BRUSHLESS DC MOTOR

PROJECT REPORT

KUMARAGURU COLLEGE OF TECHNOLOGY COIMBATORE-6
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CHARACTER IS LIFE

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submitted by

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under the guidance of

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In partial fulfilment of the requirements for the award of the degree of

BACHELOR OF ENGINEERING

In **ELECTRICAL AND ELECTRONICS ENGINEERING**

of the Bharathiar University, Coimbatore

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University Register No. ______________________

This is to certify that the Project work

"BRUSHLESS DC MOTOR"

is a bonafide work carried out by

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In partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Electrical and Electronics Engineering Branch of the Bharathiar University, Coimbatore during the academic year 1995-1996

Station : COIMBATORE

Date : 09.04.96

Guide

Head of Department

Submitted for the University Examination held on ______________

Internal Examinar

External Examinar

EEIPAD/

05th April 1996

CERTIFICATE

This is to certify that the following final year **B E ELECTRICAL AND ELECTRONICS ENGINEERING** students of **KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE** have undertaken a project **"BRUSHLESS DC MOTORS"** during the period , October 1995 to March 1996.

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The above students have taken great interest and have shown immense potential during their project work. Their conduct and character have been good and they have completed the project successfully.

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SYNOPSIS

An innovative work on brushless DC motor has been made in our project. A brushless DC motor of 0.18 hp is designed and fabricated. The C software has been used for the design aspect of the same.

A brushless DC motor is a motor without brushes. The commutator and carbon brushes are being eliminated in this motor. The problem of commutation is solved using electronic commutation. The characteristics of the brushless DC motor is more or less similar to the conventional DC motor. The commutation for brushless DC motor is done by sensing and switching which is of several types. In this brushless DC motor the sensing is done magnetically and switching by power transistors. Test results are presented in this report.

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NOTATIONS

K_{ws} : Winding Factor

d : Diameter

q : Input KVA

C_o : Output Coefficient

ac : Ampere Conductors

fp : Flux per Pole

t : Stator turns per phase

lmt : Length of mean turn

ts : Total stator conductors

z : Conductors per slot

cd : Current density

rs : Resistance of winding

b_{t60} : Flux density in stator teeth

ay : Area of yoke

lg : Air gap length

lgc : Effective airgap length

ag : Area of airgap

b_{g60} : Flux density in airgap

atg : mmf in airgap

app : Area per pole

dt : Depth of stator slot

a_{t60} : Total mmf

im : Magnetising current

vt	:	Volume of stator teeth
wt	:	Weight of stator teeth
mf	:	Maximum flux density in stator teeth
wy	:	Weight of yoke
yf	:	Flux density in yoke
lot	:	Loss in teeth
loy	:	Loss in yoke
fww	:	Frictional and windage loss
cul	:	Copper loss
tlo	:	Total lossess in the machine
eff	:	Final efficiency

CHAPTER 1

INTRODUCTION

A brushless DC motor is a polyphase motor with a permanent magnet rotor. This motor cannot operate without its electronic controller. Therefore, a brushless DC motor is a motor drive system that combines into one unit an AC motor, solid state inverter and a rotor position sensor. The solid state inverter uses transistors for low power drives and thyristors for high power drives. Rotor position sensor monitor the shaft position and sends the control signal for turning on the controlled switches of the inverter in an appropriate sequence.

A brushless DC motor is also viewed as **"inside-out"** DC motor because its construction is opposite to that of a conventional DC motor. It has permanent magnet field poles on the rotor and polyphase armature winding on the stator. fig (1.1)

The functions of mechanical commutator in a conventional DC motor is now performed by electronic commutator in a brushless DC motor. This motor possesses several advantages over conventional DC motor as outlined below.

1.1 ADVANTAGES

- As no mechanical commutator and no brushes are required, it has longer life.
- Problems relating to the radio frequency and electromagnetic

interference are minimized.

- It can run at speeds much higher than those obtained in a conventional DC motor.
- Brushless DC motors are more efficient.

The performance requirements are:

- Open loop, on-off applications
- Unidirectional speed-control motor systems
- Bidirectional speed-control motor systems
- Unidirectional speed-control systems able to handle over running loads
- Torque motors able to operate at stalled conditions
- Low inertia servo motors able to handle acceleration torque demands one order of magnitude larger than the continuous torque
- Servomotor with low torque-ripple specifications, in either low inertia or high inertia versions .

This discussion holds good for brushless DC motor systems.

1.2 THREE PHASE THREE PULSE BRUSHLESS DC MOTOR

Fig (1.2) shows an elementary form of 3-phase, 3-pulse brushless DC motor along with its electronic controller. The stator has three phase windings which is star connected. The neutral, or star point of the winding is connected to positive terminal of the DC supply. The three power transistors TR_1, TR_2 and TR_3 are turned on in appropriate sequence so that unidirectional torque is developed. When TR_1

is turned on, phase A is energised, when TR_2 is on, phase B is energised and so on. When phase windings are energized in sequence ABC, the rotor rotation is clockwise. With sequence ACB, the rotor revolves anticlockwise.

The rotor-position sensor mounted on the motor shaft provides a position feedback. It monitors the shaft position and sends signals to the drive circuitry of the inverter circuit. In response to these signals, the invertor allows the flow of current to stator phase windings in a controlled sequence so that motor produces the desired torque and speed. The commonly used rotor-position sensors are Hall-effect sensors and electro optical sensors.

1.3 BASIC OPERATING PRINCIPLE

Fig (1.3) shows an elementary form of three-phase stator winding and the permanent magnet rotor with two poles. When phase A is energized, stator S and N poles are created as shown. Stator S pole repels rotor S pole and attracts rotor N pole, thus producing clockwise torque. The magnitudes of this torque is given by

$$T = k * \phi_1 * \phi_2 * \sin\theta \qquad (1.1)$$

where ϕ_1 = stator field flux

ϕ_2 = rotor field flux

θ = torque angle

k = torque constant

strength of rotor field flux ϕ_2 is constant as it is produced by permanent magnets.

The magnitude of stator is proportional to stator current. As the stator current is constant, the stator field flux ϕ_2 can also be treated constant. In view of this, the torque expression for phase A is

$$T_{ea} = k * I * Sin\theta \qquad (1.2)$$

where I = constant stator current in phase A

As by above equation, torque developed by phase A caries sinusoidally with torque angle θ as shown in fig (1.4a) As axis of phase winding B is displaced by 120° from phase A axis, the torque T_{eb} developed by phase B is shifted by 120° from torque T_{ea} as shown in fig (1.4b). Similarly, torque developed by phase C is sketched as T_{ec} in fig (1.4c). Actually, for the operation of this motor as a brushless DC motor, phase winding A is energized through transistor TR_1 of fig (1.2) from instant 1 ($\theta = 30^{\circ}$) to instant 1′ ($\theta = 150^{\circ}$) so that positive torque T_{ea} is developed, fig (1.4d). From space instant 2 ($\theta = 150^{\circ}$) to instant 2′, phase winding B is energized through transistor TR_2 for 120° so that positive torque T_{eb} is developed. From space position 3 ($\theta = 270^{\circ}$) to instant 3′, phase winding C is excited through transistor TR_3 for 120° so that positive torque T_{ec} is produced. After this, phase winding A is again energized so as to result in continuous clockwise rotation of the brushless DC motor, each winding conducts for 120° intervals in each cycle of 360°.

On examination of fig (1.3) and fig (1.4) shows that reversal of rotation is possible if the transistor conduction is delayed by 180° electrical; from instant at 4 to 4′ for phase winding A, from instant 5 to 5′ for phase winding B etc. Reversal of the direction of rotation is also possible of the sequence of turning on the stator winding is reversed.

In case phase windings carry instantaneous currents Ia , I_b and I_c ; the instantaneous torque, from equation 1 and fig (1.4) can be expressed as

$$T_{ea} = k * I_a * \sin\theta \quad (1.3)$$
$$T_{eb} = k * I_b * \sin(\theta\text{-}120) \quad (1.4)$$
$$T_{ec} = k * I_c * \sin(\theta\text{-}240) \quad (1.5)$$

if phase currents are assumed to vary simultaneously with θ, then

$$I_a = I_m * \sin\theta \quad (1.6)$$
$$I_b = I_m * \sin(\theta\text{-}120) \quad (1.7)$$
$$\text{and} \quad I_c = I_m * \sin(\theta\text{-}240) \quad (1.8)$$

with these currents, the torque expressions for the three phases become

$$T_{ea} = k * I_m * \sin^2\theta \quad (1.9)$$
$$T_{eb} = k * I_m * \sin^2(\theta\text{-}120) \quad (1.10)$$
$$\text{and} \quad T_{ec} = k * I_m * \sin^2(\theta\text{-}240) \quad (1.11)$$

Resultant torque,

$$T_{er} = T_{ea} + T_{eb} + T_{ec} \quad (1.12)$$
$$T_{er} = k * I_m * [\sin^2\theta + \sin^2(\theta\text{-}120) + \sin^2(\theta\text{-}240)]$$
$$= 3/2 * k * I_m \quad (1.14)$$

The equation 1.14, shows that the shaft torque is independent of rotor position θ, and has linear relationship with current amplitude as in a conventional DC motor. It is seen from fig (1.4) that actually the motor torque developed in a brushless DC motor consists of torques pulsations. The ripple content in the torque profile and the torque fluctuations can be reduced if four phase ,four pulse or three phase six pulse brushless DC motors are used. For four phase, four pulse and three phase and six pulse motors, each winding would conduct for 90° and 60° respectively.

1.4 DEFINITION OF BRUSHLESS DC MOTOR SYSTEM

A brushless DC motor systems should have the torque-speed characteristics of the conventional DC permanent magnet motors. The fig (1.5) illustrates the torque-speed characteristics of a conventional DC motor hence the brushless DC motor should have the same characteristics.

The controllable AC motor system depends on a variable frequency, variable AC voltage, which has to be coordinated with the short velocity to produce a controlled **"slip frequency"** current in the rotor windings. Because the rotor-stator structure can be considered a transformer, it does not work well at low frequencies (which corresponds to low shaft speed). This is a fundamental difference between the AC motor and brushless DC motor, since the later torque is produced by the interaction of a magnetic field produced by a permanent magnet rotor, and magnetic field due to a DC current in a stator structure.

