DESIGN AND CONSTRUCTION

OF

A MECHANICAL OSCILLOSCOPE

BY

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A Thesis Submitted to the Graduate Committee
For the Degree of

MASTER OF SCIENCE

in

Electrical Engineering

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Virginia Polytechnic Institute
1936

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PLATES- CHARTS

I
INTRODUCTION

A complete analysis of many of the complex problems which harass the brains and tax the ingenuity of engineers and scientists of this machine age would be almost impossible if not very difficult without a method of dissecting the phenomena which take place.

Most or nearly all physical phenomena may be resolved into two elements or directions, one of these being proportional to elapsed time and the other proportional to the amplitude of the change under observation with respect to an arbitrary line taken as zero. When these two changes are combined into one the result is usually what may be aptly compared to the cross section of an ocean wave. The height of the wave being comparable to the amplitude and the distance from crest to crest being comparable to the wave length.

The oscillograph and the oscilloscope are assuming more and more this burden of analysing transient and recurrent actions. The oscillograph leaves a permanent record of the changes taking place while the oscilloscope enables the phenomenon to be observed directly.

Oscillo is derived from the Latin meaning to swing back and forth and graph and scope freely translated mean write and see.

The difficulty of showing this action in a portable device which needed little or no adjusting was the incentive for undertaking the building a mechanical oscilloscope.

The author wishes to express his sincere appreciation of the aid and assistance given by the members of the teaching staff in the Department of Physics Their helpful criticism has aided greatly in shaping this work.

II
HISTORY

The recording on paper of the tracings made by a point driven by a moving mechanism was probably the first form of the oscillograph. James Watt used this method of recording what took place in the cylinder of his steam engine in 1786. This indicator as devised by Watt is essentially the indicator card of today. The next major step in the development of the oscillograph was made by William Thomson (Lord Kelvin)[1] in 1867 when his siphon recorder was introduced in order to make efficient use of the first successful transatlantic cables. The first recorded adaptation of the oscillograph from the mechanical to the electrical was made by William Duddell.[2] The oscillating mirror as developed by Duddell was essentially the string oscillograph as we have it today. This development was in 1893.

Blondel[3] brought out in 1891 a moving coil galvanometer which he adapted to drive a mirror in an oscilloscope with mediocre success. The limiting factor in Blondel's galvanometer was the mass of the moving coil.

A hot wire type of oscillograph was brought out in 1907 but was never widely used because of the fact it was practically useless at frequencies above five cycles per second.

From the time William Duddell introduced his oscillating mirror the development of the oscillograph has been one of constant improvement and no one specific change can be pointed out and called the most significant advance. The developments most pertinent in the light of this investigation will be discussed in detail and are not included in the history of this subject.

III
REVIEW OF LITERATURE

One of the most logical ways for presenting literature on any subject is that of time sequence or chronologically. This method of presentation gives the reader an orderly step by step analysis.

James Watt might be called the father of the oscillograph and his application of graphical representation of what took place in his steam cylinders was of secondary importance only to his steam engine.

Lord Kelvin, with his siphon recorder, placed another stepping stone in the development of the oscillograph.

The contribution of William Duddell overshadows all improvements thus far as his ingenuity placed the oscillograph in its modern form.

Many articles were found which dealt with this and related subjects but only those which follow this development work will be reviewed in detail.

Oplinger[5] is probably the first to successfully adapt the galvanometer to be used in an oscilloscope. The difficulty as pointed out by Oplinger has been the resonant frequency of the armature falling within the range of the frequencies to be observed. This trouble was eliminated by damping the armature until its natural frequency falls above the range to be observed. This adaptation allowed the mirror size to be increased about six times the usual mirror size. The intensity of the illumination increases as the product of the dimensions of the mirror therefore this increase in mirror size allowed a corresponding decrease in the require intensity of the light source. A Thirty-two candle power automobile head light lamp was substituted for the arc lamp. The moving element in this oscillograph was made from a steel strip with the mirror mounted on one end and supported at the other.

