Summer Training Project Report

On

BRUSHLESS DC MOTOR AND DRIVE

Completed at

Giant Metrewave Radio Telescope,
National Centre for Radio Astrophysics,
Tata Institute of Fundamental Reserch.
Khodad , Pune – 410504
Maharastra , India

By

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ACKNOWLEDGEMENTS

I am very pleasure to express my deep gratitude and immeasurable thanks to my guide **Mr. Suresh Sabhapathy** who accepted me as STP student. I am highly indebted to him for providing me this opportunity to carry out such innovative work during this period. He has encouraged to gather a lot of knowledge and experience to utilize them positively in GMRT.

I am also highly grateful to Honorable Center Director NCRA-GMRT **Mr. S. K. Ghosh**, Chief Scientist **Mr. Yashwant Gupta**, and **Mrs. N.S.Deshmukh** the STP coordinator of GMRT for giving me this great opportunity to work in GMRT.

My work would not be completed without the help of the members of GMRT Servo Group. I would like to thank all of them. And I also want to give a lot of thanks to **Srinivasrao Beera** who helped me to make my work easier and by teaching me to handle this equipments in different technique.

I am also highly obliged to **Mr. Somak Bhattacharyya** and to the Head of the Dept. of Electronics and Communication of my college **Mr. Santu Sarkar** who had recommended my candidature to **Mr. Suresh Sabhapathy**.

Last but not least a special thanks for my family for providing me constant encouragement to carry out this work in GMRT.

Tania Mitra.

ABSTRACT

The project named "GMRT Brushless Motor and Drive" is done to upgrade the present servo system of GMRT. The accurate positioning of the rotor can be achieved by pulse width modulation technique by varying the speed of the dc motor. This position controller used in GMRT Rayshed named PMAC is a 17 bit position rotary encoder, part of position loop, driven by a software PEWIN32PRO. This controller is programmed to control the position and the velocity feedback by PLC program.

The testing and tuning of this motor have been done by using the software programs of PEWIN32PRO to drive the motor in clockwise and anticlockwise direction according to the requirement of the speed and position.

Date : 30th July,2010
Place :Khodad ,Pune

CERTIFICATE

This is certify that Ms. Tania Mitra of Academy of Technology (WBUT) West Bengal has successfully completed a project on "GMRT Brushless Motor and Drive" at Giant Metrewave Radio Telescope Observatory, National Centre for Radio Astronomy, Khodad, Pune, under my guidance.

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INTRODUCTION

1.1 Brief about GMRT

Giant Metrewave Radio Telescope (GMRT) located at Khodad, 80 km north from Pune in India. It is the world's largest array of radio telescope at meter wavelength. It is operated by National Centre for Radio Astrophysics (NCRA), a part of Tata Institute of Fundamental Research(TIFR), Mumbai. A nearby town is Narayangaon on Pune – Nasik highway, 15 km from GMRT.

GMRT consists of 30 fully steerable giant parabolic dishes of 45m diameter each spread over distance of upto 25km. this is unique setup for astronomical research using metrewave length range of radio spectrum. At high frequencies the study of universe can easily be done. But in so high frequency RF noise is also high in other country, but in India this RF noise level is comparatively low. Thus it is one of the most challenging program to Indian scientists and engineers.

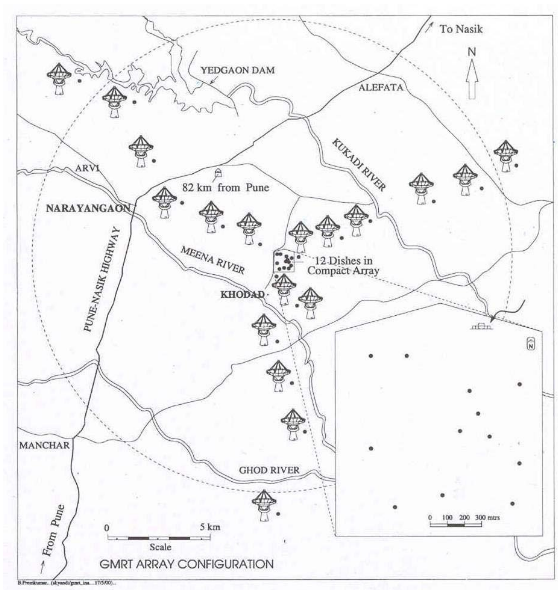
1.2 Technical Information

There are 14 telescopes randomly arranged in the central square, with a further 16 arranged in 3 arms of the nearly "Y" shaped array giving an informating baseline of about 25km. GMRT is an interferometer, uses a technique known as aperture synthesis to make image of radio sources.

Each antenna is of 45m diameter and insist of a solid surface like many radio telescopes, the reflector is made of wire rope stretched between metal struts in parabolic configuration. Each antenna has 4 different receivers mounted at the focus. Each individual receiver can rotate so that the user can select the frequency at which to observe. The array operated in six frequency bands centerd on 50, 153, 233, 325, 610 and 1420 MHz. All these feeds provide dual polarization output.

The maximum baseline in the array gives the telescope an angular resolution range from 60 arc to about 1 arc sec at the frequency 1420 MHz.

The construction of 30 large dishes at a relatively small cost has been possible due to an important technological breakthrough achieved by Indian Scientists and Engineers in the design of lightweight, low cost dishes. The design is based on what is being called the `SMART' concept for Stretch Mesh Attached to Rope Trusses.



GMRT antenna array at center squre.

GMRT antenna : C – 11.

1.3 Objective of this Project

In GMRT there are total 30 antennas and each antenna consists of four servo motors. Two for azimuth operation and two for elevation operation. Thus there are total 120 servomotors which all are brushed motor.

In early days these brushes made of copper but now a day it is of carbon. Brushes will be wear out due to constant contact during rotation between stator and rotor of these motors. Carbon powder gather in between stator and rotor. Thus commutator segments might get shorted due to the burned carbon participated in between which might result in unbalancing of motor operation.

Thus DC motor requires a periodic maintenance to prevent it from permanent damage. Thus in case of GMRT where a large number of these servo motors are used and they work constantly as GMRT is 24×7 observatory, it is a huge problem for maintenance all these 120 antennas periodically. This is costly as well as it takes a large time.

GMRT antennas have 45m diameter and they observes the universe like Jupiter, Sun, Pulser, Micro- quaser, Y- rays and X rays sources. It also observes the near Galaxies, Supernova and cluster of galaxies at very high Radio Frequency ranges. These antennas specify for the ranges 40 – 1700 MHz. But in such high frequency noise level also creates problem for these brushed motors. In case of brushless motor the RFI can be eliminated.

For these reasons a great project to replace all the brushed motor with the brushless motors in all GMRT antennas.

This chapter introduces the motor and its general physics i.e. what is motor? How it works through the magnets.

1.4 What is MOTOR?

An electric motor is a machine which converts electric energy into mechanical energy. Its action is based on the current carrying conductor placed in magnetic field.

Same DC machine can be used interchangeably as a generator & as a motor. When operating as a generator, it is driven by a mechanical machine and it develops voltage which in produces a current flow in an electric circuit. When it operating as a motor, it is supplied by electric current & it develops torque which in turn produces mechanical rotation.

Motor construction:-

There are two types of DC machines-Homopolar & Heteropolar.

Homopolar:

In this machine there is a divided magnetic circuit. The Stationary portion is of steel casting consisting of 3 rings, magnetically connected together by a number of Yoke pieces. They establish a magnetic flux density in the air gap being quite uniform. The only method of connected Armature conductors in series is by 2 Slip Rings for each Commutator, connecting Brushes upon them, so that the current can be flown through the short path of the coil and brushes.

It is suited for low voltage, very heavy machine where there is only one conductor. Thus it need not require commutator and it is difficult to collect current from slip rings. As there is only one pole, thus the Back-emf

$$e = B \times L \times \upsilon$$

where B=air gap flux (wb/m²)

L=axial length (m)

υ= (m/s).

Heteropolar:

In heteropolar dc machine there are N and S poles alternately around the total surface. Thus the commutator is very essential to conduct the current. As the length should being kept fixed, thus to get improved velocity the number of the conductors should be increased. But the apparent disadvantage is totally out weighted by the factor of number of conductors in series.

Unlike the homopolar in heteropolar machine active field system consists of number of poles arranged alternately N & S so that conductor alternates with a freq(speed, number of pairs of poles).

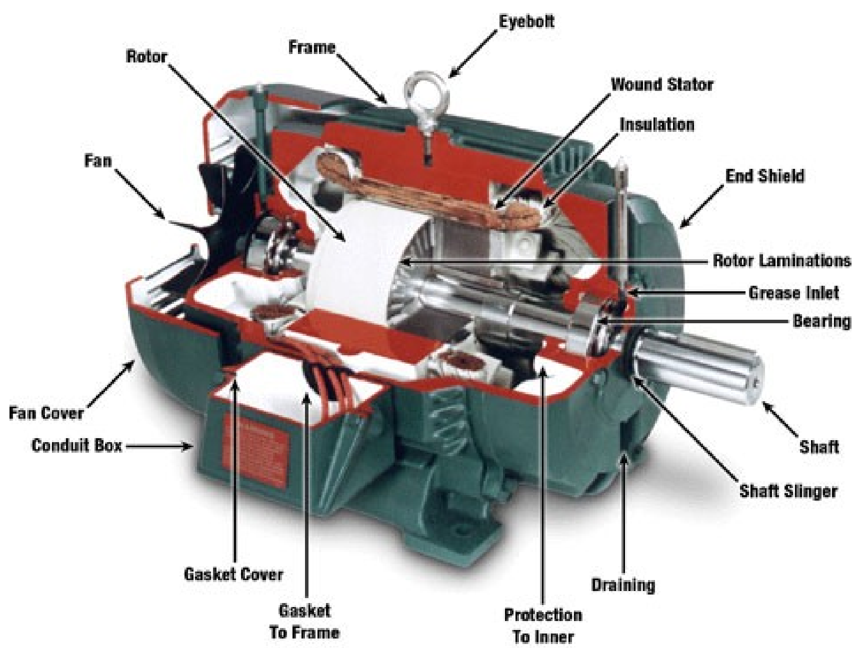


Figure 8 - Motor Construction

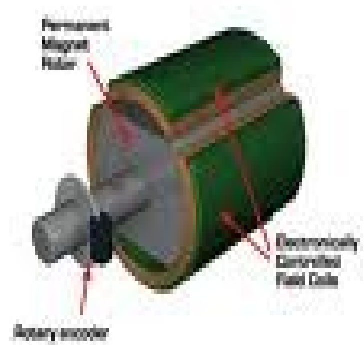


Fig 1.1 The DC motors are of two types-i) Brushed motor and ii) Brushless motor.

- Commutator and Brushes on DC Motor

It is a cylindrical structure built up of segment of high conductivity hard-drawn copper, insulated by mica from each other. It is mounted on the shaft, but in large machine it is mounted on an extension of armature hub.

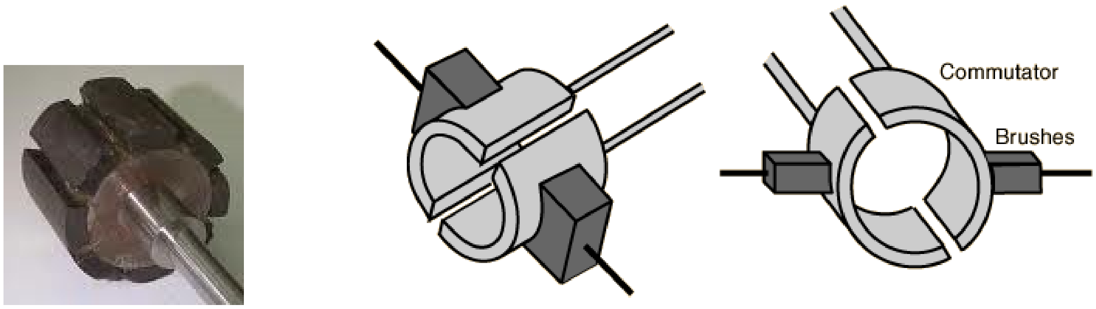


Fig 1.2 Commutator and brushes

To keep the torque on a DC motor from reversing every time the coil moves through the plane perpendicular to the magnetic field, a split-ring device called a commutator is used to reverse the current at that point. The electrical contacts to the rotating ring are called "brushes" since copper brush contacts were used in early motors. Modern motors normally use spring-loaded carbon contacts, but the historical name for the contacts has persisted

1.5 Function of Motors

- EMF Induced in the DC Mechine

Apparently, by rotating the armature the two coil sided cut through the magnetic lines of forces. It may rotate clockwise or counterclockwise and the total EMF at any instanat $e = 2 \times B \times L \times \upsilon$

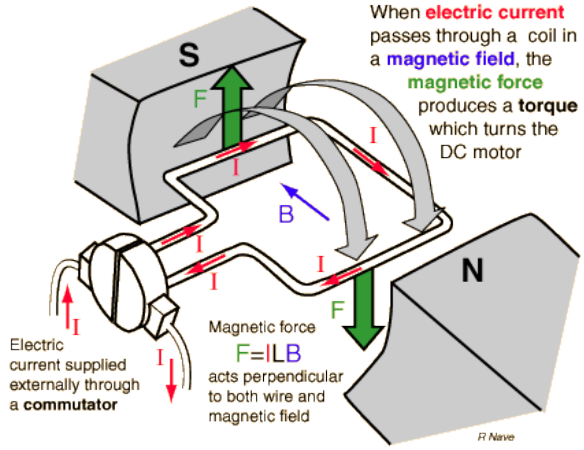


Fig 1.3 EMF induction in magnets

When it rotates the number of lines linked with the coil changes periodically and rate of change of flux is identically with the back-emf e in the above equation or e = - d ▪ /dt .

Practically this flux will pass through the teeth thus the above formula is not apparent rather than it is apparent by rotating the armature. The value of the flux of the coil be changed, thus the emf is induced in DC machine.

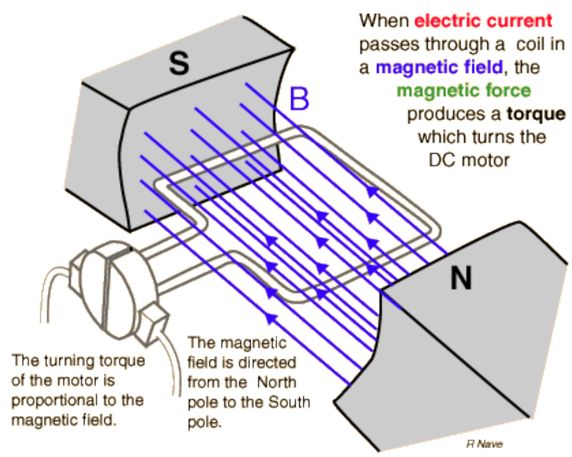


Fig 1.4 Magnetic line flows from north pole to south pole

- Wave Shape & Induced EMF

EMF is directly proportional to the value of field intensity. Thus $e \infty B$

When the flux entering the field armature,the field is not confined to the portion under the Pole-shoe and there is a certain amount of fringing out side the tip of the shoes.

- Flux distribution curve and fringing

Flux distribution dependent on the shape of pole-shoe. The air-gap between the pole-shoe and the armature should be identical in each position.

In the flux distribution curve the ordinates gives the flux density entering the armature. The total value of the induced flux ▪ = B×τ×L .

When τ = pole-pitch area(m^2), L =axial length (m).

Thus the flux density depends on the average ordinate of the flux distribution curve and the emf is maximum when it rises and falls. The value of the iron-losses in the armature can be determined by the maximum flux density and it mainly obtained in unloaded condition. But in loaded machine it occurs towards the tip of the pole-shoe. It should be expressed in terms of Field Form Factor and it is defined as the ratio of the mean air gap density over the whole pole-pitch to the maximum density in air gap. Thus

Field Form Factor = Bav/Bg = Kf

Thus ▪ = Kf×Bg×τ×L and Big =(▪ /τL)(1/Kf)

- Average value of EMF Induced in each Armature

Induced emf Ec = Bav×L×υ = Kf×Bg×L×υ

- **Force on a conductor carrying current in a Magnetic Field**

When the current flows through the conductor at right angle to a magnetic field. This force F= density of the field × current × length of the conductor. Thus F = BIaL N

Where B in Wb/m^2 , Ia in amp ,L in m.

