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TESTS ON SERVO SYSTEM OF GMRT AND SOME RELATIONS CONCERNING WIND LOADS, UNBALANCED LOAD, FRICTIONAL TORQUES, MOTOR CURRENTS AND COUNTER-TORQUE BIAS

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Key words : Servo System, Gear Boxes, Antenna system, Unbalanced Loads, Counter-torque bias, wind limits for tracking.

SUMMARY

A series of measurements have been made of the motor currents of the servo system of the GMRT for different loads, with and without counter torques, for the C3 and C12 antennas. A torque demand model has been developed considering efficiencies of the gear boxes, frictional loads, un-balance torque and wind loads. By combining these relationships with the measurements, it has been possible to estimate forward and combined efficiencies of the gear boxes, Coulomb and Viscous friction of motors, gear box frictions, unbalanced torque, etc. It is found that the overall efficiency of the elevation gear system ($N_1 =$ 25000 :1 reduction) is about 77 per cent and of the Azimuth system ($N_2 =$ 18,000 : 1 reduction) is about 84 per cent. This is due to the high efficiency of the imported planetary gear boxes supplied by M/S Rexroth.

Finally, we have considered the design torque capacities of the gear boxes in order to investigate whether the counter torque circuit using a constant value of the bias torque

will allow tracking of antennas up to a mean wind speed of 45 kmph gusting up to 55 kmph. It is concluded that the circuit used seems adequate, although some refinement may be considered if further field trials require somewhat higher torques.

1. INTRODUCTION

The purpose of this note is to verify various parameters of the mechanical drive system of the 45-m dishes based on actual measurements made on C3 and C12 antennas on which servo system has been installed. It is concluded that the BARC counter torque system seems to be adequate to satisfy the peak load demand during tracking of celestial sources at mean wind velocities of 45 kmph gusting upto 55 kmph.

Each of the elevation (EL) and azimuth (AZ) drive systems of the GMRT 45-m dishes consists of two D.C. Servo Motors of about 6 HP, each of which is connected separately to a high-efficiency Planetary Gear Box. The output of these two Gear Boxes is connected to a Bull Gear (called "pin-sector" for elevation and "slew-ring" for Azimuth) which drives the 45-m dish (Fig. 1). Brief specifications of the Mechanical Drive System are given in Appendix I, and of the Servo System in Appendix II. The servo drive units provide a counter-torque system for tracking of celestial radio sources in order to eliminate any backlash and thus provide a pointing accuracy of about 0.3 arcmin rms at wind speeds of up to about 20 or 30 kmph. The level (about 15 m above the ground) of the C12 45-m dish in the months of May to July 1992, it was noted that wind velocities were quite frequently in the range of about 30-40 kmph during the day time and these values seemed to be appreciably higher than those obtained from the published statistical data by India Meteorological Department and by Dr. Anna Mani for the Pune region. In order not to interrupt observations frequently (say not more than 10 or 15 days during the day hours during the April-June period each year due to high winds), it therefore seems desirable that we should try to provide tracking capability for a somewhat higher wind velocity than 40 kmph design value taken by TCE. Hence we have investigated whether the counter-torque servo system can provide tracking for one minute mean wind of 45 kmph (at a 10m height) gusting up to 55 kmph (3 sec gust), rather than for the mean wind of 40 kmph (gusting to 50 kmph), as specified originally. The antenna should automatically slew for stowlocking for higher winds. This will minimize frequent stow-locking during May-July season to some extent. It should be noted that the gear boxes are safe for slewing up to 80 kmph (3 sec gust), i.e. 1 minute mean speed of about 65 kmph.

In this report, we describe briefly in Section 2 the mechanical system of GMRT and then in Section 3 the relation between the wind loads, frictional torques, unbalanced load and motor currents taking into account gear ratios and forward and reverse efficiencies of the Gear Boxes. In Sections 4 to 6 are presented summary of measurements made in January-February 1993 and in Sections 7 and 8 are given results and discussions respectively. A discussion on gearbox capacity in comparison with the required motor currents in presence of counter torque is presented in Section 9 and the report ends with conclusions.

2. MECHANICAL DRIVE SYSTEM OF GMRT

The structural and mechanical systems of the GMRT 45-m dishes have been designed by M/S Tata Consulting Engineers, Bombay, in close coordination with TIFR. The calculated forces and torques on the AZ axis of the 45-m dishes for the survival wind velocity of 133 kmph (37 m/s) are summarized for the AZ axis in Table 2 of the report TCE-G18-DR-CAL-153-Yoke (dated 1990-03-07) and for the EL axis TCE-G18-DR-CAL-153-Cradle (dated 1990-02-19) (see Annexure III for Summary). The basis for calculations are given in design engineering notes TCE-G18-01-153 V-00 to V-12 (V-12 = the above cited Yoke report). To summarise, the maximum moment i.e. the

torque, T, for V_{wind} = 133 km s^{-1} is given by :

T_{Elev} = 204 Tonne-metre at Θ_{El} = 60°

T_{Az} = 186 Tonne-metre for dish at 75° elevation.

For lower winds, torque at 1:1 axis is given by

$$T_X = (V_X/V_{133})^2 \times T_{133}$$

At 80 kmph, T_{elev} = 73.9 Tonne-metre and T_{AZ} = 67.3 Tonne-metre

which are the same as in TCE report entitled (Ref. Nil) "Mechanical System for GMRT", dated July 1990.

titled

The calculations for the required motor torque at various wind speeds and input and output capacities of the Elevation and Azimuth gear boxes also are given in above TCE Report. However, in their report certain values were assumed for the frictional torques and efficiencies of the gear boxes, as could be estimated by TCE before the gear boxes were manufactured. Subsequently, M/S Mannesmann Rexroth, manufacturer of the planetary gear boxes have measured input frictional torques at various loads and speeds for all the gear boxes but efficiencies have been measured for only two AZ and two EL gear boxes (Mannesmann Rexroth, 1992). Hence it seemed desirable to verify the actual values of the input torques, after the installation of gear boxes on the C3 and C12 antennas, which included effects of frictional forces of the motor and the gear boxes, combined efficiency of the planetary gear box and the bull gear and effects of any unbalance load.

Our first measurements of the motor currents made on the elevation servo system in November 1992 showed the following problems : (a) The current varied almost sinusoidally with an amplitude of about 10-15 amp, at the period of each pin, for the C12 antenna. This was correctly ascribed by our mechanical engineers to the wrong pinion which had been machined by M/S Southern Structurals Limited but was tentatively installed for trial rotations only. Further, the current variations were only about 3 to 8 amp for the C3 antenna installed by M/S V.M. Jog

Constructions Limited. The shape of their pinion was also known to be defective. It was also seen that the pin sector seemed to have distorted or effectively machined the installed soft pinion and this was considered to be the reason for the smaller current variations in the case of C3 antenna. Recently, an ideally shaped pinion, as specified originally by TCE, has been installed by M/S SSL on C12 antenna and the current variations are found to be only 1 to 2 amp, which is negligible compared to the peak torque capacity of the gear box for continuous load corresponding to about 35 Amps. Therefore the pin to pin variation problem seems to have been solved.

(b) Further, it was noted that the current occasionally exceeded 35 amp for the EL axis even in the absence of winds. This current value is slightly higher than the input capacity of the EL gear boxes which corresponds to a current value of about 30 amps as noted above. It was found that the counter torque circuit was set at ± 15 amp instead of ± 10 amp which was specified during initial design stages. In order to have a good understanding of the behaviour of the servo system we decided to make tests for counter torque values varying from 0 to 10 amps. As described in Section 9, it is concluded that a counter-torque of ± 5 Amperes is optimum. Lower values will not be satisfactory for counter-torquing and higher values lead to current demand exceeding 35 Amp for the required tracking upto 45 kmph (1 min averaged wind).

(c) Finally, it was noted that the torque (current) demanded by the DC motor was almost zero at elevation (EL) angles from horizon of about 20° as the antenna was slewed from near-horizon to the zenith position, compared to a value of about 24 amps at EL angle of 20° for the case when the 45-m dish was slewed from the zenith towards the horizon position. It was immediately recognized that this was due to the antenna being over-balanced.

It may be noted that frictional torques and gear box efficiencies are dependent on both load values and velocity of rotation. However, these non-linear dependencies are not very sharp and hence their effects can be deduced iteratively.

It became desirable to develop a torque-demand model of the servo system in order to determine the relationship between torques and various loads from a series of measurements. This model is described in Section 3 and measurements in Sections 4-6.

3. TORQUE DEMAND MODEL OF THE SERVO SYSTEM

3.1. The GMRT servo system is shown schematically in Fig. 1. This figure refers to ~~either EL~~ the elevation axis but a similar drive system applies for the ~~AZ~~ azimuth axis. However, the numerical values of the parameters are different for the two axes.

During tracking at a given velocity of rotation, the torque supplied by the driving Motor (Motor 1 in Fig. 1) is given by

$$T_{md} = [T_f + T_{visc}]\left\{1 + \frac{1}{n_1 n_2}\right\} + \frac{T_{mb}}{n_1 n_2} + \frac{T_w}{N_g n_1} \pm \frac{T_u}{n_1} + \frac{T_{pin}}{n_1} \qquad (1)$$

Where T_{md} = Torque supplied by driving Motor (kgm)

T_f = $T_{f1} + T_{f2}$

T_{f1} = Coulomb friction of Motor (kgm)

T_{f2} = Newtonian friction of the planetary gear box (kgm)

T_{visc} = Frictional torque due to the viscosity of oil in the planetary gear box (kgm)

T_{mb} = Opposing (backing) torque of the counter-torquing motor (kgm)

T_w = Wind torque on the 45-m dish (kgm)

T_u = Unbalance torque of the 45-m dish (kgm) for the EL axis; +ve sign holds for the case when the motor drives the unbalance torque of the dish and -ve sign if the unbalance torque drives the motor. For AZ axis, the antenna is balanced.

T_{pin} = Pin to Pin torque variation (kgm)

n_1 & n_2 = Combined efficiencies of the Primary (Planetary) and the Secondary (bull-gear) gear boxes, in the forward and reverse direction respectively.

N_g = gear reduction ratio of elevation gear box and pin Sector = 25,000:1

In the case of elevation drive the unbalance torque, T_u, (e.g. for C3 and C12 antennas due to a heavier counterweight, w) is given by

$$T_u = W_u\, r \cdot \sin(\Theta - \Theta_o) \qquad (2)$$

W_u = Unbalance weight (kg)

Θ = Elevation angle (degrees)

(r, Θ_o) = Distance (m) and elevation angle of the centre of gravity of W_u with respect to elevation axis of the dish.

The relation between the current of the servo motor, I, and the applied Torque, T, is given by the motor torque constant K_t = 0.055, such that

$$T(\text{kgm}) = 0.055\ I\ (\text{amps})$$

3.2. For the case of a single motor gear box and also in the absence of wind and pin to pin variation torques, we get from Equations 1 and 2, a simpler relation :

$$T_{md} = T_f + T_{visc} \pm \frac{T_u}{n_1}$$

As shown in Fig. 2, the motor driving torque will vary sinusoidally depending upon the elevation angle, Θ, and will become equal to ($T_f + T_{visc}$) for the balance position when $\Theta = \Theta_o$. The maximum unbalance torque which corresponds for $(\Theta = \Theta_o) = 90°$, $T_{umax} = W_u \cdot r$, can be determined by measuring half the difference of torques (motor-current x K_t) observed for the dish being driven towards the horizon <u>or</u> the zenith, for relatively large values of $(\Theta - \Theta_o)$ in order to minimize errors.

4. TESTS MADE ON THE ELEVATION DRIVE SYSTEM FOR C12 ANTENNA

The following tests have been done in order to evaluate the system parameters of the model described in Section 3.

4.1 No load current has been determined for DC motors at various speeds and it is found that current varies from about 2 amp for low speeds to about 4 amp at 1500 rpm. This gives a value of

Coloumb friction of the motor (T_{f1}). More detailed tests with different loads are planned and will be presented elsewhere.

4.2 A single gear box with the DC motor in the "upper position" was installed on the elevation axis of the C12 antenna; the lower gear box and its motor were not installed. The test results are presented in Fig.3.1 to 3.7 and provide information about the frictional torques (T_{f1} plus T_{f2}), T_{visc} and also about T_u, the unbalance torque.

4.3 The lower gear box was then installed without motor and the antenna was rotated using the upper motor at 500 rpm from horizon to zenith and vice versa. After that the motor was also installed on the lower gear box but it was disconnected from the amplifier i.e. it was idling. Results of these two measurements are presented in Fig.4.1 to 4.3. They provide information about the combined efficiency of the gear boxes and about the unbalance load.

4.4 Both the motors were then powered by servo rack so as to aid each other, i.e., with zero torque bias. The results are presented in Fig. 5. The figure also shows the expected curve predicted from the torque model (see Section 7) which indicates a good match between the theoretical and experimental values.

4.5 The antenna was then rotated for different values of torque bias at 100 rpm. The tests are summarized in Fig. 6 and provide information on the combined efficiency of the gear box and on the counter-torque characteristics.

4.6 The low speed operation of servo was investigated for different counter-torque bias at 5 rpm. The tests are presented in Fig. 7 and are useful in understanding stictional effects and the counter-torque arrangement. It was observed that the motion is not smooth and it does not improve with increasing counter-torque bias.

4.7 The measured RMS error of the elevation axis antenne drive at an antenna tracking rate of a few RPM is found to be 30-seconds of arc at winds of about 20 kmphh.

5. TESTS MADE ON AZIMUTH DRIVE SYSTEM OF C12 ANTENNA

A set of tests, similar to those described in the last section, were carried out on the azimuth axis. These are described in this section.

5.1 A single motor was powered and the antenna was rotated in azimuth with the second motor present but idling. The current was found to be 10 Amps. Inference about the motor friction and bull gear teeth variation is drawn from this experiment.

5.2 The antenna was then rotated with both motors powered for various counter torque bias. The results are presented in Fig. 8 and provide information about the combined gear-box efficiencies and counter-torque characteristics.

6. PRELIMINARY TESTS ON C3 ELEVATION AXIS

Some preliminary tests were conducted on C3 antenna to estimate the overbalance in the counterweight. One motor was electrically disconnected and the antenna was rotated from zenith to horizon and back. The test was useful in estimating the overbalance and the offset in the centre of gravity of the counterweight. The experiment was repeated with the second motor driving the antenna and the first motor idling. The results of the experiments are shown in Fig. 9.

7. RESULTS

The various parameters of the torque demand model as obtained from the experiments on C12 elevation axis are listed in Table 1. The estimated torque budget based on these experiments along with the designed values is presented in Table 2.

The parameters of torque demand model for azimuth axis are presented in Table 3 and the estimated and designed torque budget is listed in Table 4.

As a result of the tests on C3 elevation axis, the overbalance in the counterweight was found to be 3.7 Tons. This has been reduced subsequently to about 1 Ton.

8. DISCUSSIONS

The tests described in the previous section were useful in quantifying the performance of the system and in comparing it with the target system, as per the original design stipulations.

