A PHOTOMULTIPLIER TUBE INK THICKNESS MONITOR

by

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INTRODUCTION

A large portion of the carbon paper produced is of the type which is used for making a single copy as in invoice or account booklets. Once the carbon paper is used it is dispensed with, thus it becomes important to the paper manufacturer from an economical standpoint to produce a paper coated with just the necessary amount of carbon ink. The purpose of this thesis was to design and construct a device for indicating during the manufacturing process the amount of ink coated on the tissue paper.

During manufacture, the paper prior to inking is received in large rolls which may weigh several hundred pounds. When ready for coating the roll is mounted horizontally in an inking machine and the paper is fed through a series of idler rollers which aid in adjusting the tension of the paper. A large bath of carbon ink and wax is heated at a constant temperature above the machine. As the paper passes under this bath the hot fluid ink is fed onto the surface of the tissue by means of ink distributing rods. These rods allow the ink to be coated smoothly and evenly. At this point the paper passes around the surface of a large cooling drum which causes the wax in the ink to solidify immediately. The coated paper is then rewound onto another roll and may at some later date be cut into the required widths.

In the coating stage it is not always possible to maintain an even distribution of ink on the paper. Variations

in the tension of the unwinding paper as well as slight changes in the consistency of the ink on the coating rods may occur. Quite often it is difficult to remedy the fault immediately, and a large section of incorrectly coated paper may result. The manufacturer felt that some type of ink thickness indicator would be a marked asset during coating.

A specially constructed Beta-Ray Thickness Gauge was purchased. The gauge was designed to measure ratiation emitted from a small ratio-active source by using an ionization chamber. The coated paper when passed between the source and the chamber, absorbed radiation in proportion to its thickness. The resulting ionization current in the chamber then gave an indication of the thickness of the coating. This small voltage was amplified and then recorded by a strip recorder. During the testing of the apparatus it was found that a rather large error was produced by static electricity built up by the moving paper. The effect of the beta particles emitted by the source was masked by the static charges, and even the use of static eliminators proved unsuccessful.

Research was begun by Edward J. Brazill[1] using a multiplier phototube with a light source positioned behind the carbon paper. Changes in the coating thickness made the paper more or less translucent, and it was found that the multiplier phototube was very sensitive to these changes and could be used as a measure of the thickness of the coating.

As it was believed that phototubes could be employed as indicators during the inking process, this thesis was initiated to design and construct a workable apparatus for monitoring the ink coating. Before the building of such an apparatus was begun, a more thorough investigation was made of the use of photomultiplier tubes as ink thickness monitors.

In addition a small densitometer employing a photomultiplier tube was constructed for use by the manufacturer for making rapid determinations of the ink coating on various papers. Previously a small spring type balance, called a jolly balance, had been employed by the manufacturer for making these measurements. It was felt that the photomultiplier tube could pick up slight variations in the ink thickness more readily than the jolly balance.

An investigation was made of the possibility of distributing small ferromagnetic particles in the ink before coating and using a specially balanced coil to monitor any changes in the density of the particles. Thus this device would act as an ink density indicator. It was found that the device proved too insensitive to properly monitor the slight changes that occured due to variations in ink density.

IV

REVIEW OF LITERATURE

A. THE PHOTOELECTRIC EFFECT

Evidence of the photoelectric effect was first noticed by Hertz in 1887 while experimenting with the transmission and reception of electromagnetic waves created by a spark coil. He found that the spark in his receiving resonance circuit was strongest when light fell on the negative electrode[2]. Further investigation by such men as Lenard, Einstein, and Millikan showed the following laws to be true:

1. Before photoelectric emmission can take place from the surface of any given metal, the incident light must be above a certain critical frequency.

2. The maximum velocity of electrons emerging from the surface of a metal is independent of the intensity of the incident light.

3. The frequency of the light governs the energy of the emerging electrons according to the formula:

$$E_{max} = h\nu - P$$

where E_{max} = the maximum kinetic energy of the emerging electron,
h = Planck's constant,
ν = the frequency of the light,
P = the energy required for the electron to break away from the surface.

Hence the photoelectric effect was further evidence in support of the quantum theory[3].

B. PHOTOTUBES AND PHOTOMULTIPLIER TUBES

The average phototube contains a large cathode coated with

a photoemissive surface and a wire anode or electron collector. The tube may be a vacuum or gas type. The characteristics of the vacuum tube depend mainly on the type of cathode coating and the transmission characteristics of the glass envelope. The relation between light flux and current is nearly linear and the reaction time of the tube is extremely short. The gas tube is able to carry almost ten times the current of a vacuum tube because the gas molecules are ionized by the electrons. In both tube types the current to the anode is extremely small and must be amplified to prove useful[4 and 5].

To increase the current output of the phototube, the photomultiplier tube was developed. This type of tube takes advantage of secondary emission, an undesirable effect in most high vacuum tubes. When an electron of sufficient energy strikes a solid surface, part of its energy may be given up and thus release other electrons from the surface. Secondary emission becomes more pronounced as the incident beam of electrons is made more oblique and as the accelerating voltage increases. One of the best surfaces having high secondary emission ratios is Cs_3Sb. By having a cathode, a series of dynodes coated for secondary emission, and an anode a single tube may have a large internal gain. A diagram of the partition-type electron multiplier is shown in Figure 1A. The cathode, C, coated on the envelope inner surface, emits electrons when exposed to light. Because dynode 1 is positive with respect to the cathode, electrons are attracted through the partition and strike the dynode surface allowing more

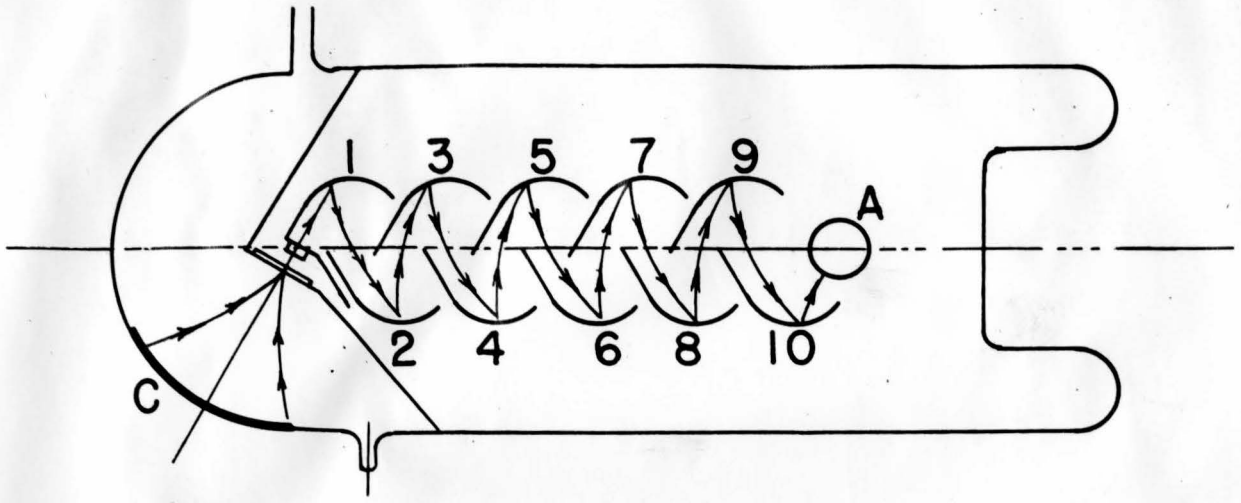


FIG. 1A. STRUCTURE OF PARTITION TYPE MULTIPLIER PHOTOTUBE

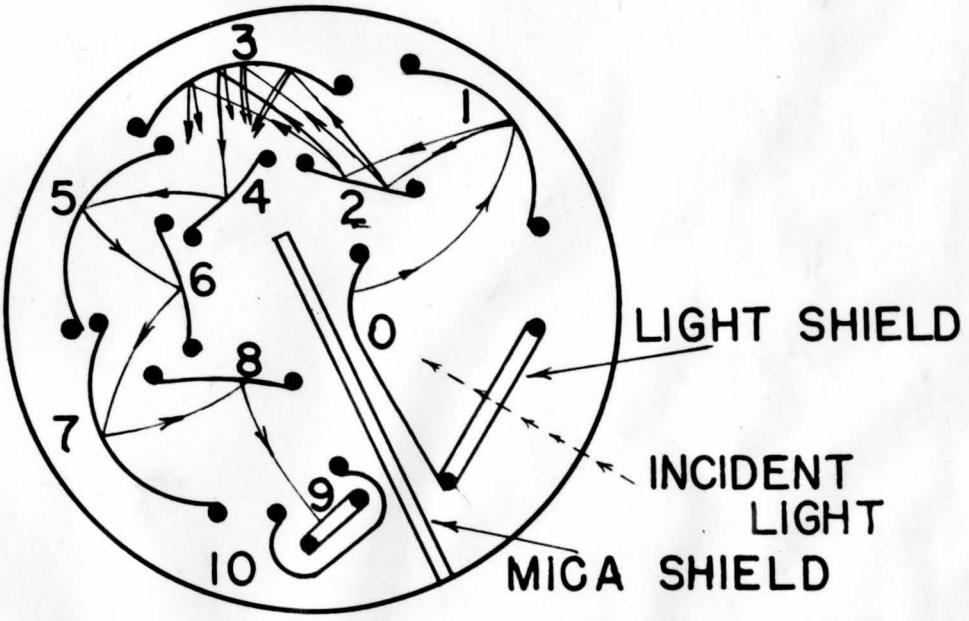


FIG. 1B. STRUCTURE OF CIRCULAR TYPE MULTIPLIER PHOTOTUBE

Key to Figure 1A

C - Cathode

A - Anode

1-10 - Focusing Dynodes

Key To Figure 1B

0 - photocathode

10- anode

1-9 - dynodes

electrons to be emitted. Each dynode is successively more positive and when struck by electrons in turn emits more electrons. Finally the electrons strike the anode, A, and are carried out of the tube. It should be noted from the diagram that the dynodes are properly curved to catch and refocus the electrons on the next dynode.[6]

A more compact arrangement for a photomultiplier is the circular type shown in Figure 1B. The 931-A tubes used in this research are of this type. This tube is most sensitive to wavelengths of approximately 4,000 Å. With 100 volts between dynodes and the last dynode and the anode, it is possible to get current amplification of one million. During experiments it was found that this tube was sensitive to ambient temperature changes, and it is recommended that for accurate readings over an extended period of time, as is the case in this research, that as nearly a constant temperature as possible be maintained. It was found also that the tube should not have an intense light concentrated on a single point of the cathode, for by doing so, a large number of electrons are released from a relatively small area, and thus it is possible to fatigue the cathode rather easily. The best method for reducing the amount of light striking the cathode is to employ filters (expecially in the red region) to absorb a portion of the light. A diminished light will then fall on the entire area of the cathode drawing a relatively few electrons from each point. Another method would be to use a

frosted glass which is semi-transparent.

V

PRELIMINARY INVESTIGATION

A. PRELIMINARY PHOTOMULTIPLIER TUBE STUDY

Before designing a workable apparatus employing the photomultiplier tube for monitoring the thickness of the ink being coated on a moving web of paper, it was decided that a more thorough study be made of the photomultiplier as used in this capacity. The main objective of this study was to investigate density changes of the tissue paper itself.

Since the density of paper on which the ink is distributed may vary to a small extent, it was desired to find the effect of these density changes on the photomultiplier tube as compared to changes in the density of the ink deposit itself. Sections of paper which had been coated only over one-half their surface were obtained. Using this paper, samples of both clear and inked sections could be taken from points relatively close together. Samples were checked against one another by both the photomultiplier tube and the analytical balance.

Measurements were made with the photomultiplier by having the multiplier housing mounted on an optical photometer chasis with a 150 watt projection lamp used as a source. A double convex lens was used to focus the light on the paper sample and another to focus the transmitted beam on the tube cathode. A 0-100 micro-

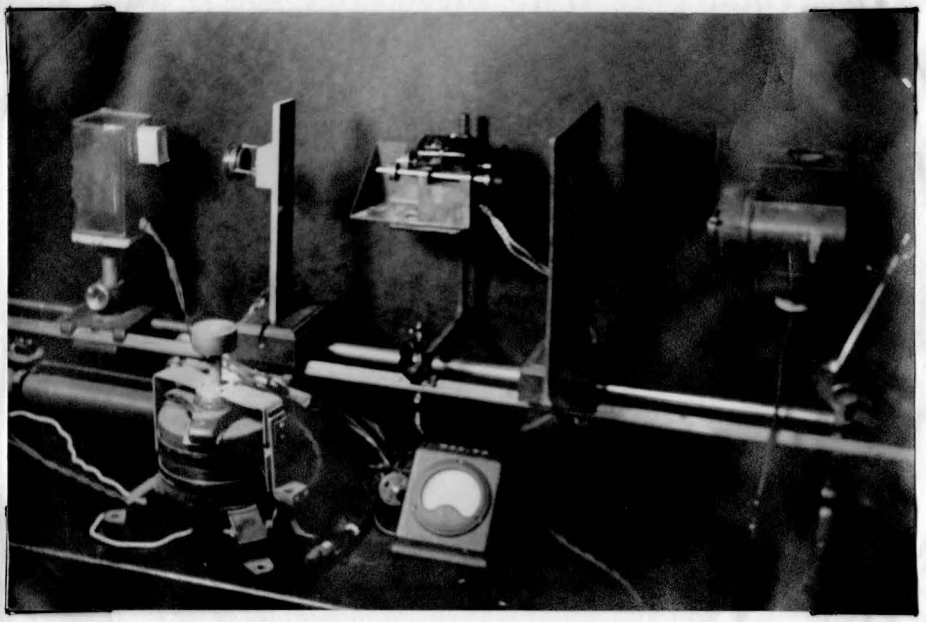


Figure 2. Apparatus for Preliminary Investigation of the Photomultiplier Tube.

TABLE I PHOTOTUBE READINGS OF ROLL "A"

a. Uncoated Area of Paper Next to Coated Section (Readings in microamperes)

Sample Number	By light coat	By medium coat	By heavy coat
1	73	75	78
2	70	75	75
3	71	81	77

b. Coated Paper (Readings in microamperes)

Sample Number	By light coat	By medium coat	By heavy coat
1	69	115	57
2	88	84	57
3	88	94	51

c. Weight of Uncoated Area of Paper Next to Coated Section (Readings in milligrams)

Sample Number	By light coat	By medium coat	By heavy coat
1	145.1	142.8	139.8
2	147.9	142.7	144.4
3	146.0	134.5	139.5

d. Weight of Coated Paper (Readings in milligrams)

Sample Number	By light coat	By medium coat	By heavy coat
1	184.5	193.5	201.6
2	182.4	192.8	199.2
3	184.5	190.4	201.1

TABLE II PHOTOTUBE READINGS OF ROLL "B"

a. Uncoated Area of Paper Next to Coated Section (Readings in microamperes)

Sample Number	By light coat	By medium coat	By heavy coat
1	75	84	82
2	71	83	75
3	72	81	92

b. Coated Paper (Readings in microamperes)

Sample Number	By light coat	By medium coat	By heavy coat
1	62	70	42
2	75	73	38
3	75	69	40

c. Weight of Uncoated Area of Paper Next to Coated Section (Readings in milligrams)

Sample Number	By light coat	By medium coat	By heavy coat
1	145.3	139.3	142.0
2	148.2	140.5	145.8
3	148.2	141.5	133.8

d. Weight of Coated Paper (Readings in milligrams)

Sample Number	By light coat	By medium coat	By heavy coat
1	186.7	194.6	200.8
2	190.8	190.7	203.8
3	192.1	194.3	200.1