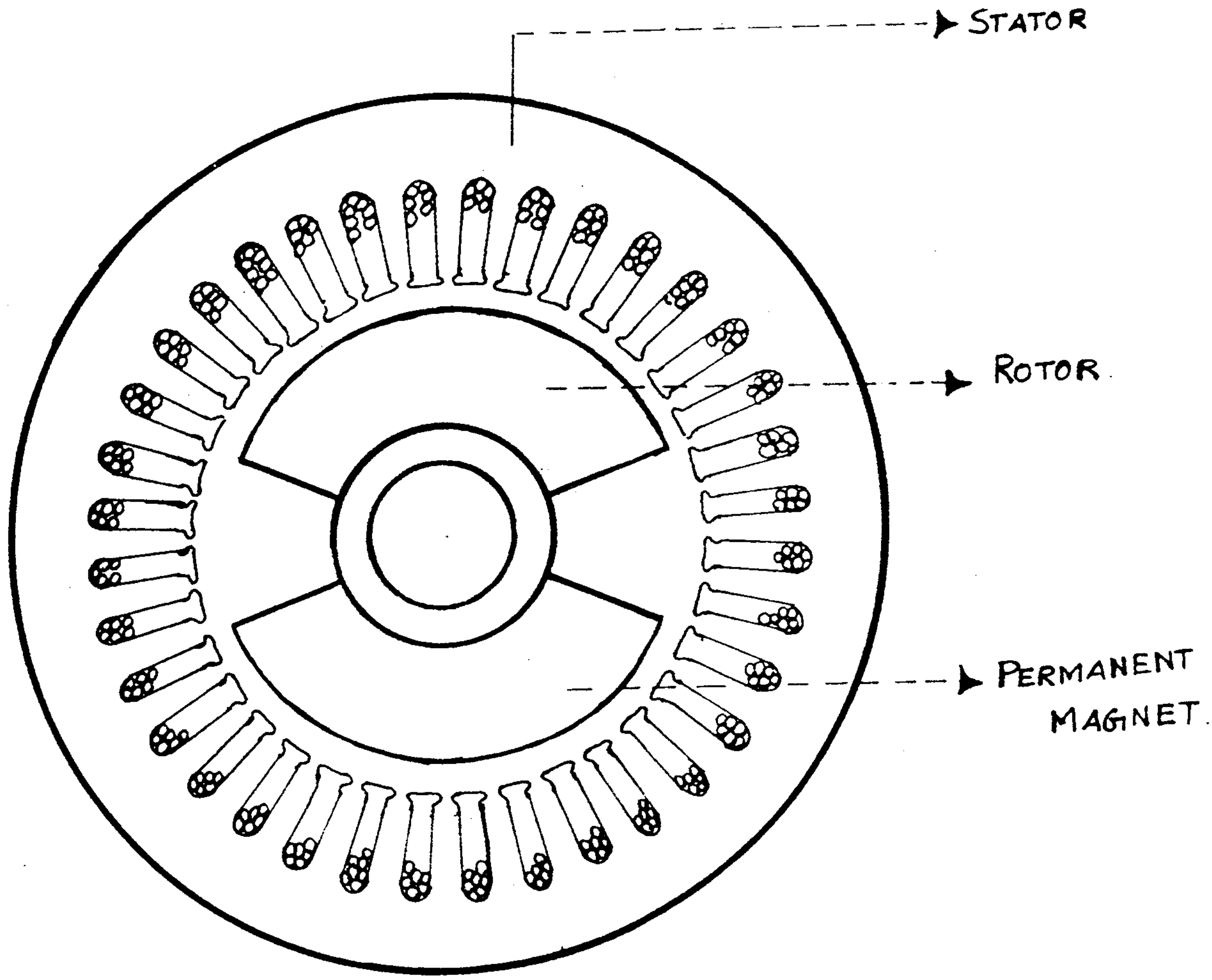


Fig 1.1
CUT-AWAY VIEW OF BRUSHLESS DC MOTOR ASSEMBLY

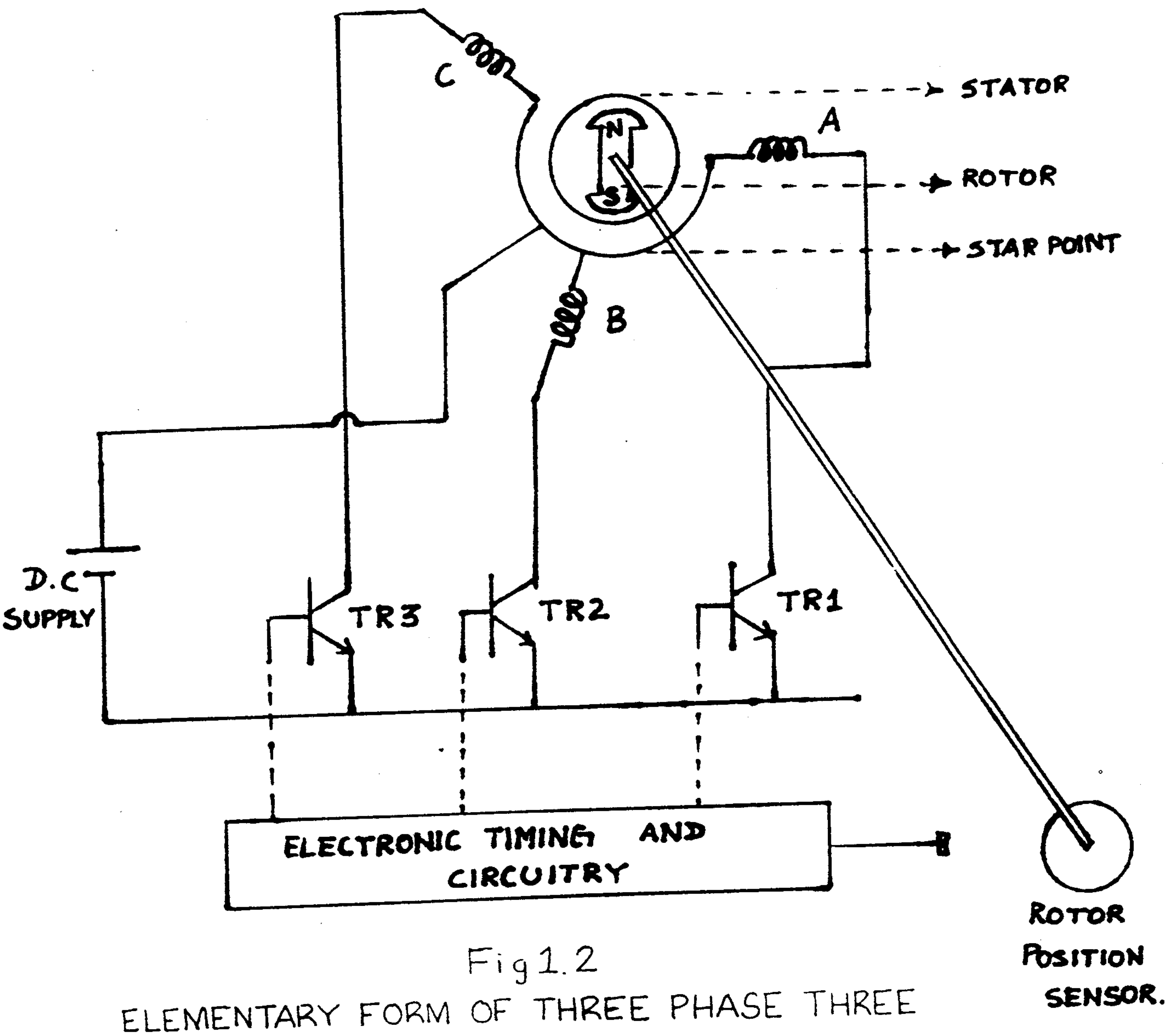


Fig 1.2
ELEMENTARY FORM OF THREE PHASE THREE PULSE BRUSHLESS DC MOTOR

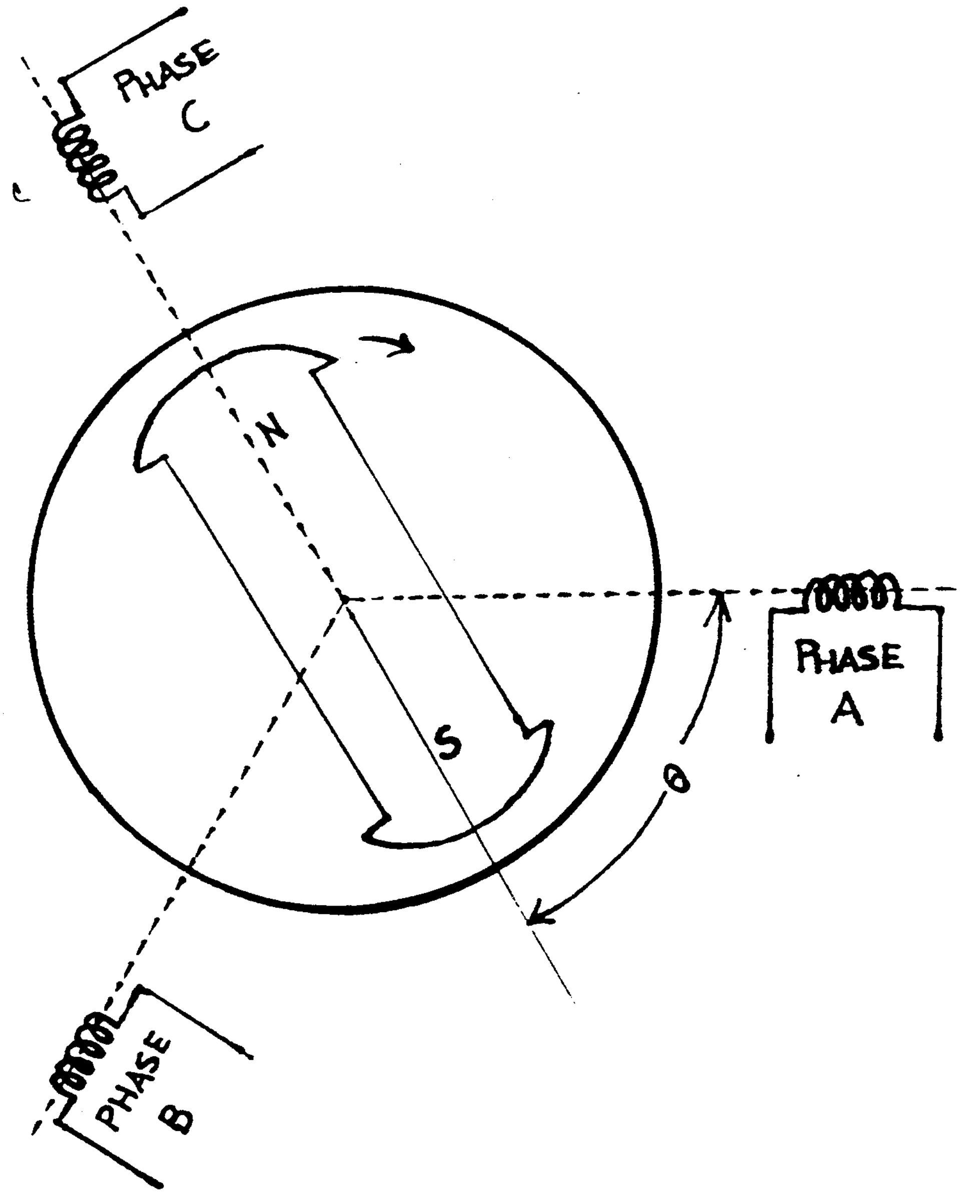


Fig 1.3
OPERATING PRINCIPLE

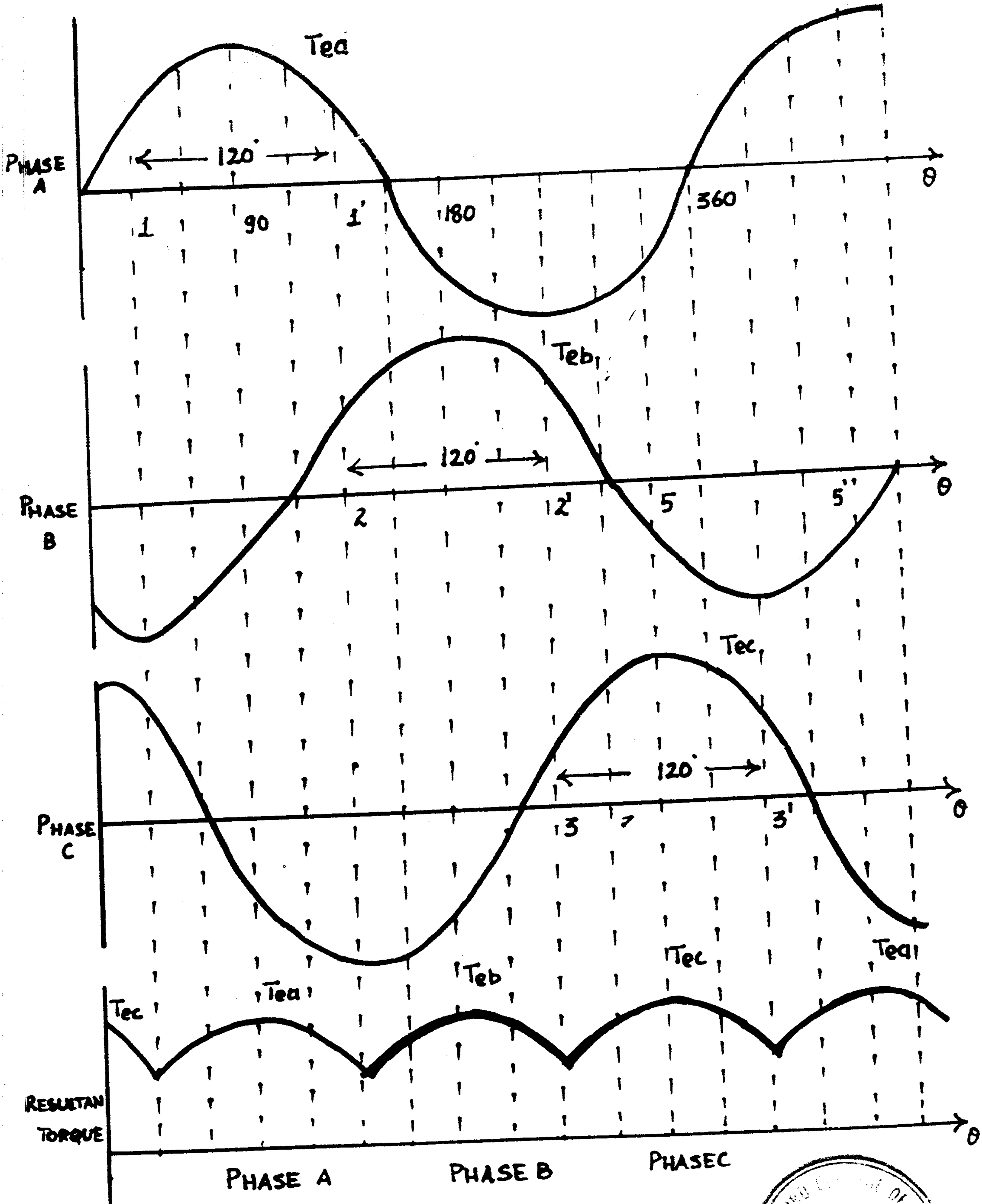


Fig 1.4 a,b,c,d
TORQUE ANGLE CHARACTERISTICS

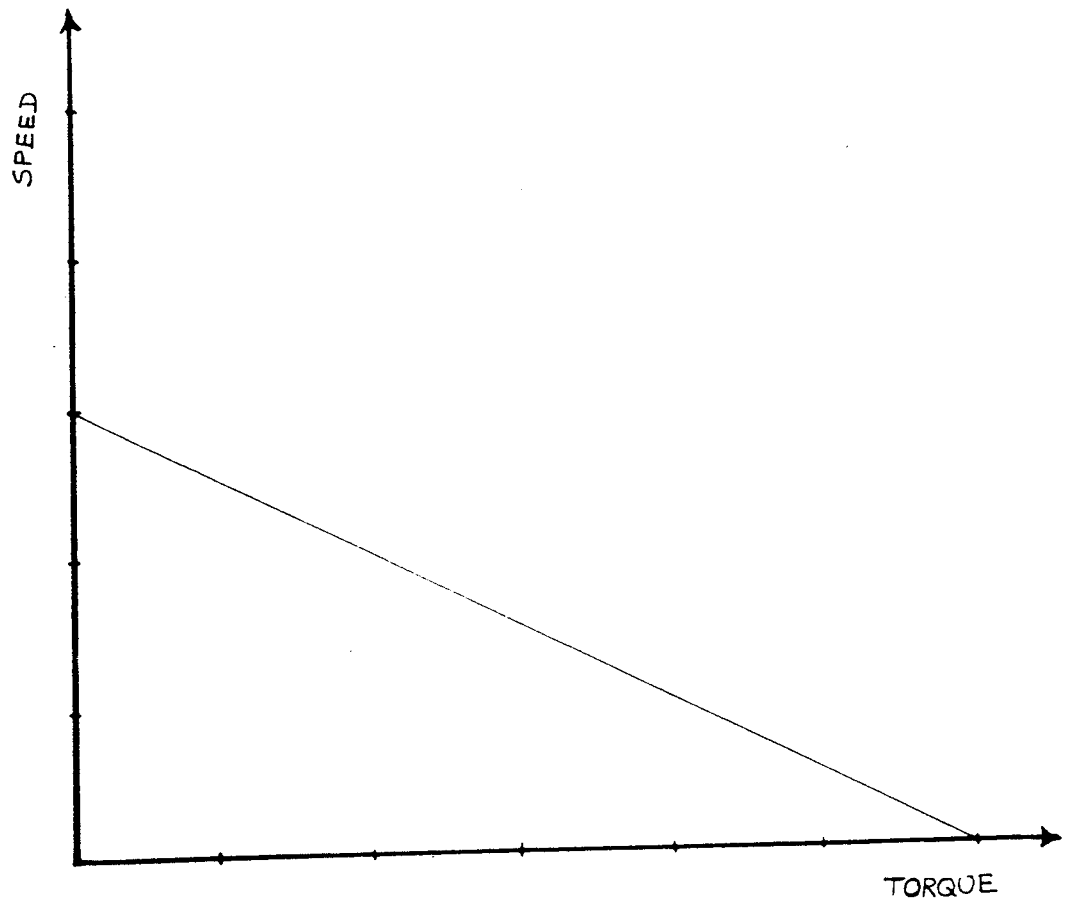


Fig 1.5

TORQUE - SPEED CHARACTERISTICS

CHAPTER 2

PERMANENT MAGNETS

2.1 INTRODUCTION

Almost all permanent magnets are **"Tailor -Made"** to suit the requirements of the customer. TO select the type of the magnet the following considerations should be followed.

1. Magnetic property.
2. Shape and size.
3. Temperature.

2.2 MAGNETIC MATERIALS

2.2.1 Ferrite (Ba OR Sr) Permanent magnets

Features

Ferrite permanent magnets are fabricated by powder metallurgy method, their remanence and reversibility are low. Coercivity is high, so they have less action of demagnetizing field and are suitable to dynamic application. Because of their low density, these magnets have a light weight, these magnets cost is low compared to ALNICO, Fe-Cr-Co AND Re-Co. They are suitable used in instrument, meter, electro acoustic device, micro-motor, duplicator, following machine, magnet-medieval apparatus.

2.3 CAST ALNICO MAGNETS

Cast ALNICO magnets are one of the most widely used permanent magnets. These are a series of alloys consisting of basic raw materials like aluminum, nickel, cobalt, iron, etc. They are characterized by excellent temperature stability and high resistance to demagnetization from vibration and shock. Being hard and brittle, the only possible way of machining is grinding.

Cast Al-Ni-Co magnets possess a higher remanence and excellent stability. The lover remanence temperature coefficient make these magnets to be demagneted less in the conditions of wider range temperature.

2.3.1 ALNICO III

They are isotropic magnet i.e.; they exhibit equal magnetic properties irrespective of the direction in which they are magnetised. They are useful when multipolar configurations are desired.