The installed system was found to perform better than the target system.

The combined gear efficiency was found to be higher. This efficiency is a product of the forward and reverse efficiencies and in the case of elevation, these were found to be 0.93 and 0.84 respectively. Table 6 shows a summary of tests conducted by M/s Mannesmann Rexroth on the gearbox supplied by them. The values of forward and reverse efficiencies from the table agree well with the measured efficiencies.

An important aspect of the experiments was to investigate whether the counter torque circuit provided by BARC will allow tracking up to 45 kmph mean wind gusting up to 55 kmph. This aspect is discussed in the next section.

9. **TORQUE CAPACITY OF GEAR BOX**

In order to operate the antenna in tracking mode at a particular wind speed, it is necessary to examine the torques in the system components in the presence of a counter torque. The critical component in this respect is the gear box as the other components (the motor, the amplifier etc.) are rated for much higher torques. The torque capacity of the gear box in the presence of a counter torque at various wind speeds are discussed in this section.

The planetary gear box (gear box ratio 821:1) supplied by M/s Mannesmann Rexroth had the following output torque capacity based on the specifications given by TCE in their tender - bid enquiry and confirmed by M/s. Mannesmann Rexroth from the calculations made by them as submitted in their tender quotation.

TCE DESIGN VALUES

WIND SPEED (kmph)	TORQUE OUTPUT * ELEVATION GEAR BOX (Nm)	NUMBER OF REVOLUTIONS (x$1\bar{0}^{6}$)
133	33000 **	Stationery
80	16100	0.02
40	11000	0.7
30	6500	1.1
20	3600	4.2

** (204 tm x 9.81 x 1000)/(2 x 30.3) for 133 kmph for each gear box assuming 100% eff. of bull gear

From the above data and the estimated combined forward efficiency = 0.84 for the elevation drive, the maximum allowable currents can be calculated for various wind speeds and are listed as follows

WIND SPEED (kmph) (1)	TORQUE AT PLANETARY GEAR BOX OUTPUT * (Nm) (2)	MOTOR CURRENT * (each motor) (Amps) (3)	
80	16100	43	✓
40	11000	30	✓
30	6500	17	✓
20	3600	10	✓

where Col (3) is calculated from the following relationship

$$(3) = \frac{(2)}{821 \times 0.84 \times 0.055 \times 9.8}$$

* TCE Design values

From Table 5 and the above data, it can be shown that it is possible to use the gear box safely up to 50 kmph mean wind speed with short gusts up to 60 kmph. The counter torque characteristics for a torque bias of 5 Amps is shown in Fig. 10. From their figure and Table 5 it can be shown that the maximum motor current will be 24 Amps in the presence of counter torque for a wind load of 55 kmph. Furthermore, the individual motor currents are less than 30 Amps upto 60 kmph wind speed and the corresponding gear box torques are less than 11000 Nm which is the nominal capacity of the gear box. Thus, the capacity of the gearbox as well as the counter torque circuit allow tracking up to mean wind speed of 50 kmph gusting up to 60 kmph. However, it is desirable to restrict tracking to mean wind of 45 kmph, gushing to 55 kmph, so that the antenna can be slewed to zenith before the wind exceeds 80 kmph.

From Table 5 it is seen that the demanded motor current is 34.5 Amps for each of the two motors at 80 kmph wind speed. Thus, the current limit is to be set at 38 Amps in order to allow stow operation.

10. CONCLUSION

The tests, described in this report, have indicated that the installed system is in good agreement with the design and it is possible to optimize the antenna operation.

It is concluded that suitable modifications in counterweight design must be carried out in order to reduce the overbalance and minimize the centre of gravity offset. The redesign of counterweight is proposed to be taken up as an independent study and a separate report will be brought out for the purpose.

As discussed in the preceding section, the antenna can be operated in tracking mode up to a wind speed of 50 kmph without any modification in the counter torque circuit. However, this requires a close check on all electrical and mechanical components as excessive piece to piece variations may preclude extension of these results to other antennas. It is also concluded that the torque bias should be set at 6 Amps and the continuous current limit should be set at 30 Amps.

Finally, it is recommended that the torque values for each antenna should be estimated and the torque budgets listed in this report should be verified.

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TABLES

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TABLE-1

MEASURED VALUES OF TORQUE MODEL PARAMETERS FOR C12 ELEVATION AXIS

S. No.	Parameters	Symbol	Unit	Expected Value	Measured Value
1.	Motor Newtonian Friction	T_{f1}, T_{f2}	kg-m	0.19	0.165
2.	Viscous Damping	T_{visc}	kgm/krpm	-	0.11
3.	Overbalance in * Counterweight	W_v	Tons	-	3.8
4.	Combined Gear efficiency @ 100 rpm	$^{n}1^{n}2$	-	0.4	0.77
5.	Combined Gear efficiency @ 5 rpm	$^{n}1^{n}2$	-	0.4	0.82
6.	Minimum Counter Torque Bias	-	Amps	10.0	4.0

* The unbalance is calculated at a radius of 4.5 m

TABLE-2

COMPARISON OF ESTIMATED AND DESIGNED TORQUE BUDGET FOR C12 ELEVATION AXIS

S. No.	Parameters	Symbol	Torque per Motor		For two Motors (Amps)
			Estimated (Amps)	Designed (Amps)*	
1.	Newtonian Friction	T_{f1}, T_{f2}	3	0	6
2.	Viscous Friction	T_{visc}	3	0	6
3.	Bull gear teeth variation	T_{pin}	1	0	2
4.	Bias Torque		5	10	10
5.	Miscellaneous (unbalanced)		2	4	4
6.	Wind Torque Bias			16	
	Total		14	30	28
	Available for Wind		16		32

This Column
* Not relevant now

TABLE -3

MEASURED VALUES OF TORQUE MODEL PARAMETERS FOR C12 AZIMUTH AXIS

S. No.	Parameters	Symbol	Unit	Expected Value	Measured Value
1.	Motor Newtonian Friction	T_{f1},T_{f2}	kg-m	0.19	0.22
2.	Viscous Damping*	T_{visc}	kgm/krpm	-	0.11
3.	Combined Gear efficiency @ 100 rpm	$n_1 n_2$	-	0.57	0.85
4.	Minimum Counter Torque Bias	-	Amps	10.0	5.0

* Assumed as identical to elevation axis.

TABLE -4

COMPARISON OF ESTIMATED AND DESIGNED TORQUE BUDGET FOR C3 AZIMUTH AXIS

S. No.	Parameters	Symbol	Torque per Motor		For two Motors (Amps)
			Estimated (Amps)	Designed (Amps)	
1.	Newtonian Friction	T_{f1}, T_{f2}	4	1.7	8
2.	Viscous Friction	T_{visc}	3	0.8	6
3.	Bull gear teeth variation	T_{pin}	1	-	2
4.	Bias Torque		8	10	16
5.	Counter Torque for the above	T_{wp}	5	10	10
6.	Miscellaneous		3	2	6
7.	Wind			15.5	
	Total		19	30	38
	Available for Wind		11		2

TABLE - 6

SUMMARY RESULTS OF REXROTH GEAR BOX TESTS

TABLE 6.1 : Idling Torque

	Range for All Gear Boxes (Nm)	Mean kg m
1. <u>Elevation Gear Boxes</u>		
100 rpm	0.3 to 0.5	.04
500 rpm	0.8 to 1.1	.095
1000 rpm	1.4 to 1.7	.155
1400 rpm	1.8 to 2.2	.20
1. <u>Azimuth Gear Boxes</u>		
100 rpm	0.7 to 0.9	.84 kgm
500 rpm	1.4 to 1.8	.016
1000 rpm	1.7 to 2.3	.20
1500 rpm	2.2 to 2.7	.24

TABLE : 6.2 : Backlash and Stiffness

Backlash	All Gear Boxes range between	
	Minimum	Maximum
Elevation Gear Boxes	36.8°	199.3°
Azimuth Gear Boxes	113.2°	322.6°

Stiffness (In the form of spring rate)	All Gear Boxes range between	
Elevation Gear Boxes	5.85 to 7.1	Nm/Rai
Azimuth Gear Boxes	4.7 to 6.5	Nm/rai

TABLE - 5

WIND TORQUE DEMAND AT VARIOUS SPEEDS

S.No.	Mode of operation	Wind Speed Vw (kmph)	Torque at elevation Axis (Ton-m)	Torque at Planetary Gear Box Output (Nm)	"Net" Torque at inputs of two Planetary Gear Boxes (kgm)	"Net" current demand (Amps) due to wind (both motors)	Motor Current for CTR-TORQUE BIAS=5 (Amps)			
							I_{fr} (Amps)	Total Demand	I_{fo} (Amps)	I_{ba} (Amps)
		(1)	(2) $\frac{204.2 \times \text{Col.}(1)}{135} \simeq 0.1154 \times (1)^2$	(3) $\frac{(2) \cancel{/} \times 9.8}{30.5 \times 0.93} = 345.4 \times (2)$	(4) $\frac{(3)}{821 \times 0.84 \times 9.8} \simeq (3)/6758$	(5) $\frac{(4)}{8.55}$	(6)	(7)	(8)	(9)
A 1.	TRACK AND SLEW	20	4.6	1590	0.235	4	7.2	11.2	10.6	0.6
2.		30	10.4	3593	0.53	10	6	16	13	3
3.		40	18.5	6392	0.95	17	6	23	16.5	6.5
		45	23.4	8085	1.20	22	6	28	19	9
		50	28.9	9985	1.48	27	6	> ~~28~~ 33	21.5	11.5
B 6.	SLEW	55	34.9	12060	1.78	32	6	38	24	14
7.		60	41.6	14370	2.13	39	6	45	27.5	17.5
8.	SLEW	65	48.8	16860	2.50	45	6	51	30.5	20.5
9.	SLEW	80	73.9	25530	3.78	63	6	69	34.5	34.5
10.	SLEW	85	83.4	28810	4.26	78	6	84	39	39
C 11.	STOW	90	93.5	32300	4.78	87	6	93	43.5	43.5
12.	STOW	133	204.2	70550	10.44	-	-	-	-	

Note : $I_{fo} = I_{forward}$; $I_{ba} = I_{backing}$; $I_{fr} = I_{friction}$

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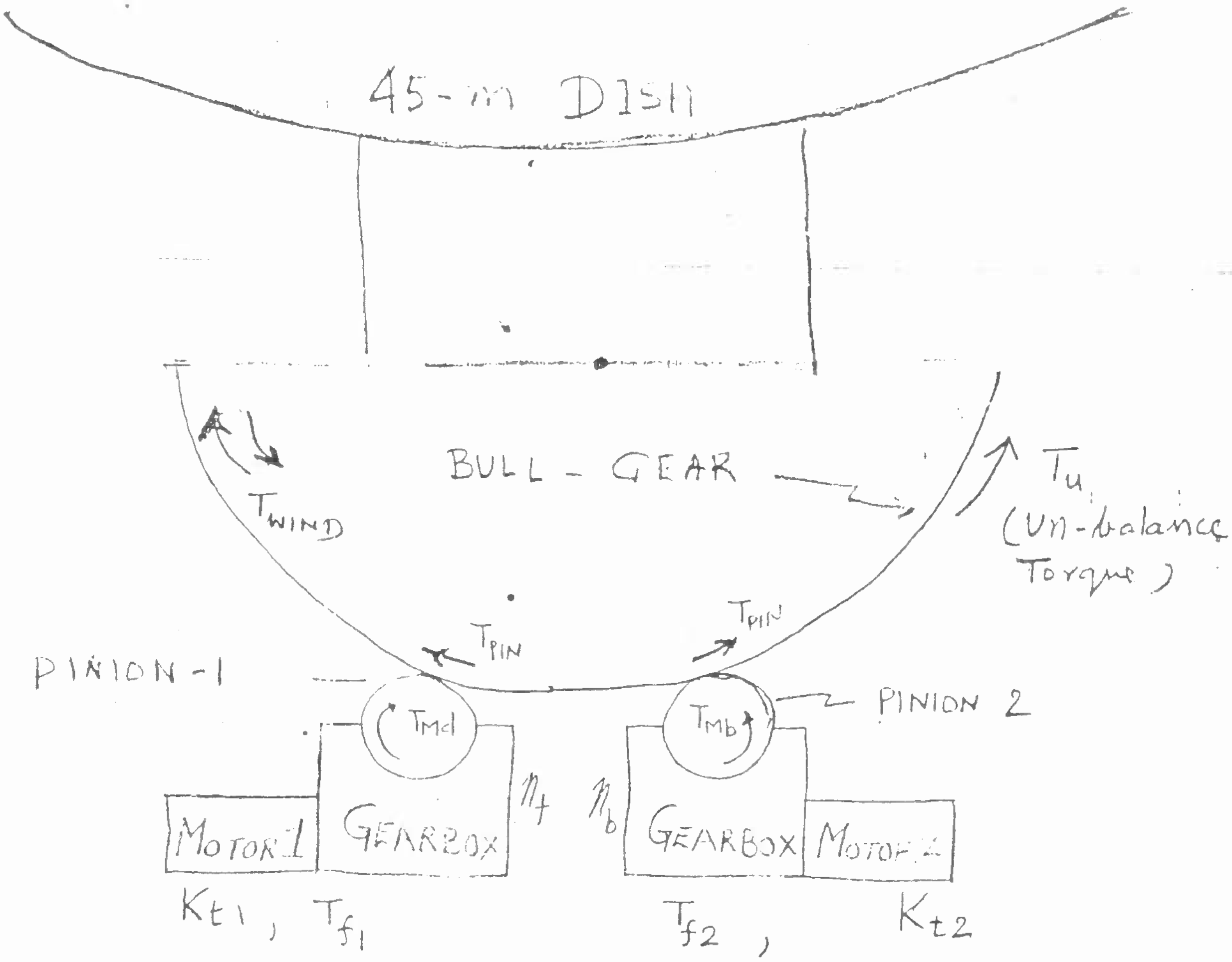


FIGURE 1 :
MECHANICAL DRIVE SYSTEM OF GMRT. For each axis, there are 2 independent gear-box - motor drives, which can be driven to aid each other for slewing or in a counter-torque arrangement for tracking.

