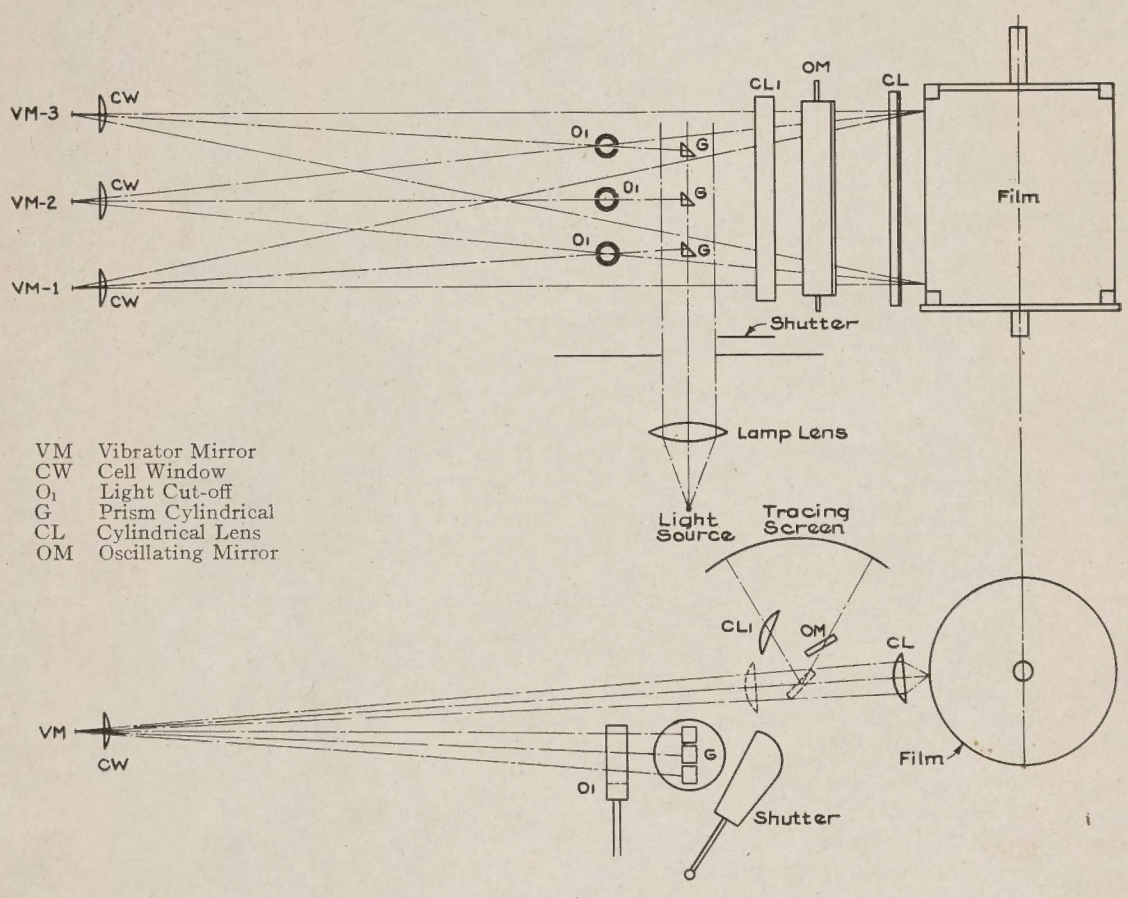


Fig. 9. Diagram of Optical System

adjusted at the factory and should not ordinarily require readjustment before using. The prisms reflect beams of light from the lamp to the respective vibrator cell windows CW, Fig. 4. Each prism has two faces which are at right angles to each other. One of these should be turned to face the incoming beam of light from the lamp and the other should face the cell window (see Fig. 9). The knurled heads H, Fig. 8, are used to control the angular adjustment of these prisms.

Hold a thin card in such a position, inside the oscillograph door, that a clearly defined silhouette of the prisms can be seen through it with the prisms on a vertical diameter of the light beam.

The three light cut-offs O_1, located between the prisms and their respective cell windows, are used for adjusting the width of the beams or for entirely cutting off any beam which is not required. Open these cut-offs by means of handles E until the maximum amount of light falls on each window.

LOCATING LIGHT SPOT ON GROUND GLASS

The lever L must be in a vertical position, as in Fig. 2, to allow the light beam to pass to the ground glass. This lever may be unlocked by pushing it toward the tracing screen.

The beam reflected from the vibrator mirror can usually be found by means of the spot produced on a small card held in front of and just above the cell window. This spot may be kept on the card and followed forward, making necessary vertical and horizontal adjustments by means of screws S and W respectively, Fig. 3, until it is located three inches (approximately) below the bottom edge of the metal top plate. When the card is removed, the spot should be seen on the ground glass. More accurate adjustment vertically is determined by removing the ground-glass slide, holding a piece of thin paper close to the slot in the front plate and observing the position of the light spots. These should be adjusted by means of the screws S, Fig. 3, until the center of each beam is in the middle of the slot.

The width of each image is adjusted by means of the corresponding light cut-off O_1, Fig. 8. The intensity of the light beam required depends upon the velocity of the spot with respect to the film. For general use a light spot 1 mm. wide is sufficient.

Close the galvanometer field switch and adjust the current to 0.35 ampere by means of the GALV. FIELD RHEOSTAT. If the light spot moves when closing or opening this circuit, with the vibrator circuit open, it is an indication of the presence of a magnetic substance between the pole tips. Open the galvanometer field circuit, take the vibrator from the cell and with a thin wooden tool, remove any foreign substance from the space between the pole tips PT, Fig. 4. It is seldom necessary to remove the damping liquid or to take the cell from the galvanometer in order to do this.

AUXILIARY ZERO TRACER

This consists of a stationary mirror adjusted by means of a ball and socket. It is located on the middle cell with its mirror slightly below the vibrator mirror and in the same beam of light. In order that this may give a true zero, the spot from its mirror must be lined up vertically on the ground glass with that from the middle vibrator. The two spots will not exactly coincide, one always being higher than the other. This tracer may be moved to either of the other cells if desired. It is of particular advantage when using a long film holder since the film cannot be given a second exposure. It is not necessary when using short films and should ordinarily be turned to one side.

CONNECTION OF VIBRATOR CIRCUITS

In all cases, before closing the circuit through a standard oscillograph vibrator, sufficient resistance should be connected in series to keep the maximum current below 0.2 ampere. The resistors for the vibrator circuits are designed for 0.2 ampere unless marked otherwise but they will stand 0.3

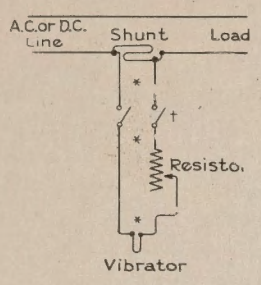


Fig. 10

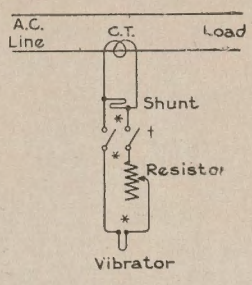


Fig. 11

Diagrams for Current Measurements

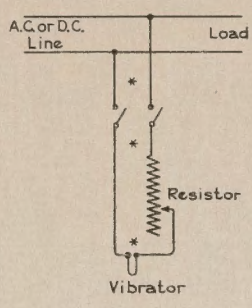


Fig. 12

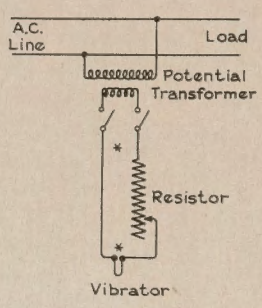


Fig. 13

Diagrams for Potential Measurements

*These leads should be twisted to prevent error due to inductance.
†The resistance of switch contacts should be kept as low as possible for all current measurements.

ampere momentarily. The current through a high sensitivity vibrator should be kept below 0.07 ampere. The oscillograph vibrator may be considered as the equivalent of the moving coil of a milli-voltmeter and when used for recording current may be connected directly to the drop terminals of a current shunt. If the drop from this shunt is more than 0.3 volt when a standard vibrator is used or 0.1 volt with a high sensitivity vibrator, resistance must be connected in series with the vibrator.

The connections for measurement of direct current are as shown in Fig. 10. If this is a high-voltage grounded circuit, the shunt should always be placed next to ground. If the circuit is not grounded and is above 2500 volts, only one vibrator can be used and the complete equipment, as well as a battery for operating the oscillograph, must be properly insulated from ground and the safety of the operator should receive special attention.

For measuring alternating current, either a shunt or a current transformer in connection with a shunt may be used as shown in Fig. 10 and Fig. 11. A current transformer should not be used for recording transient values of current. On the other hand, it is safe to use a current transformer for recording current in a line at a high potential above ground, while a shunt should not be used except with the extreme precautions mentioned above.

For potential measurements the connections are as shown in Fig. 12 and Fig. 13. If one line is grounded, the vibrator should be connected next to ground. It is advisable to connect approximately 10 ohms per volt applied in series with a standard vibrator. The high sensitivity vibrator requires about three times as much resistance in series as the standard one.

The pair of leads to each vibrator should be twisted in order to keep the circuit as nearly non-inductive as possible and prevent errors due to inductive disturbances. For current measurements the contact resistance of switches in the vibrator circuits should be kept as low as possible.

VISUAL OBSERVATION OF WAVE SHAPES

ATTACHING SYNCHRONOUS MOTOR

With the lever L still in the vertical position, as in Fig. 2, put the cam end of the cam-shaft through the upper hole in the left-hand side of the case and insert the end of the shaft in the bearing shown at K_1, Fig. 14. The synchronous motor can now be placed in position as follows: Insert the shutter end of the synchronous motor shaft in the hole in the center of the cam-shaft disk. Turn the armature until the slot in the shutter-vane clamp engages with the pin on the cam-shaft disk. Clamp the motor in position by means of screws R, Fig. 15. Before starting the

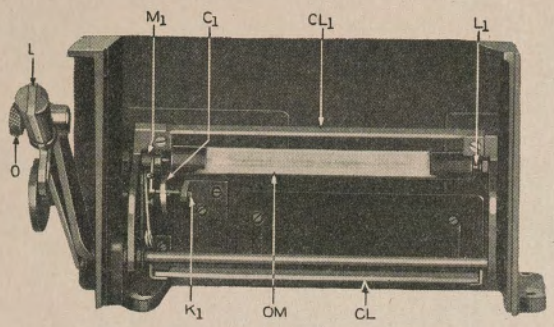


Fig. 14. Lens and Mirror Support

motor, oil all bearings indicated in the paragraph entitled "Oiling," page 16, and spin the motor armature to make sure that the bearings do not bind.