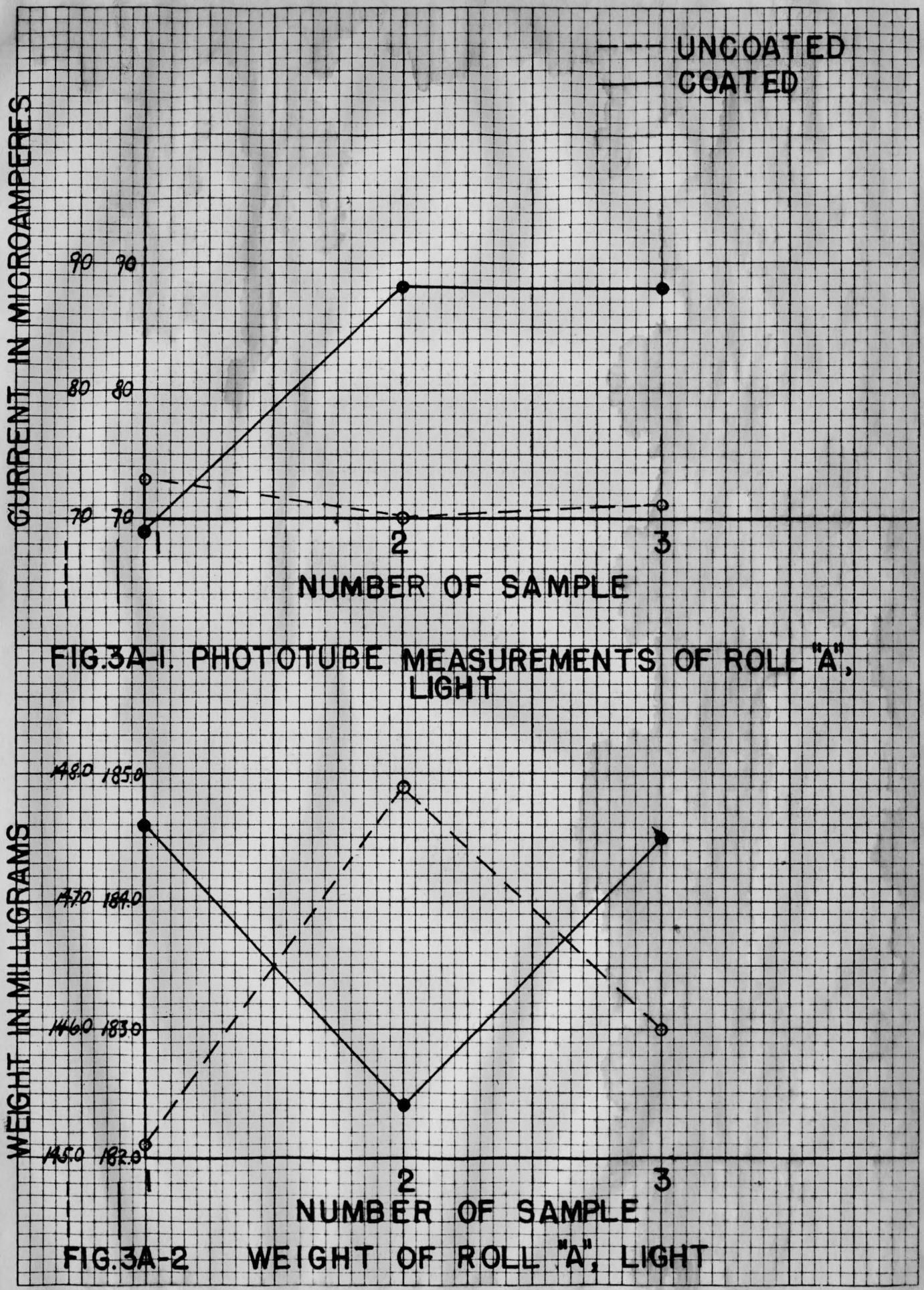
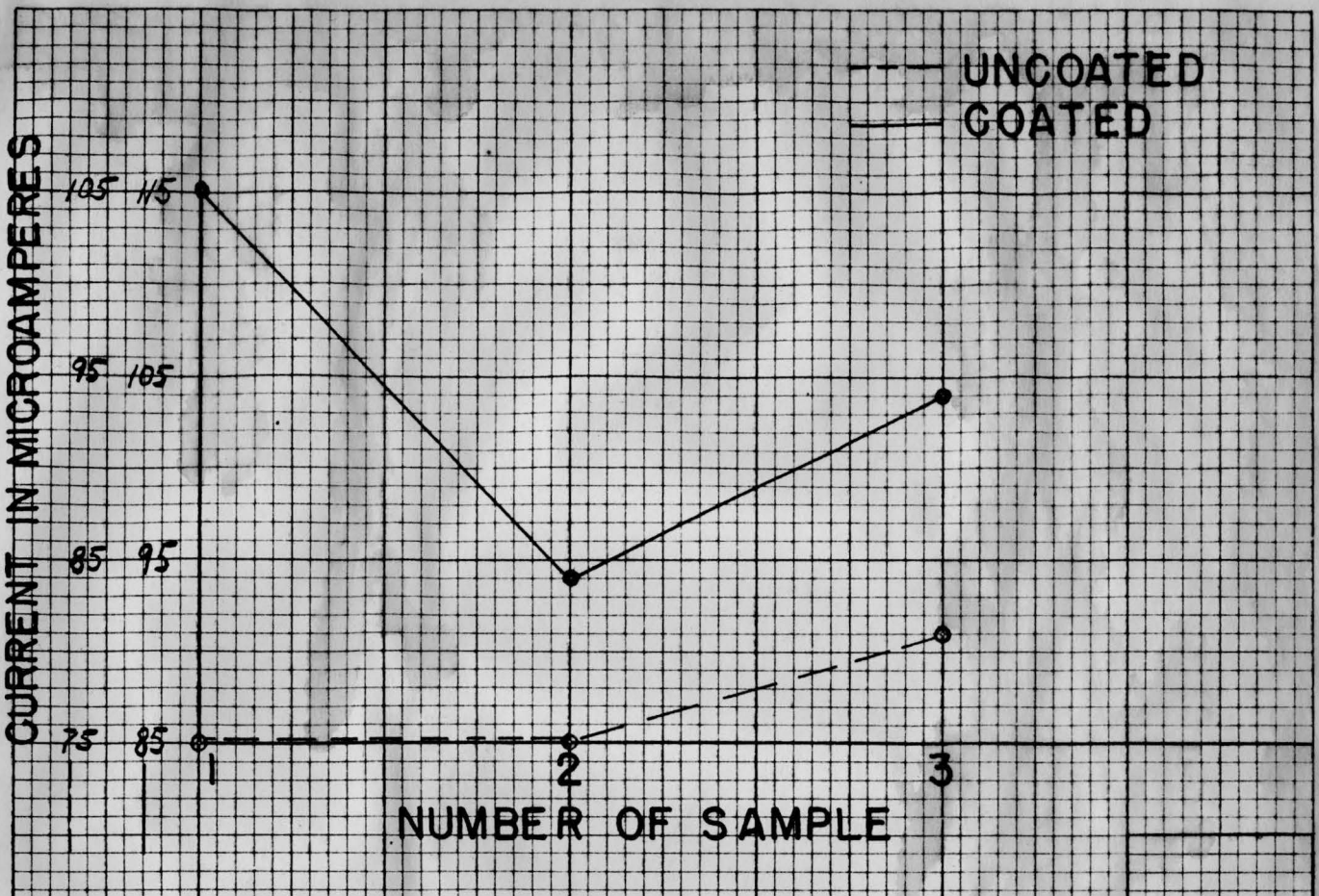


FIG.3A-1. PHOTOTUBE MEASUREMENTS OF ROLL "A", LIGHT

FIG.3A-2 WEIGHT OF ROLL "A", LIGHT



PHOTOTUBE MEASUREMENTS OF ROLL "A", MEDIUM
FIG. 3B-1

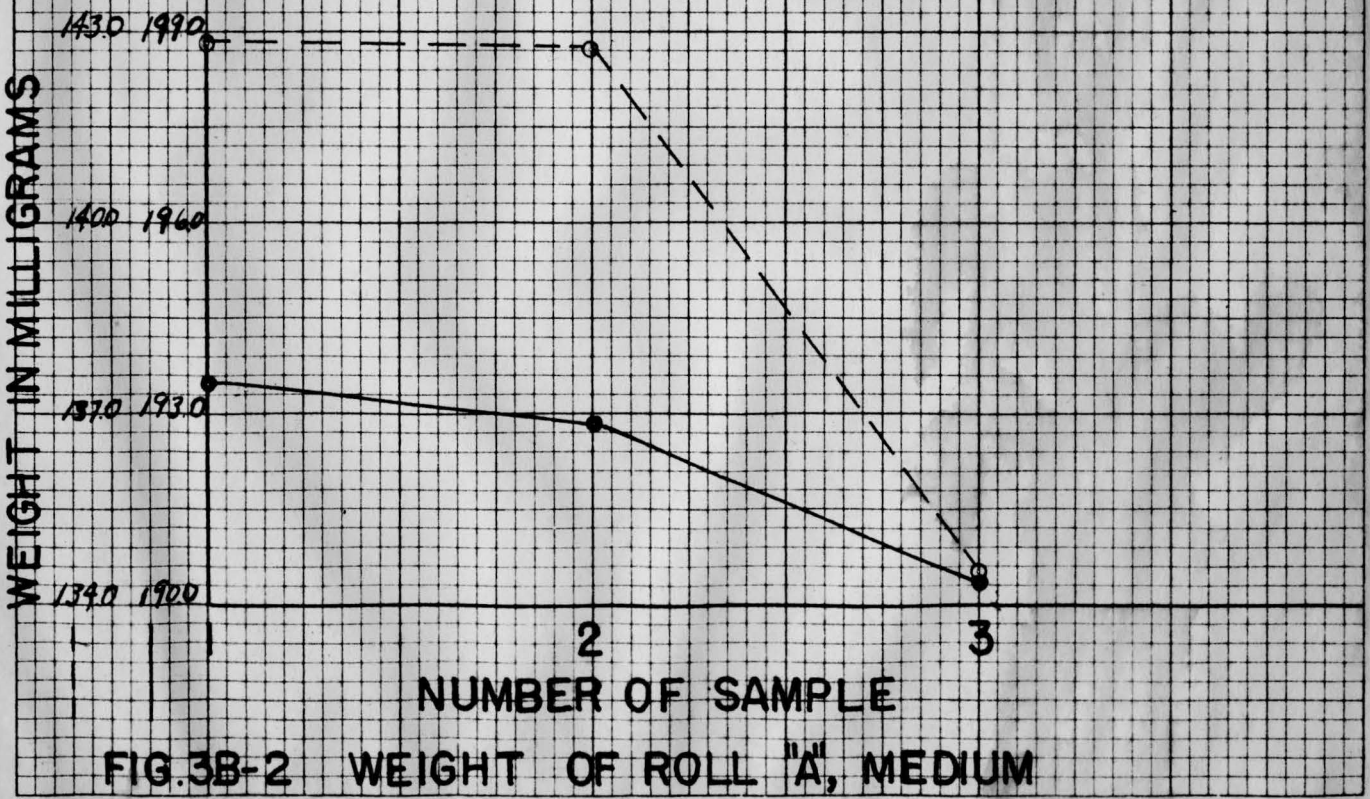
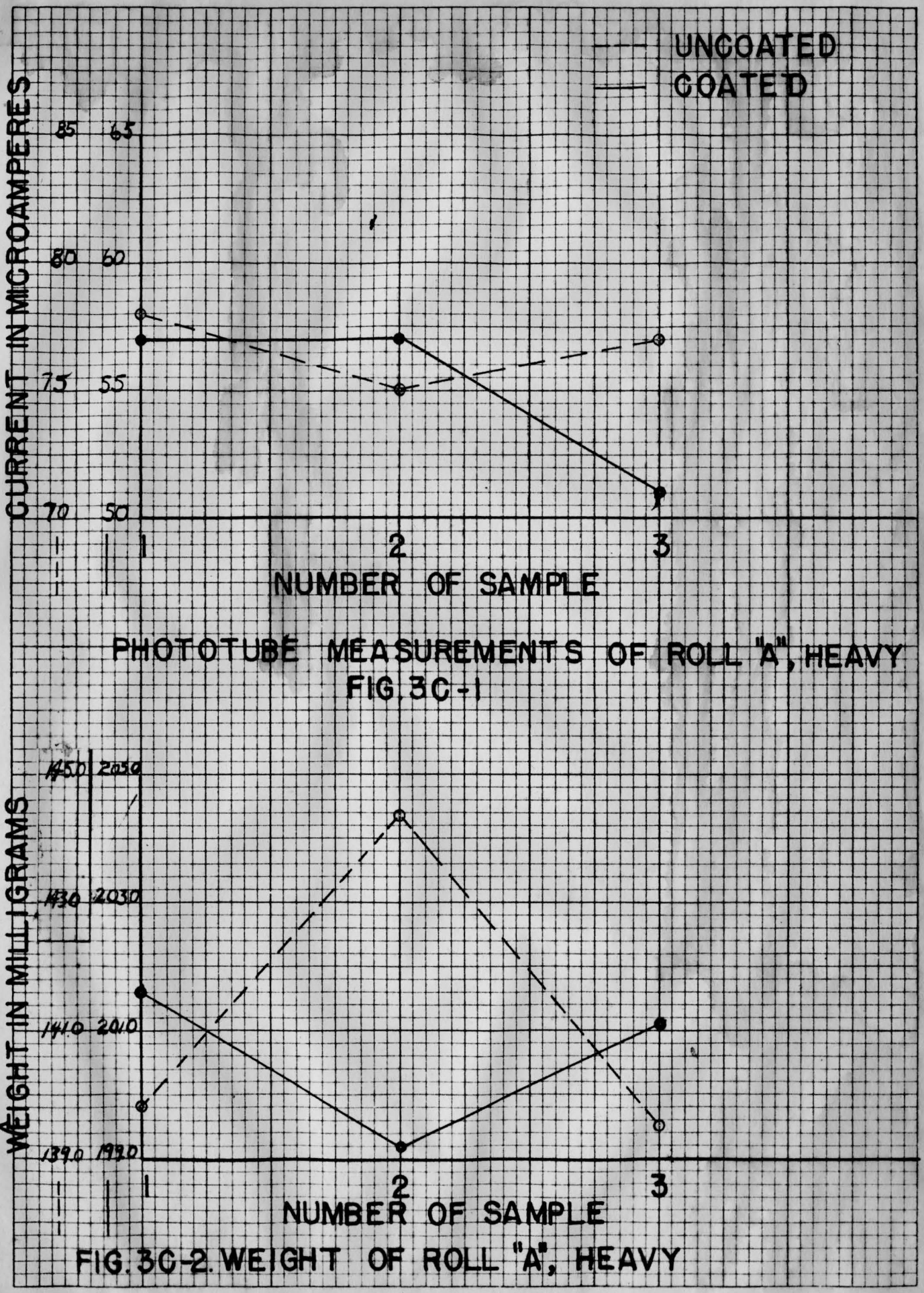
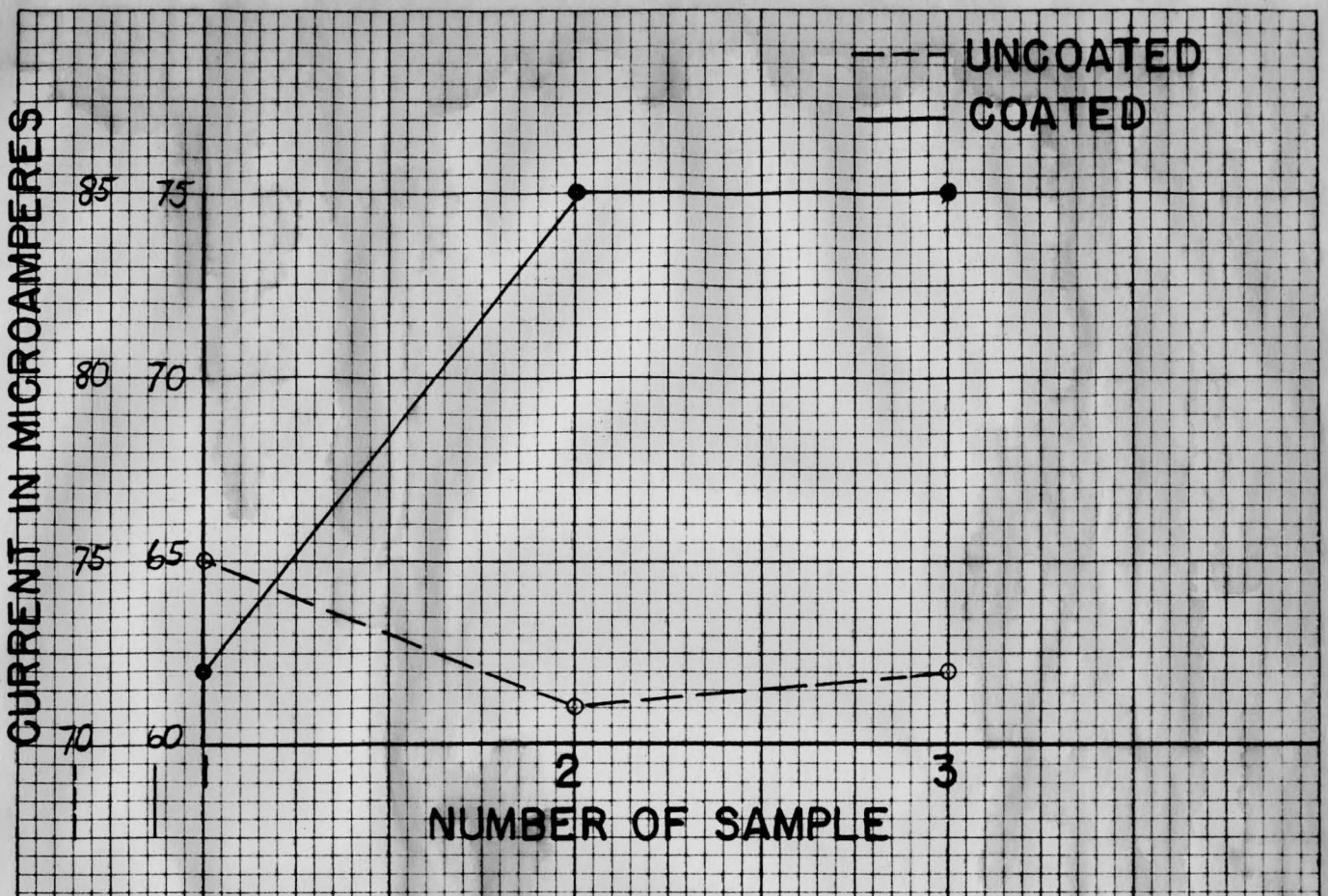


