AN ABSTRACT OF THE THESIS OF

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Title "An Improved Form of Breaker Type D.C. Amplifier"

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(Major Professor)

In some phases of experimental physics there is a need for an instrument capable of measuring small D.C. potential differences, such as those found in the contact of two dissimilar metals, e.g., thermocouples, and those due to the photoelectric effect. In order that the instrument needed be most useful, it should be highly sensitive, direct reading, and portable. Such instruments are available, and this paper describes the construction with improvement of one of them, the Perkin-Elmer Breaker Type D.C. Amplifier. The improved instrument is capable of measuring D.C. differences of potential in the range between 0.2 and 100 microvolts and has an input impedance of 2.5 ohms. Changes in the input voltage can be directly read on a meter or can be directly recorded by some recording device without the necessity of rebalancing the circuit, i.e., the output varies with the input at all times.

In operation, the Perkin-Elmer Breaker Type D.C. Amplifier converts the input voltage to a 75 cycle square wave A.C. voltage by a set of cam actuated breakers, amplifies this voltage in an A.C. electronic amplifier and then rectifies the amplified voltage with another identical set of breakers. The result is a pulsating D.C. output. The cams which actuate the two sets of breakers are on the same shaft, and their placement with respect to each other is such that any phase shift in the electronic circuit between them is compensated for, so that the output breakers fully rectify the amplified A.C. voltage. This critical placement of the cams is permanently set in the Perkin-Elmer Corporation's Laboratories and restricts the use of the breaker system to one particular electronic amplifier, i.e., the one for whose phase shift they have been set. Any changes in the amplifier's components over a period of time, e.g., the tubes and capacitors, can destroy the preset phase relation between the two cams with the result of incomplete rectification of the amplified A.C. voltage and a consequent decrease in gain and sensitivity. The improved instrument operates in the same way except that the phase difference between the input and the output of the amplifier is regulated by moving a plate upon which the output breakers are mounted. This plate can be rotated around the cam shaft by a worm gear. The working length of the worm gear provides 45 mechanical degrees of rotation in the rephasing of the two breaker systems. These 45 mechanical degrees are equivalent to 180 electrical degrees due to the shape and action of the cams and provide a phase difference regulator capable of matching the phase shift through any electronic amplifier.

AN IMPROVED FORM OF BREAKER TYPE D.C. AMPLIFIER

by

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AN IMPROVED FORM OF BREAKER TYPE D.C. AMPLIFIER

INTRODUCTION

In some phases of experimental physics there is a need for an instrument capable of measuring small D.C. potential differences, such as those found in the contact of two dissimilar metals, e.g., thermocouples, and those due to the photoelectric effect. In order that the instrument needed be most useful, it should be highly sensitive, direct reading, and portable. There are instruments available which fulfill or partially fulfill these requirements. Some of these are: the Leeds and Northrup Company's portable potentiometer (2, p.44-45); the Brown Instrument Company's Breaker Type Recording Potentiometer (1, all pages); and the Perkin-Elmer Corporation's Breaker Type D.C. Amplifier (6, all pages). Of these, the Perkin-Elmer Corporation's instrument seems the most useful. It is highly sensitive, capable of measuring D.C. differences of potential in the range between 0.1 and 300 microvolts (6, p.4), portable, and gives the results directly on a meter. Changes in the source of the input voltage can be directly read on a meter or can be directly recorded by some recording device without the necessity of rebalancing the circuit, i.e., the output varies with the input at all times. It can also be used with recording infrared spectrometers as a feedback amplifier and as a low frequency A.C. amplifier (6, p.4). Compared to the Perkin-Elmer instrument, one finds that the Leeds and Northrup instrument is not continuous reading but that it requires manual rebalancing of a bridge net-work for each change in the source of voltage. The Brown Recording Potentiometer directly records all the measurements taken but depends primarily on a thermocouple for the input source of voltage and cannot be used as a low frequency A.C. amplifier.

In operation, the Perkin-Elmer Breaker Type D.C. Amplifier converts the input voltage to a square wave A.C. voltage by a set of cam actuated breakers, amplifies this voltage in an A.C. electronic amplifier and then rectifies the amplified voltage with another identical set of breakers (Figs. 8,10,11,12). The result is a pulsating D.C. output (Fig. 15d). The cams which actuate the two sets of breakers are on the same shaft, and their placement with respect to each other is such that any phase shift in the electronic circuit between them is compensated for, so that the output breakers fully rectify the amplified A.C. voltage. This critical placement of the cams is permanently set in the Perkin-Elmer Corporation's laboratories and restricts the use of the breaker system to one particular electronic amplifier, i.e., the one for whose phase shift they have been set. Any changes in the amplifier's components over a period of time, e.g., the tubes and capacitors, can destroy the preset phase relation between the two cams with the result of incomplete rectification of the amplified A.C. voltage and a consequent decrease in gain and sensitivity.

This paper describes a D.C. amplifier similar to the Perkin-Elmer instrument with the addition of a phase control between the input and output breakers. The development of the phase control required the duplication of the Perkin-Elmer instrument. The original research on the Perkin-Elmer instrument was done by the General Motors Research Laboratory, and the instrument is licensed by them (6, p.4). The duplication and improvement has been done for research for a thesis for the degree of Master of Science and is not presented as a model for copying.

PRINCIPLE OF OPERATION

GENERAL DESCRIPTION. The instrument has been designed to amplify input voltages ranging in magnitude from 0.1 to 100 microvolts with input impedances between 2.5 and 20 ohms until they give full scale deflection on standard metering devices(6, p.4). This makes it particularly well suited for the amplification of thermal emfs where both the voltage and impedance are low.

The small D.C. potentials applied to the input of the instrument are converted to a 75 cycle A.C. voltage by a single-pole, double-throw switch (the breakers) and a transformer (Figs. 15 and 16). The A.C. output of this transformer, amplified in a three-stage, R-C coupled, Class A amplifier and rectified by a duplicate set of properly phased breakers, gives a D.C. output ready for measurement with meters of the D'Arsonval type. By converting the D.C. to A.C. for amplification, the drifts generally associated with electronic D.C. amplifiers are avoided (9, p.395-6)(6, p.5) and a more stable and linear gain is obtained.

BREAKER SYSTEM. The breakers are each made up of two pairs of contacts and are actuated by cams mounted on a shaft that is driven by a synchronous motor. As shown in Figs. 4 and 16, one contact of each pair is connected to the source of input voltage, and, as the switch is actuated, the two remaining contacts alternately feed this input voltage to opposite halves of a center tapped primary. As a result, each half of the primary alternately acts as the active primary with current flowing in an opposite direction in each. The resulting alternate reversal of flux in the primary of the transformer induces an A.C. voltage in the secondary of the same fundamental frequency as the 75 cycle square-wave produced by the breakers (Figs. 15 and 16).

PHASING MECHANISM. The phase difference between the input and the output of the amplifier is regulated by moving a plate upon which the output breakers are mounted (Figs. 8,10,11). This plate can be rotated around the cam shaft by a worm gear. The working length of the worm gear provides 45 mechanical degrees of rotation in the rephasing of the two breaker systems ($22\frac{1}{2}^{\circ}$ up or down from the horizontal position of the plate)(Figs. 2 and 11). These 45 mechanical degrees are equivalent to 180 electrical degrees due to the shape and action of the cams (Fig. 8) and provide a phase difference regulator capable of matching the phase shift through any electronic amplifier. These specially designed cams (obtained from the Perkin-Elmer Corporation) have four humps equally spaced around their circumference which actuate the breakers four times per revolution. The breakers, therefore, deliver four square waves (1,440 electrical degrees) per revolution of the cam (360 mechanical degrees); hence, the 45 mechanical to 180 electrical degree equivalent.

The correct phase relation between the input and output breakers allows only those induced voltages of the breaker frequency to give a D.C. voltage component to the rectified output. Induced voltages of all other frequencies, i.e., the adjacent 60 cycle signals, only produce A.C. voltage components in the output, and these are nullified by the action of D'Arsonval type galvanometers, which should be used with this instrument (6, p.6-7), (7, p.40-41), and (3, p.550).

THERMOELECTRIC EFFECTS AND MAGNETIC SHIELDING. The thermoelectric characteristics of all the material used in the input circuit are matched so that thermoelectric potentials due to connections in this circuit which could give rise to voltages of the same order of magnitude as those we are measuring are balanced out. The circuit is shielded from sudden temperature variations and from the surrounding magnetic and electrostatic fields, e.g., those of the transformers, the synchronous motor and the source of power. How this was done and the precautions taken are described in the following section on construction.

THE A.C. AMPLIFIER AND CONTROLS. The A.C. amplifier to which the output of the transformer is fed has its peak frequency response at approximately 75 cycles and an output impedance designed for a 500 ohm load. Controls are provided for controlling the gain or amplification, for balancing the instrument to zero, for introducing voltages in the input circuit to roughly calibrate the overall gain, and for phase control between the two breakers. The gain is controlled by varying the amount of D.C. voltage fed back (see circuit diagram, Fig. 4) from the rectified output to the input of the instrument. This type of feedback gives a stable control since there is no problem of a proper phase relation between the voltage fed back and the signal appearing on the grid of the first tube.

CONSTRUCTION

GENERAL DESCRIPTION. The instrument, enclosed in a $16\frac{1}{2}$" by 9" by 13" gray enameled, reinforced, wooden case, weighs $33\frac{1}{2}$ pounds and contains four major units (Figs. 1,2,3): the A.C. amplifier; a high-turns-ratio input transformer; an 1800 RPM, 110 volt, 60 cycle, synchronous Bodine motor; and the breaker assembly unit. The breaker assembly unit (Figs. 7 through 13) consists of the breakers, their aluminum stationary and rotating side plates, the steel cam shaft and its housing, mounting studs and rubber shock absorbers.

BREAKER ASSEMBLY. The design and construction of the breakers are such that all the parts are either in exact duplicate or quadruplicate. A layout of these parts is shown in Fig. 8 and all dimensions are given in Fig. 7. For each switch there is: an actuating cam; an aluminum rocker arm; a pair of aluminum contact arms; a micarta mounting block; a pair of 0.013" thick phosphor-bronze retaining plates and tension springs; four gold contact points; a pair of copper contact set screws and their copper holders. When the breakers are assembled (Figs. 7 and 8), the gold contacts on each lever arm and those mounted on the micarta block are held in contact by a phosphor-bronze spring (forming a closed switch). In operation, a piece of micarta, or follower, riveted to one end of the rocker arm is held in contact with the surface of the cam by a phosphor-bronze spring. As this piece of micarta follows the contour of the revolving cam, another piece of micarta riveted to the other end of the arm relays the up and down motion to the contact arms and alternately forces one of the two breakers apart (an open switch).