2.3.2 ALNICO V

These are anisotropic magnets i.e., they exhibit stronger magnetization properties in the direction of magnetisation. Simple configurations such as straight, horse shoe of circular shapes for common applications like loud speakers, pa systems, energy maters, measuring instruments, magnetic chucks, 'V'-blocks, separators, holding devices etc. are manufactured in ALNICO V because of the high energy product of these magnets.

2.3.3 ALNICO VDG

Cast ALNICO VDG is an improved grade of ALNICO V and has the highest value of energy of any presently available permanent magnet alloy. This material is produced by a special process which aligns the crystals of the magnets in the direction of magnetisation.

2.3.4 ALNICO VI

This has a higher coercive force & lower residual induction & energy product than ALNICO V magnet material. It also exhibits directional properties.

2.3.5 ALNICO VC

This is the improved version of ALNICO VI having higher coercive force but slightly lower residual induction & energy product than ALNICO V magnet material. It exhibits directional properties.

A thorough study of the above magnetic materials reveals that **ALNICO III** is well suitable for brushless DC motor. It is very important to study the direction of eventual magnetisation. Magnets should be free form imperfections which will result tin loose chips or particles under normal conditions of handling assembly & service.

CHAPTER 3

COMMUTATION SENSOR SYSTEM

Several methods are available today for the angular position sensing systems.

3.1 HALL EFFECT SENSORS

The **Hall effect sensing systems** utilises the sensor which detects the magnitude and polarity of a magnetic field. The signals are amplified and processed to form logic compatible signal levels. The sensors are usually mounted in the stator structure, where they sense the polarity and magnitude of the permanent magnet field in the air gap. The output of these sensors control the logic functions of the controller configuration to provide current to the proper coil in the stator, and the system can provide some compensation for armature reaction effects which are prominent in some more designs.

3.2 ELECTRO OPTICAL SWITCH

The angular sensing is the **electro - optical switch**, most commonly a combination of light emitting diode (LED) and a photo transistor. A shutter mechanism controls light transmission between the transmitter and the sensor. The sensor voltages can be processed to supply logic signals to the controller.

3.3 RADIO FREQUENCY SENSOR

The **radio frequency sensing** is based on inductive coupling between RF coils. The angular sensing accuracy of such devices depends on several design factors, which may limit their use in high performance systems.

3.4 PHOTOELECTRIC SENSORS

NON-CONTACT SENSING OF OBJECTS OF THE MOST DIVERSE MATERIALS USE

* Photoelectric detection modes:

  - ▶ Diffuse mode
  - ▶ Convergent mode
  - ▶ Reflective mode
  - ▶ Opposed mode

* Fibre optics operation

* Modulated beam No influence of ambient light

3.4.1 OPERATING PRINCIPLE

The principle of photoelectric detection is based on a beam of light emitted by the sensor being affected by the object into be detected, the result being evaluated by a sensors receiver. An object entering the light being will both obscure the beam and reflect some light back towards the sensor.

The sensor output is activated when light is received, known as **"light operated"**, are when the is interrupted and the light level falls, known as **"dark operated"**. The light level at which the sensor is switched is determined by several factors including reflectivity of the target and sensitivity.

Modulated light is used throughout the range of photoelectric sensors virtually eliminate the **effects of ambient light**.

3.4.1.1 SIGNIFICANCE OF LIGHT SPECTRUM

Photoelectric sensors employ light of the following types,

- ▶ Visible red : 650 nm
- ▶ Visible green : 510 nm
- ▶ Infrared : 800.....940 nm

Different light sources have advantages in particular situations, for example, infrared light has a high sensing range and is useful for detecting objects independent of their colour.

Visible red or green light is particularly useful for contrast detection. The colour of the light has to be chosen in accordance with the colour of the object. Red objects or red colour markings are easily detected with green light (complementary colours).

3.4.2 DIFFUSE REFLECTIVE SENSORS

Diffuse reflective sensors combine both emitter and receiver in one housing. Light emitted by the sensor is reflected by the object back into the receiver.

3.4.3 CONVERGENT SENSORS

Convergent sensors operate in a similar way to diffuse as reflective devices. However emmiter and receiver are focused at a defined distance. Only objects present at the focal point will operate the sensor.

3.4.4 RETRO REFLECTIVE SENSORS

Retro-reflective sensors incorporate both emmiter and receiver devices but unlike other modes employs a reflector to return the beam to the sensor. Objects passing between the sensor and reflector will reflect light much less efficiently than the reflector and thus break the beam.

3.4.5 OPPOSED SENSORS

Opposed sensors are based on separate emmiter and receiver units, the beam being established between the two devices. Objects passing between the emmiter and the receiver will obscure the beam and operate the receiver.

3.4.6 RELIABLE OPERATION OF PHOTOELECTRIC SENSORS

There are three main factors which affect the reliable operation of photo-electric sensors.

1. The emitter light intensity.
2. The reflectivity of the detected object.
3. Environmental conditions, i.e., dirt, smoke, etc.

In order to determine operating distances for photoelectric sensors, excess gain curves have been produced for each model.

Excess gain curves are based on target reflectivity of 90% (KODAK WHITE TEST CARD).

These sensors are with Alignment Indicating Device.

This system simplifies the alignment and adjustment for all applications. The alignment indicating device has **dual function:** It is illuminated when the object has been seen and the output is activated. A pulse rate is superimposed on the indicator, the frequency of which is determined by the strength of the signal received.

For excess gain of 1 (low range limit) the indicator pulse rete is 1 Hz, which is not sufficient for reliable operation. A pulse rate of three Hz or above operates the indicator within acceptable limits. The receiver sensitivity can be adjusted by an internal potentiometer to provide the require excess gain.

The advantages of the AID-system (Alignment Indicating Device) are clearly apparent when aligning opposed or retro-reflective sensors over long distances.

3.4.7 ADJUSTING HINT

By moving the receiver in the light of the emmiter it is possible to obtain the best alignment by monitoring the rate of the flash of the indicator LED. When using retro-reflective sensors either the reflector or the sensor may be adjusted to achieve to the highest pulse rate. In this way it is easy to achieve optimised sensor alignment. For all devices, the rate of the flash is in proportion to the light gain **"high rate of flash, high light gain, correct alignment"**.

All the above modes can be implemented using FIBRE-OPTICS

3.5 FIBRE-OPTICS

Sensors employing fibre-optics are particularly suited to the following applications:

- ▶ for detection of small objects.
- ▶ where high temperatures are present.
- ▶ in the vicinity of strong electro-magnetic fields.
- ▶ where space is critical.

3.5.1 FIBRE OPTICS

FIBRE OPTICS consists of high quality fibre enclosed in a protective sheath. Particular care is taken during the manufacture of fibre-optics to ensure that transmission properties of the ends of the fibres are optimised. High quality shearing material enables fibres to be used over a wide temperature range.

3.5.2 GLASS FIBRE-OPTICS

Glass fibre-optics consists of many separate fibres which are combined in a bundle of upto 3mm diameter. The bundles are secured in the end sleeves with a high quality adhesive. The end faces of fibres are polished for optimum optical performance.

Each single glass fibre consists of an inner core with different reflective index to the surrounding glass, enabling the light to be directed down the centre of the fibre without ever contacting the outside. This ensures if very low attenuation, independent of bending radius.

The **insertional loss** for fibres is less than 0.3 dB/m. This value is negligible in practise. Excess gain curves are included for fibre-optics applications, the fibre-optic attenuation in these cases is included in the characteristics of the base unit.

3.6 REFLECTORS

3.6.1 Retro-reflective targets

Reflector targets have very high reflectivity due to their structured design. An important characteristic of this type of reflector is that light is reflected back along the same path has it entered the reflector, provided the incident light is within ±15 degrees of the perpendicular. This simplifies alignment since provided these conditions are met, the target will reflect upto 90% of the incident light back to the sensor. For large angles, the reflector efficiency decrees rapidly.

3.6.2 FOIL REFLECTORS

Foil reflectors achieve a reflectivity of approximately 30%. The acceptence angle for these reflectors, however is much more than for triple reflectors.

The effective sensing distance of **retro-reflective sensors** is dependent on environmental conditions and reflector size, and is independent of object reflectivity. Where **shiny objects** may cause false signals, sensors with **anti-glare (polarising) filters** must be used. In this way the sensor is able to discriminate between reflections from shiny objects and those_from triple retro-reflective targets which rotate the polarisation plane by 90 degrees.

The most commonly used methods are Hall effect sensors, electro optical sensors and radio frequency (RF) sensors.

CHAPTER 4

CONSTRUCTIONAL DETAILS

4.1 STATOR

Stator is a cylindrical structure made up of dynamo grade laminations which are of 0.35 or 0.5 mm thick. For motors of larger size the stator cores are made of segmented laminations. The peripheral length of one segment, usually between 0.3 to 0.6 metres, is chosen to give most economical balance between the cost of dies, the cost of assembly and the amount of scrape left over in cutting the laminations from steel strips. The total number of segments is chosen in such a way as to provide an equal number of turns in the core flux paths of alternating poles. This because if the flux leaving the stator core from every south pole encounters a core joint when it turns anticlockwise, and no joint when it enters clockwise, the difference reluctances offered to the two paths will result into a net difference between the core fluxes in two directions of flow, and the resultant flux links with the shaft. This resultant flux produces an alternating voltage between the two ends of the shaft, giving rise to shaft currents which in turn may cause damage of bearings, unless the bearings are insulated from the end shields.

We have used a standard stator stamping 1071.2P which is of 36 slots Fig (4.1).

4.2 STATOR FRAMES

Frames of electrical machines are structures in which stator core is assembled. They serve for distinct purposes.

- They enclose the core and windings
- They shield the live and moving machine parts from human contact and from injury caused by intruding objects or weather exposure.
- They transmit the torque to the machine supports, and are therefore designed to withstand twisting forces and shocks.
- They serve as ventilation housing or means of guiding the coolant into effective channels.

4.3 ROTOR

Rotor cores are of small machines are often put on the shaft directly and keyed to it for transfer of torque. Washers or thrust rings are used for axial clamping. The thrust ring is put on the shaft when hot and on cooling the ring grips the shaft. In order to provide paths for ventilating air radial and axial ducts are used. The number of radial ventilating ducts provided in the rotor is equal to that in the stator.