FIG. 3B-2 WEIGHT OF ROLL "A", MEDIUM



PHOTOTUBE MEASUREMENTS OF ROLL "A", HEAVY
FIG. 3C-1

FIG. 3C-2. WEIGHT OF ROLL "A", HEAVY



PHOTOTUBE MEASUREMENTS OF ROLL "B", LIGHT
FIG. 4A-1

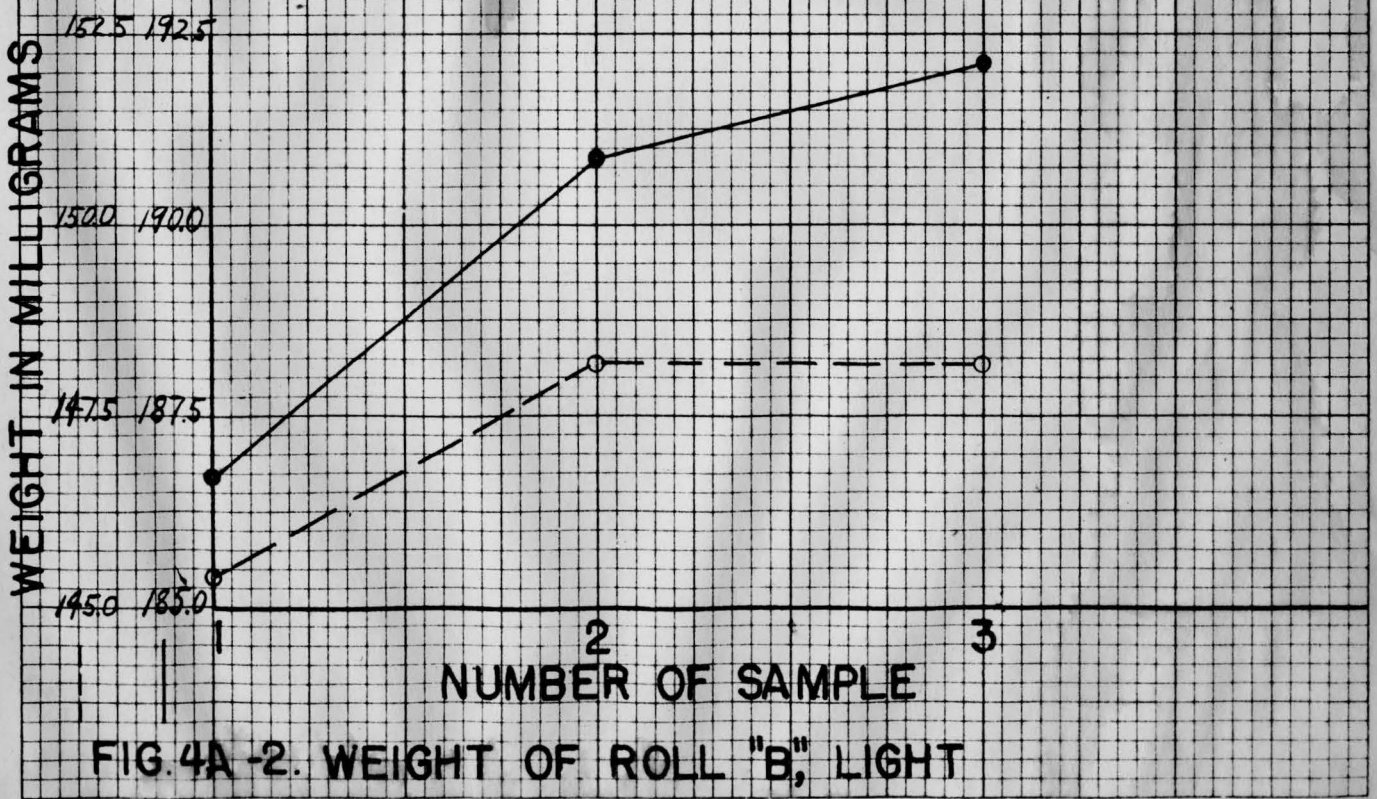
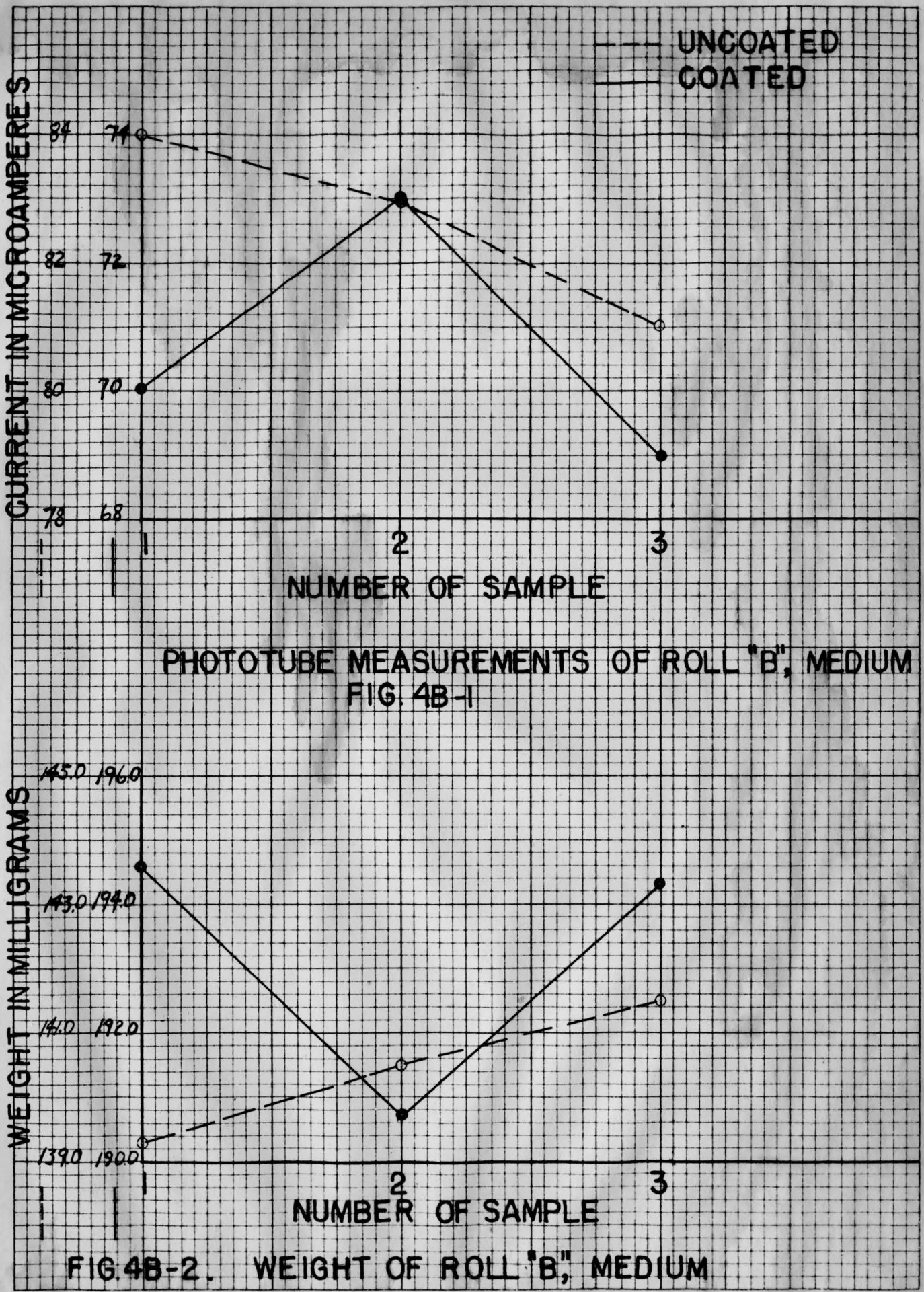
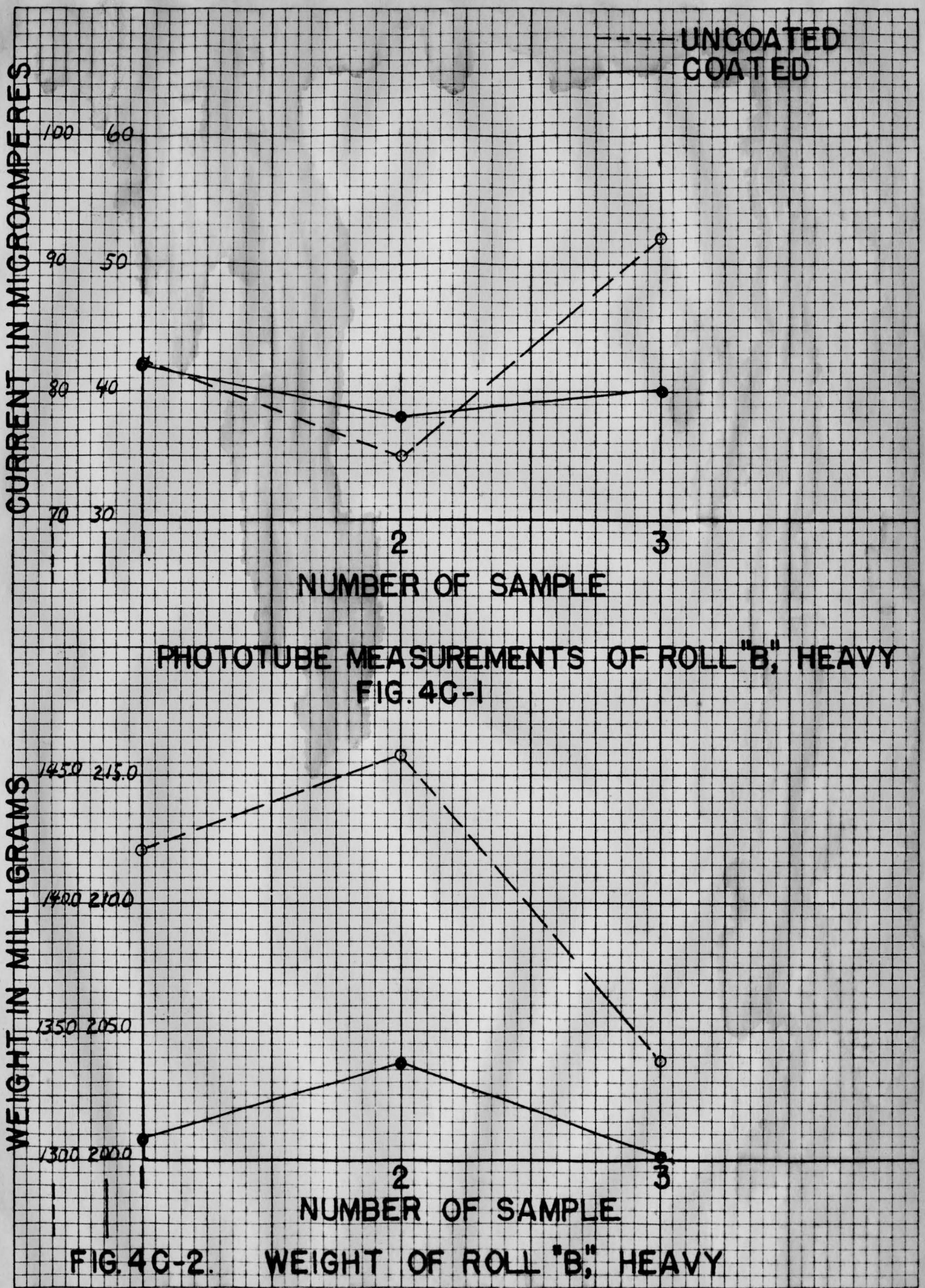


FIG. 4A-2. WEIGHT OF ROLL "B", LIGHT



PHOTOTUBE MEASUREMENTS OF ROLL "B", MEDIUM
FIG. 4B-1

FIG. 4B-2. WEIGHT OF ROLL "B", MEDIUM



PHOTOTUBE MEASUREMENTS OF ROLL "B," HEAVY
FIG. 4C-1

FIG. 4C-2. WEIGHT OF ROLL "B," HEAVY

ampere meter was placed in series with the anode circuit to indicate the intensity of light transmission. See Figure 2. The samples to be measured were cut in circular discs 3.36 inches in diameter and mounted on a shaft which was rotated by a small universal (AC-DC) series-field type motor. The speed of the motor could be controlled by a variac. Thus the rotating disc simulated the movement of the paper during manufacture. Each sample of paper had a clear and an inked disc taken from it. For each test several samples were taken from heavy, medium, and light paper to investigate density changes in each weight of coating.

Each disc was weighed on the analytical balance and a comparison made with photomultiplier readings. Figures 3A-1 to 4C-2 show these tests made on two rolls, "A" and "B". Agreement was found between paper density changes and changes of the readings of the coated paper in approximately fifty percent of the cases. Figures 3B-1, 3B-2, 4A-2, 4C-1, and 4C-2 show good correlation between the two changes. Figures 3A-1 and 4B-1 show partial correlation.

It was concluded from these tests that occasionally density changes in the paper may be recorded by photomultiplier measurement of the coated paper. In most cases these changes are relatively small and would not affect the final reading to a marked extent. It was decided that a compensating photomultiplier would be used in the ink monitoring apparatus to be designed in order to eliminate any major change that might occur in the paper density.

B. LIMITS OF INK COATING

It is desired during manufacture to keep the weight of the ink coating on the paper from 2.2 to 3.1 pounds per ream. A ream is 500 sheets of paper measuring 20 inches by 30 inches which represents 3×10^5 inches^2. The weight in grams of ink on the paper discs, 3.36 inches in diameter, was found on the analytical balance. By using the conversion equation:

wt. in grams x 75.3 16/gm-ream = lbs. per ream.

The different weights of paper may be checked with the manufacturer's specifications. It was found that most light paper was 2.8 lbs./ream; medium, 3.9 lbs./ream; and heavy 4.5 lbs./ream.

C. PHOTOMULTIPLIER TUBE DENSITOMETER

A densitometer employing the 931-A multiplier phototube was constructed to be used as a laboratory instrument for determining the density of ink coated on carbon paper. A diagram of the component parts is shown in Figure 5. The unit employs a 1000 V. power supply similar to the kind shown in Figure 12. A simple 931-A multiplier phototube enclosed in its housing was mounted in a manner such that a single slot in the top of the densitometer cabinet was the only opening through which light could pass to the tube. A small 6.3 volt bulb acting as a source was mounted in a housing on a hinged arm which allowed the source to swing down directly over the slot. The samples of paper to be tested could be positioned over the slot, and when the source

