

UNIVERSITY OF THE WITWATERSRAND

THESIS

Submitted in partial fulfilment of the
requirements for the
DEGREE OF MASTER OF SCIENCE
in
ELECTRICAL ENGINEERING.

The Re-design of Measuring Apparatus
for use with Galvanometer Recorder
and Investigations of Fluxes and Rotor
Currents in the Induction Motor.

Investigated and submitted by

D.J. BAKER

Date: October 12th, 1964.

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for the supervision of the thesis.
- ii) My mother
for her encouragement, and
preliminary typing of the thesis.

INTRODUCTION

INTRODUCTION

The prime purpose of this thesis was to re-design measuring apparatus for use with a galvanometer recorder in order to allow an investigation of the characteristics of induction motors under transient conditions, and further, to investigate one or more of these characteristics.

Throughout the design and rebuilding of the apparatus it was necessary to determine that all sections of the apparatus would give a true indication of what was being measured, and not introduce spurious results. In order to achieve this, all sections of the apparatus were individually checked, including the original damping apparatus. In order to test the completed apparatus, and to determine its capabilities, the speed - torque characteristic of various wound and squirrel cage rotors were investigated.

Finally, a theory is put forward to determine analytically the fluxes in a squirrel cage induction motor, and the results so obtained are compared with readings of fluxes taken on the machine.

Photographs of the apparatus, as well as of recordings obtained are included.

THE REASON

The torque characteristics of rotating machines have considerable importance in both design and application. The steady state torque characteristics present little difficulty, involving only equations of power output and speed measurement, whereas the determination of the same characteristic under transient conditions is a complex design and measurement problem.

Various attempts have been made to obtain and explain the torque-slip characteristic of the induction motor, particularly with respect to crawling, cogging and other phenomena which occur during the starting and braking of induction motors. The complexity of the problem is more appreciated when it is realized that slot combinations, distribution and type of winding on rotor and stator coil span and the degree of saturation at which the machine is working all affect the torque-slip characteristic. With certain combinations, the space harmonics become appreciable and produce fields whose numbers of poles are exact multiples of the poles in the main field. This has led to much theoretical conjecture, such as the theory put forward by Alger P.L., which has been neither proved nor disproved conclusively.

The minimum torque during acceleration, or Pull-up torque, is now specified by the Bureau of Standards and it thus becomes more than just a purely theoretical problem to measure and predict the torque during acceleration.

The torque characteristic
considerable importance is still
these torque characteristics give
appearance of power output and
determination of the same value
in a complete design and construction

Various attempts have
the torque-clip characteristics
with respect to strength, weight,
during the starting and braking
of the machine in some special
conditions. Disturbances in
both cases and the degree of
all affect the torque-clip when
the speed increases because
moments of forces are great
This has led to much trouble
forward by Albert P. I. ...
consequently.

The machine in
torque, is now specified
becomes more than just a
and produces the torque and

THE PRINCIPLE OF THE APPARATUS.

THE PRINCIPLE OF THE APPARATUS.

The object of the apparatus is to measure and record values of speed and torque simultaneously. With the multi-channel ultra-violet light recorder it is possible to record further variables such as flux, rotor and stator current, voltage, etc.

Considering the torque and speed, the basic principle is:-

1. The speed is measured by the voltage of a directly coupled tachometer generator.
2. The torque is measured by the reaction of the stator on an elastic mounting constrained by three ~~torion~~^{SPRING} plates. Any angular twist of the ~~torion bars~~, i.e., the stator, is measured by means of a transducer which produces a voltage directly proportional to the deflection.

The motor, as may be seen from photograph A, and detailed on Fig. A, consists of a stator mounted in a cradle. This cradle is constrained within an outer housing by three flat ~~torion~~^{SPRING} plates. When power is supplied to the motor there is a force acting upon the rotor of the machine, which in this case is the primary. Thus there must be an equal and opposite force acting upon the stator, i.e. on the cradle. This cradle, being constrained by the three flat ~~torion~~^{SPRING} plates tends to twist, and it is this displacement which is picked up by the transducer.

If the torque voltage is applied to the vertical plates of a cathode ray oscilloscope, and the speed voltage to the horizontal plates, an instantaneous plot of the torque-slip curve is obtained. If, on the other hand, the voltages are applied to separate galvanometers of the ultra-violet light recorder, speed-time and torque-time recordings are obtained.

Flux and current recording, using the ultra-violet light recorder, are made by the use of search coils and series shunts, respectively.

It must be borne in mind, however, that due to the large flywheel fitted to the machine, the starting time is of the order of five seconds. This means that any electrical transients are effectively damped out, and the machine must thus be regarded as being in a pseudo steady-state condition.

The object of the work
of speed and torque measurements
light sources is to provide for
power and motor control, which

Considering the test

The speed is measured

instrumentation

The torque is measured

strain gauges are

negative part of the

measured by means

voltage directly by

The motor, as seen

on Fig. 1, consists of a motor

connected with an output

power is supplied to the motor

machine, which is the same

and output the same

This is the, being connected

to motor, and is the same

If the torque is

calculated by the

an instrument of the

other hand, the voltage

the three-wire light

are obtained.

Time and torque

recorder, and made by the

respectively.

It must be borne

in mind that the

first second. The

changed out, and the

found ready-made

ORIGINAL APPARATUS AND REASONS FOR RE-DESIGN.

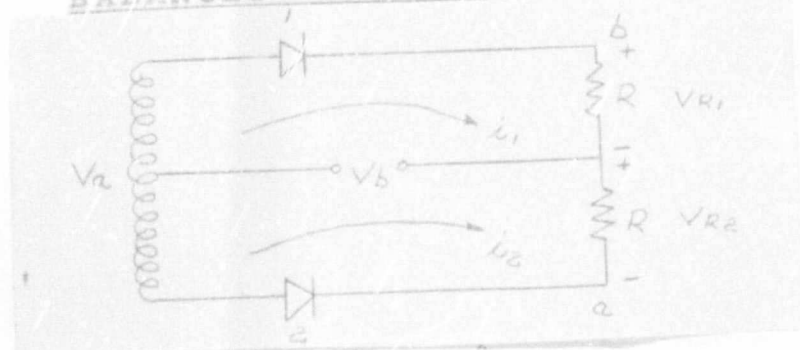
The original apparatus, for the recording of the torque, consisted of an oscillator, amplifier, demodulator, electromagnetic oscillograph and cathode ray oscilloscope. A 2,100 cps. signal from the oscillator, was fed to the primary of the transducer. The output signal from the transducer was amplified, rectified, and passed through the demodulator: directly to the plates of the cathode ray oscilloscope, and via a cathode follower to the electromagnetic recorder. As the torque could be both positive and negative, depending upon the direction of rotation of the machine, a balanced demodulator was used with considerable smoothing. A circuit diagram of the oscillator, amplifier and balanced demodulator is shown in Fig. 1.