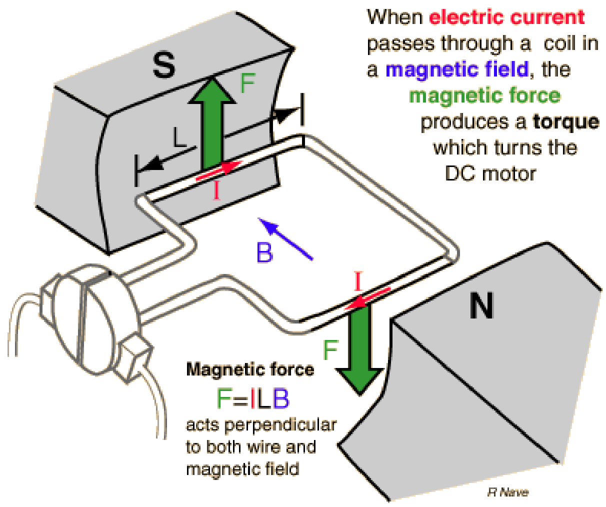


Fig 1.5 Force produced in magnets

- **Work done on moving a current through a Magnetic**

Due to the magnetic force produced between conductor and the magnetic field, if the conductor be moved in the direction it oppose to the force, thus the work done in the magnetic field is W = S×F = S×B×Ia×L

S is moving distance.

Now, ▪ = S×B×L , then, W = ▪ ×Ia webar , as ▪ is flux per pole, and there is 2p number of poles, then, total work done W =2p ▪ Ia watt-sec.

Total number of conductors in armature Za, then, W = 2pZa ▪ Ia watt-sec. 2p ▪ is called 'total magnetic loading', ZaIa is called 'total electric loading' or 'total ampere conductors on the armature'.

- **Power developed by Armature**

Power is the rate of work done thus, total power developed P = work done per revolution × number of revolution = 2p ▪ ZaIa×n H.P.

1.6 Characteristics of Motor:

- **Torque**

By the term torque is meant the turning or twisting of a force about an axis.

Torque T= F×r N-m; r is the radius at which this force acts.

Work done by this force in one revolution = Force × distance = $F \times 2\pi r \times N$ joule/sec = $(F \times r) \times 2\pi N$ = $T \times 2\pi N$ watt

When , $2\pi N$ is angular velocity ω in rad/sec.

Thus , Power developed = $T \times \omega$ watt; when N is in rpm, then , $P = (2\pi N/60) \times T = (2\pi/60)\pi \times NT$ watt.

Therefore , $T = (60/2\pi)(P/N) = 9.55 \times$ output power/N N-m

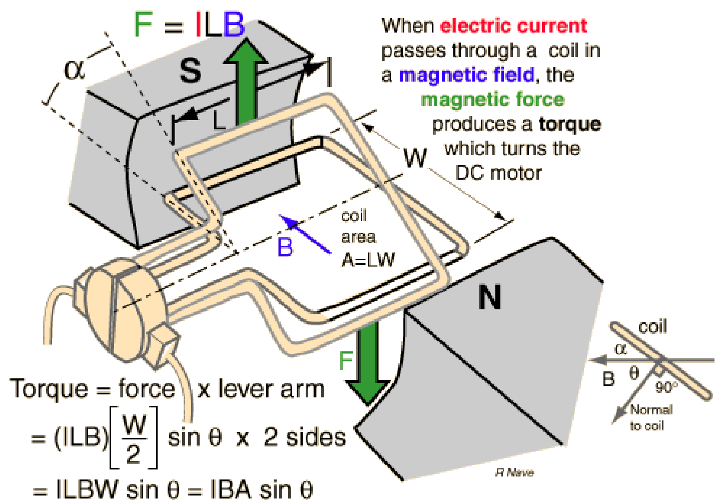


Fig 1.6 Torque produced in magnet

- **Speed Regulation**

The term speed regulation refers the change in speed of a motor with change in applied load torque. It can be defined as the change in speed when the load on the motor is reduced from rated value to zero. It is expressed in percent of rated load speed. Therefore,

$$\% \text{ speed regulation} = \frac{\text{No load speed} - \text{Full load speed}}{\text{Full load speed}}$$

$$= (dN/N) \times 100$$

- **Torque and Speed of a DC motor**

The torque of a motor is a function of flux and armature current , yet it is independent of speed. In fact the speed which depends on torque and not vice-versa.

N = K (V-IaRa)/ ▪ = K.Eb/ ▪ ,therefore, T ∞ ▪ Ia

The increase in Ia produces increase of T which increases the motor speed. Actually this is held constant as in a d.c servo motor.

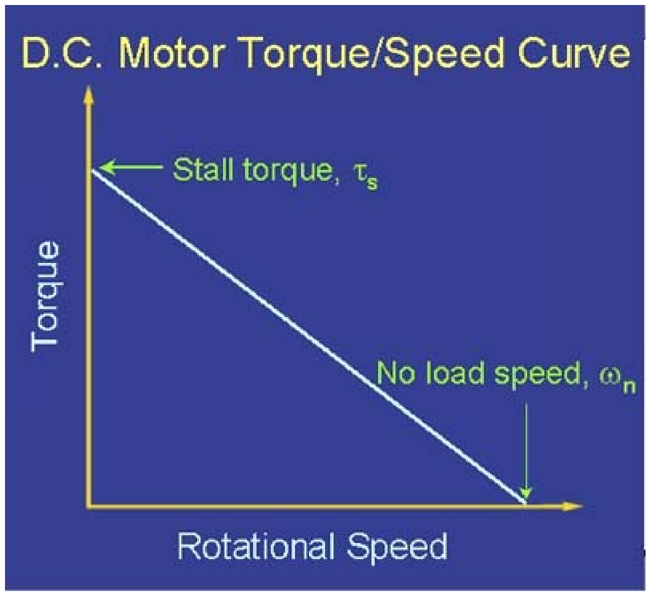


Fig 1.7 Torque – Speed characteristic curve of D.C. Motor

TESTING OF DC MOTOR

2.1 Testing Procedure

1. Connect 230VAC as input to the Transformer,
2. To get the DC value connect the output of the transformer to a Bridge rectifier circuit, we get the armature voltage from the output of the bridge rectifier circuit .
3. To get free from ripple of the regulated DC , connect the output of the bridge circuit to a capacitor filter.

4. The output regulated DC voltage is the input of the DC motor.

   To measure the current through the motor connect an ammeter in series after the capacitor.

5. To measure the voltage across the DC motor connect a voltmeter in parallel of the motor.
6. To get the speed in rpm ,connect a tachometer to the rotor end which is spinning. This is the Measured rpm.
7. We can calculate the rpm with respect to Vtacho =17V per 1000 rpm.

Thus the no-load and with load condition the torque-speed characteristics tables are shown below.

Table 1: No-load testing

Sl. No.	V armature (volt)	I armature (amp)	V tacho (volt)	Calculated rpm	Measured rpm
1.	0	0	0	0	0
2.	25	3	6.32	371.76	410
3.	50	3	12.30	723.52	770
4.	75	4	18.65	1097.05	1160
5.	100	5	24.8	1458.82	1540
6.	125	5	31.1	1841.17	1930
7.	150	5	37.05	2202.94	2300

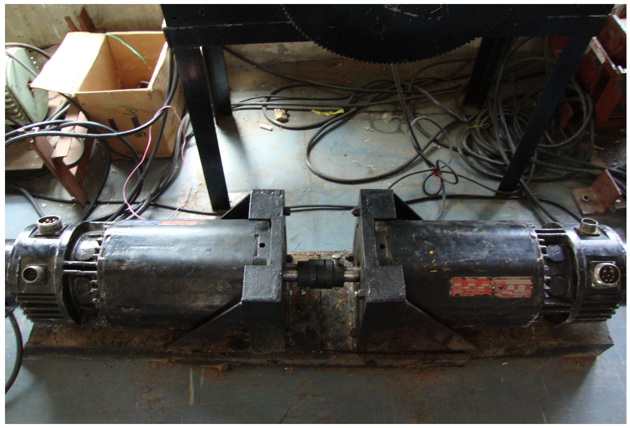
Table 2:

Sl.no.	V armature (volt)	I armature (amp)	Power (watt)	Speed (rpm)	Torque (N-m)
1	10	5	50	133	0.059
2	20	5	100	266	0.059
3	30	5	150	419	0.056
4	40	5	200	555	0.057
5	50	5	250	704	0.056

6	60	5	300	848	0.056
7	70	5	350	1005	0.055
8	75	5	375	1056	0.056

- **Conclusion**

  With the increasing of speed the torque is more or less constant in no-load operation.



2.2 Testing procedure with load

1. The same procedure like the no-load testing would be done first, then another motor should be connected to the end of the motor like the picture above.
2. The second motor acts as generator, and the load should be connected with this generator.
3. A no. of loads are connected one by one and the voltage, current and speed should be measured for each time.

Table 3: with load testing (for Varm=50 V const.)

Sl.no.	V arm (V)	Load (no. of heater)	I arm (A)	N rpm	V tacho (V)	V load (V)	Torque (N-m)
1.	50	0	6.2	727	11.7	0	4.071
2.	50	1	7.7	663	10.9	42.2	5.545

3.	50	2	9	628	10	38.6	6.842
4.	50	3	10.1	576	9.3	35.40	8.372
5.	50	4	10.9	519	8.8	32.7	10.027
6.	50	5	11.7	509	8.4	30.4	10.975
7.	50	6	13.7	456	8	29.24	14.344

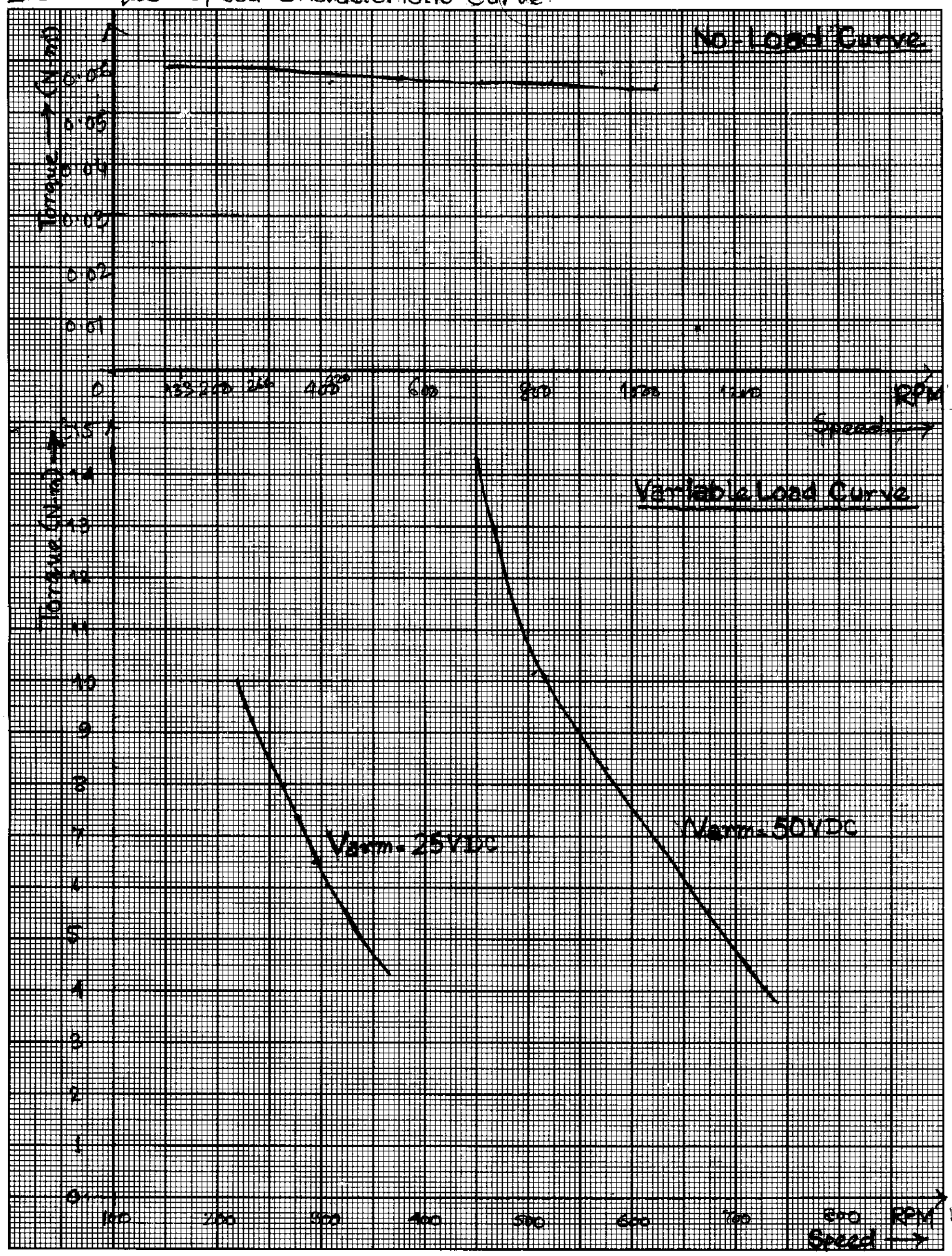
Table 4: With load testing (for Varm=25V const.)

Sl.no.	V arm (V)	Load (no. of heater)	I arm (A)	N rpm	V tacho (V)	V load (V)	Torque (N-m)
1.	25	0	7.1	335	5.5	0	5.05
2.	25	1	7.8	309	5.1	19.5	6.02
3.	25	2	8.1	293	4.8	17.8	6.59
4.	25	3	8.6	278	4.6	16.14	7.38
5.	25	4	8.9	265	4.3	15.65	8.01
6.	25	5	9.1	254	4.1	14.5	8.55
7.	25	6	9.4	242	4	13.5	9.27

- **Conclusion**

When load is increasing, the speed is decreasing but the torque is increasing as the current is increased.

2.3 Torque - Speed Characteristic Curve



BRUSHLESS DC MOTOR

3.1 INTRODUCTION

A brushless motor, without brushes, slips or mechanical commutator conventional DC rotor windings. The slips make the induction motor asynchronous , i.e, the rotor speed is no longer exactly proportional to the supply frequency. Thus the induced rotor current gives rises to I^2R losses in heat decreasing the efficiency. The torque-speed characteristics should be compatible with the torque-speed characteristic with load.

Stepper motor is an example of brushless motor. An advantage of this stepper motor is open-loop operation i.e. position control can be achieved without shaft position feedback. The torque is developed by the tendency of the rotor and stator teeth to pull into alignment. To achieve stable operation with adequate holding torque stepper motor is designed with small stepped angles. Stepper motor does not have fixed torque constant.

Actually dc brushless motor is an ac motor with electronic commutation. The speed is controlled electronically.

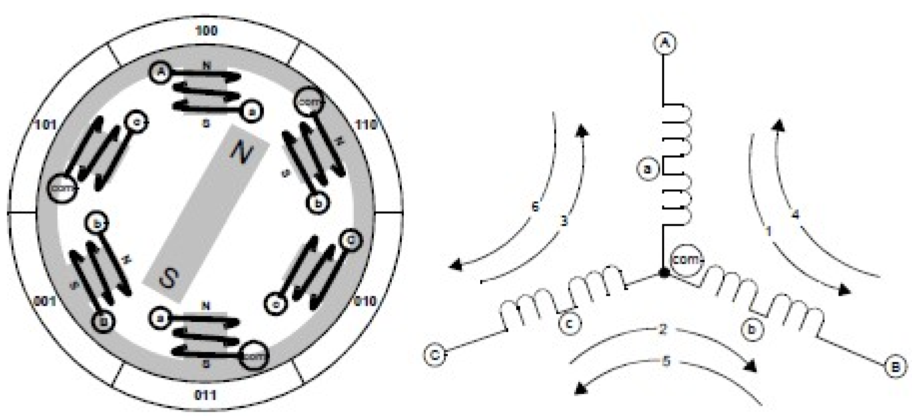
3.2 Basics of the Brushless Motor Operation

Trough the pic 3 we can supply the battery source externally through a commutator in commercial DC machine. It gives supply current to the conductor connected to the brush. The brush contacts commutator when the conductor rotates. Now, the current is flowing through the conductor and according to Fleming's left hand rule, the direction of the force can be determined. Thus the conductor tends to move upward, in the direction of the force, and clockwise. this is magnetized according to the pole of the stator. After 90º rotation the current through the conductor will not change the direction as we connect a constant dc voltage source, thus it tends to return in its previous position and oscillates, but we have to change the direction of the current to rotate the conductor successfully.

Thus we can apply an alternative current source using switch, and this will help to rotate it 360º. In this case, when the conductor reaches 90º clockwise, the direction of the current will be alternated and opposite by the switch. Thus again applying the Fleming's left hand rule when the direction of the magnetic field is unchanged, the direction of the force will be just opposite I.e. downwards. Thus the rotor rotates 180º and the process is repeatedly going on to rotate the rotor 360º successfully.

But in case of brushless dc motor, there is no brushes, on the rotor part. The magnetic coils are on the poles of the stator part and a permanent magnet is on the rotor. The main difference in brushed motor & brushless motor is,in brushed motor, the conductor is connected to the rotor ,thus it rotates. But in brushless motor, the conductor is fixed and there is no commutator and the magnet is connected to the rotor. We use external electronic commutation to rotate this rotor. This commutation is nothing but the changing of direction of the current through the conductor forcefully.