Since there is no commutator segments and carbon brushes we go for a permanent magnet rotor. The rotor is made of solid cylindrical mild steel core upon which the magnets are being placed. This whole structure forms the rotor.

The cross-sectional view of the brushless DC motor and the layout of the stator, rotor, end coverings are shown in fig (4.1) and fig (4.2) respectively.

CHAPTER 5

COMMUTATION

According to the design philosophy the control unit should have least number of power semiconductor switches to adequately meet the performance requirements. The permanent magnet is used in order to eliminate the need for slip rings in the rotor assembly.

5.1 ELECTRONIC COMMUTATION

Since the performance of brushless DC motors is intimately tied to the commutation of current in motor windings, it may be appropriate to briefly review the commutation of conventional DC permanent magnet motors. The main reason for dividing a conventional DC motor winding system of winding inductance as it related to the turn-on and turn-off behavior of current in a segment. A secondary reason for the choice of the appropriate number of winding segments is to control the torque ripple. Thus we find that a fractional horse power DC motor may have anywhere from 7 to 32 commutator bars per armature and an integral horse-power motor below 5 to 10 hp may have less than 100 bars per armature.

The commutation event is not usually viewed on an oscilloscope screen, except as seen from outside the rotor brush connections-the reason being that it is not easy to reach proper internal test points in a rotating structure. The results are viewed from the observers point by recording emitted radiation, brush and commutator heating and erosion of commutation surface or brush surface.

Electronic commutation is the heart of any brushless systems. Electronic commutation consists of a sensing curcuit, timing circuit, and switching circuit. The commutation in the conventional DC motors is done mechanically using commutator segments and carbon brushes. In electronic commutation both the commutator segments and carbon brushes are eliminated.

Here the selection and energisation of armature coils is done electronically. Electronic in the sense, the coils are energised using semiconductor devices. Mostly transistors are used for this purpose. Power transistors are used in lower rated machines whereas thyristors are used in higher rated machines.

Usually the stator coils are divided into many phases. As the number of phase increases, the accuracy of sensing and switching increases. As we contemplate the desirability of using semiconductor devises for commutation of DC permanent magnet motor we are faced with a set of new problems, and a simple translation of the brush-type motor designed to a brushless type is not practical. For example, if we take a 16 bar, two-pole DC motor and were to substitute semiconductor devices for the brush and commutator assembly to achieve the same function, we would end up with 32 power transistors, two of which would be conducting at any one given time. It would then result in a very inefficient use of semiconductors - a utilization factor of about 6%. Obviously the problem has to be solved in a new way to achieve cost effective performance.

Before we discuss brushless motor principles, let us remember the varying design constraints which conventional DC motors to face and the varying applications which exists today.

5.2 PRINCIPLE

Electronic commutation is done by sensing the rotor position and energising the appropriate coils. The sensing can be carried by several methods as explained in the previous section.

The energising of the coil is done by giving an impulse from the sensing to the switching circuit. Proper timing and sequence of switching the coils is needed for continuous rotation.

In our brushless DC motor, we have used a magnetic sensing and switching. Reed switches which are operated by magnetic field are used here. We have divided the stator coils into three phases so that each phase are placed for 120 degrees. The stator coils are connected in star. As there are three phases we go for three reed switches and three power transistors. These three reed switches are placed at 120 degrees in the motor front cover.

A small piece of magnet is placed in a aluminium disc and this disc is connected to the shaft of the motor. The magnet is placed in the disc in such a position that the magnet and the rotor pole lie in same straight line. The distance between the aluminium disc and the reed switches are usually maintained in millimeters.

We have used power transistors as drivers. The three phase of the stator coils are connected respectively to the collector terminals of the three transistors. The base of the transistors are connected to the power supply through reed switches and all the emitter terminals are grounded. The Circuit diagram is shown in fig (5.1) base-emitter voltage is fixed such that all the three transistors operate in saturation region.

Whenever the external magnet placed in the shaft crosses the reed switch placed in the motor cover, the reed switch is operated i.e., closed and energizes the particular phase. Since rotor is a permanent magnet and the stator is energised using DC supply like pole is created in the stator. This creates a force of repulsion and the rotor moves to the next position activating the second reed switch and so on. This results in continuous rotation. The speed control of this motor can be achieved by varying the supply voltage and by appropriate switching control.

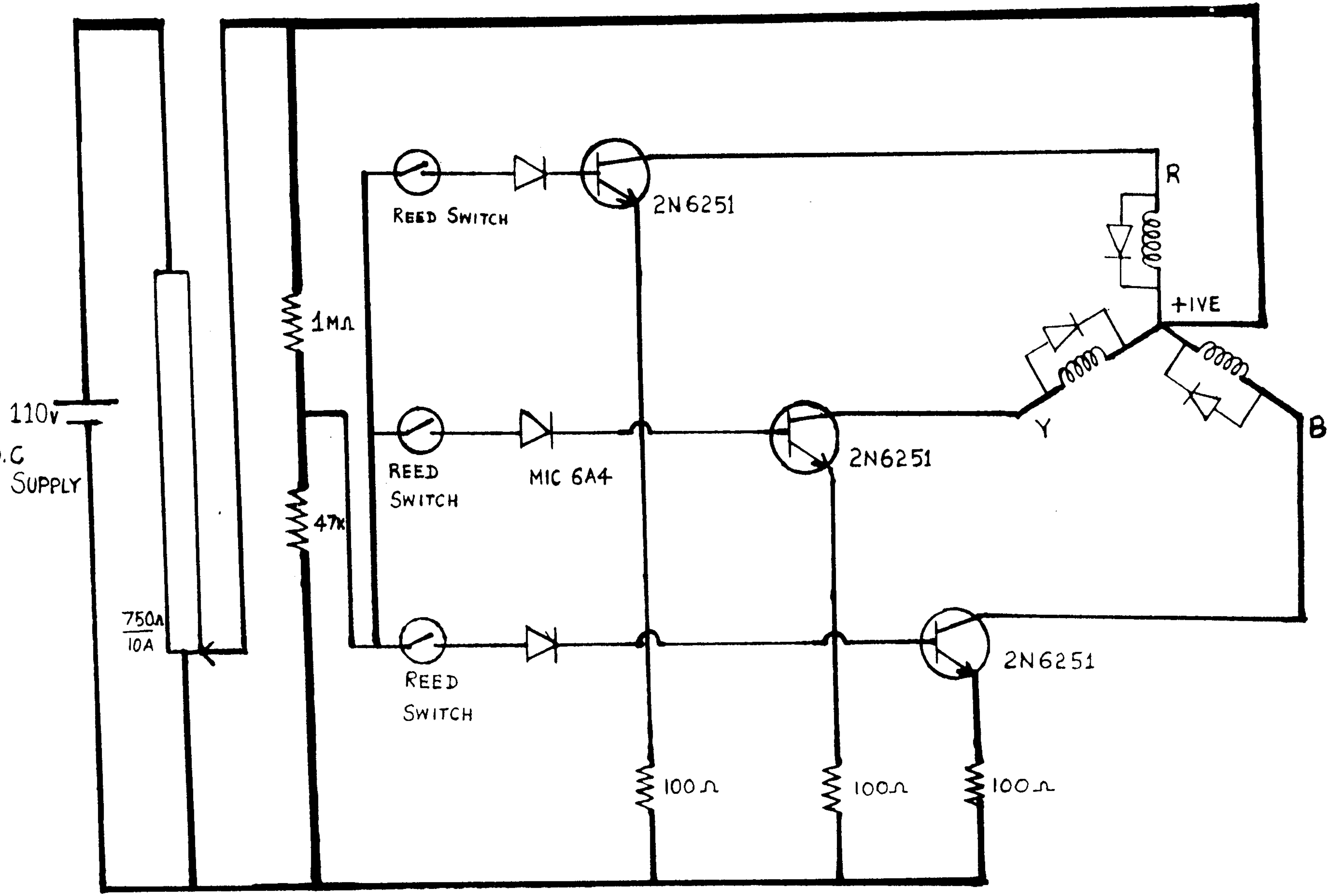


Fig 5.1 ELECTRONIC COMMUTATION CIRCUIT.

CHAPTER 6

DESIGN ASPECTS

6.1 INTRODUCTION

Design may be defined as a creative physical realization of theoretical concepts. Engineering design is application of science, technology and invention to produce machines to perform task with optimum economy and efficiency.

6.1.1 OUTPUT EQUATION

KVA i/p $Q = C_o * d^2 * l * ns$ 1

Output coefficient $Co = 11 * K_w * B_{av} * ac/1000$ 1.1

from 1 $d^2 * l = Q / (C_o * ns)$

KVA i/p $= K_w$ / eff

The rating in hp is $Q = hp * 0.746/eff$

6.1.2 MAIN DIMENSION

The product $d^2 * l$ is split up into two components d and l. The ratio of core length to pole pitch (l/τ) for various design features are

Minimum cost ⇨ 1.5 to 2

Good efficiency ⇨ 1.5

Good overall design ⇨ 1

By selecting the proper l/τ ratio diameter and length of the rotor is found out.

6.1.3 NUMBER OF STATOR SLOTS

The following factors are considered in selecting the number of stator slots.

- **Tooth Pulsation Loss:** Using large number of narrow stator slots tooth pulsation losses and noise can be minimised.
- **Leakage Reactance:** As the number of slots increases, the overload capacity decreases which inturn increases the leakage reactance.
- **Magnetising Current and Iron Loss:** Use of large number of slots results in higher iron area, hence excessive flux density in teeth giving rise to higher magnetising current and higher iron loss.
- **Cost:** With larger number of slots there are larger number of coils to wind, insulate and instal involving higher costs.

6.1.4 SIZE OF STATOR SLOTS

Insulation of winding is usually 0.3 to 0.4mm thick. The ratio of insulated conductor area to that of slot area should never exceed 0.5. This ratio doesn't exceed 0.35 if the winding process is made easy.

6.1.5 STATOR WINDINGS

Single layer lap type windings with diamond shaped coils is generally used for stators. The three phases of the winding can be connected either star or delta depending upon our requirements.

In our brushless DC motor we use **three phase, two pole star** connected single layer lap winding.