The reasons for the re-design of this apparatus were two-fold. Firstly, a Direct Writing Galvanometer Recorder (Ultra-violet light) had been purchased employing six galvanometers (the Recorder can employ twelve) with sensitivities of the order of 0.0275 mA/CM. The high voltages obtained from the original apparatus would be both unnecessary and dangerous for the galvanometers. Secondly, as may be seen from the calibration figures and graph, Fig. 2, the response of the amplifier and balanced demodulator was far from linear over the range required for a 7½ h.p. motor.

It was thus decided to retain the oscillator, to remove the amplifier and to design a balanced demodulator for the small signals required by the galvanometer Recorder.

BALANCED DEMODULATOR THEORY AND DESIGN

BALANCED DEMODULATOR THEORY.

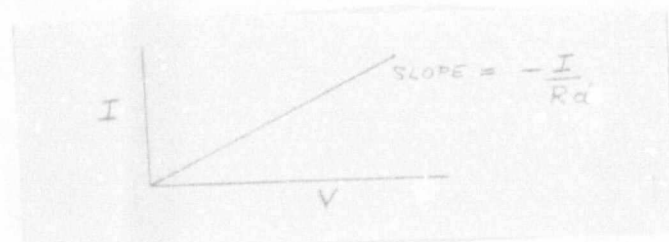


$$V_a = \text{Switching volt} = V_a \sin \theta$$

$$V_b = \text{Signal volt} = V_b \sin (\theta - \beta)$$

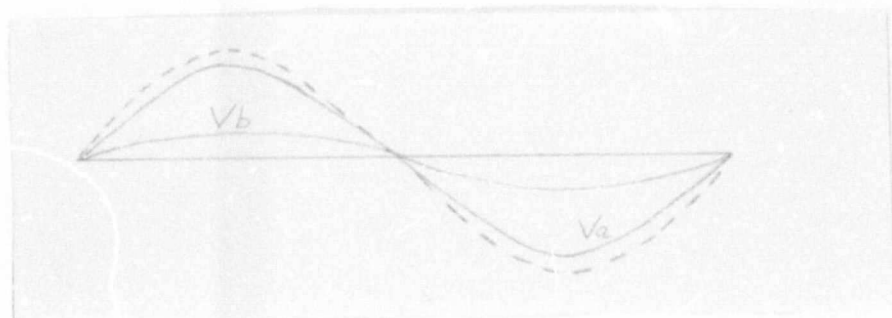
β = phase shift

The 6A85 diode follows a linear law and has resistance R_d .



Consider the half cycle with currents as shown:-

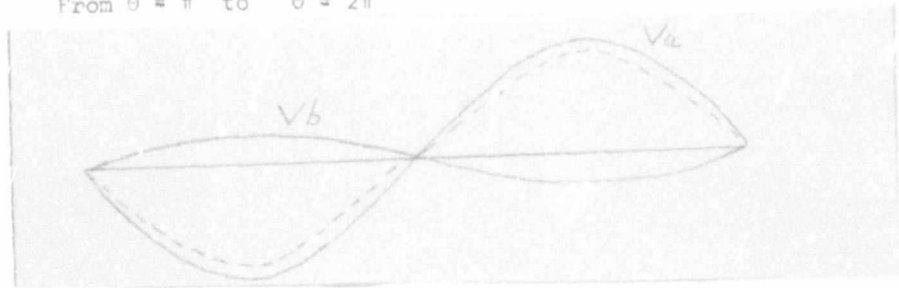
From $\theta = 0$ to $\theta = \pi$



$$i_1 = \frac{V_a \sin \theta + V_b \sin (\theta + \beta)}{R + R_d}$$

$$i_2 = 0.$$

From $\theta = \pi$ to $\theta = 2\pi$



$$i_l = 0$$

$$V_{R1} = \frac{\hat{V}_a \sin \theta + \hat{V}_b \sin (\theta + \phi) \cdot R}{R + R_d}$$

Thus,

$$V_{R1} = \frac{\hat{V}_a \sin \theta + \hat{V}_b \sin (\theta + \phi) \cdot R}{R + R_d}$$

$$V_{R2} = \frac{\hat{V}_a \sin \theta - \hat{V}_b \sin (\theta + \phi) \cdot R}{R + R_d}$$

Average value is

$$V_{R1} = \frac{R}{R + R_d} \cdot \frac{1}{2\pi} \int_0^\pi \{ \hat{V}_a \sin \theta + \hat{V}_b \sin (\theta + \phi) \} d\theta$$

$$= \frac{R}{R + R_d} \cdot \frac{1}{2\pi} \left[-\hat{V}_a \cos \theta - \hat{V}_b \cos (\theta + \phi) \right]_0^\pi$$

$$= \frac{R}{R + R_d} \cdot \frac{1}{2\pi} \left[2\hat{V}_a + 2\hat{V}_b \cos \phi \right]$$

$$= \frac{R}{R + R_d} \cdot \frac{1}{\pi} \left[\hat{V}_a + \hat{V}_b \cos \phi \right]$$

$$\text{Similarly, } V_{R2} = \frac{R}{R + R_d} \cdot \frac{1}{\pi} \left[-\hat{V}_a + \hat{V}_b \cos \phi \right]$$

The voltage across ab is the sum $V_{R1} + V_{R2}$

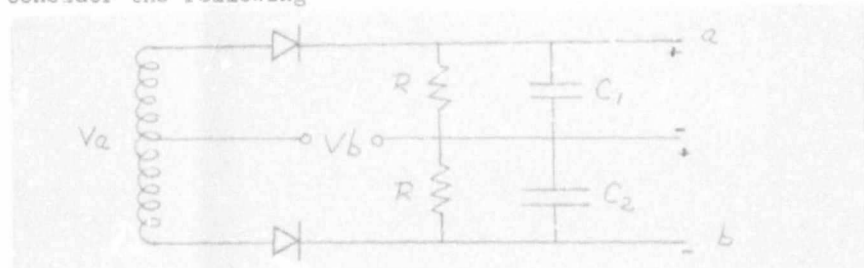
$$\text{i.e. } V = \frac{R}{R + R_d} \cdot \frac{1}{\pi} \{ \hat{V}_a + \hat{V}_b \cos \phi - \hat{V}_a + \hat{V}_b \cos \phi \}$$

$$= \frac{R}{R + R_d} \cdot \frac{2}{\pi} \hat{V}_b \cos \phi$$

From this we see that the output depends only on the in-phase component.