Fig 1

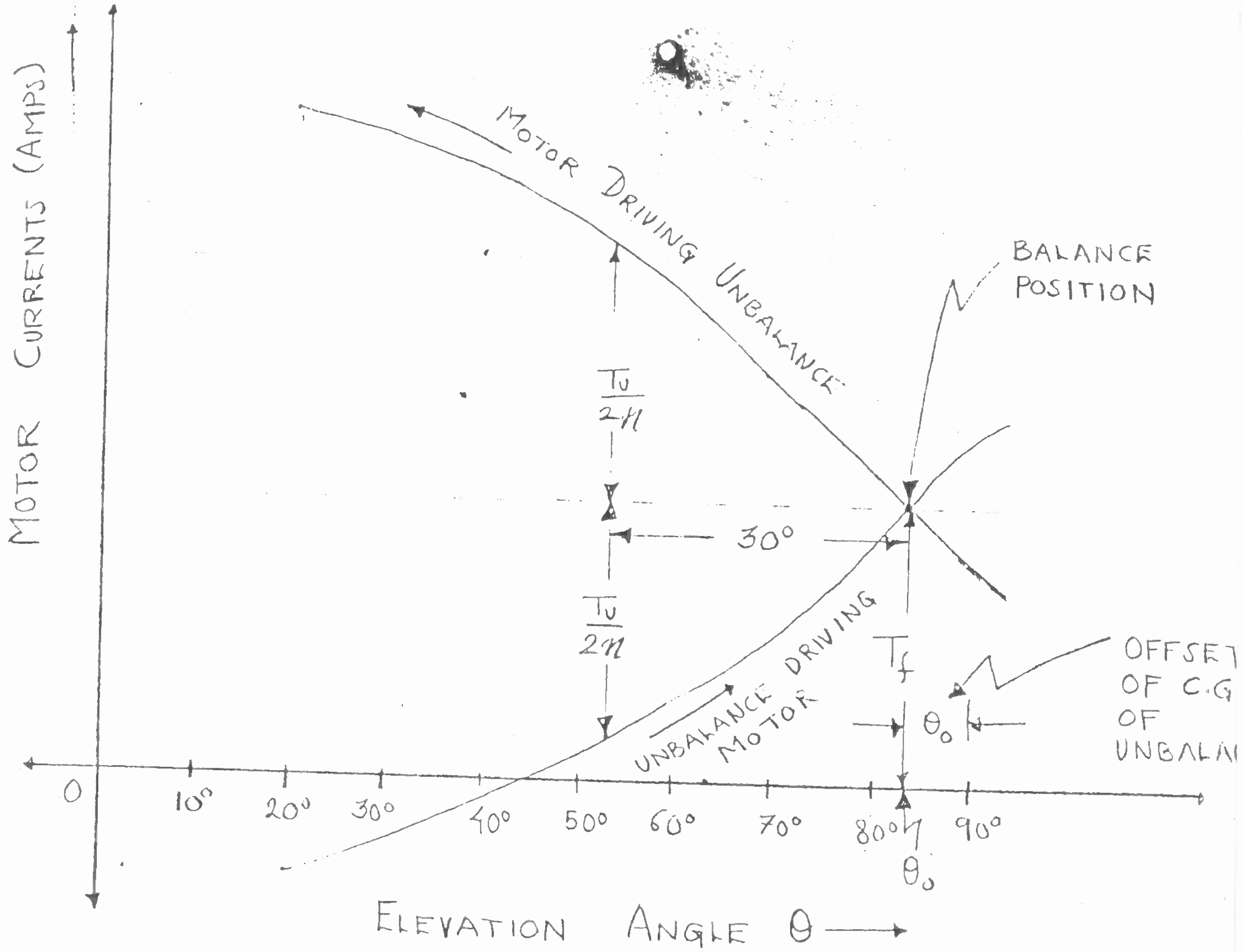


FIGURE 2: THE motor currents in the presence of a mass unbalance torque.

Fig 2

Tu = [illegible]

SINGLE-MOTOR ON EL AXIS:
UPPER GEAR BOX ONLY

C12 ANTENNA

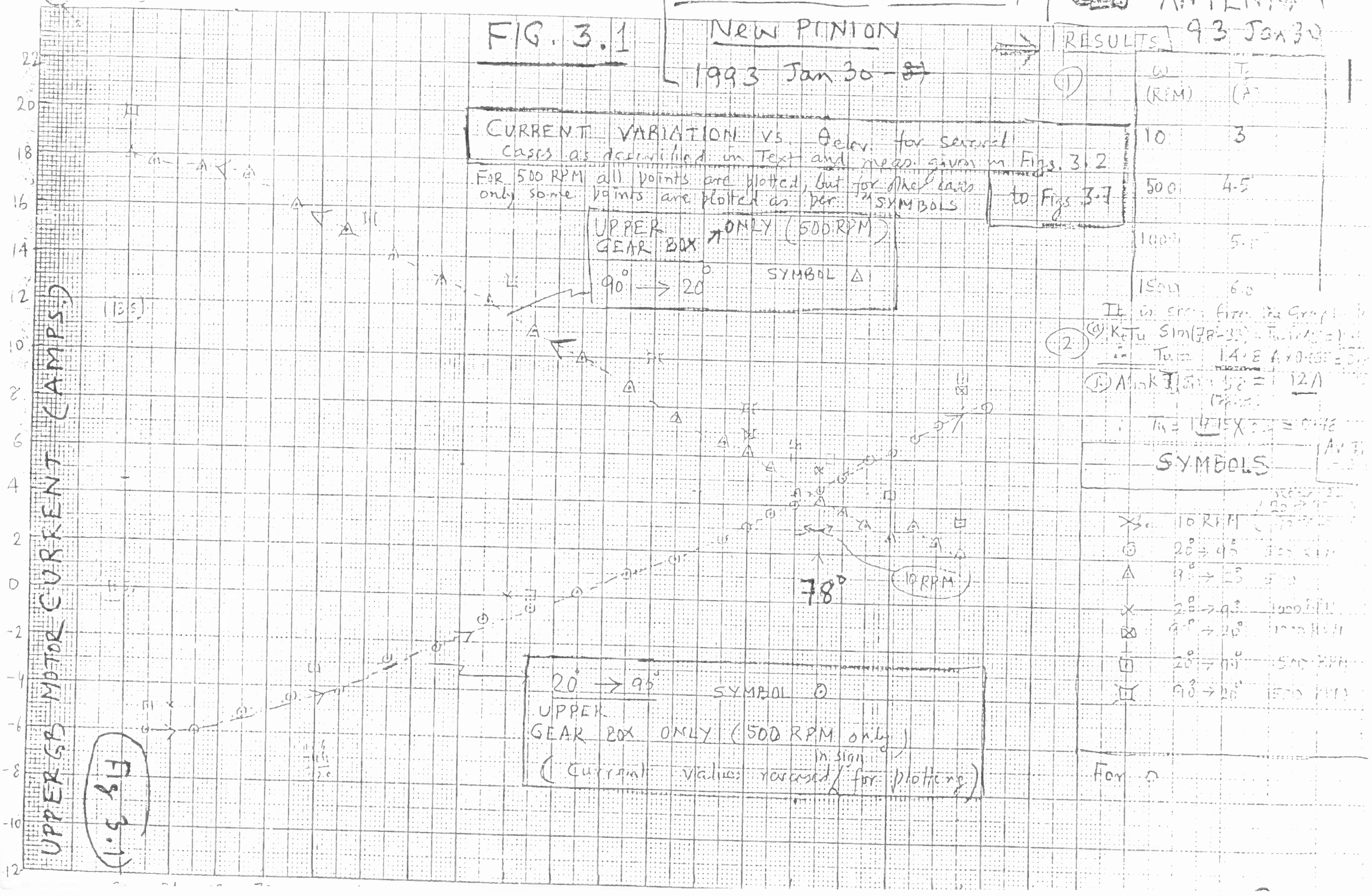
New PINION
1993 Jan 30 -

93 Jan 30

FIG. 3.1

CURRENT VARIATION vs. $\theta_{elev.}$ for several cases as described in Text and meas. given in Figs. 3.2 to Figs 3.7

For 500 RPM all points are plotted, but for other cases only some points are plotted as per "SYMBOLS"



UPPER GEAR BOX ONLY (500 RPM)
90° → 20° SYMBOL △

20° → 95° SYMBOL ⊙
UPPER GEAR BOX ONLY (500 RPM only)
(Current values reversed in sign for plotting)

RESULTS ①

ω (RPM)	T (A
10	3
500	4.5
1000	5.[illegible]
1500	6.0

It is seen from the Graph [illegible]

② (a) $K_t T_u$ Sin(78-3[illegible]) [illegible]
∴ Tu = 1.4 E A × 0.[illegible] = [illegible]

(b) A [illegible] = 12A

Tu = [illegible] X [illegible] = [illegible]

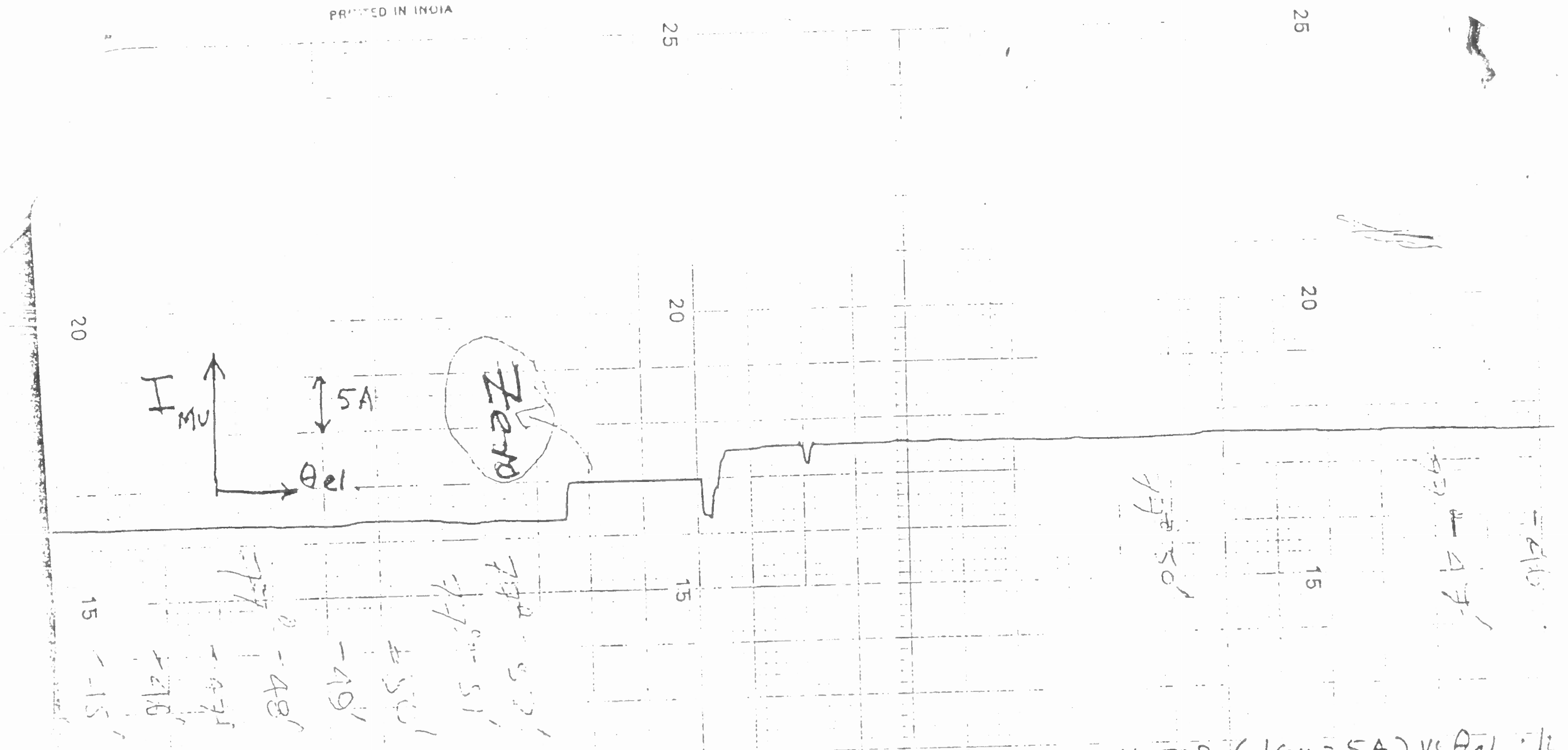


FIG. 3.2
ANT C12 : A pot) EMU CURRENT OF MOTOR (1cm=5A) vs θel. : li
ELEV (~ 10 RPM) upper Gear Box only

$\theta_{el} = 77^\circ 45' \rightarrow 77^\circ 52'$

AND $77^\circ 52' \rightarrow 77^\circ 46'$

Fig 3.2

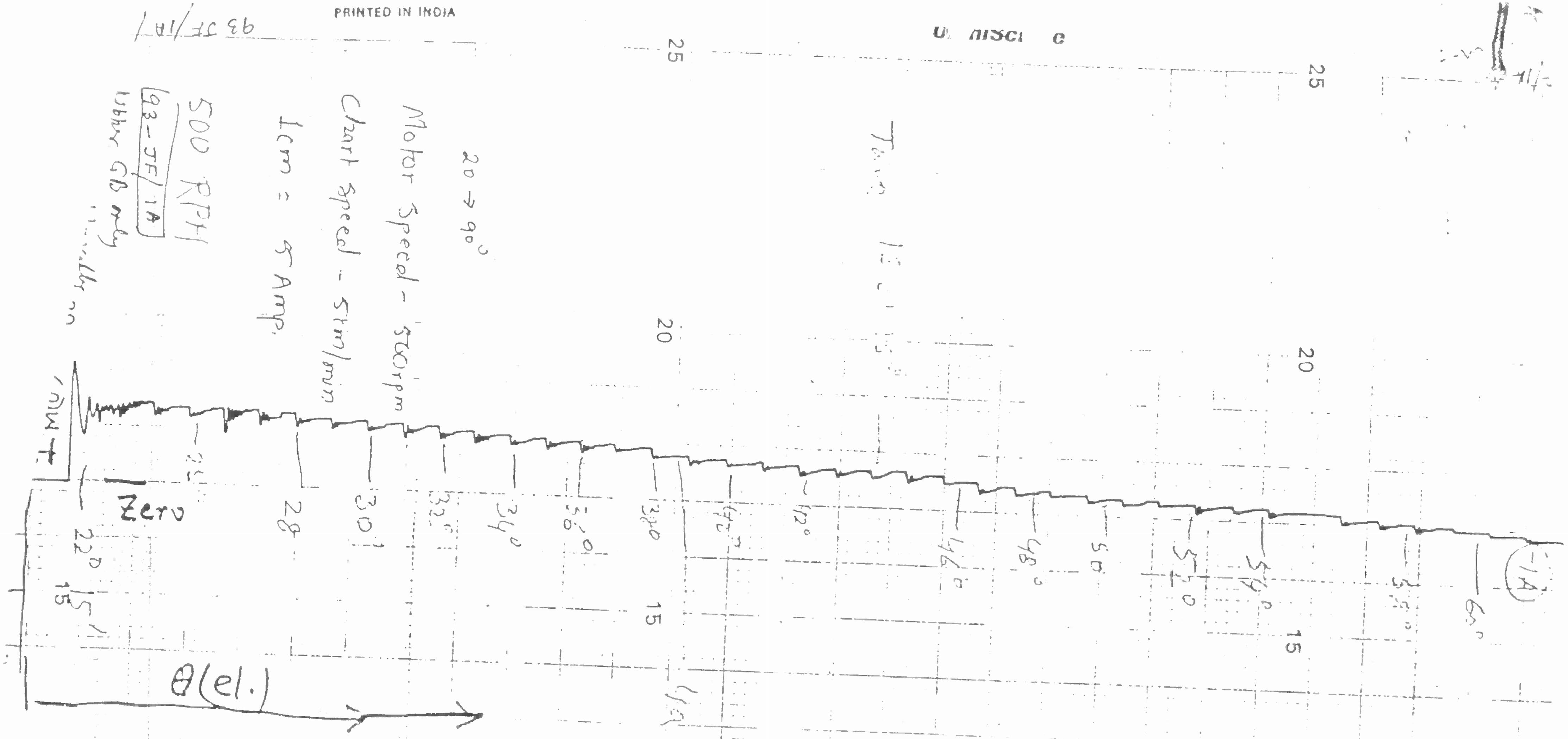


FIG. 3.3 A PLOT of CURRENT, I_{MU} of upper GB, Motor (1cm=5A) VS. Elev angle : $\theta_{el.}$ (500 RPM)