In 3-phase commutation circuit there are 3 coils and at a time two coils work and other one remains in floating condition. The switching is actually done by the transistor circuit. When the circuit is on ,the current flows through Q1 and enters to coil A and exits through Q2 and coil C. thus + to coil A as current enters and – to coil C as it exits.



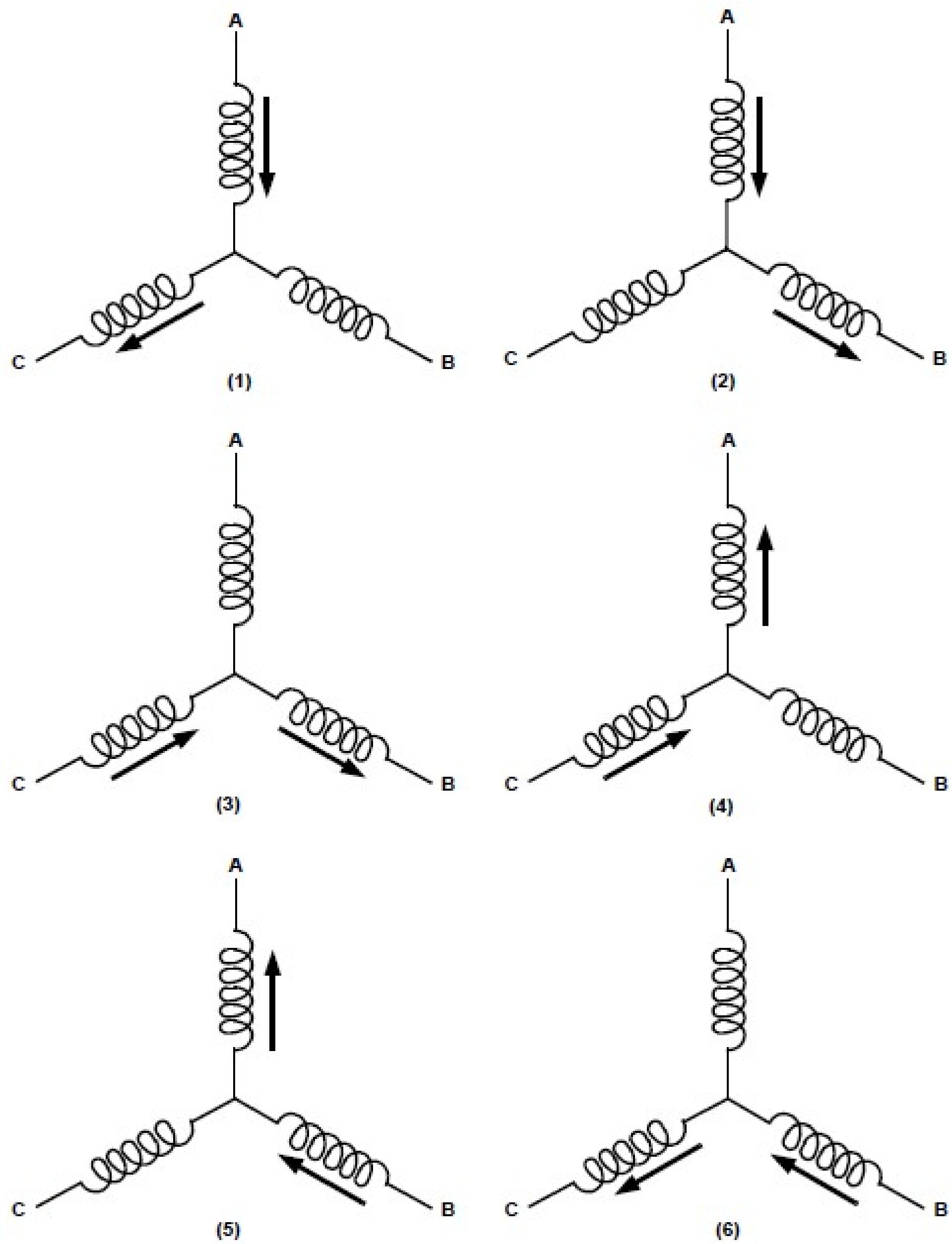


Fig 3.6 Direction of current through the coils in each 60º phase

And after 60º ,it again flows through A & B ,after another 60º the current flows through Q5 - C – B – Q6. thus 180º is completed. In another 180º the current flows as

1st 60º in Q5 –C – A –Q4

2nd 60º in Q3 – B – A – Q4

3rd 60º in Q3- B – C – Q2 and so on.

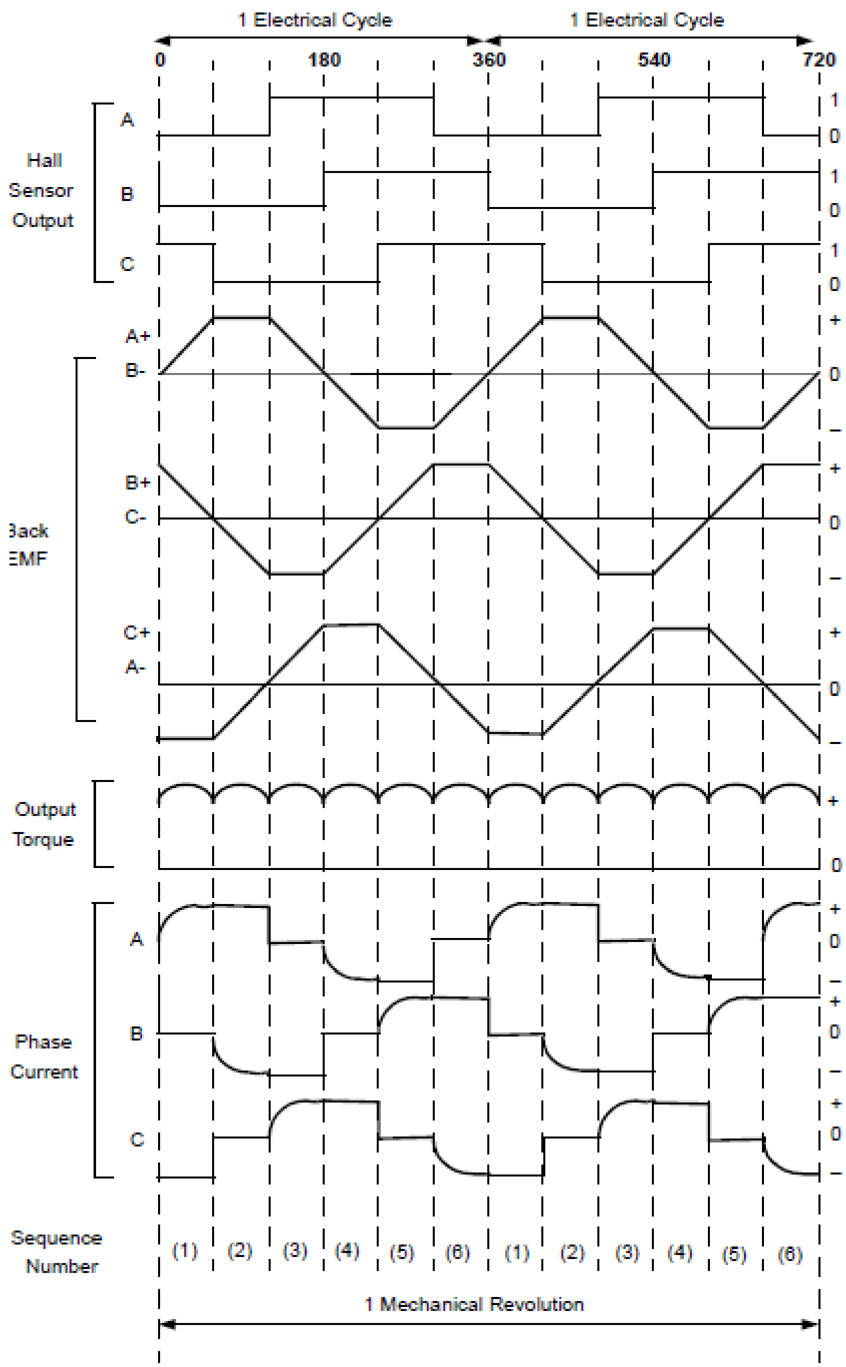


Fig 3.7 Waveform of Hall sensor output, back emf, output torque and phase current

We can observe from the waveform that in once a 60º , 2 coils at a time active, one in '+/ and another in '-' but the 3rd one is in floating condition. Thus the current waveform has zero value at this dead time foe each conductor.

Thus we can see that each conductor is active for every 120º and in dead time for 60 deg. In this time the voltage curve also be described as the polarity of the coils changes.

Thus the direction of the current through the conductor is changed and again by using Flemimg's left hand rule the direction of the force can be determined as upward and downward for every 180º alternatively.

The position of the rotor is very important. To rotate the rotor the position should be accurately to the stator. Thus we use the HALL SENSOR on the rotor part rather than the stator. As stator is fixed the rotot cannot be set accurately with the stator, but if the HALL SENSOR is placed on the rotor it stays at accurate position with the stator and gives same result. These HALL SENSOR shifts at 60º or 120º phase shift, to each other among the 360º phases. Thus the HALL SENSOR signals can change the state of the rotor. And it takes 6 steps at an electric cycle to complete the rotation.but it cannot complete a mechanical cycle of this rotor. Thus for each pole pairs one electrical cycle is completed.

3.3 Working of a brushless motor

The brushless motor consists of two parts: stator and rotor. . In a typical DC motor, there are permanent **magnets** on the outside and a spinning **armature** on the inside. The permanent magnets are stationary, so they are called the **stator**. The armature rotates, so it is called the **rotor**.

In a **brushless DC motor** (BLDC), the permanent magnets are on the rotor and the electromagnets to the stator can be moved by using software.This system has all sorts of advantages:

- Because a computer controls the motor instead of mechanical brushes, it's more precise and more efficient.
- There is no sparking and much less electrical noise.
- There are no brushes ,thus it requires no maintenance.
- Voltage and current rating is high.
- With the electromagnets on the stator, they are very easy to cool.
- It has longer life.

3.4 How the rotor rotates in BLDC

In the rotating field, pole pair A is first fed with a DC pulse which magnetises pole A1 as a south pole and A2 as a north pole holding the magnet in its initial position. The other poles are not energised. Then the current to pole pair A is switched off and pole pair B is fed with a DC pulse causing pole B1 to be magnetised as a south pole and B2 to be a north pole. The magnet will then rotate clockwise to align itself with pole pair B. By pulsing the stator pole pairs in sequence the magnet will continue to rotate clockwise to keep itself aligned with the energised pole pair. In practice the poles are fed with a polyphase stepped waveform to create the smooth rotating field.

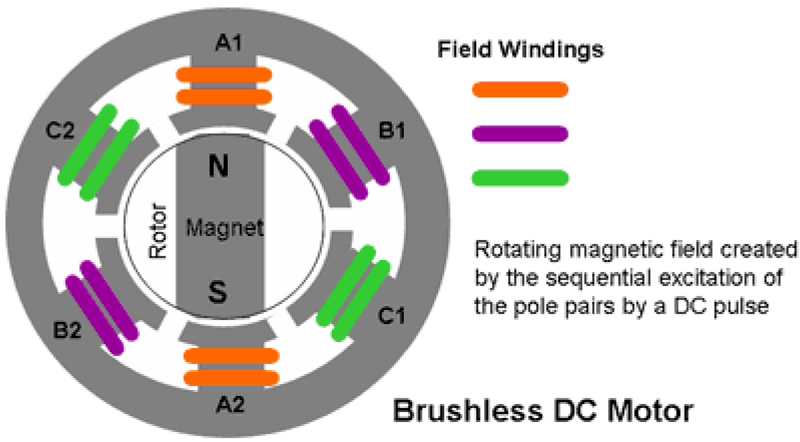


Fig 3.1 Winding in stator and permanent magnet on rotor of BLDC

The speed of rotation is controlled by the pulse frequency and the torque by the pulse current.

A three-phase BLDC motor has six states of commutation. When all six states in the commutation sequence have been performed the sequence is repeated to continue the rotation. The sequence represents a full electrical rotation. Thus a four-pole BLDC motor uses two electrical rotation cycles to per mechanical rotation depending on the number of electrical rotations in rpm.

The brushless motors are externally commutated, this depends on the circuits.

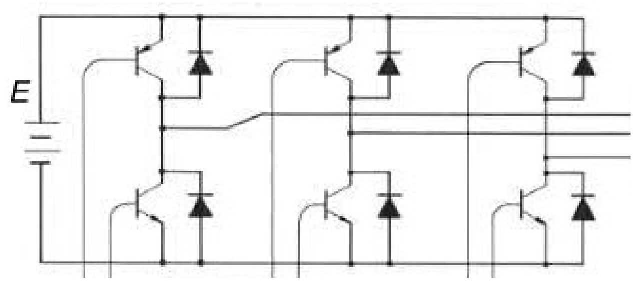


Fig 3.2 Pulse commutator circuit

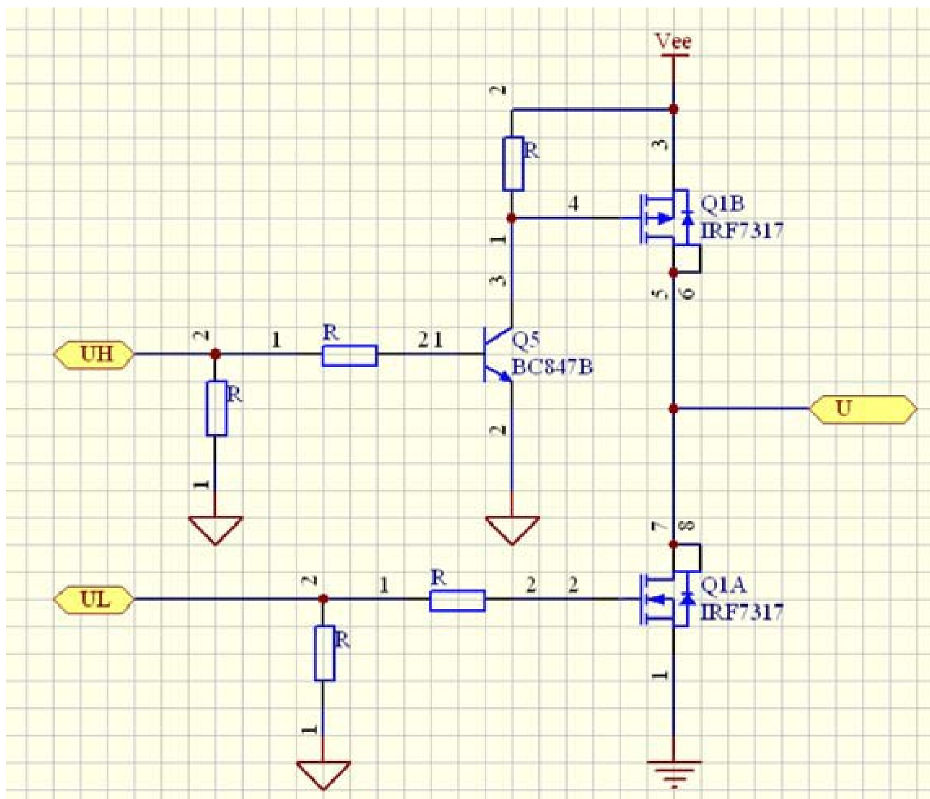


Fig 3.3 Driver circuit of the 3-phase motor

The 3-phase 4-pole (per phase) synchronous motor (Figure below) will rotate at 1800 rpm with 60 Hz power or 1500 rpm with 50 Hz power. If the coils are energized one at a time in the sequence φ-1, φ-2, φ-3, the rotor should point to the corresponding poles in turn. Since the sine waves actually overlap, the resultant field will rotate, not in steps, but smoothly.