In order to smooth out any ripple a ladder (filter) network had to be included.

Consider the following



The voltage across the condensor, and resistor, approaches the peak value of the impressed sine. voltage wave.

If the inputs are in phase

$$V_a = \hat{V}_a \sin \theta$$

$$V_b = \hat{V}_b \sin \theta$$

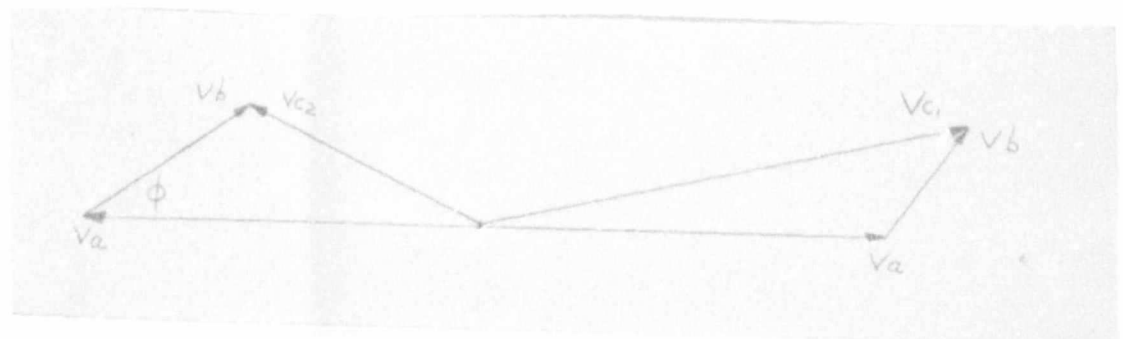
Thus, with the polarities shown C_1 , will charge up to $V_a + V_b$ during the time 0 to π , and will maintain this voltage.

During the time π to 2π the condensor C_2 will, with polarities shown, charge to a value $V_a - V_b$.

Hence, total voltage across ab is $V_a + V_b - (V_a - V_b) = 2V_b$, on condition that $V_a > V_b$. If $V_a < V_b$ C_1 , will still charge to $V_a + V_b$ in time 0 - π , but C_2 will charge to $V_b - V_a$ in time $\pi - 2\pi$. In this case the D.C. volt would be

$$V_a + V_b - (V_b - V_a) = 2V_a$$

When V_a and V_b are not in phase the summation must be done vectorially as shown.



$$V_{c_1}^2 = V_a^2 + V_b^2 + 2V_a V_b \cos \phi$$

$$V_{c_2}^2 = V_a^2 + V_b^2 - 2V_a V_b \cos \phi$$

$$\text{Let } V_a = k V_b$$

$$\begin{aligned} \text{Then, } V_{c_1}^2 &= k^2 V_b^2 + V_b^2 + 2k V_b^2 \cos \phi \\ &= V_b^2 (k^2 + 1 + 2k \cos \phi) \end{aligned}$$

$$\text{Therefore } V_{c_1} = V_b (k^2 + 1 + 2k \cos \phi)^{1/2}$$

$$\text{Similarly } V_{c_2} = V_b (k^2 + 1 - 2k \cos \phi)^{1/2}$$

To find the volt across ab it is necessary that the peak values be summed algebraically, not vectorially.

$$V_{ab} = V_{c_1} - V_{c_2} = V_b \{ (k^2 + 1 + 2k \cos \phi)^{1/2} - (k^2 + 1 - 2k \cos \phi)^{1/2} \}$$

$$\text{Put } k^2 + 1 = m$$

$$V_{ab} = V_b \{ (m + 2k \cos \phi)^{1/2} - (m - 2k \cos \phi)^{1/2} \} \quad \text{--- (1)}$$

By the Binomial Theorem we have that

$$(a + b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{2!} a^{n-2} b^2 + \dots$$

and

$$(a - b)^n = a^n - na^{n-1}b + \frac{n(n-1)}{2!} a^{n-2} b^2 - \dots$$

$$\text{Thus, } (a + b)^n - (a - b)^n = 2na^{n-1}b + \frac{2n(n-1)(n-2)}{3!} a^{n-3} b^3$$

+

Thus, expanding equation (1), we get

$$V_{ab} = V_b \left\{ 2 \cdot \frac{1}{2} m^{-1/2} \cdot 2k \cos \phi + 2 \cdot \frac{1}{2} \cdot (-1/2) \cdot (-3/2) m^{-5/2} \cdot 8k^3 \cos^3 \phi + \dots \right\}$$

$$= V_b \left\{ \frac{2k \cos \phi}{(k^2 + 1)^{1/2}} + \frac{k^3 \cos^3 \phi}{(k^2 + 1)^{5/2}} + \dots \right\}$$

If k is much larger than 1, then it may be assumed that

$$(k^2 + 1)^{1/2} \approx k, \quad (k^2 + 1)^{5/2} \approx k^5$$

Thus,

$$\begin{aligned} V_{ab} &= V_b \left(\frac{2k \cos \phi}{k} + \frac{k^3 \cos^3 \phi}{k^5} \right) \\ &= V_b \left(2 \cos \phi + \frac{\cos^3 \phi}{k^2} \right) \\ &= 2V_b \left(\cos \phi + \frac{\cos^3 \phi}{2k^2} \right) \end{aligned}$$