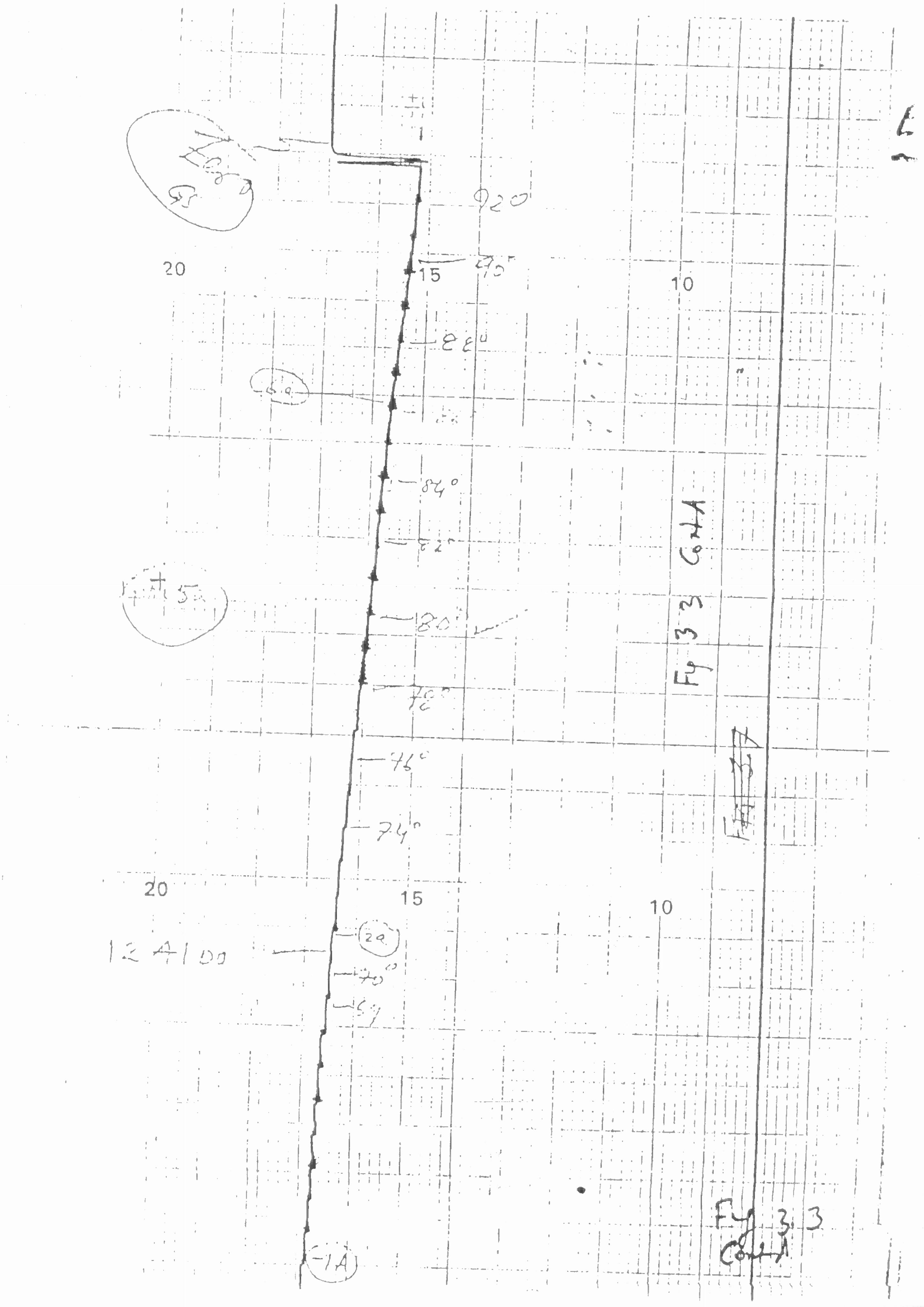
ELEVATION Speed, 500 RPM : ~~ELE~~ ROTATION 22° → 92°

ANT. C12 — EL: UPPER GEAR-BOX + Ⓜ

(LOWER GEAR BOX Removed)

Fig 3.3

(90° to 20° rotation plotted rather slow speed & hence not presented here.)



20
15
10
20
15
10
92°
90°
88°
84°
82°
80°
78°
76°
74°
70°
69
12 41 00
2a
1A
Fig 33 Cont'd
Fig 33
Cont'd

