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Review of the Torque Values of the GMRT Servo Motors and Proposed Method of Measurement using Stopping Time.

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Extended Summary:

A**dequate torque value of the brakes** of any moving vehicles (cycle or motor bike or a car) or the GMRT antennas and their periodic adjustment or replacement is very important, since brakes get worn during operation.

(i). For the GMRT antennas, it is important to review torque values of the torques of the Servo motors that were specified during early 1990s. The required value of torques of the brakes of the Servo motors for resisting the survival wind velocity of 140km/h is calculated as 45 N-m for each of the 120 motors, rather than the present value of only 30N-m. From the data sheet of the Brushless Motor AKM73M, selected by the Servo group (data sheet provided to me Shri Sabhapathy),the Failsafe Holding static torques of the Brakes is 53 N-m, that is adequate. However the brakes are fitted at the backside of the Motors and it is not possible to measure the above torque, once the Motors are mounted on the Planetary Gear Boxes of the 45 m dishes, unless one introduces a special coupling between the Motors and the Gear Boxes.

(ii). Alternative to the special coupling, or even in that case, we may investigate whether measuring stopping times of the antenna from a relatively low speed, e. g. 100 RPM will provide a reasonable estimate of the static torques of the 120 nos. of the El and Az Motor Brakes, instead of the present manual basis every few months (2 for El and 2 for Az of the counter-torque system of each of the 30 antennas, every few months as it is time consuming).

In this Note, I discuss the following topics:

In Section 2 of this Note, a r*eview is made of the required Torque values of the Brakes of the El and Az motors*, particularly if the 30 nos. of the GMRT antenna do not get STOWLOCKED, by the time wind reaches 90 kmph during a severe storm or a squall. Very high winds do occur a few times during 15 March to 15 June and again during Sept. I have summarized the wind statistics of squalls earlier in some of the earlier Technical Notes (I plan to write a new Note summarizing the wind statistics again). During a SQUALL, the wind velocity can reach 140 kmph at a height of 10m with a probability of 65% in 50 years. Such a high wind has indeed been measured at the Pune airport some years ago. A value of 140kmph is the essential design requirement for the Pune region, according to the Indian Standard Institution: IS-875. During the design of the GMRT, we considered survival wind velocity of only 133 kmph for a 3 second gust. In 1990, TCE specified a value of 40 N-m for the brakes **bu**t M/s Industrial Drive were able to supply brakes of only 32 N-m for the brakes made by their sub-contractor STROMAG, because of our requirements of a manual drive at the input of the motors that we could use in emergency AND that we could use for measuring torque of motors. The required torque values of the brakes were calculated by me as 31.5 Nm for El motors and 39.5 Nm for the Az motors in 1996 for 133 kmph. (GTN/Ant-Mech brakes/GS/960315/R00117). For the new, Brushless Motors, we should multiply the required torque values for El and Az brakes by a factor

$(140/133)^2$ = 1.108. I have given the required Torque values for 140 kmph in the revised document: (GTN/Ant-Mech brakes/GS/960318/R00117-Rev1). As I conclude that it is important to specify a value of Brake Torques of 45 N-m for each of the 120 motors, rather than the present value of only 30N-m, in case antennas do not get stowlocked (which must be ensured in any case). As need not be overemphasized that we should be conservative regarding the required value of Brake Torques

In Section 3, is discussed possibility of m*easuring Brake Torques by* an alternate method, instead of the present manual basis, **by measuring stopping time after the Brakes are applied**. This method was proposed by me in 1997 and also tested in 1997: (see attachment: GTN-ANT-Brakes/GS/970220). We could not implement this method routinely at that time, as the data communication between the antennas and the control room was rather slow, being serial, and hence it was not possible to measure values of the current (corresponding voltage) of each of the four Tachos of each of the 30 antennas (or the readings of the elevation and azimuth encoders) **with the required sampling time of 1ms or better if brakes are applied only when the antenna speed becomes low, say 50 RPM**. With the new control and monitor system it should be possible to record values of the currents of the Tachos at ~ 1ms or better, each time brakes are applied or only periodically, as practical. Thus values of the brake torques could be checked by the GMRT telescope operators from the Control Room after developing a relatively simple programme.