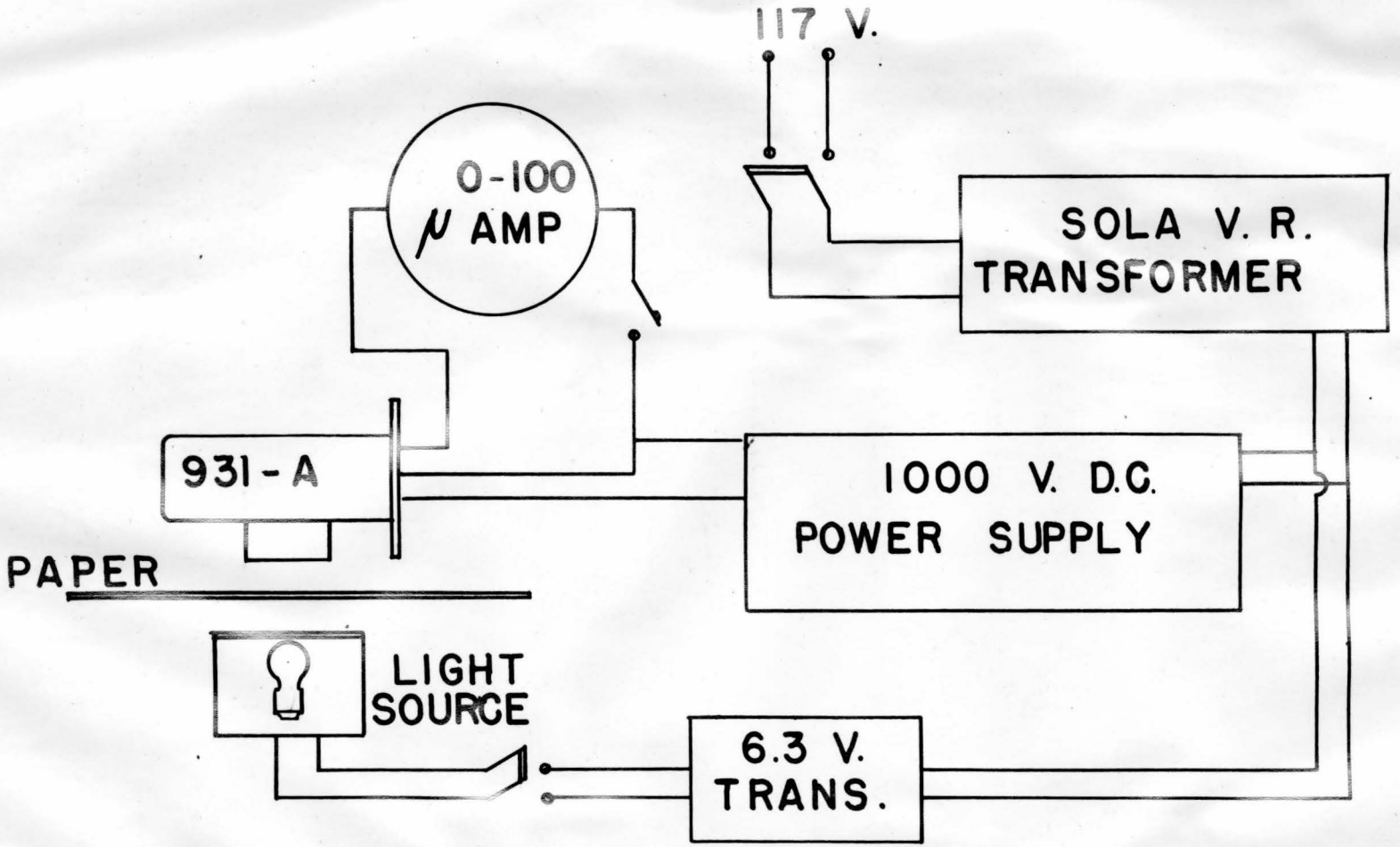


FIG. 5. BLOCK DIAGRAM OF
MULTIPLIER PHOTOTUBE DENSITOMETER

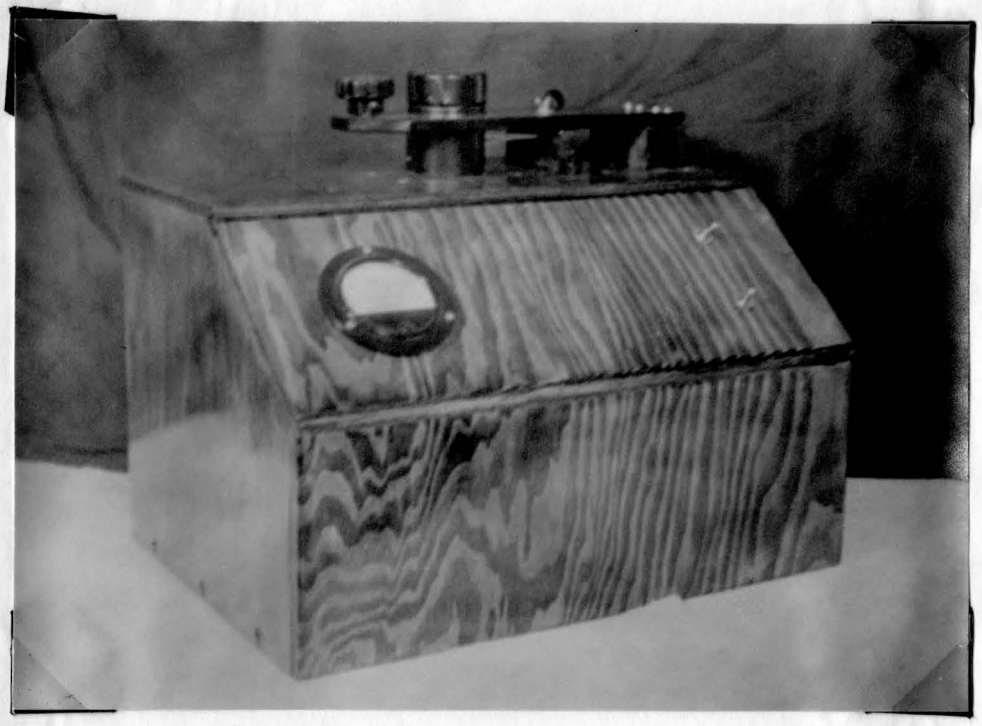


Figure 6A Front View of Photomultiplier Densitometer.

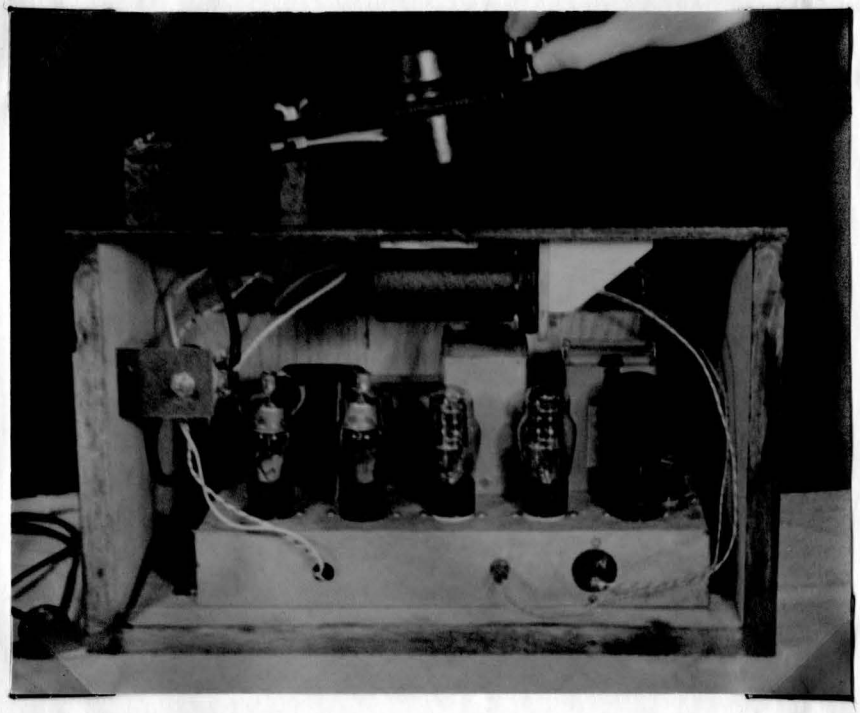


Figure 6B. Rear View of Photomultiplier Densitometer.

was swung down on top of the paper, a 0-100 microammeter indicated the quantity of light passing through the inked paper and thus gave a measure of the ink density. Within the cabinet were mounted the power supply, the photomultiplier tube and housing, the 6.3 volt transformer for the source, and the meter. A constant voltage transformer is necessary for accurate operation but was not built into the set.

The instrument can be calibrated to read between any limits of ink thickness that might be required by varying the intensity of the source. A paper with a minimum ink thickness is first placed in the instrument and the intensity of the source varied to give nearly a maximum meter reading. Then a paper of maximum thickness is placed in the instrument and the reading noted. After this, any paper may be determined as the meter reading is a linear function of the ink thickness.

D. QUANTITATIVE FERROMAGNETIC INDICATOR

Apart from the investigation of the use of photomultiplier tubes to monitor ink density changes, a ferromagnetic indicator was studied. This device was to be used to give a quantitative indication of the amount of ferromagnetic particles present in a given area. Ferromagnetic particles with a high permeability would be mixed in the ink before coating. The density of the particles in a given area would then serve as a measure of the weight of the ink coating in that area. [7 and 8].

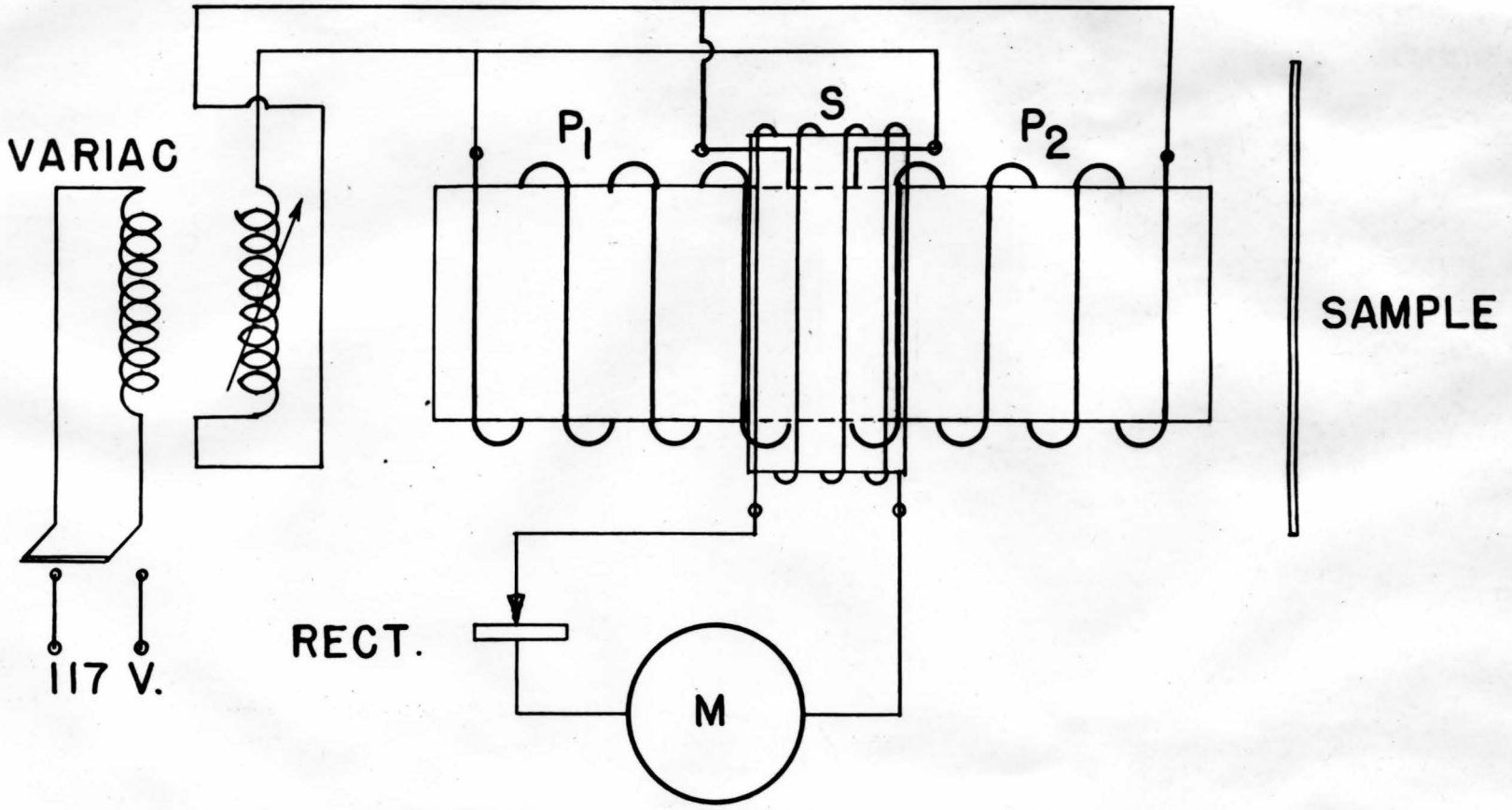


FIG. 7. DIAGRAM OF FERROMAGNETIC INDICATOR

Key to Figure 7

P_1 - primary coil winding

P_2 - primary coil winding

S - search coil

M - 0-50 microammeter

Rect. - Selenium rectifier

Sample - ferromagnetic sample to be tested.

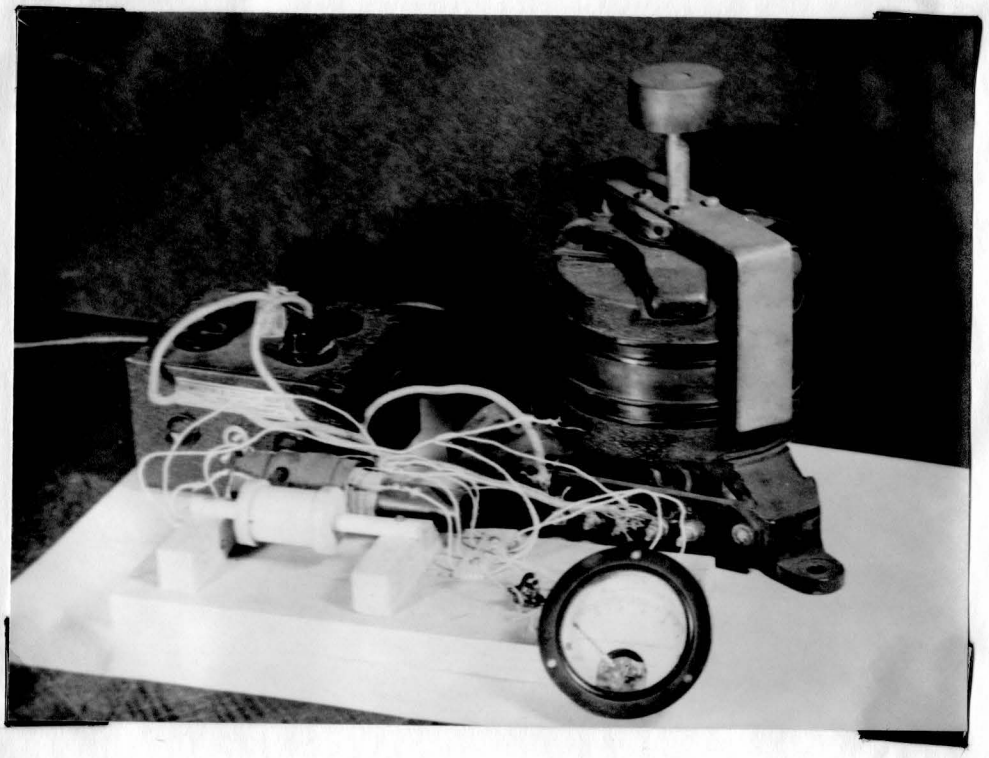


Figure 8. View of Ferromagnetic Indicator.

An indicator (see Figure 7) was constructed employing two opposed primary coil windings positioned adjacent to each other on the same axis. The coils were wound around a hollow, non-magnetic, non-conductive cylinder, thus enabling any type of core to be inserted. A movable search, or secondary, coil was then placed over the adjacent point of the two primary coils. When an alternating current was passed through the primary coils, a secondary current was induced in the search coil. This secondary current was rectified and read by a d.c. microammeter. By moving the search coil a balance point could be reached between the two opposing coils, and at this point there was no current in the search coil. Now by introducing a ferromagnetic substance within the vicinity of the end of either primary coil, the permeability of the core of that coil could be changed. The balance of the search coil would then be affected, and a current would be established in the secondary winding which would be indicated on the meter.

It was found that the permeability change caused by a carbon paper with ferromagnetic particles distributed in the ink was too slight to be measured by the instrument. It was decided that the photomultiplier tube would prove a more sensitive measuring device for ink thickness.

VI

PRIMARY INVESTIGATION

A. INTRODUCTION

In order to simulate the movement of the carbon paper as it

is coated during manufacture, a special unwinding device was constructed by the manufacturer to be used in this thesis. An ink coating monitoring device was then designed and constructed under the thesis to measure and record the thickness of the ink coated on the tissue paper.

The apparatus of the complete measuring unit can be divided into four main parts which are (1) the rewinding device or machine for similating the movement of paper during manufacture which allows a roll of paper to be unwound and rewound, (2) the phototube heads and the stand which allows them to be properly positioned over the moving paper, (3) the control units which contains necessary power supplys and relays for operating the phototubes, and (4) the recorder and its amplifier for making a continuous record of changes in ink density.

As the paper is passed through the photohead units, an indication of the density of the paper can be had either by using the dial meter on the control panel or the recording meter.

B. DESCRIPTION OF APPARATUS

1. The Rewinding Device

The rewinding device (See Figure 9) handles a roll of carbon paper eight inches wide and approximately 6,000 feet long. The roll is mounted on a spindle which rides in a roller bearing cradle. This movement may be completely free or it may be retarded with a brake shoe on one side of the spindle. Paper is fed from this roll over a set of horizontal rollers which hold a section of the paper in a suitable position for placing the

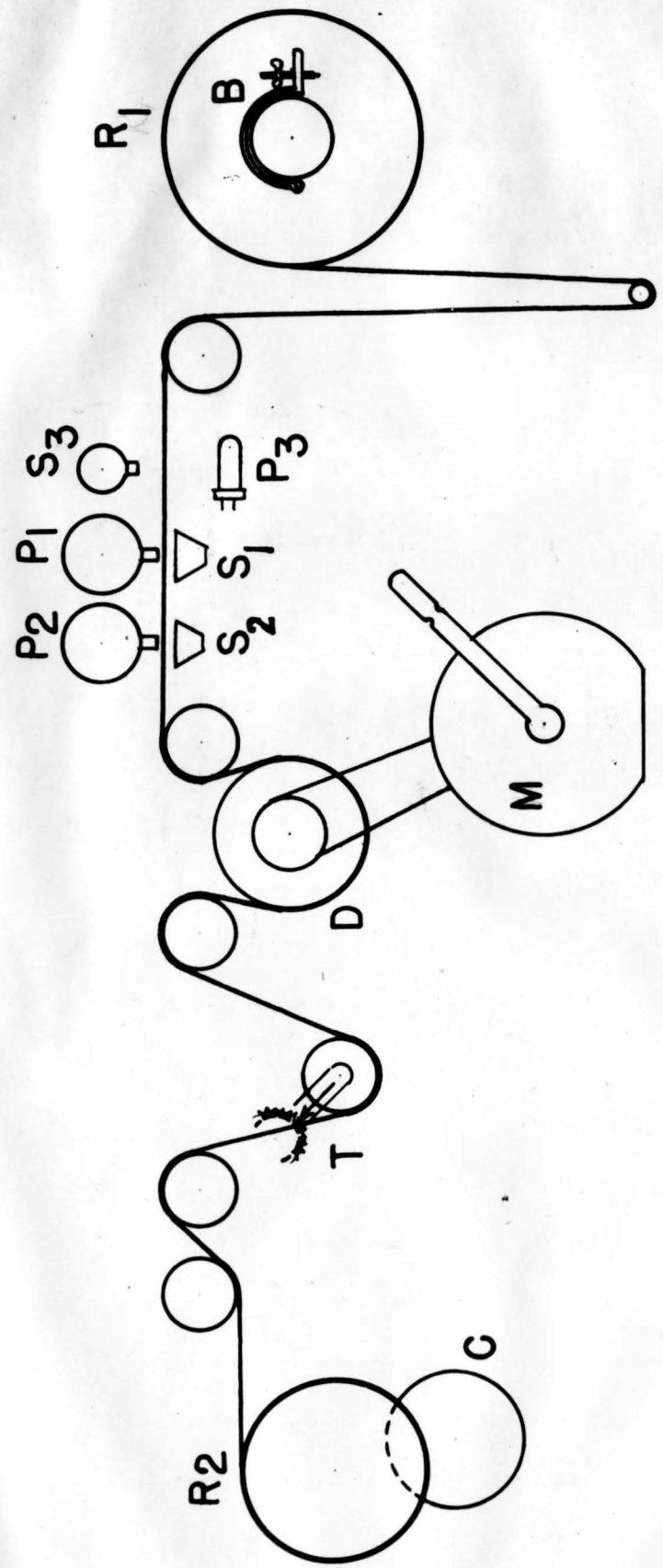


FIG. 9 DIAGRAM OF REWINDING DEVICE

Key to Figure 9

R_1 - roll being unwound

R_2 - roll being wound

C - magnetic clutch

T - rheostat controlling idler

D - driving drum

M - variable speed drive

P_1 - main photomultiplier head

P_2 - compensating photomultiplier head

P_3 - photoelectric tube

S_1 - source for P_1

S_2 - source for P_2

S_3 - source for P_3

B - brake on unwinding roll.

phototubes over the surface. From this point the paper is passed around a driving roller which may be run at various speeds by a variable diameter pulley drive. Then the paper is fed over a roller on a lever arm which actuates a rheostat. This rheostat is connected to a magnetic clutch on the final winding drum and allows a constant tension to be kept on the paper. The magnetic clutch may be controlled by a manual rheostat and thus increase or decrease the tension.