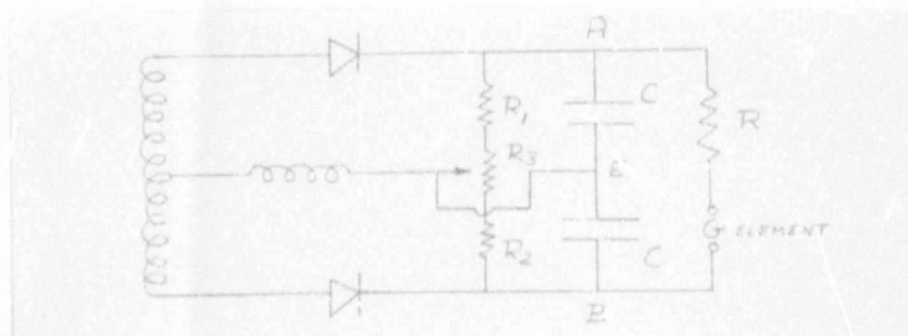
This consists of a fundamental term $2V_b \cos \phi$ and an "error" term $\frac{2V_b \cos^3 \phi}{2k^2}$. Thus it is seen that the ratio $\frac{V_a}{V_b}$ should be large to reduce the error. (In actuality k was made $\gg 10$). The voltage V_b was obtained by direct coupling of the signal voltage from the transducer. Phase shift in the apparatus is small since the transducer shift is small. The values of the condensers in the detector filter circuit were determined by the requirements of the detector to follow a varying envelope (modulation) as well as to filter out all high frequency switching voltage. If the time constant of this circuit is too large the output does not follow the modulation and "diagonal clipping" results. For the transducer used the signal voltage is small compared to the switching voltage and thus fractional modulation is small.

Bibliography.

In main bibliography.

Design of new Balanced Demodulator for N.E.P. six channel,
Galvanometer Recorder.

Signal voltage, from transducer, is 300m V rms. i.e. 425 mv. peak.
Switching voltage should be considerably larger than this, say 5 volts
rms. from the centre tap.



The transformer will have to handle this and the voltage applied to the primary must be adjusted to suit. This voltage is not critical - but must be larger than the signal voltage of 0.3 volts.

$$\begin{aligned} \text{D.C. voltage A to E (no signal)} &= 5 \times 2^{\frac{1}{2}} \neq 7 \text{ volts} \\ \text{" " B to E (" ")} &= 0 \text{ volts} \end{aligned}$$

$$\text{D.C. voltage A to E (signal applied)} = 5 \times 2^{\frac{1}{2}} + 0.3 \times 2^{\frac{1}{2}} \neq 7.425 \text{ V}$$

$$\text{D.C. voltage B to E (signal applied)} = 5 \times 2^{\frac{1}{2}} - 0.3 \times 2^{\frac{1}{2}} \neq 6.575 \text{ V}$$

$$\text{Voltage A - B} = 7.425 - 6.575 = 0.850 \text{ volts.}$$

The 130 cps element (recorder) has a sensitivity of 26 $\mu\text{A}/\text{cm}$, so for 3 cms, say, on each side (which is rather high) of zero, the current should be $3 \times 26 = 78 \mu\text{A}$.

$$\text{Therefore } R = \frac{0.85 \times 10^6}{78} = 10.9 \text{ K.OHMS}$$

Thus, in practice a 25K variable resistor can be used which will control sensitivity.

Finally when the actual working range is experimentally determined it might consist of a fixed resistor of sufficient size to prevent damage and a variable resistor to control sensitivity.

Footnote:

The signal voltage of 300 mV is for the maximum displacement of the transducer.

Resistances R_1 and R_2 should be of the same order as R and should, if possible be low with respect to the reverse resistance of the diodes.

Peak reverse voltage on diode # 2 ≈ 7 volts say 15 volts.

From curve (0A85) the reverse current is 5 micro. Amps. Thus the diode is effectively a resistance of $\frac{15 \times 10^6}{5} = 3$ megs.

If R_1 is 5000 ohms the reverse effect will be small.

R_2 is 5000 ohms and R_3 can be approximately 1000 ohms, variable, for balancing the signal voltage.

The REACTANCE of C should be small with respect to R_1 at 2500 cps.

$$\text{If } C = 0.1 \mu\text{fd } X_c = \frac{10^6}{2500 \times 0.1 \times 2\pi} = \frac{10^6}{500\pi} \approx 640 \text{ ohms}$$

This is still large.

$$C = 0.5 \mu\text{fd } X_c = \frac{10^6}{2500 \times 0.5 \times 2\pi} = \frac{10^6}{2500\pi} \approx 127 \text{ ohms}$$

This is of a better size.

A circuit as shown in Fig. III was set up and connected to the 130 cps. natural frequency, 0.0065 ma/cm galvanometer. It was immediately discernable that further filtering would be necessary.

The circuit including this added filtering is shown in Fig. IV. The two variable resistors are ganged and used to control the amplitude of the signal to the galvanometer.

Due to the fact that the 0A85 diodes were not matched, it was found necessary to unbalance the two 10K resistors. One being 10K and the other of the order of 8K, but this depends upon the diodes used.

The frequency response was recorded and is shown in Fig. V. This response is quite adequate for torque measurement.

FIG. III



FIG IV

TO OSCILLOSCOPE



Frequency Response of Load (Filter) Network.

Input	Frequency	Output
1	0.5 Hz	4 v (R.M.S.)
2	1	4 v
3	2	3.7 v
4	5	3.7 v
5	10	3.5 v
6	20	3.5 v
7	50	3.2 v
8	100	2.3 v
9	200	1.3 v

I, D.J. Baker, certify that:

- 1) This is my own work.
- 2) The work forming the basis of this Thesis has not been incorporated in any other work submitted for another Degree at any other University

Signed:



October 12th, 1964.

of the inertia was considerably incorrect and hence the damping is not as satisfactory as one would conclude from the calculated and test results.

It was then decided to investigate whether this oscillation was not also perhaps being introduced by the transducer itself. This was found to be the case, and by increasing the tension on the transducer almost all oscillation was removed. Photo IV.

More torque time graphs were recorded, and as seen from Photo V, still contained more oscillations than were shown in the original apparatus. This is due to the very much increased sensitivity of the galvanometer recorder; these oscillations being completely damped out by the slower pen Brush recorder. The general shape of the two graphs, however, were exactly the same.

In order to determine the capabilities of the measuring apparatus it was decided to replace the squirrel cage by a wound secondary. In order to get a direct comparison between the two configurations, the resistances of the two should be identical. As the bars were still to be used it was only necessary to replace the end rings by end-connections of the same resistance. Due to the limited space available, this was found to be impossible. As large a gauge wire as could be fitted was used. The various resistances are shown over page. The design of the wound secondary is as shown in Fig VI.

Here again difficulty was found in obtaining satisfactory connection between the end leads and the copper bars; poor connection was immediately discernible by the vibration of the motor caused by secondary unbalance. This difficulty was overcome by using large brass terminals into which the end leads were soldered. These terminals were then placed over the rods protruding from the copper conductors, aluminum foil was placed between the two surfaces, and then the terminals were tightened down. The torque-time oscillograms obtained for this "wound" secondary are shown in Photos. VI and VII. The first is for a star connection and the second for a delta connection. A combination wound and squirrel cage secondary was also tested. The end leads from one side of the secondary were removed and replaced by an end-ring. The oscillogram obtained is shown in Photo. VIII.