STARTING SYNCHRONOUS MOTOR

See that screw O, Fig. 14 and Fig. 15, is tightened at the near end of the slot. Connect the synchronous motor to the circuit, the wave shape of which is to be observed. Close the circuit (see page 19 for current values required) and start the motor armature toward you by hand and at the same time raise the starting handle Q, Fig. 15, allowing the circuit to be broken by the contactor striking on the interrupter on the motor shaft. Hold the handle in this position until synchronous speed is obtained then lower it and reduce the current to the running value. **If synchronous speed is not reached in less than 10 seconds, let the motor stop until the contacts cool.** If the arcing is continued long, it will heat the contacts sufficiently to destroy them.

Unlock lever L and move it toward the galvanometer until it locks in the other position as shown in Fig. 15. This lowers the cylindrical lens CL_1, Fig. 14, and the oscillating mirror OM into the path of the beam and cuts off the light from lens CL and the ground glass. Loosen the screw O and push it carefully to the far end of the slot and fasten it. A straight zero line should now be seen across the tracing screen from front to back. Close the galvanometer field and vibrator switches and a wave should be seen on the tracing screen. Adjust the amplitude of the wave by cautiously changing the resistance in series with the vibrator.

If two cycles appear instead of one, the motor is running at half speed. Reset the lever L in the vertical position and screw O at the near end of the slot. Start the motor as before and see that only one cycle appears on the screen.

When through using the tracing screen, always return lever L to the vertical position.

PHOTOGRAPHIC RECORDS

GENERAL PREPARATION

For driving the film holder a motor of at least 1/20 h.p. should be used. This should be belted to the step pulley on the film driving head using the belt cord furnished. To prevent irregularities in driving the film a long splice should be used in this belt. The film holder should be made to turn counterclockwise facing the step pulley on the driving head. On the portable table the motor is adjustable for the purpose of tightening the belt and can be clamped in any position by

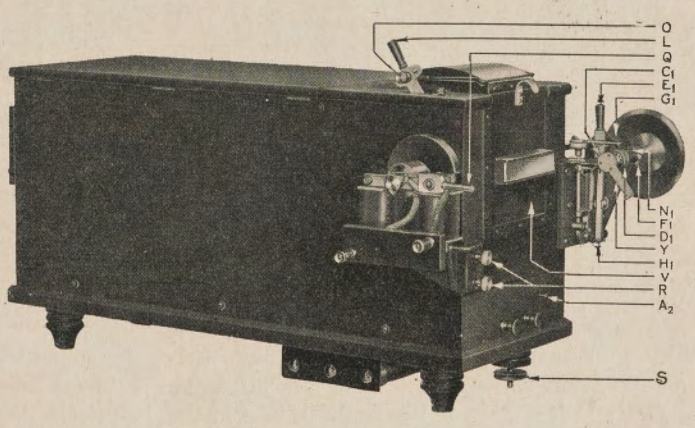


Fig. 15. Oscillograph Showing Photographic and Tracing Features

means of the knob just back of the idler pulleys on the table top.

In arranging the curves, by observation of the spots on the ground glass, it should be borne in mind that deflections from left to right will give a curve from the bottom to the top of the printed oscillogram. The record from vibrator No. 3 will appear at the top and that from vibrator No. 1 at the bottom of the print.

A photographic or other suitable dark room should be provided for the loading of film holders and the developing of films. The films are extremely sensitive and should be handled carefully even under the ruby light to prevent fogging and to obtain the best results.

SHORT FILM HOLDER

To load the short film holder, hold the revolving drum with the driving end of its shaft toward the operator. Fasten one end of the film, with emulsion side up, under the spring clips and bring it around in a clockwise direction, fastening the other end under the same spring clips, lapping over the first end. Replace the drum in the holder and see that it turns freely in a counter-clockwise direction looking at the driving end. Turning in the reverse direction will pull the film from the drum. Set the index lever on the film holder shutter in the closed position indicated by C on the end of the holder. Screw the driving dog X, Fig. 2, in the end of the shaft, fastening it with the lock-nut.

When taking oscillograms the lever L, Fig. 15, must be in a vertical position and the synchronous motor armature secured with the word OPEN in sight to keep its revolving shutter from obstructing the light beam. Remove the ground glass slide V, and replace it with the loaded film holder with the driving end to the right, pushing it down against the stop. Engage the driving dog in the driving arm Y, Fig. 15 and Fig. 16. Close the electromagnetic shutter SH, Fig. 8, mechanically by turning knob D. It can now be operated by either of the shutter controls described hereafter. The motor for driving the film may now be started. The film holder shutter is opened for exposure by setting its index lever at O and closed again immediately after exposure by setting the lever at E. This shutter should not be left open longer than necessary for making the exposure and never when the film drum is not rotating. A second exposure may be made with the vibrator switches open to obtain zero lines.

ELECTROMAGNETIC SHUTTER

This shutter is designed for operation from the direct-current source which is used for the galvanometer field, etc., sufficient series resistance being mounted under the oscillograph base. When making adjustments which require more than a few seconds, this shutter should be locked open mechanically (see top of page 8). It may be held open momentarily, as when observing the light spots just before making an exposure, by pressing the push button A_2, Fig. 15, on the front of the oscillograph.

Two controls are provided, one of which is adjustable for starting the record at the beginning of the film and the other is instantaneous for recording non-recurring transients. If the shutter circuit is allowed to remain closed through any one of the three control contacts, except while the film is being exposed, the magnet coils will be damaged.

The condenser which is mounted inside the case, is connected across the control contacts for the purpose of absorbing voltage rises when the circuit is opened. As this condenser remains charged for some time, if it is necessary to handle the bare contacts, the shutter circuit should be opened and the condenser discharged by pushing button A_2.

ELECTROMAGNETIC SHUTTER CONTROLS

Adjustable Shutter Control.—With this control the exposure does not begin until approximately one revolution after pulling the trigger. It is adjustable so that the exposure may be made to start at the beginning of the film. This control is set by pushing

the lever Z, Fig. 16, down as far as it will go. It is tripped by pulling a cord of non-conducting material attached to the trigger A, and should be reset **immediately** after each operation.

To compensate for the shutter lag and to open the shutter at the beginning of the film, it is necessary to close the circuit through the coil which operates it a definite time before this part of the film reaches the slot. The angle of advance required depends upon the film speed to be used. The worm contact wheel D_1, Fig. 16, has twelve equally spaced holes around one side. When the locking bolt C_1, is set in the hole marked 0, the circuit will be closed when the driving arm points toward the slot in the oscillograph front plate. For film drum speeds up to 200 r.p.m. the locking bolt should be set in this hole, for each 200 r.p.m. additional it should be set one hole farther forward, i.e., in hole marked 1 for speeds from 200 to 400 r.p.m., etc. An accurate setting can not be predetermined as the lag of various shutters differs slightly, but the above will give a good approximate setting for the first trial record. A closer setting may then be made as a result of this trial. When the worm contact wheel is correctly set, the shutter should open when the lap of the film is directly opposite the slot and remain open for one complete revolution of the film drum.

The shutter has been so set that there will be very little lap or gap in the record. If, after continued use, it is found that the lap has increased, the shutter should be reset by turning the shutter tension screw STS, Fig. 8, clockwise ⅛ to ¼ turn. (Do not make more than a complete turn or the spring will be damaged.) This screw can be reached with a small screwdriver through a hole in the shutter case without removing the oscillograph case. Film drum speeds above 1200 r.p.m. are not recommended. At speeds higher than this, the film may be thrown from the drum and the spring clips may be damaged.

The contact arm K, Fig. 16, is adjusted correctly so that the average travel before making contact on D_1 is one revolution. This requires no adjustment unless accidentally shifted, in which case it can be readjusted by means of screw S_1, which regulates the distance of the return travel of this arm.

Instantaneous Shutter Control.—With this control the shutter circuit closes immediately on pulling the trigger, but the exposure may start at any point on the film. This is particularly suitable for recording a non-recurring event.

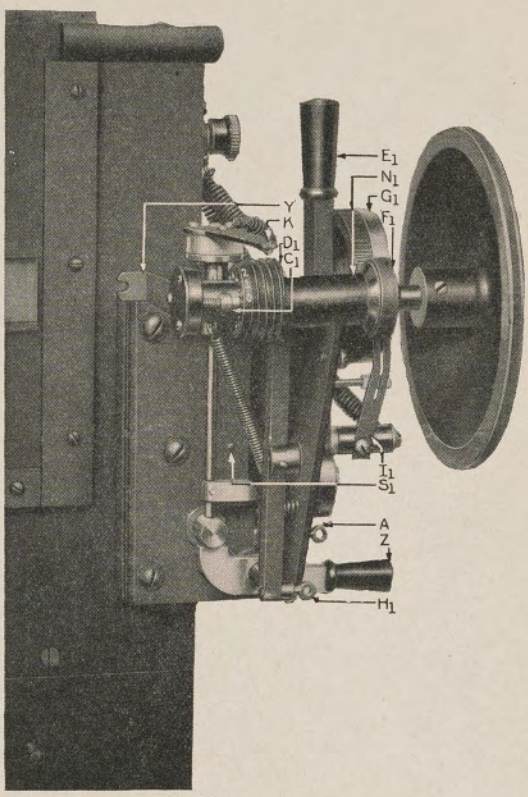


Fig. 16. Film-driving Head and Shutter-control Mechanisms

This control is set by pushing lever E_1, Fig. 16, away from the rubber driving wheel F_1, and turning the contact disk G_1 toward the driving wheel until it strikes the stop. It is tripped by pulling a cord of non-conducting material attached to the trigger H_1. The contact brush I_1 has a

slot under the clamp screw for making adjustment for immediate contact when the trigger is tripped. For remote control, any suitable electromagnetic tripping device may be used to release the trigger.

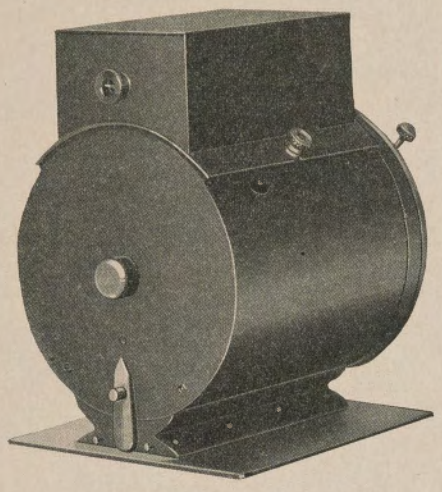


Fig. 17. Long Film Holder

SHORT FILMS

The photographic films ordinarily used are made especially for the oscillograph and are known as "Transparent Non-Curling Films for the Oscillograph, 3⅞ in. by 12¾ in." These are about the same speed as ordinary roll films for use in cameras.

"Super-speed" films, known as "Eastman Portrait Films, 3⅞ in. by 12¾ in.," are also available. These are better suited for use when an incandescent lamp is the source of light. When using an arc lamp, the width of beams can be reduced, thus giving finer lines on the record. These films are made from thicker stock and have also the "safety" feature which makes them practically fireproof.