2. The Phototubes

Two 931-A photomultiplier tubes are positioned over the paper, one aligned directly over the inked portion of the paper and one over the clear portion. Each tube is enclosed in a housing which is light tight except for a single opening. It is necessary that this opening be as close to the size of the cathode as possible to allow light to strike the whole cathode area. Fitted over the opening is a filter holder to allow as many filters as necessary to be added to reduce the light to the required minimum. Each of these tubes is mounted on an arm which holds the light source for the tube. See Figures 9 and 16. These sources are 6.3 volt bulbs in a housing which allows light to pass out through a diffusing screen onto the underside of the paper. The phototubes are mounted directly above these positions. Each arm holding a tube and source can be moved horizontally across the paper to cover any section desired. A reciprocating device may be mounted on the arm covering the inked portion to allow the head to have a transverse movement which will avoid a continuous reading of streaks in the

ink. A third photoelectric tube (see Figure 9) is mounted ahead of the photomultipliers. When the inked portion of the paper becomes clear this photoelectric tube actuates a relay which opens the photomultiplier circuit and prevents fatiguing of the photomultiplier which under these conditions would be exposed to a strong light. The photoelectric tube (type CE-2-T) has a very small anode current, and for this reason, the tube cannot be separated from the amplifier chassis and still retain the desired sensitivity. The complete unit is therefore mounted below the paper and the source mounted on the third arm of phototube rack. See Figures 9 and 11.

3. The Control Unit

The control unit contains (1) the power supply (see Figure 12) for both photomultiplier tubes. This unit employs two 2X2 rectifier tubes used as voltage doublers in order to supply from 900 to 1,200 volts output; (2) a 117-volt constant voltage Sola transformer from which all power used by the electronic equipment is taken, (3) a 6.3 volt transformer for the three light sources used, (4) a relay system for opening the photomultiplier circuits; (5) a panel of switches for all equipment, and (6) a 0-50 microampere meter in the photomultiplier circuit.

4. The Recorder and Amplifier

For a continuous record of changes in ink density along the entire roll of paper, a strip recorder is used. This instrument is an Esterline - Angus - 0-1 milliampere d.c. recorder requiring

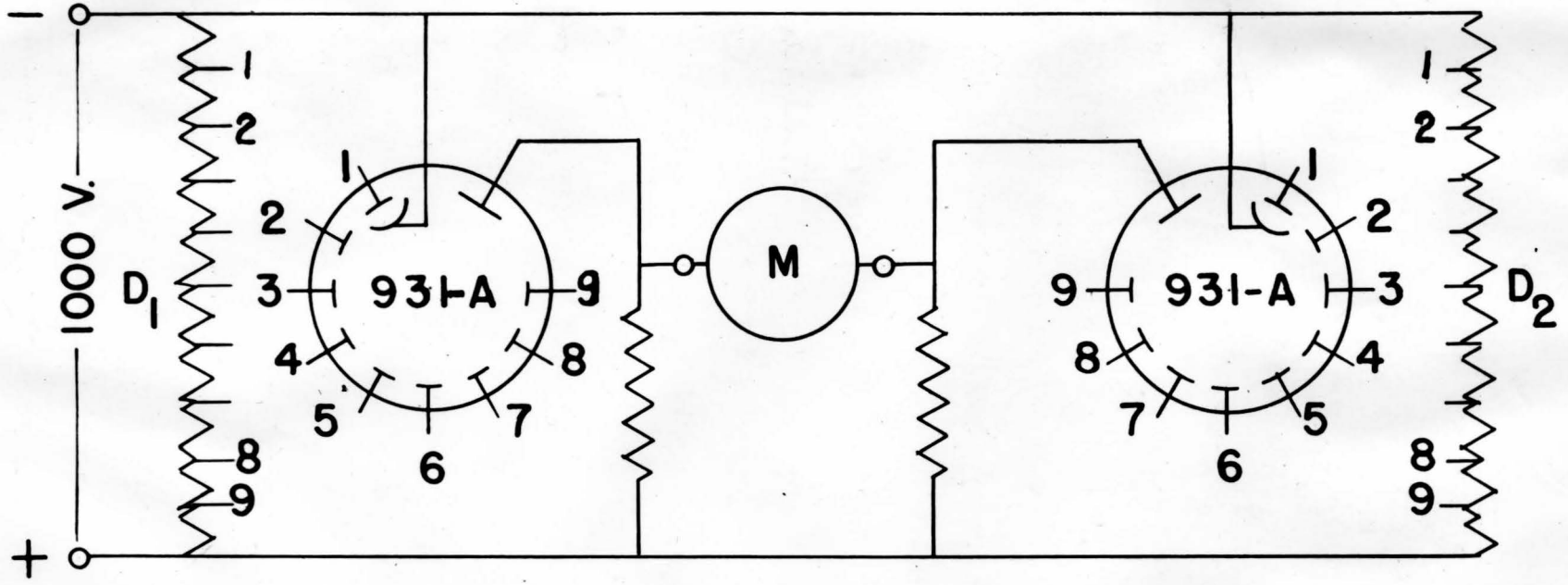


FIG. 10. DIAGRAM OF COMPENSATING MULTIPLIER PHOTOTUBE CIRCUIT

Key to Figure 10

D_1 - Voltage divider network

D_2 - Voltage divider network

M - Voltmeter or recorder

Resistances in anode circuits are 1000 ohms. Anode current causes RI drop and voltmeter M registers amount of drop.

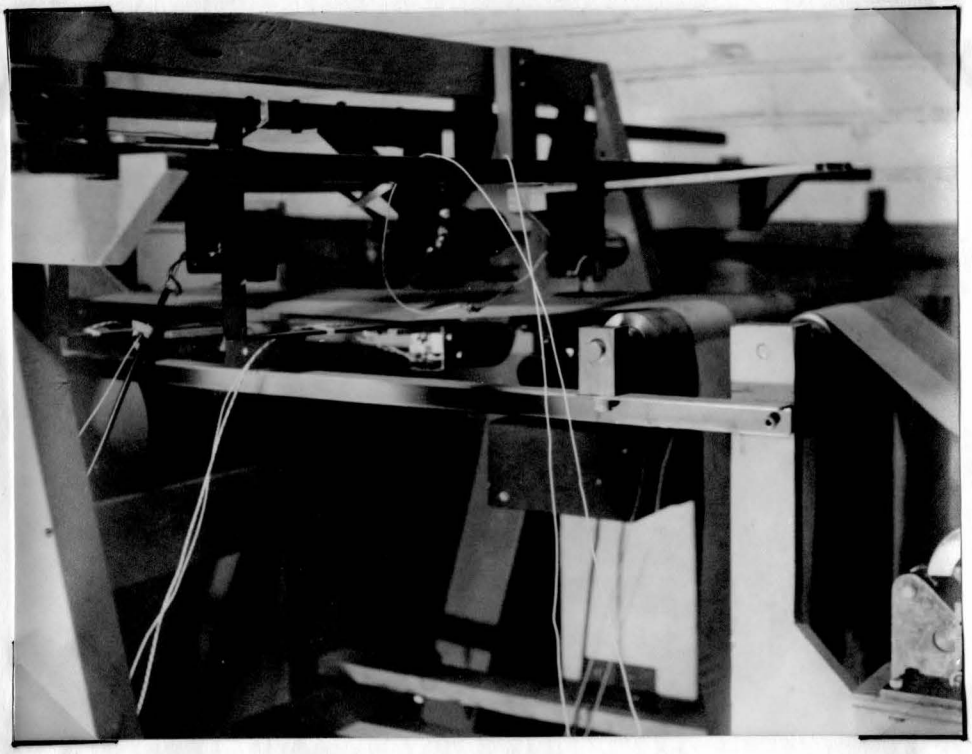


Figure 11. View of Phototubes over Paper.

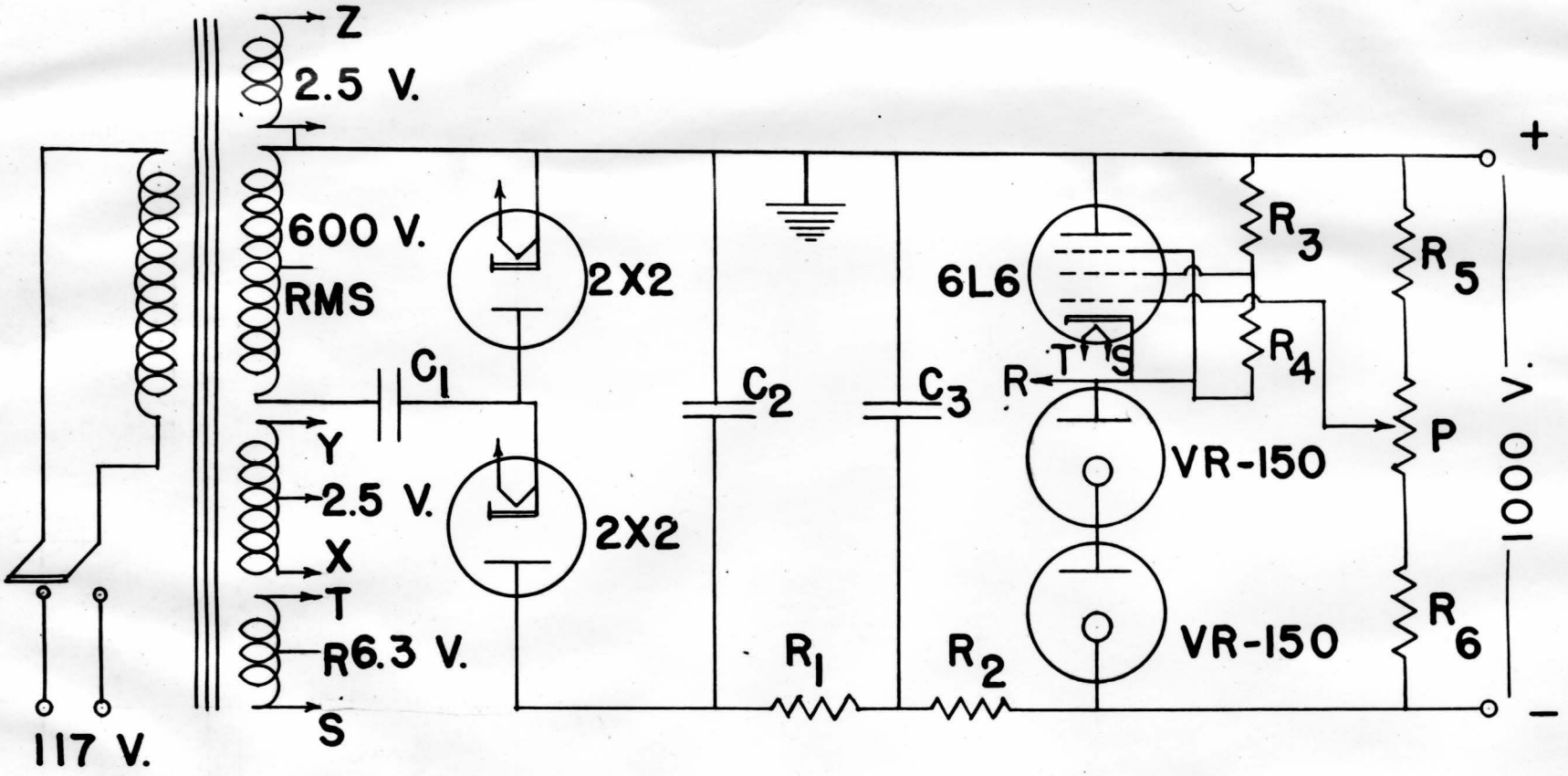


FIG.12. DIAGRAM OF POWER SUPPLY

Key to Figure 12

R_1 - 15,000 ohms, 2 watts

R_2 - 7500 ohms, 2 watts

R_3 - 0.5 megohm, 1 watt

R_4 - 20,000 ohms, 1 watt

R_5 - 0.7 megohm, 1 watt

R_6 - 0.27 megohm, 1 watt

P - 1 megohm, potentiometer

C_1 - 1 microfared, 3000 volts

C_2 - 2 microfarads, 3000 volts

C_3 - 2 microfarads, 5000 volts

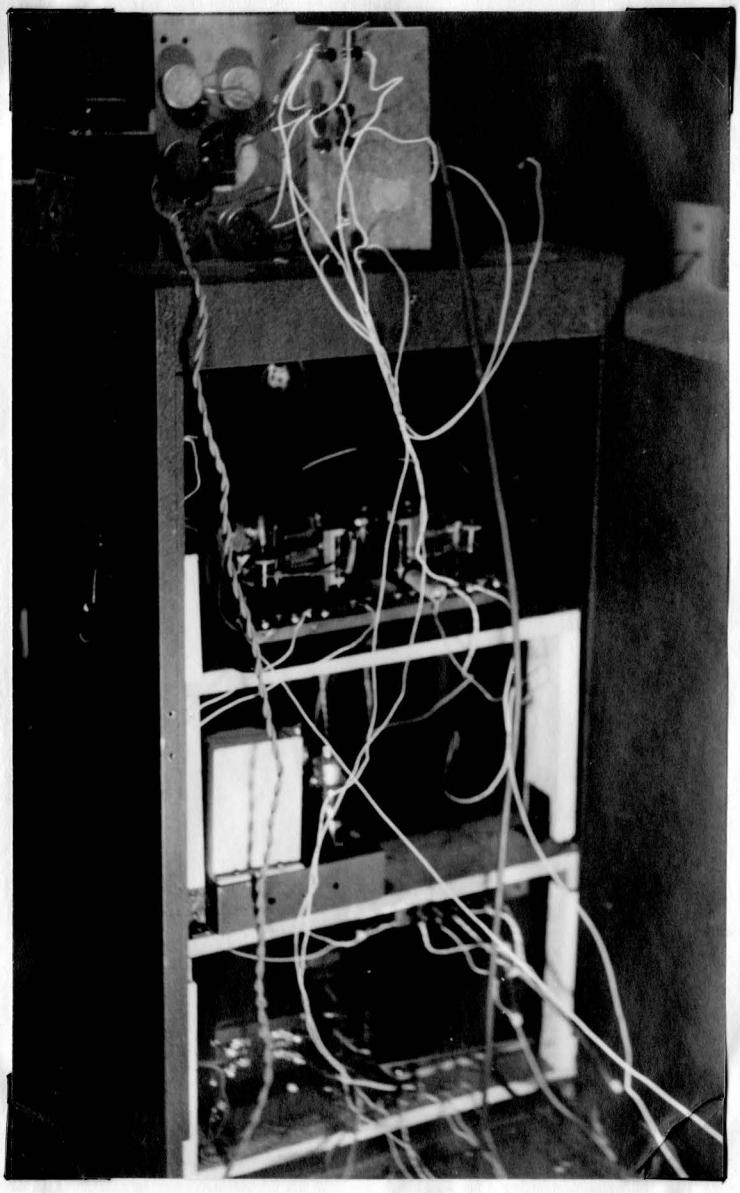


Figure 13. Rear View of Control Panel Showing D.C. Amplifier on Top of Cabinet, Relays on Top Shelf, and Powder Supplies on Lower Shelves.

1.4 volts to give a full scale reading of the meter. The chart drive unrolls the recording chart at either 3 inches per hour or 3 inches per minute.

The voltage and current output of the photomultiplier circuit were insufficient for successful full scale deflection of the recording milliammeter, thus a d.c. voltage amplifier was necessary. See Figure 14. The amplifier used employs two 12AT7 duo-triode miniature tubes with a cathode to cathode connection of the meter. A power supply of 260 volts is necessary for sufficient amplification. The unit is capable of amplifying the 50 microamperes at 0.2 volts input to over 1 milliampere at 1.4 volts and higher.

C. Procedure

1. Procedure Using Meter

The paper tested in this research was coated with three types of ink: TW-10, TW-12, and X-75*. Each roll was eight inches wide with half of the width inked and the other half clear. Three segments of approximately two thousand feet each made up the complete roll. Each segment was coated with a different weight of ink varying from light to heavy.