6.1.6 CHOICE OF AMPERE CONDUCTOR PER METRE

- **Copper Loss:** A larger value of ampere conductors results in a greater value of copper employed in turn results in higher copper loss and large temperature rise.
- **VOLTAGE:** Selection of ampere conductors should be small for high voltage machines as the space for insulation is large.
- **OVERLOAD CAPACITY:** Larger value of ampere conductors will result in larger number of turns. This means the leakage reactance of the machine would become high and would result in reduced value of overload capacity.

For induction motors the value of ampere conductors normally lies between 4000 to 12000 (ac/m).

Flux per pole $\phi_m = B_{av} * \pi * D * L/P$

Total stator turns per phase $T_m = E/(4.44 * f * \phi_m * k_{wm})$

Total stator conductors $ts = 3 * 2 * t$

conductors per slot $z = ts/ns$

Current density $\rho = i/as$

The current density in the stator winding is usually between 3 to 5 A/sq.mm. For lower values of current, round conductors would be most convenient to use for higher values of current bars or strips conductors are used.

Net iron length $lt = 0.9 * l$

Area of teeth $at = ns * w * lt/p$

The dimension of slot determines the value of flux density in the teeth. Higher value of flux density leads to a higher value of iron loss and a greater magnetising mmf.

Flux density in stator teeth $b_t = f_p * 2/(ns * w * lt)$

$b_{t60} = 1.36 * b_t$

6.1.7 STATOR TEETH :

Care must be taken while selecting the stator stamping such that the flux density in the stator teeth is not very excessive. The stator teeth density bt60 can generally vary from 1.4 to 1.7 Wb/m^2. The flux density in the stator teeth should be less for the losses and noises to be low. For general purpose machines a flux density may vary from .1 to 1.65 Wb/m.^{2} for high torque it may go up to 1.8 Wb/m^2.

The maximum flux density in iron parts is directly proportional to the average flux density in the air gap. The maximum value of flux density in teeth occurs where the tooth width is smallest.

Area of core = **lt * yt**

Flux density in core = **1.1 * b_t**

6.1.8 STATOR CORE :

The flux density in the stator core should not exceed 1.5 Wb/m^2. Generally it lies between 0.8 to 1.5 Wb/m^2.

6.1.9 LENGTH OF AIR GAP

The following factors should be considered when estimating the length of the air gap.

- **Power Factor:** By reducing the length of air gap we can increase the power factor.
- **OverLoad Capacity:** The length of air gap affects the value of zig-zag leakage reactance which forms a large part of total leakage reactance in the case of induction motors. If the length of air gap is large, the zig-zag leakage flux is reduced resulting in a reduced value for leakage reactance. So the overload capacity will increase.
- **Pulsation loss:** For larger air gaps pulsation loss is less.

- **Pulsation loss:** For larger air gaps pulsation loss is less.
- **Unbalanced magnetic pull:** If the length of air gap is small even a small deflection or eccentricity of the shaft would produce a large irregularity in the length of air gap and is responsible for the production of large unbalanced magnetic pull.
- **Cooling:** If the length of air gap is large the distance between the stator and the rotor is large. This provides better ventilation and hence cooling.
- **Noise** : The noise of the motor is reduced by increasing the length of the air gap.

The following empirical relation gives the value of length of air gap in millimeter.

(i) $l_g = 0.007 \times d/\sqrt{p}$

(ii) $l_g = 0.2 + 2\sqrt{(d * l)}$

(iii) $l_g = 0.125 + 0.35 * d + l + 0.015 * V_a$

(iv) $l_g = 0.2 + d$

(v) $l_g = (id\text{-}d)/2$

Effective air gap length $l_{gc} = k_g * l_g$

For the operation of electric machinery some air gap necessary in magnetic path, but these air gap should be kept minimum of length and maximum of flux so as to reduce their reactance. A long airgap of small cross section would require a large mmf resulting in large coils of many turns and would also result in a tendency for the flux to wander away from its mean path.

Area of air gap $ag = \pi * d * lt/4$

Flux density in air gap $b_{g60} = 1.36 * b$

mmf in air gap $atg = 800000 * b_{t60} * lgc$

Area per pole $app = \pi * d * l/p$

Depth of stator slot = $(od-id)/2-y * d$

The values of ampere turns for bt60 and bc are selected from the array acy.

6.1.10 MAGNETISING CURRENTS

$$i_m = 0.427 * p * a_{t60}/(t * k_{ws})$$

The magnetising of a machine is directly proportional to the mmf required to force the flux through the air gap and the iron parts of the machine. The consideration of the magnetising current is very important as an increased value of magnetising current means a low operating power factor.

Volume of stator teeth $vt = at * lt$

Weight of stator teeth $wt = vt * den$

Maximum flux density in teeth $mf = \pi * bt/2$

Volume of yoke $vy = ay * lt$

Weight of yoke $wy = vy * den$

Flux density in yoke $yf = 1.1 * mf$

Iron loss per Kg for mf and yf are selected from the array bcy.

Friction and windage loss $fww = 1.5 * ws/100$

Length of mean turn $l_{mt} = 2 * l + (2.3 * \pi * d/p) + 0.24$

Winding resistance $rs = ro * l_{mt} * t/as$

Copper loss $cul = 3 * i^2 * rs$

Total loss (tlo) is the sum of loss in teeth, yoke, copper loss and windage loss.

Efficiency $f_{eff} = ws/(ws + tlo) * 100$

TABLE 6.2 ARRAY BCY

LOSS FACTOR

W/M	B_{T60}
0.90	1.60
0.92	1.65
0.94	1.75
0.96	1.80
0.98	1.90
1.00	2.00
1.02	2.10
1.04	2.20
1.06	2.30
1.08	2.40
1.10	2.50
1.12	2.65

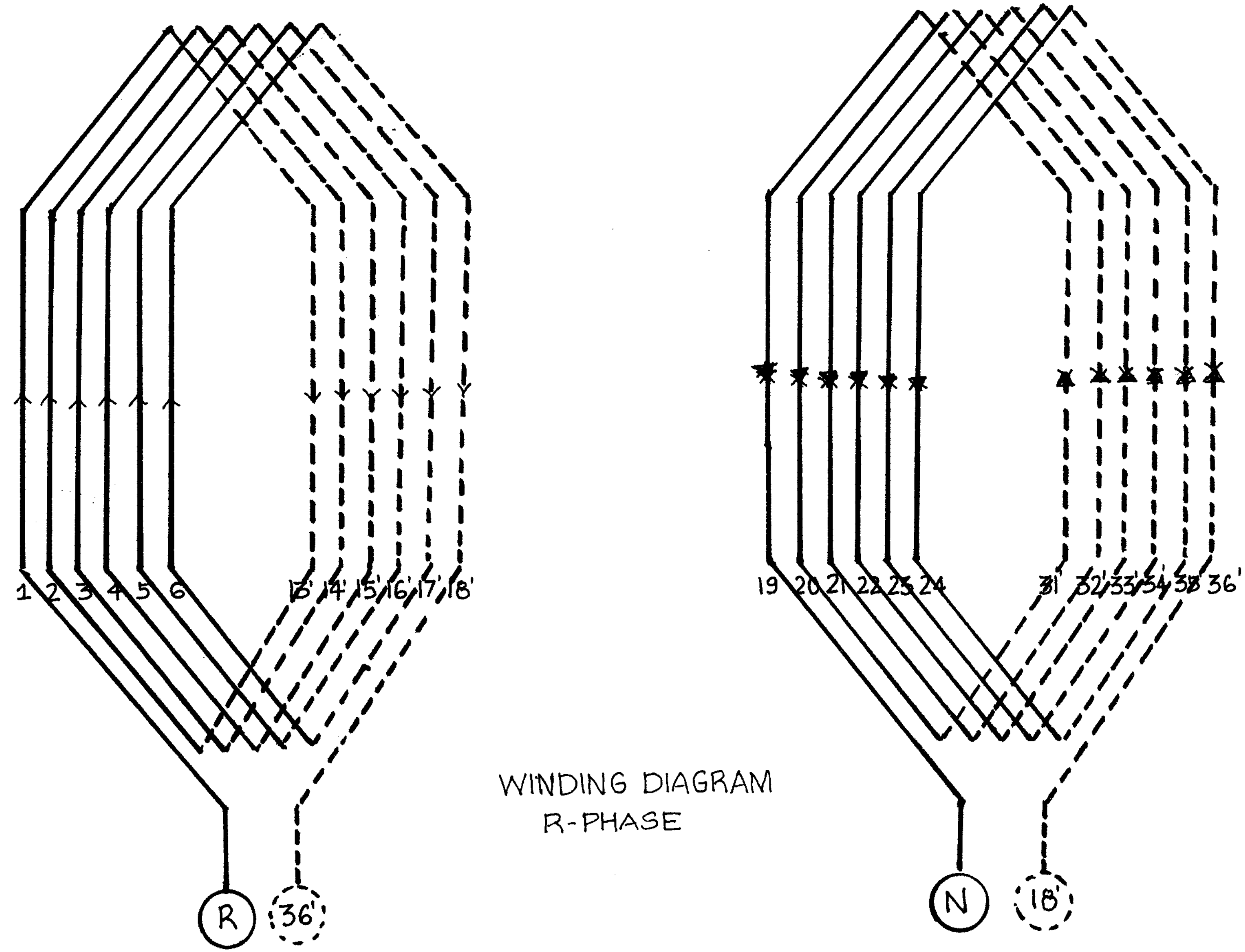
W/M	B_{T60}
1.14	2.75
1.18	3.00
1.20	3.15
1.22	3.25
1.24	3.40
1.26	3.55
1.28	3.65
1.30	3.80
1.32	3.95
1.34	4.10
1.36	4.20
1.38	4.40
1.40	4.55
1.42	4.70
1.44	4.85
1.46	5.00
1.48	5.20
1.50	5.35
1.52	5.55
1.54	5.70
1.56	5.85
1.58	6.00
1.60	6.15
1.62	6.30
1.64	6.50