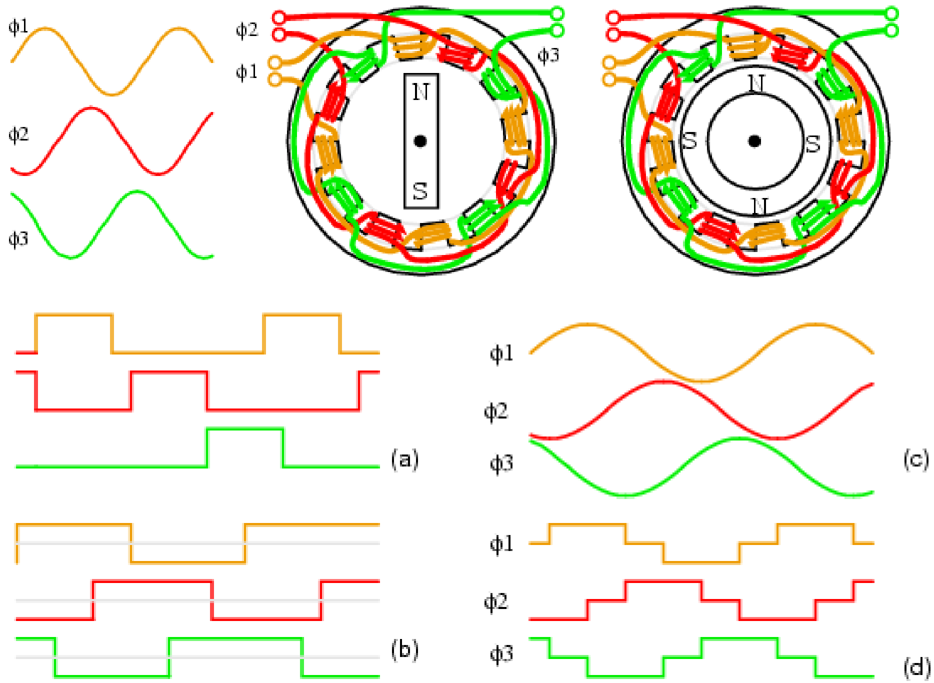


Fig 3.4 Variable reluctance motor drive waveforms: (a) unipolar wave drive, (b) bipolar full step (c) sinewave (d) bipolar 6-step.

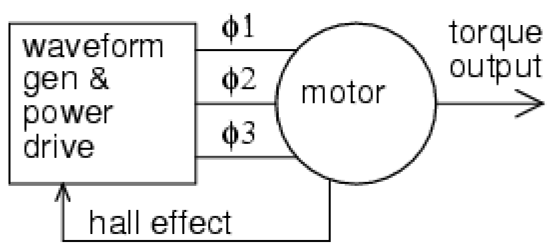


Fig 3.5 Block diagam of electronic synchronous motor.

3.5 Requirement of Bruahless Motor

The brushed motors contains brushes and commutators, but after somedays due to rotation of the commutators carbon granules form there, which causes a number of problems there. The soft carbon causes far less damage to the commutator segments. There is less sparking with carbon and , the higher resistance of carbon results in fewer problems from the dust collecting on the commutator segments. These also results in a greater voltage drop of 0.8 to 1.0 volts per contact, or 1.6 to 2.0 volts across the commutator.

And another cause is hat he brushed motors are affected by the RFI problem. Brushless motor can over come both of this problem, thus we required the brushless motor instead of the brushed motors.

The brushless motors are commutated electronically by using some software.

In GMRT RAYSHED the brushless servo motor used of the series no. is **AKM73M-KK C22-XX.**

TESTING OF BLDC MOTOR WITH SERVOSTAR

4.1 AKM series Brushless Servomotor

AKM Series Brushless Servomotors

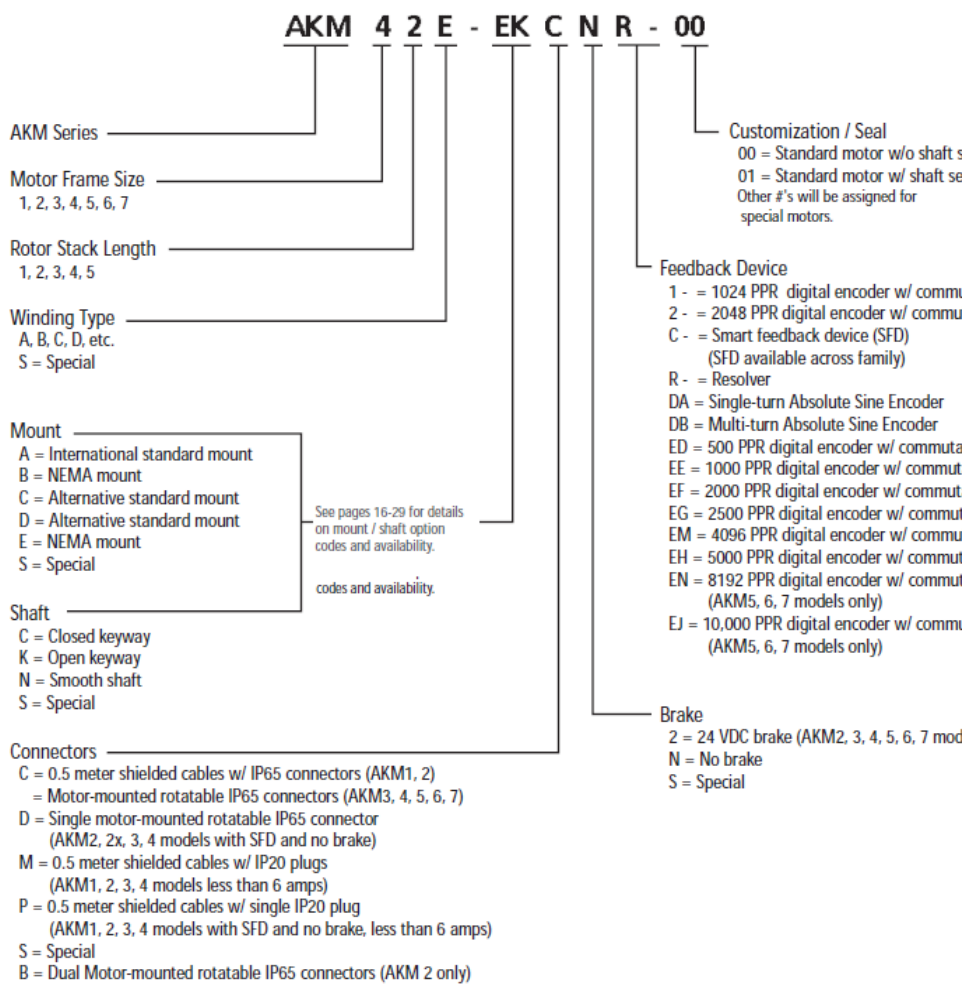


Fig 4.1 Part no.of AKM series Brushless motor.

4.2 AKM series motor and its technical data sheet

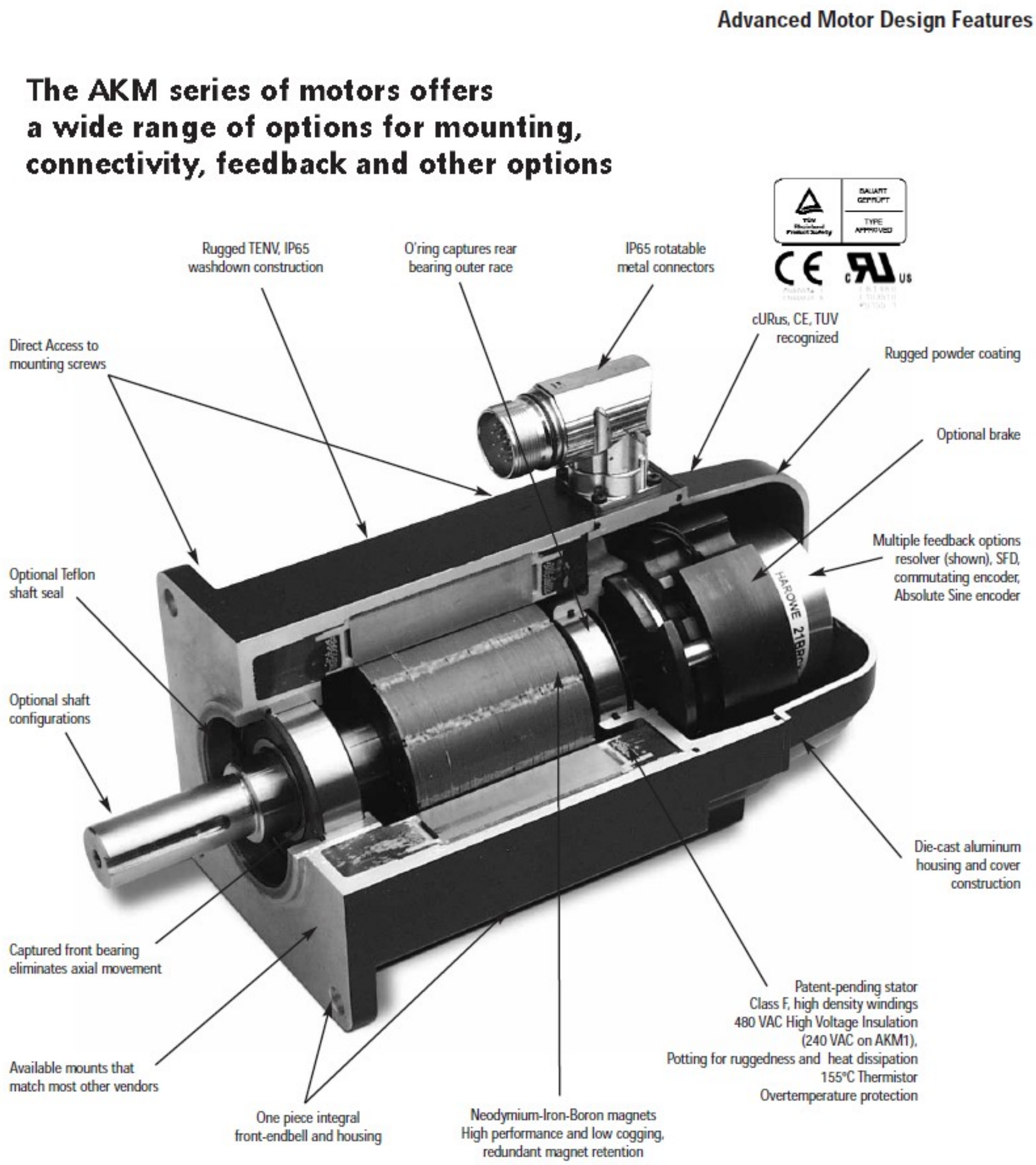


Fig 4.2 AKM series motor

AKM7x - Up to 640 VDC

See system data beginning on page 8 for typical torque/speed performance.

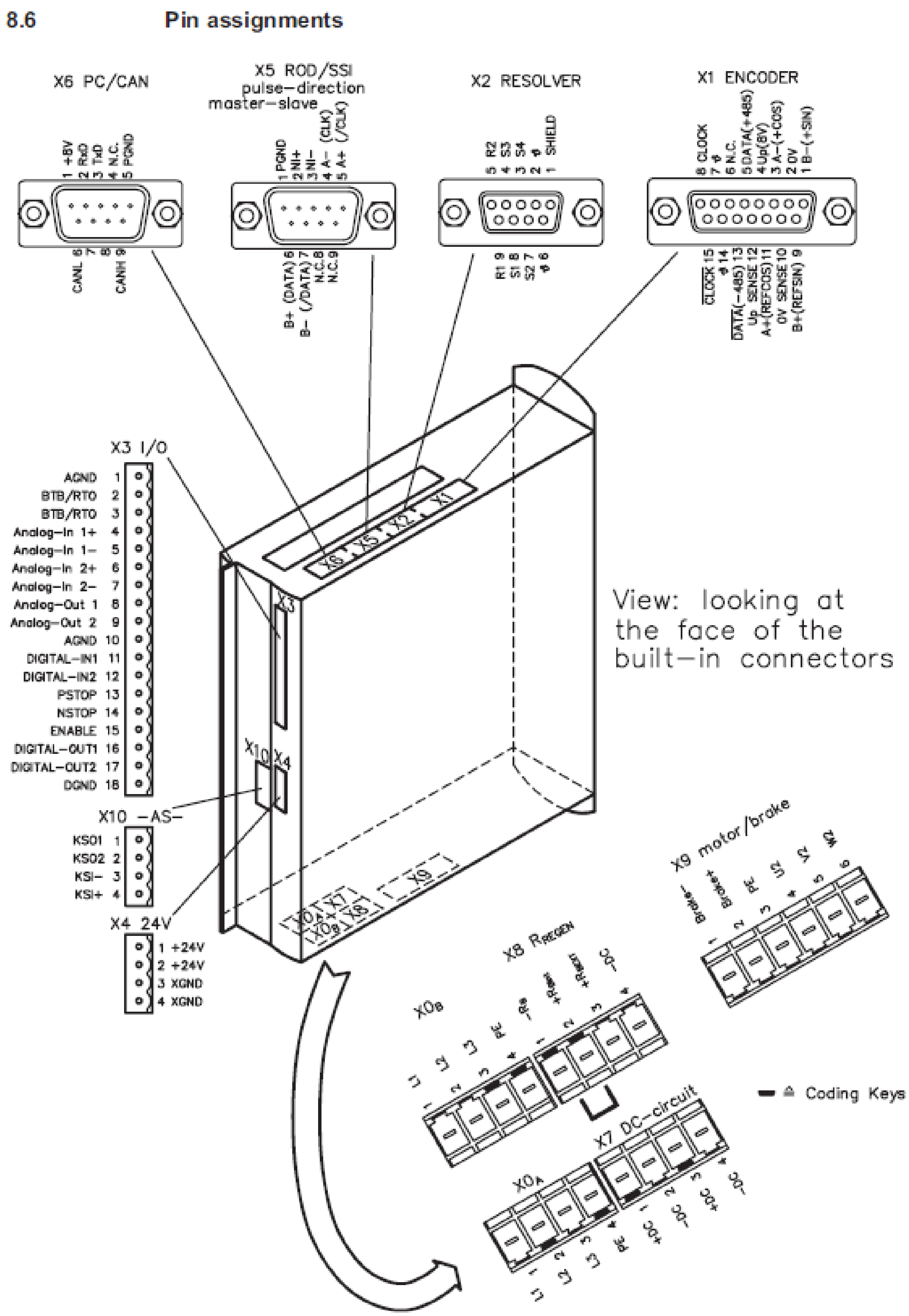
	PARAMETER	Tol	SYMBOL	UNITS	AKM72 K	AKM72 M	AKM72 P	AKM73 M	AKM73 P	AKM74 L	AKM74 P
	Max Rated DC Bus Voltage	Max	Vbus	Vdc	640	640	640	640	640	640	640
	Continuous Torque (Stall) for ΔT winding = 100°C ①②⑦⑧⑨	Nom	T_{cs}	N-m lb-in	29.7 263	30.0 266	29.4 260	42.0 372	41.6 368	53.0 469	52.5 465
	Continuous Current (Stall) for ΔT winding = 100°C ①②⑦⑧⑨	Nom	I_{cs}	A_{rms}	9.3	13.0	18.7	13.6	19.5	12.9	18.5
	Continuous Torque (Stall) for ΔT winding = 60°C ②	Nom	T_{cs}	N-m lb-in	23.8 211	24.0 212	23.5 208	33.6 297	33.3 295	42.4 375	42.0 372
	Max Mechanical Speed ⑤	Nom	N_{max}	rpm	6000	6000	6000	6000	6000	6000	6000
	Peak Torque ①②	Nom	T_p	Nm lb-in	79.2 701	79.7 705	78.5 695	113 997	111 985	143 1269	142 1253
	Peak Current	Nom	I_p	A_{rms}	27.8	38.9	56.1	40.8	58.6	38.7	55.5
75VDC	Rated Torque (speed) ①②⑦⑧⑨⑩		T_{rtd}	N-m lb-in	- -	- -	- -	- -	- -	- -	- -
75VDC	Rated Speed		N_{rtd}	rpm	-	-	-	-	-	-	-
75VDC	Rated Power (speed) ①②⑦⑧⑨		P_{rtd}	kW Hp	- -	- -	- -	- -	- -	- -	- -
160VDC	Rated Torque (speed) ①②⑦⑧⑨⑩		T_{rtd}	N-m lb-in	- -	- -	- -	- -	- -	- -	- -
160VDC	Rated Speed		N_{rtd}	rpm	-	-	-	-	-	-	-
160VDC	Rated Power (speed) ①②⑦⑧⑨		P_{rtd}	kW Hp	- -	- -	- -	- -	- -	- -	- -
320VDC	Rated Torque (speed) ①②⑦⑧⑨⑩		T_{rtd}	N-m lb-in	- -	- -	23.8 211	- -	34.7 307	- -	- -
320VDC	Rated Speed		N_{rtd}	rpm	-	-	1800	-	1300	-	-
320VDC	Rated Power (speed) ①②⑦⑧⑨		P_{rtd}	kW Hp	- -	- -	4.49 6.01	- -	4.72 6.33	- -	- -
560VDC	Rated Torque (speed) ①②⑦⑧⑨⑩		T_{rtd}	N-m lb-in	25.1 222	23.6 209	20.1 178	33.8 299	28.5 252	43.5 385	39.6 350
560VDC	Rated Speed		N_{rtd}	rpm	1500	2000	3000	1500	2400	1200	1800
560VDC	Rated Power (speed) ①②⑦⑧⑨		P_{rtd}	kW Hp	3.94 5.29	4.94 6.63	6.31 8.46	5.31 7.12	7.16 9.60	5.47 7.33	7.46 10.01
640VDC	Rated Torque (speed) ①②⑦⑧⑨⑩		T_{rtd}	N-m lb-in	24.0 212	22.1 196	18.2 161	32.1 284	26.3 233	41.5 367	35.9 318
640VDC	Rated Speed		N_{rtd}	rpm	1800	2500	3500	1800	2800	1400	2000
640VDC	Rated Power (speed) ①②⑦⑧⑨		P_{rtd}	kW Hp	4.52 6.06	5.79 7.76	6.67 8.94	6.05 8.11	7.71 10.34	6.08 8.16	7.52 10.08
	Torque Constant ①	±10%	K_t	N-m/A_{rms} lb-in/A_{rms}	3.23 28.6	2.33 20.6	1.58 14.0	3.10 27.4	2.13 18.9	4.14 36.6	2.84 25.1
	Back EMF constant ⑥	±10%	K_e	V/k_{rpm}	208	150	102	200	137	266	183
	Resistance (line-line) ⑥	±10%	R_m		1.22	0.64	0.33	0.68	0.35	0.85	0.43
	Inductance (line-line)		L	mH	20.7	10.8	5.0	12.4	5.9	16.4	7.7
	Inertia (includes Resolver feedback) ③		J_m	kg-cm^2 lb-in-s^2	65 0.057			92 0.082		120 0.11	
	Optional Brake Inertia (additional)		J_m	kg-cm^2 lb-in-s^2	1.64 1.46×10^{-3}			1.64 1.46×10^{-3}		1.64 1.46×10^{-3}	
	Weight		W	kg lb	19.7 43.4			26.7 58.8		33.6 74.0	
	Static Friction ①⑩		T_f	N-m lb-in	0.16 1.4			0.24 2.1		0.33 2.9	
	Viscous Damping ①		K_{dv}	N-m/k_{rpm} lb-in/k_{rpm}	0.06 0.5			0.13 1.2		0.2 1.8	
	Thermal Time Constant		TCT	minutes	46			53		60	
	Thermal Resistance		R_{thw-a}	°C/W	0.43			0.37		0.33	
	Pole Pairs				5			5		5	
	Heatsink Size				18"x18"x½" Aluminum Plate			18"x18"x½" Alum. Plate		18"x18"x½" Alum. Plate	

