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TRANSIENT ANALYSIS OF A G. E.
SERVO-DEMONSTRATION UNIT

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
Howard Edmonds Gerlaugh
1948

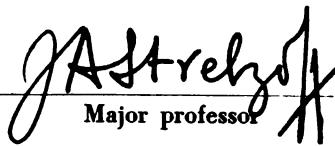
This is to certify that the
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**Transient Analysis of A G.E.
Servo-Demonstration Unit**

presented by

Howard Edmonds Gerlaugh

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of the requirements for

M.S. degree in E.E.


Major professor

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TRANSIENT ANALYSIS OF A
G. E. SERVO-DEMONSTRATION UNIT

By
HOWARD EDMONDS GERLAUGH

A THESIS

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I. Introduction

Since the development of large sources of power, man has become increasingly interested in its control so that it may be made to perform more useful and exacting work. In particular it is the starting, stopping, and governing of these forces that are included in the field of "control!"

Systems which regulate the flow of energy may be class-
ed into four broad classes: open cycle, closed cycle, dis-
continuous, and continuous. In all of these different types
the amount of control energy bears no relation to the power
released or governed.

If an electric motor is connected to a source of power
and set in motion or stopped by closing or opening a switch,
we have a simple discontinuous control. The system is dis-
continuous in that the current to the motor is completely
on or off and there are no intermediate positions possible.
If we replaced the switch with a rheostat, the system would
become continuous because now the power supplied to the mo-
tor has a range values from fully on to off.

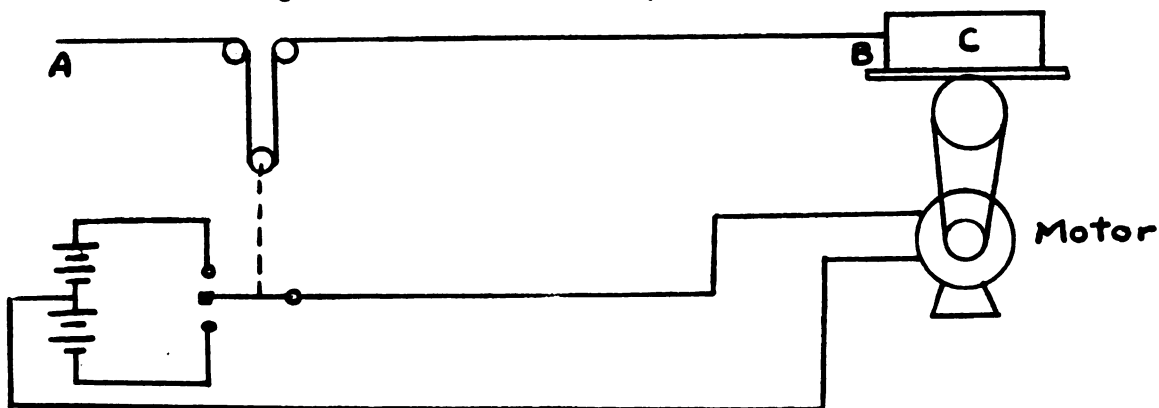


Figure 1

Howard E. Gerlaugh

In the system shown in Figure 1 the switch controlling the direction of rotation of the motor is operated by the difference in position between points A & B and some reference. In this system the point C is made to follow the point A by letting the error or deviation control the rotation of the motor; thus a complete loop or cycle is present. For this reason the control is a closed cycle system and at the same time discontinuous since the switch either turns the motor completely on or off. If a slide wire rheostat, with the sliding arm connected to the differential, were to replace the switch in the above control, it would become closed cycle and continuous.

A servo mechanism consists of an input member, an output member, a differential device which compares the instantaneous positions of the input and output, a controller consisting of an amplifier and output drive motor, and a stabilizing device. These components are so arranged that if the position of the input were $x(t)$ and the output $y(t)$, $x(t)$ would equal $ky(t)$.

It shall be the purpose of this paper to describe a typical servo system, develop a mathematical expression for its performance, determine the constants of the elements, and to compare the calculated characteristics with those determined experimentally.

II. Description of System Analyzed

The analysis which follows was made on a closed cycle, continuous position control servo system. The system was

manufactured by General Electric and is designated as the "Amplidyne Servo Demonstrator". T

The block diagram of the system is shown in Figure 2.

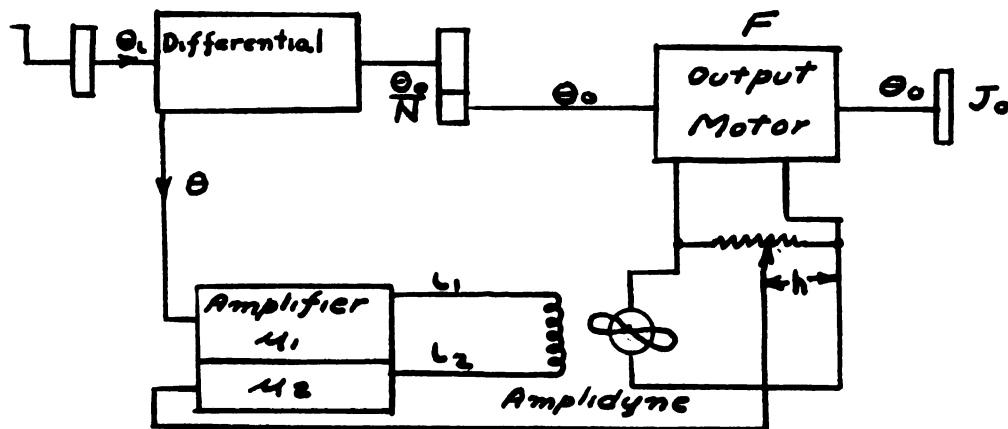
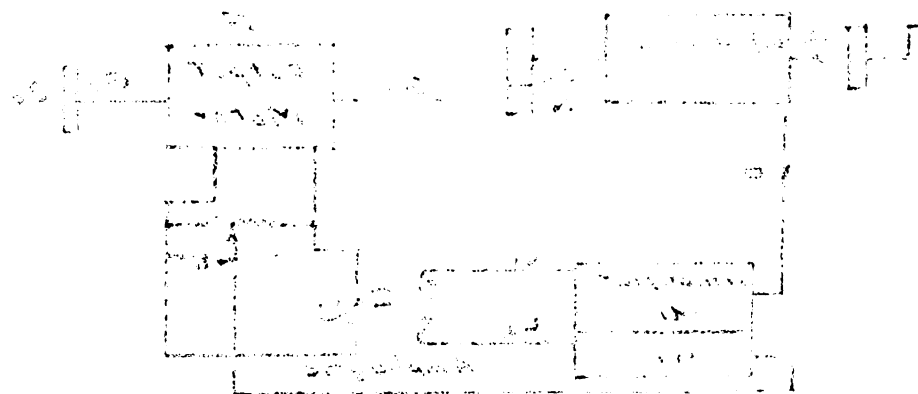


Figure 2.

The input shaft whose angular position is θ_1 is connected to a selsyn generator is converted to three single phase 60 cycle output voltages whose amplitudes are proportional to the cosine of the angle between the magnetic axis of the rotor and stator. The angular position of the output motor shaft θ_0 is connected through a gear train with a gear ratio of 24:1 to a selsyn transformer. The three output voltages of the selsyn generator is connected to the stator of the transformer and the output of the rotor is a 60 cycle voltage whose amplitude is proportional to the sine of the angle between the generator rotor and transformer rotor. The combination of the selsyn generator and transformer are indicated in Figure 2 as a differential whose output signal is proportional to the error θ , where θ is the difference between θ_1 and $\frac{\theta_0}{N}$.

The error voltage is fed into an amplifier of gain u_1 which in turn supplies the field current of the amplidyne.



The diagram illustrates a building layout, possibly a floor plan or a site plan. It shows a central rectangular area with several smaller rectangular sections attached to its sides and top. The diagram is drawn with dashed lines, suggesting it might be a conceptual or preliminary plan. There are some handwritten annotations and numbers within the diagram, such as "100" and "10" in the top right section, and "100" in the bottom right section. The overall shape is irregular, with a central core and several protruding sections.

The text below the diagram is very faint and mostly illegible. It appears to be a series of paragraphs, possibly describing the building's layout, its purpose, or the surrounding context. The text is written in a serif font, typical of older documents.

The first paragraph discusses the building's location and its relationship to the surrounding area. It mentions "the building" and "the site". The second paragraph describes the building's layout and its various sections. It mentions "the central area" and "the smaller sections". The third paragraph discusses the building's purpose and its use. It mentions "the building" and "the site".

The fourth paragraph discusses the building's history and its development over time. It mentions "the building" and "the site". The fifth paragraph discusses the building's future plans and its potential for development. It mentions "the building" and "the site".

The sixth paragraph discusses the building's current status and its role in the community. It mentions "the building" and "the site". The seventh paragraph discusses the building's impact on the surrounding area and its potential for future development. It mentions "the building" and "the site".

The eighth paragraph discusses the building's overall significance and its contribution to the community. It mentions "the building" and "the site". The ninth paragraph discusses the building's future plans and its potential for development. It mentions "the building" and "the site".

The tenth paragraph discusses the building's current status and its role in the community. It mentions "the building" and "the site". The eleventh paragraph discusses the building's impact on the surrounding area and its potential for future development. It mentions "the building" and "the site".

The twelfth paragraph discusses the building's overall significance and its contribution to the community. It mentions "the building" and "the site". The thirteenth paragraph discusses the building's future plans and its potential for development. It mentions "the building" and "the site".

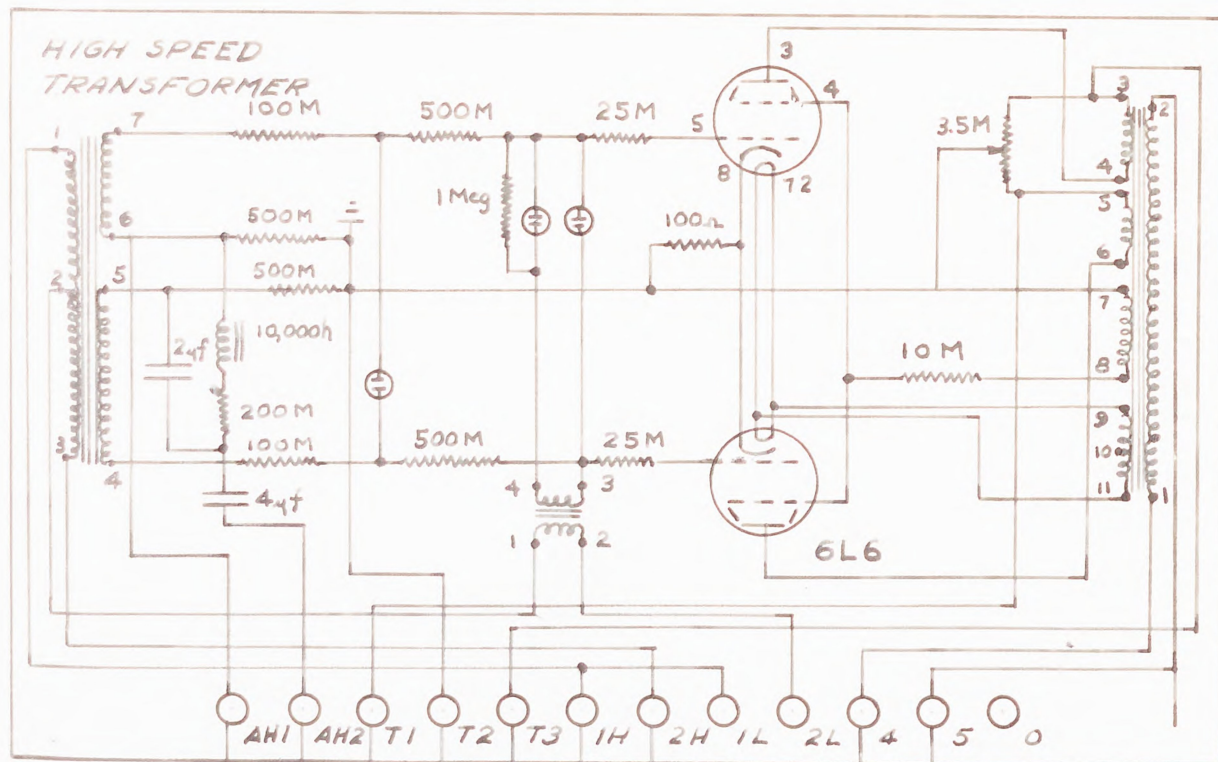
The fourteenth paragraph discusses the building's current status and its role in the community. It mentions "the building" and "the site". The fifteenth paragraph discusses the building's impact on the surrounding area and its potential for future development. It mentions "the building" and "the site".

The sixteenth paragraph discusses the building's overall significance and its contribution to the community. It mentions "the building" and "the site". The seventeenth paragraph discusses the building's future plans and its potential for development. It mentions "the building" and "the site".

The eighteenth paragraph discusses the building's current status and its role in the community. It mentions "the building" and "the site". The nineteenth paragraph discusses the building's impact on the surrounding area and its potential for future development. It mentions "the building" and "the site".

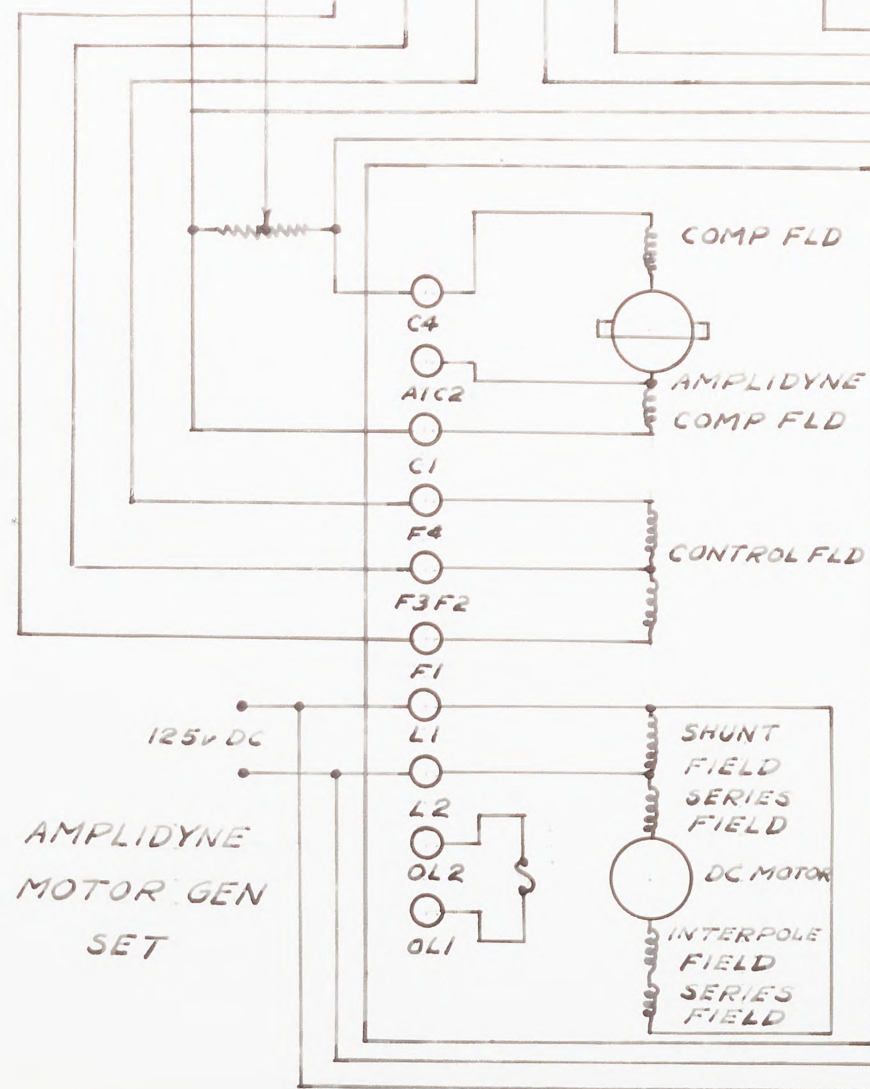
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AMPLIFIER UNIT

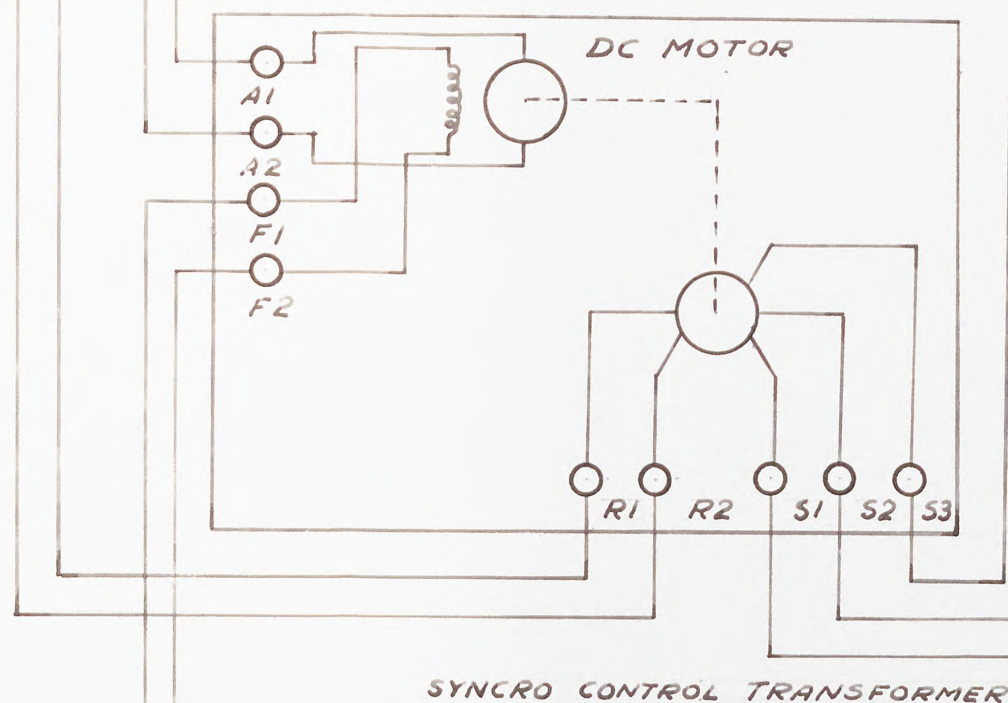


POWER TRANSFORMER

AMPLIDYNE SERVO DEMONSTRATOR WIRING DIAGRAM GENERAL ELECTRIC

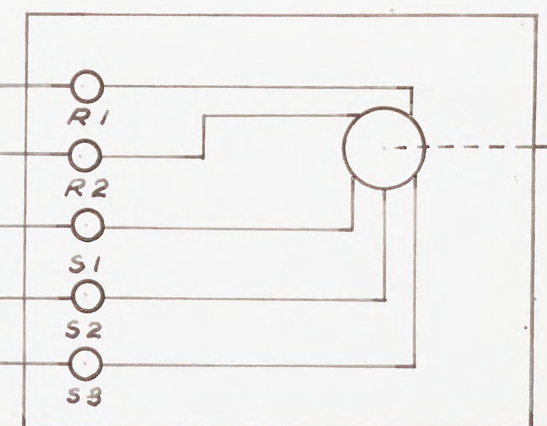


RECEIVER REGULATOR UNIT



POSITION CONTROL UNIT

HANDWHEEL



SYNCR0 GENERATOR

FIG. 3



The complete wiring diagram is given in Figure 3. The amplifier is shown to consist of a pair of 6L6 tubes operating as half wave grid controlled rectifiers, the grid potentials being controlled by the error signal. An error signal of a given A.C. polarity increases the grid potential and output of one tube and decreases the output of the other tube by a like amount. An A.C. voltage of opposite polarity reverses the tube system. The plate voltage on the tubes is supplied from the same 60 cycle source as the selsyns since it serves as a reference to determine the A.C. polarity of the error signal. The neon lamps across the grid circuits of the tube serve to provide overload protection. The feedback circuit of the amplifier returns a portion of the voltage across the armature of the output motor through a differentiating circuit. This provides feedback for the amplifier with a gain of u_2 .