MARKING FILMS

It is advisable to mark an arrow on the film before taking it from the drum to indicate the sequence of events on the record. To do this properly hold the drum with the driving end of its shaft toward the operator. Mark the arrow with a lead pencil on the beginning of the film to the right of the lap at the far side. The arrow should point to the right of the operator. This arrow then points in a direction which is opposite to the rotation of the drum, but in the direction of the sequence of events. If desirable to place a number or other notation on the film before developing, this may be conveniently placed near the arrow but on the left of the lap. With this system of marking, the arrow will be in the lower left-hand corner and the number in the lower right-hand corner of the finished print.

DEVELOPER

Any good photographic developer suitable for films may be used.

LONG FILM HOLDER

The long film holder, Fig. 17 and Fig. 18, consists of a case and drum similar to that of the short film holder, with a film magazine mounted on the top. The film is wound onto

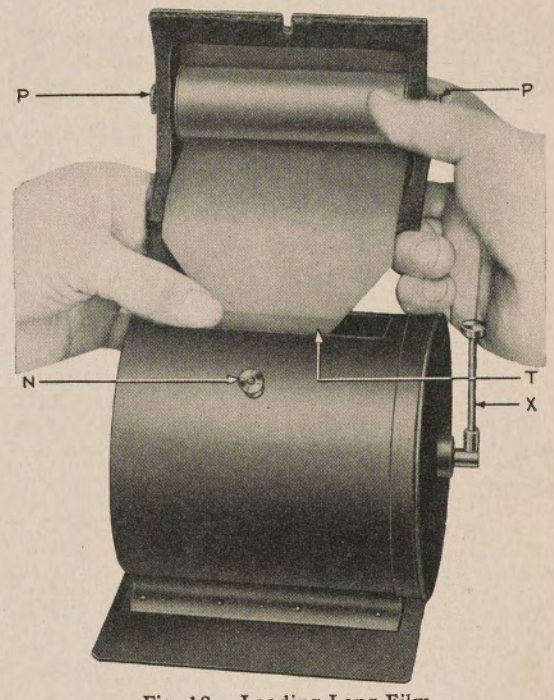


Fig. 18. Loading Long Film Holder

the drum from the spool in the magazine during the exposure. This holder is designed to use a non-autographic film on a spool approximately 3¾ in. long overall. Eastman No. 101, Eastman No. 122 (non-autographic), or Ansco No. 18 films may be used. From the above, films may be chosen which will give records ranging from two to five feet long (see Supplies, page 18).

In order to put the film spool in the magazine, pull out the spool-pin P at each end and drop the spool in place, allowing the spool pins to snap back into the ends of the spool. It is usually convenient to lock one of the spool pins out by turning it slightly clockwise after pulling it out. This leaves one hand free to handle the spool. After the pin is in place in one end of the spool, the other can be released, thus fastening the spool. The magazine is reversible and only the way the film is put into it determines which way it should be assembled with the holder.

Place the holder with the flat side down on the table in front of you with the driving shaft to your right. Screw the driving dog X into the hole in the end of the shaft, securing it with the lock-nut, and turn the drum until the driving dog points up. A slot T will then be seen in the drum as shown in Fig. 18, into which the end of the paper covering the film should be inserted. Hold the magazine above the holder as shown in the figure so that, when the seal on the film roll is removed, the paper can be unrolled from the bottom of the spool with its black side up. The end of the paper should now be inserted in the slot T and the drum turned about one revolution in a counter-clockwise direction looking at the driving end. The black side of the paper should now be seen on the outside of the drum and the film will later be on the outside of the paper with its emulsion side out. The magazine should then be replaced on the holder and fastened down by means of the two thumb-nuts N. There will still be enough paper on the spool for about one more turn around the drum. This is sufficient to allow the film to start from rest and get up to uniform speed before the exposure begins. Drum speeds above 400 r.p.m. are not recommended with this film holder.

Before making an exposure with this film holder, the shutter SH, Fig. 8, should be opened mechanically by turning knob D and the shutter in the film holder should also be opened as described for the short film holder. The shutter in a long film holder need never be closed unless records covering only a portion of the length of the film are desired. The auxiliary zero tracer should be adjusted before inserting the film holder in the oscillograph front plate.

This holder may be driven from the same motor as a short film holder except for drum speeds below 40 r.p.m. In this case it is advisable to use a speed reduction unit or a larger pulley.

While this holder may be loaded in daylight it must be unloaded in the dark room. The magazine is removed and the end of the paper is pulled out through the opening in the holder. When the film appears, an arrow should be marked on it pointing toward the end of the film. This indicates the sequence of events on the record. It is also advisable to place a number or other designating mark on the film before developing it.

CARE

DAMPING

In all oscillograph records and especially in recording rapid transients it is important that proper damping be used to give correct deflections. The best test for damping is to make and break a direct-current circuit one or more times during a revolution of the film drum and take an oscillogram of the current flowing, using deflections and film speeds at least as great as are to be used for the oscillogram of the transient.

If the damping is not great enough, the vibrator mirror will travel too far when the circuit is first closed or opened and then drop back to the steady value, producing what is called "over-shooting." On the other hand,

if the damping is too great, there will be a lag in the travel of this mirror in reaching a steady value, which rounds off the corners of the record. Correct damping should give practically square corners to the record in the above test.

Since the damping properties of any oil depend upon its viscosity and therefore upon its temperature, it is advisable to place a thermometer on the galvanometer with its bulb near the back of the cell and note the temperature at which the best results are obtained in the damping tests mentioned above. The best galvanometer temperature when using the damping liquid furnished will probably be found between 30 deg. and 35 deg. C. This temperature can usually be held very closely by regulating the time the excitation is kept on the galvanometer field. At ordinary room temperature, it will usually be found that if the excitation is kept on the galvanometer field for about half an hour before taking the first oscillogram and after that only while records are being taken, the galvanometer temperature will remain nearly constant. A thermometer may not be necessary for any tests except where the magnitude of a rapid variation is the important part of the record.

GROUNDING

Each element of the galvanometer is provided with a grounding post on the magnet core, MP, Fig. 3. A vibrator may be grounded by connecting the nearer of its terminals, VT, to its grounding post. Each vibrator which is connected to a circuit of 200 volts or over **must** be thus grounded.

When the potential between the vibrators is more than 1000 volts, keep the different pairs of vibrator leads within the case free from each other and from the galvanometer field and field connections.

The maximum permissible potential between vibrators is 2500 volts with each vibrator grounded to its magnet core.

CLEANING VIBRATOR CELLS

If the damping liquid in the cells becomes cloudy or dirty, empty and clean the cells thoroughly and refill with fresh damping liquid. After a vibrator has been burned out, examine the cell to see if pieces of the vibrator strip are left in the damping liquid. Such pieces should **never** be allowed to remain in the cells. These can often be fished from the cell with a fine wire without removing the cell from the galvanometer.

CLEANING OPTICAL SYSTEM

The whole optical system including all lenses, prisms and mirrors **must** be kept clean. Good photographic records can not be obtained unless this is done. If the damping liquid does not come above the top of the cell window, or if an air bubble is allowed to remain between the pole tips and cell window, indistinct and inaccurate records will be obtained.

OILING

Keep the following bearings well oiled with good light oil: bearing N_1, Fig. 16; the armature bearings of the synchronous motor; the cam shaft bearing at K_1, Fig. 14; the pivots of the synchronous mirror at L_1 and M_1. (This is most conveniently done by removing the tracing screen, opening the shutters under it by moving the handle L, Fig. 15, down to the tracing position and using a small wire to direct the drop of oil.) See that the cam surface C_1, Fig. 14, is kept lubricated with good vaseline.

SHIPPING

Never ship the oscillograph with the galvanometer in place. The vibrators should be removed and packed in the parts box, together with other small parts as indicated by the index on the inside of the cover. The damping liquid should be emptied and the galvanometer packed separately.

REPAIRS

MOUNTING SUSPENSION ON STANDARD VIBRATOR

Clean the vibrator thoroughly, using gasoline or benzol, and be sure there is no dirt in the slots of bridges B and B_1, Fig. 19. Retin

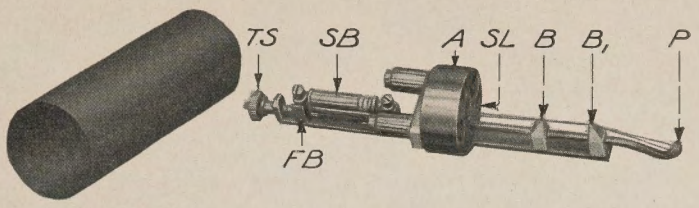


Fig. 19. Standard Vibrator and Shipping Case

the lips J and J_1, Fig. 20, if necessary, using the non-corrosive soldering flux furnished with the oscillograph, and making sure that no excess solder, short pieces of vibrator strip or dirt of any kind is short-circuiting the vibrator terminals at this point.

The block FB, Fig. 19, is then brought to its highest position by tension screw TS. The end of the suspension strip is soldered to the lip J, Fig. 20. The strip is then put in place in the slot SL, Fig. 19, and is carried **without twisting** over the bridges B and B_1, under and around the pulley P, to the right and alongside of the bridges B_1 and B, back through the slot SL and on the top of the lip J_1. The strip is then held by the thumb against the block A as shown in Fig. 20, while being soldered to the lip J_1. After soldering, the strip is raised into the slots on the bridges by means of a large needle or a toothpick. The strips should lie flat in the slots so as to come in the same plane when viewed edgewise between the bridges. The proper tension should now be applied by the tension screw TS (see paragraph 2 under "Inserting Vibrators," page 4).

MOUNTING SUSPENSION ON HIGH SENSITIVITY VIBRATOR

This vibrator has two copper leads from the binding posts to a terminal block just above the upper bridge. The pulley is mounted on a link. These modifications shorten the suspension and make its resistance almost as low as that of the standard vibrator. The suspension is mounted on this vibrator in a manner similar to that of the standard vibrator except that the suspension is soldered to the two copper leads at the terminal block.

CEMENTING MIRROR TO SUSPENSION

The mirrors are most easily handled with a small, sharp, wedge-pointed wooden tool,

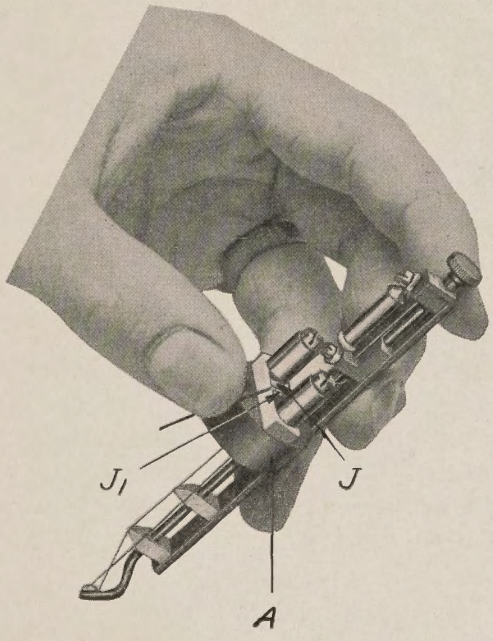


Fig. 20. Mounting Suspension on Standard Vibrator

which has been moistened. (This can be made from a match or toothpick.) Place a thin coating of the mirror cement furnished with the oscillograph on the suspension midway between the bridges and place the vibrator mirror VM, Fig. 4 (silver down), on the cement. Press the mirror down gently and evenly on the strips. The long edges of the mirror **must** be parallel with the outside of the strips in order to prevent the mirror from striking the pole tips when the vibrator is in place. Allow the cement to set in air at least 6 hours before using the vibrator. Any cement adhering to the face of the mirror should then be carefully removed with a sharp knife.