Notes:

1. Motor winding temperature rise, ΔT=100°C, at 40°C ambient.
2. All data referenced to sinusoidal commutation.
3. Add parking brake if applicable for total inertia.
4. Motor with standard heatsink.
5. May be limited at some values of Vbus.
6. Measured at 25°C.
7. Brake motor option reduces continuous torque ratings by 1 N-m.
8. Non-Resolver feedback options reduce continuous torque ratings by:
   AKM72 = 2.0 N-m AKM73 = 2.7 N-m
   AKM74 = 3.4 N-m
9. Motors with non-Resolver feedback and Brake option, reduce continuous torque by:
   AKM72 = 3.9 N-mAKM73 = 5.1 N-m
   AKM74 = 6.2 N-m
10. For motors with optional shaft seal, reduce torque shown by 0.25 N-m (2.21 lb-in), and increase T_f by the same amount.

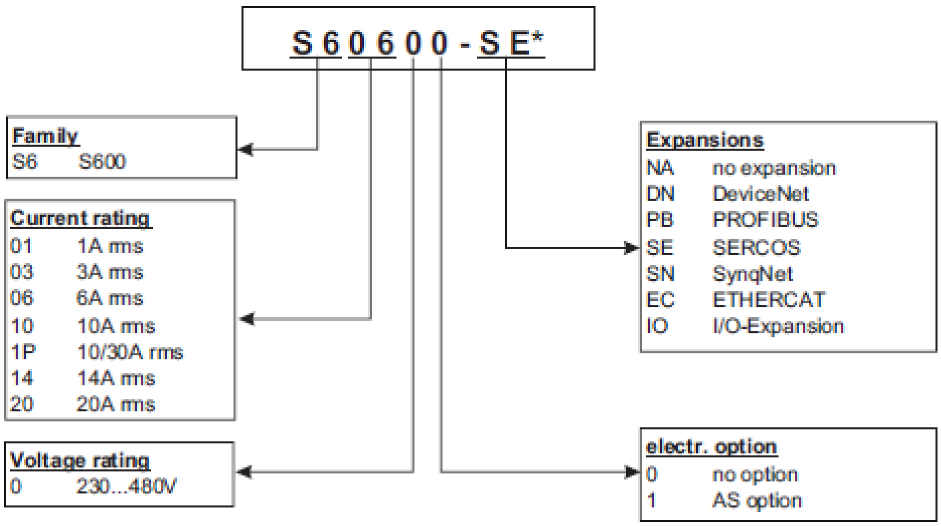
Fig 4.3 Datasheet of AKM series motor

4.3 SERVOSTAR pin configuration



4.4 Part number scheme of SERVOSTAR and Technical Data Sheet

Part number scheme



* additional coding defines customer specific specials.

Comparison (without expansion) device name -> part number

Device Name	Part Number
SERVOSTAR 601	S60100-NA
SERVOSTAR 603	S60300-NA
SERVOSTAR 606	S60600-NA
SERVOSTAR 610	S61000-NA
SERVOSTAR 610-30	S61P00-NA
SERVOSTAR 614	S61400-NA
SERVOSTAR 620	S62000-NA

Technical data

Rated data	DIM	SERVOSTAR 601	603	606	610	610-30	614	620
Rated supply voltage (grounded system)	V~	3 x 230V$_{-10\%}$ ... 480V$^{+10\%}$, 50 Hz						
	V~	3 x 208V$_{-10\%}$ ... 480V$^{+10\%}$, 60 Hz						
Rated installed load for S1 operation	kVA	1	2	4	7	7	10	14
Rated DC bus link voltage	V=	290 - 675						
Rated output current (rms value, ± 3%)	A_{rms}	1.5	3	6	10	10	14	20
Peak output current (max. ca. 5s, ± 3%)	A_{rms}	3	6	12	20	30 (2s)	28	40
Clock frequency of the output stage	kHz	8 (16 with VDCmax=400V)						
Technical data for regen circuit	—	⇨ p.22						
Overvoltage protection threshold	V	450...900						
Max. load inductance	mH	150	75	40	25	24	15	12
Min. load inductance	mH	25	12	7.5	4	4	2.5	2
Form factor of the output current (at rated data and min. load inductance)	—	1.01						
Bandwidth of subordinate current controller	kHz	> 1.2						
Residual voltage drop at rated current	V	5						
Quiescent dissipation, output stage disabled	W	15						
Dissipation at rated current (incl. power supply losses, without regen dissipation)	W	30	40	60	90	90	160	200
Inputs								
Setpoint 1/2, resolution 14bit/12bit	V	±10						
Common-mode voltage max.	V	±10						
Input resistance to AGND	kΩ	20						
Digital inputs	V	according to IEC 61131						
Digital outputs, open collector	V	according to IEC 61131						
BTB/RTO output, relay contacts	V	DC max. 30, AC max. 42						
	mA	500						
Aux. power supply, electrically isolated without brake	V	24 (-0% +15%)						
	A	1 (max. 16)						
Aux. power supply, electrically isolated with brake (consider voltage loss!)	V	24 (-0% +15%)						
	A	3 (max. 16)						
Min./max. output current, brake	A	0,15 / 2						
Connections								
Control signals	—	Combicon 5.08 / 18 pole , 2,5mm²						
Power signals	—	Power Combicon 7.62 / 4x4 + 1x6-pole, 4mm²						
Resolver input	—	SubD 9pole (socket)						
Sine-cosine encoder input	—	SubD 15pole (socket)						
PC-interface, CAN	—	SubD 9pole (plug)						
Encoder simulation, ROD (EEO) / SSI	—	SubD 9pole (plug)						
Mechanical								
Weight	kg	4					5	7.5
Height without connectors	mm	275						
Width	mm	70					100	120
Depth without connectors	mm	265						

Fig 4.4 Technical data of Servostar 610

Conductor cross-sections

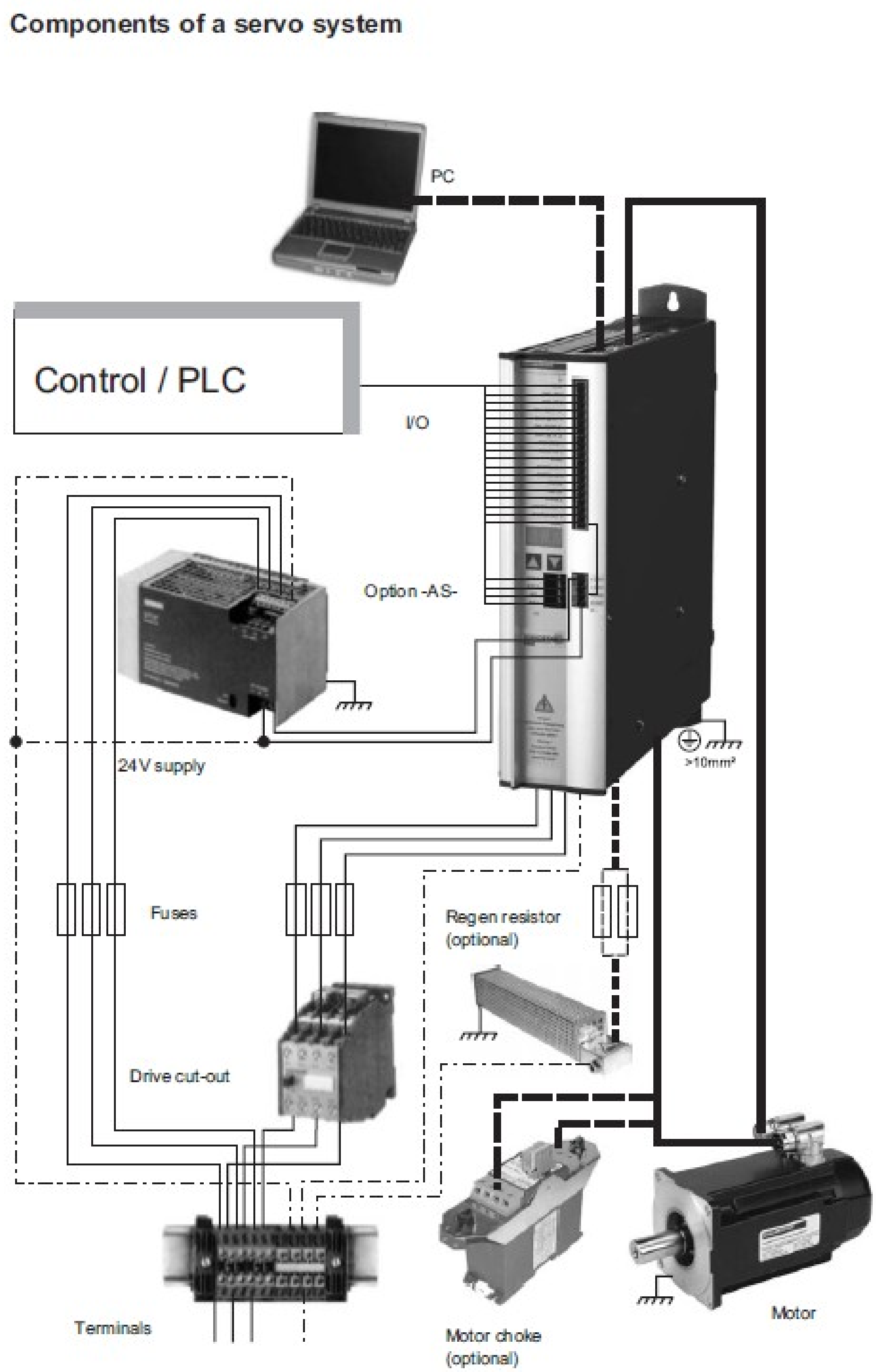
Technical data for connection cables ⇨ p.42. Following EN 60204 (for AWG: table 310-16 of the NEC 60°C or 75°C column), we recommend for **single-axis systems**:

AC connection	SERVOSTAR 601-610: 1.5 mm² (14awg) SERVOSTAR 614/620: 4 mm² (12awg)	600V,105°C (221°F), twisted
DC bus link	SERVOSTAR 601-610: 1.5 mm² (14awg) SERVOSTAR 614/620: 4 mm² (12awg)	600V,105°C (221°F), shielded for lengths>20cm
Motor cables up to 25 m length*	SERVOSTAR 601-610: 1-1.5 mm² (14awg) SERVOSTAR 614/620: 2.5 mm² (12awg)	600V,105°C (221°F), shielded, capacitance <150pF/m
Motor cables 25 to 100 m length*, with motor choke 3YL	SERVOSTAR 601-606: 1 mm² (14awg) SERVOSTAR 610-620: 2.5 mm² (12awg)	600V,105°C (221°F), shielded, capacitance <150pF/m
Resolver, thermostat-motor, max.100m length*	4x2x0.25 mm² (22awg) twisted pairs, shielded, capacitance <120pF/m	
Encoder, thermostat-motor, max.50m length*	7x2x0,25 mm² (22 awg) twisted pairs, shielded, capacitance <120pF/m	
Setpoints, monitors, AGND	0.25 mm² (22awg) twisted pairs, shielded	
Control signals, BTB, DGND	0.5 mm² (20awg)	
Holding brake (motor)	min. 0.75 mm² (18awg), 600V,105°C (221°F), shielded, check voltage drop	
+24 V / XGND	max. 2.5 mm² (12awg), check voltage drop	
For multi-axis systems, please note the special operating conditions in your installation. To reach the max. permitted cable length, observe cable requirements ⇨ p. 42.		

* Danaher Motion North America delivers cables up to 39m length.
Danaher Motion Europe delivers cables up to the maximum length.

Fig 4.5 Chart of conductor cross section used in Servostar 610

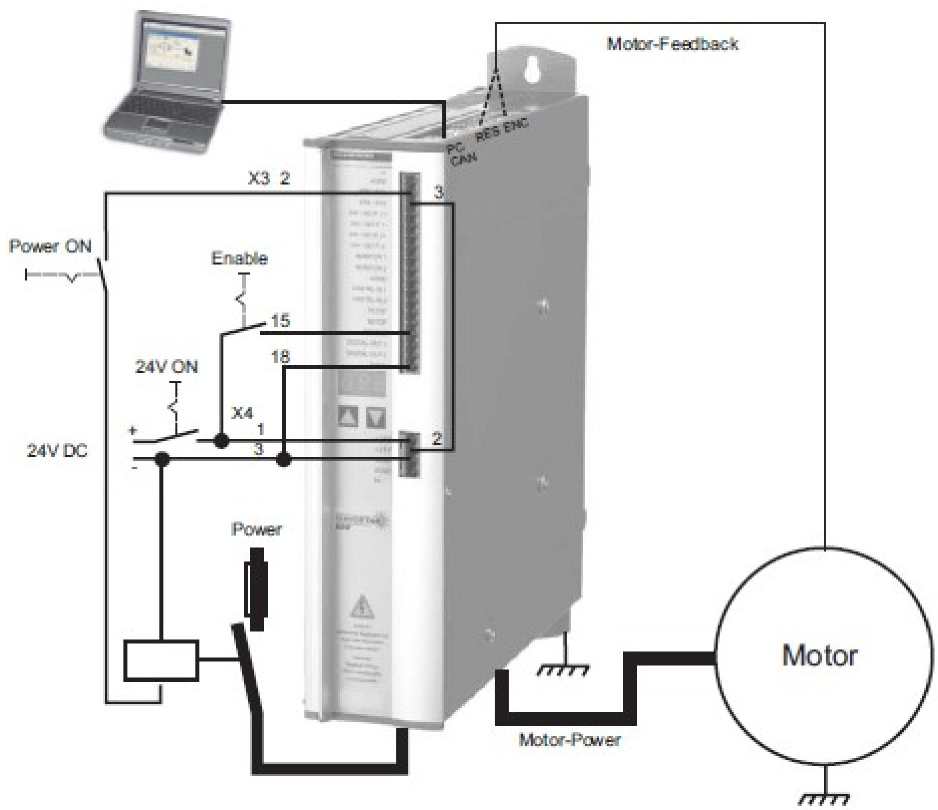
4.5 Components of the total servo system



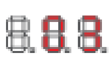
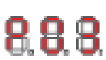
4.6 Minimum wiring for testing motor with SERVOSTAR

Minimum Wiring for Drive Test

This wiring does not fulfill any requirements to safety or functionality of your application, it just shows the required wiring for drive testing without load.