This alternate opening of opposite breakers results in the delivery of the square-wave to the transformer. The transformer has a turns-ration of 1:185 for one half of the primary to the secondary,a primary impedance of 10.6 ohms, and is wound on a silica-steel core. Any difference in size between duplicate or quadruplicate parts of the breakers, e.g., like lever arm lengths, could cause a slight time difference in the operation of the breakers, which would affect the shape of the input wave or make the proper rectification of the output wave impossible. To compensate for this, the common contact point of each set of breakers is on the head of a copper 6-32 screw and may be raised or lowered to correct the spacing between the points. These screws have hexagonal heads (for raising and lowering with a small wrench) and are held in flat, rectangular copper holders (Figs. 7 and 8) tapped for their threads. These copper screw holders, firmly glued to the micarta blocks, were split diagonally through the screw hole after it had been tapped, and the halves rejoined with two 0.08 screws. By splitting the holders after tapping, the screw holes are slightly smaller when the two halves are rejoined. As a result, the contact screws, once located for correct breaker spacing, are firmly held in this position by the tension of the 0.08 screws.

PHASING MECHANISM. The end of the rotating plate, upon which the output breakers are mounted, is supported by a bearing, coaxial with the cam shaft, and the other end is supported by the teeth of a worm gear. The worm shaft is vertical, and rotation of the worm raises or lowers that end of the plate upon which the breakers are mounted (Figs. 10 and 11). This causes the breaker assembly to rotate about the axis of the cam shaft. The input and output cams are mounted on a cam shaft so that, when the output breaker's mounting plate is horizontal (Fig. 11), the output and input breakers are mechanically in phase. This side plate is held firmly in place without side or end play. That end of the plate which is coaxial with the cam shaft rotates between two relatively wide bearing surfaces and is held under constant pressure on its rotating bearing by the placement of the worm gear. A flanged brass bearing is firmly pressed into the plate and provides the bearing surface between the plate and shaft housing (Figs. 8,9,10). The flange on this bearing provides the side bearing surface between the rotating plate and the stationary side piece (Fig. 10). The second side bearing surface is the wide head of a knurled aluminum screw. This screw, with a hole through its center to allow the passage of the cam shaft, is screwed into the threaded end of the cam shaft housing (Figs. 9 and 10). The flat inner surface of the screw's head holds the rotating plate on the shaft housing while acting as one of the side bearing surfaces, and the part of this screw which penetrates the housing acts as a retainer for the shaft's ball bearing race.

The vertical worm shaft is held in place on the stationary side plate by two brass thrust bearings, one above and one below the worm. These thrust bearings have been mounted so that, when the worm which they support and the cogs on the rotating plate are meshed, a constant pressure is exerted on the brass mounting bearing of the plate (Figs. 10 and 11).

The actuating cams were obtained from the Perkin-Elmer Corporation because their manufacture requires a special jig. The four rounded humps around their circumference are swung with equal radii from uncommon centers, none of which coincide with the common center of the cam. The development of these symmetrical humps is such that they allow the breakers to have a short period of overlap during which time both contacts are closed. The shaft on which these cams are mounted is driven by the synchronous motor, which rotates at 30 rev./sec. The pulleys on the motor shaft and the cam shaft, respectively, have diameters in the ratio of approximately 1 to $1\frac{1}{2}$ (Fig. 14), so that the cam shaft revolves at approximately 18.5 rev./sec. This speed of rotation and the four actuating humps on the cams results in the 75 $sec.^{-1}$ breaker frequency.

THERMOELECTRIC EFFECT AND SHIELDING. Precautions taken to minimize temperature effects are: the isolation of the breaker contacts from heat generating bearings and cam followers by the rocker arm; the rigid construction of the contact arms so that sliding or relative motion of the contacts does not occur after closure (thereby eliminating frictional heat); the matching of all the materials used in the input circuit (6, p.6); and the enclosure of the entire breaker unit in a cork lined box.

The thermoelectric characteristics are matched by making corresponding copper lead wires in the input circuit the same size and length, by avoiding joints wherever possible, and by making those joints which cannot be avoided with a special solder or with pure copper Stak-Ons. The special solder has a low thermoelectric potential with respect to copper and was obtained from the Perkin-Elmer Corporation. To further reduce the effects of induced contact difference of potential, the contact points have been made of

24 karat gold and the contact arms of aluminum, both of which have a low thermoelectric potential difference with respect to copper (4, p.1945). Metal to metal contact is avoided wherever possible by separating the metal parts with non-conducting micarta, e.g., the micarta followers between the rocker arms and the cams.

For comprehensive discussion of thermoelectric potentials and their magnitudes, refer to (5, p.73-74), (4, p.1945), (2, p.20-21), and (8, p.245-249).

The effects of surrounding magnetic and electrostatic fields are minimized by: the selection of the 75 cycle operating frequency, which minimizes the effects of induced 60 cycle signal; by enclosing the breaker unit and the transformer in separate shields, the shielding of all lead wires; and the utilization of material with low permeability.

The input transformer is enclosed in a capped $2\frac{1}{2}$ by 3 inch iron nipple and placed outside of the cork lined #29 gauge silica-steel[1] box enclosing the breaker system. At the 75 cycle operating frequency, the iron pipe effectively shields the input transformer from the radiation of magnetic or electrostatic fields, and the cork lined box magnetically shields the breakers while protecting them from dust and sudden temperature variations.

The breakers have an overlap period in the make and break of their contacts when both pairs of the contacts are closed (Figs. 16 and 19), which reduces the effects of induced 60 cycle voltages and

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1. Transformer A core stock which has 0.58 watts loss/lb. at 10,000 gauss and 60 cycles.

noise in the input circuit. The contact arms, which move up and down in the surrounding magnetic fields, and which are in direct contact with the breaker circuit, are made of aluminum. The combination of the magnetic shielding and the low permeability of the material used in these moving parts also reduces the effect of induced voltages.

Voltage can be induced in a piece of metal moving in a magnetic field, and the magnitude of this induced voltage can be changed by changing the position of the moving part in the magnetic field. For this reason, the output breakers have been placed on the rotating plate so that, if rephasing becomes necessary during operation (i.e., the changing of the position of the breaker's moving parts in the surrounding magnetic field), the balance of the instrument is not affected. Such a change in induced voltage in the input circuit would be appreciable upon amplification. Its effect on the amplified output is negligible.

AMPLIFIER. The A.C. amplifier is a conventional-type, three-stage, resistance-capacitance coupled, Class A amplifier whose components have been selected to give a 75 cycle peak frequency response. It has been designed to match a 500 ohm load. As can be seen in the circuit diagram (Fig. 4), it incorporates two 6SJ7 and a 6N7 output tube, all of which have 6.3 volt filaments and 300 volt plates. Fixed bias is maintained on the two 6SJ7 tubes by one volt Mallory bias cells. The parallel arrangement of the 6N7 components provides twice the gain of a single triode with the same value of grid signal voltage. The amplifier contains a power supply filter and can be used with a power supply having an unfiltered output.

The usual precautions were taken in its construction. These were: a careful layout of components so that the high impedance grid and plate circuits are not too close to each other or to an A.C. field; the placement of transformers and filter chokes with their fields at right angles to reduce the effect of inductive coupling; the prevention of inductive loops within the chassis; the placement of a common ground near the cathode of the input tube; and the running of twisted filament wires as close to and along the corners of the chassis as possible.

CONTROLS AND OPERATION

GENERAL DESCRIPTION. Controls are provided for controlling the gain of the instrument; for balancing the instrument to a zero point over a wide range of unwanted input emfs; for obtaining a test signal; and for adjusting the phase relation between the input and output breakers. These controls have been brought out to a panel on the front of the instrument (Figs. 1 and 2) and are clearly marked. Also marked are the input plug on the left side of the instrument and the output plug and the A.C. amplifier's power supply plug on the back of the instrument. The 110 volt, synchronous motor is turned on or off by a switch on the lower center of the panel. After the connections have been made to the instrument's input, output, and source of operating power, the motor is turned on, and the instrument is allowed to warm up. The warm up period required depends on the type of work being done and the ambient temperature. One half hour usually suffices to bring the amplifier to equilibrium (6, p.15).

GAIN CONTROL. The A.C. amplifier in this instrument has been permanently set so that its amplification is at the maximum value, and the overall gain is controlled by changing the feedback ratio between the output and input circuits. This feedback ratio is controlled by a potentiometer as shown in Fig. 4. This control is on the lower left corner of the control panel and is marked for three calibrated positions of gain.

ZERO CONTROL. Unwanted emfs in the input circuit are balanced out by a bucking voltage supplied by a 1.5 volt flashlight cell. The amount of this bucking voltage fed to the input circuit is controlled by two potentiometers in parallel, as shown in Fig. 4. These potentiometers, one coarse and one fine, permit the accurate balancing of the instrument to the zero point over a wide range of unwanted emfs in the input circuit and are brought out to the right side of the control panel. They are marked "Balance Coarse" and "Balance Fine," and a balance is obtained by making most of the adjustment with the coarse potentiometer and the final adjustment by the fine potentiometer. The battery or bucking voltage is turned on and off by a switch on the upper center of the control panel, marked "Battery." When not in operation, this switch should be on "Off" position to prevent unnecessary drain on the battery.

TEST SIGNALS. Known D.C. potentials can be supplied to the input circuit from the same battery that provides the balancing current. This provides a means for rapidly checking the amplifier's gain and for a rough calibration. These potentials, 0.1, 1, 10, and 100 microvolts, can be selected by a multiposition switch on the upper left corner of the control panel marked "Microvolts." This switch allows the proper dropping resistor to be put into the circuit between the battery and input so as to obtain 0.1, 1, 10, or 100 microvolts in the input (Fig. 4). In order for test signals or the balancing current to have any affect on the output, the input circuit must be closed.

PHASE CONTROL. The phase relation between the input and output breakers is adjusted by a knurled knob on the end of the worm gear shaft. This knob is marked "Phase" and is on the left side of the control panel. The proper phase relation can be obtained by adjusting the phase control until a maximum output is obtained for some constant input voltage, or by observing the wave shape across the output breakers on an oscilloscope. The former method is more easily accomplished since all that is needed is a meter on the output. To obtain the correct phase relation by this method: close the input circuit; set the "Gain" at maximum or #3 position; throw the battery switch "On" and the "Microvolt" switch to the 1 or the 10 microvolt position. With a meter on the output, turn the "Phase" control knob left or right until a maximum reading on the meter is observed. The same procedure is followed in the oscilloscope method, only, here, the development of the sine wave can be observed across the output breakers (Fig. 15c). Fig. 20 shows the wave shape obtained when the control is 1/3 revolution out of phase.

PERFORMANCE

The performance of the instrument is illustrated by gain curves (Figs. 21 through 24) showing the response for small and large input voltages. The operating conditions under which each curve was taken are indicated on the figure.