The output of the amplidyne is connected to the armature of the motor. The voltage is a function of the error and also of the rate of change in error. When the rate of change of error is maximum the degenerative feedback voltage is largest, decreasing the armature voltage of the motor and preventing the output shaft from overshooting the zero error point as far as it normally would with out feedback. The output angle θ_o is measured from the motor shaft and is connected through a step down gear train to the selsyn transformer.

The moment of inertia of the output is designated.

J_0 and includes that of the motor and associated gear train. The resistor across the terminals of the output motor armature permits adjustment of the feedback voltage. The ratio h represents the ratio of the feedback voltage to the total armature voltage.

In operation the output shaft, where the angle is $\frac{\theta_0}{N}$, is made to follow the input shaft with an angle of θ_1 . The accuracy of correspondence during transient and steady state conditions is dependent upon the constants of the system. A quantitative analysis of the system follows.

III. Derivation of Equations.

If the input shaft displacement is made a sinusoidal function of time, the output shaft displacement and the difference between the two or error will also be a sinusoidal function of time with the same frequency but of different amplitudes and phase angles with one another. These functions are shown vectorially in Figure 4.

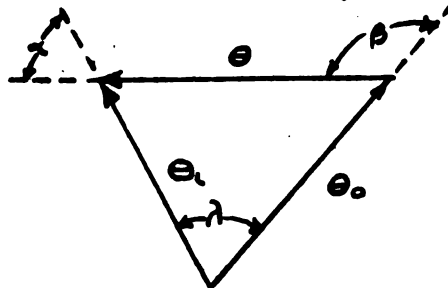


Figure 4

In Figure 4 we see that

$$\theta = \theta_1 - \theta_0 \quad (1)$$

and that the output vector θ_0 lags behind the input vector θ_1 by the phase angle λ . α and β are the angles between the error θ and input θ_1 vectors and the error θ and output

θ_0 vectors respectively. From these geometric considerations, it is seen that the relation between the output displacement and the input displacement can be expressed by the equation

$$\frac{\theta_2}{\theta_1} = A e^{j\lambda} \quad (2)$$

Similarly the relation between the output and error is

$$\frac{\theta_2}{\theta_e} = B e^{j\beta} \quad (3)$$

and the error and input

$$\frac{\theta_e}{\theta_1} = C e^{j\alpha} \quad (4)$$

Using the above relations

$$B e^{j\beta} = \frac{\theta_2}{\theta_e} = \frac{\theta_1 - \theta_e}{\theta_e} = \frac{\theta_1}{\theta_e} - 1 \quad (5)$$

from which

$$\frac{\theta_1}{\theta_e} = 1 + B e^{j\beta} \rightarrow \frac{\theta_e}{\theta_1} = \frac{1}{1 + B e^{j\beta}} = C e^{j\alpha} \quad (6)$$

Thus knowing $\frac{\theta_2}{\theta_e}$, it becomes possible to calculate θ_e/θ_1 , and follows that

$$\frac{\theta_2}{\theta_1} = A e^{j\lambda} = \frac{\theta_2}{\theta_e} \times \frac{\theta_e}{\theta_1} = \frac{B e^{j\beta}}{1 + B e^{j\beta}} \quad (7)$$

The term $B e^{j\beta}$ is given the name of transfer function of a servo system since it relates the ratio between θ_0 and θ_1 . In the derivation which follows the transfer function will be developed for the G. E. Servo Demonstrator.

In the first case the feedback ratio h of the system will be made zero. The relation between the error θ and the total amplidyne field current I , is

$$I = \frac{u_1 \theta}{1 + p T_1} \quad (8)$$

where u_1 is the gain of the amplifier in ma./radian taken with respect to the output motor shaft, p is the Heaviside operator equal to the first derivative with respect to time,

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and T_1 is the time constant of the amplifier field L_1/R_1 with the units of seconds. The product of u_1 and Θ give the resultant field current in milliamperes. When the differential equation is solved it has the form

$$I_1 = 4.0(1 - e^{-\frac{t}{T_1}}) \quad (8a)$$

In equation 8 we assume that the amplification of the amplifier u_1 is constant over range of error found in the system; in the tests which follow this is found to be true.

The torque of a D.C. shunt motor, such as is shown in Figure 3 to be employed in this system, is proportional to the field strength and armature current. In this servo system the field is held constant so that the torque is equal to a constant times the armature current. The output current I_3 of the amplidyne in terms of the field current I_1 may be given by the relation

$$I_3 = \frac{K_1 I_1}{1 + pT_2} \quad (9)$$

where K_1 has the units of amperes/ma. and T_2 is the time constant of the armature of the amplidyne L_2/R_2 . The expression for the torque of the output motor may be immediately written

$$T = K_2 I_3 = \frac{K_2 K_1 I_1}{1 + pT_2} \quad (10)$$

where K_2 is a constant with the units of ft.-lbs./amp.

Let

$$K = K_1 K_2, \quad (11)$$

then

$$T = \frac{K I_1}{1 + pT_2} = \frac{K 4 \Theta}{(1 + pT_1)(1 + pT_2)} \quad (12)$$

[illegible]
$$\frac{d}{dt} \left(\frac{\partial L}{\partial \dot{q}} \right) = \frac{\partial L}{\partial q}$$

the torque T having the units of ft.-lbs. Also the torque of the motor is related to the moment of inertia and friction of the output system by the equation

$$T = J_o p^2 \theta_o + F p \theta_o \quad (13)$$

J_o having the units of slug-ft.² and the friction coefficient F , the units of ft.-lbs./radian/sec. Equating 12 and 13

$$\frac{K u_1 \theta}{(1+pT_1)(1+pT_2)} = (J_o p^2 + F p) \theta_o \quad (13a)$$

and solving for the transfer function $\frac{\theta_o}{\theta}$ we have

$$\frac{\theta_o}{\theta N} = B e^{j\beta} = \frac{K u_1}{N p (1+pT_1)(1+pT_2)(J_o p + F)} \quad (14)$$

By dividing 14 by the gear ratio N , measurements of the output displacement may be taken at the selsyn transformer.

For equation 13 to predict accurately the performance of the servo the output current of the amplidyne must be directly proportional to the field current and the torque be a linear function of the armature current. These assumptions are true until saturation takes place in the former, in the field of the amplidyne, and in the latter, in the armature of the motor.

In the case where h has some finite value giving the amplifier degenerative feedback, the equation for the transfer function becomes much more complicated. As the first step, if the voltage across the armature of the motor is taken as E_o as shown in Figure 5, the voltage at the output terminals of the amplifier E due to the feedback hE_o at its input is given by the expression

$$E_2 = \frac{h E_o u_2 (1+pRC)}{1+pRC - u_2 h pRC} \quad (15)$$

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where u_2 is the amplification of the feedback voltage in the amplifier with the units of volts/volt and R and C are the fundamental elements in the differentiating circuit.

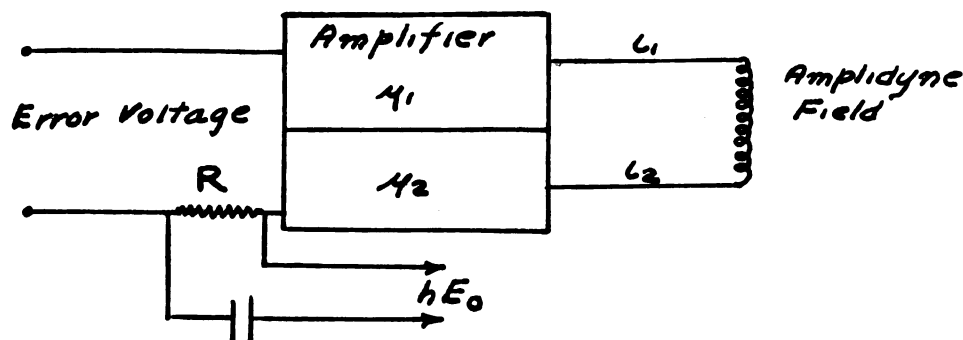


Figure 5

As before the component of the field current due to the error voltage is

$$I_1 = \frac{\mu_1 \theta}{1 + pT_1} \quad (8)$$

The component of the amplidyne field currents due to the feedback voltage is

$$I_2 = \frac{E_2}{R_1(1+pT_1)} = \frac{hE_0\mu_2(1+pRC)}{R_1(1+pT_1)[1+pRC(1-\mu_2h)]} \quad (16)$$

The component of the output voltage of the amplidyne due to I_1 is as in equation 9

$$E_{g1} = \frac{K_1 I_1}{1+pT_2} \quad (9)$$

and the component due to I_2 is

$$E_{g2} = \frac{K_1 I_2}{1+pT_2} \quad (17)$$

Using the superposition theorem the amplidyne's total generated voltage E_{gt} may be expressed in the relation

$$E_{gt} = E_{g1} + E_{g2} \quad (18)$$

[illegible]

The voltage at the output terminals is seen to be

$$E_o = E_{gt} - I_3 R_2 \quad (19)$$

where I_3 is the output current. E_o may also be expressed in terms of the parameters of the motor by

$$E_o = K_3 \phi N_m + I_3 R_a \quad (20)$$

Let

$$K_3 \phi = C_1 \quad (21)$$

and

$$N_m = C_2 p \theta_o \quad (22)$$

so that C_1 will have the units of volts/rad./sec. and C_2 will have no units if the speed of the motor N_m is in radians/second. Rewriting 19 we find that

$$E_o = C_1 C_2 p \theta_o + I_3 R_a \quad (23)$$

The motor torque T may be expressed as

$$T = C_3 I_3 = J_o p^2 \theta_o + F p \theta_o \quad (24)$$

or by equations 18 and 22, solving for I_3 and substituting in 22, the motor torque is

$$T = \frac{C_3 E_{gt} - C_1 C_2 C_3 p \theta_o}{R_a + R_2} \quad (25)$$

If now the right hand side of 23 is solved for I_3 and substituted in 22 and the result used to replace E_o in (16), the component of field current due to feedback is

$$I_2 = \frac{h [C_1 C_2 C_3 p \theta_o + T R_a] \mu_2 (1 + p R C)}{R_1 (1 + p T_1) C_3 [1 + p R C (1 - \mu_2 h)]} \quad (26)$$

Combining 8, 9, 26, and 17 the total generated voltage of the amplidyne is

1. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

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$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

6. $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

$$E_{gt} = E_{g1} + E_{g2} = \frac{K_1 \mu_1 \Theta}{(1+pT_1)(1+pT_2)} + \quad (27)$$

$$\frac{K_1 h \mu_2 (C_1 C_2 C_3 p \Theta_0 + TR_a)(1+pRC)}{R_1 C_3 (1+pT_1)(1+pT_2)[1+pRC(1-\mu_2 h)]}$$

or simplifying

$$E_{gt} = \frac{K_1 \mu_1 \Theta R C_3 [1+pRC(1-\mu_2 h)]}{R_1 C_3 (1+pT_1)(1+pT_2)[1+pRC(1-\mu_2 h)]} + \frac{K_1 h \mu_2 (C_1 C_2 C_3 p \Theta_0 + TR_a)(1+pRC)}{R_1 C_3 (1+pT_1)(1+pT_2)[1+pRC(1-\mu_2 h)]} \quad (28)$$

substituting the value of T shown on the right side of 24

in 28 and collecting coefficients of Θ and Θ_0

$$E_{gt} = \frac{\Theta \{K_1 \mu_1 R_1 C_3 [1+pRC(1-\mu_2 h)]\} \textcircled{1}}{\{R_1 C_3 (1+pT_1)(1+pT_2)[1+pRC(1-\mu_2 h)]\} \textcircled{2}} \textcircled{29} + \frac{\Theta_0 \{K_1 \mu_2 (1+pRC)[C_1 C_2 C_3 p + (J_0 p^2 \Theta_0 + Fp)R_a]\} \textcircled{3}}{\{R_1 C_3 (1+pT_1)(1+pT_2)[1+pRC(1-\mu_2 h)]\} \textcircled{2}}$$

The circled numbers beside the brackets will be used in future expressions to refer to the bracketed quantity on its left. Combining 24, 25, and 29 we have an expression for the transfer function in terms of the system parameters

$$B e^{j\beta} = \frac{\Theta_0}{\Theta N} = \frac{C_3 \textcircled{1}}{N(J_0 p^2 + Fp) - C_3 \textcircled{2} + C_1 C_2 C_3 p \textcircled{3}} \quad (30)$$

Equation 30 defines the operation of the system under transient and steady state conditions. After the constants of the above expressions have been determined experimentally, the equation will be solved for a sinusoidal input by substituting

$$p = j\omega \quad (31)$$

and then the transfer function plotted for values of ω .

By use of equations 6 and 7, $CE^{j\alpha}$ and $AE^{j\lambda}$ may be plotted

giving the complete representation of the performance of the system.

IV. Experimental Determination of System Constants

In the tests enumerated below the various constants of the system are determined. The tests were made over the same range of values as used in the system for a normal input. Using the resulting curves our assumptions may be proven to hold or be in error, as the case may be, and compensating corrections made.

Test No. 1. The output Inertia of the Motor and Gear Train.

The output inertia of the system is contributed to by the motor armature and two large gears connecting the motor shaft to the output selsyn transformer. The total inertia J_0 will be computed with respect to the motor shaft.

To accurately measure the moment of inertia of the irregular armature, a fly wheel whose inertia could be computed was suspended from a piece of long piano wire. It was set to oscillating as a torsional pendulum and its period recorded. The fly wheel was then replaced by the motor armature and its period of oscillation recorded.

Neglecting any damping due to the wire or air resistance, the period of a torsional pendulum is given in seconds by

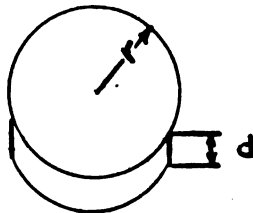
$$T = 2\pi \sqrt{\frac{I}{K}} \quad (32)$$

I being the moment of inertia of the system in slug-feet² and K the spring constant of the wire. Solving 32 for I and setting up a ratio for two masses using the same wire we find that

$$\frac{I_f}{I_a} = \frac{\frac{T_f^2 K}{4\pi^2}}{\frac{T_a^2 K}{4\pi^2}} = \frac{T_f^2}{T_a^2} \quad (33)$$

and

$$I_a = I_f \frac{T_a^2}{T_f^2} \quad (33a)$$



$$r = 2.25 \text{ in.}$$

$$d = 0.75 \text{ in.}$$

$$\omega = 3.41 \text{ lb.}$$

Figure 6

The moment of inertia of the flywheel depicted in Figure 6 is

$$I_a = \frac{1}{2} \frac{W}{g} r^2 = 0.5 \times \frac{3.41}{32.2} \times \left(\frac{2.25}{12}\right)^2 = 1.862 \times 10^{-3} \text{ slug-ft}^2 \quad (34)$$

The data taken in determining T_f of flywheel is :

Test	No. of oscillations	Time	Period
#1	10	123 sec.	12.3 sec.
#2	10	122	12.2
#3	10	124	12.4
T_f average = 12.3 sec.			