W/M	B_{T60}
1.66	6.65
1.68	6.80
1.70	7.00
1.72	7.20
1.74	7.35
1.76	7.50
1.78	7.75
1.80	8.00

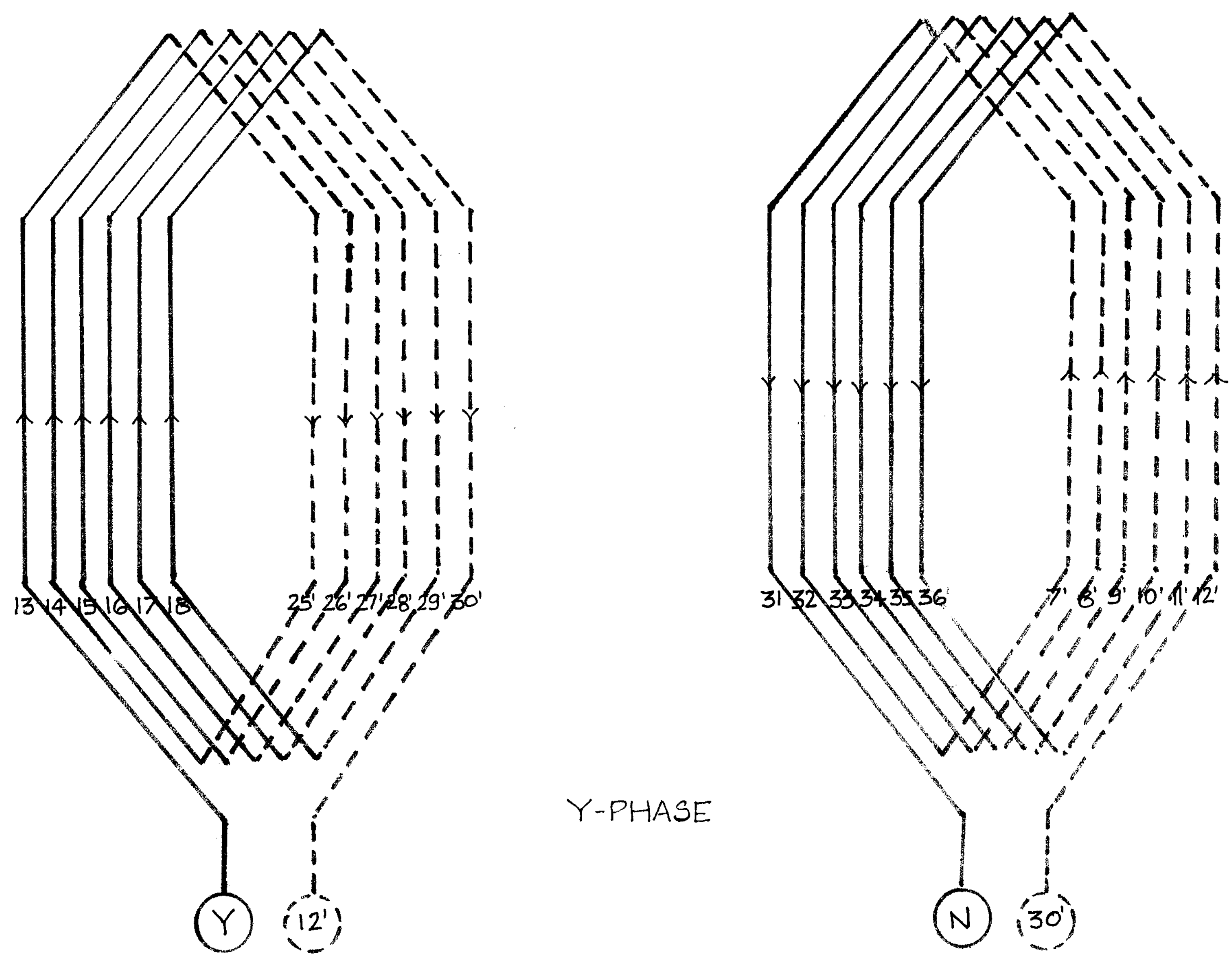
ARRAY ACY

B	AMPERE TURNS
0.10	0.80
0.15	0.80
0.20	0.80
0.30	0.80
0.35	0.80
0.40	0.80
0.45	0.80
0.50	0.80
0.55	0.82
0.60	0.83
0.65	0.84

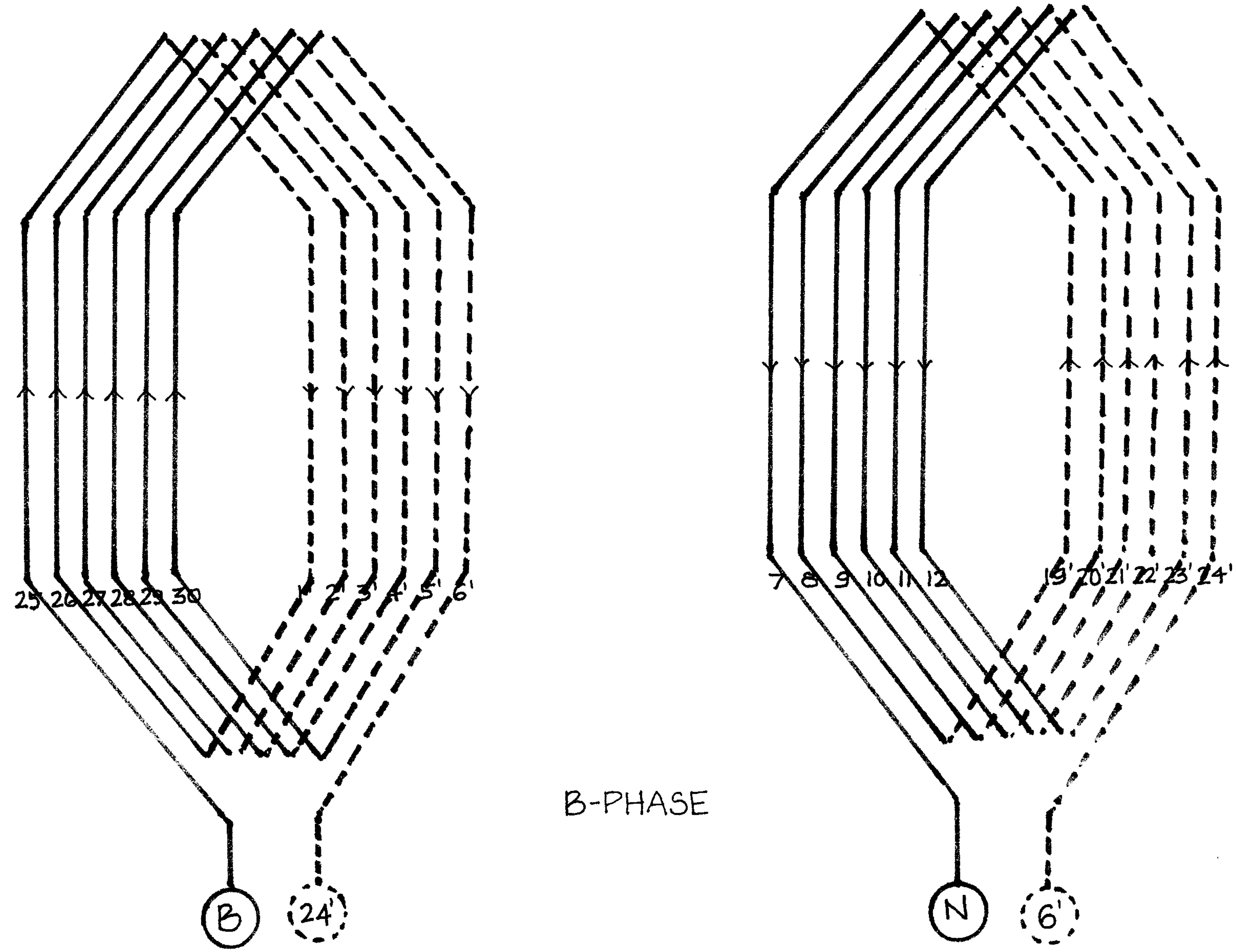
B	AMPERE TURNS
0.70	0.85
0.75	0.86
0.80	0.87
0.85	0.88
0.90	0.92
0.95	0.95
1.00	0.99
1.05	1.50
1.10	2.20
1.15	3.50
1.20	5.50
1.25	8.10
1.30	8.80
1.35	9.50
1.40	25.0
1.45	50.0
1.50	80.0
1.55	120.0
1.60	145.0
1.65	160.0



WINDING DIAGRAM
R-PHASE


13 14 15 16 17 18
25' 26' 27' 28' 29' 30'
Y
12'
31 32 33 34 35 36
7' 8' 9' 10' 11' 12'
N
30'

Y-PHASE



B-PHASE

CHAPTER 7

SOFTWARE ASPECTS

7.1 SOFTWARE DESIGN

Some motor rules, vital in motor design where identified and used to device an algorithm for automatic motor design. Interactive software has been developed on the basis of this algorithm in C . Thus the resulting design method and algorithm is highly practicable for the motor design that satisfies all the conditions imposed by the equipment in which the motor is to be used.

7.2 ADVANTAGES OF CAD

Literally it is a known that electrical technology has developed amazingly in the recent past. But recently it have been chipped and shaped attractively to the final stage. The incoming of computers in the field of design is yet another land mark in the field of electrical technology.

The concept of CAD ,the modern trend in the design field, has emerged as a boon to the design engineers. It enables creations followed by rigorous testing of graphic models without involving the chores of making physical models.

The design procedure resides as a very general software which is user alterable. The user can alter the design as and when he wants according to given specifications. It is also possible for him to emphasis on any part of design according to the needs.

This vital advantage of flexibility in the design procedure is evident when modifications and alterations are sought after. Apart from the flexibility, the incredible speed with which the complex mathematical manipulations are done adds to the versatility.

7.3 ALGORITHM

STEP 1:

Input the power in watts, efficiency, rated voltage, rated current,number of ampere conductors,flux density,rated speed,required parameters for the motor design.

STEP 2 :

The loss factor array and the ampere turns calculations array are given as input.

STEP 3:

Calculate the current, output coefficient, input kva

STEP 4:

Calculate the diameter, length of the rotor by selecting appropriate l/τ ratio. Hence the rated current is found.

STEP 5:

Calculate the flux density in airgap, flux density in stator teeth and in yoke

STEP 6:

For the value of flux density in stator teeth, flux density in yoke calculate the ampere turns from the array acy and bcy.