The first point on each curve of Fig. 21 indicates the noise level for that particular position of the "Gain" control. In Fig. 22, the distortion of the curves for "Gain" positions #2 and #3 (500 ohm load on output) is seen to appear in both cases at the same input voltage (70 microvolts) and is probably due to the driving of the input tube. The curve for "Gain" position #1, while showing distortion for the same input voltages, also shows the affect of the appreciable decrease in D.C. feedback at this position. The curve of Fig. 23 shows that the gain is constant for small input voltages with matched (2.5 ohm) input impedances and no load. This represents the operating conditions which exist when a thermocouple or piezoelectric crystal is on the input and a vacuum tube voltmeter on the output. Fig. 24 shows that there is non-linearity in the instrument's response when there is no load on the output and essentially zero ohms on the input.

The small input voltages necessary for these tests were obtained by a circuit, part of which was a 0.01 ohm pure copper resistor across the input terminal of the instrument. The input voltage seen by the instrument was taken to be the product of the resistance of this copper resistor and the current through it. The current measured is the total current through the 0.01 ohm resistor and the 2.5 ohm input impedance. The current through the latter is negligible.

In all tests it was found advisable to place a 150 microfarad capacitor across the output to cut down fluctuations in the output meter (meter dance).

Due to the similarity of design and construction of this instrument to the Perkin-Elmer instrument, it is advised, if possible, to refer to the Operating Manual (6, all pages) of the Perkin-Elmer instrument for additional information concerning trouble shooting and maintenance.

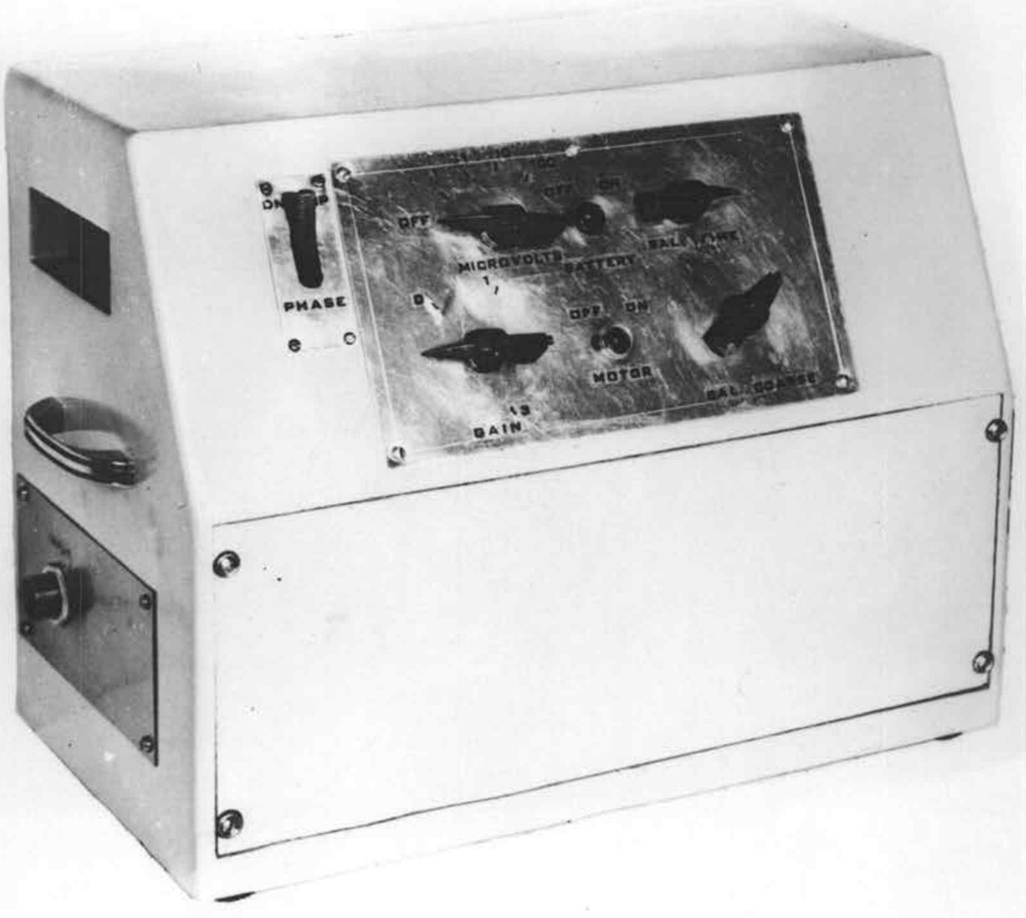


Fig. 1. Front view of instrument.

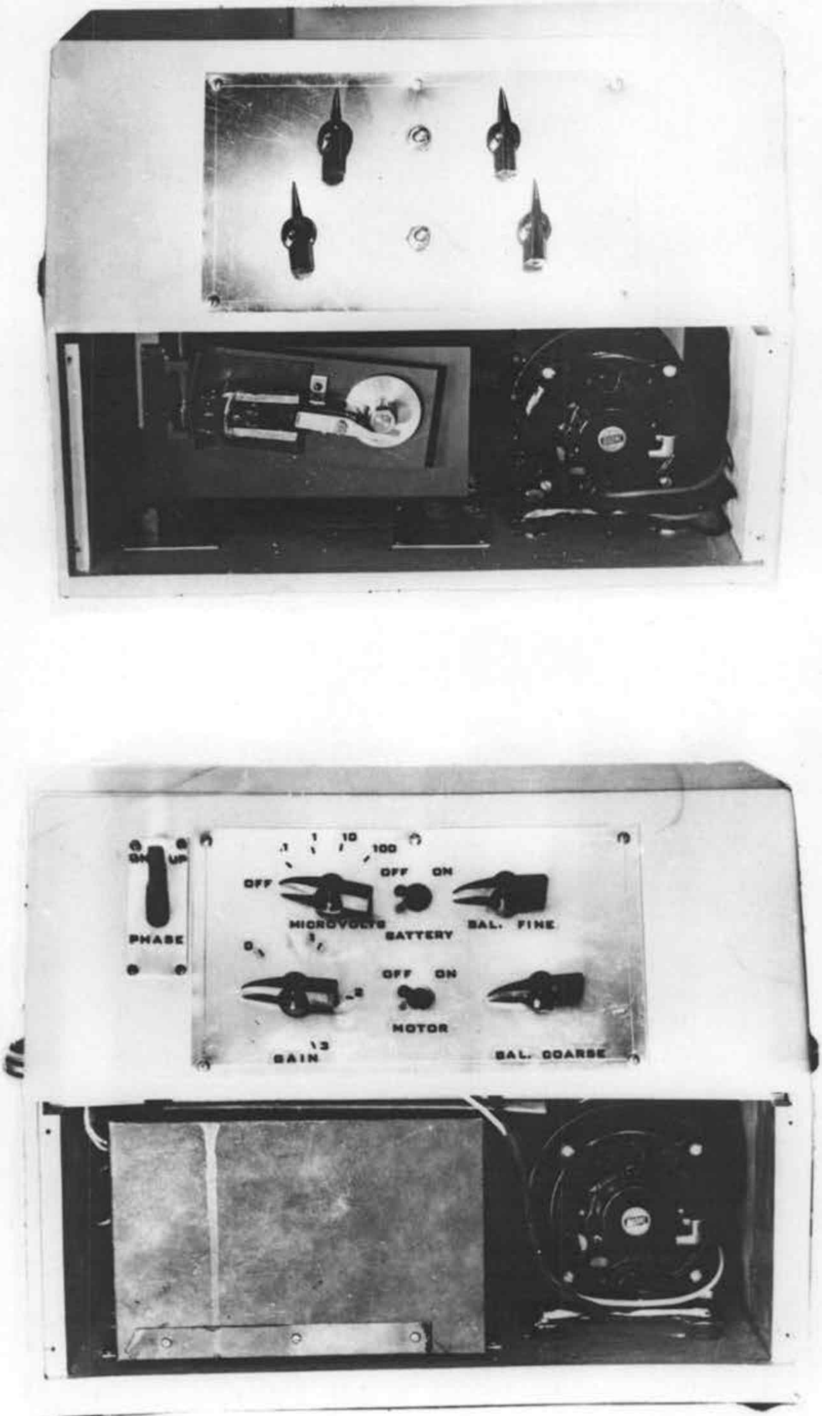


Fig. 2. The breaker assembly unit shielded and unshielded.

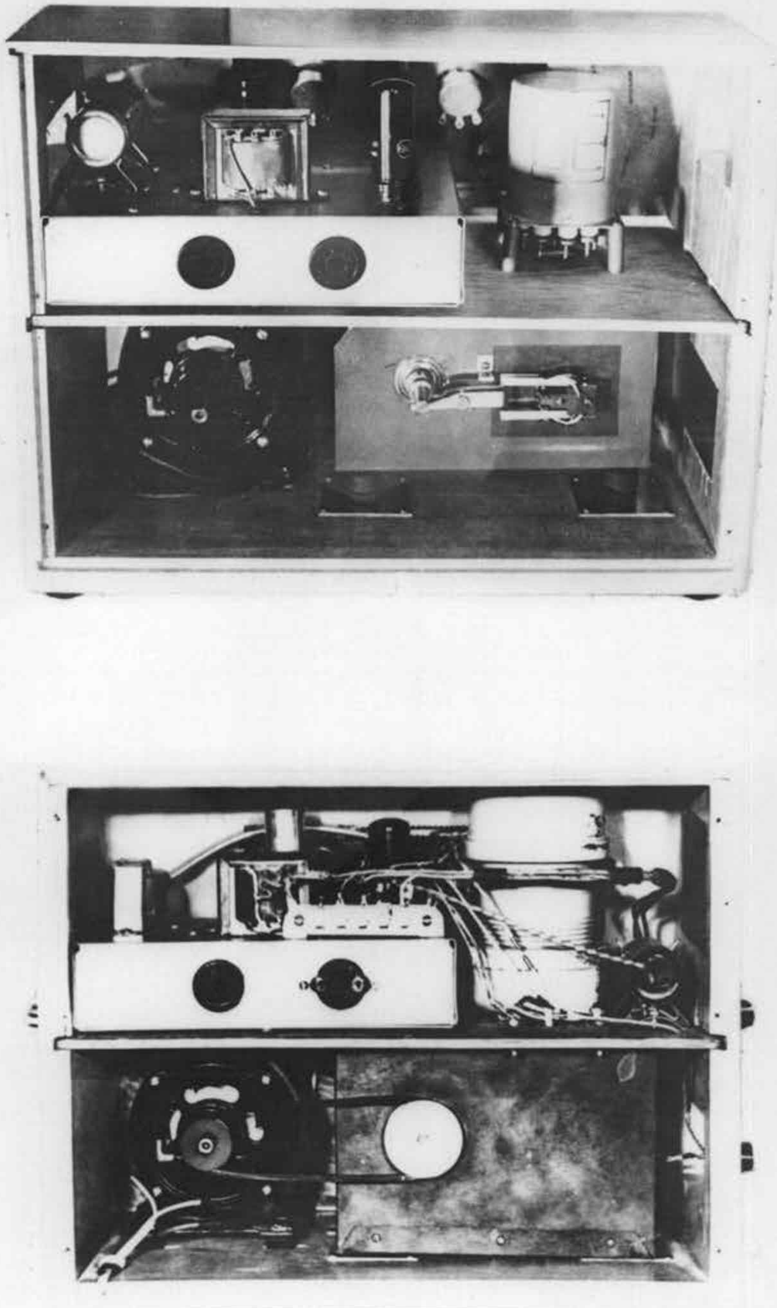


Fig. 3. Back view showing the four major units shielded and unshielded.