A polar oscillograph has been built by Marrison[6] and its outstanding feature is the method used for driving the oscillating mirror. The mirror is pivoted centrally along one axis and a permanent magnet type of loud speaker was placed so that its driving pin and the free edge of the mirror were in line. A flexible coupling between this driving pin and the mirror allowed it to vibrate freely. The mirror was one-half inch in diameter, being relatively large for an oscillograph. The large size of the mirror made possible the use of a flashlight lamp as the light source. A photographic film was so placed and driven by clockwork or by motor that upon applying a transient or by manual control, the oscillograph,the instant a transient was applied was placed in operation automatically. This gave a circular or polar form to the transient or recurrent phenomena taking place. An illuminating arrangement caused the face of a clock to be photographed at the instant the oscillograph was placed in operation thus giving the time of the transient.

The apparatus used at the last Worlds Fair was described by Mallina[7] and differs from all the different types discussed. This oscilloscope used no lens but the vibrating mirror was parabolic; the light source at one focal point and the screen at the other. A small incandescent lamp was used as the light source. A rotating mirror of many faces was used; so spaced that the light spot was leaving the screen at one end when another appeared at the other end. The vibrator was of the electro-dynamic type.

One of the more interesting types of oscillograph is the on built by Legg.[8] Previously only one pattern could be shown with one vibrating mirror but the oscillograph to be described here can show two waves simultaneously. A switching device shifts the vibrating mirror from one source of excitation to another in the interval from the disappearance of the spot of light from one end of the screen and its reappearance atthe other end. The mirror driv-element is of the string oscillograph type. With this switching arrangement several interesting connections are possible. The power factor in alternating current circuits may be shown by having one pattern showing the voltage wave and the other pattern showing the current drawn by an inductive device such as in induction motor. Alternating currents before and after rectification may be shown very easily by the correct connection . An interesting possibility is a circuit by which an oscillating discharge with a 60 cycle timing wave showing simultaneously may be obtained. Figure I on the plate with four diagrams of different circuits shows a simple connection for showing the current drawn by in induction motor. Figure II gives the connection for showing an alternating current wave and the same wave when half rectified. Figure III illustrates the connections for showing an oscillatory discharge and a timing wave simultaneously. The last figure shows the connections for showing the lag of the current behind the voltage in an induction motor or the power factor angle. Figures two three and four may only be used by the addition of a simply commutating device to the rotating mirror as will be explained in more detail. If the source of excitation is shifted from one place to another while the screen is dark the eye will see,due to the persistence of vision,two waves each from a different source. The mirror speed might have to be increased to give continuoss wave form.

IV
THE INVESTIGATION

The Object of Investigation

The purpose of this investigation was to develop a portable or semi portable oscilloscope with a light source needing no adjusting and giving sufficient illumination to enable the observer to see clearly the changes taking place on the screen. The brilliancy of the image must be so that the wave pattern may be analysed in detail and also that waves of different frequencies may be caused to stand stationary on the screen. This oscilloscope must include an amplifier so that minute currents may be amplified enough to actuate the vibrating mechanism.

METHOD OF PROCEDURE

The most difficult problem of the investigation was attacked first. The light source must be so that it will require little or no adjusting and this narrowed the field down to an incandescent lamp with a concentrated filament. An automobile headlight filament is concentrated and gives the required brilliancy and a 21 candle-power lamp was selected.

The optical system was devised so that the light from the lamp passed thru a pin hole immediately in front of the lamp and passed thru a long tube which prevented any extraneous light from falling on thr screen and then struck the vibrating mirror which was placed just beyond the end of the tube. After leaving the vibrating mirror the light passed thru a condensing lens which focused an image of the pinhole on the screen. The size of the light spot on the screen was approximately equal to the ratio of the distances from the screen to the lens and from the pin hole to the lens times the area of the pin hole.