Starting Current:

N.P.S. primary. Wound secondary, started on both sides.

C.T. - Siemens Type T 13ED No. 2894314

Range 1200/5.

Ammeter-Weston Electric No. 71979. 0 - 5A

Supply Voltage: 128^V, I = 2.50 amps.

220^V, I = 540 amps.

D.C. Resistance measurement of Secondary:

Ammeter: Megger No. 62742 0 - 100A

Voltmeter: F.G. Slack & Co. No. 31-2 0 - 60 mV

1. mV.

30.5 270 across one phase.

13.0 " input lead. }

1.8 " one bar. }

12.8 " end connection. }

mean for 3 phases

50.0 450

22.0

Mean Resistance

3.0

21.8

Phase:

8.98×10^{-3}

leads:

4.42×10^{-4}

bar:

6.0×10^{-5}

90 820

end connection:

3.26×10^{-4}

41.5

5.48

40.5

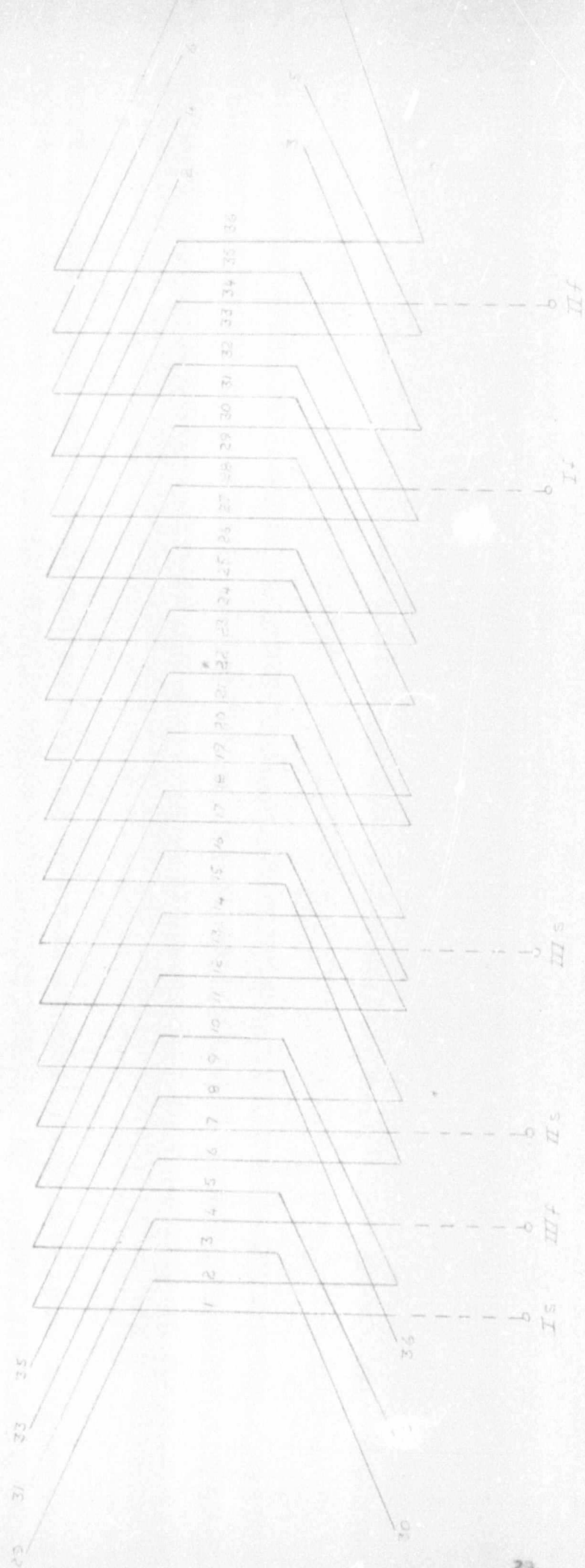
At this stage, due to the very much increased sensitivity of the recording apparatus, it was decided to try and determine the torque produced by the residual magnetism of the primary. The primary was left disconnected, and the rotor was driven at 1500 r.p.m. by means of a 10 H.P. D.C. motor, which was connected to the rotor by means of two V-belts. This torque is either non-existent or of too small a magnitude to be measured on the apparatus.

The complete torque-time curve was obtained by allowing the machine to run up to full speed in one direction and then reversing two of the phases. As a 10 H.P. D.C. motor was available it was decided to use this to drive the induction motor against its own torque, in order to determine that the phase-reversal procedure did not have an effect upon the graphs obtained. The comparison of the graphs obtained by the two methods is shown in Fig. VII.

From the results obtained, it was felt that the N.E.P. Recording apparatus and associate circuitry was quite satisfactory.

DESIGN OF STATOR (SECONDARY) WINDING

FIG VI



12 END CONNECTIONS SPAN 12 SLOTS & (1/15)
3 END CONNECTIONS SPAN 3 SLOTS & (1/3)

FIG. VII

CURVES SUPERIMPOSED AT ALL POINTS



DAMPING APPARATUS:

Results as checked from original design by M.F.L. Badham

(B.Sc. Thesis November 1953)

B _g	.2	.4	.6	.8	1.0	1.2	1.5	1.6	1.8
AT	620	1511	2409	3220	4047	4901	6328	6792	7761