Fig 3.4

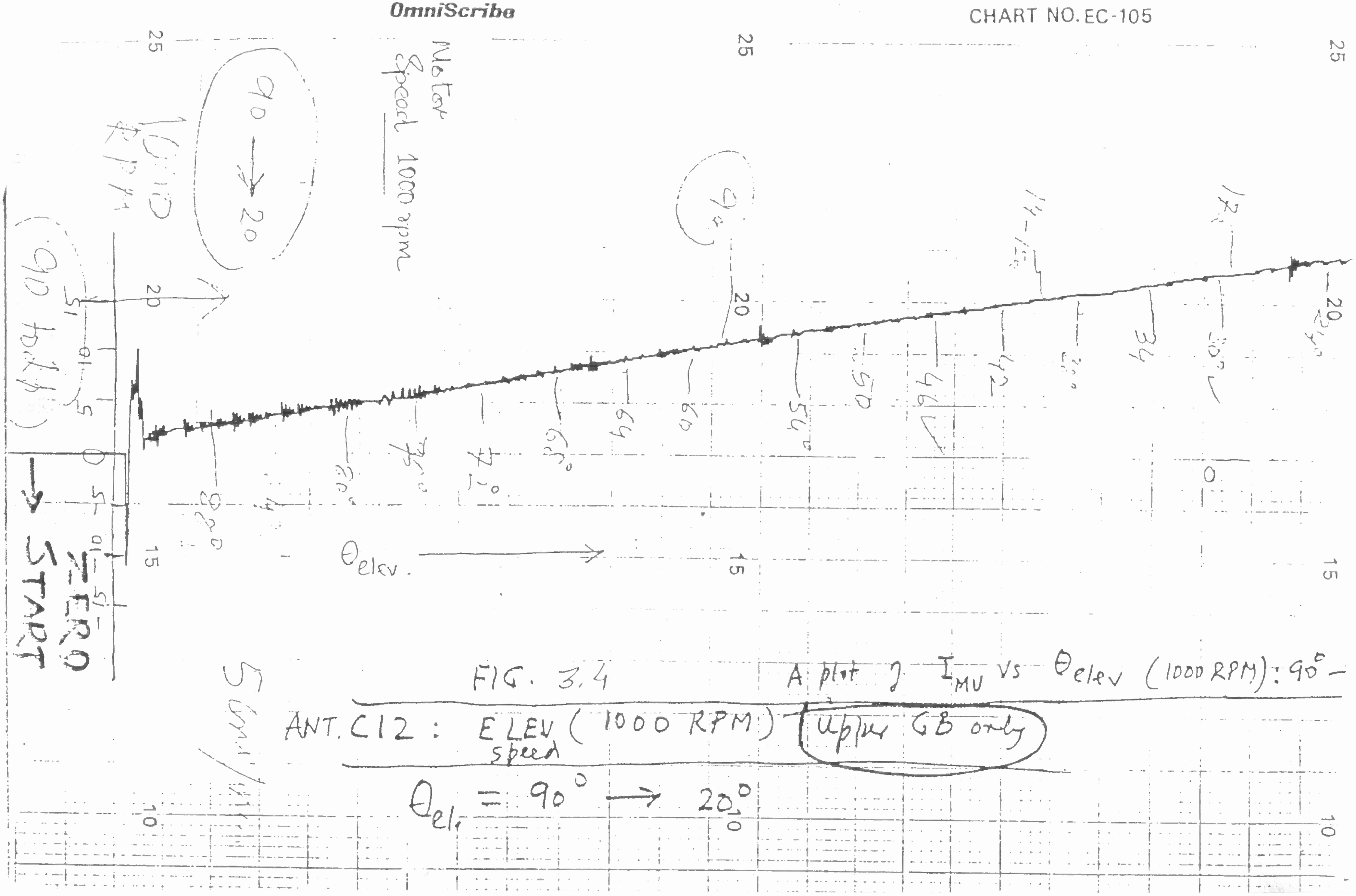


FIG. 3.4 A plot of I_{MU} vs θ_{elev} (1000 RPM): 90° –

ANT. C12 : ELEV speed (1000 RPM) Upper GB only

$\theta_{el} = 90° \rightarrow 20°$

20 → 90
1000 rpm

Motor Speed 1000 rpm

1000 RPM

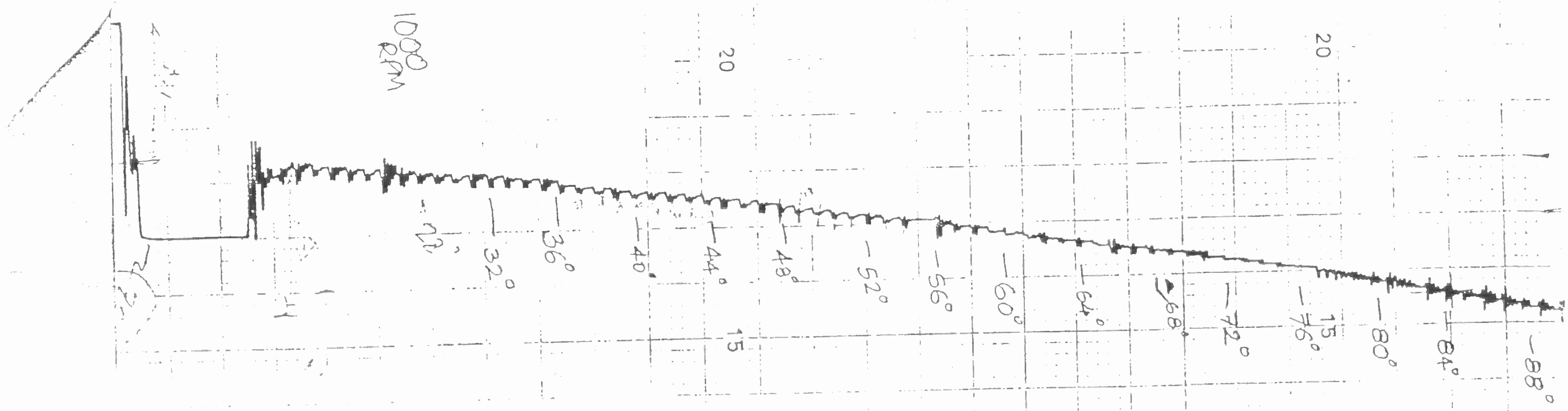


FIG. 3.5 A plot of I_{MU} vs θ_{el} (1000 RPM) 20° →

ANT. C12 Elev speed (1000 RPM) upper CB only

θ_{el} = 20° → 90°

Fig 3.5

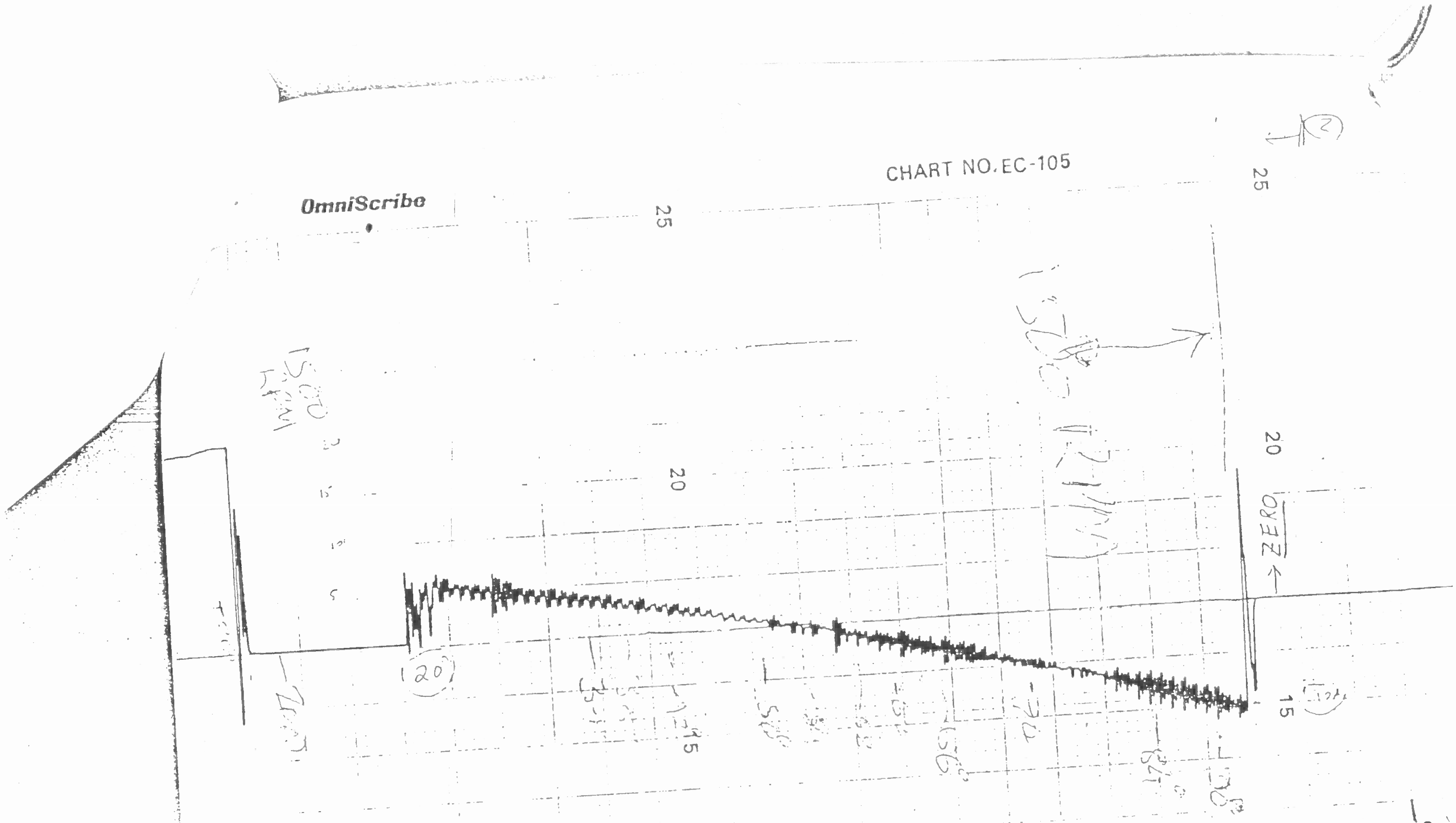
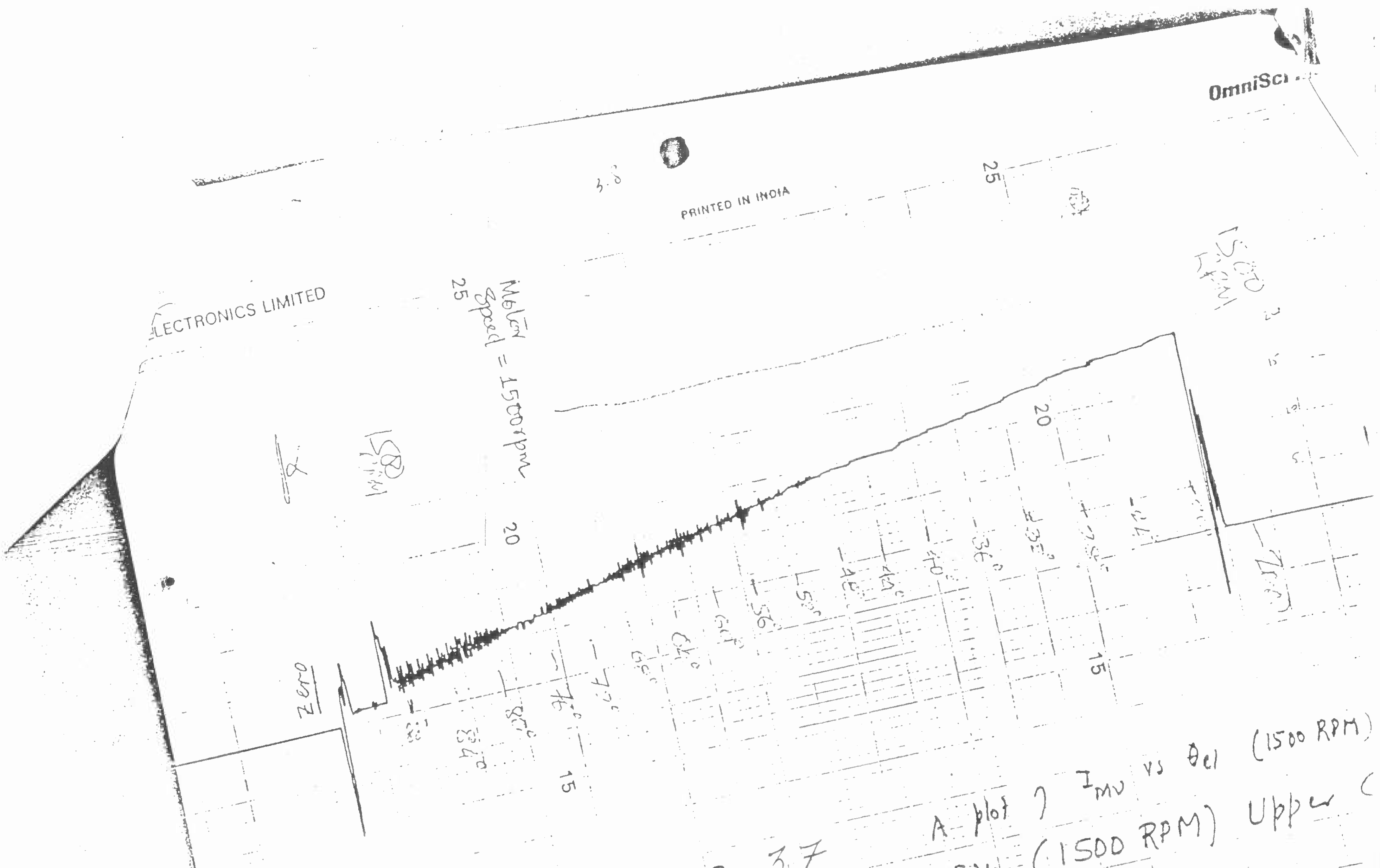


FIG. 3.6 A plot) Imu vs θel. (1500 RPM) 20 → 90°

ANT C12 : Elev. (1500 RPM) UPPER GEAR BOX

$\theta_{el} = 20^\circ \rightarrow 90^\circ$

Fig 3.



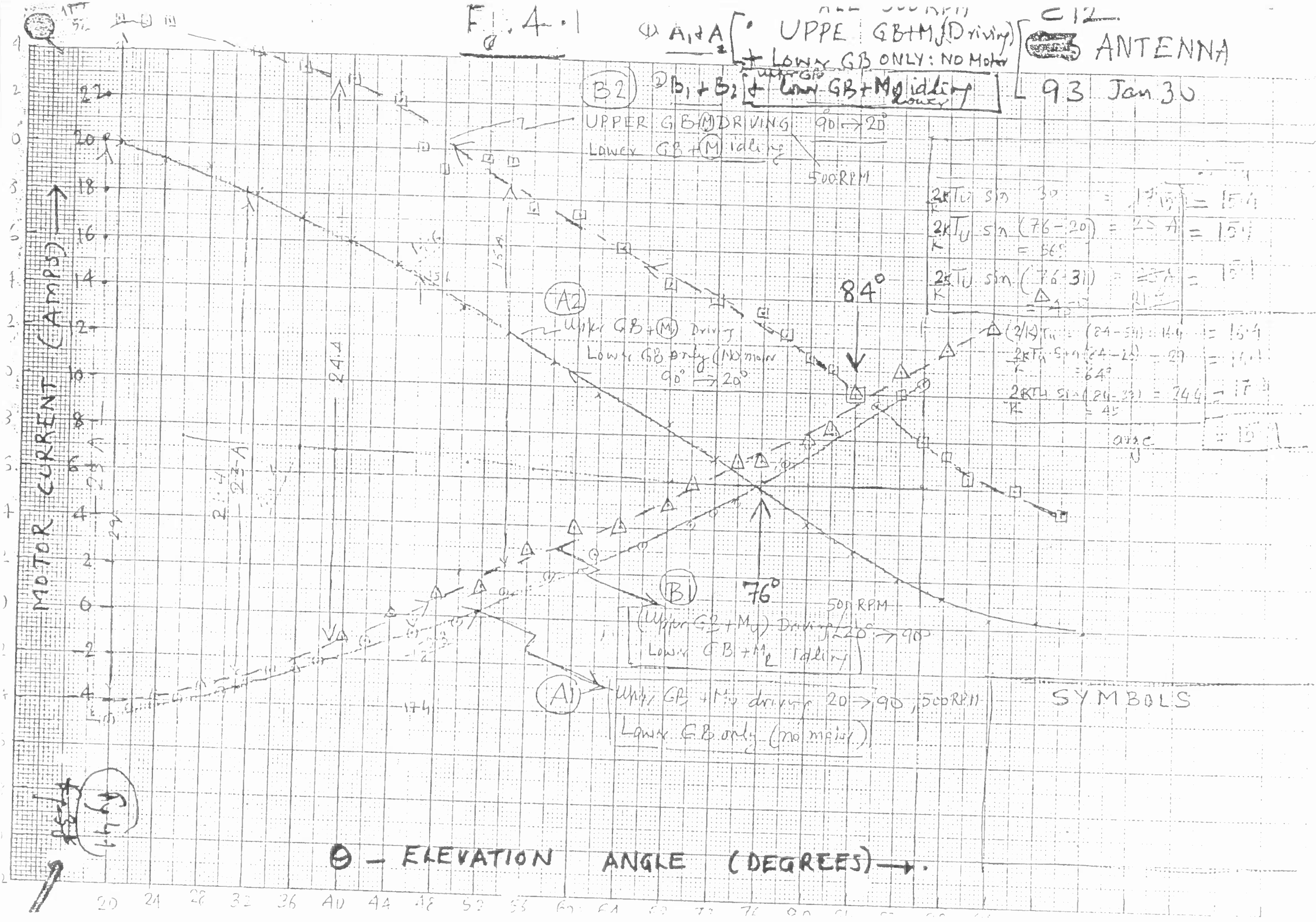
A plot) I_{MV} vs θ_{el} (1500 RPM)

FIG. 3.7 (1500 RPM) Upper (

ANT C12 : ELEV

θ_{el} = 90° $\xrightarrow[10]{}$ 20

Fig. 4.1


ALL 500 RPM
① A1 & A2 [UPPER GB+M (Driving) + Lower GB ONLY: NO Motor
② B1 + B2 [Upper GB + Lower GB+M idling
C12 ANTENNA
93 Jan 30
B2
UPPER GB+M DRIVING 90 → 20
Lower GB+M idling
500 RPM
A2
Upper GB+M Driving
Lower GB only (No motor)
90° → 20°
84°
76°
B1
500 RPM
(Upper GB+M) Driving 20° → 90°
Lower GB+M idling
A1
Upper GB+M driving 20 → 90, 500 RPM
Lower GB only (no motor)
SYMBOLS
2K/K Tu sin 30 = 15 = 15.4
2K/K Tu sin (76 − 20) = 25 A = 15
= 56°
2K/K Tu sin (76 − 31) = 15
(2/K) Tu = (84 − 31) = 15.4
2K/K Tu sin (84 − 20) = 16
= 64°
2K/K Tu sin (84 − 39) = 24.4 = 17
= 45
= 15
avg
24.4
22 A
17.4
MOTOR CURRENT (AMPS) →
Θ — ELEVATION ANGLE (DEGREES) →
22
20
18
16
14
12
10
8
6
4
2
6
2
4
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92

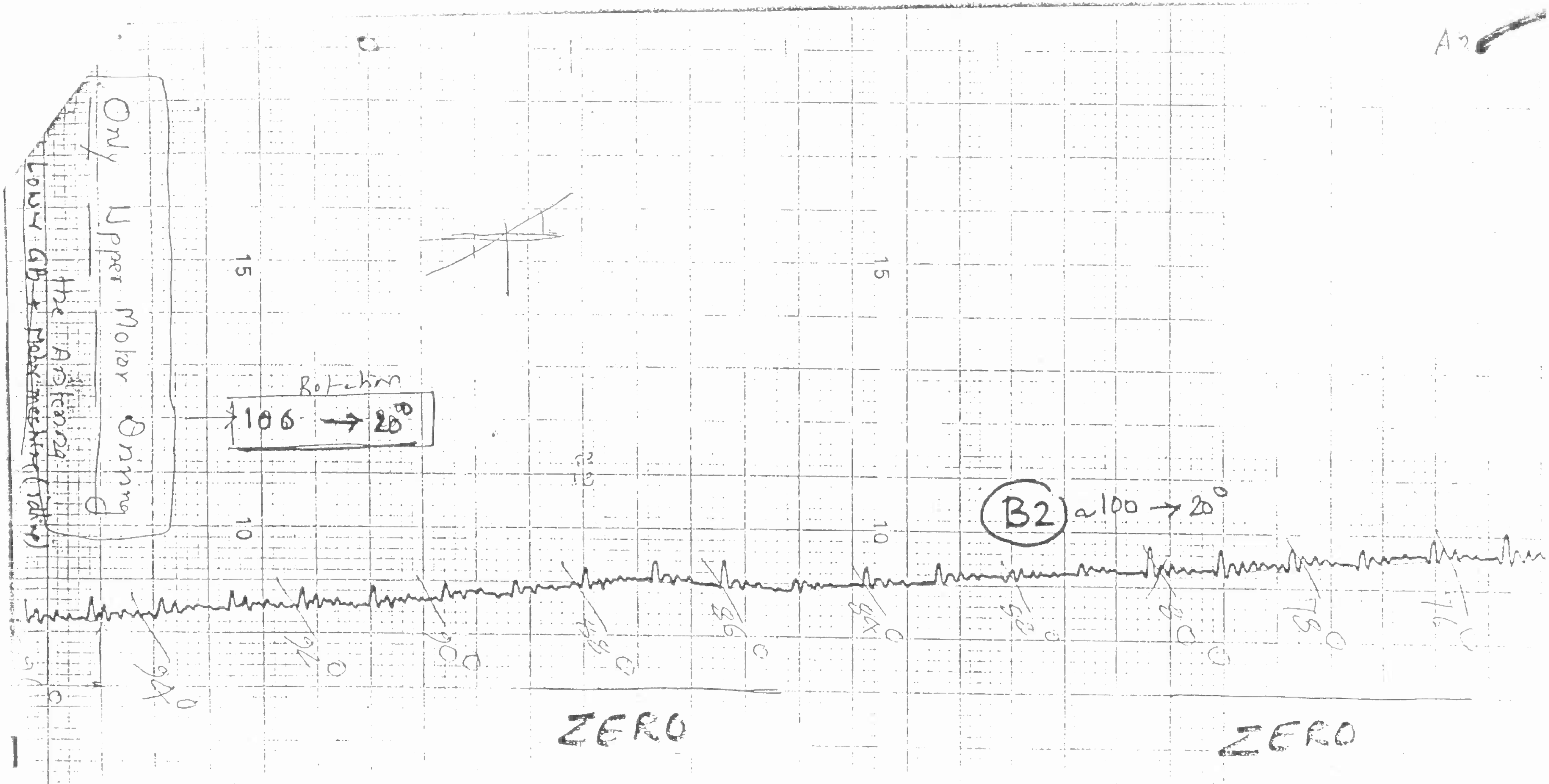


FIG. 4.2 Plot of IMU vs θel (500 RPM) Rotation from 100° → 20°

with
- Upper GB + MU Driving
- lower GB + ML Idling

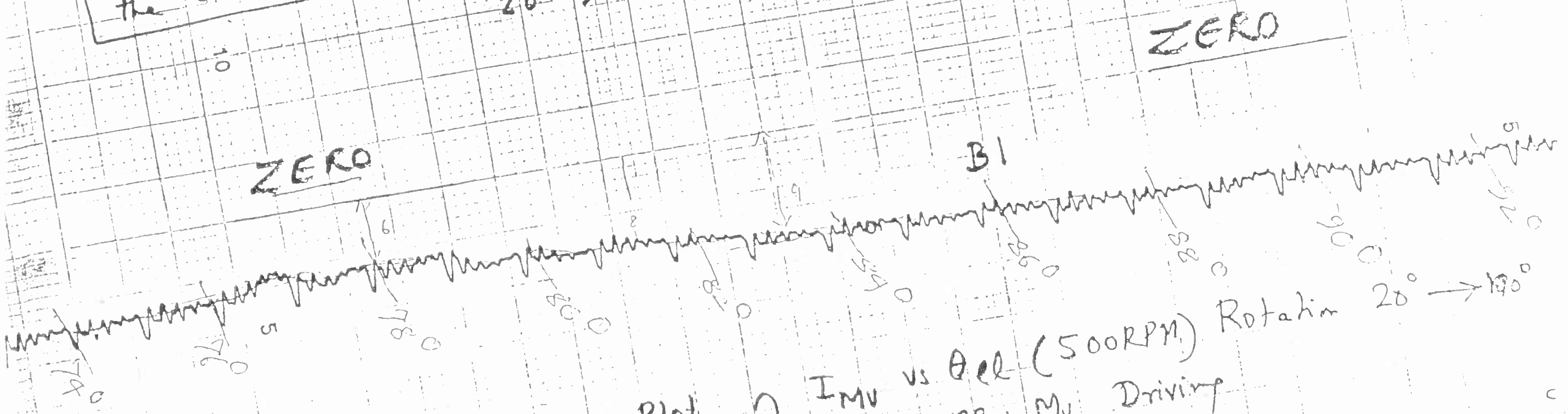
It seems that behaviour is [illegible] for this case!