SUPPLIES

CARBONS

The horizontal (positive) carbons are ¼ in. by 8 in. solid. The vertical (negative) carbons are ¼ in. by 6 in. cored. Sold in lots of one or more dozen pairs.

DAMPING LIQUID

Furnished in 4 oz. bottle sufficient for one filling of the cells.

FILMS FOR SHORT FILM HOLDER

"Transparent Non-Curling Films for the Oscillograph, 3⅞ in. by 12¾ in." are furnished in lots of one or more dozen by the General Electric Company, Schenectady, N. Y., or they may be obtained in lots of six or more dozen from the Eastman Kodak Company, Rochester, N. Y.

Super-Speed films, known as "Eastman Portrait Films, 3⅞ in. by 12¾ in.," may be obtained in lots of one or more dozen from the General Electric Company, Schenectady, N. Y.

FILMS FOR LONG FILM HOLDER

Eastman No. 101 Film.
6-Exposure, about 2 ft. long.
12-Exposure, about 4 ft. long.
Eastman No. 122 Film.
6-Exposure, about 3 ft. long.
10-Exposure, about 5 ft. long.
Ansco No. 18-A Film.
6-Exposure, about 3 ft. long.
Ansco No. 18-B Film.
10-Exposure, about 5 ft. long.

Eastman films may be obtained at local Kodak agencies or in lots of one or more dozen from the General Electric Company, Schenectady, N. Y.

Ansco films may be obtained only from agencies handling this line of products.

MAZDA LAMPS

Suitable 6-volt, 108-watt Mazda Lamps for the Oscillograph may be obtained only from the General Electric Company, Schenectady, N. Y.

MIRRORS

For standard vibrators, Type V: 0.060 in. long; 0.017 in. wide; 0.006 in. thick.

For high sensitivity vibrators, Type SV: 0.030 in. long; 0.015 in wide; 0.006 in. thick.

Either size sold only in standard packages of one dozen mirrors.

MIRROR CEMENT

This is furnished in ¼ oz. bottles.

SOLDERING FLUX

This is a non-corrosive soldering flux and is furnished in ¾ oz. bottles.

SUSPENSION STRIPS

For standard vibrators, Type V (silver alloy), 0.007 in. by 0.00075 in.

For high sensitivity vibrators, Type SV (silver alloy), 0.006 in. by 0.00055 in.

Either size sold only in standard packages of one dozen strips.

ORDERS FOR SUPPLIES

Any supplies listed above may be obtained from the General Engineering Laboratory, General Electric Company, Schenectady, N. Y., marking order "Oscillograph Supplies."

SUMMARY OF DATA ON TYPE EM, FORM C, OSCILLOGRAPH

GALVANOMETER

Resistance of field—250 ohms approximately.

Field current—0.35 ampere.

Maximum permissible potential between vibrators is 2500 volts with each vibrator grounded to its magnet core.

STANDARD VIBRATOR, TYPE V

Normal tension—6 ounces, as indicated by the spring balance.

Allowable tension—4 to 10 ounces.

Suspension resistance (between terminals) —1.5 ohms approximately.

With 6 oz. tension on this vibrator, the sensitivity is approximately 0.005 ampere per millimeter deflection on the ground glass or film. The natural frequency, undamped, is approximately 5000 cycles per second.

HIGH SENSITIVITY VIBRATOR, TYPE SV

Normal tension—4 ounces, as indicated by the spring balance.

Allowable tension—2 to 6 ounces.

Suspension resistance (between terminals) —1.5 ohms approximately.

With 4 oz. tension on this vibrator, the sensitivity is approximately 0.0015 ampere per millimeter deflection on the ground glass or film. The natural frequency, undamped, is approximately 3000 cycles per second.

SYNCHRONOUS MOTOR

Voltage—100 to 125 a-c. with rheostat in series.

The average starting current at 25 or 60 cycles is 1.5 to 2.5 amperes and the running current from 1.5 to 2.0 amperes.

ARC LAMP

Operated from 100-125 volt d-c. source.

Normal current 6 amperes.

Current for high-speed work 6 to 8 amperes.

MAZDA LAMP

Operated from 110 or 220 volts a-c. stepped down to 6 volts or from 6-volt battery.

Normal current 18 amperes.

Current for high-speed work not over 20 amperes momentarily.

ELECTROMAGNETIC SHUTTER

Operated from the same d-c. source as arc lamp.

GENERAL ELECTRIC COMPANY

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May, 1927 (2m)

INSTRUCTIONS GEI-4663

PORTABLE OSCILLOGRAPH

TYPE PM-12-A1

GENERAL ELECTRIC COMPANY

SCHENECTADY, N. Y.

June, 1930 (200)

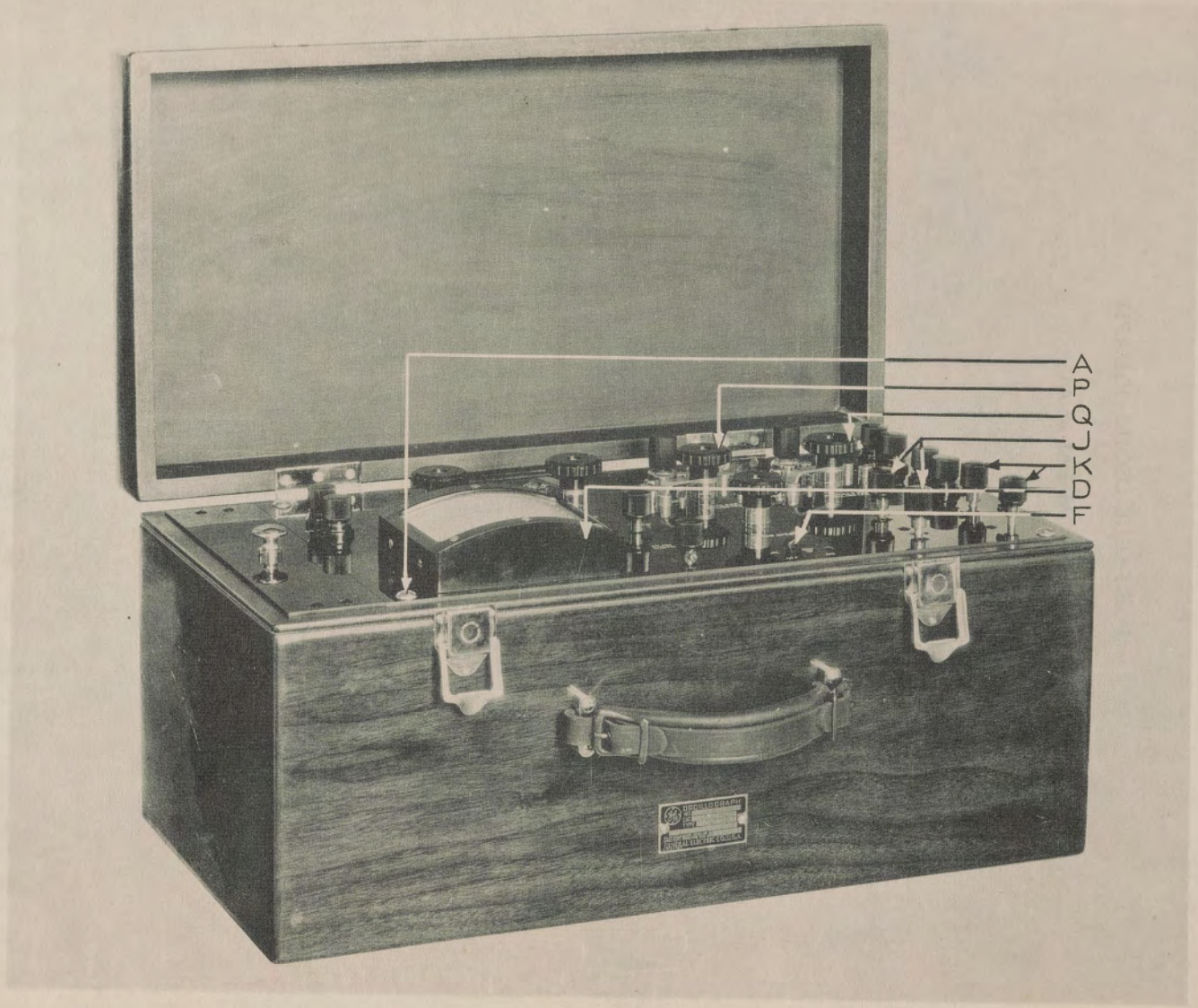


Fig. 1. Type PM-12-A1 Oscillograph

PORTABLE OSCILLOGRAPH
TYPE PM-12-A1

The following are included as standard equipment with the Type PM-12-A1 oscillograph:

2 galvanometers
1 spare lamp
1 film holder
1 Eastman No. 120 roll film
1 folding viewing hood
1 bottle of damping liquid
1 box of vibrator suspension strips
1 box of vibrator mirrors
1 bottle of mirror cement
1 bottle of soldering flux
1 box of six galvanometer fuses

The two galvanometers are shipped in their mountings ready for use as in Fig. 2. They are completely assembled and filled with damping liquid. When a spare galvanometer is furnished, this will be found in a storage compartment within the case. The spare lamp is also mounted in a socket on the bottom of the case. The film holder is shipped in its compartment at the left end of the oscillograph panel.

PRELIMINARY INSPECTION AND ADJUSTMENTS

After unpacking the oscillograph, carefully brush away any dust that may have accumulated on the case and panel during shipment. All adjustments have been made at the factory and it should be possible, if the oscillograph has not been damaged in shipment, to use it immediately as instructed under "Operation" on page 5. It may be advisable, however, before operating it, to remove it from its case for inspection, for cleaning the optical system and for oiling the bearings. To do this, place the oscillograph on a table and remove the cover; the hinges can be slipped apart for this purpose by pushing the cover to the left after it has been raised. Remove the four round-headed screws A, Fig. 1, at the corners of the panel, and lift the panel from the case by grasping the binding posts at each end. Set the panel on the table in the position shown in Fig. 2. Each galvanometer is clamped in its mounting by means of a knurled screw B. These screws should be kept tight at all times. See that the leads are fastened securely to the binding posts on the back of the galvanometers. With a clean soft cloth, polish the front of the lenses in the galvanometers and be careful not to touch them with the fingers thereafter. With a piece of cotton or cloth, polish both sides of the cylindrical lens C. This can best be accomplished by means of a swab formed by wrapping the cloth or cotton around the end of a lead pencil. Now remove the viewing screen D from its place on the panel by pulling upward, and carefully polish the surface of the oscillating mirror, E. If oil has accumulated on the mirror, it should be cleaned off with a cotton swab moistened with carbon tetrachloride or carbona, and polished afterward. Use extreme care in cleaning this mirror to touch it lightly, as it is made of very thin material.