The data for T_a of motor armature is:

Test	No. of oscillations	Time	Period
#1	10	83.0 sec.	8.3 sec.
#2	10	82.5	8.25
#3	10	83.0	8.3

$$T_a \text{ average} = 8.3 \text{ sec.}$$

Using equation 34 I_a is found to be

$$I_a = 1.862 \times 10^{-3} \times \frac{8.3^2}{12.4^2} = 848 \times 10^{-6} \text{ slug-ft}^2 \quad (35)$$

The two large gears were initially thought to contribute a larger amount of inertia than is actually the case. Their moment of inertia was calculated since they are of

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symmetrical shape and difficult to remove from their assembly. The calculations are given below:

Gear A $r = 2.05$ in. density of steel $\rho = 0.284$ lb/in³
 $d = 0.1875$ in.

$$M = \frac{V\rho}{g} = \frac{\pi r^2 d \rho}{g} = 0.0216 \text{ slugs} \quad (36)$$

$$I_{GA} = \frac{1}{2} M r^2 = 0.5 \times 0.0216 \times \left(\frac{2.05}{12}\right)^2 = 0.313 \times 10^{-3} \text{ slug-ft}^2 \quad (37)$$

Gear B. $r = 3.03$ in.
 $d = 0.1875$ in.

$$M = 3.14 \times 3.03 \times 0.1875 \times \frac{0.284}{32.2} = 0.0475 \text{ slugs} \quad (38)$$

$$I_{GB} = 0.5 \times 0.0475 \times \left(\frac{3.03}{12}\right)^2 = 1.511 \times 10^{-3} \text{ slug-ft}^2 \quad (39)$$

The moment of inertia of the gear as seen from the motor shaft is

$$I'_{GA} = \frac{I_{GA}}{N^2} \quad (39a)$$

with a similar expression for I'_{GB} . The gear ratio of the train is shown above each pair of

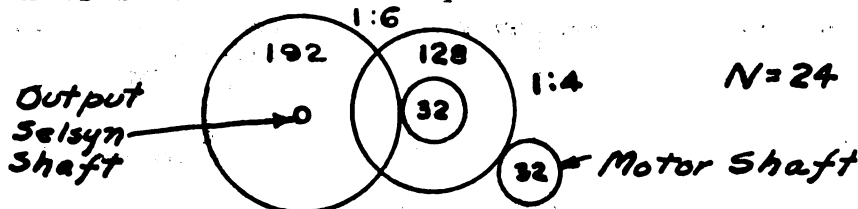


Figure 6

gears and the number inside each gear represents the number of teeth on each gear. The total gear ratio N is the product of the two or 24. The total inertia referred to the motor shaft is

$$J_0 = 848 \times 10^{-6} + \frac{0.913 \times 10^{-3}}{4^2} + \frac{1.511 \times 10^{-3}}{24^2} \quad (39 \text{ b})$$

$$J_0 = (848 + 22) 10^{-6} = 870 \times 10^{-6} \text{ slug-ft}^2$$

Test No. 2. The Time Constants of the Amplidyne.

In order to determine the time constant of the amplidyne field a Westinghouse oscillograph was used to record the transient current when the circuit was closed. The set-up employed is shown in Figure 7. From the curve of the transient, the length of time for the current to reach 62.3% of its final value was determined. The final current was limited by the resistor to 20 ma. The resistance of one half the field R , was found to be 830 ohms and that of the resistor R_h to be 300 ohms. Using the familiar expression for an RL circuit

$$i = \frac{E}{R} (1 - e^{-\frac{R}{L}t}) \quad (40)$$

the inductance of the one half of the field was determined.

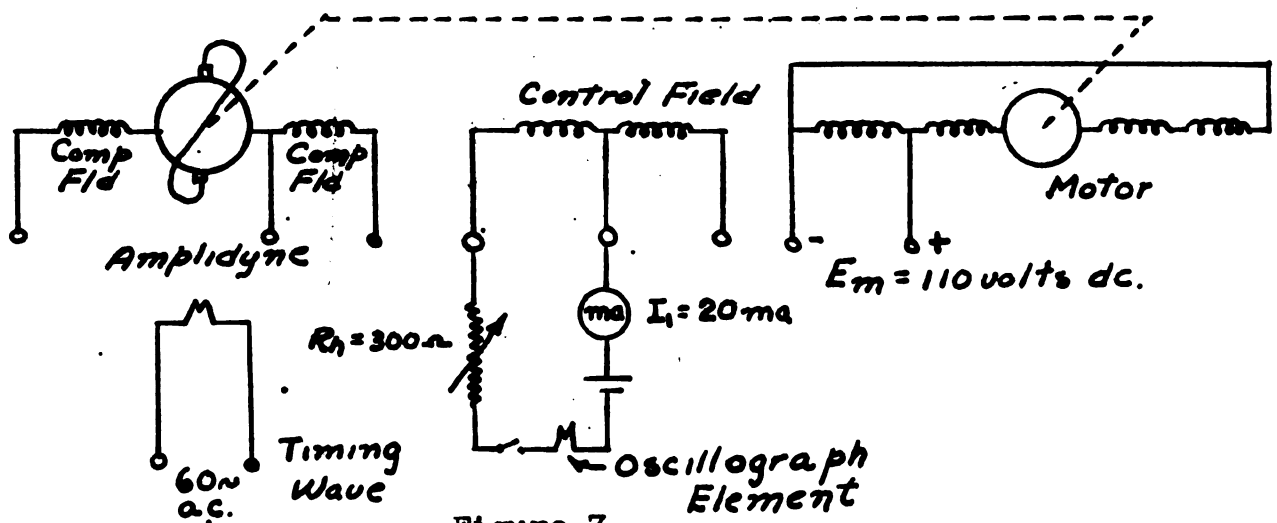


Figure 7

A series of three oscillographs were taken, one of which is shown in Figure 8. The average of the three time constants was found to be $T_1 = 0.0262$ seconds since

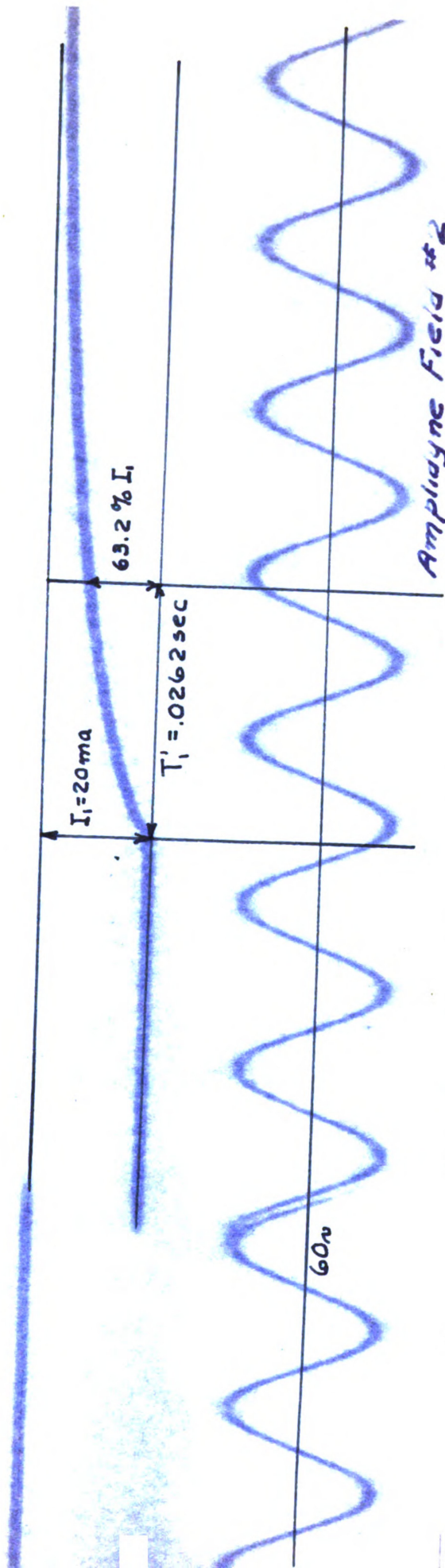


Fig 8

$$T_1' = \frac{L_1}{R_T} = 0.0262 = \frac{L_1}{830 + 300}$$

$$L_1 = 29.6 \text{ henries}$$

(40a)

The time constant of the field alone is found by

$$\frac{\frac{L_1}{R_T}}{\frac{L_1}{R_1}} = \frac{T_1'}{T_1} \rightarrow T_1 = \frac{1130}{830} \times 0.0262 = 0.0357 \text{ sec.} \quad (40b)$$

In Figure 9 is shown the circuit diagram followed in obtaining the oscillograms of the amplidyne armature current when the field is suddenly applied.

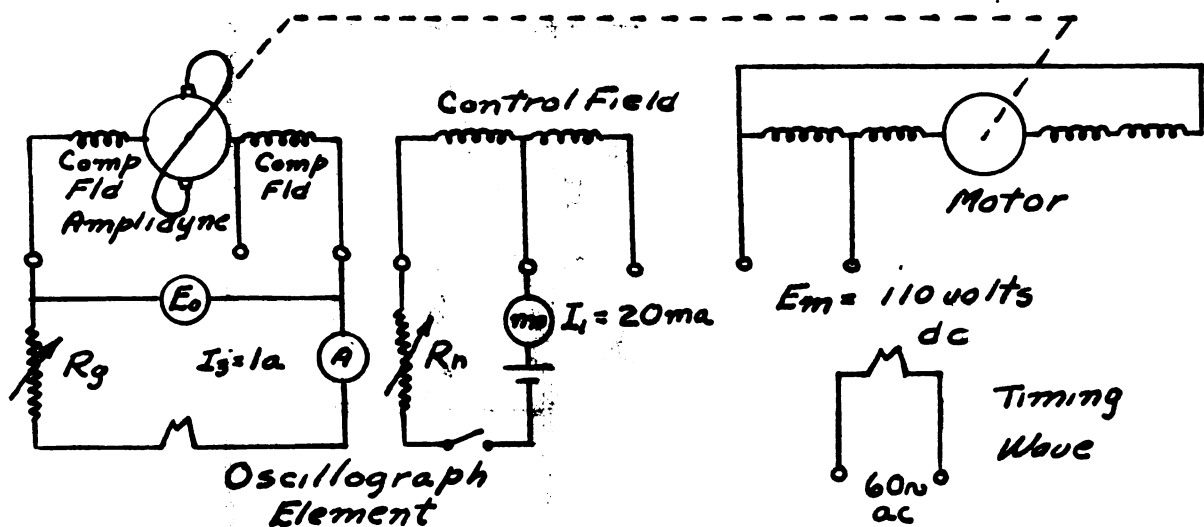


Figure 9

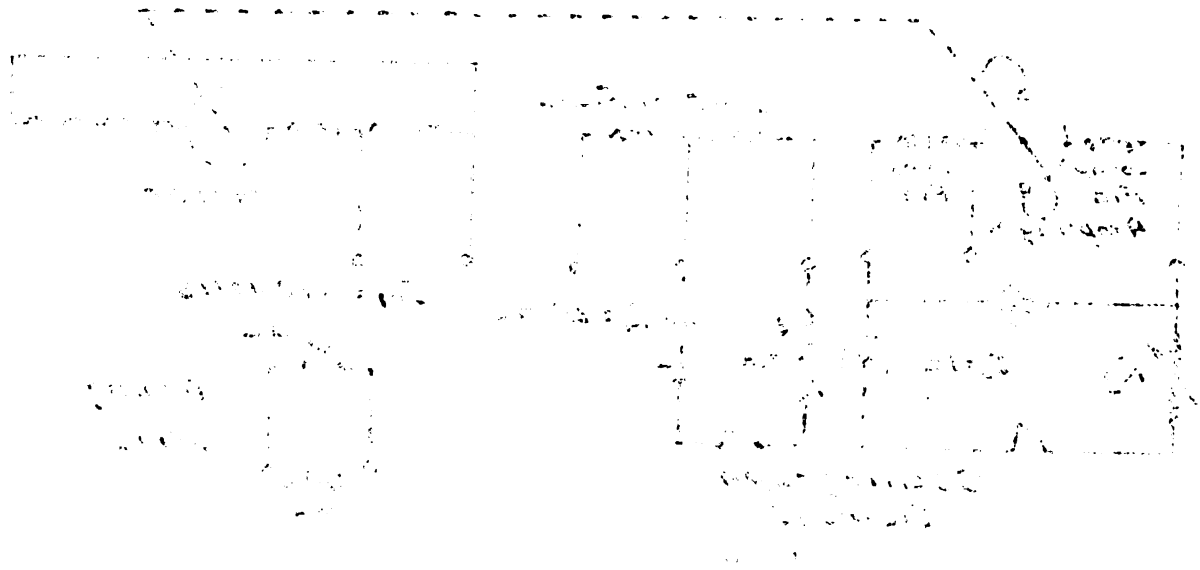
The resistors R_n and R_g were set to give an I_1 of 20 ma. and I_3 of 1 ampere respectively. When measured R_n was found to be 300 ohms and R_g , 260 ohms. The resistance of the armature R_2 measured by the volt-ammeter method while the motor was running had the value of 54 ohms.

A series of six oscillographs were made, two of which were discarded because the motor voltage E_m varied from 110 volts. The time to rise to a value of armature current equal to 0.634 amperes was scaled from each one and found to have a value of 0.0333 seconds. A typical oscillograph is shown in Figure 10.

177

177

177



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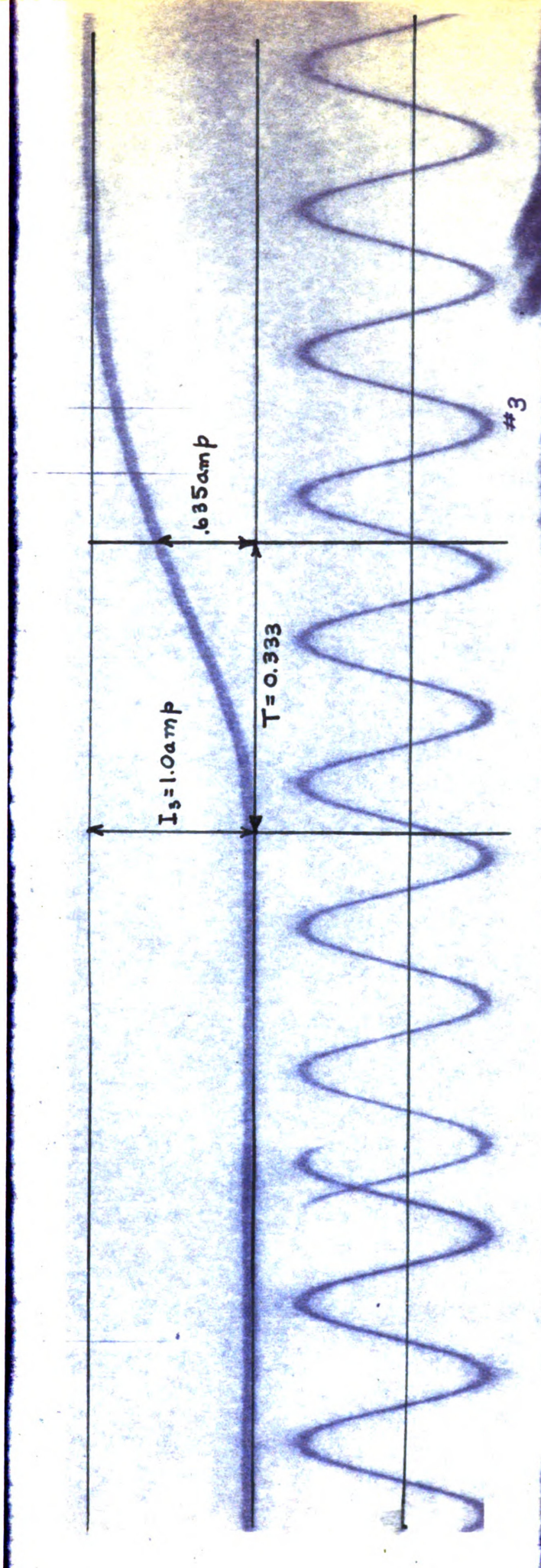


Fig. 10

The current I_3 follows the equation

$$I_3 = \frac{KE_1}{R_1 R_2} \left[1 + \frac{e^{-\frac{R_1}{L_1} t}}{\left(\frac{L_2 R_1}{R_2 L_1} - 1\right)} + \frac{e^{-\frac{R_2}{L_2} t}}{\left(\frac{L_1 R_2}{R_1 L_2} - 1\right)} \right] \quad (41)$$

When the values taken from the oscillograph and the above circuit constants are substituted in 41, the resulting transcendental equation may be solved by trial and error for L_2 . The value found for L_2 is 1.9 henries and the equation 41 appears as

$$I_3 = 1 \left[1 + \frac{e^{-\frac{.0333}{.0262} t}}{\left(\frac{1.9}{.0262 \times 314} - 1\right)} + \frac{e^{-\frac{314 \times .0333}{1.9} t}}{\left(\frac{.0262 \times 314}{1.9} - 1\right)} \right] \quad (42)$$

With R_g in the circuit the time constant is

$$T'_2 = \frac{L_2}{R_2} = \frac{1.9}{314} = 0.00605 \text{ sec.} \quad (43)$$

and of the armature alone

$$T_2 = \frac{1.9}{54} = 0.0352 \text{ sec.} \quad (44)$$

Test No. 3. Speed-Torque Curve of Output Motor with Input From Lab Supply

In this test the voltage across the motor armature was obtained from the lab outlet as shown in Figure 11. The motor was coupled mechanically to a small one-eighth horsepower generator with adjustable shunt field which served as a dynamometer. The motor was loaded by increasing the generator field while its output was dissipated in resistors. The torque of the motor was measured by a spring balance connected to the generator and the speed of the motor by a stroboscope. The resistance of the armature R_a is 23 ohms.