When loaded on the unwinding machine, the paper is put under a slight tension by the magnetic clutch on the receiving spindle. At this position both photomultipliers and the photo-electric tube may be adjusted. The main photomultiplier head is aligned in the central section of the inked side of the paper

* Manufacturer's Code Numbers

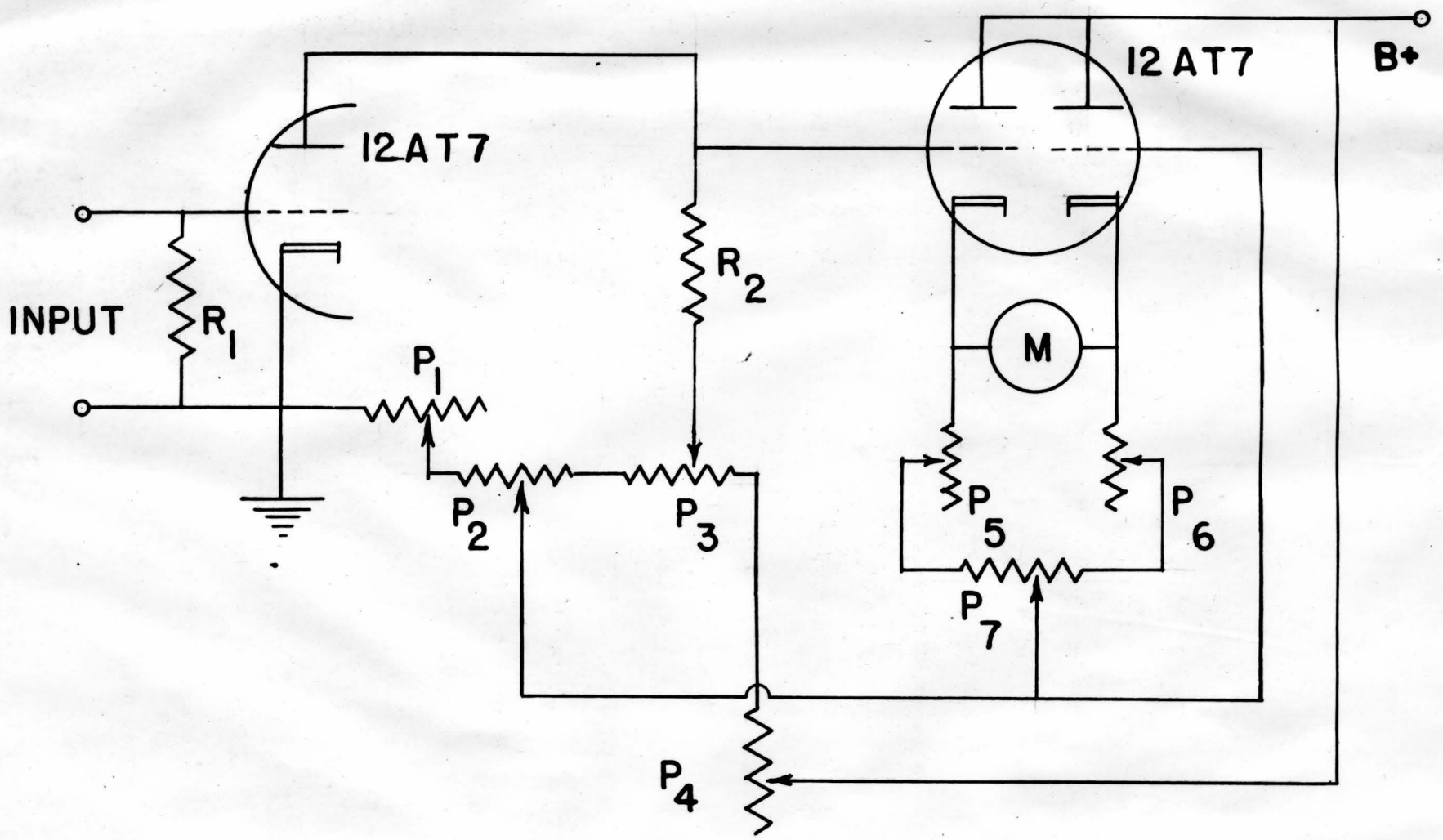


FIG. 14. DIAGRAM OF D. C. AMPLIFIER

Key to Figure 14

R_1 - 1 megohm

R_2 - 5000 ohms

P_1 - 5000 ohms

P_2 - 1000 ohms

P_3 - 1000 ohms

P_4 - 5000 ohms

P_5 - 1000 ohms

P_6 - 1000 ohms

P_7 - 1000 ohms

M - recorder meter

B+ - 260 volts

P_5 and P_6 on same shaft.

while the compensating head is set over the clear side. Directly behind the main photomultiplier head, the photoelectric tube is positioned under the inked region and its light source aligned directly overhead. As soon as a section of inked paper becomes clear between segments, or is accidently broken, the photoelectric tube receives sufficient light from its source to cause the relays (see Figure 16) to be tripped. The relays, when tripped, open the meter and the main photomultiplier circuit. Thus a strong light falling on the main photomultiplier is not able to fatigue the tube by causing an excessive current from the cathode. Neither is the meter harmed by too great a current.

In order to allow the powder supply to become stable it should be turned on at least a half hour before operation is to begin. See TableIII and Figure 18. To obtain a balance between inked and clear portions of the paper is is necessary first to know the limits of the ink density which are to be recorded. This determination should be made prior to testing a complete roll by using small segments of paper of the desired limits. When the lightest coated segment is placed between the main photomultiplier and its source, the meter should be adjusted for approximately a full scale reading (from 48 - 50 microamperes). Insertion of a heavily coated segment should cause the meter to drop roughly to a one-fifth scale reading. At this point the compensating photomultiplier is adjusted to reduce the scale reading to nearly zero when a clear portion of paper is inserted in its head. By such an adjustment any changes in the density of the paper

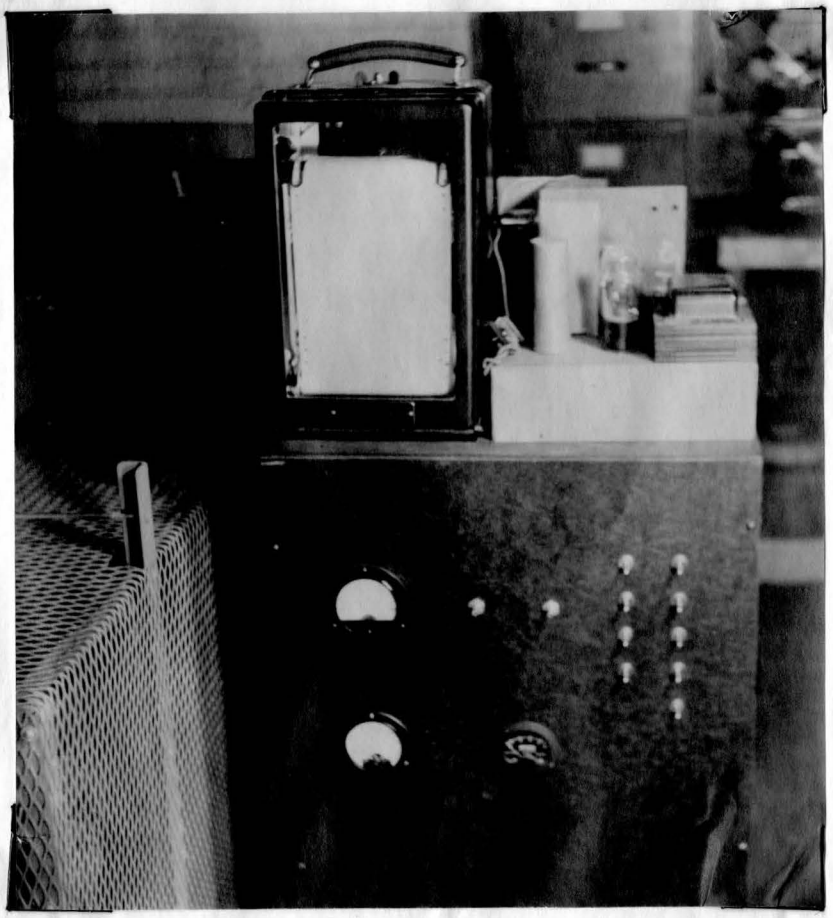


Figure 15. View of Strip Recorder and D.C. Amplifier.

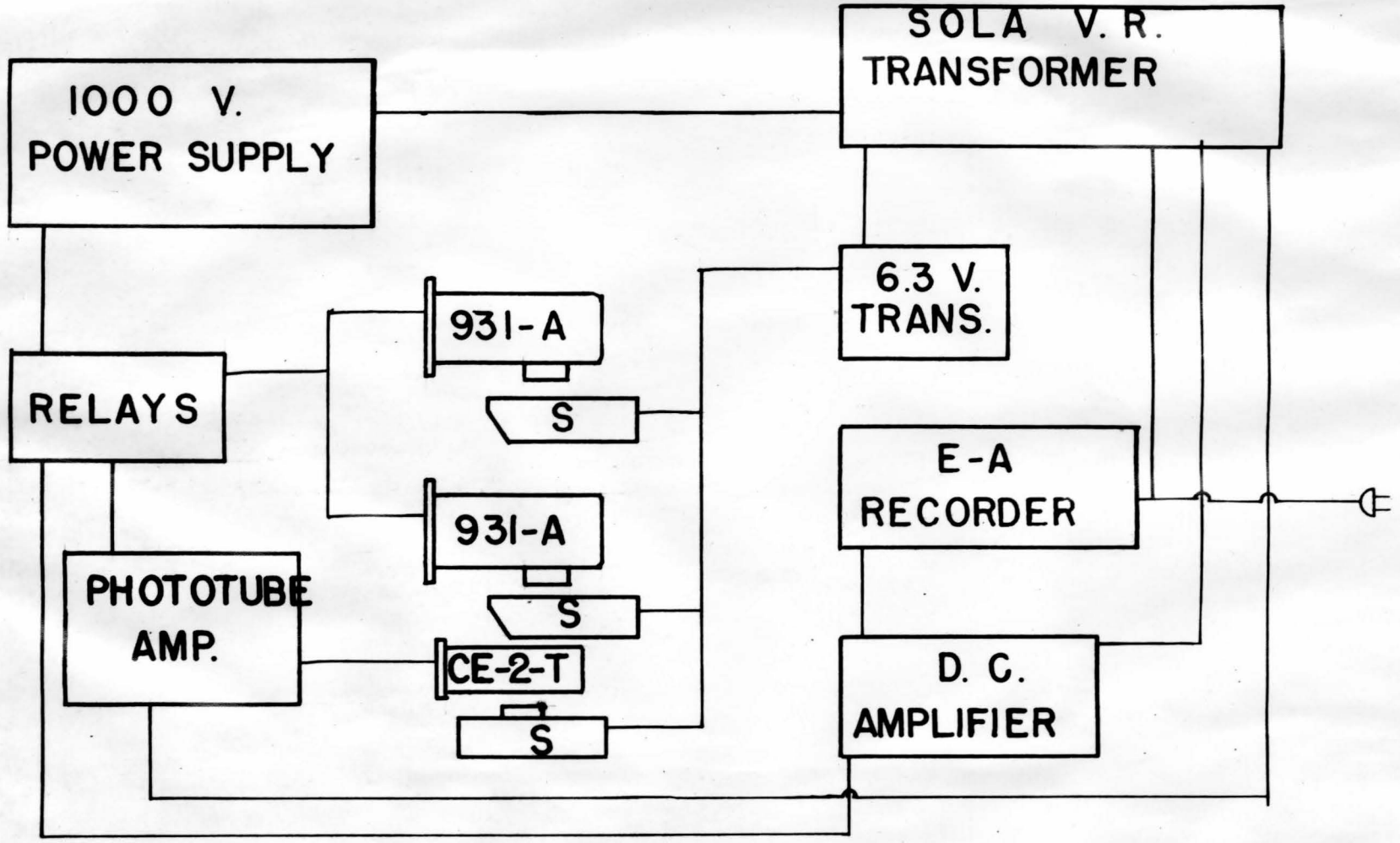


FIG.16. DIAGRAM OF INK THICKNESS INDICATOR

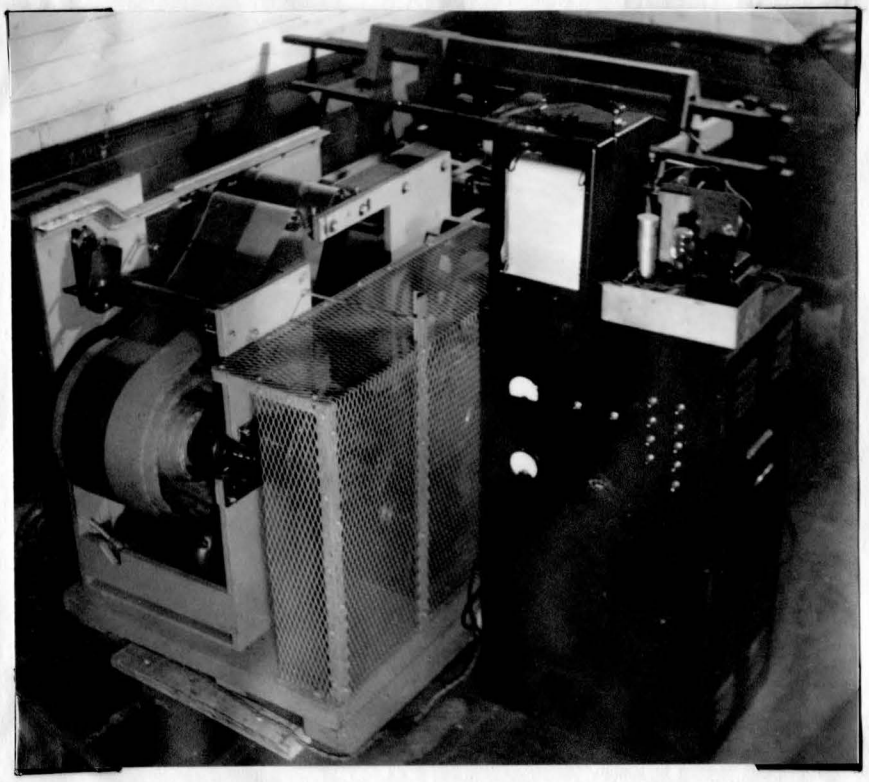


Figure 17. View of Ink Thickness Indicator and Rewinding Device.

itself will be subtracted from the final meter reading. Thus the reading indicates only the amount of ink deposited on the paper.

TABLE III

Stability Time for Photomultiplier (Red Filters Used Over Photomultiplier tube)

Time in Minutes	Current in microamperes
0	21.8
1	20.4
2	19.3
3	19.0
5	17.9
6	17.5
8	16.8
9	16.3
10	16.0
11	15.4
12	15.1
14	14.5
16	14.0
20	13.2
24	12.3
31	1116
103	11.4
108	11.1
114	10.9

After the roll of paper to be tested is loaded on the unwinding machine and is under tension, but unmoving, the photomultiplier circuits are closed and the meter checked. At this point the paper is set in motion and the density changes read from the meter.

2. Procedure Using Recorder

Before using the recorder the d.c. amplifier should be turned on at least a half hour before use. While the chart drive is stationary, the recorder meter may be used for adjustment in a manner similar to that of the panel meter. The desired gain

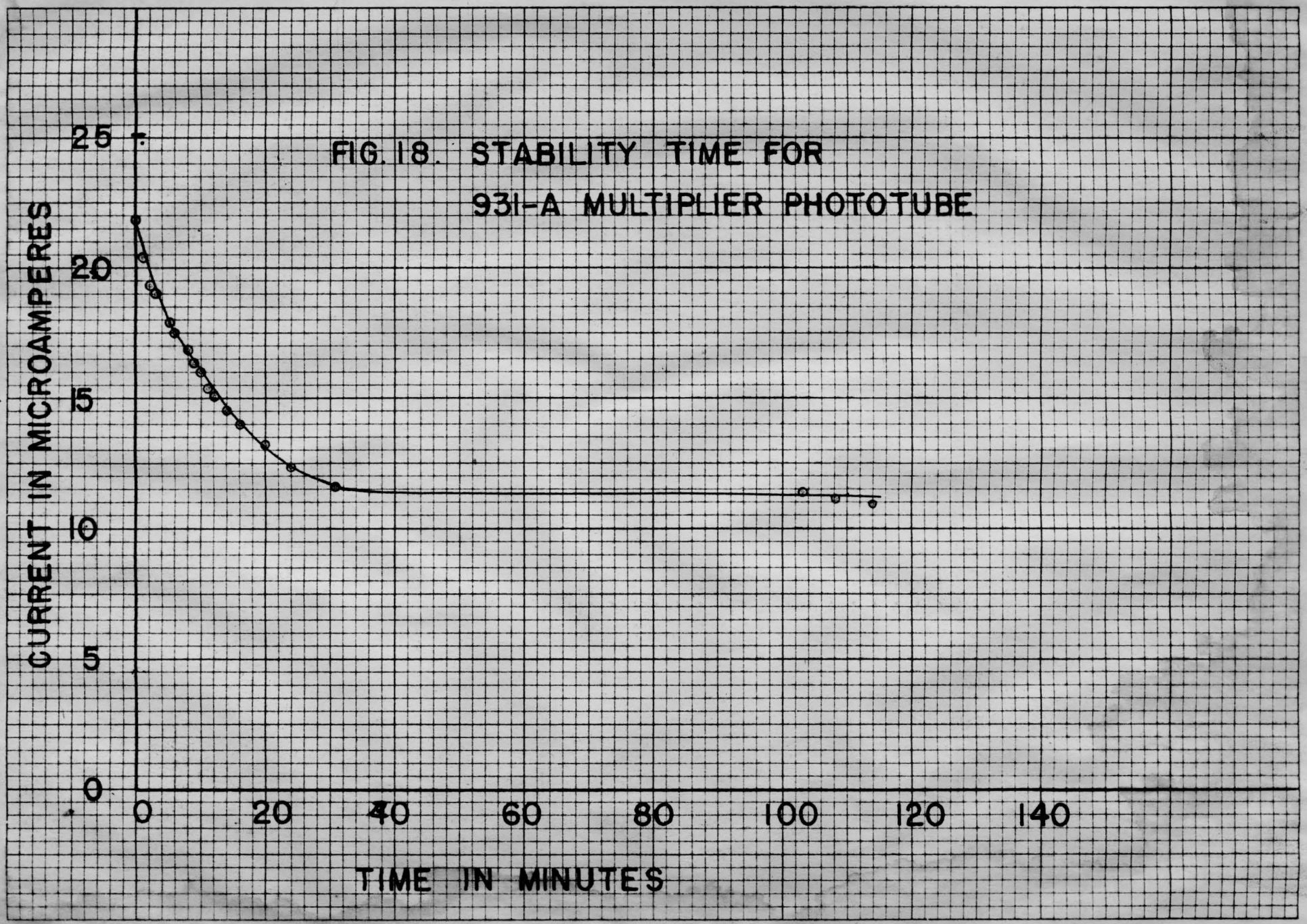


FIG. 18. STABILITY TIME FOR
931-A MULTIPLIER PHOTOTUBE
CURRENT IN MICROAMPERES
25
20
15
10
5
0
0
20
40
60
80
100
120
140
TIME IN MINUTES

may be obtained from the amplifier so that any portion of the full scale value may be used. After satisfactory adjustment is made the chart drive is started and testing may proceed.