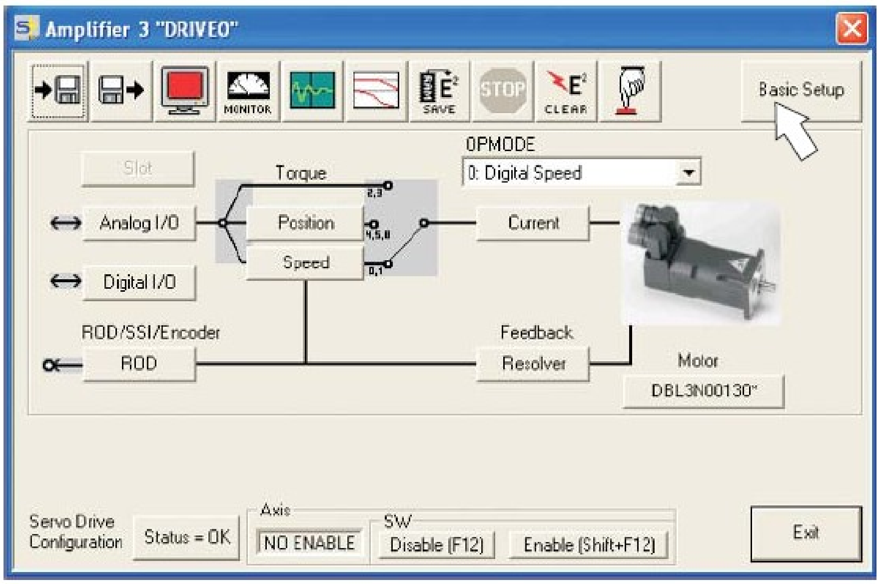


4.7 TESTING PROCEDURE

An interface cable is connected on PC and to the serial interface X6 of the servo amplifier. After switch on (24V logic power supply) until the front display of servo amplifier displays  (for 3 amps). When the power is switched on it displays a leading **P** e.g.  after completing these connection it will operated through the software.

First double-click the Drive.exe icon on the desktop screen to start the software.It may be ONLINE or OFFLINE. During ONLINE select the interface ,connected to the servo amplifier.

After staring the screen make sure the amplifier is disabled.



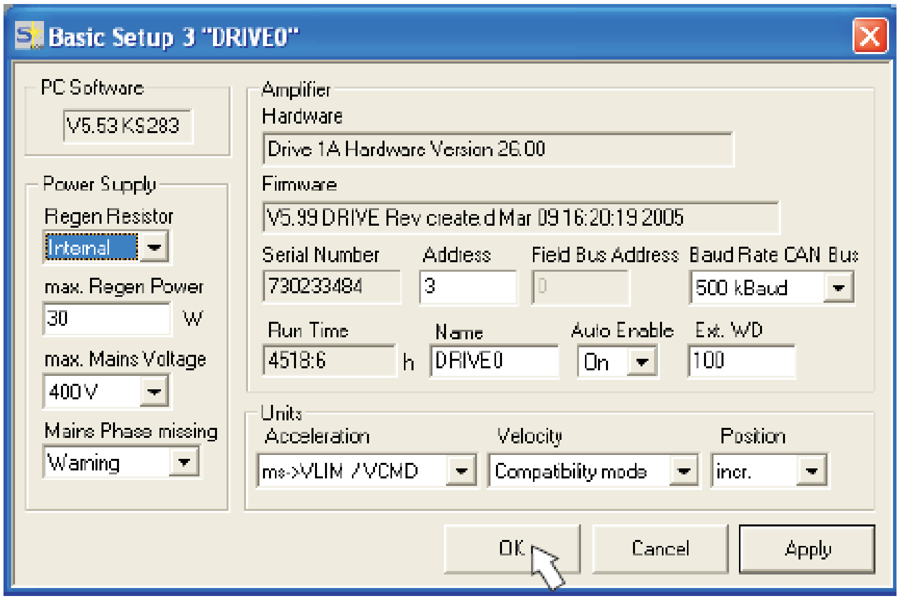
Basic Setup :

Click on **Basic Setup** .

Regen Register: here used external regen register.

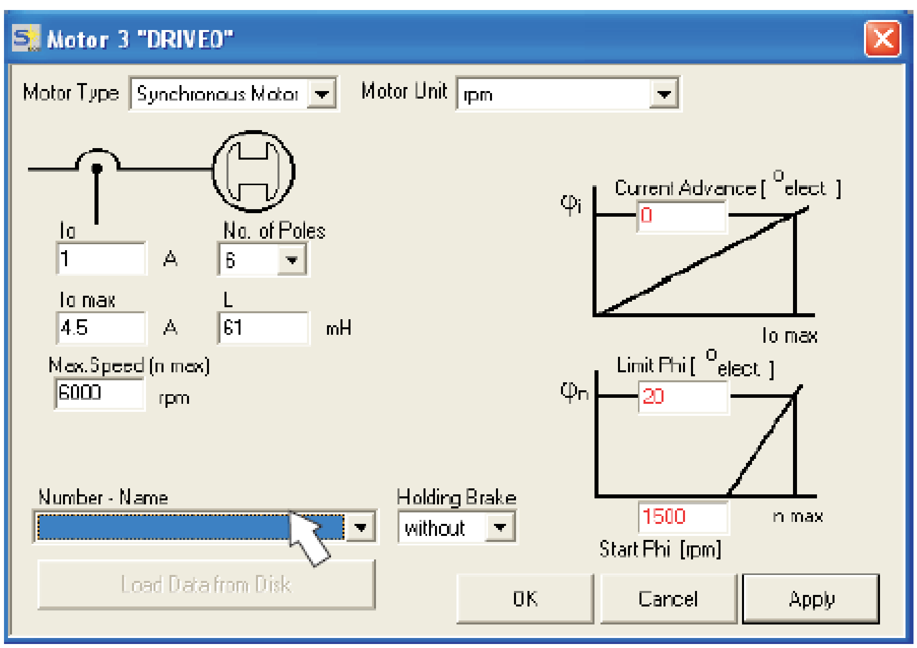
Max Mains Voltage: nominal AC voltage.

All other fields are unchanged.



Click on **OK**. On the start screen click **Motor** button.

Motor(synchronous)



Motor Type: synchronous motor.

Click OK.

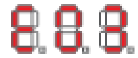
Speed control of the motor

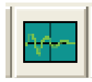
Jogging the motor

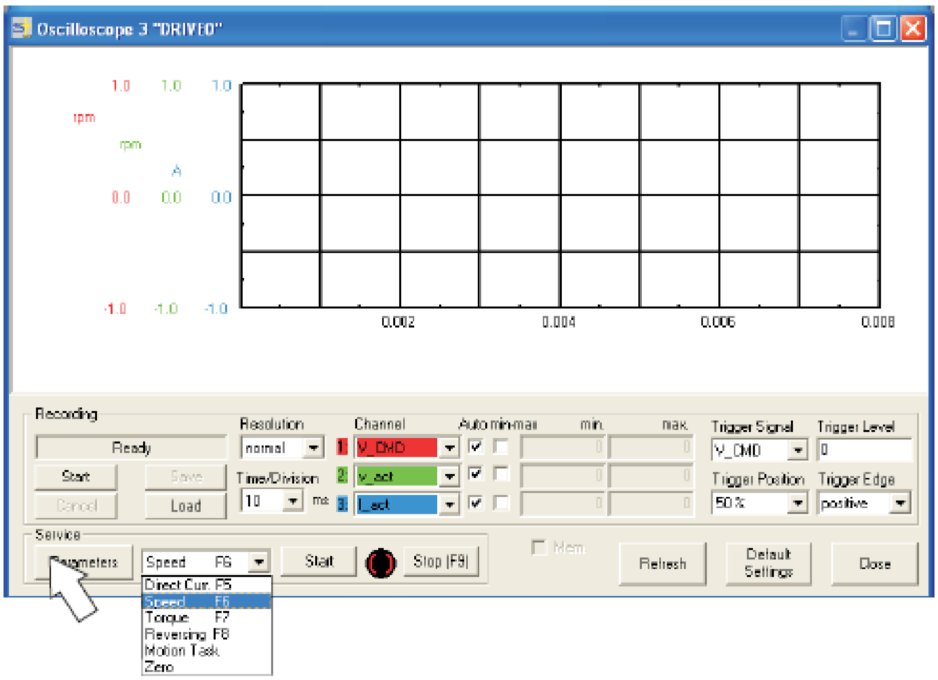
Switch on the power supply.

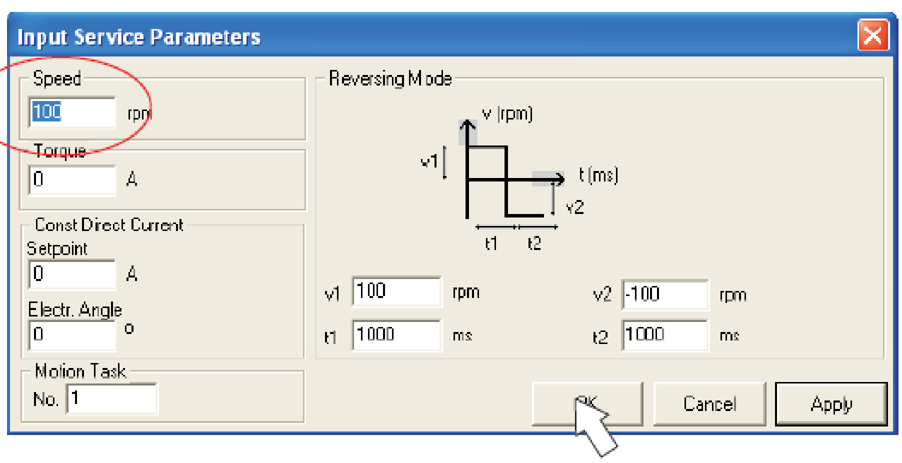
Hardware-Enable: +24 VDC to enable(connector X3 pin 15)

Click **Enable** 

on start screen ,if enable it displays 

Click icon oscilloscope  .





Click **Parameter** and select **speed F6** . and enter a safe speed at **Speed.** Click **OK.**

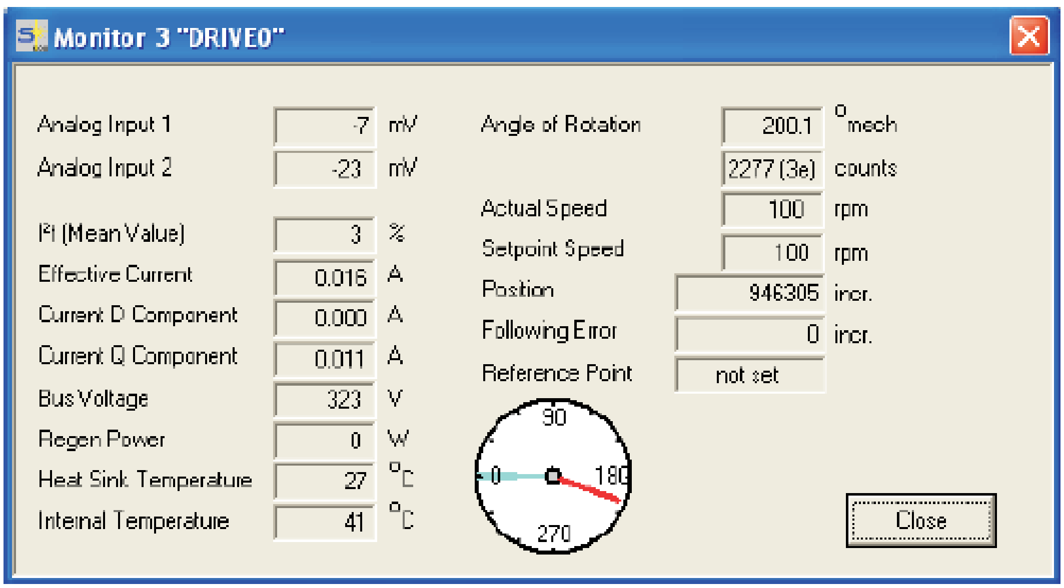
To start the service function click **Start or F6.**

The function is active until it click **Stop or F9.**

4.8 OBSERVATION

Click on Monitor 

This screen shows all important electrical and mechanical actual values.



From this Monitor screen the Observatory values can be analyzed.

We did not give any analog input as we use the RS232 interfacing with PC, thus, **analog input**s are not applicable.

Effective Current: There is used 3-Φ AC conduction, thus for each of the three conduction phase have no desired current from them. Thus Current D component and Current Q components are also not applicable.

Bus Voltage: we have used the external commutation circuit with the supply voltage. for this AKM73M motor it may be 560VDC or 640VDC.

Heat Sink Temp: it should be equal to normal temperature 25° .

Angle of Rotation: it can be observed from the position of the pointer of the rotation and may be by count also.

Actual Speed & Set Point Speed: We have set the speed on input service parameter screen.

Position: This is not desired in this case.

Table : 4.1

Parameters	**Expected values**	**Observed values**
Analog input 1	N.A.	-7mv
Analog input 2	N.A.	-23mv
I^2t(mean value)		3%
Effective current	No desired value	0.016amps
Current D component	N.A.	0.000A
Current Q component	N.A.	0.011A
Bus voltage	560VDC 640VDC	323VDC
Regen power		
Heat Sink Temperature	25° c (normal temp)	27° c
Internal Temperature	N.A.	41° c
Angle of rotation		200.1° mech
Actual Speed	100 rpm	100 rpm
Setpoint Speed	100 rpm	100 rpm
Position	N.A.	946305 incr
Following error	N.A.	0 incr
Reference position	N.A.	Not set

Conclusion

The observed values of these above parameters are more or less equal to the expected value.

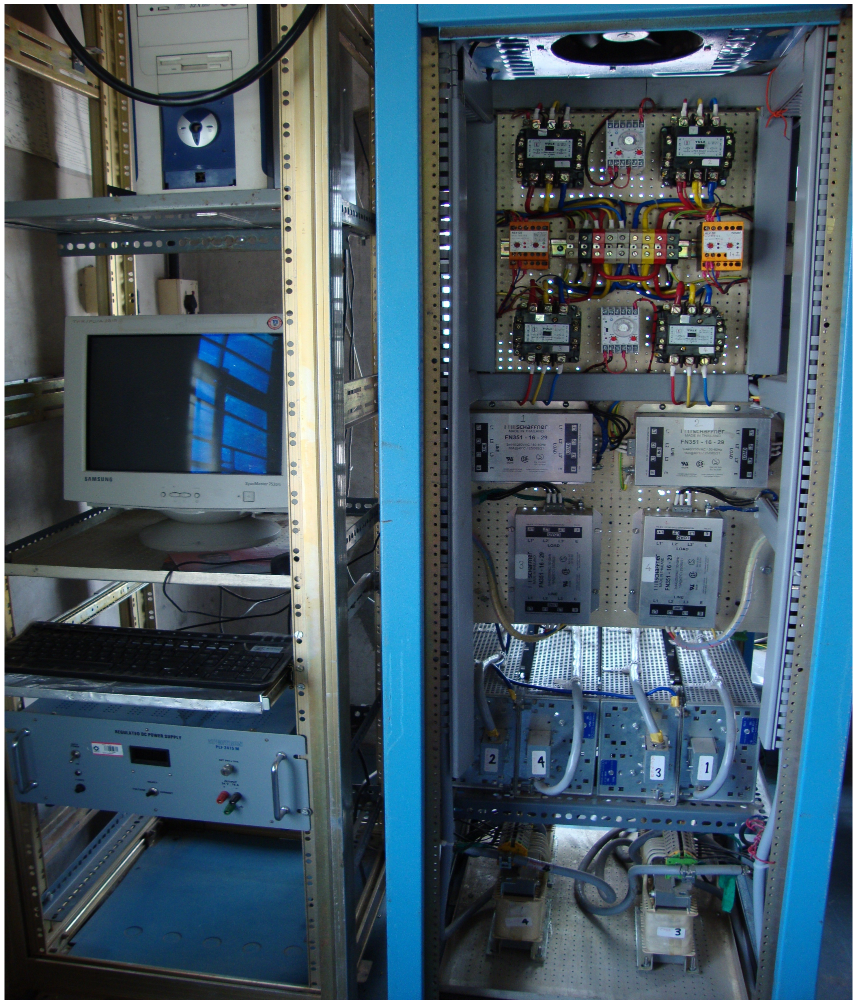


Fig 4.6: Front face of the SERVOSTAR rack at GMRT Rayshed.