1. *Phragmites* (Common Reed) - A tall, grassy plant with long, narrow leaves and dense, upright flower stalks. It is often found in wetlands and along water bodies.

1. The first step in the process is to identify the problem or issue that needs to be addressed. This involves gathering information and understanding the context of the problem.

$$\lim_{n \rightarrow \infty} \frac{f(n)}{g(n)} = \frac{\lim_{n \rightarrow \infty} f(n)}{\lim_{n \rightarrow \infty} g(n)} = \frac{2}{\infty} = 0$$

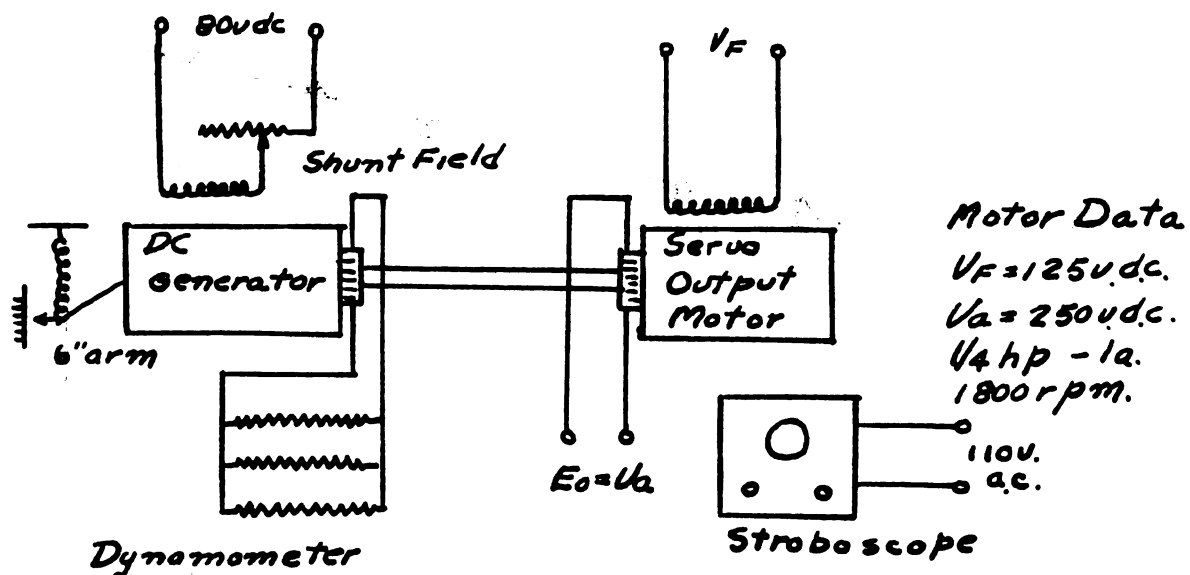


Figure 11

The data taken in the test is as follows:

Part A $E_o = V_a = 250 \text{ v.}$ $V_f = 109 \text{ v.}$

N-rpm	F -oz.	T- ft.lb.
1960	0.5	0.0156
1940	4.0	0.125
1900	8.0	0.250
1870	12.0	0.375
1840	16.0	0.500
1800	20.0	0.625
1780	24.0	0.750

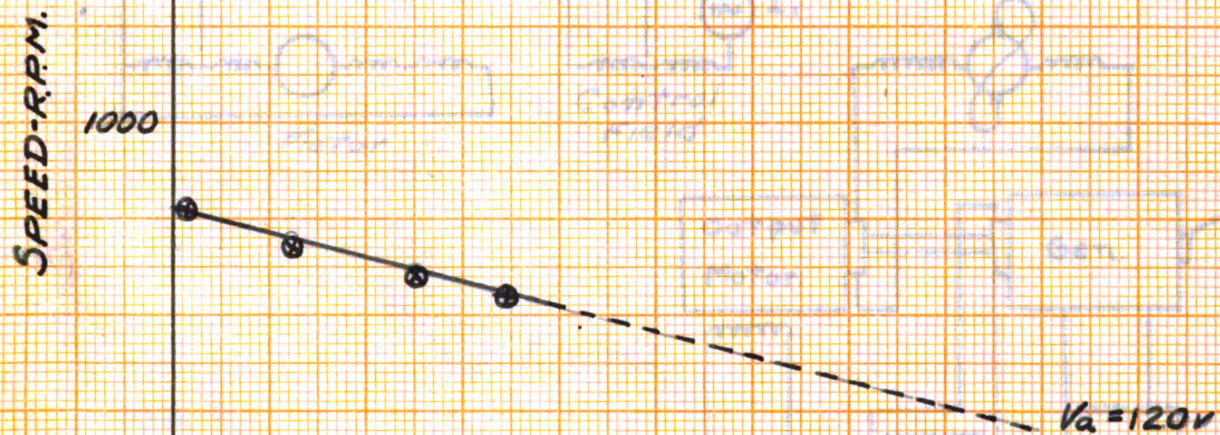
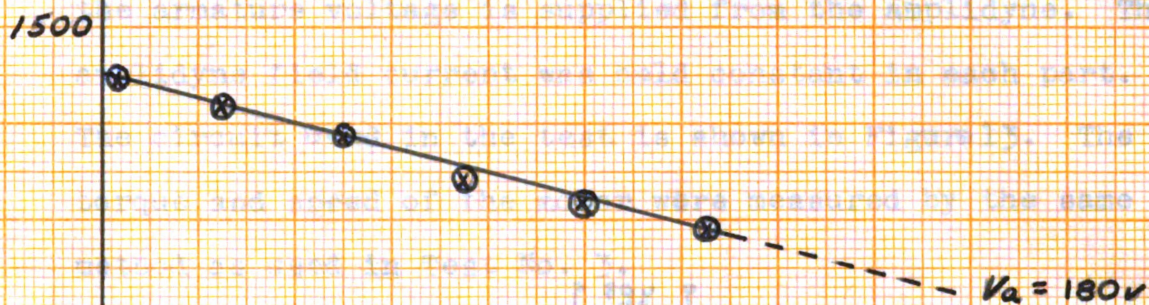
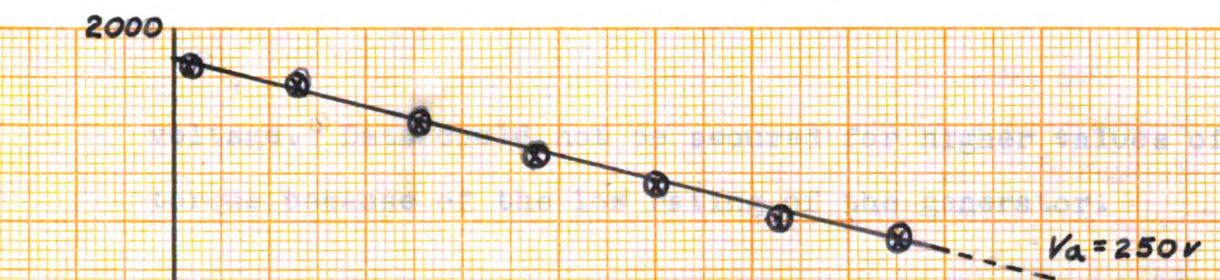
Part B $E_o = V_a = 180 \text{ v.}$ $V_f = 109 \text{ v.}$

1445	0.5	0.0156
1420	4.0	0.125
1385	8.0	0.250
1342	12.0	0.375
1320	16.0	0.500
1290	20.0	0.625

Part C $E_o = V_a = 120 \text{ v}$ $V_f = 109 \text{ v}$

910	0.5	0.0156
870	4.0	0.125
840	8.0	0.250
820	11.0	0.344

and is plotted in Figure 12. Of interest is the observation that the speed torque relationship is linear since curves are straight lines. The curves are parallel and their distance from one another are proportional to the armature



GRAPH OF
 SPEED VS TORQUE
 OF OUTPUT MOTOR OF SERVO-
 DEMONSTRATION UNIT
 FIELD VOLTAGE = 109V.
 ARMATURE VOLTAGE = 250, 180, 120V

0 0.2 0.4 0.6 0.8

voltage. Data could not be secured for higher values of torque because of the low rating of the generator.

Test No. 4. Speed- Torque Curve of Output Motor with Input from Amplidyne

This test is a duplication of Test No. 3 except that the armature voltage is supplied from the amplidyne. The amplidyne field current was held constant in each part. The circuit used in the test is shown in Figure 13. The torque and speed of the motor were measured by the same method as used in Test No. 3.

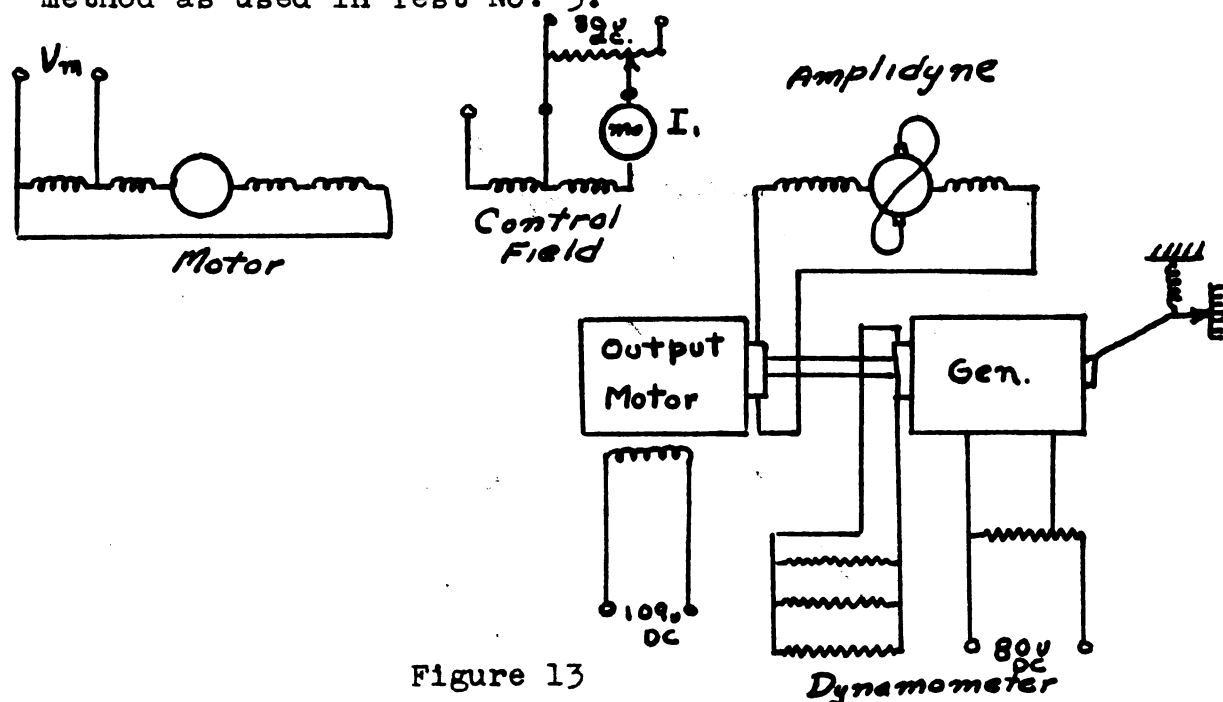


Figure 13

The data taken in the above test is as follows:

Part A $V_m = 109$ v $I_1 = 20$ ma.

N - rpm	F- oz.	T-ft.lb.
2710	0.8	0.025
2580	4.0	0.125
2420	8.0	0.250
2220	12.0	0.375
2100	16.0	0.500
1960	20.0	0.625
1815	24.0	0.750
1670	28.0	0.875
0		2.05

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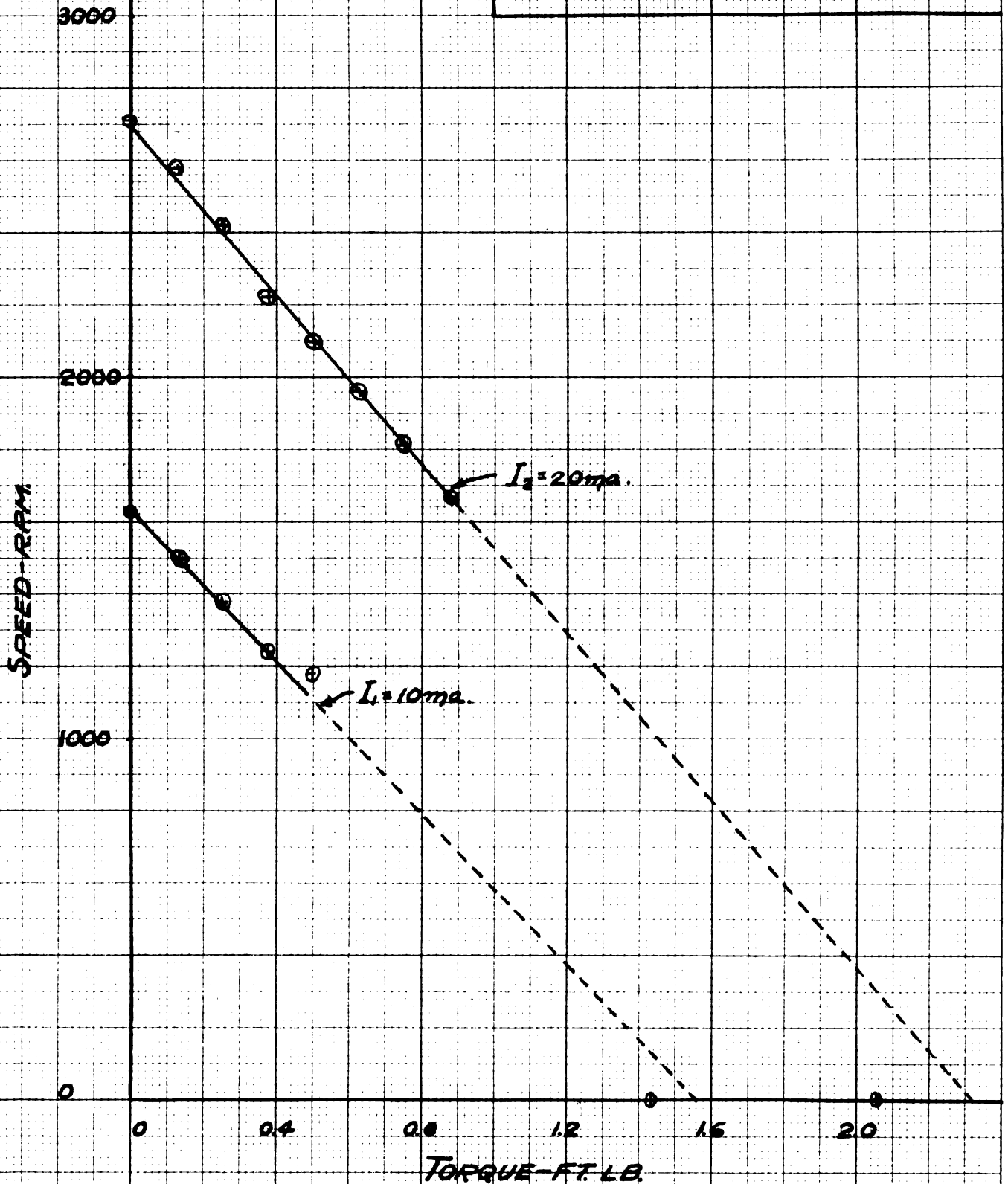
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100

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GRAPH OF
SPEED VS TORQUE
OF OUTPUT MOTOR OF SERVO-
DEMONSTRATION UNIT DRIVEN
BY AMPLIDYNE



Part B $V_m = 109 \text{ v}$ $i_l = 10 \text{ ma.}$

N- rpm	F - oz	T - ft. lb.
1620	0.4	0.0125
1500	4.0	0.125
1375	8.0	0.250
1245	12.0	0.375
1185	16.0	0.500
0		1.425

Figure 14 shows the curves plotting the above data. The points showing the blocked rotor torque are to the left of the values indicated by the extended dotted lines because of the saturation in the motor armature. There is a greater decrease in the blocked rotor torque at 20 ma. because of the saturation in the amplidyne field.

From these curves the K of equation 11 was determined and is found to be

$$K = \frac{1.56}{10} = 0.156 \text{ ft. lb./ma.} \quad (45)$$

In equation 13 and 24 the motor torque is equal to the force due to inertia and the frictional force which is proportional to the speed of the motor shaft. The torque necessary to overcome the friction is given by

$$T = F p \theta_0 \quad (46)$$

or

$$F = \frac{T}{p \theta_0} \quad (47)$$

This is the inverse of the slope of the motor's speed-torque curve; the friction coefficient becoming

$$F = \frac{1.56}{\frac{1630}{60} \times 6.28} = 9.15 \times 10^{-3} \text{ ft. lb./rad/sec.} \quad (48)$$

2. The second part outlines the various methods and tools used to collect and analyze data. It mentions the use of surveys, interviews, and focus groups to gather qualitative information, as well as statistical analysis for quantitative data.

3. The third part describes the process of identifying and addressing the needs and concerns of the stakeholders. It highlights the importance of active listening and communication in this process.

4. The fourth part discusses the role of leadership in driving change and innovation within the organization. It stresses the need for clear vision, strategic planning, and effective communication.

5. The fifth part concludes by summarizing the key findings and recommendations of the study. It reiterates the importance of ongoing monitoring and evaluation to ensure the success of the implemented changes.