The illumination obtained on the screen is proportional to the product of the dimensions of the mirror when this optical system is used and this fact led to its adaptation to this oscilloscope. The light spot size is independant of the mirror size and the intensity of the spot is directly proportional to the mirror size thus the only limiting factor in the mirror size is apparently the power necessary to drive it. A dynamic type of loud speaker was available for this use. A mirror about one-half centimeter was made from a very thin labratory cover glass. The silvering of this cover glass was done by the Rochelle Saits method.(See any handbook on chemistry) Several sizes of mirrors were tried to see which gave the best results before the size mentioned was adopted.

The dynamic speaker had been used to drive an eight inch cone in air so the power available was considerable. The cone was removed as was all the cone mountings which consisted of one metal ring about nine inches in diameter. A thin strip of phosphor bronze spring obtained from an automobile speedometer was stretched across the face of the speaker and about one half an inch from the driving coil. The mirror was mounted on this strip and connected to the driving coil by means of a lever arm arrangement. Thus any movement of the driving coil caused the mirror to vibrate about an axis which coincided with the lenial axis of the phosphor bronze strip.

Considerable difficulty was encountered in obtaining or devising a satisfactory method of driving the oscillating mirror as the high rate of flexing quickly caused failure of the phosphor bronze driving strip first tried. Several expedients were tried with no success until a leather drive was tried. This driving method gave promise of doing the work satisfactorily.

Considerable amplitude of the spot on the screen was found to be due to the direct current ripple in the rectified alternating current used in the speaker field. A coil was wound on the field magnet core and so connected in series with the driving coil as to reduce this residual amplitude to zero.

The apparatus required an audio-frequency amplifier which was constructed with a standard amplifier circuit which may be found in any text or handbook dealing with radio. A complete diagrammatic sketch of the oscilloscope including the amplifier will be found listed under table of contents. The connections to the moving coil were brought out to a suitable switching arrangement so that other phenomena than those necessitating amplification may be shown.

Results

Preliminary tests were run before the final form and placing of the various parts was determined upon and several interesting facts were brought to to light. The frequency of the vibrating mirror and of the moving coil system could be changed almost at will by increasing or decreasing the damping of the moving coil. The use of frequency here is intended as synonymous with resonant frequency. By increasing the damping the mirror size could be increased. The frequency was lowered until maximum response was obtained at about 200 cycles per second with no damping pads. The comparatively large mass of the moving coil and its mountings was the determining factor in this low maximum frequency response.

More light struck the mirror when the angle of incidence approached zero and consequently more light was reflected ; therefore the light source and the speaker were placed so that this condition was approached as closely as was expedient. The same condition arose in placing the rotating mirror and the same conditions were simulated.

The placing of the condensing lens was more a matter of choosing the lesser of two evils than of a scientific approach. One possible position was farther from the light source as measured along the beam of light and this position gave a small spot of light on the screen, was very intense but gave low maximum amplitude and very bad distortion on the peaks of the waves. The other alternative gave a larger spot of light which was consequently less intense with much greater amplitude and less distortion on the wave peaks. This condition placed the condensing lens near the vibrating mirror. The latter position was chosen for the permanent location of the lens. The time axis could be shown in two ways; one by means of a rotating mirror and the other by a mirror vibrating in a plane at right angles to the first mirror. The latter method could be used to advantage if a parabolic mirror could be used as the first mirror and the second could be placed close to the first so that a small size could be used for the second. If the second could be driven in synchronism with the first,with a wave with both sides symmetrical to be shown this system could be worked out very nicely. If an unsymmetrical wave were to be shown a device would have to be introduced to stop the light during the instant when the light spot was going one way on the screen. The rotating type of time axis mirror lends itself very readily to showing waves of different frequencies and,since this type was available, was selected for this oscilloscope. It consisted of four mirrors set at right angles and mounted on a vertical shaft so mounted that the driving motor ran 40 times faster than the mirror. The gearing was of the worm type and gave an even control over the mirror speed by means of a potentiometer in the motor circuit.

Speech sound waves show their complex formation on this oscilloscope with great brilliancy. The response is much greater at the lower frequencies as was pointed out previously. Sixty cycle current or voltage waves show the sine curvature with good detail. The uses of this device are legion and no attempt will be made to enumerate them all.