1. Introduction:

I discussed recently with Shri Kale about the status of the **Torque values of the brakes** made by STROMAG for the 120 DC motors of the SERVO system of the GMRT. He told me that measurements are being done routinely every few months for all the 30 antennas using a torque wrench. I have requested him to send the data for the last few years so that I would be able to compare values measured in 1997; I have also requested to inform as to how many brakes have been replaced during the last 5 years, if any. The manual checking is indeed time consuming (only 8 out of 30 antennas every month) and further has the danger of water entering if sudden rain takes place during checking. During mid 1990s, I was not happy with the manual method of measurements of Brake Torques by applying a load, and therefore, I proposed an alternate method in 1997, instead of the manual basis, **by measuring stopping time after the Brakes are applied** and it was tested also in 1997 and gave results comparable to manual measurements. We could not implement this method routinely at that time, as the data communication between the antennas and the control room was rather slow., being serial, and hence it was not possible to measure values of the current (corresponding voltage) of each of the four Tachos of each of the 30 antennas **with the required sampling time of 1ms or better**.

Originally, the capacity of the DC motors of the Servo system was specified as 6 HP and brake torque of 40kgm by TCE based on calculated values of the torque applied on 45m dishes by the wind and gear ratio. I reviewed their calculations, considering safety of the GMRT antennas, in case of occurrence of very high velocity of the wind. We had also specified value of the survival

wind as 133 kmph, based on wind statistics using IMD data for Pune (Kapahi and Swarup 1987). The ISI code IS 875 came soon after but we did not use it. We purchased Industrial Drive motors of 6 HP, with brakes made by STROMAG that were economical but brakes had capacity of only 30kgm that was considered acceptable at that time as we were considering automatic stowlocking system. It may be noted that torque applied on the 45m dishes by the wind is (i) maximum for the Elevation axis when the dishes are pointed towards the zenith (El. 90 degree) and (ii) maximum for the Azimuth axis when the dishes are pointed towards the horizon.

In Section 2 of this Note are discussed the required values of the Brake Torques for the Elevation and Azimuth Motors based on the Wind Torques for survival wind velocity taken from the TCE structural design report by TCE. In Section 3, is discussed a proposed method of determining values of the brake torques by measuring stopping time after the Brakes are applied. Conclusions are given in Section 4 and references in Section 5.

2: Required values of the minimum 'rated Torques' and of 'Brake Torques' of the GMRT Servo Motors

2(a) BRAKE TORQUES:

The calculations giving the required Brake torque values are given in the attached document :(GTN/Ant-Mech brakes/GS/960315/R00117-Rev1). Here, we give a summary.

The required value of the Torque of each of the two Brakes of the two Servo motors, T_b, of the GMRT motors is given by

$$T_b = 0.5\,[T_i\,(v) / N]\,\eta, \qquad (1)$$

where, the factor 0.5 arises as the antenna torque is shared by two motors of the counter-torque system of the Servo drive, T_i = torque applied on the elevation (El) or azimuth (Az) axis of the 45 m dishes by the value as determined by the structural group of TCE for the expected survival wind velocity, v, N is the overall gear ratio between the El and Az axis of rotation and the servo motor, and η is the overall efficiency of the gear trains (bull gear, its pinion and the main gear box for the El axis; and the slew ring gear, its pinion and the main gear box of the Az axis).

For the Elevation axis of the GMRT, N = 25162 and for the Azimuth axis of the 45m dishes, it is 18963 (TCE report vide letter G18/664-dt29/07/1990- copy with me). Gear train efficiencies have been found to be about 0.78 +/- 0.02 for both cases by Swarup et al. (1993) and by Joshi et al. (1994). Based on detailed structural design, Yogi of TCE calculated torque due to the wind loads, T_i (El) = 206000 kgm and T_i (Az) = 186 000 kgm for the assumed value of survival wind as133 kmph. As described in Summary, we should now consider survival wind velocity as 140 kmph, whence we should multiply the above T_i values by $(140/133)^2 = 1.108$. Hence, we have calculated the required Brake Torques as follows:

For Elevation: value of T_b (140 kmph) *for **each** of the two brakes* is given by

$$T_b\,(El) = 0.5x\,[(140/133)^2 \times (206000/25162) \times 9.81 \times 0.78]\ \text{N-m}$$

$$= 34.70\ \text{N-m} \qquad (2)$$

For Azimuth:: value of T_b (140 kmph) for ***each*** *of the two brakes* is given by

$$T_b\,(Al) = 0.5x\,[(140/133)^2 \times (186000/18963) \times 9.81 \times 0.78]\ \text{Nm}$$

$$= 41.58\ \text{N-m} \qquad (3)$$

In 1990, TCE specified a value of 40 Nm for all the brakes. However, M/s Industrial Drive were able to supply brakes of only 32 Nm for the brakes made by their sub-contractor STROMAG, because of our requirements of a manual drive at the input of the motors that we could use in emergency AND that we could use for measuring torque of motors.

The required torque values of the brakes were calculated by me for the wind velocity of 133 kmph as **31.5 N-m for El motors and 39.5 N-m for the Az motors in 1996** (GTN/Ant-Mech brakes/GS/960315/R00117). In that Report, I had considered gear box rations as 25000 for El and 18000 for Az. Now I have considered the correct values from a TCE report with me. Shri Kale will be able to verify the same

Table 3 of the above ITR00117 gives observed values of Brake Torques of 15 nos. of the Central Square of the GMRT. For Elevation Brakes, the observed the average values of the two motors varied from 28 Nm to 32 Nm but only 24 N-m for C9 antenna. For Az brakes, the average values of the two motors varied from 30 Nm to 35N-m.

It is clear that the existing Brakes are not safe whereby the antennas will start rotating widely if a storm of 140 kmph occurs in future (cannot be ruled out). Hence, it is NECSSARY that antennas are parked at zenith if average value of wind over 1 minute exceeds 50 kmph.

Since I have calculated, as above, the required values of the Brake torque for 140 kmph, as 35 N-m for El and 42 N-m for Az, I conclude that it is advisable to specify a value of **static** Torques of at least 45 Nm for the Brakes of all the Brushless Motors and if possible for the Brushless motors already identified, as even 50 Nm considering their wear out over 10 or 20 years.

2(b) RATED TORQUE of the MOTORS:

The existing Planetary Gar Boxes of all the 120 motors are safe for rotation, considering both static and dynamic factors, ONLY for wind torques applicable at wind velocities <100kmph. For higher winds, no rotation is expected and hence only static factors are considered.

From Eqs. (2) and Eqs. (3), we find that at 100 kmph, the required values of the Motor Torques should be at least 17.7 Nm for El motors and 21.21 Nm for the Az motors. Multiplying by a safety factor of say 1.2, we calculate Rated Torque of 21.24 for El and 25.45 Nm for Az,

Shri Suresh Sabhapati has informed me that for the Brushless Motors selected by him are from Kollmorgen as follows:

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1) GMRT BL motor operation mains Voltage is 400V AC,

2)Torque of AKM73M BL motor at 1500 rpm :

Torque - 33.8 N-m
Power - 5.31 Kw
Standstill torque - 42.0 N-m
Peak Torque - 113 N-m

3) The cost of EMCO make brake assembly are around Rs25000/-per piece. But we may need only to replace the brake 'discs' which wear out after a number of years of use. The cost of 'disc' alone will be around Rs5000/-

The Original ID brakes may be more expensive than EMCO make brakes by a factor of 5 or 6.

I find Rated Torque as 33.8 N-m as satisfactory. For the AKM7 series of Brakes according to a Catalogue sent to me by Shri Sabhapati the Static 'Holding torque' of their Brakes is 55N-m.It is not clear as to what is the Brake torque of Motors purchased by the GMRT servo group. As shown below.

Failsafe, Holding Brake

The holding brake is designed to provide static holding torque to the motor shaft with the brake coil de-energized. The brake must first be released (coil energized) prior to commanding motor rotation as determined by its drop-out time. The brake is intended for holding or "parking" of a stationary motor. It may be used for a limited number of emergency stop conditions, however such use will eventually cause wear, leading to eventual malfunction of the brake.