Before placing the oscillograph back in its case, it will be well to adjust the positions of the galvanometers and to check the adjustments of the optical system. To do this, connect the terminals marked 110 volts a-c. to any 110 volt alternating-current lighting circuit, and throw the switch F, to the ON position. Turn the knob marked MOTOR SPEED to the extreme left to prevent the motor from running and move the switch marked LAMP to the position marked 1. The lamp should now burn. Turn the shutter control knob first to the SET and then to the OPEN position, and rotate the disc shutter G, Fig. 8, by hand until a beam of light shines out from the end of the prism housing H, Fig. 2. Open each aperture as wide as possible by turning

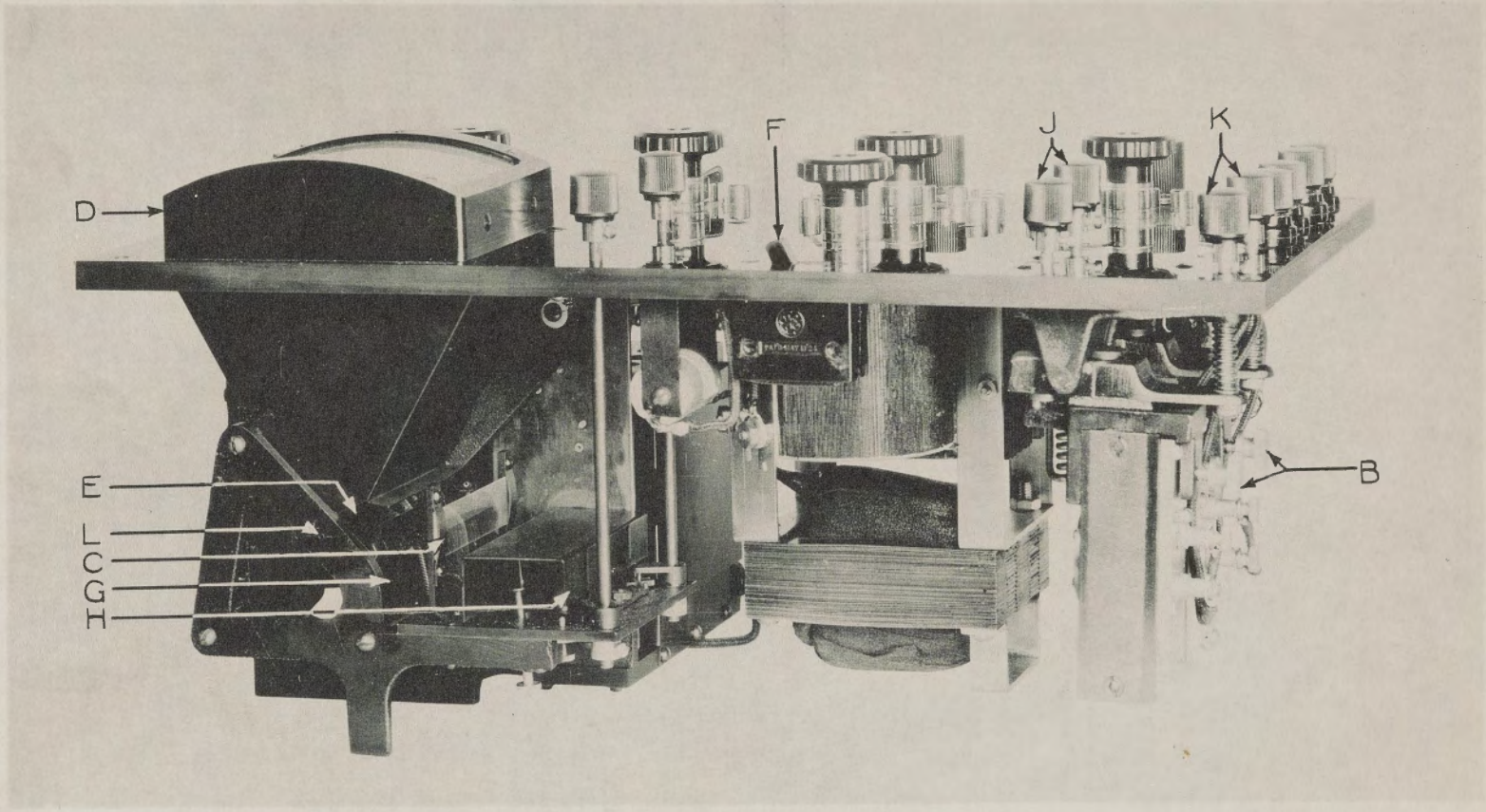


Fig. 2. Type PM-12-A1 Oscillograph
Removed From Its Case

the knobs marked BEAM WIDTH to the extreme left. A brilliant image of the lamp filament will now appear on the front of each galvanometer if the prisms are properly adjusted. These images should be located so that the small mirror in each galvanometer is approximately in the center of the spot of light. If the light spots do not fall on the mirrors, the prisms must be adjusted according to the instructions under the heading "Prism Adjustment" on page 9.

If the prisms are in proper adjustment, each galvanometer mirror will reflect a small beam of light, and each galvanometer should be moved in its mounting by means of the knobs J and K, Fig. 2, until these beams fall approximately through the center of the cylindrical lens C. Each galvanometer lens will also reflect a beam of light that should not be confused with the beam from the mirror. The beam from the mirror is narrow and elongated, and is an image of the aperture, while the beam from the lens surface is circular in shape. The lens has been tilted properly in its mounting so that these two beams will not coincide. The beams may be easily located if the adjustments are made in a room that is somewhat darkened.

When the beams from the galvanometer mirrors are adjusted to fall upon the center of the cylindrical lens C, two brilliant spots of light will appear on the viewing screen. These should be narrowed down to small spots by turning the BEAM WIDTH controls on the panel. These are the spots that trace the curves, and they may be moved at will from the top of the screen to the bottom by turning the knobs "J", or along the screen from left to right by turning the shutter disc G, Fig. 8. Now start the motor by turning the knob marked MOTOR SPEED to the extreme right, and after it has started, turn the knob again toward the left to prevent it from running too fast. Each spot of light should now trace a narrow but brilliant line across the screen from left to right, and the lines should extend completely to the ends of the screen.

The oscillograph should now be ready for operation, but before placing it back in the case, the moving parts should be oiled with a good grade of light machine oil. The oil can best be applied with a piece of wire that has been flattened on one end, and the places that should be oiled are the following:

(1) One bearing at each end of vibrating mirror shaft; one of these is shown at L, Fig. 2.

(2) Three bearings in the link mechanism that transmits motion from the cam to the vibrating mirror.

(3) The oiler that provides lubricant for the cam. This oiler is shown clearly at M in Fig. 5. Several drops of a heavy oil should occasionally be placed in the small cup N. Vaseline is especially recommended for this purpose, and it can be introduced into the cup without removing the motor unit by melting it and dropping it in with the flattened wire. Each time this cup is filled, the adjustment of the oiler should be checked according to instructions under the heading "Periodical Oiling" on page 11.

Now carefully place the oscillograph back in the case and fasten it down with the four round-headed screws.

OPERATION

All that it is now necessary to do to place the oscillograph in operation is to connect the binding posts marked 110 VOLTS, A. C. to any 110-volt alternating-current lighting circuit and the voltage and current whose wave-shapes are to be observed to the binding posts marked POTENTIAL GALV. and CURRENT GALV., respectively, but before doing this, be sure that



Fig. 3. Type PM-12-A1 Oscillograph
With Film Holder in Place

switch F, Fig. 1, is off and that the galvanometer rheostats P and Q are each on the OFF button.

The voltage applied to the POTENTIAL GALV. terminals should not exceed 220 volts, and the current through the CURRENT GALV. terminals should not exceed 7 amperes, both of the above being root-mean-square or effective values. Now be sure that the shutter is open by turning the knob marked SHUTTER to SET and then to OPEN. Then turn knob marked LAMP to position 1, throw the switch to ON, and bring the motor to speed by turning the knob MOTOR SPEED to the extreme right. After the motor has started, turn the knob about one-half revolution back to the left to prevent the motor from running too fast. By means of knobs J, Fig. 1, move the zero lines on the viewing screen to the position desired. It is usually best to place them both in coincidence with the black line across the screen so that it can serve as an X-axis. Now close the galvanometer circuits and adjust the amplitude of the waves to their desired values by means of the galvanometer rheostat knobs P and Q and adjust the motor speed until the waves on the screen are stationary. The number of complete cycles visible depends on the speed of the motor and is, therefore, under the operator's control, although it is usually best on 60-cycle circuits to run the motor at a speed that produces a curve a little over one cycle in length. This corresponds to a motor speed of 1800 revolutions per minute, and it is not advisable to run it faster than this, although it may be used at slower speeds if desired.

After the waves have been made stationary, adjust knobs K, Fig. 1, until they are of maximum brilliancy. It should not be necessary to move these adjustments again unless the galvanometers are moved or changed in their mountings.

The positive direction of the time axis on the screen is from left to right so that if the two galvanometers are connected in their circuits correctly, the two waves will appear on the screen in their proper phase relation to each other. If, however, one is reversed with respect to the other, the angle between the two waves will be the correct angle plus or minus 180 degrees. If it is known that the phase angle is less than ninety degrees, as is usually the case, there can be no danger of an erroneous result in its determination due to a reversed connection, as this will make the angle appear greater than ninety degrees. If, however, nothing is known in regard to the phase relation, care must be taken to see that the galvanometers are connected correctly in their circuits. The instantaneous relative polarity of the terminals in this case should be determined by connecting the galvanometers in series in such a way that the two waves on the screen coincide. The two terminals that are tied together in the series connection will then be of opposite instantaneous polarity.