V
DISCUSSION OF RESULTS

As far as it has been able to ascertain, this type oscilloscope has never been used to ascertain the frequency of an observed wave although a large number of articles have been read on this and related subjects. When a wave pattern is observed the mirror motor speed may be varied until the wave pattern is stationary. A tachometer may be used for determining the motor speed. The relation between motor and mirror speed is a constant, therefore the mirror speed or rotations per minute are known. The distance from the rotating mirror is fixed at ten inches and the wave pattern may be measured directly on the screen. This gives enough data to determine the frequency of the observed wave. The following formula explains the procedure.

$$f = \frac{2\pi \times 10}{60 \times 40} \times \frac{R.P.M.}{L} = 0.02618 \times \frac{R.P.M.}{L}$$

Where: f = cycles per second
L = length of wave in inches
RPM = rotations per minute of motor

It may readily seen from this relation that doubling the R.P.M. would double L if the frequency remains the same. This is exactly what happens and provides a means of checking observations. A chart showing the relation between motor speed and wave lengths with lines of constant frequency, between limits of approximately 2000 cycles per second andzero cycles per second.

Many improvements have become self evident as work has progressed and some of these will be tabulated.

A mirror driving unit with a higher frequency response would add greatly to the utility and versatility of this oscilloscope. Higher order harmonics could be shown in more detail. Band pass, high and low frequency filters could be applied to the input and their effect shown visually.

A rotating mirror with a large number of faces would show the patterns with greater brilliance as the motor speed and consequently the mirror speed could be reduced. The periods of darkness of the screen would be reduced and frequencies over a wide range could be shown as a continous wave at much slower mirror speeds. The maximum number of mirror faces for the rotating mirror would be directly proportional to the length of the screen and to the distance of the rotating mirror from the screen.

One of the primary uses for this oscilloscope and one which the author hopes and believes is to enable the student of physics to better understand the wave form and nature of many of the complex;of our everyday life;problems.

Sincere effort has been expended to make this investigation thorough and complete and to compile a report which would be a credit to the author and to the school. A feeling that these efforts have been mediocre prevails.

VI

Appendix

1
William Thomson, 1824-1907, was one of the worlds greatest physicists and was raised to the peerage for his brilliant work. His title was Lord Kelvin.