Fig 4.2

93 Jan 30

C12 Elev.

Upper GB ~~&~~ + (M) driving LGB + (M) idling
the antenna WITH 20 → 90°



Plot of I_{MV} vs θ_{el} (500RPM) Rotation 20° → 180°
with • upper GB + M_U Driving
• lower GB + M_ℓ Idling

FIG. 4.3

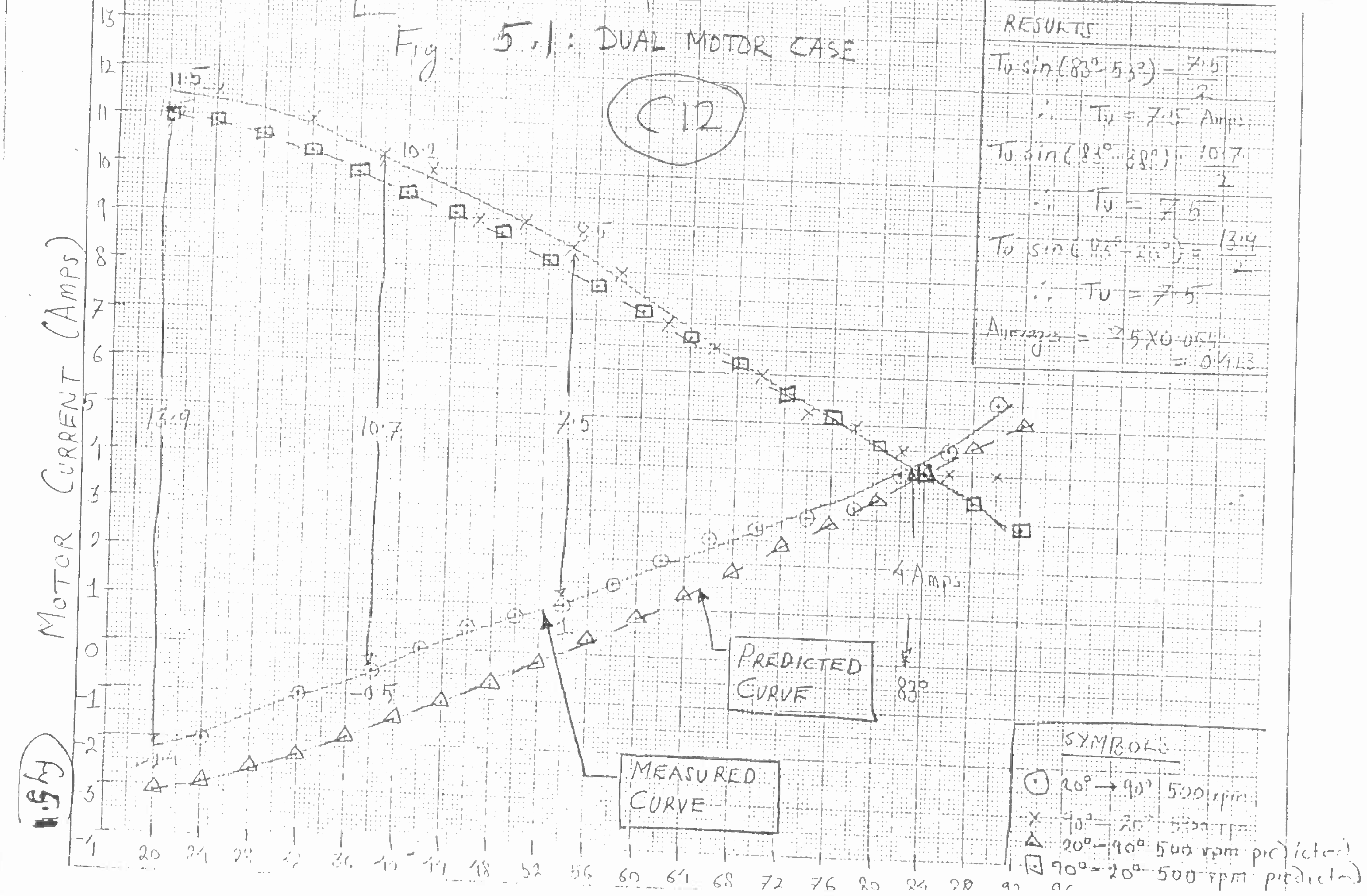
fig 4.3

1500 rpm
No counter Torque

93 Feb 3

Fig. 5.1: DUAL MOTOR CASE

C12



RESULTS

$T_0 \sin(83° - 53°) = \frac{7.5}{2}$

$\therefore T_0 = 7.5$ Amps

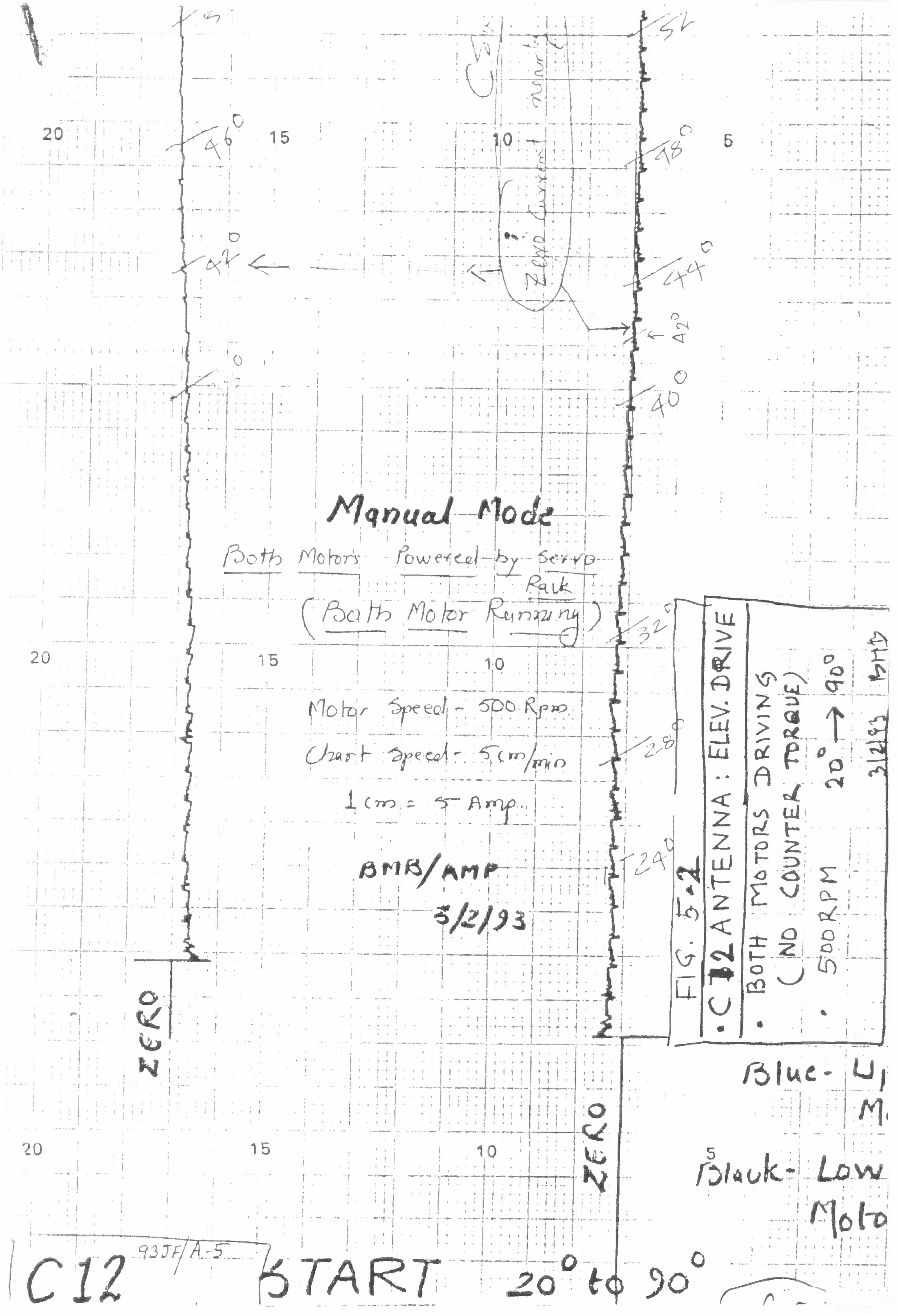
$T_0 \sin(83° - 38°) = \frac{10.7}{2}$

$\therefore T_0 = 7.5$

$T_0 \sin(83° - 20°) = \frac{13.4}{2}$

$\therefore T_0 = 7.5$

Average $= 7.5 \times 0.055$
$= 0.413$



Zero Current near to C

Manual Mode

Both Motors Powered by Servo Rack

(Both Motor Running)

Motor Speed - 500 Rpm.

Chart Speed - 5 cm/min

1 cm = 5 Amp.

BMB/AMP

3/2/93

FIG. 5.2

- C12 ANTENNA : ELEV. DRIVE

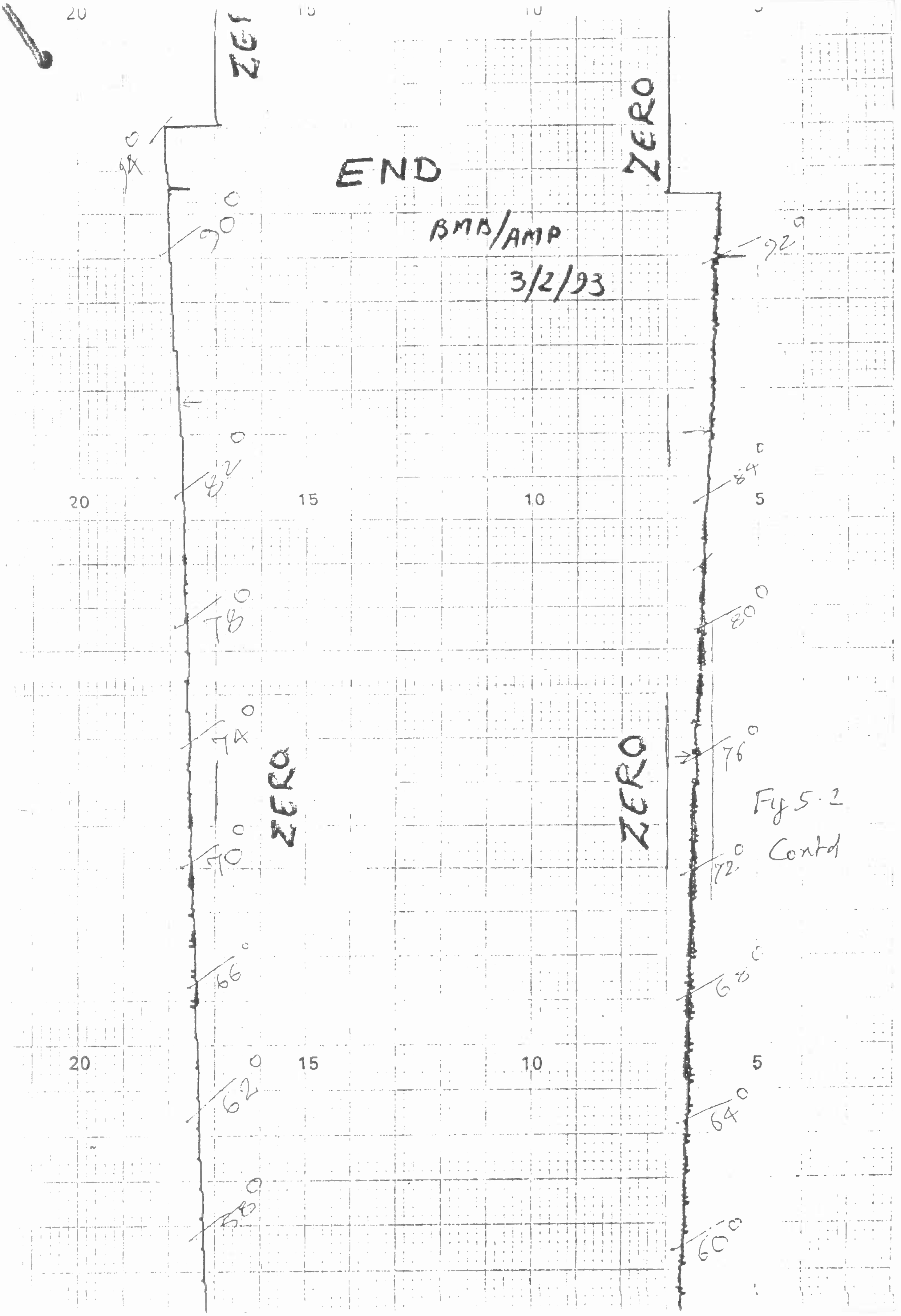
- BOTH MOTORS DRIVING (NO COUNTER TORQUE)
- 500RPM 20° → 90°