$$F/v = 1.67 B^2 \quad \text{Ns/cm/sec.}$$

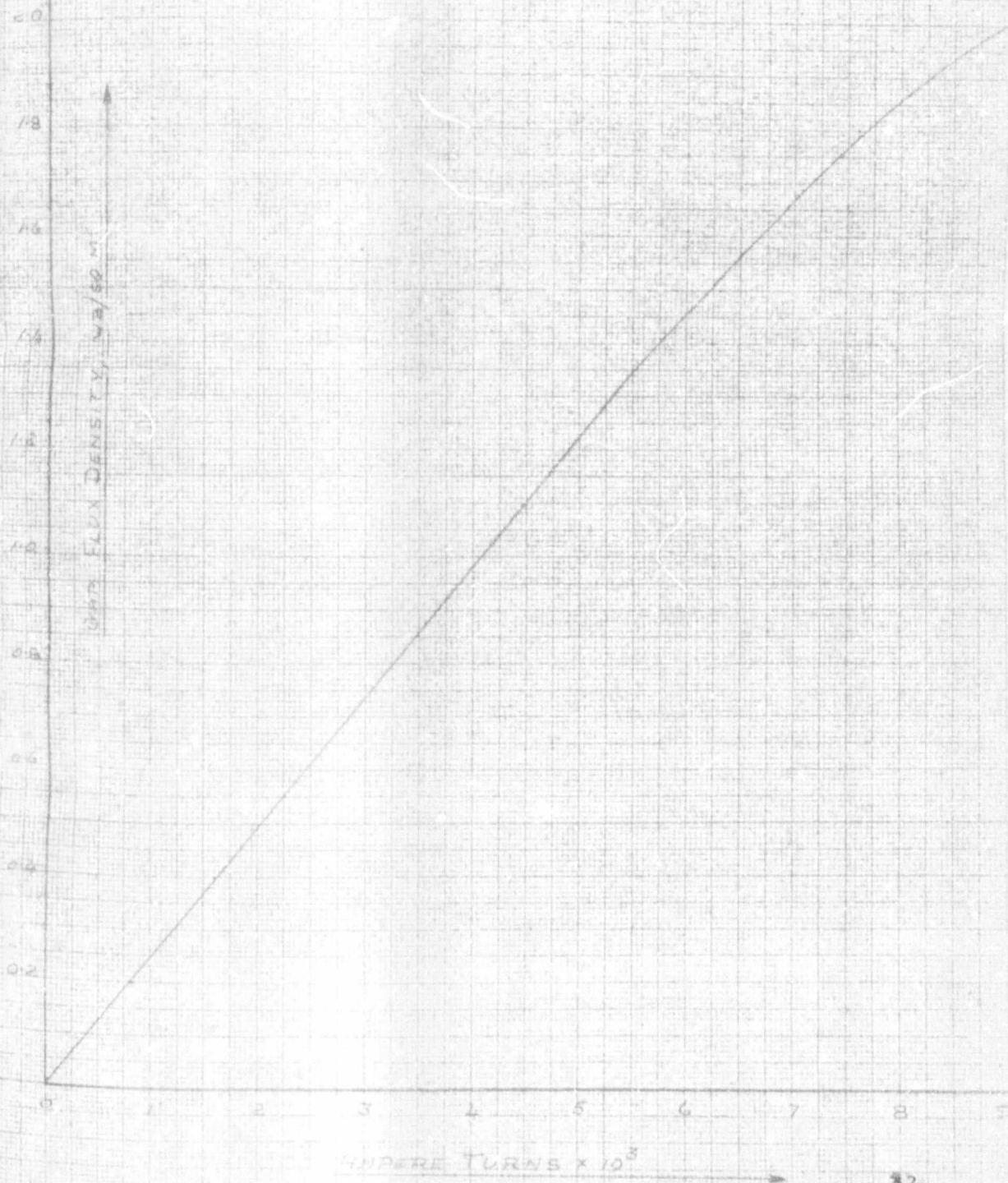
If B = Flux density in Wb/sq. cm.

Comparison of Calculated and Test Results:

(Test results were taken from Badham's Thesis)

AT.	B	B ²	F/v calc.	F/v test.
3794	0.989	.97804	1.635	2.43
4993	1.225	1.500	2.500	3.46
5991	1.450	2.103	3.518	4.26
6985	1.650	2.723	4.550	5.32
7986	1.835	3.367	5.620	6.40
9983	2.135	4.558	7.600	7.72
2300	0.560	0.3136	0.924	0.89
3450	0.850	0.7225	1.205	1.76
4600	1.120	1.254	2.130	2.84
5750	1.4	1.960	3.280	4.08
6900	1.635	2.673	4.46	5.24
8050	1.845	3.404	5.700	6.04
9200	2.030	4.121	6.880	6.66
10350	2.170	4.709	7.860	6.92

THEORETICAL MAGNETISATION CURVE OF DAMPING APPARATUS



2) C.R.O. RECORDING.

A Philips Type GM566 single beam oscilloscope was used. The output from the tachometer was fed, via a smoothing filter consisting of a variable resistance and three 8 micro Farad condensers in parallel and a 3 : 1 voltage divider, to the horizontal plates. The output from the balanced demodulator was fed directly to the vertical plates. Thus a direct torque-slip graph was obtainable.

On increasing the vertical gain of the oscilloscope it was immediately discernible that the 2300 cps carrier to the transducer was coming through onto the oscilloscope. A parallel - T filter was designed to eliminate this carrier and was found to be perfectly adequate. This design is shown overleaf.

In order to obtain satisfactory photographs of the torque-slip graph, it was necessary to use the maximum gain of the vertical amplifiers. At this gain, however, there was an extremely large 50 cps hum. In order to eliminate this hum, the maximum gain was such that the largest torque deflection was only one major division on the oscilloscope screen, as may be seen in photograph IX. A parallel - T filter was designed and tried but rejected because of the large attenuation of the over-all signal.

It was then found that the magnitude of this 50 cps hum could be reduced by adequate earthing of the entire apparatus. One leg of the excitation (2300 cps) to the transducer was earthed and the return to the demodulator from the transducer was placed in a shielded cable which was earthed. The demodulator was run unbalanced in order to be able to earth one side, and both the oscilloscope and galvanometer chassis were earthed. In order to ensure that the earthing was satisfactory, all the earth leads were connected and run to a bolted earth in the laboratory. The earthing connections for the oscillator, demodulator and filter circuit are shown in Fig. VIII.

With this system of earthing it was found that the hum, even at maximum gain of the vertical amplifiers was less than one tenth of a major division on the oscilloscope calibration scale.