2
William DuBois Duddell, 1872-1907, was a brilliant British Electrical Engineer.

3
Andre E. Blondel, a French Electrical Engineer and Professor at the National Mechanical College in Paris.

4
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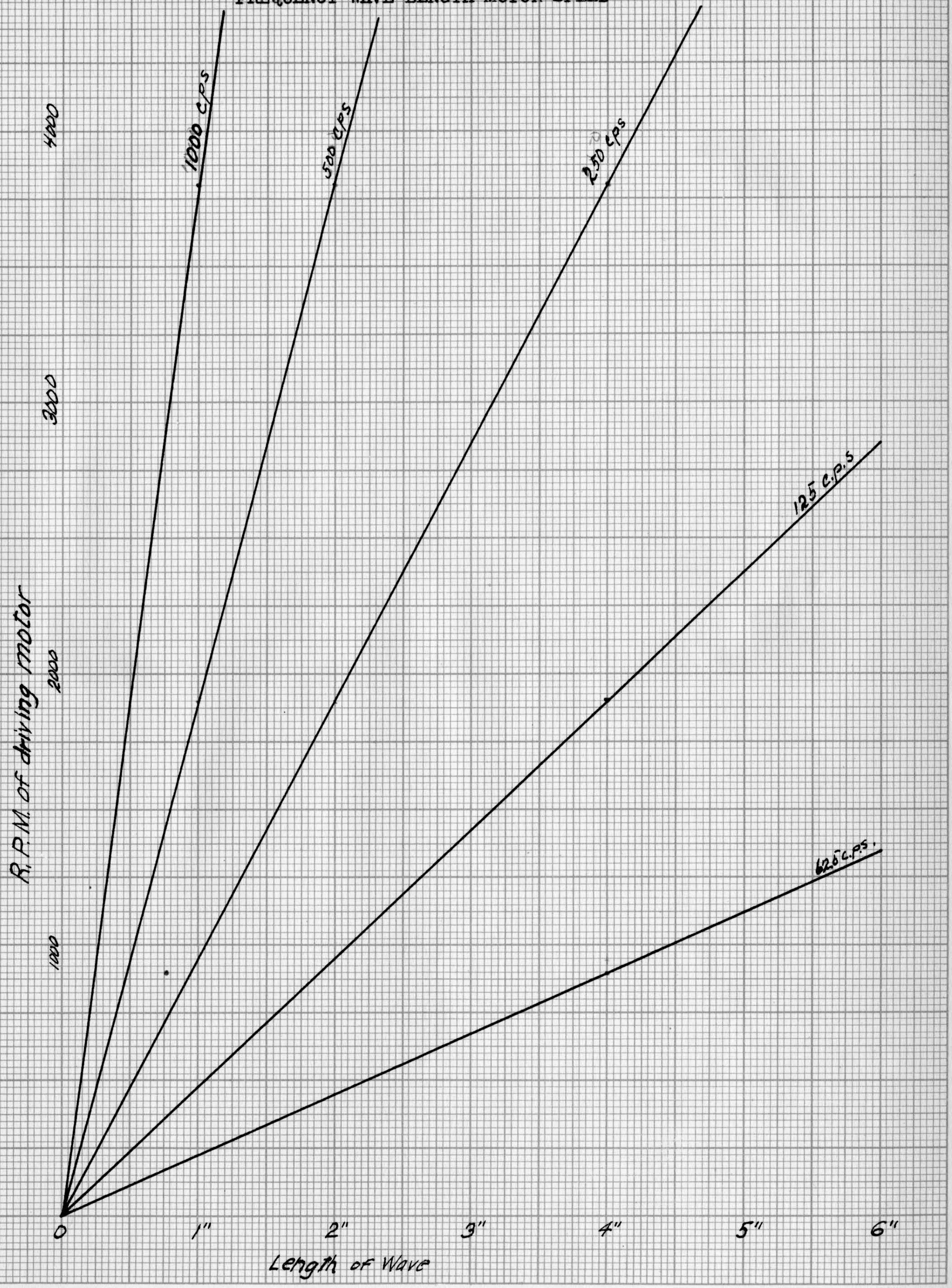