TUNING OF BLDC MOTOR

Introduction

5.1 PMAC and Software PEWIN

This tuning of brushless motor is done by the PMAC or Programmable Multi Axes Controller and the software PEWIN32PRO. PMAC is a family of high-performance servo motion controllers capable of commanding up to eight axes of motion simultaneously with a high level of sophistication. The block diagram of the PMAC is given below:

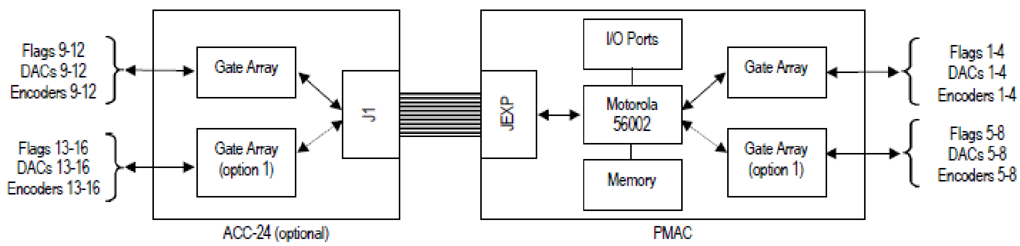


Fig 5.1 Block diagram of PMAC

The easiest way to program and setup PMAC is done by using the PMAC Executive program PEWIN. PEWIN has following main tools and features:

- A terminal window, this is the main window of communication between the user and PMAC.
- Watch window for real-time system information & debugging.
- Position window for displaying the position,velocity & following error if all motors on the system.

5.2 PMAC Programming

Motion or PLCs programs are entered in any text file and then download with PEWIN to PMAC. PEWIN provides a text editor for this purpose. Most PMAC commands can be issued on the terminal window of PEWIN. These online commands allow to jog the motor, change variables, report variable values, start and stop programs query for status information and even write short programs and PLCs.

Downloading process is just a sequence to enable the PMAC commands sent from the text file of PEWIN.

Connecting with SERVOSTAR, to compute the new commended position and read the new actual position to compute the difference between them – is the main function of PMAC.

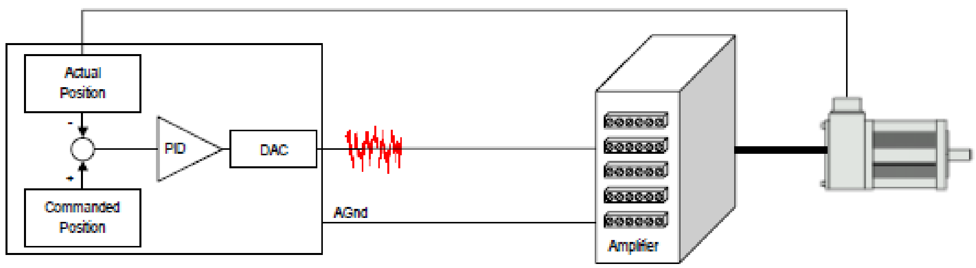
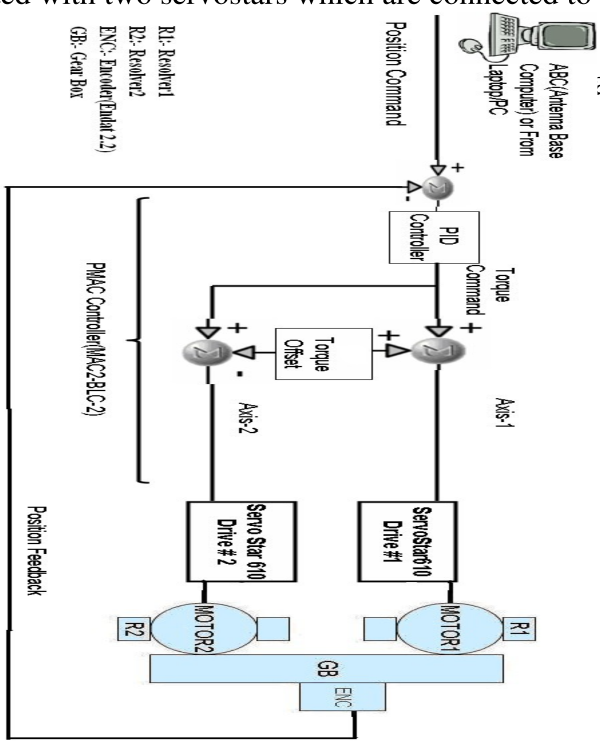


Fig 5.2: Connection of PMAC, SERVOSTAR amplifier and Motor

5.3 Tunning of Motor with PMAC

There are several ways to tune PMAC system. For tuning PMAC , in PEWIN the I-variables are very important to describe the tuning programming. It can control 8 axes at a time activated through the commands. The tuning procedure are of two types – open loop and closed loop i.e. it contains feedback with encoder or resolver. In our experiment there is one PMAC, connected with two servostars which are connected to two motors separetly.

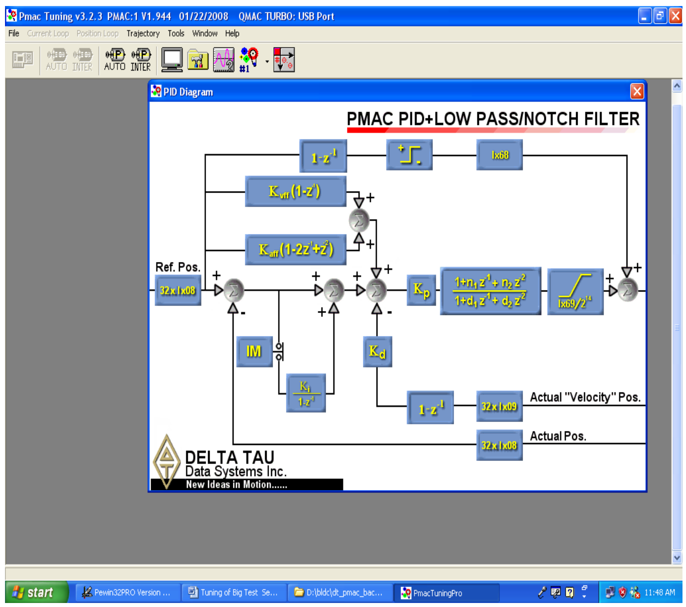
5.4 … ack

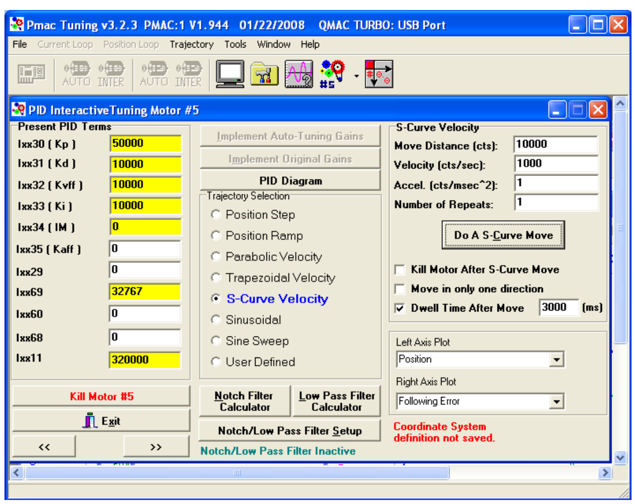


5.5 Tuning procedure (open loop)

1. Start the PMAC software PEWIN32PRO from desktop.
2. Go to the following window of PEWIN is Terminal window, where the commands can be issued to jog this motor. To start the motor1 and motor2 give the command #1o0 #2o0 at the command box. Thus the two servostar 610 will be connected with two motors through channel #1 & #2.
3. the operation is open loop when motor1 i.e. channel #1 is tunning and motor2(channel #2) is idle and encoder is not connected.

4. Another window- Position window is there, which shows the position, velocity and status bar and current reading of the motor.





5. The PID values can be changed in this window

6. To see the motor status follow the process: File → Download File → Open

7. For enabling the Xth no. of motor in open loop condition where IX00 command is for motor activation in general and X= (1,2,-------8), the following program is to be downloaded.

```
I7016,2,10=1;4
I100,2,100=1;6
I122,2,100=15;7
I119,2,100=1;8
I123,2,100=5;10
I124,2,100=$20001;11
I130,2,100=500000;13
I131,2,100=5000;14
I132,2,100=5000;15
I133,2,100=10000;16
I134,2,100=0;17
I169,2,100=16384;19
I7110=3;22
CLOSE
```

8. Similarly we can do this process with motor2 keeping motor1 in idle.

5.6 Program Explanation

I7016,2,10=1;4 /*It means that servo IC of channel 0 selects only one mode to operate. And the value 1 suggest that the signal output for external DAC are desired. */

I100,2,100=1;6 /*This command used to activate the motor1 between 2 motors and the 100th position can define the no. of motor which should be activated.*/

I122,2,100=15;7 **/***It assigns the jogging speed of this motor1 and its unit is counts/msec. e.g here we use 15counts for this motor.*/

I119,2,100=1;8 /*It assigns the max speed or the acceleration of this motor.*/

I123,2,100=5;10 /*It assighs the home speed and direction of the motor.*/

I124,2,100=$20001;11 /*It determines no limit switches are used.*/

I130,2,100=500000;13 /*It assigns the PID proportional gain(Kp).*/

I131,2,100=5000;14 /* It assigns the PID derivative gain(Kd).*/

I132,2,100=5000;15 /* It assigns the PID velocity feed forward gain(Kvff).*/

I133,2,100=10000;16 /* It assigns the PID integral gain(Ki).*/

I134,2,100=0;17 /* It assigns the PID integral mode. And the value 0 describes the position error integration performed all the time.*/

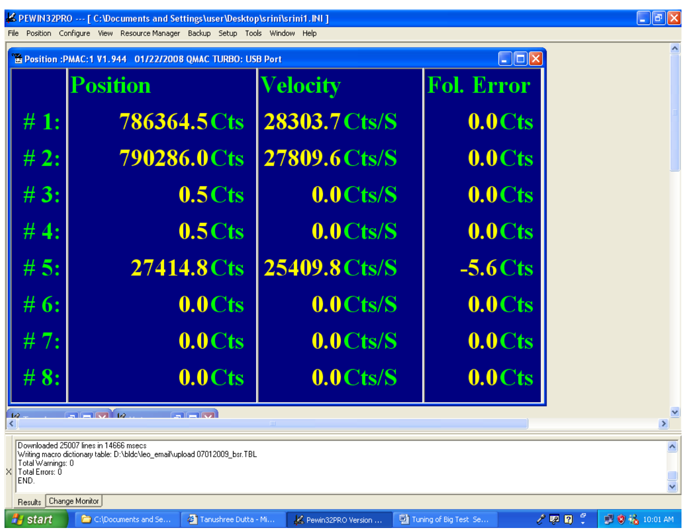
I169,2,100=16384;19 /*It defines 10V differential DAC output.*/

I7110=3;22 /*It defines servo channel1 activates only one encoder control and counts in positive direction.*/

CLOSE

In the setup diagram encoder is also used ,but now we are not using as a feedback.

1. The encoder is connected to channel 5, and it also required command #5o0 to be enabled.
2. Now the resolver counts of both motors and encoder counts of channel 5 in PMAC to check the polarity of position and velocity is shown below,



5.7Procedure of Backlash measurement

1. This is done by keeping motor #1 in closed loop “holding position” with command #1j/

   and moving motor #2 in open loop by giving varying torque from 3% (#2o3)to 10% (#2o10) and noting the counts in channels #2 and #5 of PMAC.

Now repeat this step by giving varying torque in opposite direction by giving commands (#2o-3) to (#2o-10) and note down the counts in channels #2 and #5 of PMAC.

2. Repeat above tests with Motor # 2 in closed loop and motor #1 in open loop.
3. Tabulate the result as below and the backlash measured is 1110 counts which corresponds to around 5% of maximum continuous torque.

Commands	Motor Encoder (Resolver)	Load Encoder
#1j/		
#1hmz#2hmz#5hmz		
#2o-10	#2: -36013	#5: -1456
#2o10	#2: 34318	#5: 1385
	70331	2841
#2j/		
#1hmz#2hmz#5hmz		
#1o10	#1: 39209	#5: 1022
#1o-10	#1: -33039	#5: -1172
	72248	2194
#1j/		
#1hmz#2hmz#5hmz		
#2o-5	#2: -10732	#5: -399
#2o5	#2: 27597	#5: 828
	38329	1227
#2j/		
#1hmz#2hmz#5hmz		
#1o5	#1: 36716	#5: 1389
#1o-5	#1: -981	#5: -139
	37697	1527

5.8 Tuning with Backlash in Position Loop Feedback

1. To implement the Backlash with the motor, PLC0 program should be downloaded this programming is attached at the end.
2. Then the preload programming is to be downloaded to PMAC to move the motor with backlash.

```
i7016,2,10=1            ; true DAC Output

i100,2,100=1            ; activate axis
i122,2,100=15           ; slow default speed
i119,2,100=1            ; higher acc + dec

i123,2,100=5            ; homing speed
i124,2,100=$20001       ; no limit switches

i130,2,100=500000       ; PID Settings
```

```
i131,2,100=5000
i132,2,100=5000
i133,2,100=10000
i134,2,100=0

i169,2,100=16384                ; 10V diffential DAC Output

; load encoder setting
i7110=3                                        ; changing
counting direction
```

PLCC0 real-time task for torque offset and active damping;

standard position/speed control loop at axis 5;

control output of axis 5 distributed to axes 1 and 2;

adding a torque offset;

axes 1 and 2 must be activated via command O0;

when killing axes 1 and 2, torqueOffset must be reset to 0;

```
#define velocityLoad       M574   ; filtered (unfiltered is M166)
#define velocityMotor1     M174   ; filtered (unfiltered is M266)
#define velocityMotor2     M274   ; filtered (unfiltered is M366)
#define torque1            M179
#define torque2            M279
#define desTorque          M568
#define cmdPos             M561
#define actPos             M562

#define posError           P1     ; position control deviation
#define FRICTION_Offset    P2     ;
#define D1                 P3     ; damping coefficient 1
#define D2                 P5     ; damping coefficient 2
```

```
#define GR                 P6      ; gear ratio
#define MAX_TORQUE         P7      ; Nm scaled to 16 bit integer
#define TORQUE_OFFSET      P8      ; Nm scaled to 16 bit integer
D1          = 0
D2          = 0
GR          = 8.64257
MAX_TORQUE    = 32768
TORQUE_OFFSET = 1150

I5 = 3      ; PLC program control enabled
I8 = 0      ; PLCC 0 called every sample;

 motor encoders used for velocity feedback

I8008 = $E00100     ; sum of motor 1 and 2 encoders written into
; motor 5 velocity feedback register

i500 = 1
i503 = $3505
i504 = $3509

i508 = 96
I509 = 4          ; motor 5 velocity scaling factor half of default value 96 to get average of
motor 1 and 2
considering the different resolution of motor and load
i524 = $20001

OPEN PLC 0 CLEAR

; friction compensation
```

```
posErrror = cmdPos - actPos;

If (posError > 0)
  desTorque = desTorque + FRICTION_Offset;
EndIf

If (posError < 0)
  desTorque = desTorque - FRICTION_Offset;
EndIf

; torque offset

If (desTorque < 0)
  torque2 = desTorque/2 - TORQUE_OFFSET;
  If (torque2 < -MAX_TORQUE/2)
    torque2 = -MAX_TORQUE/2
  EndIf
  torque1 = desTorque - torque2
Else
  torque1 = desTorque/2 + TORQUE_OFFSET;
  If (torque1 > MAX_TORQUE/2)
    torque1 = MAX_TORQUE/2
  EndIf
  torque2 = desTorque - torque1
EndIf

; active damping
```

```
torque1 = torque1 - D1 * (velocityMotor1 - velocityMotor2) - D2 * (velocityMotor1 +
velocityMotor2 - 2*velocityLoad/GR)
torque2 = torque2 + D1 * (velocityMotor1 - velocityMotor2) - D2 * (velocityMotor1 +
velocityMotor2 - 2*velocityLoad/GR)

; saturation

If (torque1 > MAX_TORQUE/2)
  torque1 = MAX_TORQUE/2
EndIf

If (torque1 < -MAX_TORQUE/2)
  torque1 = -MAX_TORQUE/2
EndIf

If (torque2 > MAX_TORQUE/2)
  torque2 = MAX_TORQUE/2
EndIf

If (torque2 < -MAX_TORQUE/2)
  torque2 = -MAX_TORQUE/2
EndIf

CLOSE   ; PLC 0
```

To view this again open PEWIN32PRO. Then go through File → Download and should wait for no error.

3. After downloading this program in Terminal window the following commands should be given: #1o0 #2o0 #5o0
   #5j+

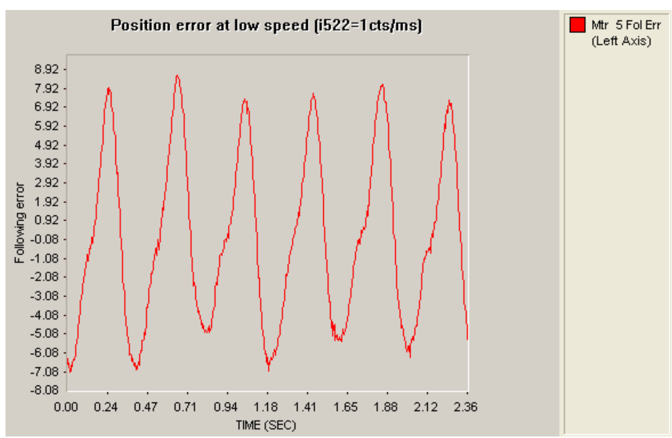
These commands (#1o0 #2o0) release the breaks from these two motors and activate them in open loop as well as it activates the channel 5 also. And #5j+ is to jog the motors connected with the 17 bit encoder feedback at channel 5.