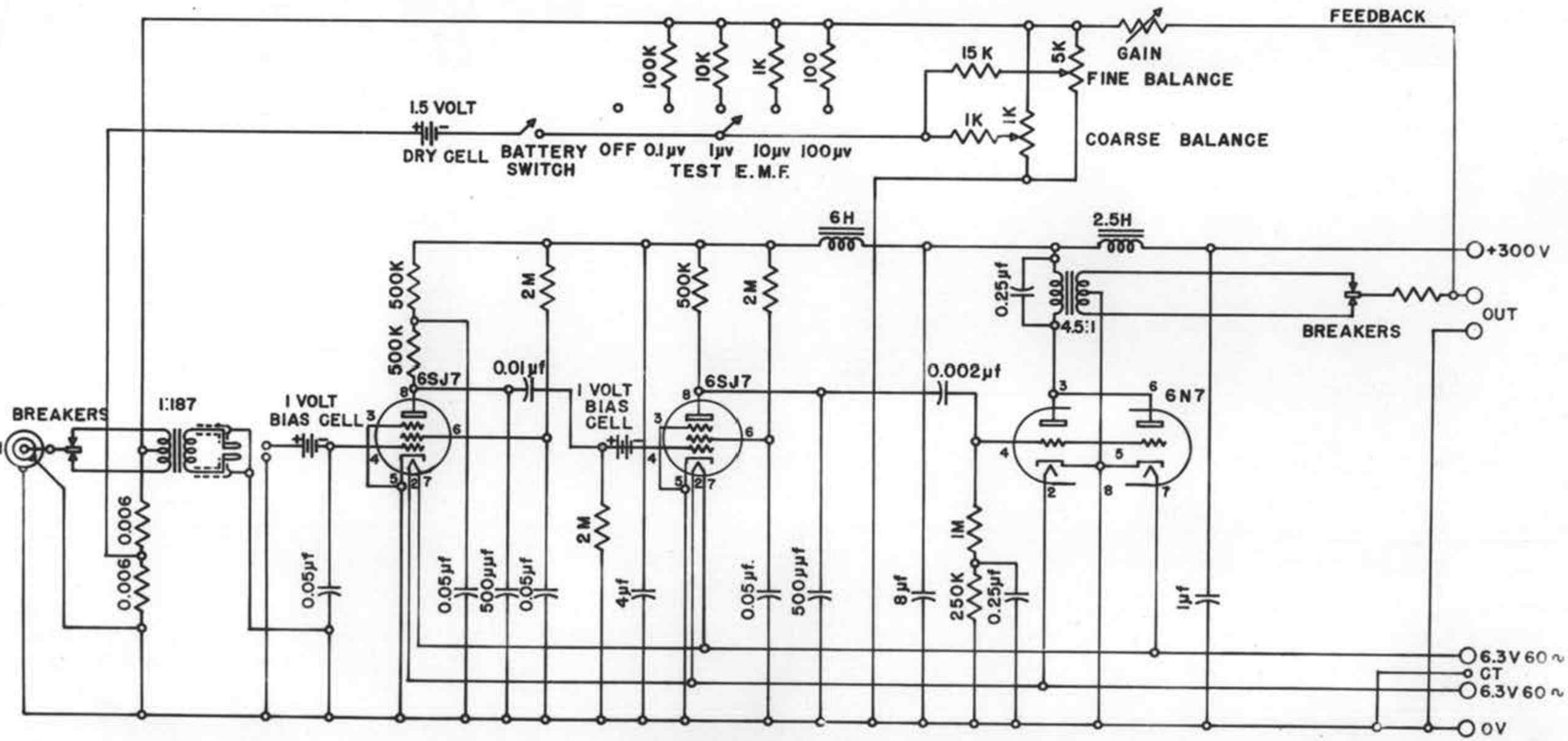


FIGURE 4
WIRING DIAGRAM

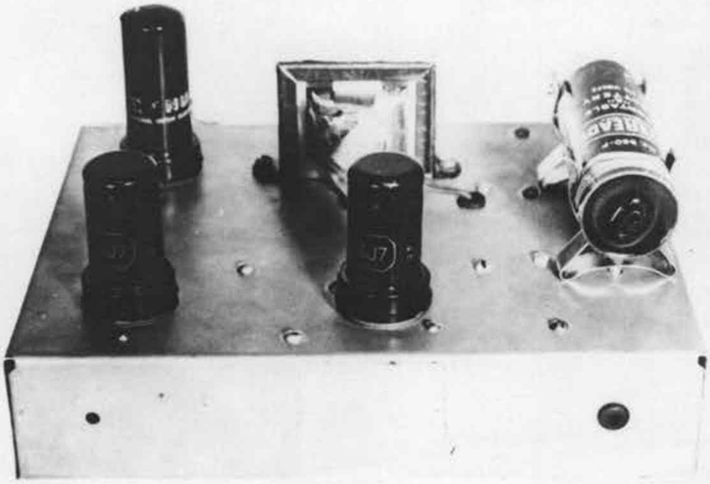


Fig. 5. Top view of A.C. amplifier.

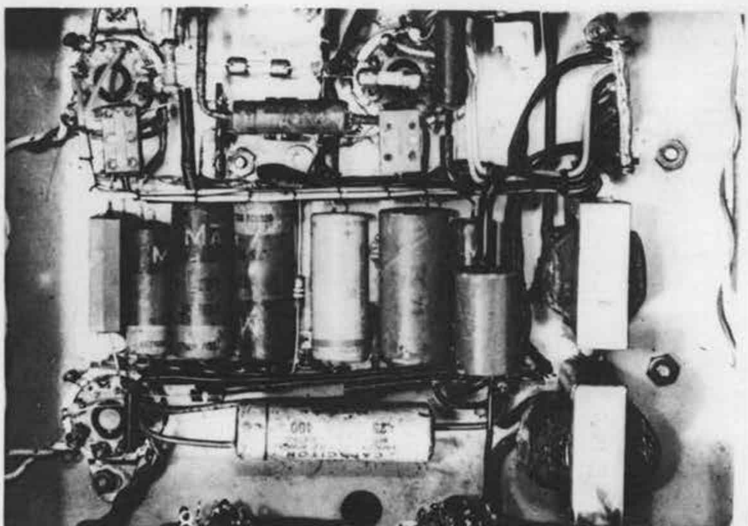
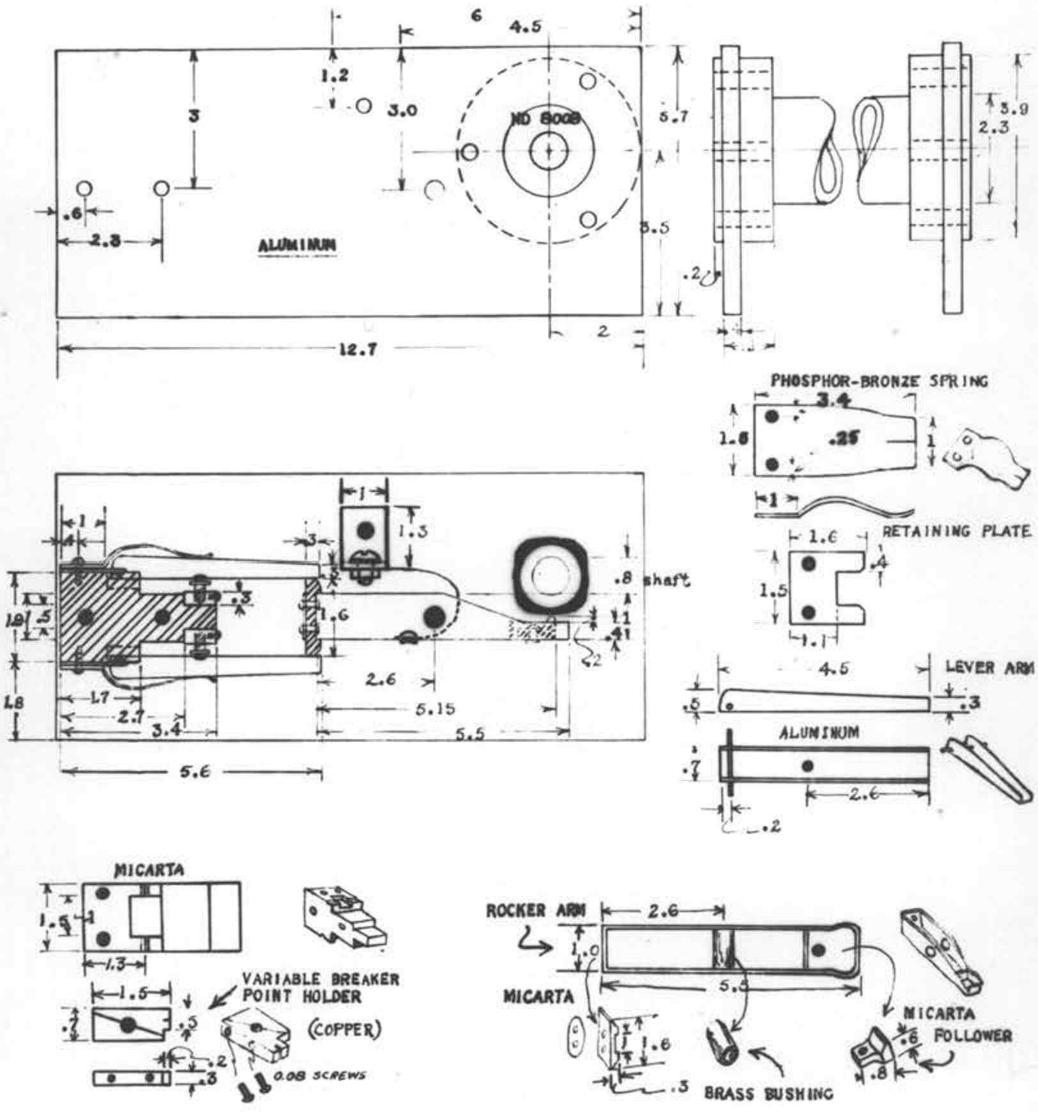


Fig. 6. Bottom view of A.C. amplifier showing layout of components.