The following table provides a detailed overview of the data collected during the study. It includes information on the number of participants, the distribution of responses, and the key themes identified.

Category	Sub-category	Frequency	Percentage
Demographics	Age Group		
	18-25	15	15%
	26-35	25	25%
	36-45	20	20%
Attitudes	Positive	30	30%
	Neutral	10	10%
	Negative	5	5%
Behaviors	Adopted	20	20%
	Not Adopted	10	10%

Based on the data presented in the table, it is evident that a significant portion of the participants (30%) hold positive attitudes towards the initiative. However, there is still a need for further engagement and support to encourage the adoption of the new behaviors.

The findings suggest that the most effective way to achieve this is through a combination of clear communication, training, and ongoing support. By addressing the specific concerns and needs of the stakeholders, the organization can foster a more positive and engaged workforce.

In conclusion, the study highlights the importance of a holistic approach to change management. It is not enough to simply implement a new initiative; rather, the organization must create a supportive environment that encourages and sustains the desired changes.

Test No. 5 Saturation Curve of Amplidyne

A saturation curve of the amplidyne was run in order to determine if there was a linear relationship between the field current and terminal voltage and to determine the constant K_1 of equation 9.

The circuit is shown in Figure 15 and the data taken in the test follows.

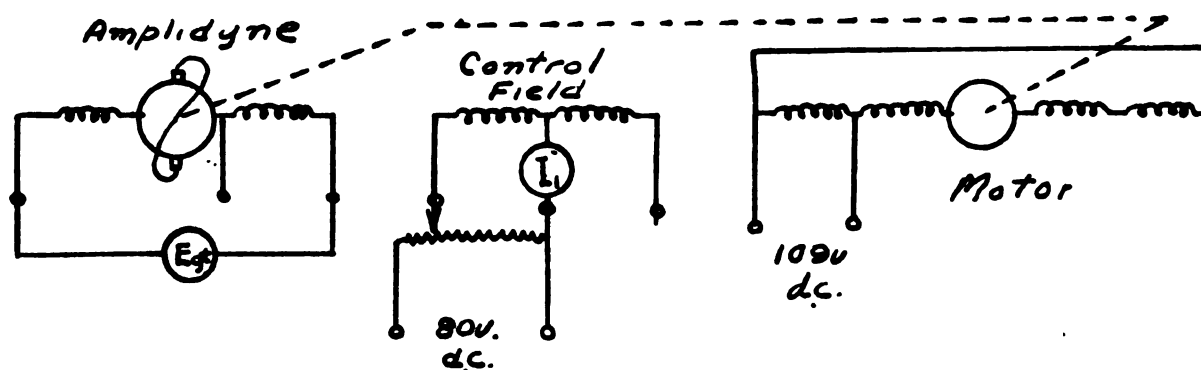


Figure 15

i_1 - ma	E_{gt} - volts
0	5
2	32
4	69
6	109
8	151
10	189
12	229
14	266
16	298
18	326
20	348

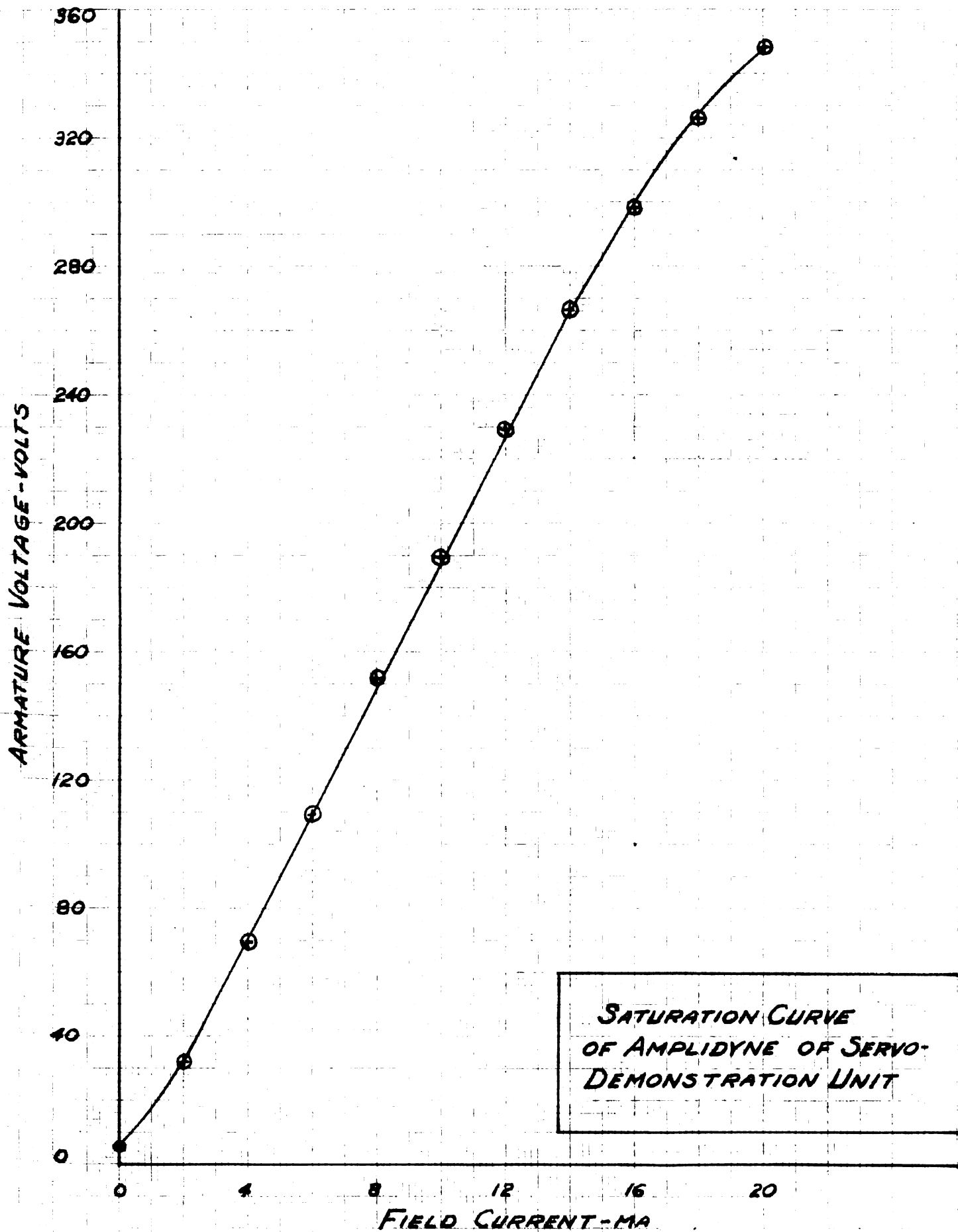
The data is plotted in Figure 16 and K_1 is determined to be

$$K_1 = \frac{300}{10.4} = 19.22 \text{ volts /ma.} \quad (49)$$

The voltage is shown to be linear up to about 17 ma.



1. The first part of the document is a list of names and addresses, which are arranged in a table-like format. The names are listed in the first column, and the addresses are listed in the second column. The names are: John Doe, Jane Smith, and Bob Johnson. The addresses are: 123 Main St, 456 Elm St, and 789 Oak St.



Test No.6. Amplidyne Output Voltage vs Current

In studying further the characteristics of the amplidyne a current vs. voltage curve was taken. The circuit diagram is shown in Figure 17 followed by the test data.

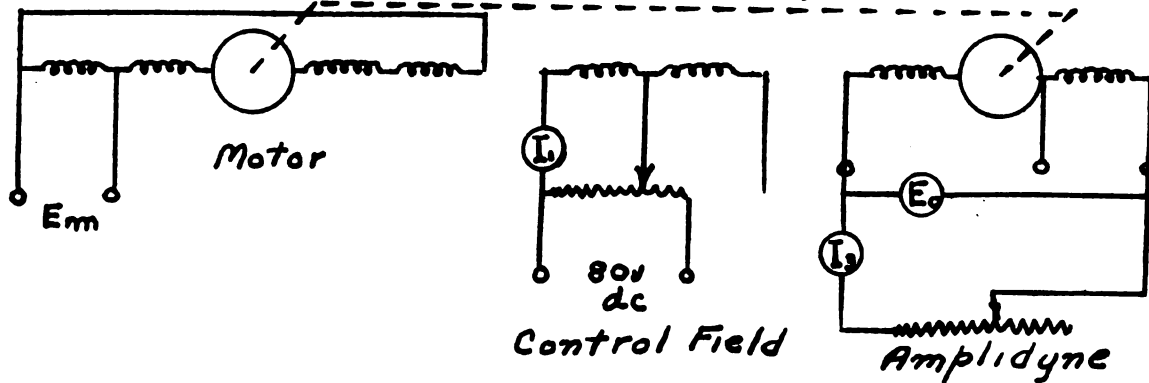


Figure 17

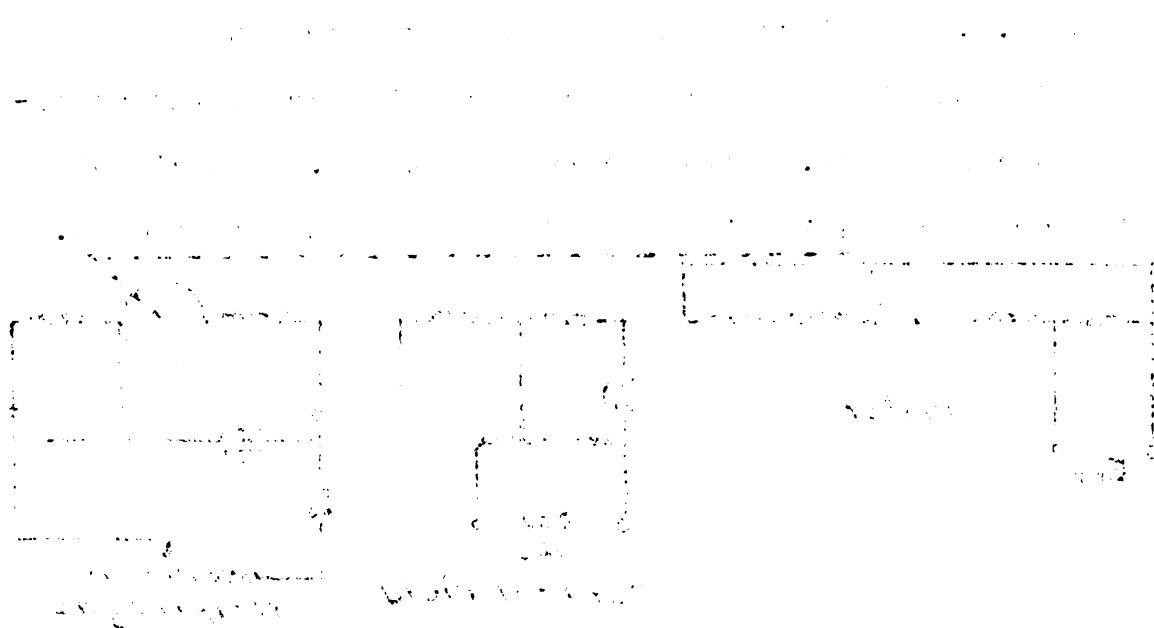
Part A $E_m = 109v$ $i_1 = 10$ ma.

E_o - volts	i_2 - amps
216	0
191	0.33
175	0.50
154	0.75
137	1.00
118	1.25

Part B $E_m = 109v$ $i_1 = 20$ ma.

E_o - volts	i_2 - amps
362	0
310	0.52
286	0.75
260	1.00
236	1.25

In the curves plotted in Figure 18, we see that there is not quite a linear function between the field current and armature current because of the saturation in the field at 20 ma. The curves are not exactly parallel; whether this is due to the fact that the machine was cold during the 10 ma run or to plotting is not known.



List of Rooms and Areas	
1. Hall	100
2. Kitchen	101
3. Room 1	102
4. Room 2	103
5. Room 3	104
6. Room 4	105
7. Room 5	106
8. Room 6	107
9. Room 7	108
10. Room 8	109
11. Room 9	110
12. Room 10	111
13. Room 11	112
14. Room 12	113
15. Room 13	114
16. Room 14	115
17. Room 15	116
18. Room 16	117
19. Room 17	118
20. Room 18	119
21. Room 19	120
22. Room 20	121
23. Room 21	122
24. Room 22	123
25. Room 23	124
26. Room 24	125
27. Room 25	126
28. Room 26	127
29. Room 27	128
30. Room 28	129
31. Room 29	130
32. Room 30	131
33. Room 31	132
34. Room 32	133
35. Room 33	134
36. Room 34	135
37. Room 35	136
38. Room 36	137
39. Room 37	138
40. Room 38	139
41. Room 39	140
42. Room 40	141
43. Room 41	142
44. Room 42	143
45. Room 43	144
46. Room 44	145
47. Room 45	146
48. Room 46	147
49. Room 47	148
50. Room 48	149
51. Room 49	150
52. Room 50	151
53. Room 51	152
54. Room 52	153
55. Room 53	154
56. Room 54	155
57. Room 55	156
58. Room 56	157
59. Room 57	158
60. Room 58	159
61. Room 59	160
62. Room 60	161
63. Room 61	162
64. Room 62	163
65. Room 63	164
66. Room 64	165
67. Room 65	166
68. Room 66	167
69. Room 67	168
70. Room 68	169
71. Room 69	170
72. Room 70	171
73. Room 71	172
74. Room 72	173
75. Room 73	174
76. Room 74	175
77. Room 75	176
78. Room 76	177
79. Room 77	178
80. Room 78	179
81. Room 79	180
82. Room 80	181
83. Room 81	182
84. Room 82	183
85. Room 83	184
86. Room 84	185
87. Room 85	186
88. Room 86	187
89. Room 87	188
90. Room 88	189
91. Room 89	190
92. Room 90	191
93. Room 91	192
94. Room 92	193
95. Room 93	194
96. Room 94	195
97. Room 95	196
98. Room 96	197
99. Room 97	198
100. Room 98	199
101. Room 99	200

The floor plan shows a building with a large central hall and several smaller rooms. The rooms are numbered from 1 to 100. The hall is located in the center of the building and is connected to all the rooms. The rooms are arranged in a grid-like pattern around the hall. The kitchen is located in the top right corner of the building. The drawing is done in a simple, sketchy style with dashed lines for walls and solid lines for furniture or fixtures. There are some handwritten notes and numbers scattered around the plan.

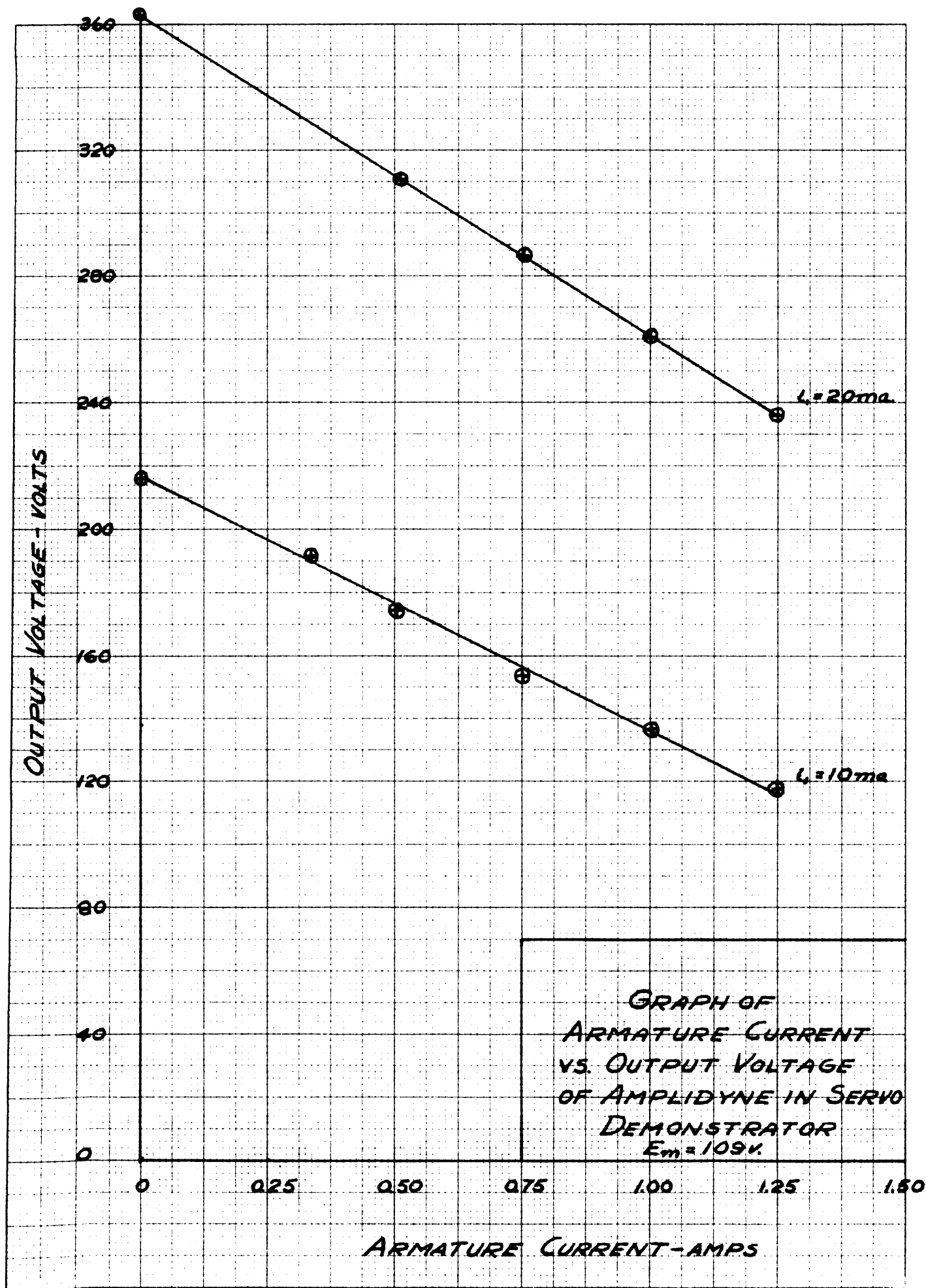


FIG 18

Test No. 7. Curve of Armature Current vs. Torque

In order to determine the constant C_3 in equation 24 a curve of armature current vs. torque of the output motor was made. Also a check as to linearity of the torque and armature current can be made. The same equipment was employed as in Test No 3 with the addition of an ammeter in the motor circuit to measure the armature current. The data taken in the test is plotted in Figure 19. The armature voltage was taken from the lab supply and held constant at the values indicated.