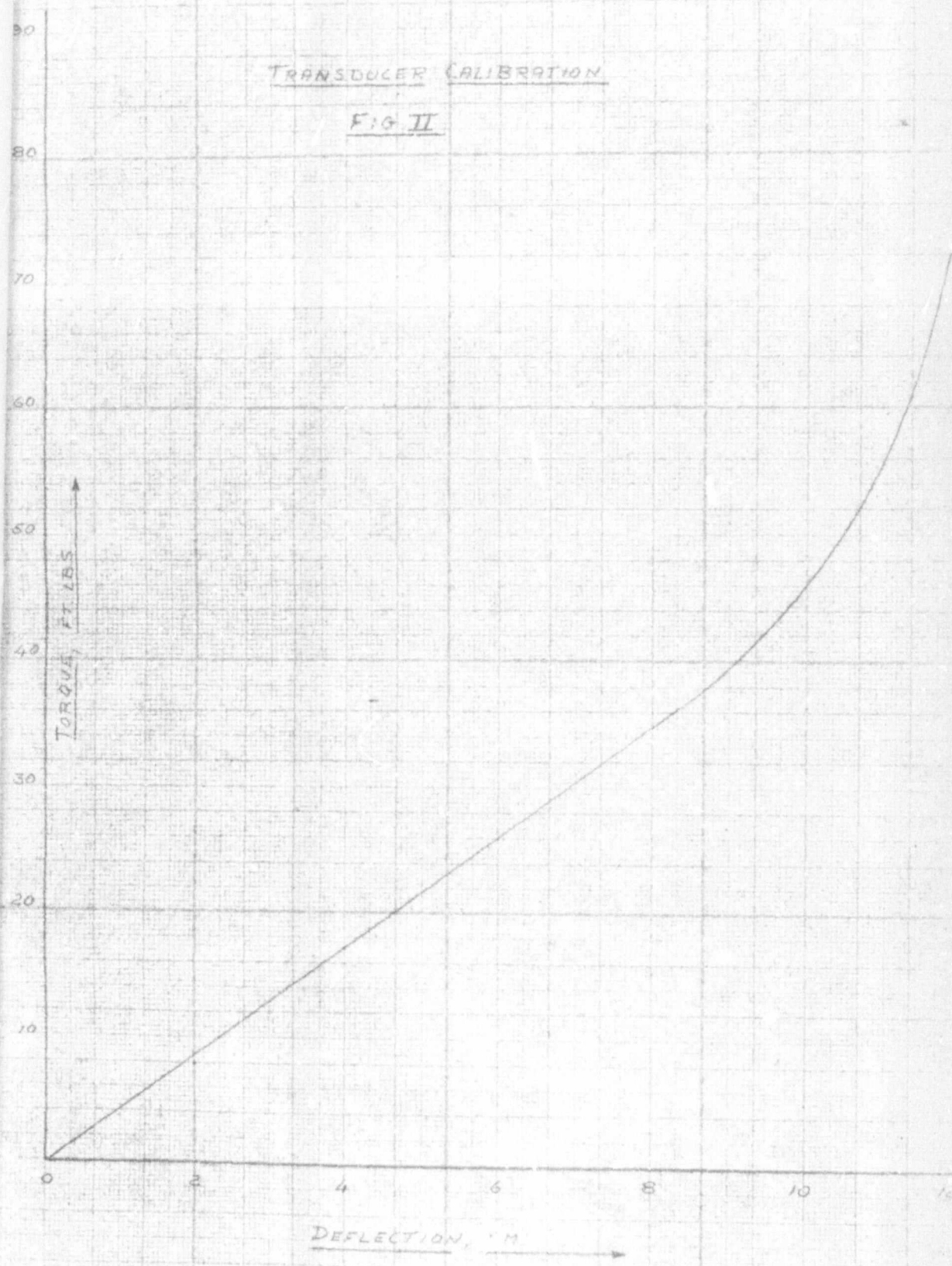
All the experiments performed in order to test the capabilities of the N.E.P. recorder were repeated, using the oscilloscope, and photographs taken. These photographs are shown, number X to XII. Comparing these to photograph XIII, which was taken using the original apparatus, it will be observed that the general shape of the curve, for a squirrel cage rotor, appears to be the same but with a very much larger number of high frequency oscillations. This is due to the fact that there is very much less damping in the re-designed demodulator. In order to prove that the "general shape" of the curves taken on the original and re-designed apparatus was the same, a 1 micro Farad capacitor was placed directly to the two leads to the oscilloscope. This value of capacitance was chosen in order to eliminate only the higher frequency oscillations and not to affect the shape of the overall curve. As may be seen from photographs XIV and XV the curves obtained are identical to those obtained using the original apparatus.

Calibration of Transducer.

Length of arm = 1.5 ft.

Weight of holder = 0.75 lbs.

Weight lbs.	Actual Weight lbs.	Deflection mm	Torque ft. lbs.
0	0	0	0
0	0.75	0.3	5.25
5	5.75	2.0	31.50
10	10.75	3.8	16.12
15	15.75	5.5	23.44
20	20.75	7.2	31.20
25	25.75	8.8	38.96
30	30.75	9.8	46.90
35	35.75	10.8	53.80
40	40.75	11.2	61.00
45	45.75	11.8	68.00
50	50.75	12.5	76.00
57	57.75	12.8	83.80



CONTINUOUS RECORDING

DEFLECTION IN INCHES

DEFLECTION IN INCHES	TORQUE FT LBS
0	0
0.1	0
0.2	0
0.3	0
0.4	0
0.5	0
0.6	0
0.7	0
0.8	0
0.9	0
1.0	0
1.1	0
1.2	0
1.3	0
1.4	0
1.5	0
1.6	0
1.7	0
1.8	0
1.9	0
2.0	0
2.1	0
2.2	0
2.3	0
2.4	0
2.5	0
2.6	0
2.7	0
2.8	0
2.9	0
3.0	0
3.1	0
3.2	0
3.3	0
3.4	0
3.5	0
3.6	0
3.7	0
3.8	0
3.9	0
4.0	0
4.1	0
4.2	0
4.3	0
4.4	0
4.5	0
4.6	0
4.7	0
4.8	0
4.9	0
5.0	0
5.1	0
5.2	0
5.3	0
5.4	0
5.5	0
5.6	0
5.7	0
5.8	0
5.9	0
6.0	0
6.1	0
6.2	0
6.3	0
6.4	0
6.5	0
6.6	0
6.7	0
6.8	0
6.9	0
7.0	0
7.1	0
7.2	0
7.3	0
7.4	0
7.5	0
7.6	0
7.7	0
7.8	0
7.9	0
8.0	0
8.1	0
8.2	0
8.3	0
8.4	0
8.5	0
8.6	0
8.7	0
8.8	0
8.9	0
9.0	0
9.1	0
9.2	0
9.3	0
9.4	0
9.5	0
9.6	0
9.7	0
9.8	0
9.9	0
10.0	0
10.1	0
10.2	0
10.3	0
10.4	0
10.5	0
10.6	0
10.7	0
10.8	0
10.9	0
11.0	0
11.1	0
11.2	0
11.3	0
11.4	0
11.5	0
11.6	0
11.7	0
11.8	0
11.9	0
12.0	0

The apparatus was calibrated by applying weights to the arm carried on the stator frame and observing the deflection on both the N.E.P. recorder and the oscilloscope. This was found to be quite satisfactory for obtaining deflection in one direction, viz. anti-clockwise, but in order to obtain deflection in the clockwise direction, it was found necessary to use a pulley mounted above the torsion arm. The results obtained are shown below. It will be observed that the torque-deflection curve is now linear to above 60 foot pounds.