Dimensions are given in centimeters.

Fig. 7. Breaker assembly unit.

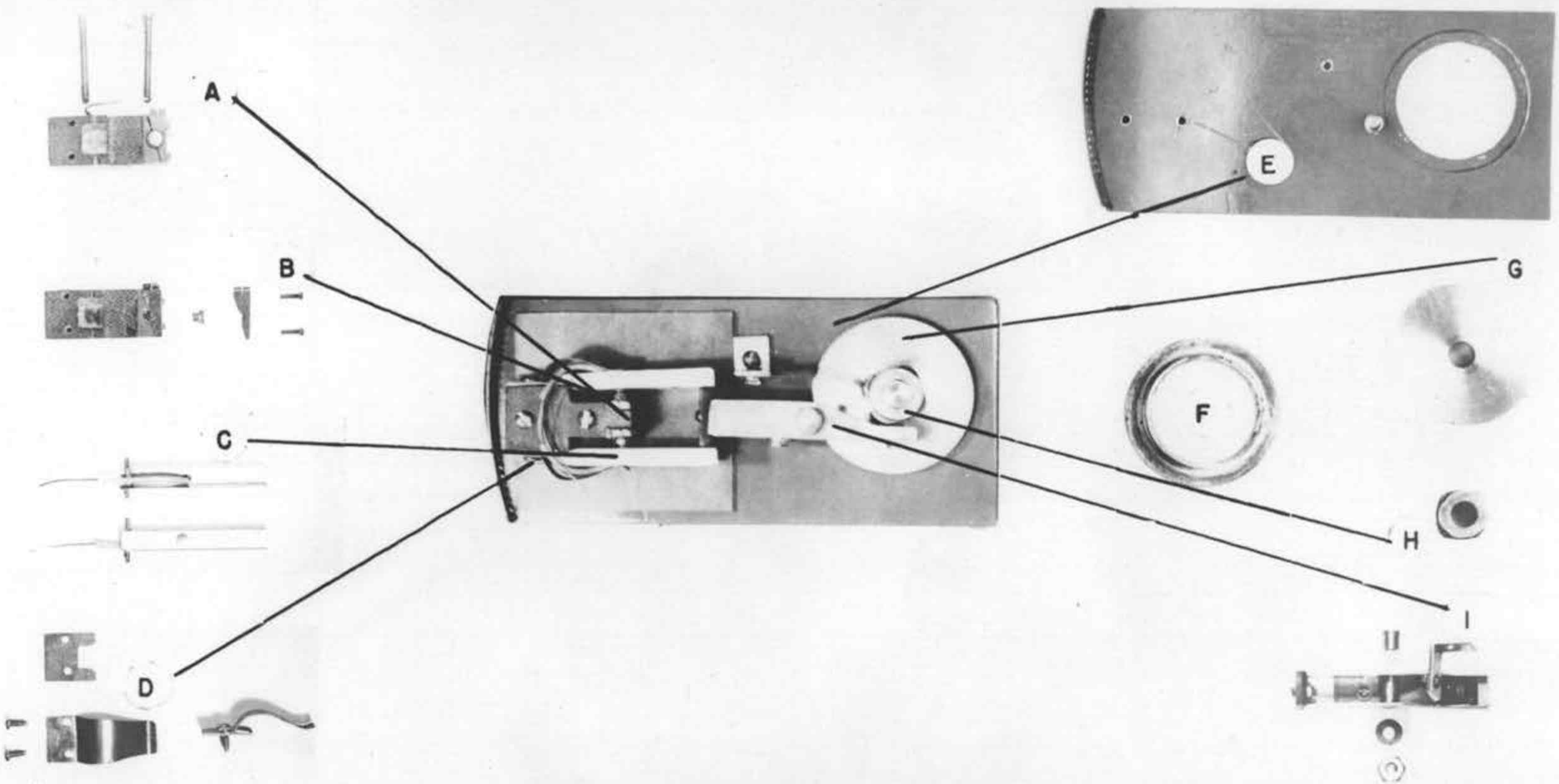


Fig. 8. Layout of breaker assembly. A. Micarta mounting block and assembled set screw holder. B. Set screw and split set screw holder. C. Contact arms showing gold contact button. D. Contact arm retainer plate and spring. E. Variable side plate. F. The flanged brass bearing. G. Aluminum retaining screw. H. The cam.

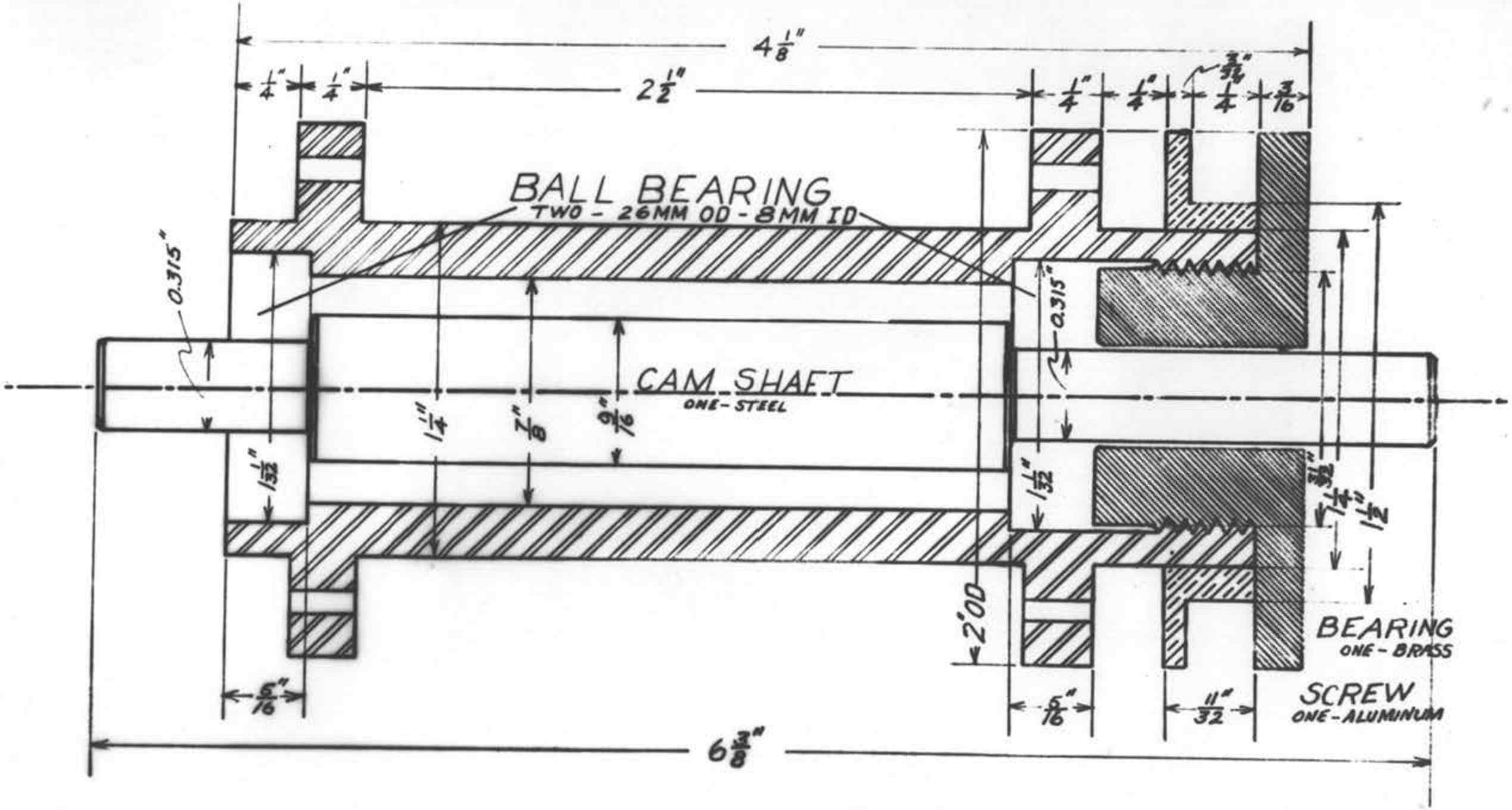


FIG. 9. THE CAM SHAFT AND CAM SHAFT HOUSING ASSEMBLY.

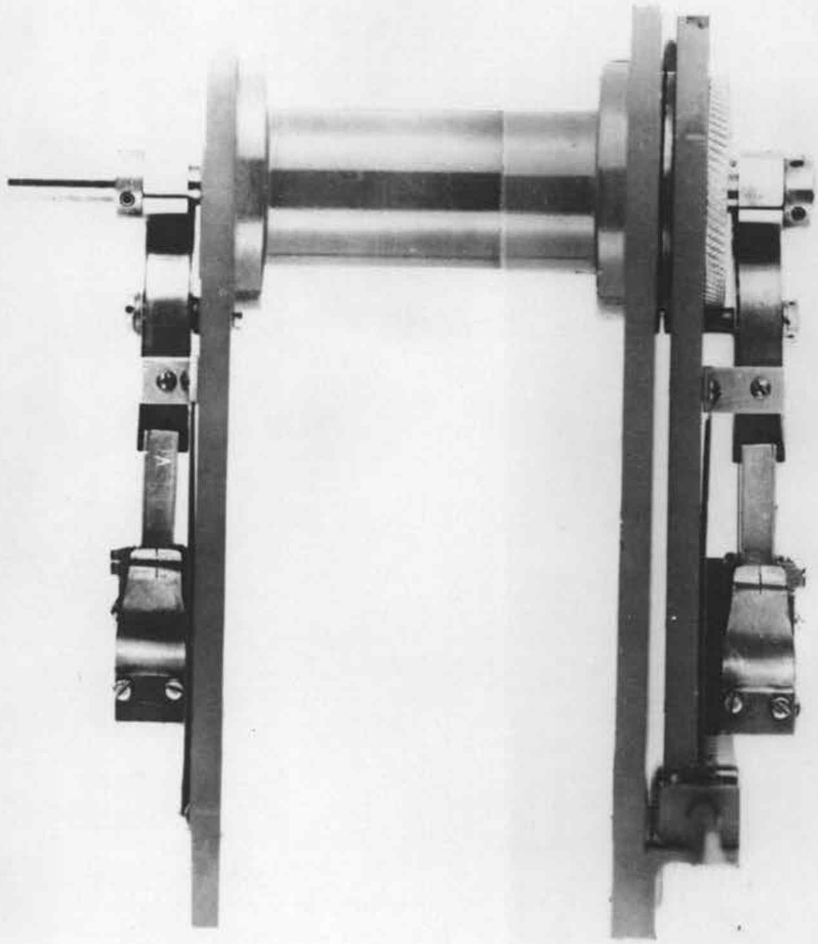


Fig. 10. Top view of assembled breaker unit.