Part A $E_m = 108v$ $E_f = 108 v$

I_a - amps	F - oz	T-ft. lbs.
0.14	0.6	0.0188
0.20	2.2	0.0688
0.27	4.0	0.125
0.36	6.0	0.1875
0.43	8.0	0.250
0.50	10.0	0.312
0.52	11.2	0.350

Part B $E_m = 220v$ $E_f = 108 v$

I_a - amps	F - oz	T- ft. lb.
0.14	0.5	0.0156
0.21	2.0	0.0625
0.28	4.0	0.125
0.38	6.0	0.1875
0.44	8.0	0.250
0.52	10.0	0.312
0.58	12.0	0.375
0.75	16.0	0.500
0.91	20.0	0.625
1.06	24.0	0.750
1.20	28.0	0.875

The constant C_3 which is the inverse of the slope of the curve is found to be

$$C_3 = \frac{0.60}{0.72} = 0.834 \text{ ft. lb./amp.}$$

• $\text{dim}(V) = 3$ und $\dim(W) = 2$ (wegen $W \subset V$)

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$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

• $\dim(V) = 3$ und $\dim(W) = 2$ (wegen $W \subset V$)

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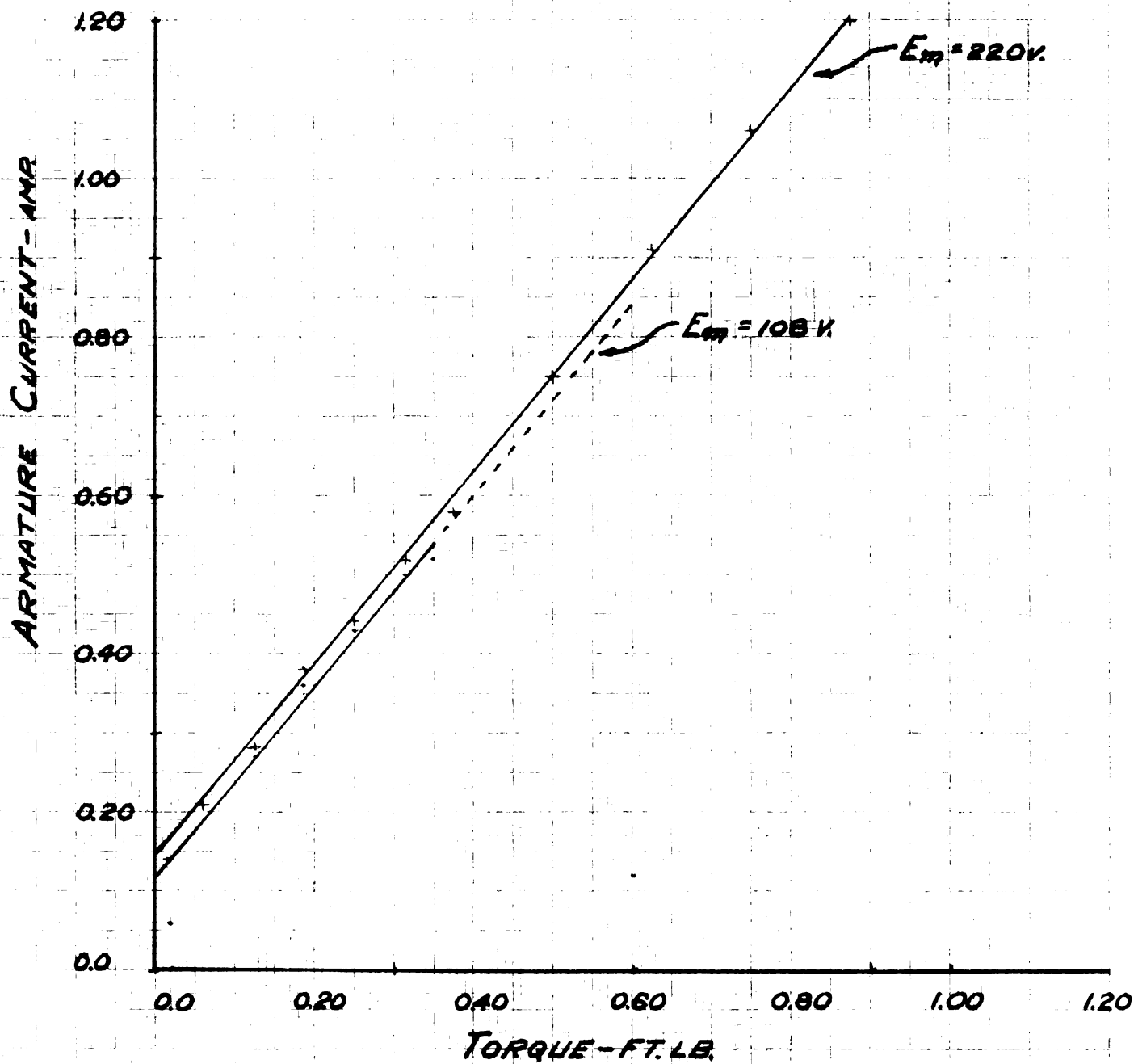
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

• $\dim(V) = 3$ und $\dim(W) = 2$ (wegen $W \subset V$)

• $\dim(V) = 3$ und $\dim(W) = 2$ (wegen $W \subset V$)

$$y(0) = 2 \quad \text{te} \quad y(0) = \frac{1}{2} \frac{d^2 y}{dx^2} = 2$$

• $\dim(V) = 3$ und $\dim(W) = 2$ (wegen $W \subset V$)



GRAPH OF
ARMATURE CURRENT
VS TORQUE FOR SERVO
OUTPUT MOTOR

Test No. 8 . Gain of Amplifier Without Feedback

In this test we will determine the relation between the angular error and the resultant field current at the output of the amplifier. The rotor of the selsyn transformer on the output shaft was blocked, making the angular displacement of the selsyn generator on the input shaft the error. Figure 20 shows the arrangement of the equipment in making the test. The feedback voltage was zero.

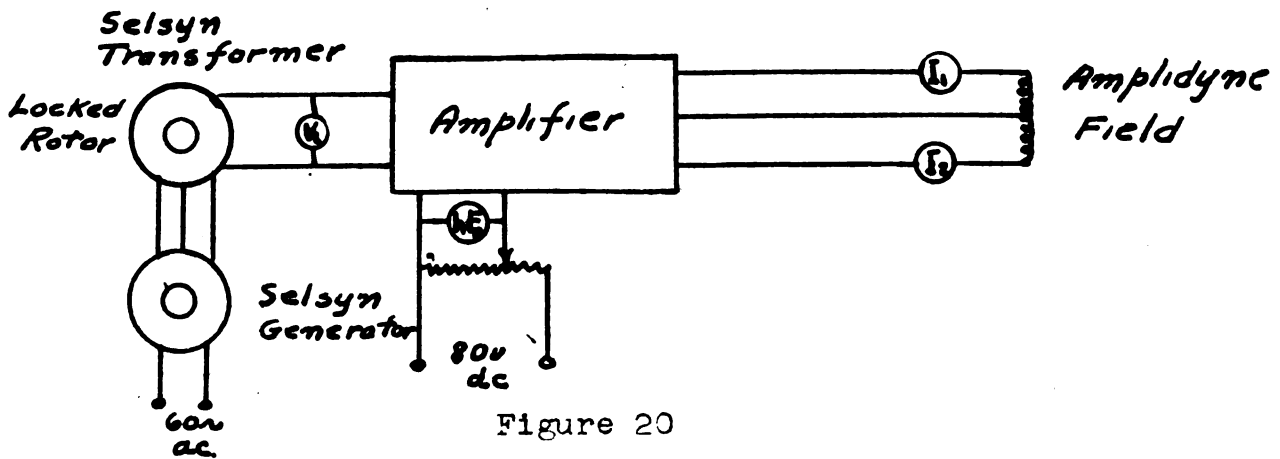


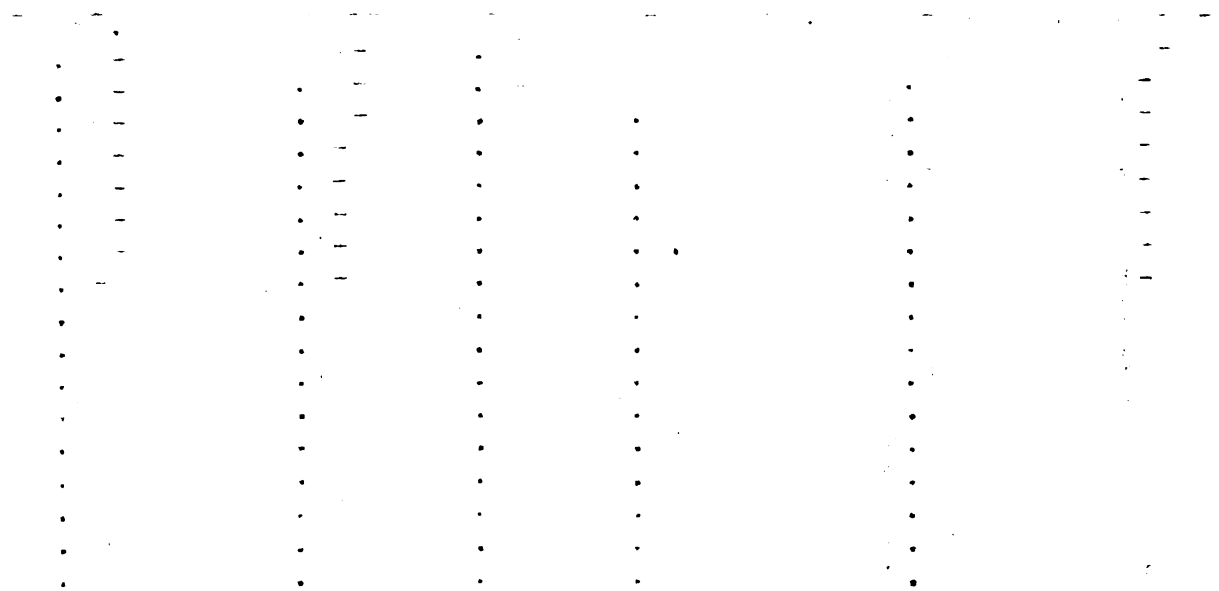
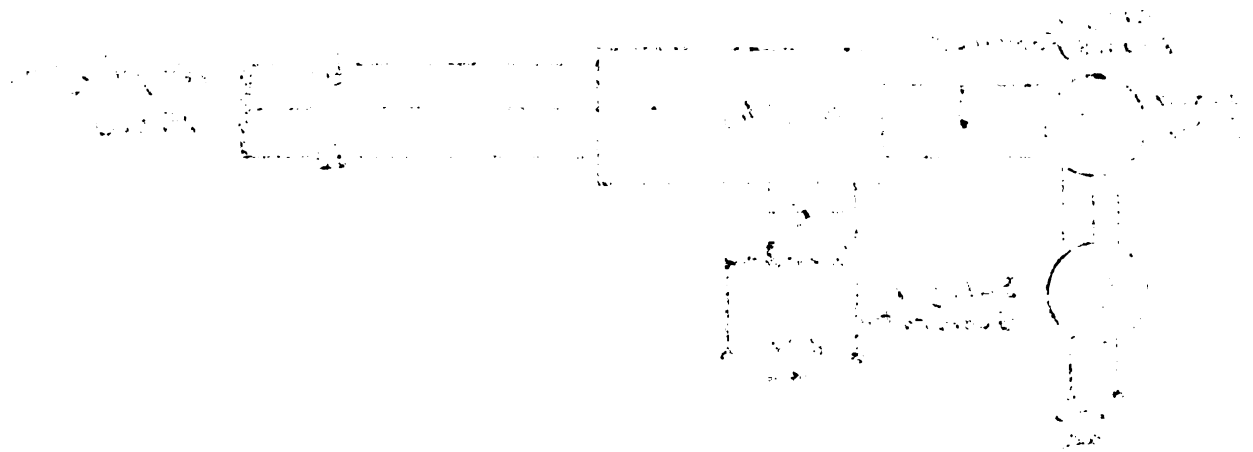
Figure 20

θ - teeth	V_1 -volts, ac	i_1 -ma	i_2 -ma	θ -degree	(i_1-i_2) -ma
-10	17	0	41.0	-19°	-41.0
-8	13.8	0	41.0	-15.2	-41.0
-6	10.6	1.0	40.5	-11.4	-39.5
-4	7.1	2.4	39.0	-7.6	-36.6
-3	5.2	5.4	37.3	-5.7	-31.9
-2	3.4	10.7	33.4	-3.8	-22.7
-1	1.7	16.8	27.7	-1.9	-10.9
$-\frac{1}{2}$	0.9	20.0	24.8	-0.95	-4.8
0	0.08	23.9	21.3	0.0	2.6
$\frac{1}{2}$	0.23	26.1	19.2	0.95	6.9
1	1.04	29.8	16.0	1.9	13.8
2	2.8	36.4	9.2	3.8	27.2
3	4.4	41.0	4.6	5.7	36.4
4	6.0	43.5	2.4	7.6	41.1
6	9.5	45.0	1.0	11.4	44.0
8	13.2	45.0	0.5	15.2	44.5
10	16.3	45.0	0.0	19.0	45.0

Equilibrium position:

$$V_1 = 0.32v ; i_1 = 24.2 \text{ ma} ; i_2 = 23 \text{ ma.}$$

190 teeth in gear.



1. The first part of the document is a title page, which includes the title of the document, the author's name, and the date of publication.

2. The second part of the document is an abstract, which provides a brief summary of the main findings of the study.

3. The third part of the document is the introduction, which provides background information on the topic and states the purpose of the study.

4. The fourth part of the document is the methodology, which describes the methods used to collect and analyze the data.

5. The fifth part of the document is the results, which presents the findings of the study.

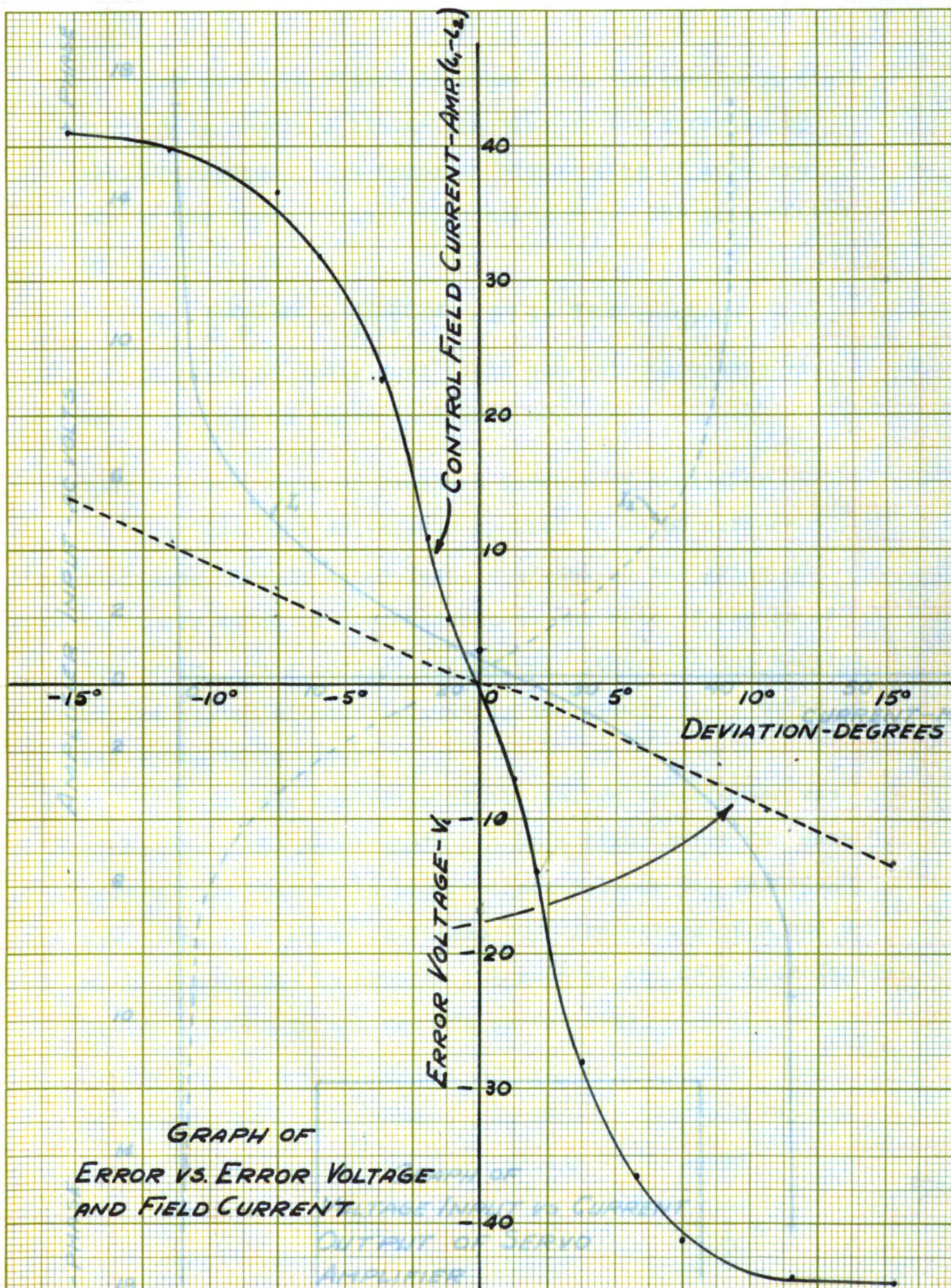
6. The sixth part of the document is the discussion, which interprets the results and discusses their implications.