3/2/93 BMB

Blue - U
M

Black - Low
Moto

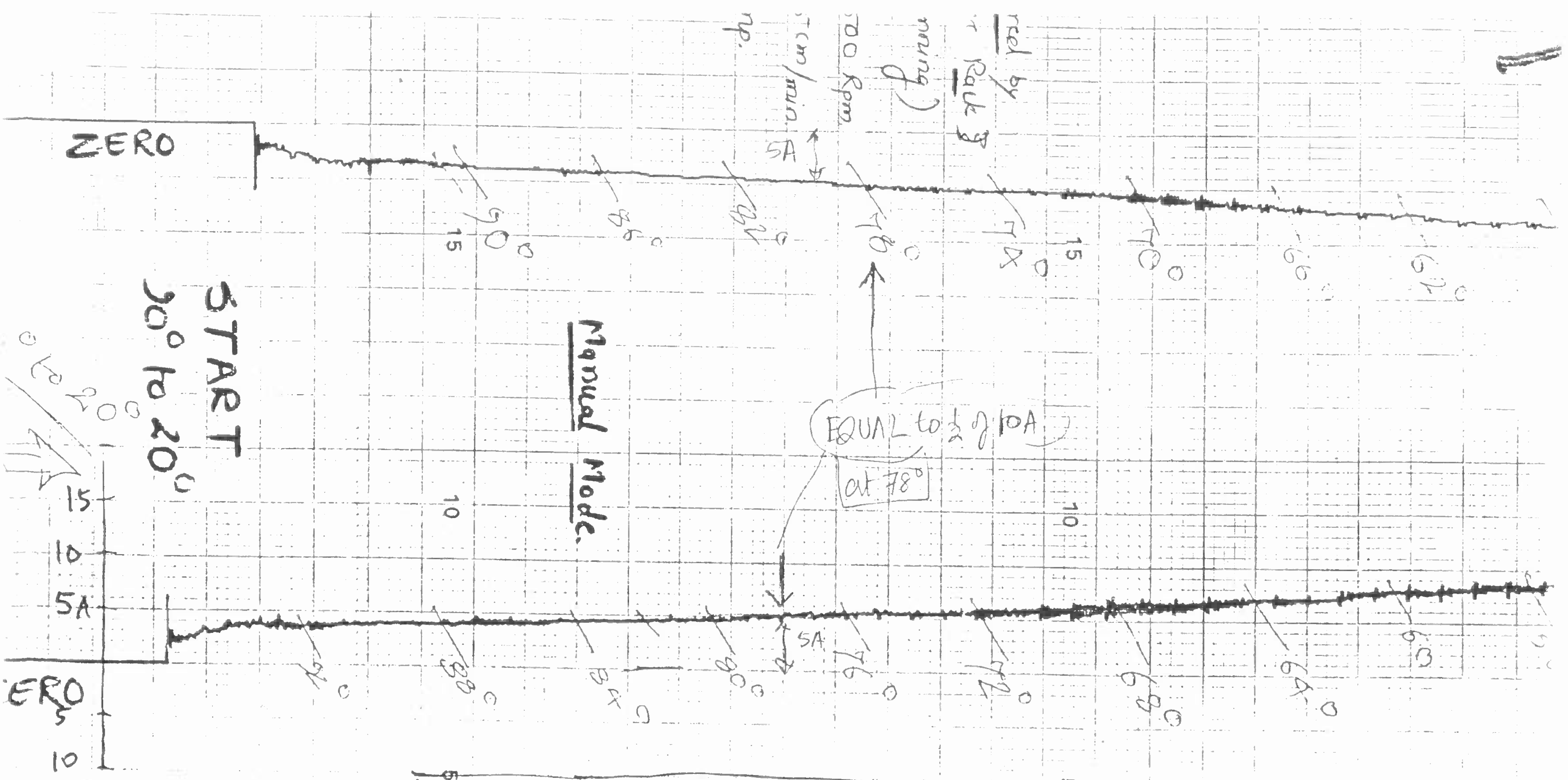
C12 START 20° to 90°



END

BMB/AMP
3/2/93

Fig 5.2
Contd



CB2

FIG. 5·3 BOTH MOTORS : NO Counter-torque

500 RPM : 92 → 20°

3/2/93
BMB

Fig 5·3

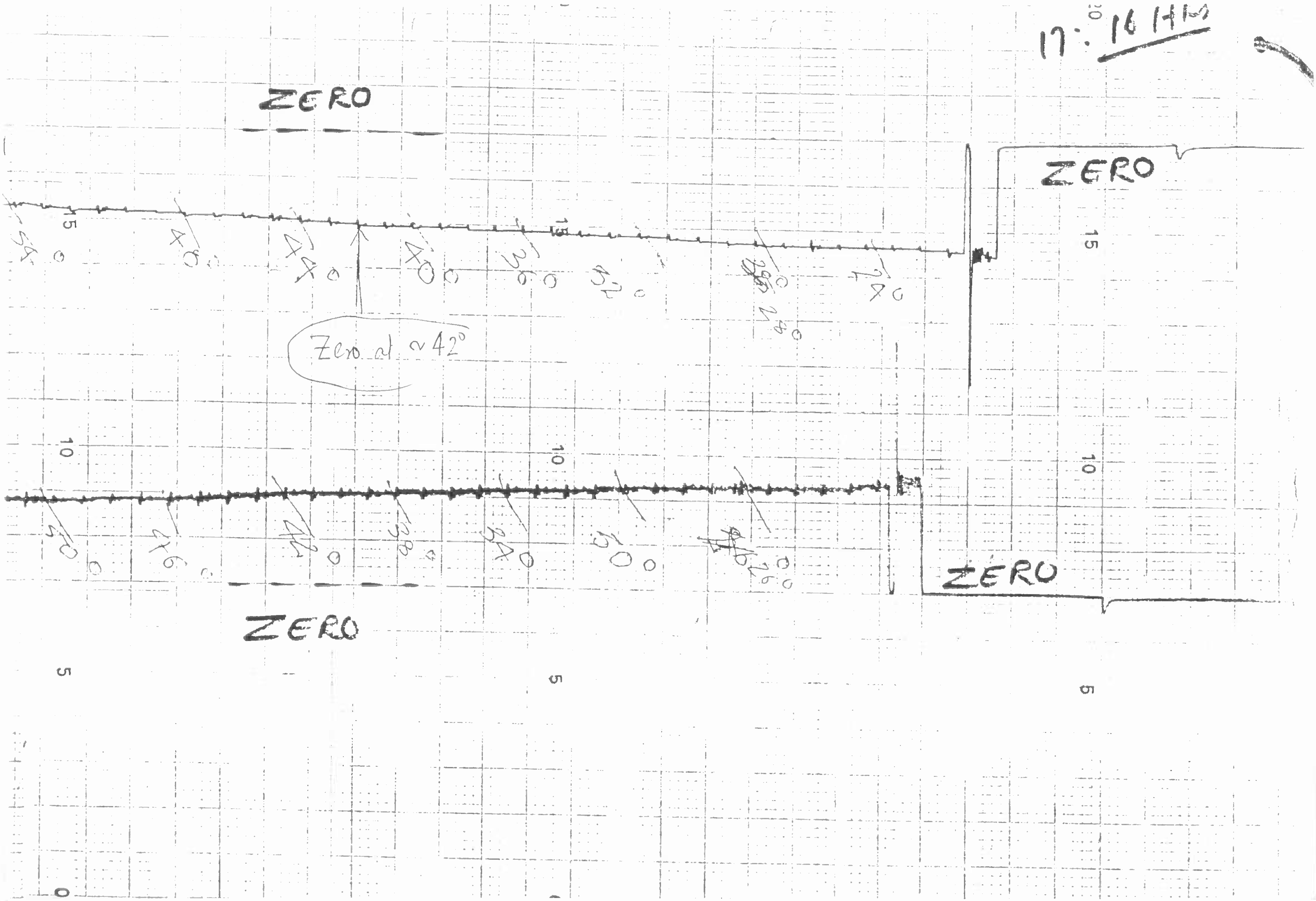
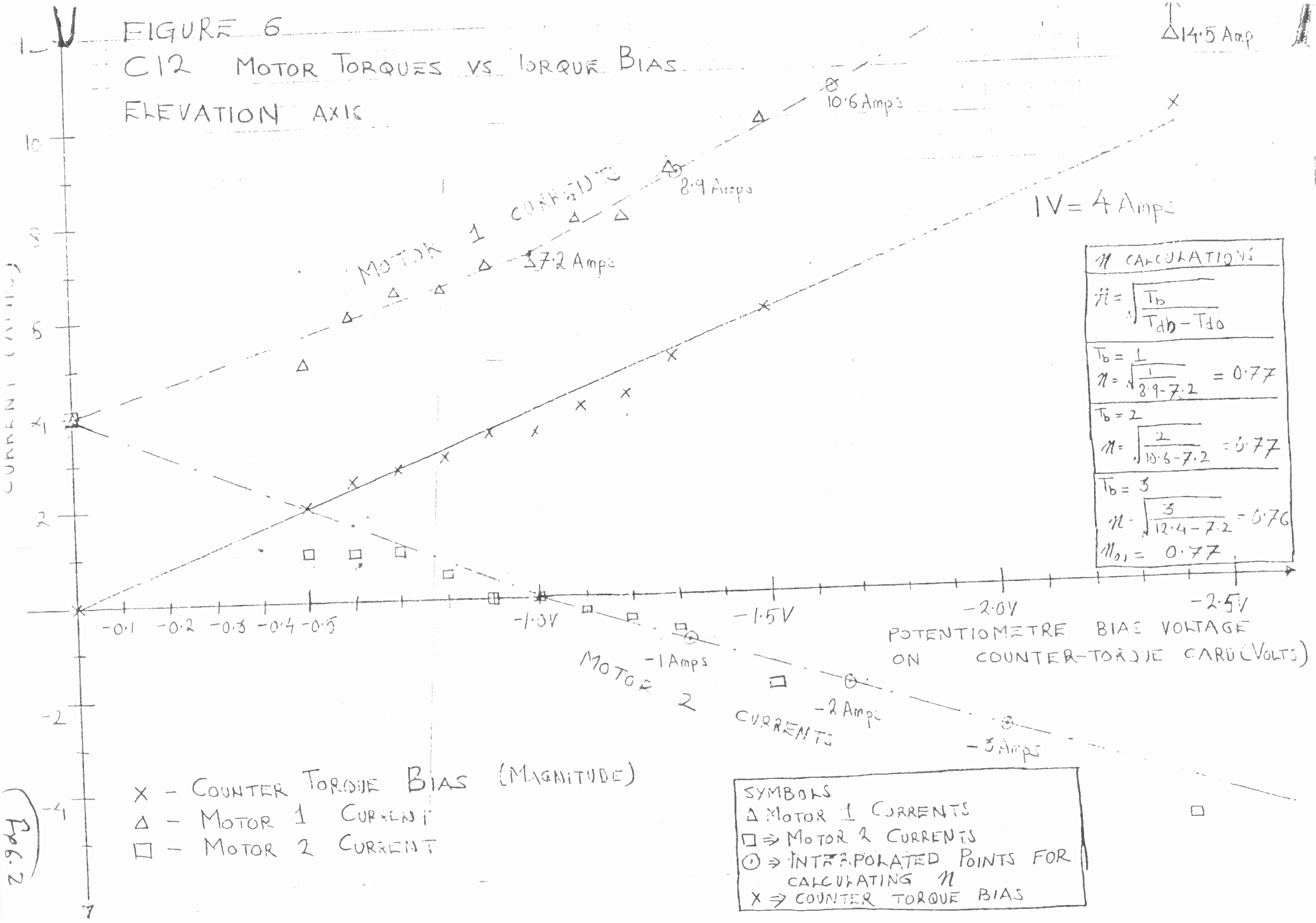

17:16 Hrs
ZERO
ZERO
52°
48°
44°
40°
36°
32°
28°
28°
24°
Zero at ~42°
50°
46°
42°
38°
34°
30°
26°
ZERO
ZERO
15
10
5
0