The waves as seen on the screen may easily be photographed at any time for preservation or analysis with the film holder that is found in the compartment to the left of the panel. The film holder should be loaded with standard 2 1/4 in. by 3 1/4 in. non-autographic roll film in the same manner as an ordinary camera. Be sure, however, that the film passes under the small rolls at the ends of the transparent cylindrical surface. After the end of the paper has been started on the re-winding spool, replace the cover, make sure that the slide is completely closed, wind the film through until the figure 1 is directly below the red window, and place the film holder over the opening in the panel in place of the viewing screen as shown in Fig. 3. Then turn the shutter knob to CLOSE, and move the LAMP switch to position 2, increasing the brilliancy of the lamp. Press the film holder down on the panel, withdraw the slide as far as possible, and move the shutter knob to the position EXP. Release it after holding it in this position for a moment, close the slide in the film holder, and move the LAMP switch back to position 1. To open the shutter again for visual use, move the SHUTTER knob again to SET and then back to OPEN. It is not necessary for the curves on the screen to be stationary when a

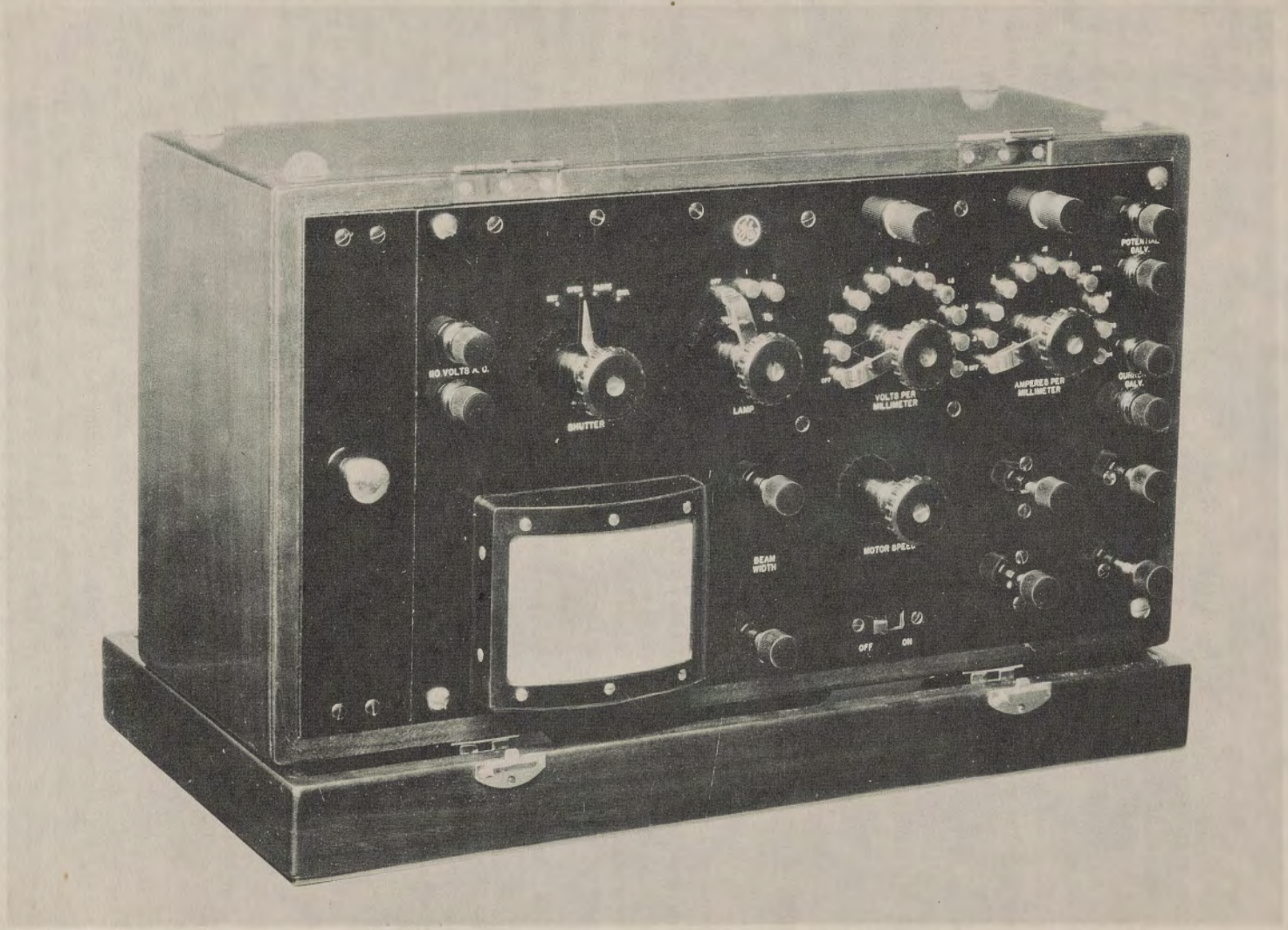


Fig. 4. Type PM-12-A1 Oscillograph in Vertical Position For Lecture Room Demonstration

photograph is taken because the shutter is automatically controlled by the vibrating mirror mechanism in such a way as to permit the beams of light to trace the curves on the film surface only once.

Since the oscillograph will operate in any position, it may be placed with the panel in a vertical position as shown in Fig. 4, and if the room is sufficiently darkened, the waves can then be seen by a large audience. If it is necessary to operate the oscillograph in a very light room, the screen should be shielded with the folding viewing hood that is supplied.

THE OPTICAL SYSTEM

The optical system has been adjusted at the factory and should require no further adjustments than can be made with the panel controls if the oscillograph is handled with reasonable care. However, if the waves as traced on the screen become of less brilliancy or sharpness than normal, the optical system should be checked according to the instructions under "Preliminary Inspection and Adjustments" on page 3.

If the light beams on the galvanometers are not symmetrically located with respect to the galvanometer mirrors when the apertures are wide open, the prisms should be adjusted until this condition is obtained.

PRISM ADJUSTMENT

Each prism is supported by a ball that is clamped in a socket on the under side of the prism housing. Each ball is clamped firmly in place by three screws R, Fig. 6, which surround it and the adjustment handle S.

If it is necessary to adjust the position of a prism, loosen very slightly each of the three clamping screws and carefully move the prism by means of the handle S until the beam is centered on the galvanometer mirror. Now tighten the three screws again, thus clamping the prism in its new position.

If one beam appears to be more intense than the other, it may be that one of the prisms is not properly located in the light beam from the lamp housing, or that one prism is casting a shadow on the other. This may be corrected by loosening the screws T and sliding each prism mounting until an intense beam is thrown on each galvanometer.

LAMP

The oscillograph is designed to use a 32-candle-power automobile headlight lamp with the standard single-contact bayonet base. A 21-candle-power lamp may be used if desired in an emergency, although the curves produced will not be so brilliant.

The lamp can be replaced after removing the two knurled screws U, Fig. 8, and taking off the cover to the lamp housing.

CLEANING THE OPTICAL SYSTEM

The whole optical system, including all lenses, prisms and mirrors must be kept clean. Brilliant lines and good photographic records cannot be obtained unless this is done. The galvano-

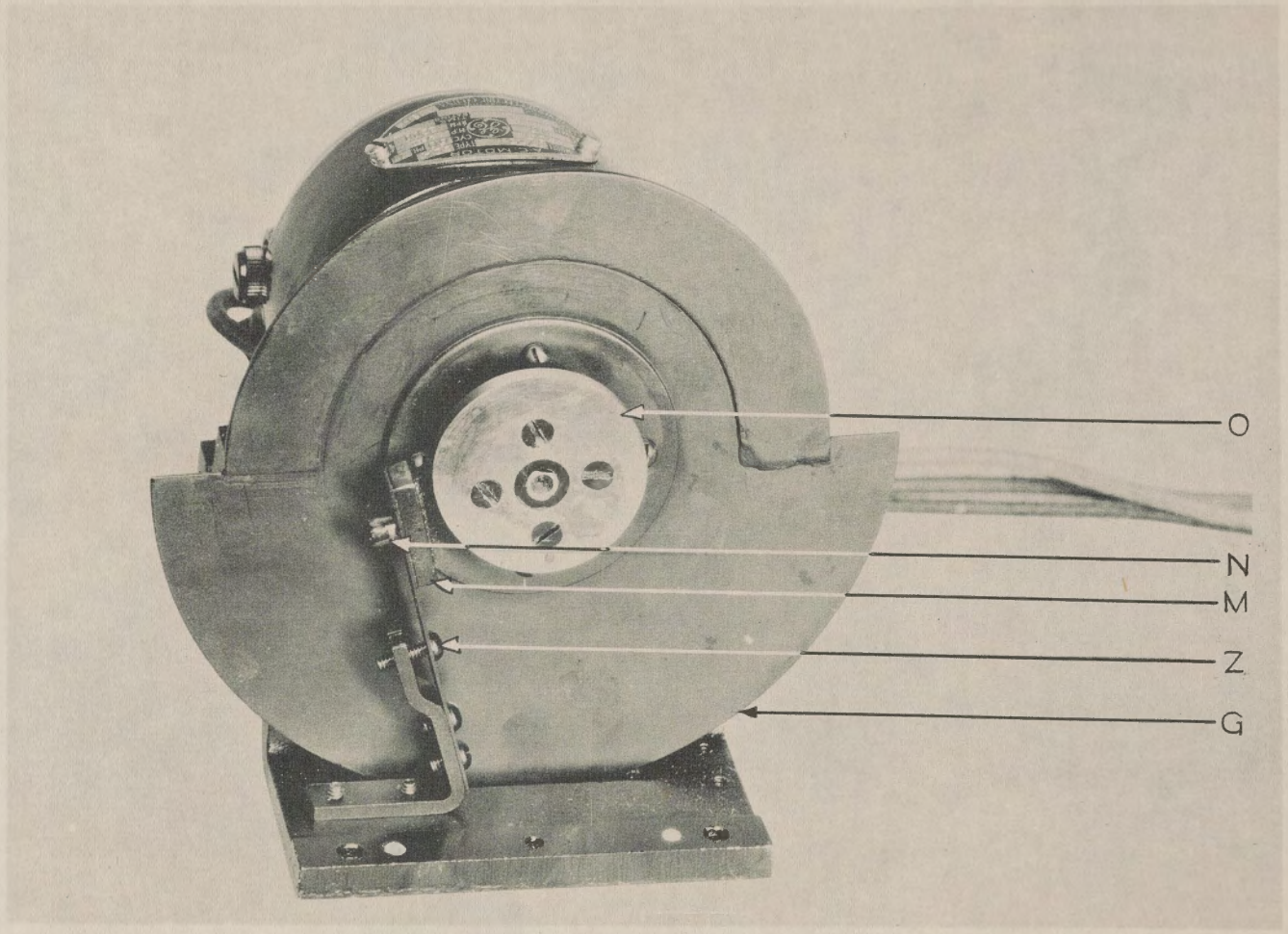


Fig. 5. Type PM-12-A1 Motor Unit, Showing Disc Shutter, Cam and Cam Oiler

meter lenses, the cylindrical lens, and the vibrating mirror should occasionally be polished according to the instructions under "Preliminary Inspection and Adjustment". The prisms should also be cleaned occasionally. This can best be done by taking out the two screws T, Fig. 6, and removing the entire prism and its mounting. Then carefully clean the prism with a piece of cotton moistened with carbon tetrachloride, carbona or gasoline, taking care not to loosen it from its mounting. It will, of course, be necessary to adjust it again after putting it back in place.

THE GALVANOMETERS

The galvanometers are very rugged and will easily withstand all jars incident to any reasonably careful use of the oscillograph. They have been adjusted, filled with damping liquid, and sealed at the factory, and should require no more attention whatever except in the case of accidental injury. If a galvanometer becomes damaged, it may either be returned to the General Electric Company, Schenectady, New York for repair and adjustment, or it may be repaired by the operator according to the following instructions:

REPAIRING A DAMAGED SUSPENSION

The only part of an oscillograph galvanometer that is likely to become damaged by ill treatment is the suspension or moving element, which consists of a loop of fine metallic ribbons stretched tightly between two ivory bridges, and with a small mirror cemented to the loop midway between the bridges.