5
K. A. Oplinger, Electrical Engineering, Volume 53, 1934, page 290.

6
W. A. Marrison, Bell Telephone Laboratories Journal, Volume 8 page 368, 1929.

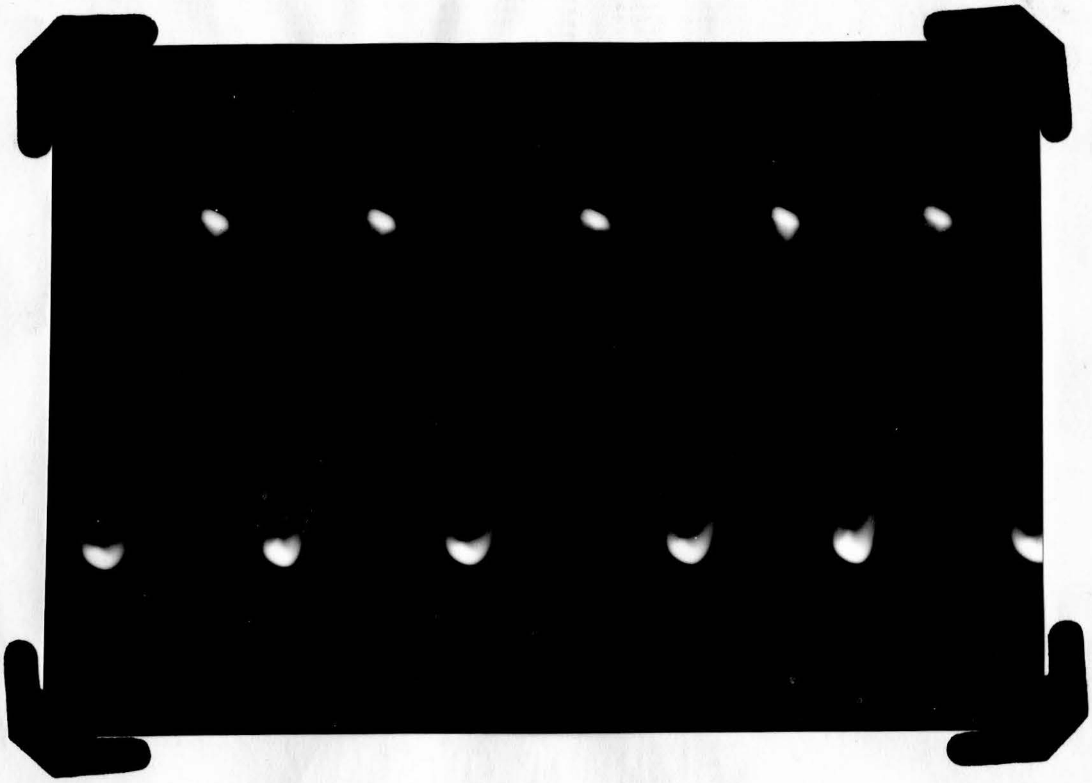
7
R. F. Mallina, Bell Laboratories Record, Volume 13, No. 1 Sept. 1934, page 17.