FIGURE 6

C12 MOTOR TORQUES VS TORQUE BIAS

ELEVATION AXIS



η CALCULATIONS

$$\eta = \sqrt{\frac{T_b}{T_{db} - T_{do}}}$$

$T_b = 1$

$$\eta = \sqrt{\frac{1}{8{\cdot}9 - 7{\cdot}2}} = 0{\cdot}77$$

$T_b = 2$

$$\eta = \sqrt{\frac{2}{10{\cdot}6 - 7{\cdot}2}} = 0{\cdot}77$$

$T_b = 3$

$$\eta = \sqrt{\frac{3}{12{\cdot}4 - 7{\cdot}2}} = 0{\cdot}76$$

$\eta_{01} = 0{\cdot}77$

Fig 6.2

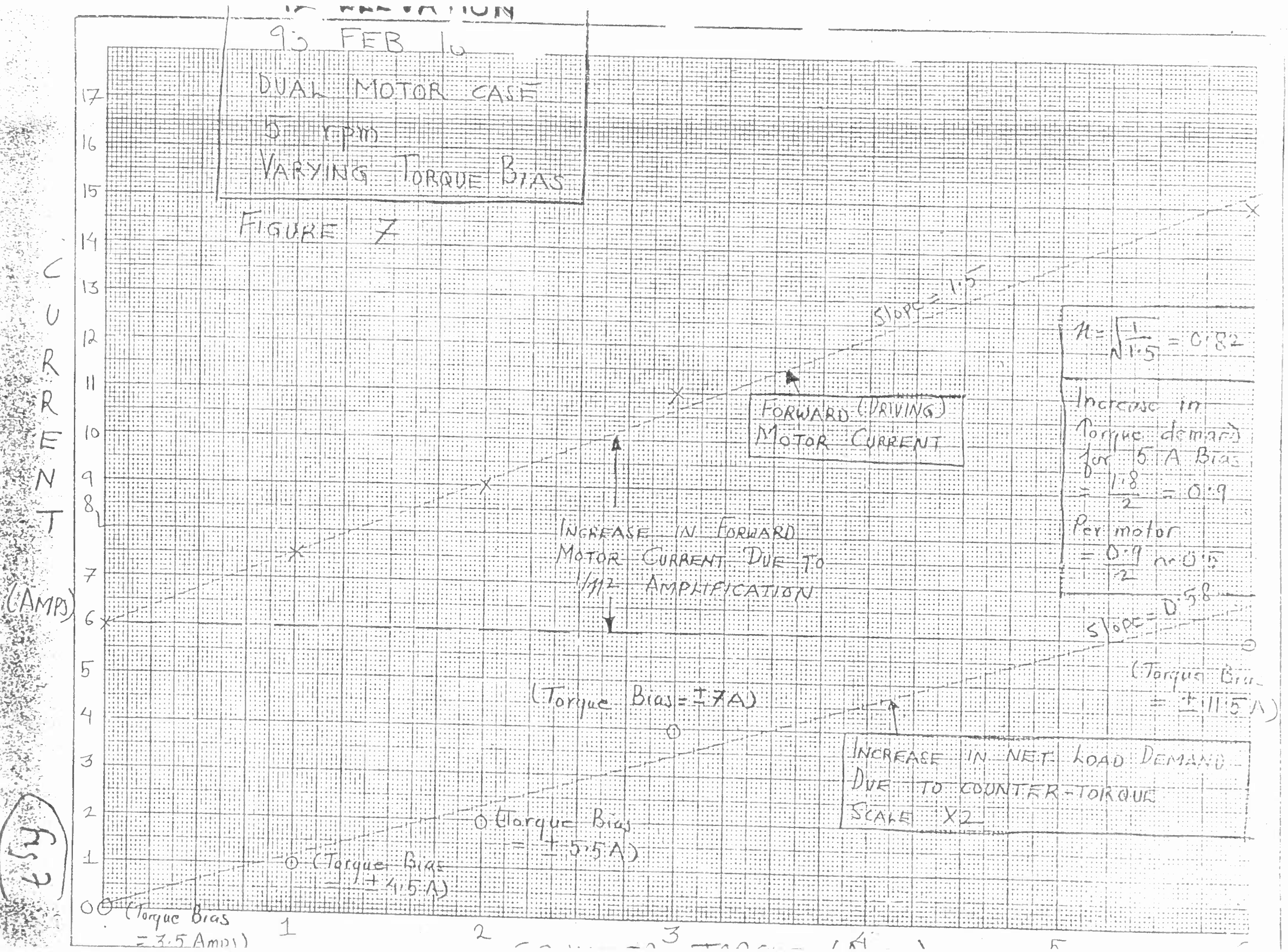
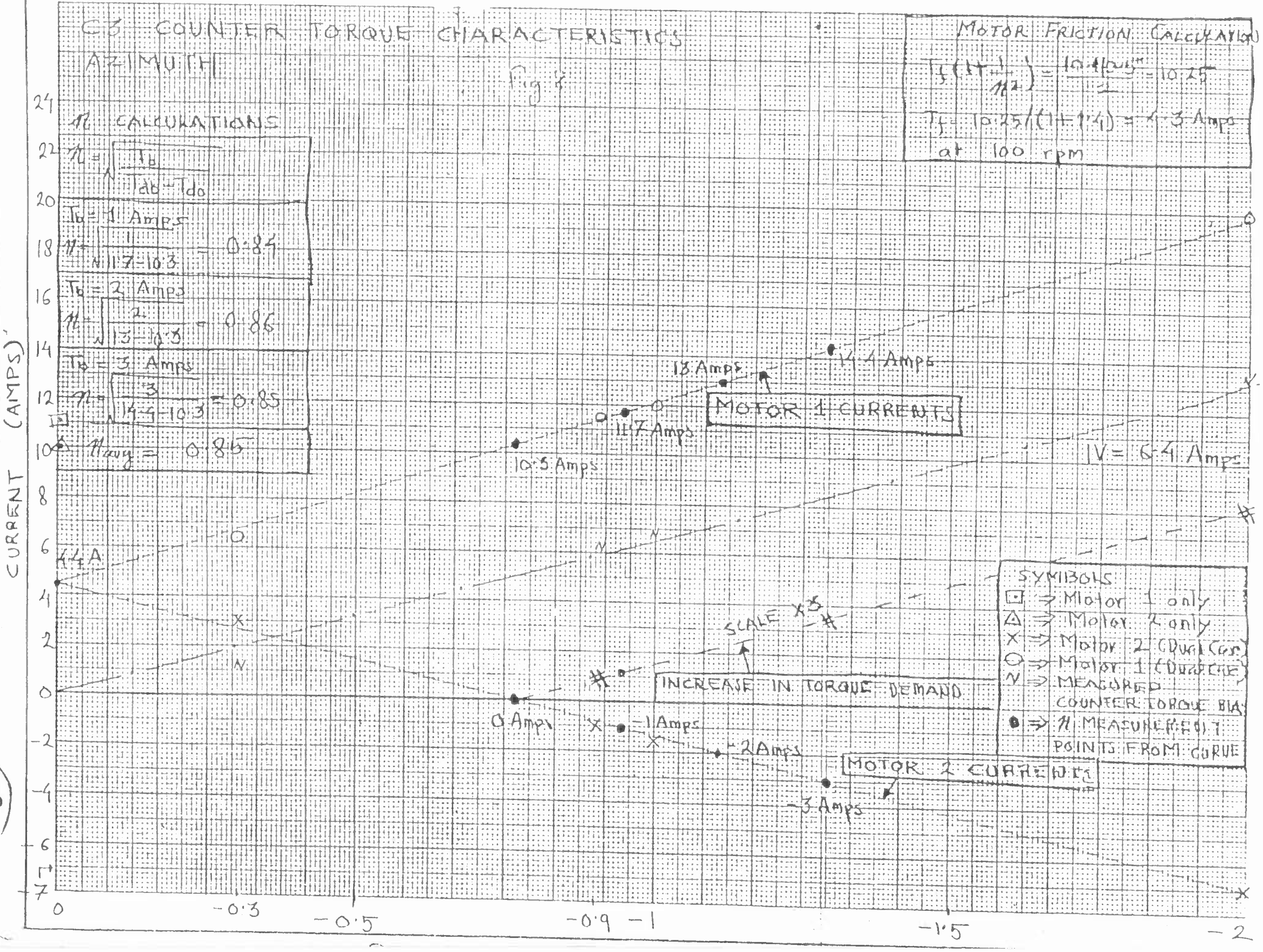


FIGURE 7

fig 7

FIG. 8

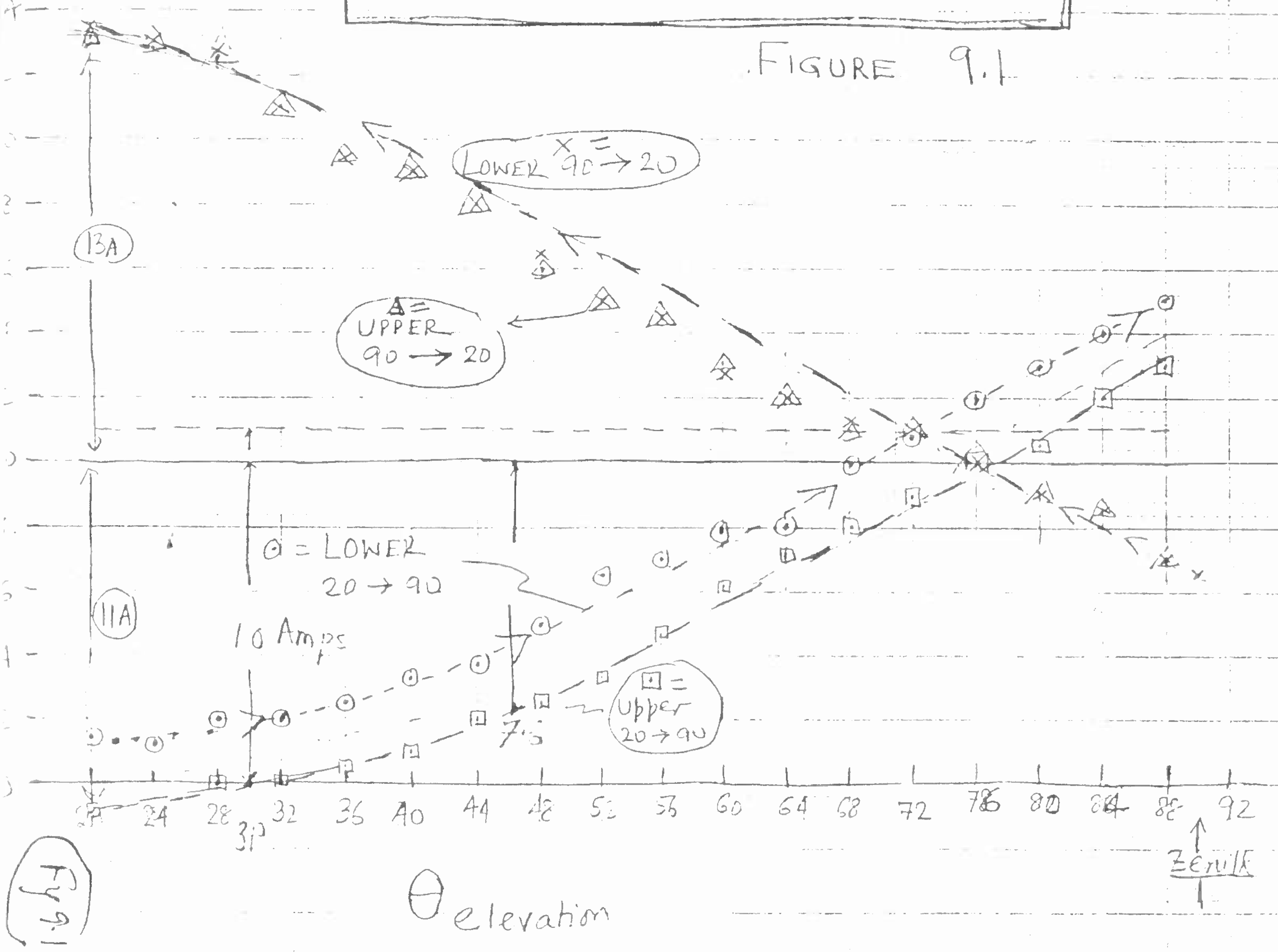

C3 COUNTER TORQUE CHARACTERISTICS
AZIMUTH
Fig 8
CURRENT (AMPS)
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-7
0
-0.3
-0.5
-0.9
-1
-1.5
-2
η CALCULATIONS
$\eta = \sqrt{\frac{T_b}{T_{db} - T_{do}}}$
T_b = 1 Amps
$\eta = \sqrt{\frac{1}{11.7 - 10.3}} = 0.84$
T_b = 2 Amps
$\eta = \sqrt{\frac{2}{13 - 10.3}} = 0.86$
T_b = 3 Amps
$\eta = \sqrt{\frac{3}{14.4 - 10.3}} = 0.85$
$\eta_{avg} = 0.85$
MOTOR FRICTION CALCULATION
$T_f\left(1 + \frac{1}{\eta^2}\right) = \frac{10.4 \text{ avg}}{2} \cdot 10.25$
$T_f = 10.25/(1 + 1.4) = \sim 3$ Amps
at 100 rpm
4.4 A
10.5 Amps
11.7 Amps
13 Amps
14.4 Amps
MOTOR 1 CURRENTS
IV = 6.4 Amps
SCALE X5
INCREASE IN TORQUE DEMAND
0 Amps
-1 Amps
-2 Amps
-3 Amps
MOTOR 2 CURRENTS
SYMBOLS
⊡ ⇒ Motor 1 only
△ ⇒ Motor 2 only
X ⇒ Motor 2 (Dual Cur)
○ ⇒ Motor 1 (Dual Cur)
N ⇒ MEASURED COUNTER TORQUE BIAS
● ⇒ η MEASUREMENT POINTS FROM CURVE

$\frac{1.5}{0.86}$ = 2·6

Battery

SINGLE MOTOR
C3 ELEVATION AXIS (OLD PINION)
DECEMBER 92

FIGURE 9.1



CALCULATIONS

① I_θ at 45° = $\frac{10+12}{2}$ = 11

$I_u \sin(76° - 31°) = 11$ amps

$I_u = 11/0{\cdot}707$

= 15·5 Amps

② $I_u(\sin(76-45)) = 7{\cdot}6$

$I_T/I_t = 7 \cdot 5$

I_u = 15·2 Amps

Ⓐ Torque Based on AV as given in ③

$T_{u\,(181)\,AV} = 15{\cdot}2 \times 0{\cdot}555 \times 25070 \times 0{\cdot}3$

= 16·77 Ton m

$W_u = \frac{15{\cdot}13}{4{\cdot}5} = 3{\cdot}7$ T

③ I_u at 23° = $\frac{11+13}{2}$ = 12

$I_u \sin(75 - 23°) = 12$

$I_u = 12/0{\cdot}8 = 15{\cdot}53$

Avg ① to ③ $I_{av} = \frac{15{\cdot}5 + 15{\cdot}2 + 15}{3}$

= 15·2 Amps

Fig 9.1

25.0/2 = 12·5

52

56

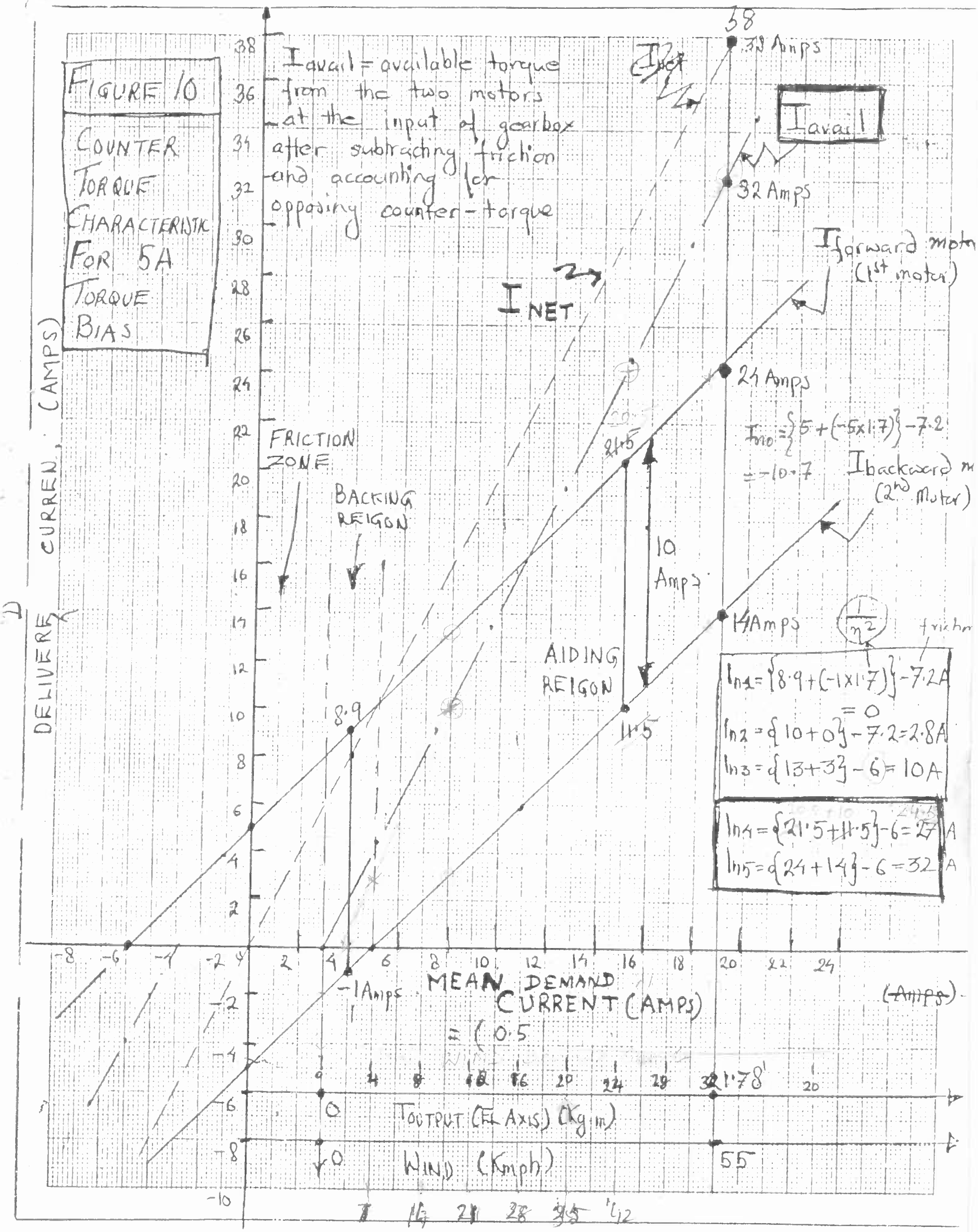


FIGURE 10
COUNTER TORQUE CHARACTERISTIC FOR 5A TORQUE BIAS

Fig 10