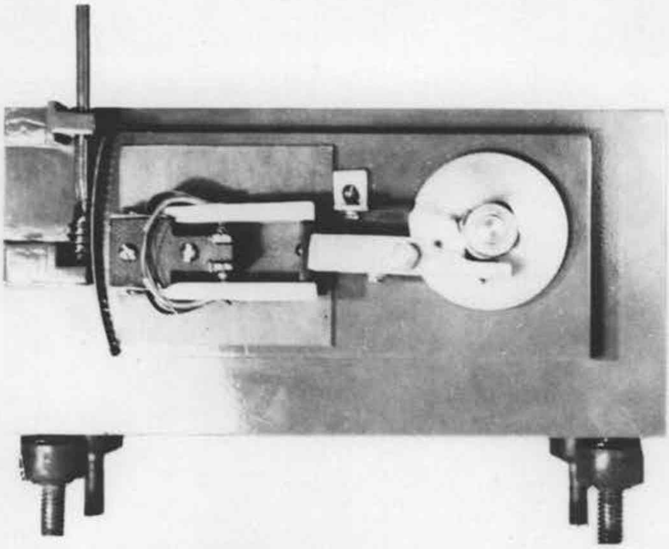


Fig. 11. Side view of breaker unit showing assembled output breakers, the rotating side plate, and the worm gear.

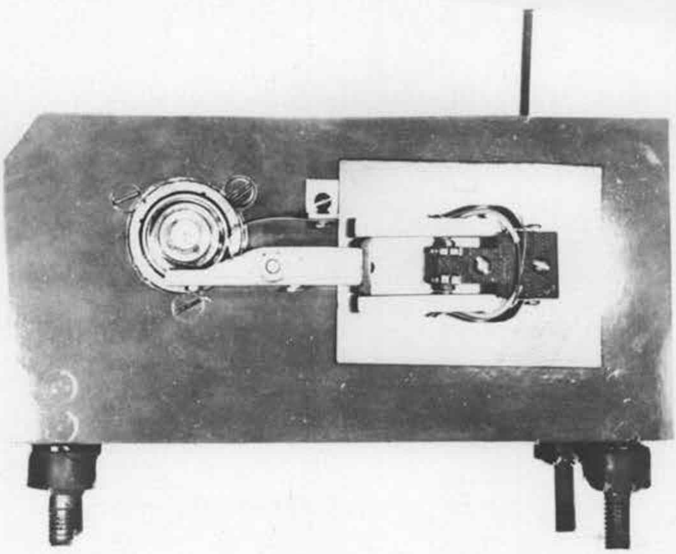


Fig. 12. Side view of breaker unit showing assembled input breakers.

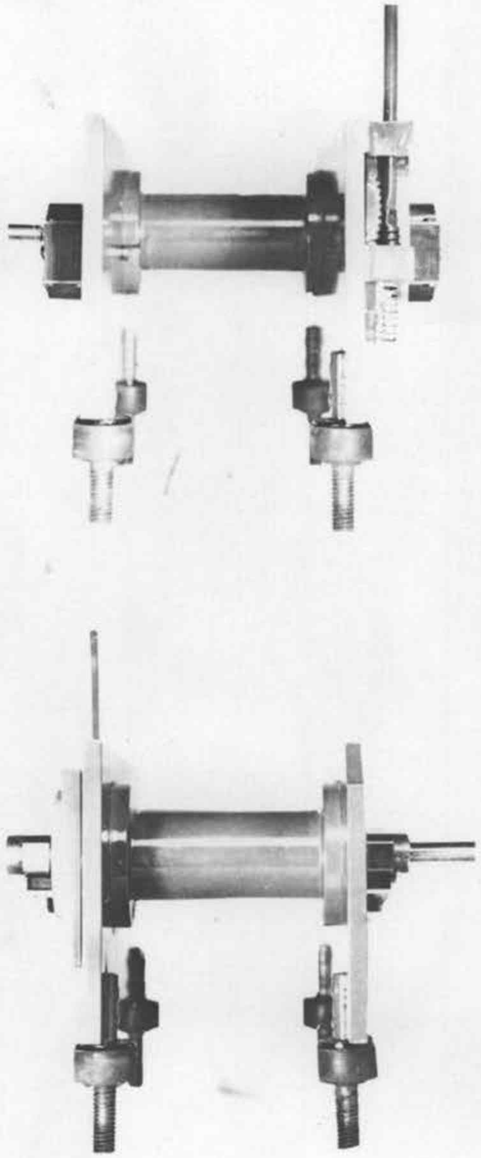
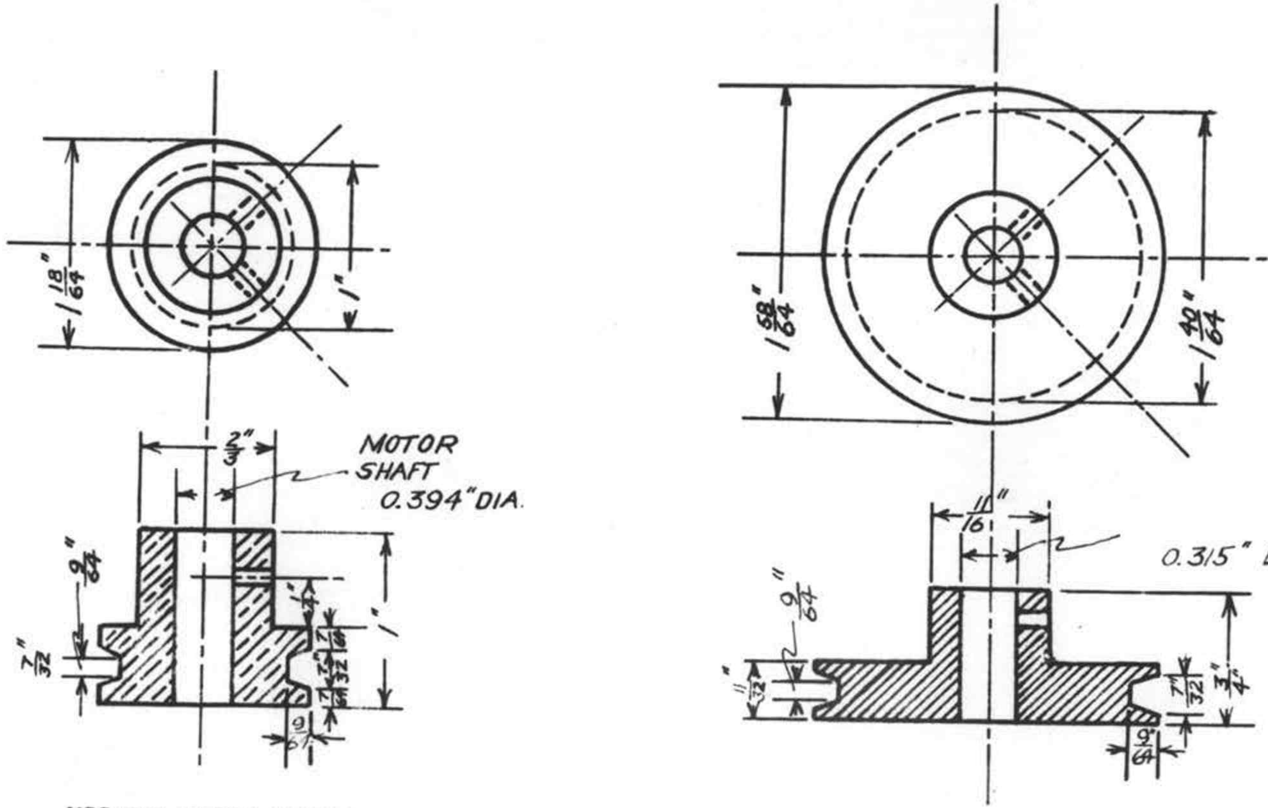


Fig. 13. End views of the breaker unit showing the cam shaft housing, the mounting studs and shock absorbers, and the worm gear.

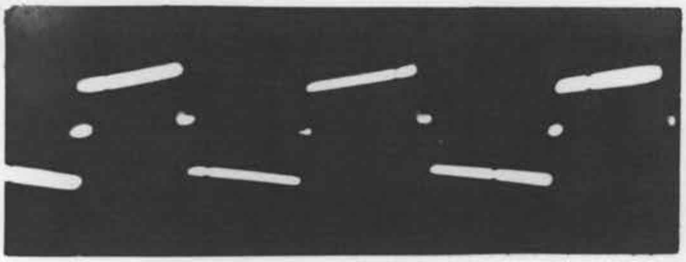


MICARTA MOTOR PULLEY

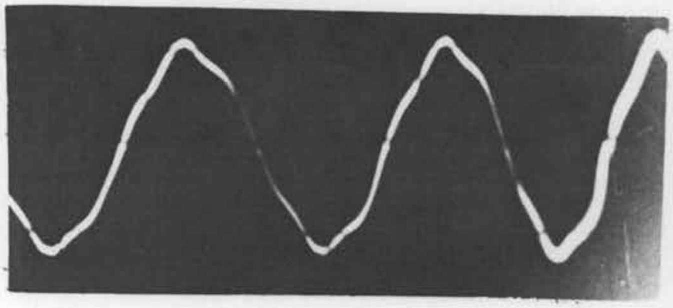
ALUMINUM CAM SHAFT PULLEY

Fig. 14. The motor and cam shaft pulleys.

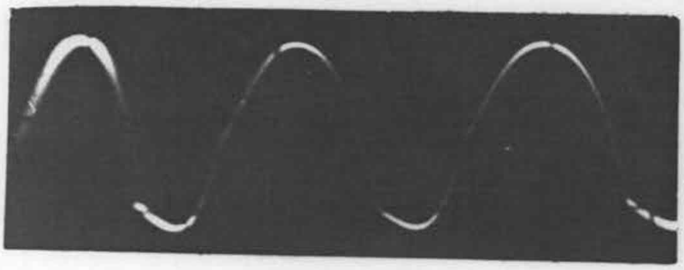
A.



B.



C.



D.

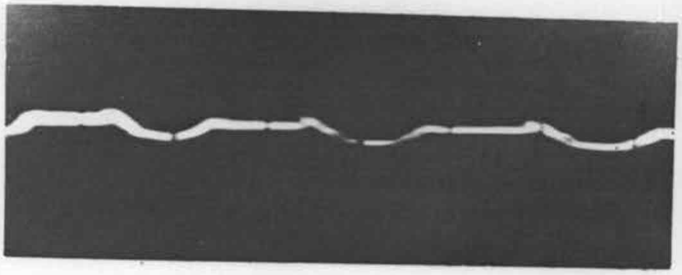


Fig. 15. The above oscillograms show the voltage wave shape in succeeding portions of the circuit. A. The wave shape across the output of the input breakers. B. The wave shape across the output of the input transformer. C. The wave shape of the unrectified output of the A. C. amplifier. D. The pulsating D. C. output of the instrument.