8
Joseph W. Legg, Electrical Journal, July 1927, Volume 24, No.7 page 341.

FREQUENCY WAVE LENGTH MOTOR SPEED

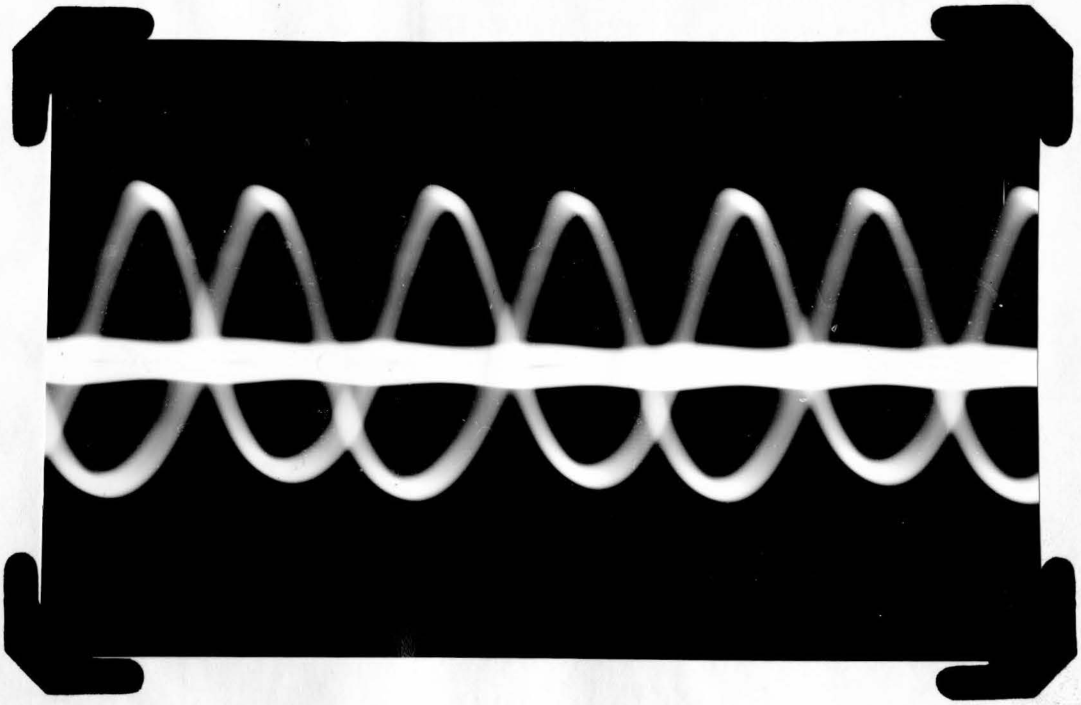


SINE CURVE



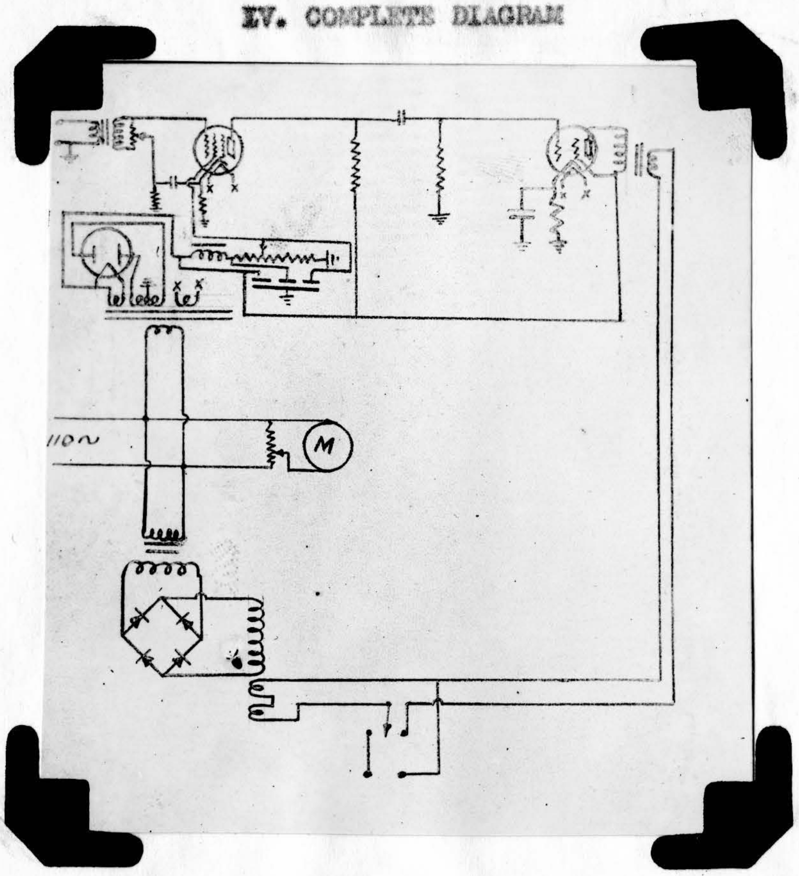
This picture was taken by allowing the light from the oscilloscope to fall directly on the film and the irregularity is probably due to the difficulty of placing the film so that the time axis mirror could rotate freely.

III. TWO SINE CURVES WITH ZERO AXIS



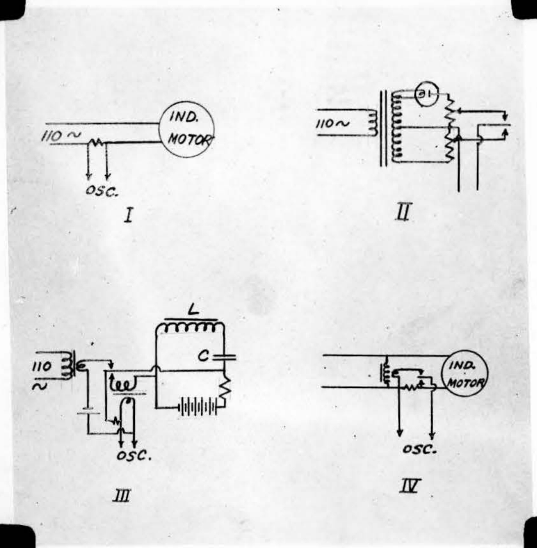
This exposure was made similar to number II.with the exception that a time axis was given and a wave 180 degrees out of phase with the first wave. The curvature at one peak was found to be due to iron filings in the air gap of the dynamic speaker.

IV. COMPLETE DIAGRAM



This is a complete diagram of all connections in the oscilloscope .

V. USEFUL CIRCUITS



These circuits are explained in the text and may be used for very interesting experiments.