AKM Motor Brake Options

Motor Family	Minimum Static Totque @120°C		Weight		Power Consumption @24V, 20°C	Current @24V, 20°C	Inertia		Closing Time (engage)	Opening Time (release)	Backlash③	
	N-m	lb-in	Kg	lbs	Watts +/- 7%	ADC	$kgcm^2$	$lb\text{-}in\text{-}sec^2$	msec	msec	Maximum deg.	Typical deg.
AKM2	1.42	12.6	0.27	0.59	8.4	0.35	0.011	0.97E-05	18	20	1.01	0.46
AKM3	2.5	22.1	0.35	0.77	10.1	0.42	0.011	0.97E-05	10	25	1.01	0.46
AKM4	6.0	53.1	0.63	1.39	12.8	0.53	0.068	6.02E-05	15	35	0.81	0.37
AKM5	14.5	128	1.1	2.42	19.5	0.82	0.173	1.53E-04	15	80	0.71	0.31
AKM6	25	221	2	4.4	25.7	1.07	0.605	5.35E-04	20	105	0.51	0.24
AKM7	53	469	2.1	4.62	35.6	1.48	1.644	1.46E-03	35	110	0.44	0.20

1. Contamination of the motor internal compartment by oil or other foriegn materials will result in failure of the brake. Check the suitability of motor sealing for the working environment.
2. Operating Voltage: 24 VDC +/- 10%.
3. Maximum backlash is calculated using worst-case tolerancing, and typical backlash is calculated using statistical tolerancing.

3: Measurement of Brake Torques

For the existing Industrial Drive Motors of the Servo System of the GMRT 45m dishes, torques of the Brakes are measured periodically by applying a torque at the input of the motors. I understand that measurements are done for at least 8 antennas every month. It is a cumbersome procedure as one has to climb up to the elevation platform, open waterproof covers and then make measurements.

Further, I understand that for the new Brushless motors, the drive shaft of the motor does not extend towards the input side. Hence, it has been proposed to connect a coupling between the motor and the input shaft of the Planetary Gear boxes, that is likely to be cumbersome and costly.

I discuss in this Section, the possibility of m*easuring Brake Torques by* an alternate method, instead of the present manual basis, **by measuring stopping time after the Brakes are applied**. This method was proposed by me in 1997 and also tested in 1997: (see attachment: GTN-ANT-Brakes/GS/970220). We could not implement this method routinely at that time, as the data communication between the antennas and the control room was rather slow, being serial, and hence it was not possible to measure values of the current (corresponding voltage) of each of the four Tachos of each of the 30 antennas **with the required sampling time of 1ms or better**. With the new control and monitor system it should be possible to record values of the currents of the Tachos at ~ 1ms or better, each time brakes are applied or only periodically, as practical. Thus values of the brake torques could be checked by the GMRT telescope operators from the Control Room after developing a relatively simple programme.

3.1. A Relation for stopping time of the GMRT antenna (

When brakes are applied, we have the following relation for the rotation of the antenna:

$$I\,(d^2\theta/d^2t) = T_B\ , \qquad (1)$$

where I is the inertia, $(d^2\theta/d^2t)$ is the deceleration and T_B is the brake torque. Therefore,

$$I\,(d\theta/dt) \text{ at } t = 0 = T_B\,\Delta t, \qquad (1A)$$

where, $(d\theta/dt)$ is the initial velocity,v, final velocity being zero and Δt is the time taken for antenna to come to zero speed. Therefore,

$$\Delta t = [I(kgm^2) \text{ x vel (rad/sec)}] / [9.81 \text{ x } T_B(kgm)] \qquad (2)$$

3.2. Measurements

On 20th Februrary, 1997, measurements were done of the stopping time for the C2 antenna using an Industrial time by Shei Ajit Kumar, Ms. Gauri and Shri Hotkar under my guidance by measuring the Tacho output of the motors. Results are given in (attachment: GTN-ANT-Brakes/GS/970220). Here I present a summary and suggestions for further work.

We applied brakes for the El drive, when the antenna speed was about 400 RPM. It was seen that the Tacho output firstly decreased gradually and then decreased rapidly in a linear way as expected from Eq. (1A), (see Figs in the above attachment: one of those is reproduced here as Fig. 1).