To replace a damaged suspension, lay the galvanometer with its lens downward on a table and remove the eight screws on the back. Then remove the back plate by pulling straight upward on the binding posts. If the plate sticks, it may be loosened by inserting the point of a small screw driver in the recess at each end and prying upward.

After removing the back plate and the vibrator element that is attached to it, transfer the damping liquid to a clean receptacle and carefully examine both it and the interior of the galvanometer cell for pieces of the old suspension. If the damping liquid is clean and all pieces of the old suspension are removed, it may be used again, but if it appears dirty, new liquid should be used.

Now clean the vibrator element in carbon tetrachloride, carbona or gasoline and lay it on the table in front of you across two blocks of wood or other supports with the binding post downward, or clamp the element lightly in a small vise. Solder one end of a suspension strip that is supplied with the oscillograph to the lower pin V, Fig. 7, using a small, clean, sharp-pointed soldering iron and the special flux supplied for the purpose. With the pulley toward you, lay the strip flat in the left slot in each of the two bridge supports. Pass it under and around the pulley without twisting it, and then back through the slots in the right of the bridges. Pull the strip until the lever carrying the pulley is exactly vertical, and then solder it to pin W. Cut off the excess strip. Apply a little mirror cement to the strips exactly midway between the bridges, and place one of the mirrors on the cement with its reflecting side upward. The mirror can best be handled by sticking it to the end of a moistened toothpick. Press the mirror down gently and evenly with the end of a toothpick, being careful to keep the mirror centrally located on the strips and with its long edges parallel to them. Then with the toothpick apply a little more cement to the back of the suspension strips below the mirror, and place the vibrator element in a place where it will not collect dust for four or five hours before placing it back in the damping liquid. If it is necessary to use the galvanometer immediately, the cement can be dried rapidly

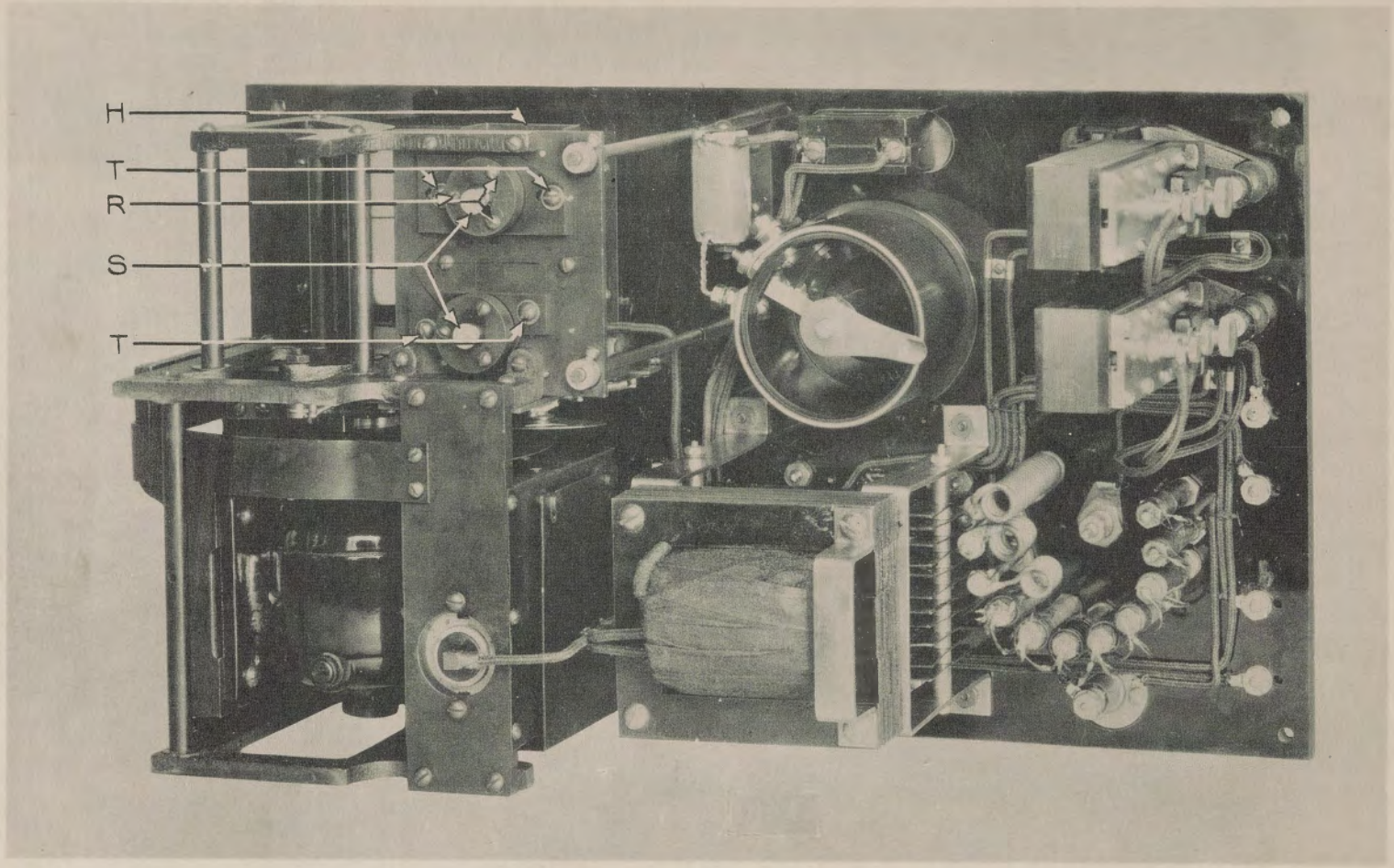


Fig. 6. Type PM-12-A1 Oscillograph Showing Lower Side of Panel

by holding a warm iron near the mirror but without touching it.

Before placing the vibrator back in the cell, the cavity should be filled with damping liquid again to about one-quarter inch below the outside surface. The vibrator element can be replaced in only one position because one dowel pin is larger than the other. Be sure to tighten the screws equally. Use a small screw-driver and do not tighten them too much. The gasket has been impregnated with a wax that makes it unnecessary to tighten the screws a great deal to prevent leakage of oil.

CALIBRATION OF GALVANOMETERS

After a galvanometer has been restrung, it is necessary to adjust its sensitivity again to the standard value if the calibration on the current and potential galvanometer rheostats is to be used without a correction factor, although if the suspension is mounted so that the pulley lever X, Fig. 7, is vertical and if the tension nut Y is not moved, the calibration will be approximately correct.

The calibration of the potential galvanometer can be checked by applying a known d-c. voltage to the potential galvanometer terminals, and comparing the deflections on the screen with the quotient obtained by dividing the applied voltage by the volts-per-millimeter factor indicated by the galvanometer rheostat. The calibration of the current galvanometer can be checked in a similar way with a known direct current through the current galvanometer circuit.

The deflection of either galvanometer may be increased or decreased by loosening or tightening, respectively, the knurled tension nut Y, Fig. 7. When the galvanometers are adjusted to standard sensitivity, a current of 60 milliamperes will produce a 30-millimeter deflection on the screen, and the suspension then has a natural frequency of about 3000 cycles per second.

FUSES

The fuses in the galvanometer circuits will effectively protect the galvanometers from damage due to the accidental application of excessive current. For this reason, it is very improbable that it will ever be necessary to repair a galvanometer suspension.

The fuses are located in holders on the panel directly above the galvanometer rheostats in Fig. 4. They may be removed by unscrewing the insulated caps which cover them. These caps should not be screwed down tighter than necessary to hold the fuses firmly in place. No fuses should be used in these holders except those supplied for the purpose.

PERIODICAL OILING

The two vibrating mirror bearings and the three bearings of link mechanism that transmits motion from the cam on the motor shaft to the vibrating mirror should be oiled frequently with a good light machine oil. The oil can be easily applied to the bearings with a small wire flattened at one end as explained in "Preliminary Inspection and Adjustments", page 3.

The cam surface is continuously lubricated by means of the oiling pad shown at M in Fig. 5. Once in each revolution, the high point of the cam touches this pad and collects a small quantity of oil. The cup N, should be occasionally filled with vaseline. This can be done easily without removing the motor, by melting the vaseline and dropping it in the cup with the flattened wire.

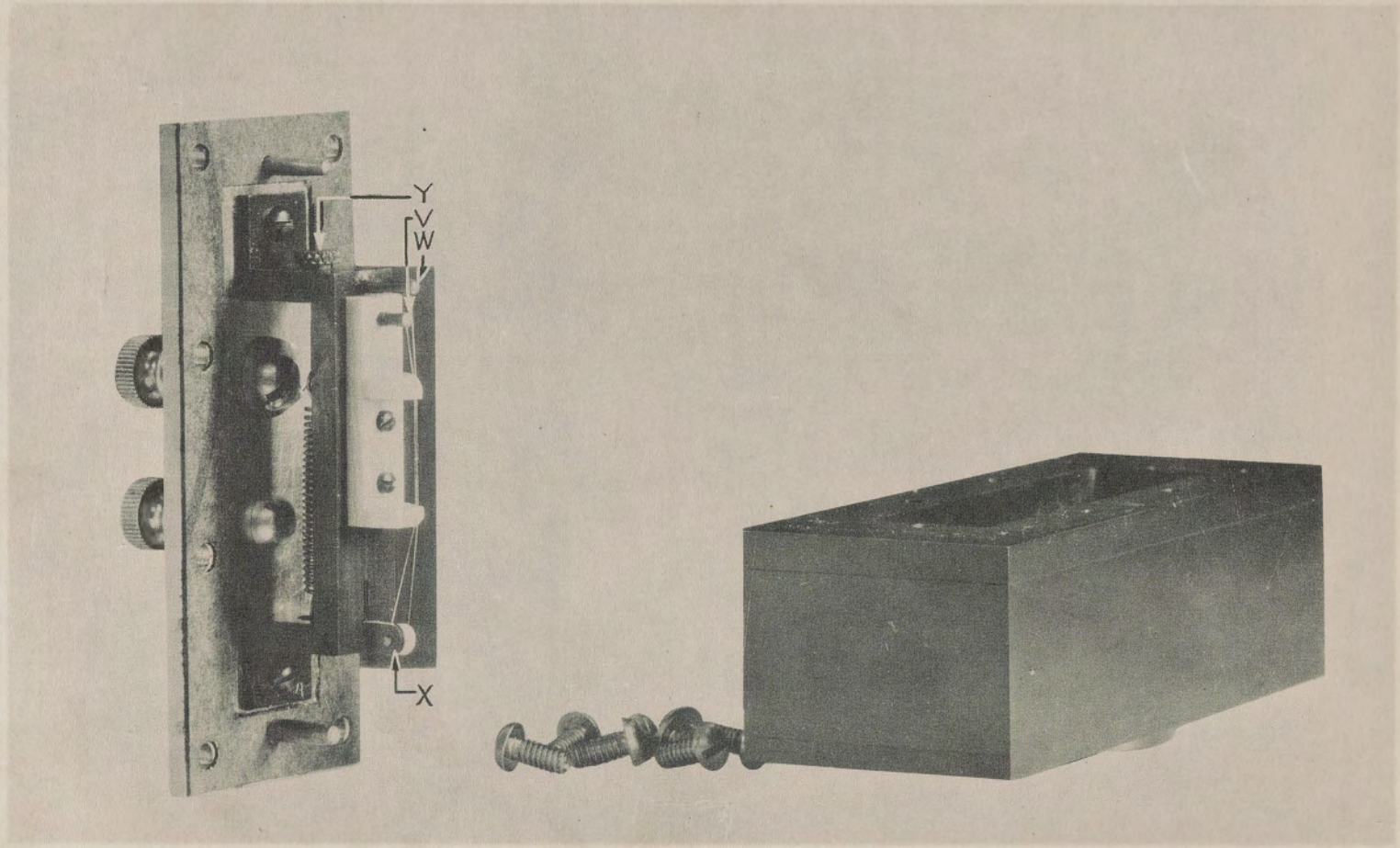


Fig. 7. Vibrator for Type PM-12-A1 Oscillograph Removed from Cell Box

The screw Z, Fig. 5, is for the purpose of adjusting the position of the oiling pad J with respect to the cam O. This adjustment should be checked occasionally, as the pad surface may in time wear away. The pad should be adjusted so that it is lightly touched by the high point of the cam. Note that the adjusting screw Z can be reached with a screw-driver without removing the motor unit.