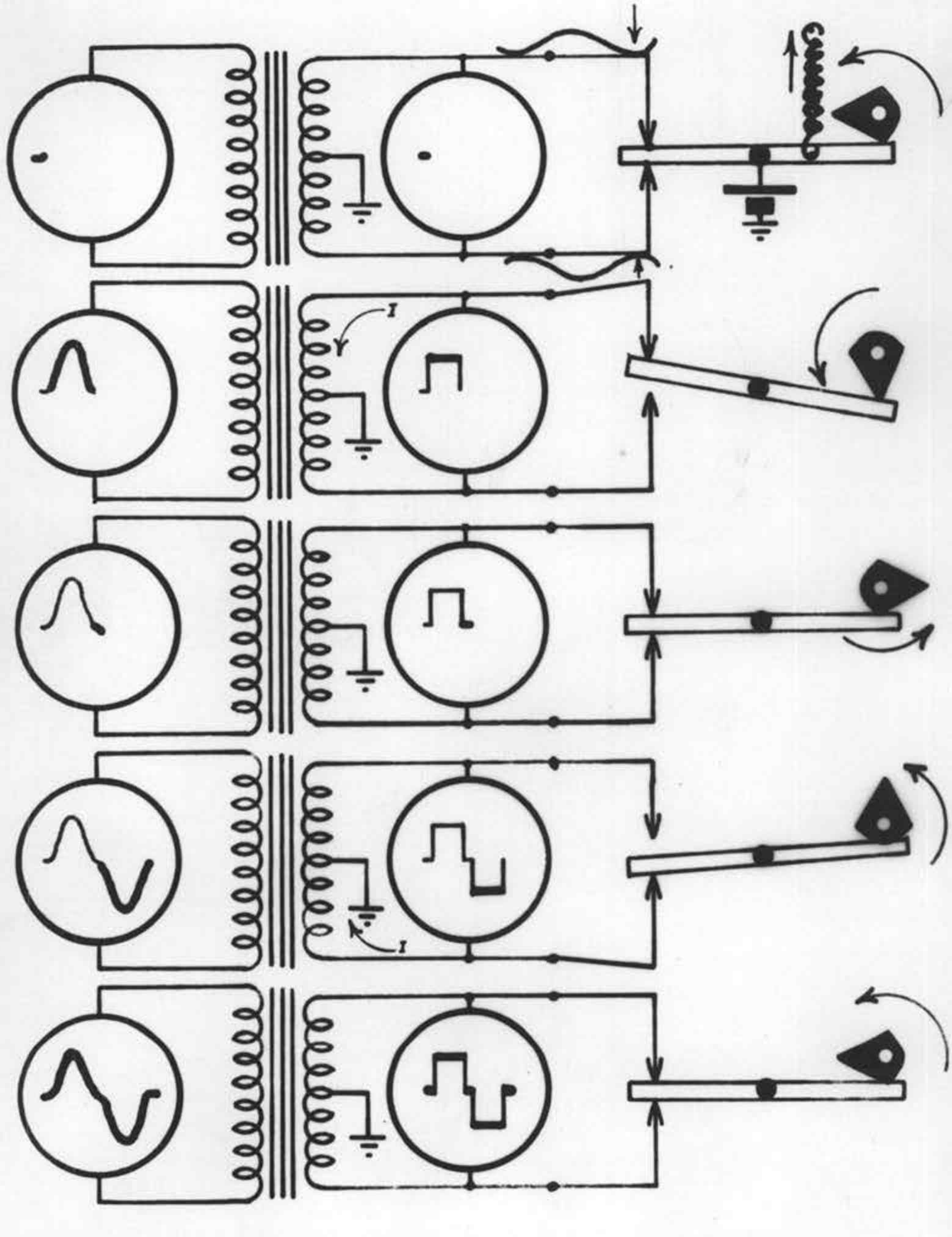


Fig. 16. Diagrammatic views showing the wave shape across the input breakers and on the output of the input transformer for succeeding positions of the actuating cam. The heavy lines indicate that part of the wave developed by that position of the cam, and the bottom view indicates the completed cycle.

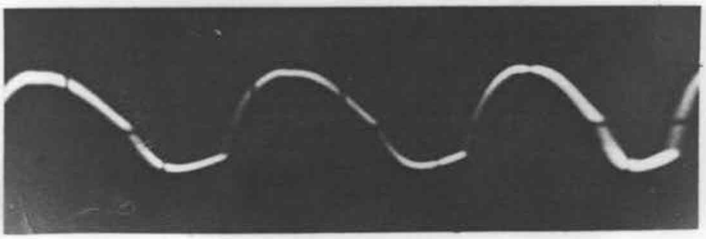


Fig. 17. The half wave rectification of the sine wave across the output breakers by the top half of the output breakers.

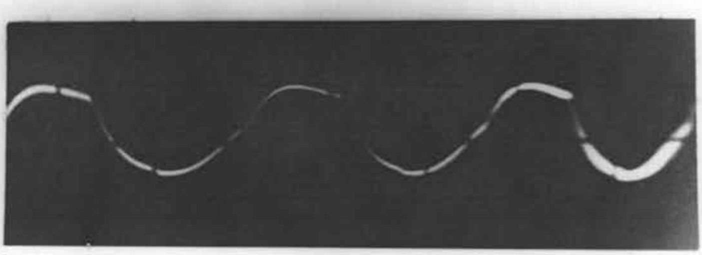


Fig. 18. The half wave rectification by the bottom half of the output breakers.

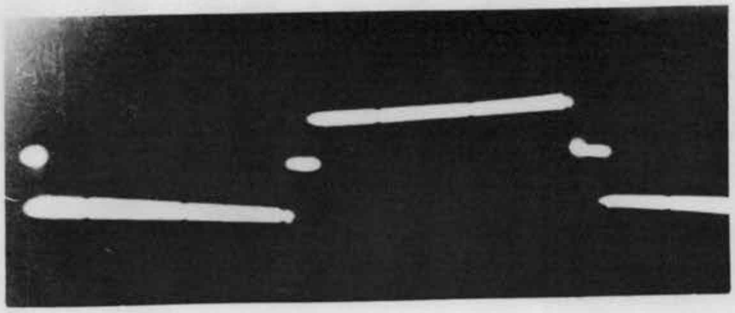


Fig. 19. Square wave across input breakers showing the brief period of overlap.

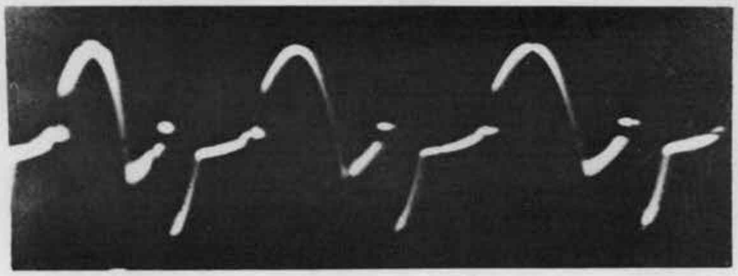


Fig. 20. The wave shape observed across the output breakers when the "Phase" control is 1/3 of a revolution out of the correct phase position.

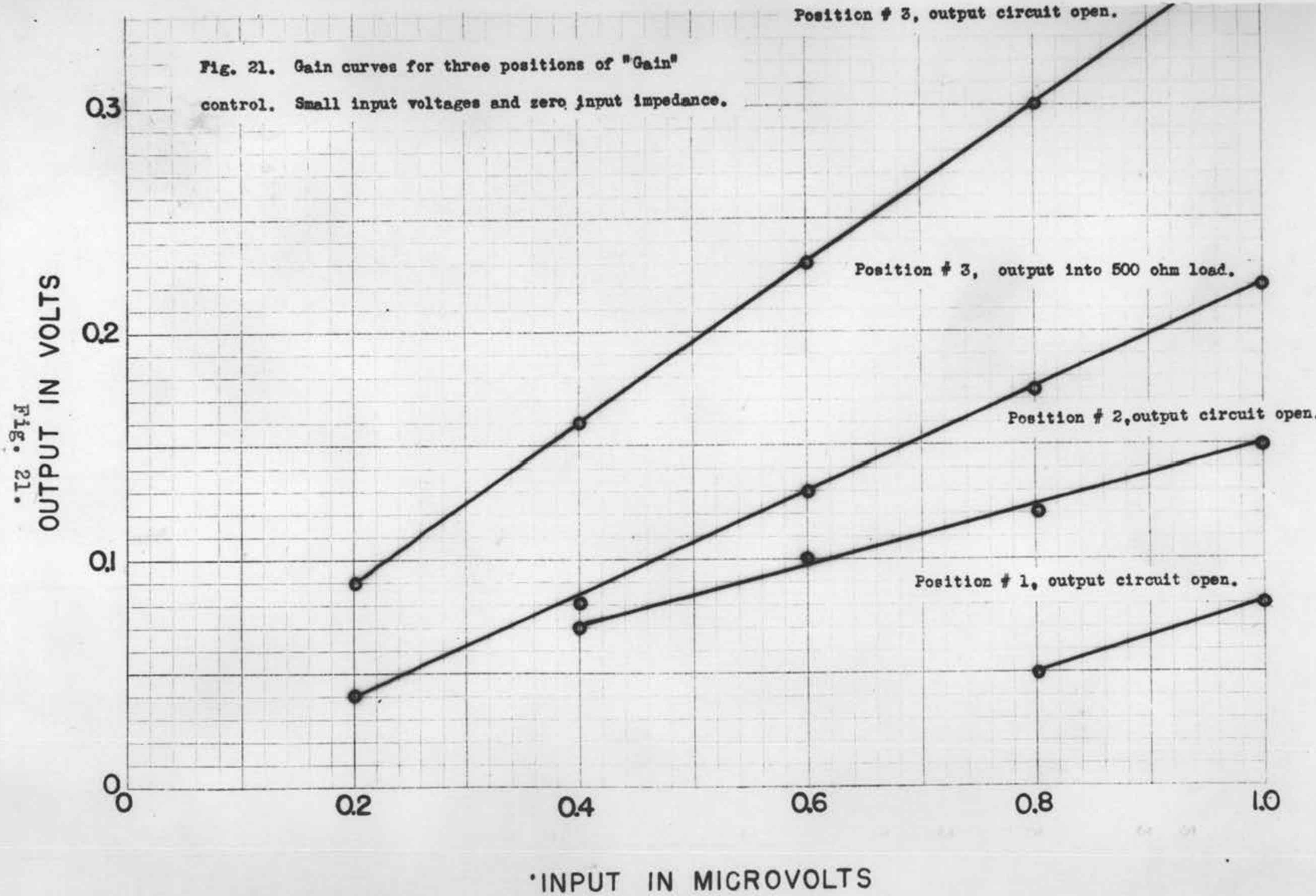


Fig. 21. Gain curves for three positions of "Gain" control. Small input voltages and zero input impedance.