This behavior was explained by Shri Hotkar as follows: (a) First the output voltage of the Servo system is disconnected from the motor and the resulting reverse current gets discharged through the diodes to the Mains, explaining the slow decrease of the speed. (b) after sometime, the Servo system applies the Brakes and the speed decrease linearly (Eq. 1A).

3. 3. Comparison of the calculated and measured values

3.3.1: Elevation Brake Torques: stopping time

For the Elevation gear system, the *Inertia as seen at the input of the Elevation motor* is given by

$$I_m = \{[I_{ant\text{-}el.axis}/ (N_{total})^2] + [2x\ I_{pinion}/ (N_{ElGearBox})^2 + 2 \text{ x } I_{gearboxinput+motorshaft}, \qquad (3)$$

Values of the above parameters were taken from the TCE design reports; for the motor shaft from the motor data sheet. Hence, we get

$$I_m = \{ [7.33 \times 10^6/25000^2] + [2 \times 1600/ 825^2] + 2 \times 0.064\}$$

$$= 0.144 \text{ kgm}^2$$

The torque of the brake of the two motors together for the C2 antenna was measured by the mechanical engineers = 53 Nm = 53 kg m sec^{-2}. The velocity of the driving El. motor was observed as 394 rpm when the antenna was stopped and brakes applied. Therefore, the calculated value of the stopping time using Eq. 2 is given by

$$\Delta t(s) = [I(\text{kgm}^2) \times \text{vel (rad/sec)}] / [9.81 \times T_B(\text{kgm})]$$

$$= [0.144 \text{ kgm}^2 \times (v(\text{rpm}) \times 2\pi/60\text{sec})]/T_{b(}\text{Nm})]$$

$$= [0.144 \times 394\text{rpm} \times 2\pi/60]/53$$

$$= 112 \text{ ms}$$

From Fig. A2-1 of (attachment: GTN-ANT-Brakes/GS/970220)., the measured value of stopping time was determined as 109 ms (see Fig. 1 of this Note). Hence, it is seen that the stopping time provides a reasonable estimate of the Brake torque of two El motors of C2 antenna.

We may note that motors are stopped when the speed decreases to 50 rpm and only then brakes are applied. Applying Brakes at higher motor speed will wear them out (see Attachment GS/STROMERG). Hence, the estimated values of the Brake torque may have higher errors. I suggest measurements be made for the 50 RPM and 100 RPM cases as a trial.. One could consider higher RPM value once a month only, that may require developing suitable software by the SERVO-System group.

3.3.: Azimuth Brake Torques: Stopping Time

For Azimuth gear system, Inertia at the motor shaft is given by

$$I_m = \{ [9.08 \times 10^6/18000^2] + [2 \times 6400/ 1500^2] + 2 \times 0.064\}$$

$$= 0.162 \text{ kg m}^2$$

Brake torques measured for the 2 Az motors was found to be 55Nm. Therefore, the calculated stopping time is given by

$$\Delta t(s) = [I(\text{kgm}^2) \times \text{vel (rad/sec)}] / [9.81 \times T_B(\text{kgm})]$$

$= [0.162\ kgm^2 \times (v(rpm) \times 2\pi/60sec)]/T_{b(}Nm)]$

$= [0.162 \times 303\ rpm \times 2\pi/60]/55$

$= 93$ ms.

The measured value was 94 ms.

Hence, it is seen that the stopping time provided a reasonable estimate of the Brake torques of 2 Az motors of C2 antenna. I may add, however, that another experiment done on the same day when the brake got applied at 354 rpm gave stooping time of 132 ms instead of the calculated value of 93 ms. Reason for discrepancy was not investigate. Therefore, it is recommended that 2 3 measurements should be done and reasons for any discrepancy may be investigated.

4: Conclusion

As found in the investigation made in 1997, m**easuring stopping time after the Brakes are** applied provides an estimate of the torques of the Brakes of the GMRT servo motors.