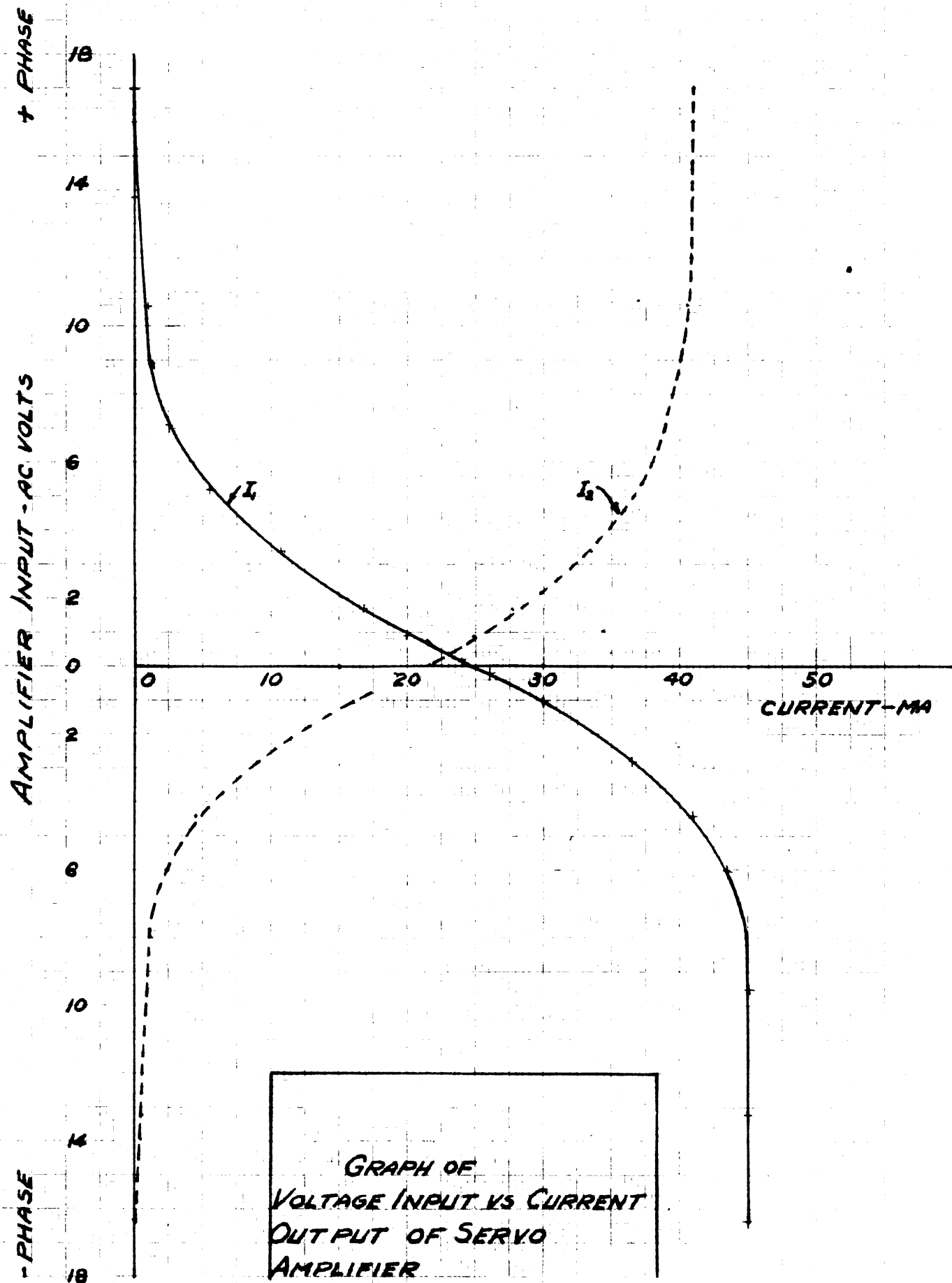
7. The seventh part of the document is the conclusion, which summarizes the main findings and provides recommendations for future research.

8. The eighth part of the document is the references, which lists the sources used in the study.

9. The ninth part of the document is the appendix, which contains supplementary information related to the study.

10. The tenth part of the document is the index, which provides a list of the topics covered in the document.





The curve in Figure 21 shows that the resultant field current is nearly a linear function of the error up to about 5 degrees. The humps on either side of zero are due to the error voltage flattening out. The gain of the amplifier u_1 is

$$u_1 = \frac{\Delta(I_1 - I_2)}{\Delta \theta} = \frac{22.5 + 28}{3.7 + 3.75} \times 57.3 = 388 \text{ ma/rad.} \quad (50)$$

A graph of individual field current components vs. error voltage is shown in Figure 22.

Test No. 9. Gain of Feedback Circuit of Amplifier

The feedback voltage is applied to an RC differentiating circuit which feeds a signal to the grids of the tubes which is proportional to the rate of change of the error. This circuit effectively increases the damping of the system without increasing the steady state error to any appreciable extent.

In the test the rotor of the selsyn transformer was blocked and the input shaft set at a fixed error for each part of the test while the feedback voltage was varied. The circuit is shown in Figure 20, The values of R and C used in equation 15 are: R= 1.2 megohms and C= 2 microfarads. The data taken in the test is as follows:

Part A $\theta = 0$

hE_0 - volts	i_1 - ma	i_2 - ma	$(i_1 - i_2)$ - ma.
0	25.1	23.5	1.6
5.2	21.2	27.1	-5.9
10	18.1	29.8	-11.7
15	15.0	32.4	-17.4
20	12.0	34.2	-22.2
24.9	10.0	35.9	-25.9
30	7.9	37.2	-29.3

Part B $\theta = 2.5^\circ$

hE_0 -volts	i_1 -ma	i_2 -ma	(i_1-i_2) -ma
0	41.0	5.0	36
5	40.1	6.1	34
10	39.5	7.8	31.7
15	38.0	10.0	28.0
20	36.8	12.2	24.6
25	34.9	14.8	20.1
30	31.9	18.2	13.7

Part C $\theta = -2.5^\circ$

hE_0 -volts	i_1 -ma.	i_2 -ma.	(i_1-i_2) -ma.
0	8.2	35.8	-27.6
5	6.2	36.6	-30.4
10	4.9	37.2	-32.3
15	3.6	38.1	-34.5
20	2.7	38.5	-35.8
25	2.0	38.9	-36.9
30	1.5	39.2	-37.7

The curves in Figure 23 are not parallel because of the fact that the tubes draw appreciable grid current and the input transformer becomes saturated at higher values of feedback voltage. In the determination of the gain u_2 in equation 15, an average value was determined to be

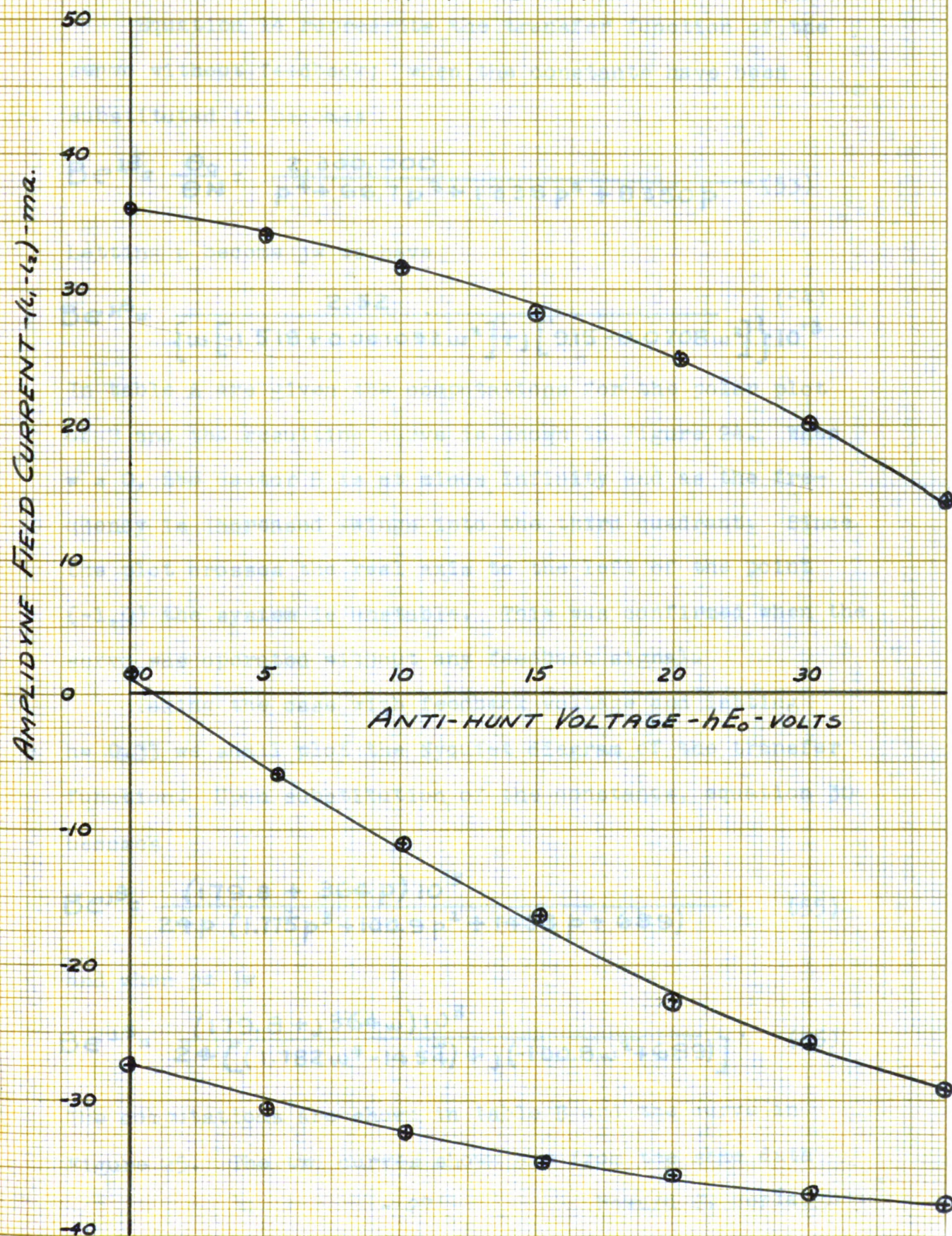
$$u_2 = \frac{\Delta(e_1 - e_2)}{\Delta hE_0} R_1 = \frac{16 \times 830}{28.15} = 0.462 \text{ volts/volt} \quad (51)$$

IV. Calculations and Performance Curves.

In the last section the constants of the servo system with and without feedback were determined. As the next step we will make the substitutions and draw a polar plot or Nyquist diagram of the transfer function. A sinusoidal input will be assumed and it follows that the error and output will also be sinusoidal functions of the same frequency but differing in phase and amplitude. Since this is to be a sinusoidal analysis, the differential equations will be solved by making

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GRAPH OF
ANTI HUNT VOLTAGE VS
AMPLIDYNE FIELD CURRENT



$$p = j\omega \quad (52)$$

Equation 14 represents the transfer function of the servo without feedback; when the constants have been substituted it becomes

$$Be^{j\beta} = \frac{\theta_o}{\theta_N} = \frac{2,300,000}{p^4 + 66.7p^3 + 1338p^2 + 8350p} \quad (53)$$

Letting p become $j\omega$ we have

$$Be^{j\beta} = \frac{2.52}{\{\omega[-1.518 + 0.001092\omega^2] + j[9.15 - 0.0708\omega^2]\} 10^{-3}} \quad (54)$$

In table A are given the computations for the polar plot of B and the resulting curve is shown in Figure 24. When $\omega = 0$, the vector B is at minus infinity and as the frequency is increased swings into the third quadrant. Since the plot crosses the real axis to the left of the point $(-1, 0)$ the system is unstable. This was confirmed when the servo was operated without any feedback signal.

Taking the case with feedback voltage and letting $h = 0.33$ we shall plot the Nyquist diagram of the transfer function. Upon substitution of the constants, equation 30 becomes

$$Be^{j\beta} = \frac{(179.8 + 364p) 10^3}{24p(1.775p^3 + 100.9p^2 + 1453p + 689)} \quad (55)$$

and when $p = j\omega$

$$Be^{j\beta} = \frac{(179.8 + j364\omega) 10^3}{24[(1.782\omega^3 - 1454) + j(-100.8\omega^2 + 689)]} \quad (56)$$

The computations are shown in table B and the curve in Figure 25. The two curves shown are from the same data

10.11.14

1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \int_0^x f(t) dt$. It is shown that $f(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $f(0) = 0$.

2. In the second part of the paper, we consider the function $g(x)$ defined by the equation $g(x) = \int_0^x g(t) dt$. It is shown that $g(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $g(0) = 0$.

3. In the third part of the paper, we consider the function $h(x)$ defined by the equation $h(x) = \int_0^x h(t) dt$. It is shown that $h(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $h(0) = 0$.

4. In the fourth part of the paper, we consider the function $k(x)$ defined by the equation $k(x) = \int_0^x k(t) dt$. It is shown that $k(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $k(0) = 0$.

5. In the fifth part of the paper, we consider the function $l(x)$ defined by the equation $l(x) = \int_0^x l(t) dt$. It is shown that $l(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $l(0) = 0$.

6. In the sixth part of the paper, we consider the function $m(x)$ defined by the equation $m(x) = \int_0^x m(t) dt$. It is shown that $m(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $m(0) = 0$.

7. In the seventh part of the paper, we consider the function $n(x)$ defined by the equation $n(x) = \int_0^x n(t) dt$. It is shown that $n(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $n(0) = 0$.

8. In the eighth part of the paper, we consider the function $o(x)$ defined by the equation $o(x) = \int_0^x o(t) dt$. It is shown that $o(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $o(0) = 0$.

9. In the ninth part of the paper, we consider the function $p(x)$ defined by the equation $p(x) = \int_0^x p(t) dt$. It is shown that $p(x)$ is a constant function and that its value is zero. This result is obtained by using the fundamental theorem of calculus and the fact that $p(0) = 0$.