Calibration of Transducer.

Length of arm = 1.5 ft.

Weight of holder = 0.75 lbs.

N.E.P. Recorder.

Weight lbs.	Actual Weight lbs.	Deflection cms		Torque ft. lbs.
		+	-	
0	0	0	0	0
5	5.75	0.2	0.21	8.61
10	10.75	0.35	0.352	16.10
15	15.75	0.54	0.545	23.50
20	20.75	0.70	0.73	31.20
25	25.75	0.90	0.90	38.50
30	30.75	1.10	1.11	46.00
35	35.75	1.30	1.26	53.80
40	40.75	1.43	1.45	61.00
35	35.75	1.28	1.27	53.80
30	30.75	1.10	1.10	46.00
25	25.75	0.91	0.92	38.50
20	20.75	0.75	0.72	31.20
15	15.75	0.542	0.544	23.50
10	10.75	0.351	0.35	16.10
5	5.75	0.21	0.21	8.61
0	0	0	0	0

Calibration of Transducer.

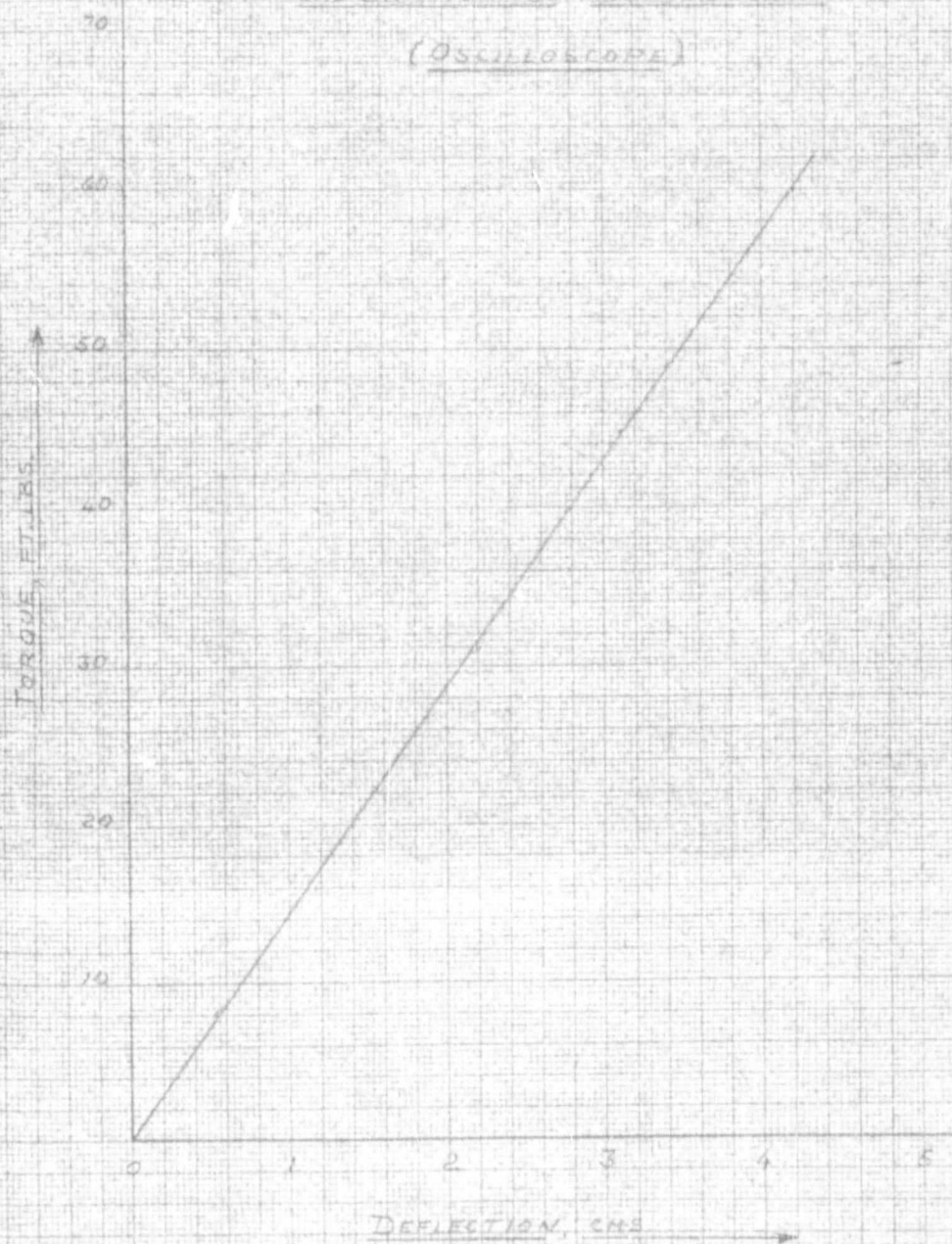
Length of arm = 1.5 ft.

Weight of holder 0.75 lbs.

C.R.O.

Weight	Actual Weight	Deflection		Torque
lbs.	lbs.	cm		ft. lbs.
		+	-	
0	0	0		0
5	5.75	0.5	0.51	8.61
10	10.75	1.0	1.05	16.10
15	15.75	1.5	1.5	23.50
20	20.75	2.2	2.1	31.20
25	25.75	2.6	2.6	38.50
30	30.75	3.05	3.10	46.00
35	35.75	3.6	3.5	53.80
40	40.75	4.05	4.05	61.00
35	35.75	3.5	3.5	53.80
30	30.75	3.10	3.10	46.00
25	25.75	2.58	2.60	38.50
20	20.75	2.2	2.1	31.20
15	15.75	1.5	1.5	23.50
10	10.75	1.05	1.0	16.10
5	5.75	0.5	0.5	8.61
0	0	0		0

CALIBRATION OF TRANSDUCER
(OSCILLOSCOPE)



Author Baker Derek John

Name of thesis The re-design of measuring apparatus for use with galvanometer recorder and investigations of fluxes and rotor currents in the induction motor. 1964

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