It is recommended that the SERVO System group may do a similar experiment as was done on 20 th Feb. 1997 by me, Ajit Kumar and others. At that time, we used an Industrial PC at C2 antenna. The SERVO group may investigate possibility of the measurements to be made from the Control; Room using the new Control and Monitoring System that has been installed on a few antennas.

5. References

Kapahi, V.K., and Swarup, G., “Specifications of extreme wind speed at Nayangaon for the GMRT antennas, TIFR Centre, Bangalore, June 1986 (copy with me: I plan to make a report”.

Swarup, G.; (GTN/Ant-Mech brakes/GS/960318/R00117); gives required torque values of the brakes that were calculated as 31.5 Nm for El motors and 39.5 Nm for the Az motors in 1996 for 133 kmph wind velocity.

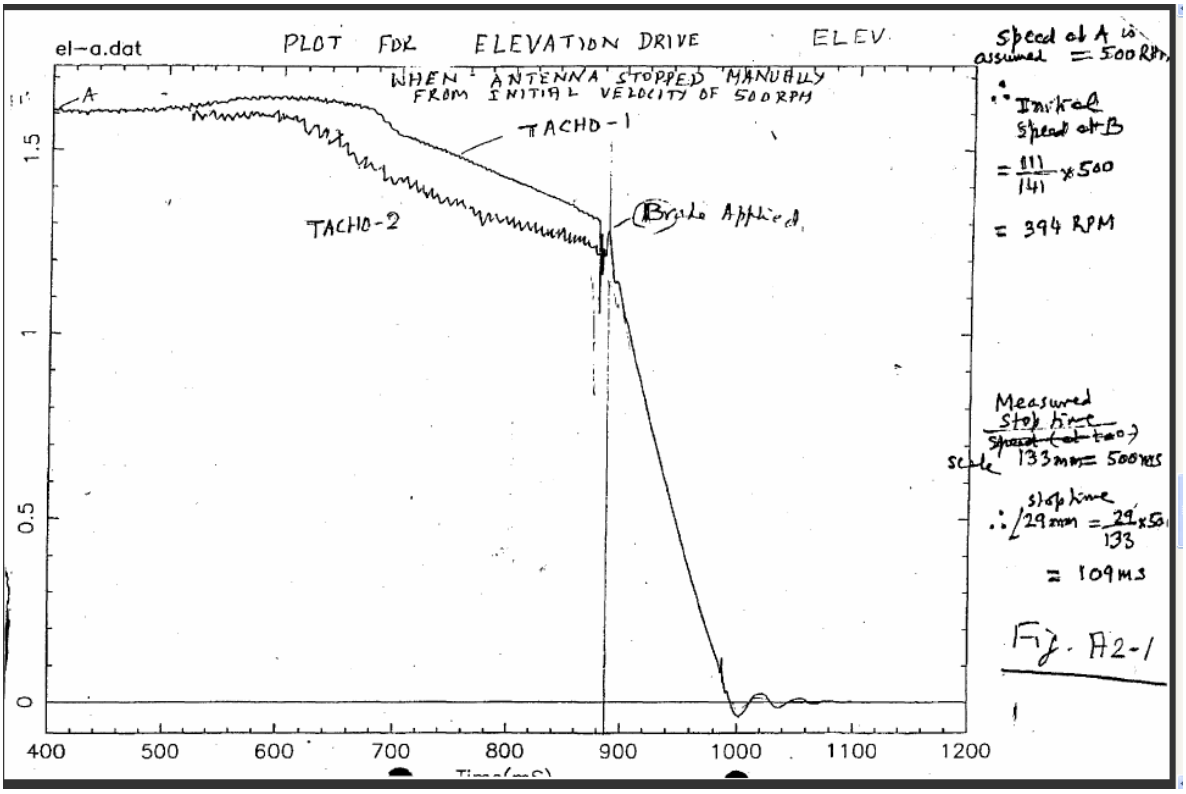
Swarup, G. GTN-ANT-Brakes/GS/970220; describes possible measurement of Brake Torques (instead of the present manual basis), by measuring stopping time after the Brakes are applied.

Swarup, G., GTM/ANT/BRAK/GS/961115; Tech. Memo, GMRT Brakes, Visit to M/s Stromag Inc. Ohio.