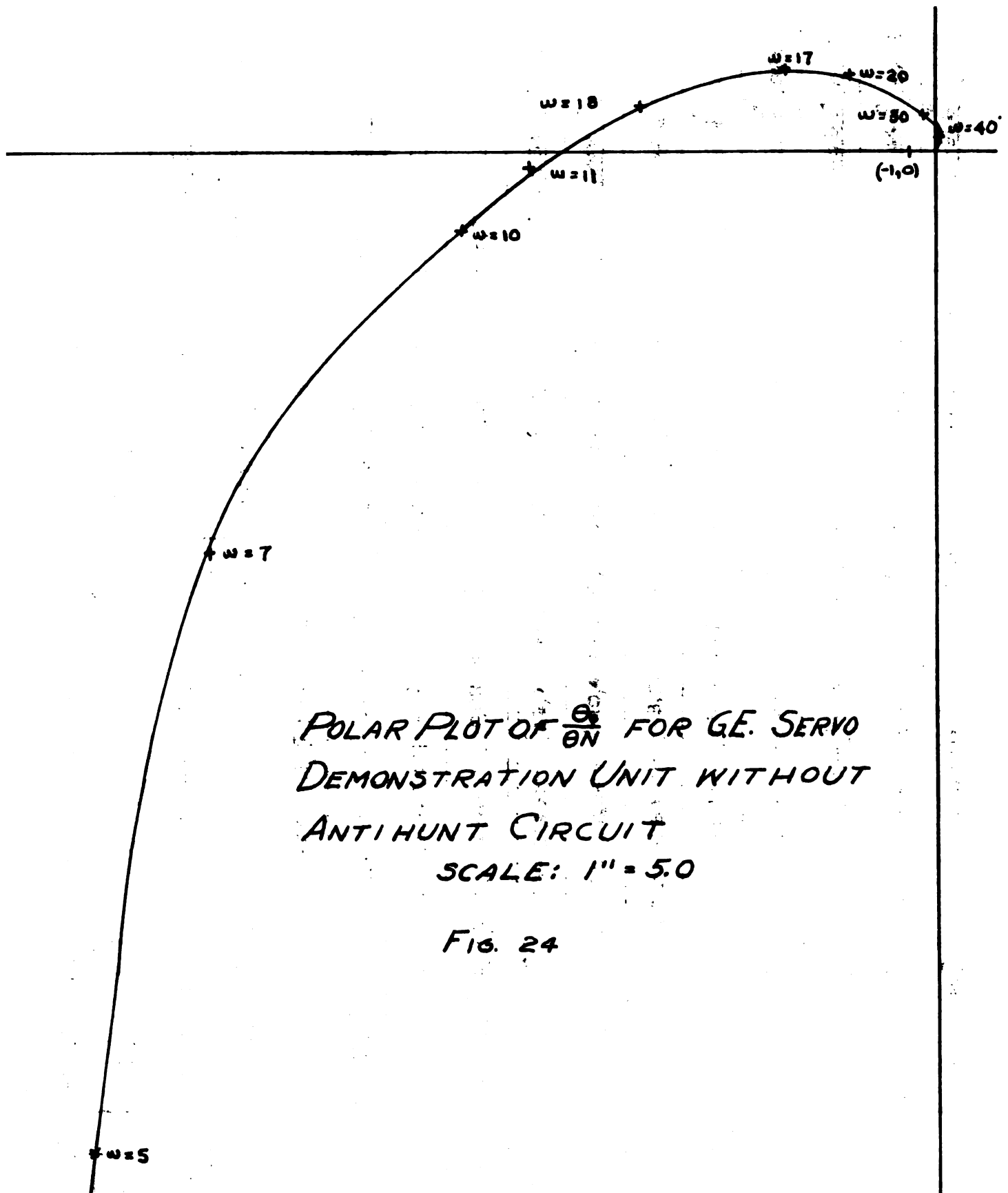
TABLE A COMPUTATION OF $\frac{\theta_2}{\theta_N}$ WITHOUT ANTIHUNT CIRCUIT

ω Rad/sec	A	B	A ²	B ²	A ² +B ²	$\frac{K_1 M_1}{W(A^2+B^2)}$	RLE	$B = \frac{\theta_2}{\theta_N}$
0	0	9.15×10^{-3}	0	83.7×10^{-6}	83.7×10^{-6}	∞	$9.15 \times 10^{-3} \angle -90^\circ$	$\infty \angle -90^\circ$
1	-1.517×10^{-3}	9.08×10^{-3}	2.3×10^{-6}	82.4×10^{-6}	84.7×10^{-6}	29,800	$9.20 \times 10^{-3} \angle 99.5^\circ$	$27.4 \angle -99.5^\circ$
5	-7.47×10^{-3}	7.38×10^{-3}	55.8×10^{-6}	54.4×10^{-6}	110.2×10^{-6}	4590	$10.5 \times 10^{-3} \angle 135.3^\circ$	$48.3 \angle -135.3^\circ$
7	-10.27×10^{-3}	5.68×10^{-3}	105.5×10^{-6}	32.2×10^{-6}	137.7×10^{-6}	2620	$11.7 \times 10^{-3} \angle -151^\circ$	$30.6 \angle -151^\circ$
10	-14.09×10^{-3}	2.07×10^{-3}	198.5×10^{-6}	4.28×10^{-6}	202.8×10^{-6}	1240	$14.23 \times 10^{-3} \angle -164.6^\circ$	$17.64 \angle -164.6^\circ$
11	-15.24×10^{-3}	0.59×10^{-3}	232.5×10^{-6}	$.348 \times 10^{-6}$	232.8×10^{-6}	985	$15.24 \times 10^{-3} \angle -177.8^\circ$	$15.0 \angle -177.8^\circ$
13	-17.34×10^{-3}	-2.84×10^{-3}	301×10^{-6}	8.06×10^{-6}	309×10^{-6}	629	$17.52 \times 10^{-3} \angle -189.1^\circ$	$11.0 \angle -189.1^\circ$
17	-20.45×10^{-3}	-11.30×10^{-3}	419×10^{-6}	127.8×10^{-6}	547×10^{-6}	272	$23.3 \times 10^{-3} \angle -209^\circ$	$6.33 \angle -209^\circ$
20	-21.6×10^{-3}	-19.2×10^{-3}	466×10^{-6}	369×10^{-6}	835×10^{-6}	150.8	$28.9 \times 10^{-3} \angle -221.7^\circ$	$4.37 \angle -221.7^\circ$
25	-20.9×10^{-3}	-35.0×10^{-3}	436×10^{-6}	1225×10^{-6}	1761×10^{-6}	26.0*	$40.7 \times 10^{-3} \angle -239.1^\circ$	$2.33 \angle -239.1^\circ$
30	-16.0×10^{-3}	-54.5×10^{-3}	254×10^{-6}	2970×10^{-6}	3224×10^{-6}	26.0	$56.7 \times 10^{-3} \angle -253.6^\circ$	$1.475 \angle -253.6^\circ$
40	$+9.29 \times 10^{-3}$	-104.1×10^{-3}	86.3×10^{-6}	10.94×10^{-3}	10.94×10^{-3}	5.76	$104.3 \times 10^{-3} \angle +84.9^\circ$	$0.601 \angle 84.9^\circ$
50	$+60.5 \times 10^{-3}$	-168×10^{-3}	3660×10^{-6}	28.2×10^{-3}	31.86×10^{-3}	1.585	$180.3 \times 10^{-3} \angle 70.4^\circ$	$0.248 \angle 70.4^\circ$
60	145.4×10^{-3}	-246×10^{-3}	21.2×10^{-3}	60.5×10^{-3}	80.7×10^{-3}	0.514	$286 \times 10^{-3} \angle 59.4^\circ$	$0.147 \angle 59.4^\circ$
80	438×10^{-3}	-444×10^{-3}	192×10^{-3}	197×10^{-3}	389×10^{-3}	0.0812	$757 \times 10^{-3} \angle 45.4^\circ$	$0.0614 \angle 45.4^\circ$
100	940×10^{-3}	-669×10^{-3}	883×10^{-3}	488×10^{-3}	1371×10^{-3}	0.01835	$1171 \times 10^{-3} \angle 36.6^\circ$	$0.0216 \angle 36.6^\circ$

* CORRECTION: 57.4

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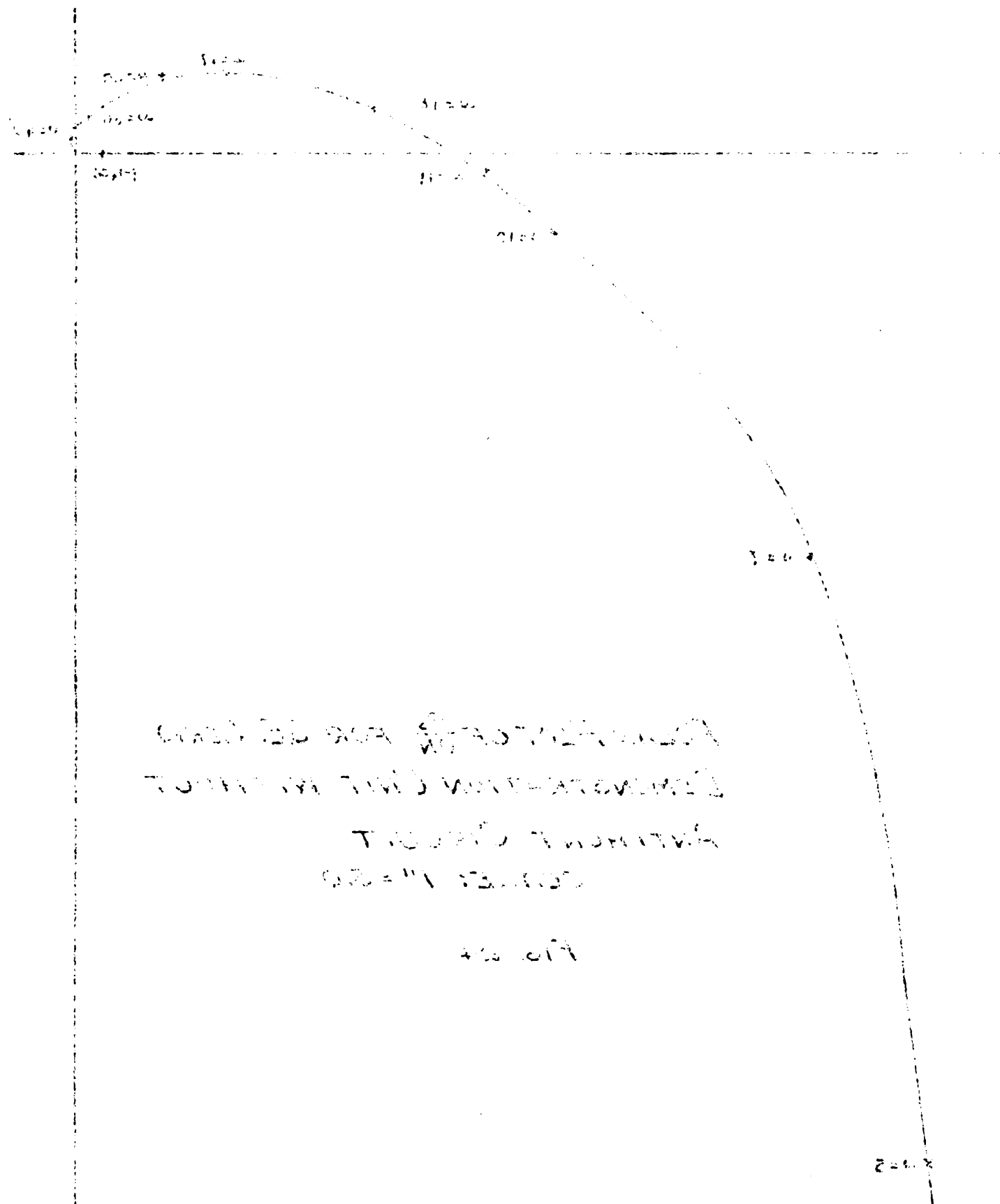
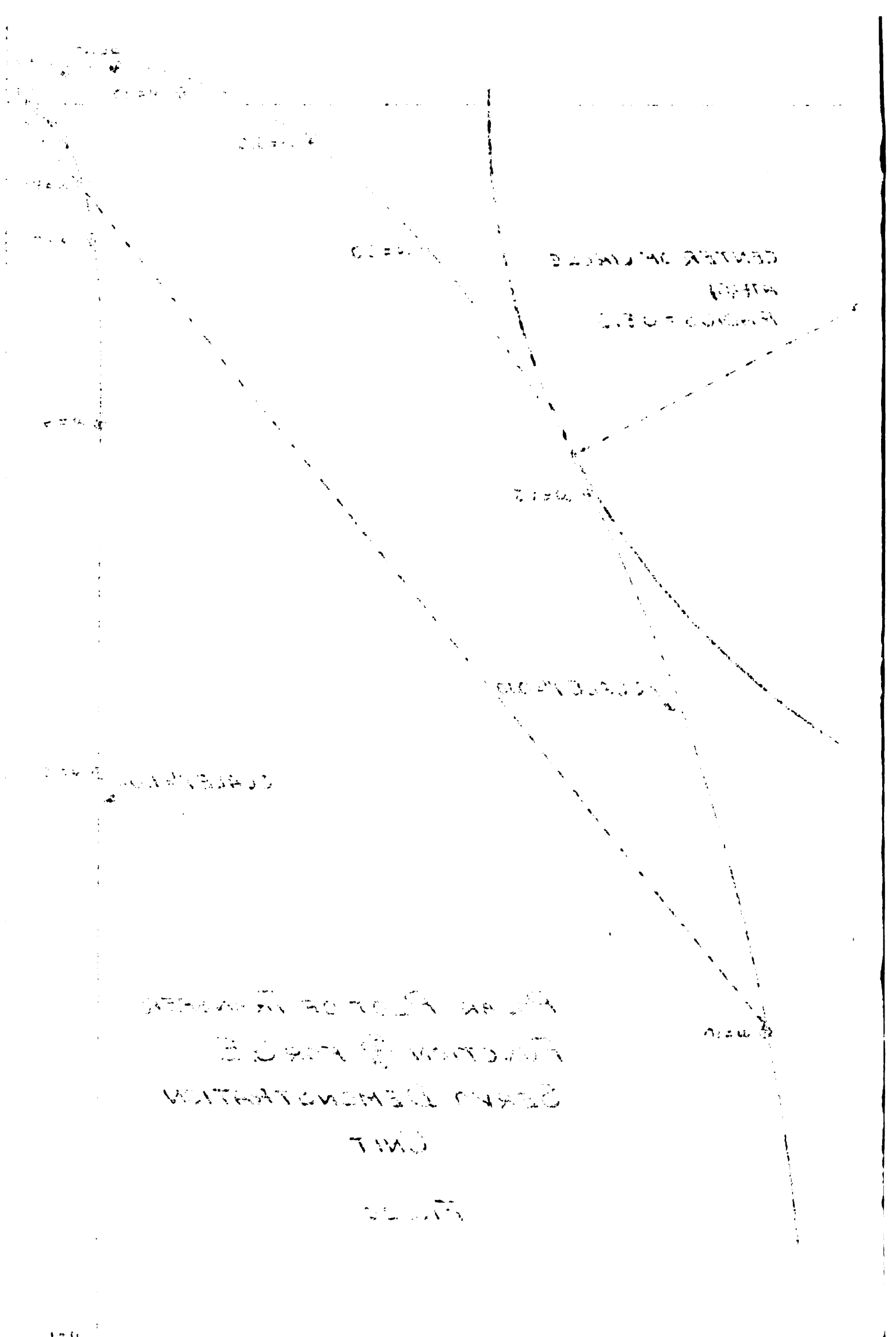


TABLE B COMPUTATION OF $\frac{\theta}{\text{ON}}$ WITH ANTIHUNT CIRCUIT

ω RAD/ SEC	A+J B	M L α	C+J D	C+J D	N L β	$\frac{\theta}{\text{ON}} = \frac{10^3 \text{ ML} \alpha}{\text{N L} \beta} \frac{24}{\text{HRS}}$
0	179.8+J0	179.8 L 0	0 + J 689	0+J 689	689 L 90°	∞ L -90°
1	179.8+J 864	406 L 63.9°	(1.782-1454)+J(-100.8+689)	-1452+J 588	1564 L 157.9°	10.88 L -94.0°
2	179.8+J 728	748 L 76.2°	(14.26-2908)+J(403+689)	-2894+J 286	2894 L 174.3°	5.43 L -98.1°
4	179.8+J 1456	1465 L 83°	(114.2-5830)+J(-1612+689)	-5716 -J 923	5780 L 189.2°	2.66 L -106.2°
8	179.8+J 2912	2930 L 86.5°	(915-11640)+J(-6470+689)	-10,720-J 5780	12,200 L 208.3°	1.25 L -121.8°
10	179.8+J 3640	3640 L 87.2°	(1782-14540)+J(-19080+689)	-12,760-J 9390	15,810 L 216.4°	0.967 L -129.2°
15	179.8+J 5460	5460 L 88.0°	(6330-21800)+J(-22,700+689)	-15,770-22,000	27,000 L 234.3°	0.567 L -146.3°
20	179.8+J 7280	7280 L 88.6°	(14,280-29,080)+J(-40,400+690)	-14,800-J 39,700	42,300 L 249.5°	0.358 L -160.8°
25	179.8+J 9100	9100 L 89.0°	(27,900-36,400)+J(-63,200+700)	-8500 -J 62,500	63,000 L 262.3°	0.242 L -173.3°
30	179.8+J 10,920	10,920 L 89.04°	(48,100-43,700)+J(-90,800+700)	+4400 -J 90,100	90,100 L 272.8°	0.136 L -183.8°
40	180+J 14560	14560 L 90°	(14,000-58,200)+J(-161,400+700)	+55,800-J 160,700	169,500 L -70.8°	.0895 L -160.8°
50	180+J 18,200	18,200 L 90°	(223,000-72,700)+J(-252,000+700)	+150,300-J 251,300	293,000 L -59.1°	.0518 L -149.1°
70	180+J 25,500	25,500 L 90°	(611,000-101,800)+J(-495,000+700)	509,200-J 494,000	708,000 L -44.2°	.0215 L -134.2°
100	180+J 36,400	36,400 L 90°	(1,782,000-145,000)+J(-1,008,000+700)	1,637,000-J 1,007,000	1,920,000 L -31.6°	.0079 L -121.6°



but are drawn to different scales in order to bring out its general shape and to see its characteristics when crossing the real axis. It crosses at the point $(-0.196, 0)$ and the servo is therefore stable.

The radius of the circle with center at the point $(-1, 0)$ and tangent to the transfer locus is a measure of the stability of the system and its dampening constant. It is interesting to note that no matter what type of damping the system employs, all systems with the same damping coefficient will have the stability circle tangent at the same point. With a radius of 0.615, the damping coefficient is 0.45.

Some period of time was spent in trying to obtain the curve in Figure 25 experimentally. The loop was opened by blocking the rotor of the selsyn transformer on the output shaft and disconnecting it mechanically from the output motor. Selsyn generators were connected to the input and output shafts so as to obtain an A.C. voltage proportional to their respective angular displacement.

The input shaft was then driven back and forth about the zero reference point sinusoidally. This was done by mounting a long rod eccentrically on the shaft of a drive motor and connecting the other end of the rod to the outer rim of the flywheel geared to the input shaft. As the motor revolved the input was moved with a sinusoidal motion of about 2.5 degrees amplitude and with the same number of cycles per second as the motor made revolutions per second.

The speed of the motor was varied for each test and an oscillograph used to photograph the voltages from the input and output selsyns.

The amplitude of the error was constant and the amplitude and phase of the output could be then measured from the oscillographs. Using this data the polar plot of the transfer function could be made.

The difficulty encountered in the above procedure was due to the fact that the output shaft of the servo did not oscillate about one point but slowly "crept". This was caused by not having the input vibrating about the exact zero error point of the system. This point is very critical and changes with small fluctuations in line voltage and operating temperature.

Further investigations into experimentally obtaining this polar plot of the transfer function might use the output voltage of the amplidyne and convert it into the output displacement by certain derived expressions.

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