4. To measure the accuracy of this backlash #i522=0.5 should be defined at the terminal window.

5. For plotting the curve the following steps should be done:

   Tools→ PMAC plot pro → possible choices select (e.g. 5th axis following error)→ add to left/right → motor to gather → gather period = 1 → ok → define gather buffer → begin gathering → ()after some time) end gather →upload data → ok → plot data → ok.

   The following plot shows following error with set speed i522=1cts/ms, i.e. 66.6 rpm of motor and Kp=500,000 Kd=10,000 Kvff=10,000 Ki=10,000



5.9 Tuning of BLDC with velocity feedback loop

1. In GMRT rayshed for tuning PMAC with velocity loop feedback, 10V analog input is given to backlash compensator MAC2-BLC-2. It stores in register M563.
2. After that this analog value is derived with the scaling factor 96×32×c/32767 and this stored in register M567. In this register this value is also digitized and goes to the comparator.

3. The another input of the comparator is actual velocity. It is the average value of two resolver, connected with two motor 1& 2 respectively.
4. thus the error velocity is produced from the compensator and it goes to two servostar 1 & 2, connected with motor 1& 2 respsctively, through PLC0 program. This program is below:

```
#include "Tp2mvar.pmc"

close
endg
del gat

i7016,2,10=1                    ; true DAC Output

i100,2,100=1                    ; activate axis
i122,2,100=15                   ; slow default speed
i119,2,100=0.2                        ; higher acc + dec

i123,2,100=5                    ; homing speed
i124,2,100=$20001                     ; no limit switches

i130,2,100=120000                     ; PID Settings
i131,2,100=1050
i132,2,100=1050
i133,2,100=10000
i134,2,100=1

i169,2,100=16384                      ; 10V diffential DAC Output

; AZ load encoder setting (connected to ENC5 input)
i7110=7                               ; changing counting direction
```

```
; load encoder at antenna needs
; that orientation (17.04.2009)

; #3 encoder is EL1 encoder and needs an oppoiste counting
; direction since the motor is mounted in the opposite orientation
; output of the BLC is hardwired in the opposite way (Servostar input)
i7030=3

; EL load encoder setting (connected to ENC6 input)
i7120=3

; definitions for the analog input reading
I7106 = $1FFFFF                          ; ADC strobe word
M5063->Y:$78115,8,16,s                   ; ch7 A-D channel
M5064->Y:$7811D,8,16,s                   ; ch8 A-D channel

; --------------------------------------------------------
; PLCC0 real-time task for torque offset and active damping

; standard AZ position/speed control loop at axis 5
; control output AZ of axis 5 distributed to axes 1 and 2
; adding a torque offset
; axes 1 and 2 must be activated via command o0
; when killing axes 1 and 2, torqueOffset must be reset to 0

; standard EL position/speed control loop at axis 6
; control output EL of axis 6 distributed to axes 3 and 4
; adding a torque offset
; axes 3 and 4 must be activated via command o0
; when killing axes 3 and 4, torqueOffset must be reset to 0
```

```
#define AZvelocityLoad       M574   ; filtered (unfiltered is M566)
#define AZvelocityMotor1     M174   ; filtered (unfiltered is M166)
#define AZvelocityMotor2     M274   ; filtered (unfiltered is M266)
#define AZtorque1            M179
#define AZtorque2            M279
#define AZdesTorque          M568
#define AZcmdPos             M561
#define AZactPos             M562

#define ELvelocityLoad       M674   ; filtered (unfiltered is M666)
#define ELvelocityMotor1     M374   ; filtered (unfiltered is M366)
#define ELvelocityMotor2     M474   ; filtered (unfiltered is M466)
#define ELtorque1            M379
#define ELtorque2            M479
#define ELdesTorque          M668
#define ELcmdPos             M661
#define ELactPos             M662

#define AZposError           P1     ; position control deviation
#define AZFRICTION_Offset    P2     ;
#define AZD1                 P3     ; damping coefficient 1
#define AZD2                 P5     ; damping coefficient 2
#define AZGR                 P6     ; gear ratio
#define AZMAX_TORQUE         P7     ; Nm scaled to 16 bit integer
#define AZTORQUE_OFFSET      P8     ; Nm scaled to 16 bit integer
#define AZcmdVelScaling      P9

#define ELposError           P11    ; position control deviation
#define ELFRICTION_Offset    P12    ;
```

```
#define ELD1                P13     ; damping coefficient 1
#define ELD2                P15     ; damping coefficient 2
#define ELGR                P16     ; gear ratio
#define ELMAX_TORQUE        P17     ; Nm scaled to 16 bit integer
#define ELTORQUE_OFFSET     P18     ; Nm scaled to 16 bit integer
#define ELcmdVelScaling     P19

AZD1          = 0
AZD2          = 0
AZGR          = 8.64257
AZMAX_TORQUE    = 32768
AZTORQUE_OFFSET = 1000
AZcmdVelScaling = 200

ELD1          = 0
ELD2          = 0
ELGR          = 8.64257
ELMAX_TORQUE    = 32768
ELTORQUE_OFFSET = 1000
ELcmdVelScaling = 200

I5 = 3                          ; PLC program control enabled
I8 = 0                          ; PLCC 0 called every sample

; motor encoders used for velocity feedback

I8008 = $E00100                 ; sum of motor 1 and 2 encoders written into
; motor 5 velocity feedback register
I8009 = $E00302                 ; sum of motor 3 and 4 encoders written into
; motor 6 velocity feedback register
```

```
i500 = 1
i503 = $350B
i504 = $3509
i506 = 1                    ; enable master encoder (handwheel) in order
                            ; for setting the desired vel input signal via
                            ; m567 (scaled by 1/(32*i507)
i507 = 96
i508 = 96
I509 = 48                   ; motor 5 velocity scaling factor
                            ; set to half of the scaling of i508 since
                            ; summation of to input = resolver are considered
i530 = 5000000              ; PID Settings
i531 = 128
i532 = 0
i533 = 0
i534 = 1
i538 = 0
i539 = 0
i519 = 0.0002
i522 = 1
i523 = 1
i524 = $20001
i568 = 0                    ; Friction FF term
i511 = 0
i512 = 0                    ; setting the error limits to zero in order to
                            ; avoid any influence to the velocity loop

i600 = 1
i603 = $350B
```

```
i604 = $350A
i606 = 1                    ; enable master encoder (handwheel) in order
                            ; for setting the desired vel input signal via
                            ; m667 (scaled by 1/(32*i607)
i607 = 96
i608 = 96
I609 = 48                   ; motor 6 velocity scaling factor
                            ; see scaling calculation of 21.04.09
                            ; of motor 3 and 4
                            ; considering the different resolution of motor and load
i630 = 1000000              ; PID Settings
i631 = 128
i632 = 0
i633 = 0
i634 = 1
i638 = 0
i639 = 0
i619 = 0.0002
i622 = 1
i623 = 1
i624 = $20001
i668 = 0                    ; Friction FF term (not checked yet)
i611 = 0                    ; disable following Error
i612 = 0

OPEN PLC 0 CLEAR

 ============================================================
; AZ PART
```

```
;
==================================================================

; analog input reading and scaling
m567 = 96 * 32 * m5063 * AZcmdVelScaling / 32767

; friction compensation
/*
AZposError = AZcmdPos - AZactPos;

If (AZposError > 0)
  AZdesTorque = AZdesTorque + AZFRICTION_Offset;
EndIf

If (AZposError < 0)
  AZdesTorque = AZdesTorque - AZFRICTION_Offset;
EndIf
*/

; torque offset

If (AZdesTorque < 0)
  AZtorque2 = AZdesTorque/2 - AZTORQUE_OFFSET;
  If (AZtorque2 < -AZMAX_TORQUE/2)
    AZtorque2 = -AZMAX_TORQUE/2
  EndIf
  AZtorque1 = AZdesTorque - AZtorque2
Else
  AZtorque1 = AZdesTorque/2 + AZTORQUE_OFFSET;
  If (AZtorque1 > AZMAX_TORQUE/2)
```

```
    AZtorque1 = AZMAX_TORQUE/2
  EndIf
  AZtorque2 = AZdesTorque - AZtorque1
EndIf

; active damping
/*
; Remark: consider the filtered velocity needs to be checked, because of the steps in
the signal!!!
AZtorque1 = AZtorque1 - AZD1 * (AZvelocityMotor1 - AZvelocityMotor2) - AZD2
* (AZvelocityMotor1 + AZvelocityMotor2 - 2*AZvelocityLoad/AZGR)
AZtorque2 = AZtorque2 + AZD1 * (AZvelocityMotor1 - AZvelocityMotor2) - AZD2
* (AZvelocityMotor1 + AZvelocityMotor2 - 2*AZvelocityLoad/AZGR)
*/

; saturation

If (AZtorque1 > AZMAX_TORQUE/2)
  AZtorque1 = AZMAX_TORQUE/2
EndIf

If (AZtorque1 < -AZMAX_TORQUE/2)
  AZtorque1 = -AZMAX_TORQUE/2
EndIf

If (AZtorque2 > AZMAX_TORQUE/2)
  AZtorque2 = AZMAX_TORQUE/2
EndIf

If (AZtorque2 < -AZMAX_TORQUE/2)
```

```
  AZtorque2 = -AZMAX_TORQUE/2
EndIf



;
================================================================
; EL PART
;
================================================================

; analog input reading and scaling
m667 = 96 * 32 * m5064 * ELcmdVelScaling / 32767

; friction compensation

/*
ELposError = ELcmdPos - ELactPos;

If (ELposError > 0)
  ELdesTorque = ELdesTorque + ELFRICTION_Offset;
EndIf

If (ELposError < 0)
  ELdesTorque = ELdesTorque - ELFRICTION_Offset;
EndIf
*/

; torque offset

If (ELdesTorque < 0)
```

```
  ELtorque2 = ELdesTorque/2 - ELTORQUE_OFFSET;
  If (ELtorque2 < -ELMAX_TORQUE/2)
    ELtorque2 = -ELMAX_TORQUE/2
  EndIf
  ELtorque1 = ELdesTorque - ELtorque2
Else
  ELtorque1 = ELdesTorque/2 + ELTORQUE_OFFSET;
  If (ELtorque1 > ELMAX_TORQUE/2)
    ELtorque1 = ELMAX_TORQUE/2
  EndIf
  ELtorque2 = ELdesTorque - ELtorque1
EndIf

; active damping
/*
; Remark: consider the filtered velocity needs to be checked, because of the steps in
the signal!!!
ELtorque1 = ELtorque1 - ELD1 * (ELvelocityMotor1 - ELvelocityMotor2) - ELD2 *
(ELvelocityMotor1 + ELvelocityMotor2 - 2*ELvelocityLoad/ELGR)
ELtorque2 = ELtorque2 + ELD1 * (ELvelocityMotor1 - ELvelocityMotor2) - ELD2 *
(ELvelocityMotor1 + ELvelocityMotor2 - 2*ELvelocityLoad/ELGR)*/

; saturation

If (ELtorque1 > ELMAX_TORQUE/2)
  ELtorque1 = ELMAX_TORQUE/2
EndIf

If (ELtorque1 < -ELMAX_TORQUE/2)
  ELtorque1 = -ELMAX_TORQUE/2
```

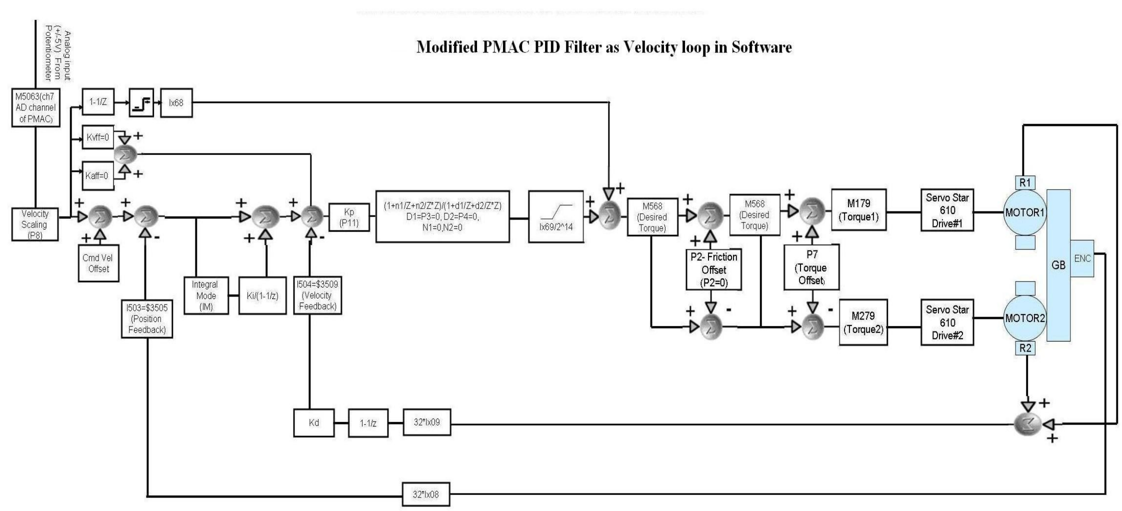
```
EndIf

If (ELtorque2 > ELMAX_TORQUE/2)
  ELtorque2 = ELMAX_TORQUE/2
EndIf

If (ELtorque2 < -ELMAX_TORQUE/2)
  ELtorque2 = -ELMAX_TORQUE/2
EndIf

CLOSE   ; PLC 0
```

5. To start the performance first start PEWIN32PRO software. And download file **bsr_adc_blc_19032010.pmc,** the PLC30 program, given below:

```
I5=3                              ;PLC program ON for enabling in terminal
window.
I7106=$1FFFFF        ;ADC strobe word default value for A/D  conversion.
M5063-> Y:$78115,8,16,S     ;analog i/p connected to channel 7.
M5067-> Y:$7811D,8,16,S    ;analog i/p connected to channel 8.

Open plc30 clear

If(m5063>16383)
   P0=(m5063-32768)*10/16383
Else
   P0= m5063*10/16383
Endif

Close;
```

6. After downloading this file, in terminal window the enable commands should be given: #1o0 #2o0 #5o0 to enable two motors and the feedback loop. Now, for velocity loop feedback the feedback is taken from channel 7. thus channel 5 has to be assigned in channel 7 and it should be enable by #7o0 command from terminal window.
7. To run the PLC30 program ENABLE PLC30 command should be given.
8. The digitized value proportional to the analog value, stored in register M5063 can be seen in channel 7 by following steps: View → Watch window

5.10 Test setup of Velocity Feedback Tunning



FUTURE

At present gmrt is using brushed motors and as we know it is becoming slowly obsolete and the maintenance aspects are increasing everyday, so brushless motors are planned to be replaced in all the 30 antennas. At present test serving is being done in rayshed and all the extensive testing and tuning are being done with these brushless motors in one of these antennas.

At present we are testing with all these antennas with position sensor named Hall Sensor. But it also can be used as sensor less motor.

REFERENCES

- A E Clayton & N N Hancook :“Performance and Design of DC Machine “;

Low Price Edition(1958)

- J. R. Hendershot Jr & TJE Miller "Design of Brushless Permanent – Magnet Motors" ; Magna Physics Publication – Oxford Science Publication(1994) .
- Dr. Duane Hanselman : "Brushless permanent Magnet Motor Design"; second edition, The Writter,s Collective
- Muhammed Rashid: "Power Electronics - Circuits, Devices and Applications"; PHI,Pearson Education N Delhi-1(1994)
- B. L. Theraja & A. K. Theraja :"A Textbook of Electrical Technology"; vol ii in S.I. units (AC & DC machine) ;S Chand & Company LTD (1998)
- H. Cotton :"Advanced Electrical Technology"; Wheeler Publishing (1983)
- http://www.ibiblio.org/kuphaldt/electricCircuits/AC/AC_13.html
- http://www.allaboutcircuits.com/vol_2/chpt_13/6.html
- http://www.google.co.in/images?hl=en&q=dc+motor&um=1&ie=UTF-8&source=univ&ei=KhdQTPiBIsO_rAeJyYz1DQ&sa=X&oi=image_result_group&ct=title&resnum=4&ved=0CD8QsAQwAw
- http://en.wikipedia.org/wiki/Torque