D. RESULTS

Preliminary tests were made of the behavior characteristics of the ink thickness monitoring equipment before the strip recorder and d.c. amplifier were employed. The data listed from Tables 4 to 8 were obtained from five tests made on three rolls of carbon paper coated with X-75, TW-10, and TW-12 type inks. During each test readings were taken from the microammeter and were recorded every five seconds. Graphs of these readings plotted against time are shown in Figures 19 to 23. Each reading taken is plotted in the graphs, but only every twelfth reading and the readings before and after a major change are listed in the tables.

Figures 19, 20, and 21 show the normal step functions obtained as first heavy, then medium, and then light sections of carbon paper passed under the monitoring equipment. Slight variations of the ink coating within small areas were recorded, but no major change occurred in any one section.

The compensating photomultiplier head was adjusted to subtract from three to eight microamperes from the meter reading to compensate for changes in the paper density.

Figure 22 shows the roll coated with X-75 ink run in the opposite direction of the first three tests. The first section of light coated paper was monitored before the equipment was turned on long enough to become stable. The same behavior may

be noted in Figure 23 for the roll coated with TW-10 ink.

After these tests, the recorder with the d.c. amplifier was used to record the ink thickness changes on the roll coated with TW-10 ink. Figure 24 shows a record of the change from light to medium coated paper. At the point where the two sections were joined the paper was uncoated, and the photomultiplier circuit was opened by the phototube relays, thus preventing damage to the main photomultiplier tube. Figure 25 shows the change from light to medium and then to heavy paper.

VII

CONCLUSIONS

From the tests made with the ink thickness monitor using both a meter and a recorder, it was shown that a definite change was indicated by the equipment as a section of moving carbon paper changed in thickness. It is felt that this equipment can be used successfully during the manufacture of carbon paper to show at all times the amount of ink being coated on the paper.

TABLE IV MICROAMMETER READINGS OF CARBON PAPER COATED WITH X-75INK

(Compensating light intensity - 4 microamps.)

Time in Minutes	Current in Mircoamperes
0:00	4
1:00	5
2:00	4
3:00	3
4:00	6
5:00	6
6:00	5
7:00	3
7:15	3
7:25	13
8:00	15
9:00	14
10:00	14
11:00	14
12:00	14
13:00	14
14:00	13
15:00	13
15:40	13
15:50	38
16:00	39
17:00	35
18:00	33
19:00	32
20:00	34
21:00	32
22:00	35
23:00	37
24:00	34

TABLE V MICROAMMETER READINGS OF CARBON PAPER COATED WITH TW-10 INK

(Compensating light intensity - 3 microamps.)

Time in Minutes	Current in Microamperes
0:00	4
1:00	7
2:00	11
3:00	17
4:00	10
5:00	14
6:00	12
7:00	20
7:45	19
7:55	27
8:00	27
9:00	25
10:00	26
11:00	25
12:00	24
13:00	23
14:00	24
15:00	23
16:00	23
17:00	22
17:35	21
17:45	41
18:00	40
19:00	40
20:00	41
21:00	40
22:00	39
23:00	40
24:00	40
25:00	41
26:00	42
27:00	41
28:00	40

TABLE VI MICROAMMETER READINGS OF CARBON PAPER COATED WITH TW-12 INK

(Compensating light intensity - 4 microamps)

Time in Minutes	Current in Microamperes
0:00	4
1:00	2
2:00	3
3:00	3
3:45	3
3:55	20
4 :00	18
5:00	19
6:00	19
7:00	20
8:00	20
9:00	20
10:00	19
11:00	19
12:00	18
13:00	17
14:00	20
15:00	20
16:00	17
17:00	20
18:00	21
18:10	20
18:25	35
19:00	37
20:00	37
21:00	35
22:00	39
23:00	35
24:00	40
25:00	40

TABLE VII MICROAMMETER READINGS OF CARBON PAPER COATED WITH X-75 INK

NOTE: Paper Run in Reverse Direction
(Compensating light intensity - 8 microamps)

Time in Minutes	Current in Microamperes
0:00	35
1:00	41
2:00	45
3:00	39
4:00	36
5:00	35
5:20	35
5:30	8
6: 00	7
7:00	7
8:00	7
9:00	6
10:00	5
11:00	6
11:40	5
11:50	1
12:00	-1
13:00	-1
14:00	-1
15:00	1
16:00	1
17:00	2
18:00	2

TABLE VIII MICROAMMETER READINGS OF CARBON PAPER COATED WITH TW-10 INK

NOTE: Paper Run in Reverse Direction
(Compensating light intensity -8 microamps)

Time in Minutes	Current in Microamperes
0:00	45
1:00	45
2:00	40
3:00	41
4:00	40
5:00	38
6:00	38
7:00	36
8:00	35
9:00	34
10:00	34
11:00	33
12:00	32
13:00	31
13:10	20
13:20	14
14:00	9
15:00	10
16:00	11
17:00	11
18:00	10
19:00	9
20:00	10
21:00	9
21:30	8
21:40	4
22:00	5
23:00	2
24:00	2
25:00	-1
26:00	-1
27:00	0
28:00	1

COMPENSATING CURRENT: —4 MICROAMPS

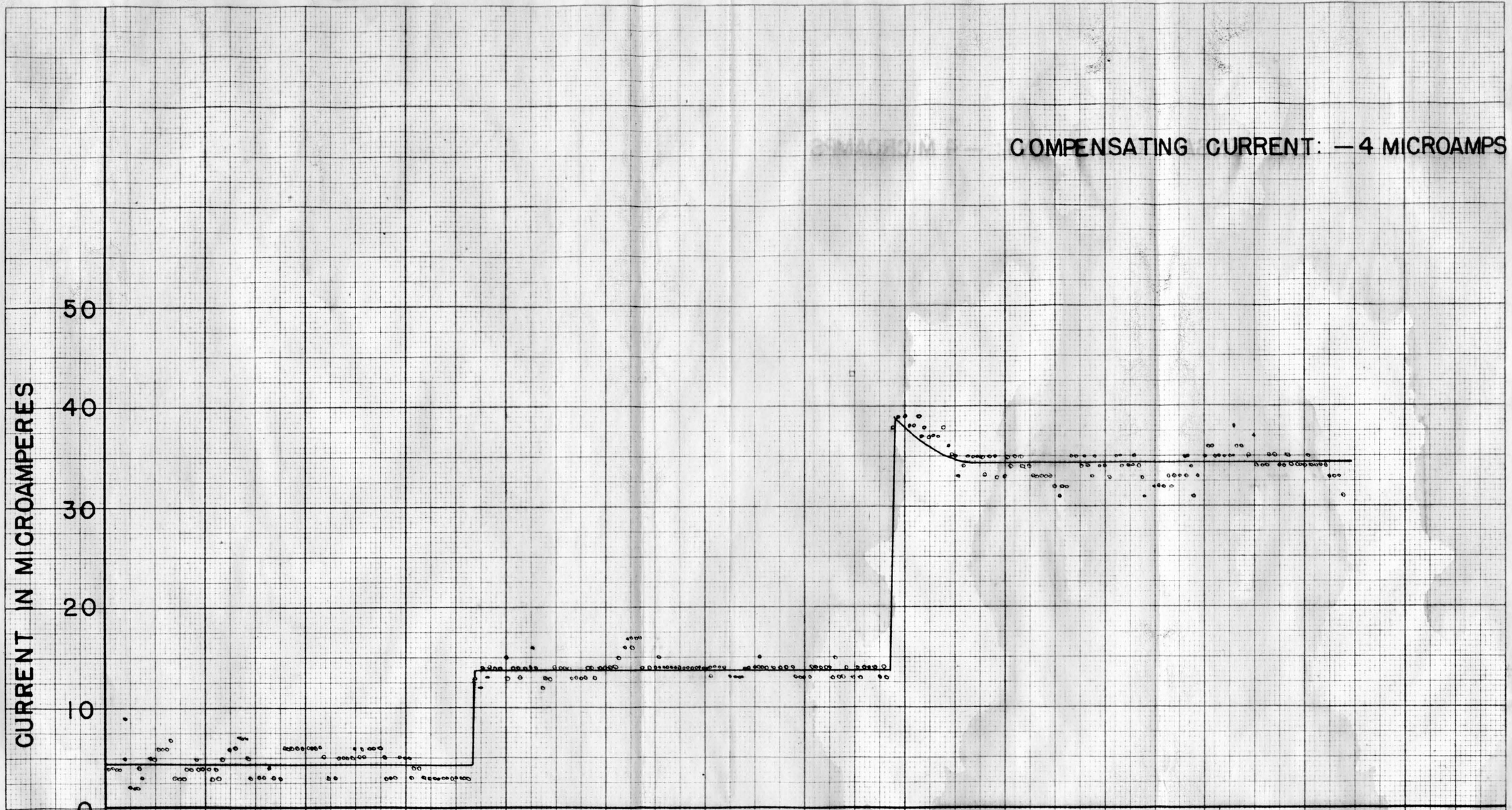


FIG. 19. PHOTOTUBE CURRENT VS. TIME FOR X-75 INK

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EUGENE DIETZGEN CO. NO. 346 D

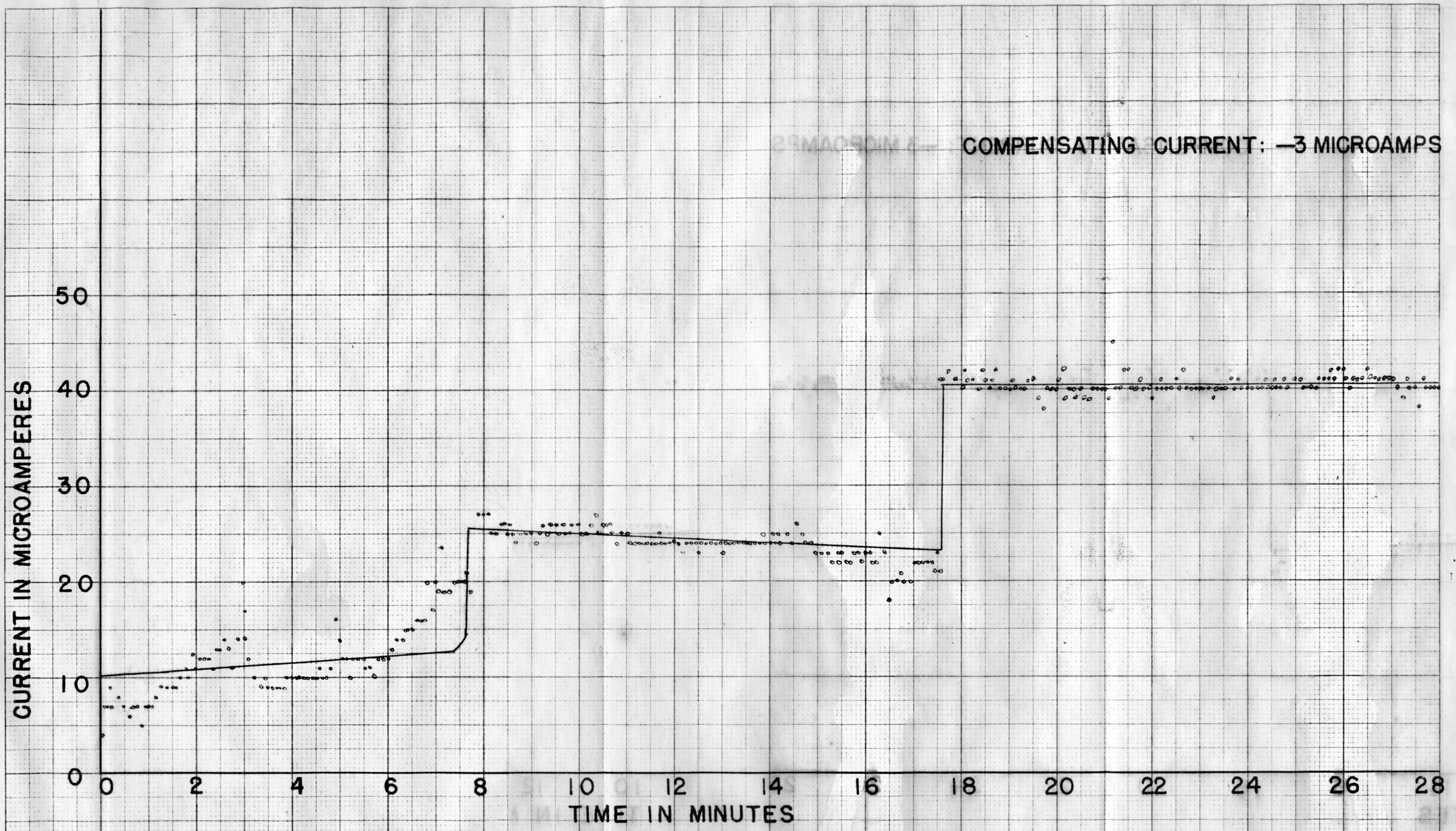

FIG. 20. PHOTOTUBE CURRENT VS. TIME FOR TW-10 INK

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COMPENSATING CURRENT: —4 MICROAMPS

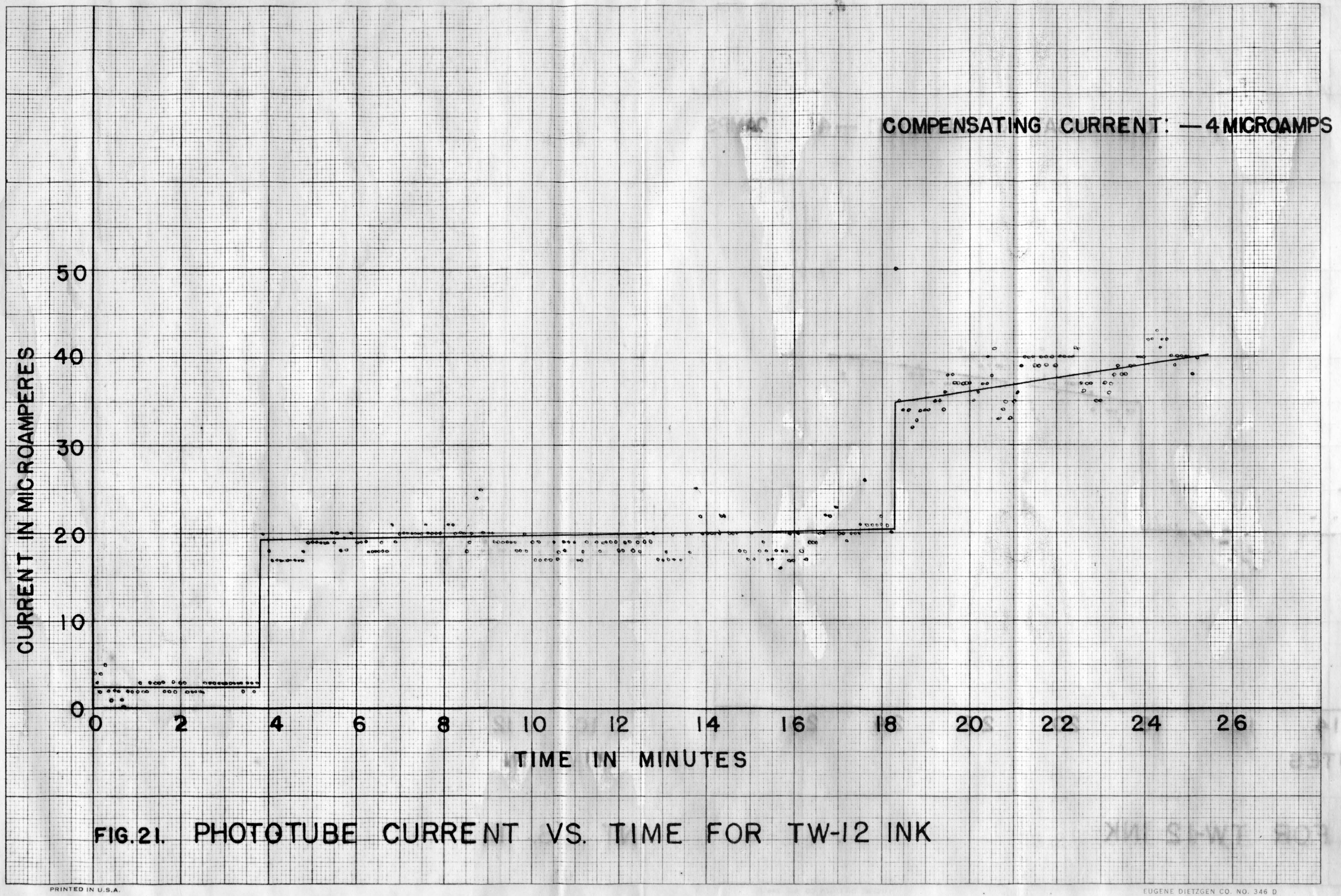

FIG. 21. PHOTOTUBE CURRENT VS. TIME FOR TW-12 INK

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COMPENSATING CURRENT:—8 MICROAMPS