Fig. 21.

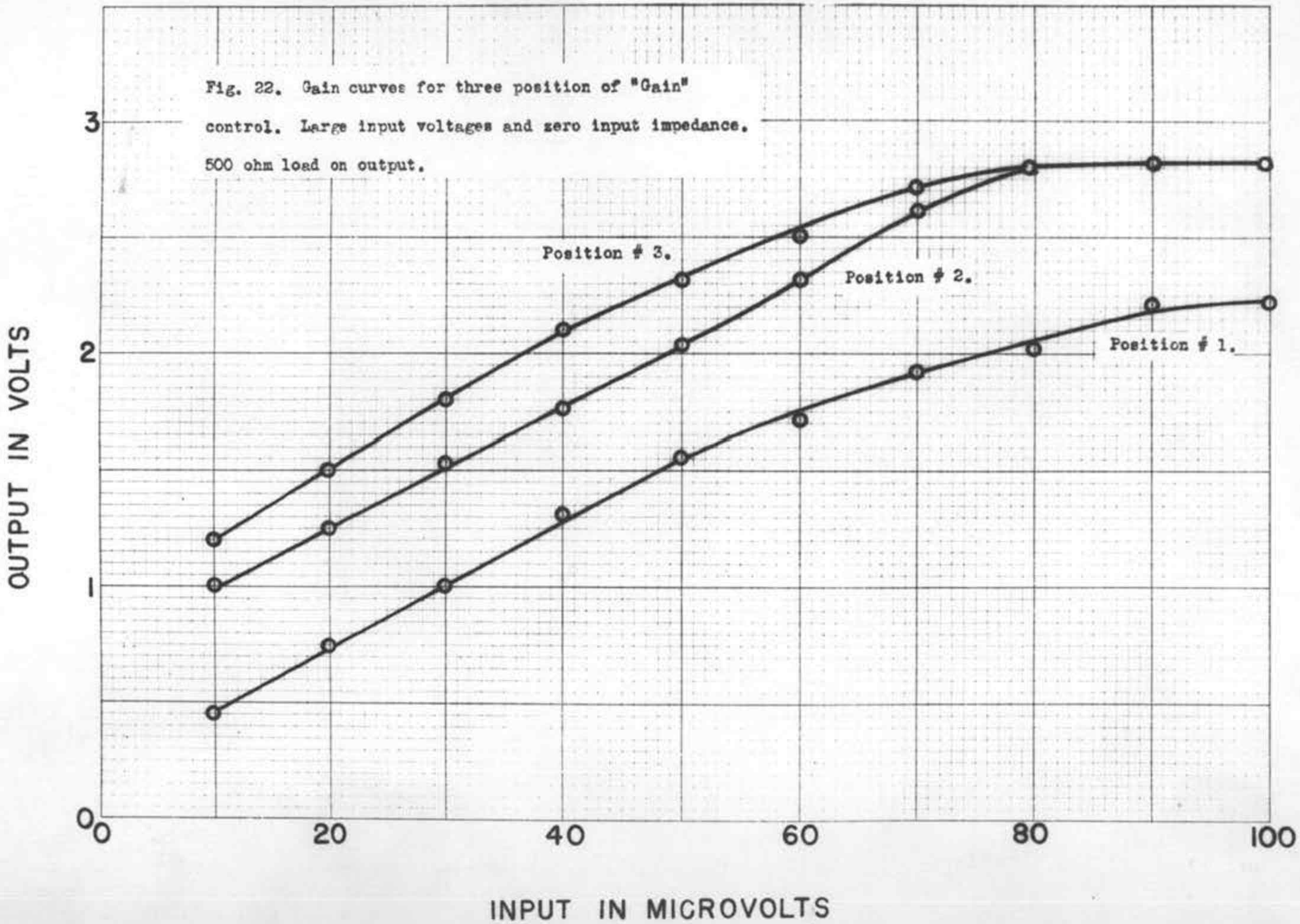


Fig. 22. Gain curves for three position of "Gain" control. Large input voltages and zero input impedance. 500 ohm load on output.

Fig. 22.

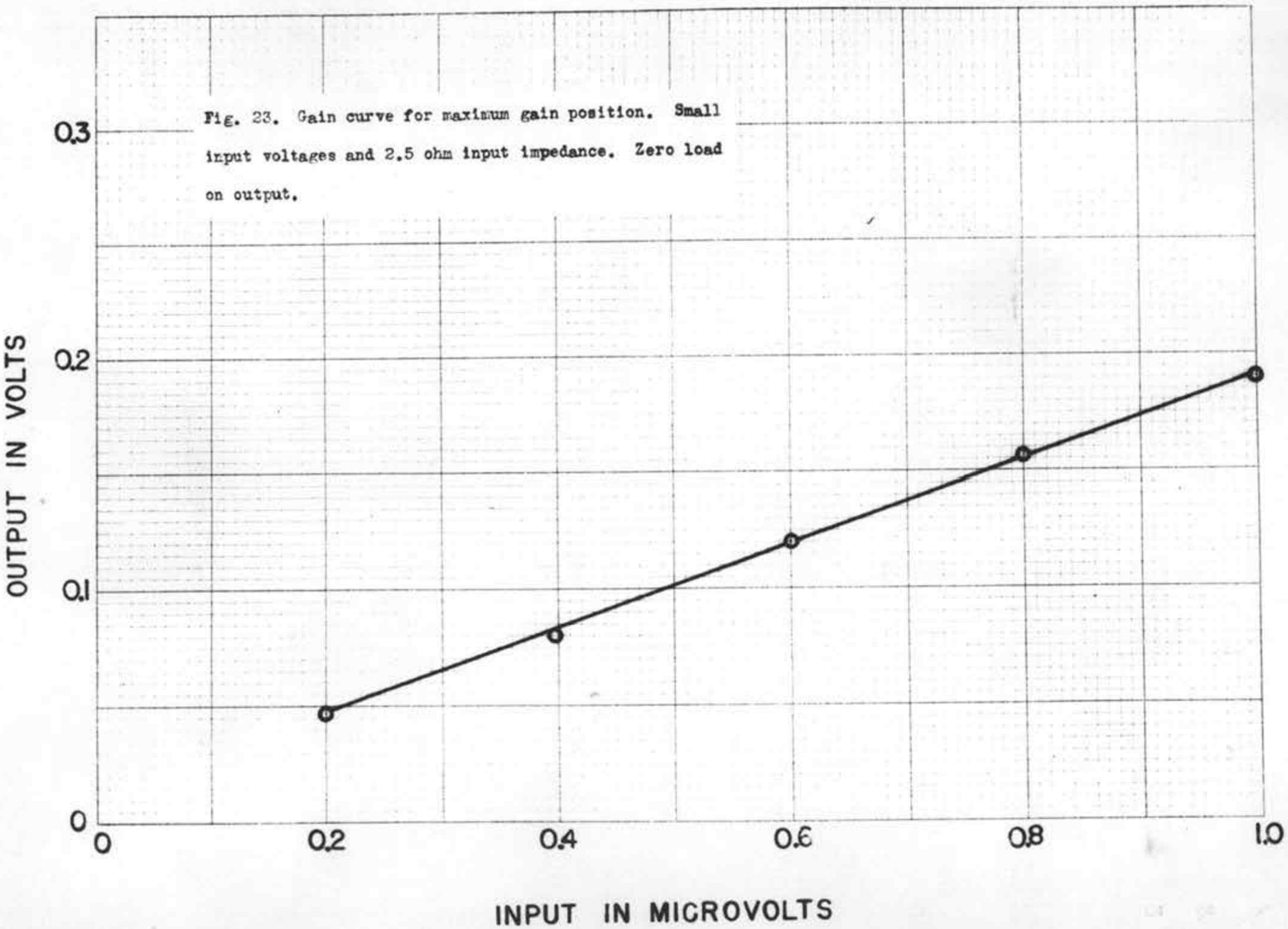
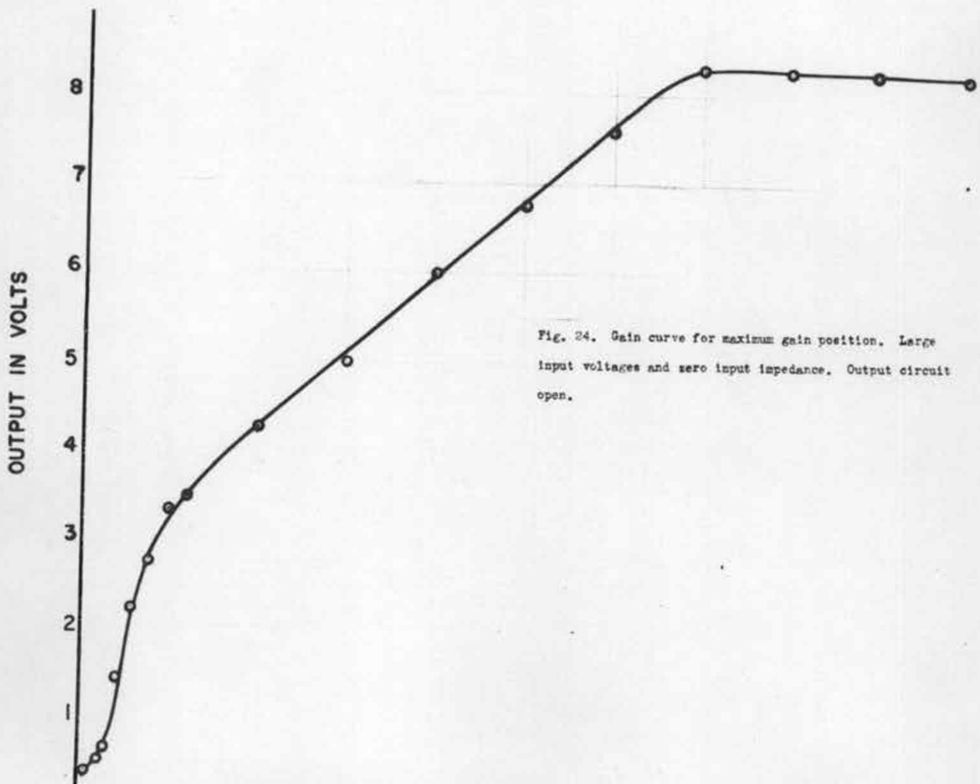


Fig. 23. Gain curve for maximum gain position. Small input voltages and 2.5 ohm input impedance. Zero load on output.

Fig. 23.



OUTPUT IN VOLTS
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
INPUT IN MICROVOLTS
Fig. 24. Gain curve for maximum gain position. Large input voltages and zero input impedance. Output circuit open.

Fig. 24.

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