The motor bearings should be oiled occasionally but it is not necessary to do this as frequently as the above. An oil hole is provided in each bearing, and these can be reached with the flattened wire if the oscillograph is removed from its case and placed on end with the motor downward. A small oil can with a long spout may also be used for this purpose.

SUPPLIES

Unless otherwise specified the following supplies must be obtained from the General Engineering Laboratory, General Electric Company, Schenectady, New York, by marking the order "Oscillograph Supplies".

LAMP

Mazda No. 1133, 32 cp., 6 to 8 volts, single-contact bayonet base automobile headlight lamp. This lamp may also be obtained from local dealers in automobile supplies.

FILM

Either Eastman No. 120 non-autographic six-exposure roll film, or Agfa-Ansco No. B-2 roll film may be used. These should be obtained from local dealers in photographic supplies.

FUSES

Specify Cat. No. GE2547 one half ampere fuses. These are furnished in boxes of six each.

DAMPING LIQUID

This is furnished in two-ounce bottles. Two ounces is sufficient for filling four galvanometers.

SUSPENSION STRIPS

In ordering suspension strips, specify that they are to be used in Cat. No. 3859770G3 galvanometers. These are furnished in standard packages of one dozen each.

MIRRORS

In ordering mirrors, specify that they are to be used in Cat. No. 3859770G3 galvanometers. These are furnished in standard packages of one dozen each.

MIRROR CEMENT

Specify mirror cement for oscillograph galvanometers. This is furnished in 1/8—oz. bottles.

SOLDERING FLUX

Specify soldering flux for oscillograph galvanometers. This is furnished in 1/2—oz. bottles.

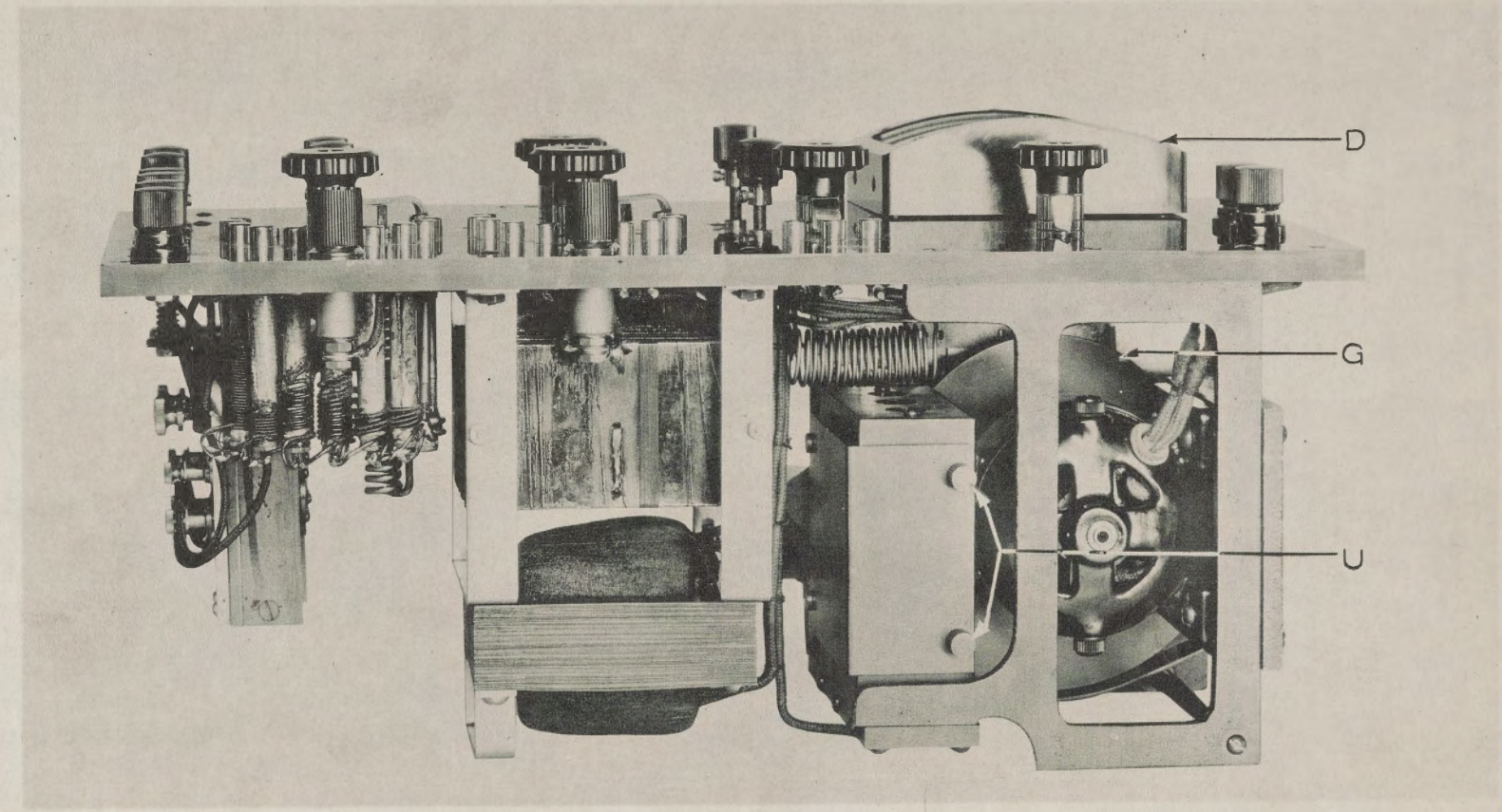


Fig. 8. Type PM-12-A1 Oscillograph Removed From Its Case

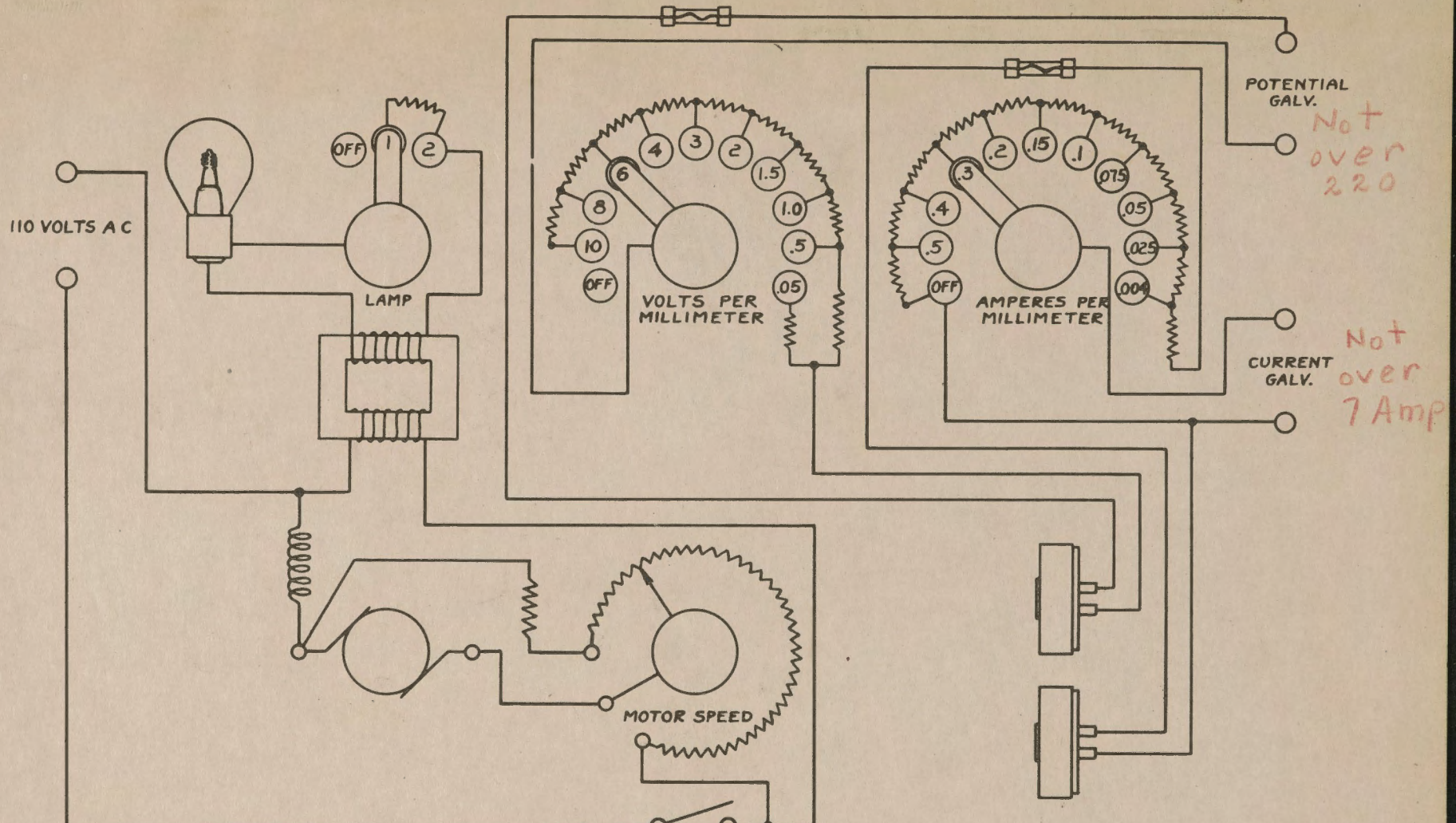


Fig. 9. Circuit Diagram of Type PM-12-A1 Oscillograph

APPROVAL.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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