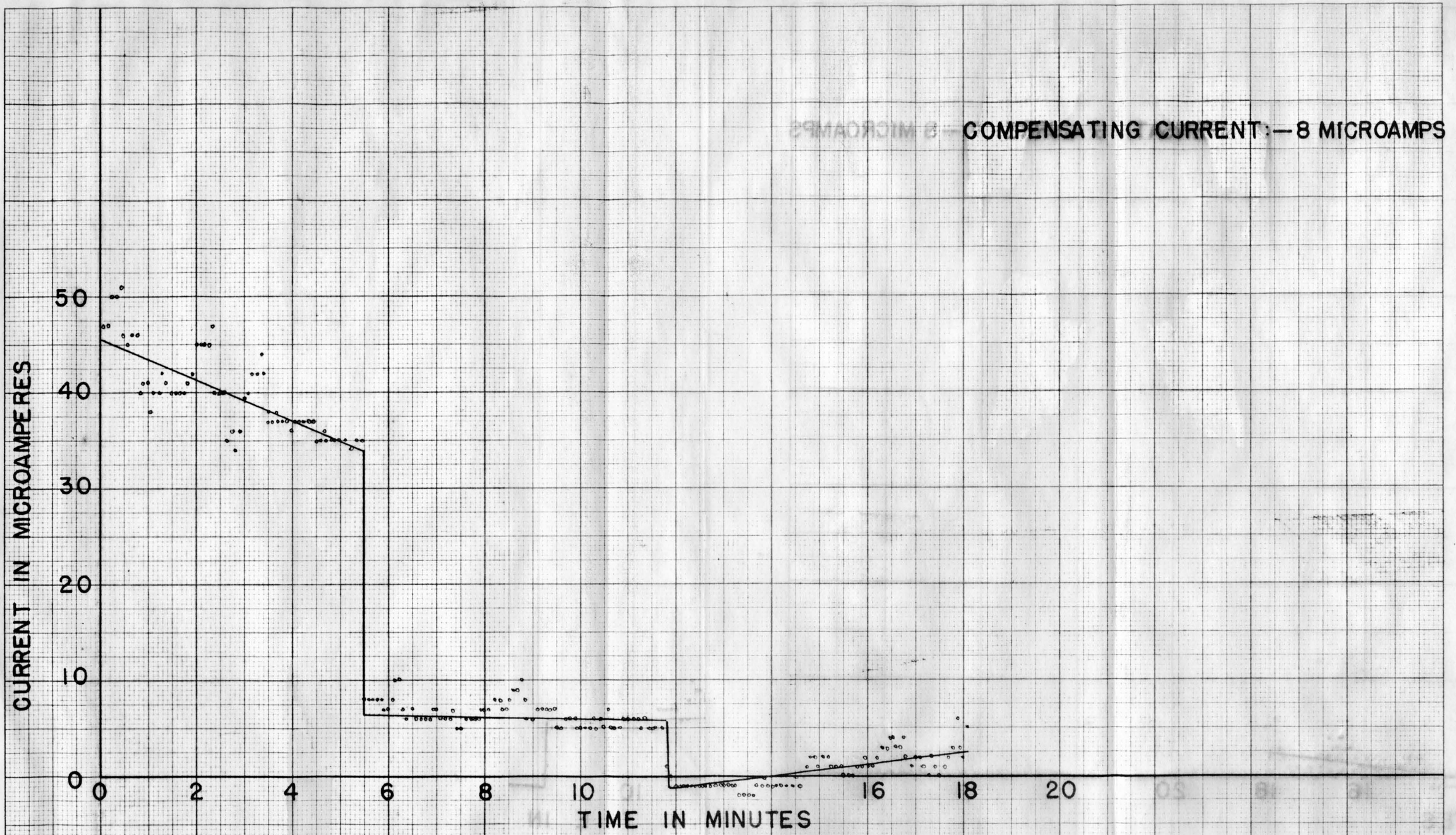

FIG. 22. PHOTOTUBE CURRENT VS. TIME FOR X-75 INK

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COMPENSATING CURRENT: −8 MICROAMPS

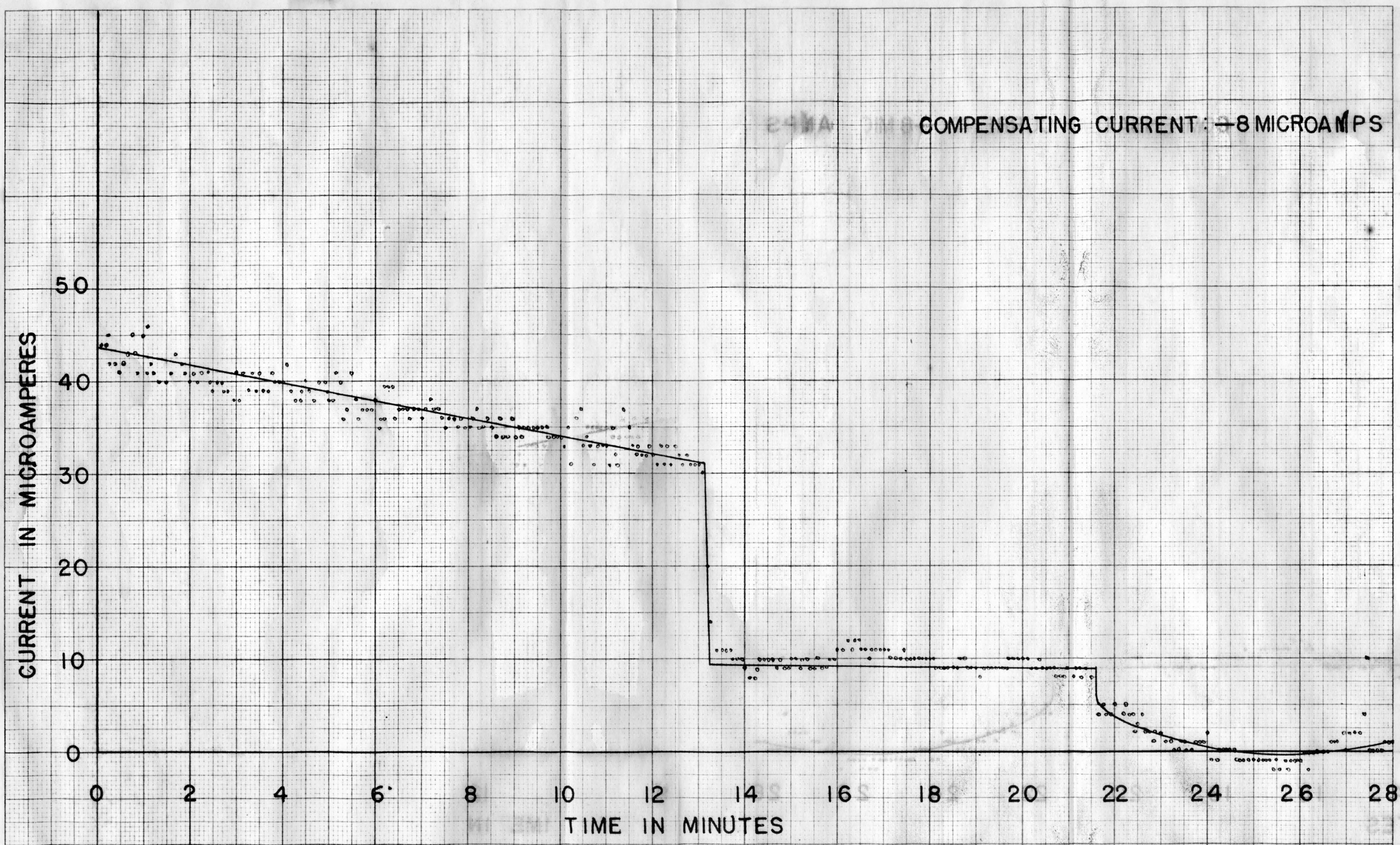

FIG. 23. PHOTOTUBE CURRENT VS. TIME FOR TW-10 INK

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EUGENE DIETZGEN CO. NO. 346 D

MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. ES

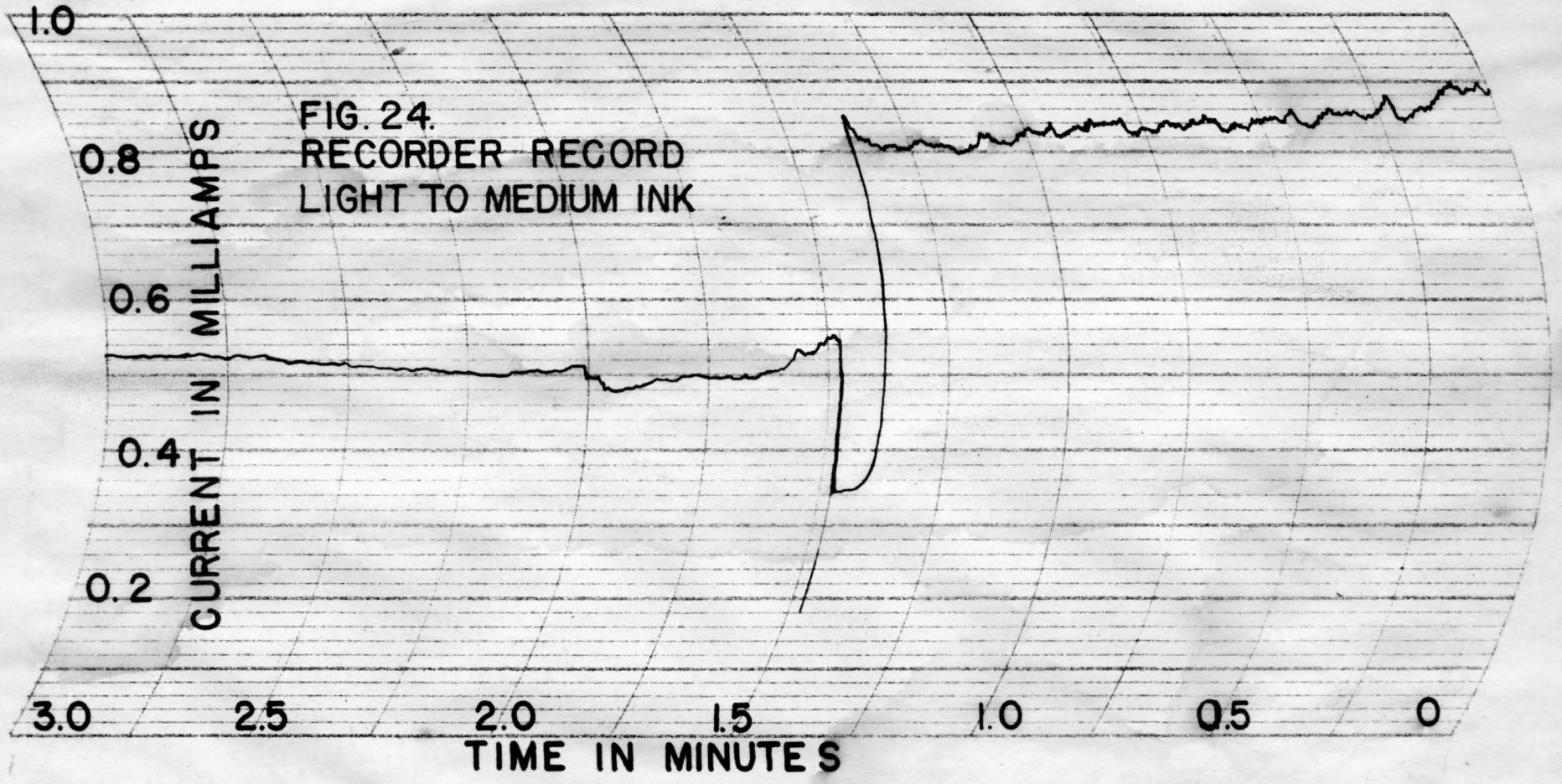

FIG. 24.
RECORDER RECORD
LIGHT TO MEDIUM INK

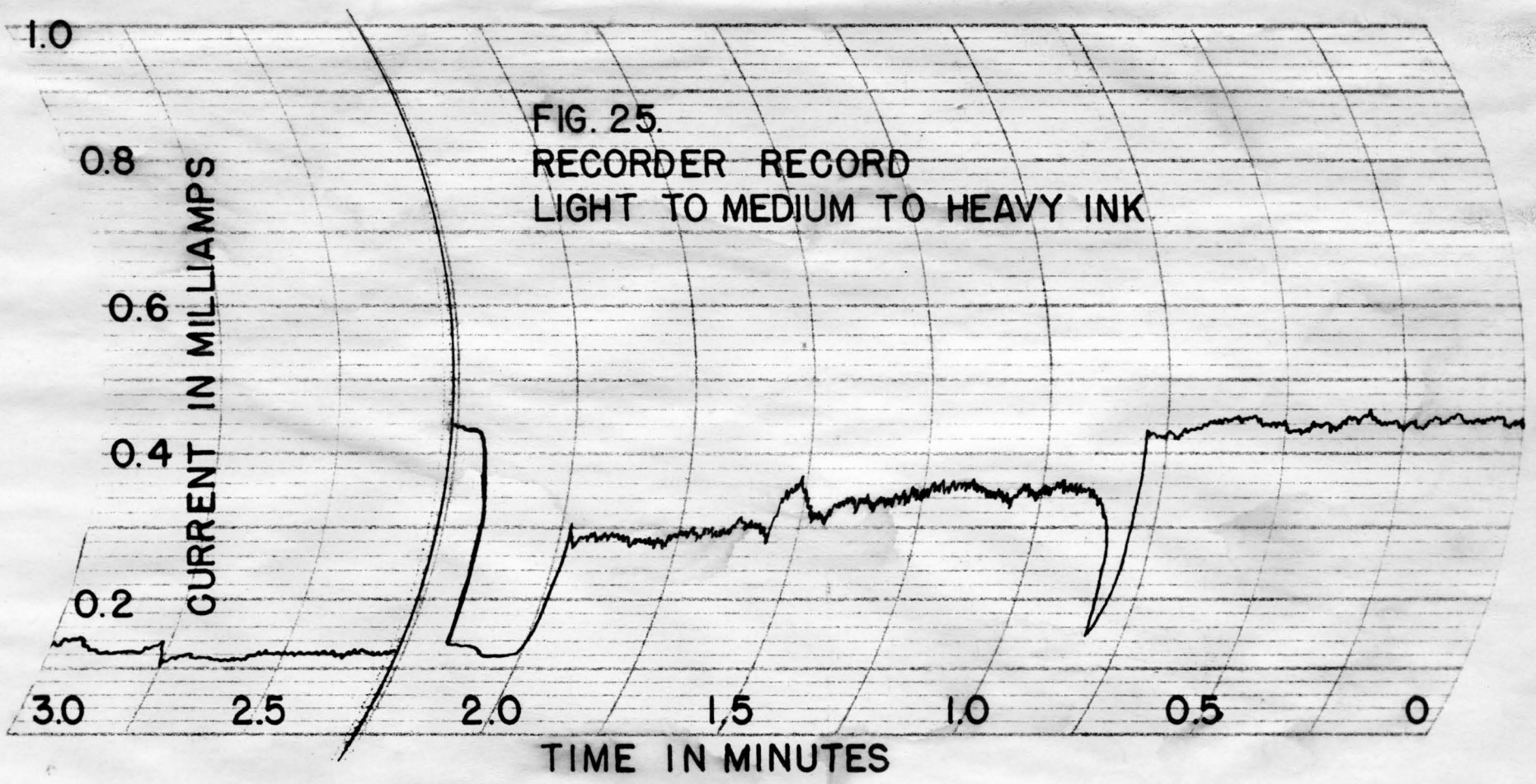

FIG. 25.
RECORDER RECORD
LIGHT TO MEDIUM TO HEAVY INK

VIII

ACKNOWLEDGMENTS

To Professor W. Richardson I should like to express my deepest appreciation for his guidance and helpful suggestions during the research and writing of this thesis. I want to thank the Standard Register Company of Dayton, Ohio, for their interest and cooperation which made this thesis possible. Also I wish to thank Dr. H. Y. Loh, Dr. F. L. Robeson, Professor J. F. Ryman, the late Mr. E. S. Bishop, and the other members of the V. P. I. Physics Department as well as Professor R. R. Wright of the Electrical Engineering Department for their help. Last but not least, I want to express my indebtedness to my wife, for her patience in being a combination lab assistant, typist, and draftsman.

IX

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