TCE Structural Computer outputs 1991: NCRA library: Red bound books in an almirah.(TCE.G18/DR/CAL/153-DISHCRAD, dated 18/20 Feb. 1990 (final space truss pin-joint analysis)

Figures: Copied from Swarup, G. GTN-ANT-Brakes/GS/970220

Fig. A2-1



X axis: Time in millisec; Y axis: Tacho Voltage proportional to Motor Speed: speed when brake applied =394 RPM; time for stopping rotation = 109 ms

Estimate of Brake Torques of two El motors of C2 antenna by measuring time for stopping after brakes are applied. (Fig. A2-1 of GTR-ANT-Brakes/GS/ 970220).

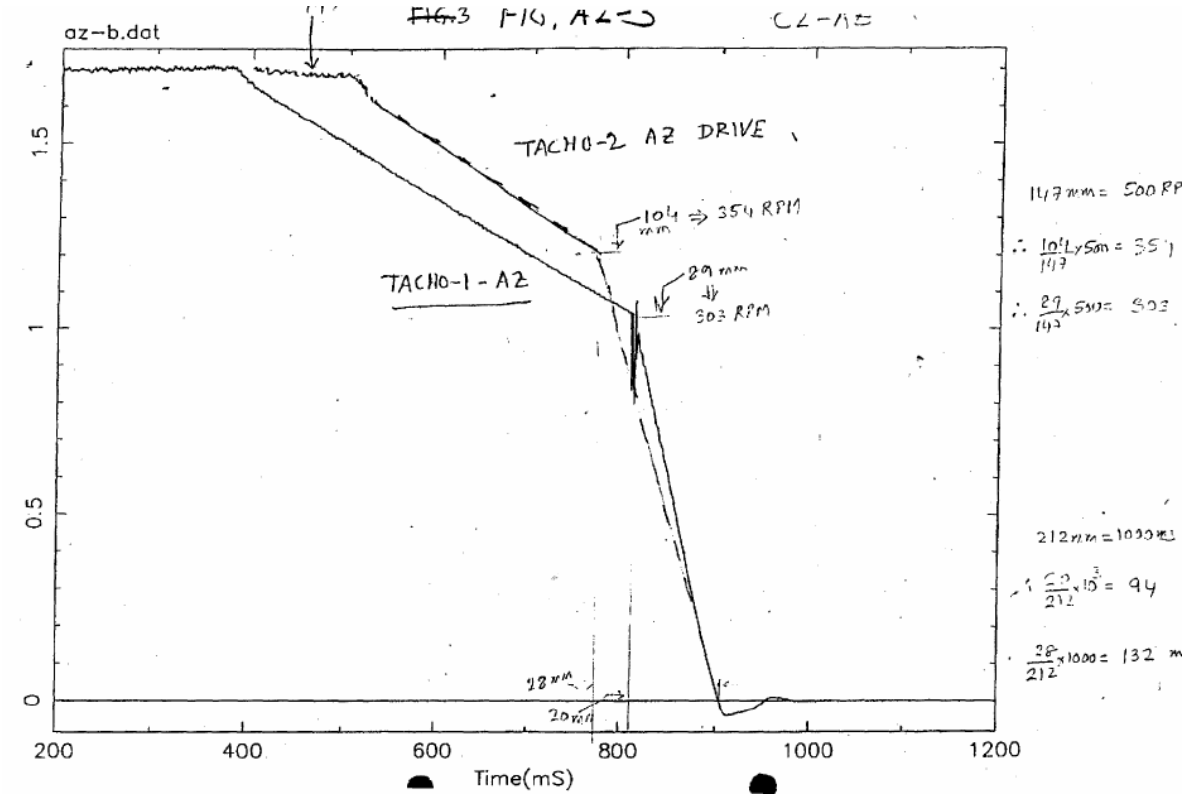


Fig. 2: X axis: Time in millisec; Y axis: Tacho Voltage proportional to Motor Speed: speed when brake applied =303 RPM.; time for stopping rotation = 94 ms

Estimate of Brake Torques of two El motors of C2 antenna by measuring time for stopping after brakes are applied. (Fig. A2-3 of GTR-ANT-Brakes/GS/ 970220).