STEP 7:

Calculate the magnetising current and sum up the ampere turns found in the previous steps.

STEP 8:

Calculate the volume of stator teeth ,volume of yoke, weight of stator teeth, weight of stator yoke.

STEP 9:

Calculate the flux density in stator teeth and in yoke. For the values of the above find the loss/kg from the array BCY.

STEP 10:

Calculate the frictional windage loss and sum up the loss found in the previous steps. Find the total loss.

STEP 11:

Calculate the final efficiency using the values of input wattage and total loss.

STEP 12:

Print the values of rotor diameter, length, final efficiency, total loss, flux densities in yoke, airgap, teeth and mmf in the above.

STEP 13:

Terminate the program.

7.4 FLOWCHART

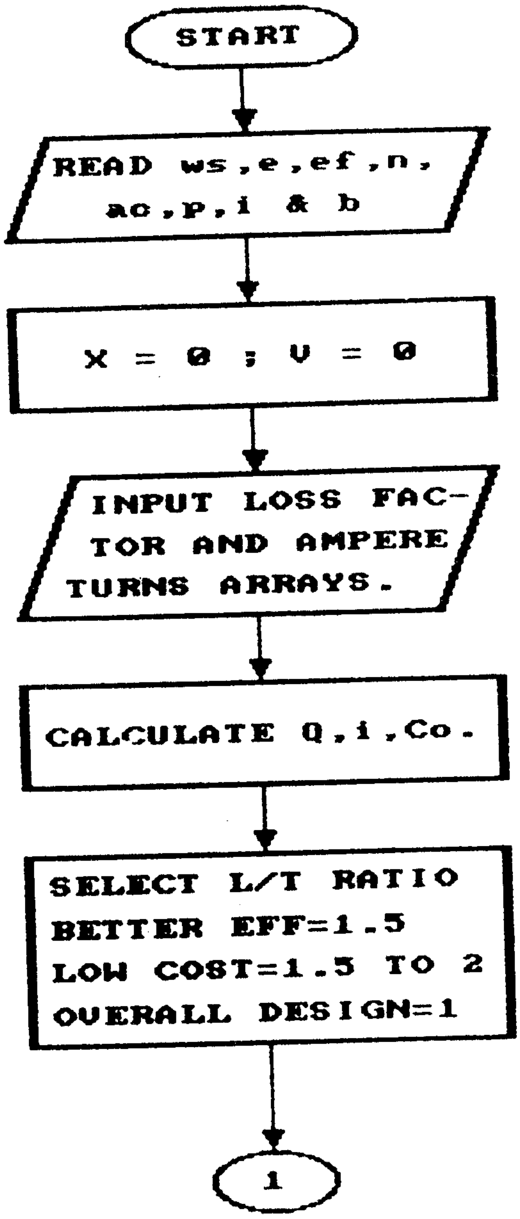
The detailed flowchart for the design is given is figure (8.1).

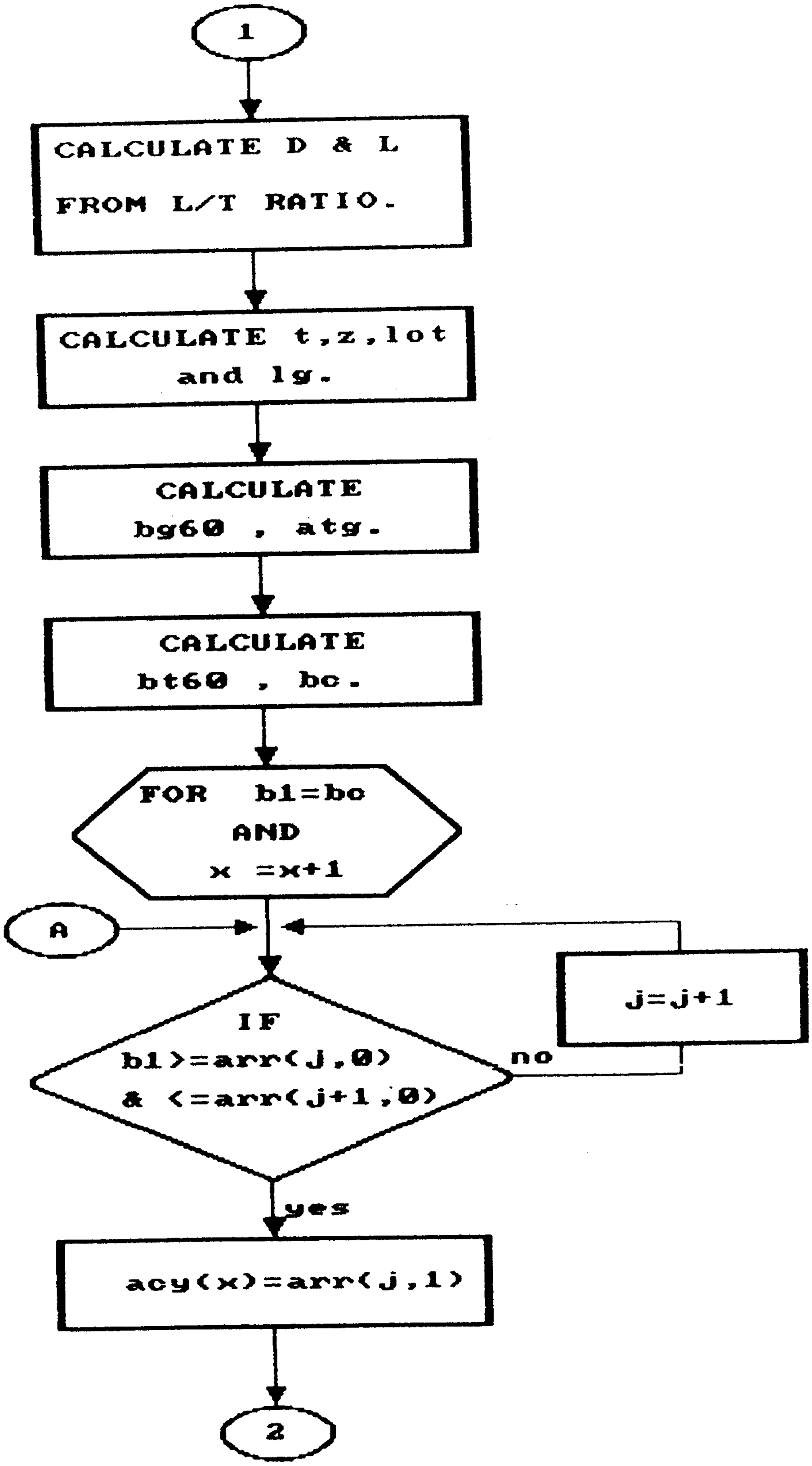
7.5 PROGRAM

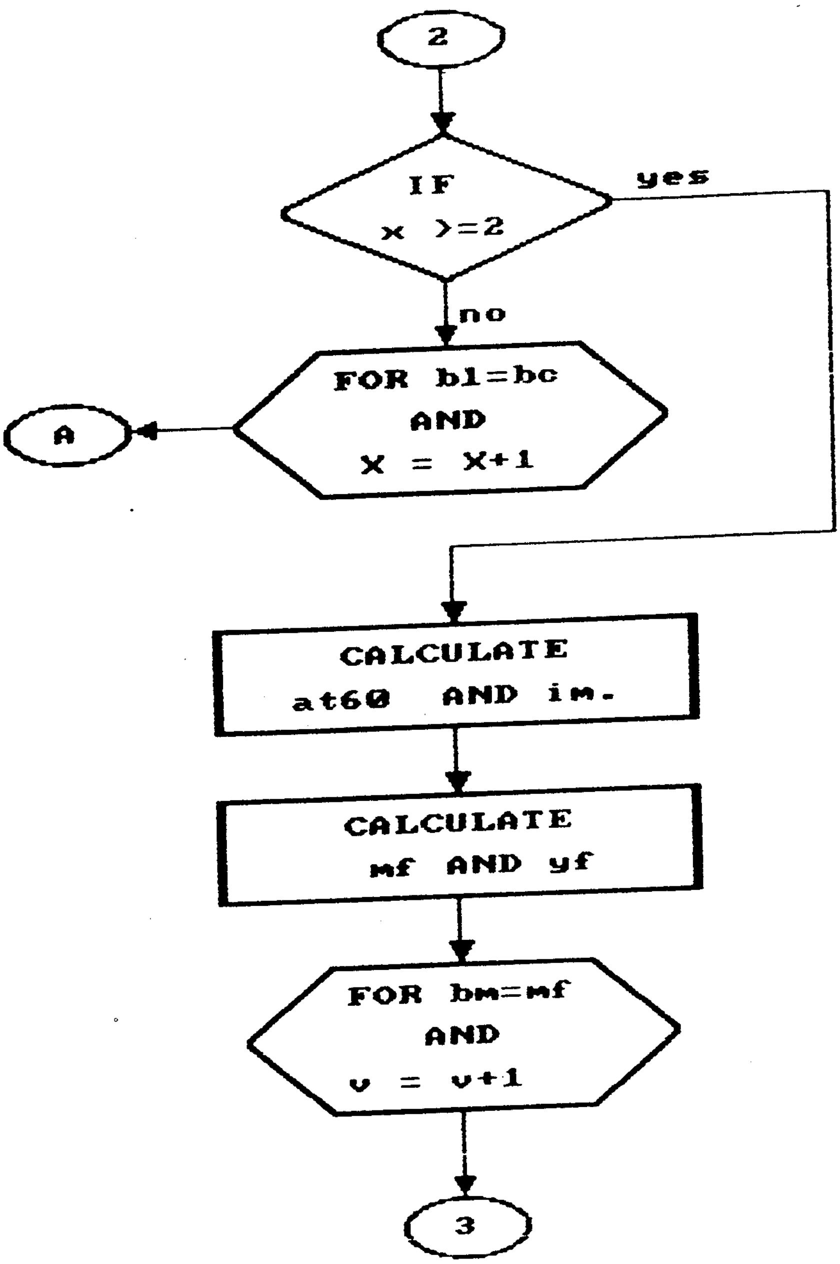
A computer program written in C language for the design of this motor is engrossed at the end of this chapter.

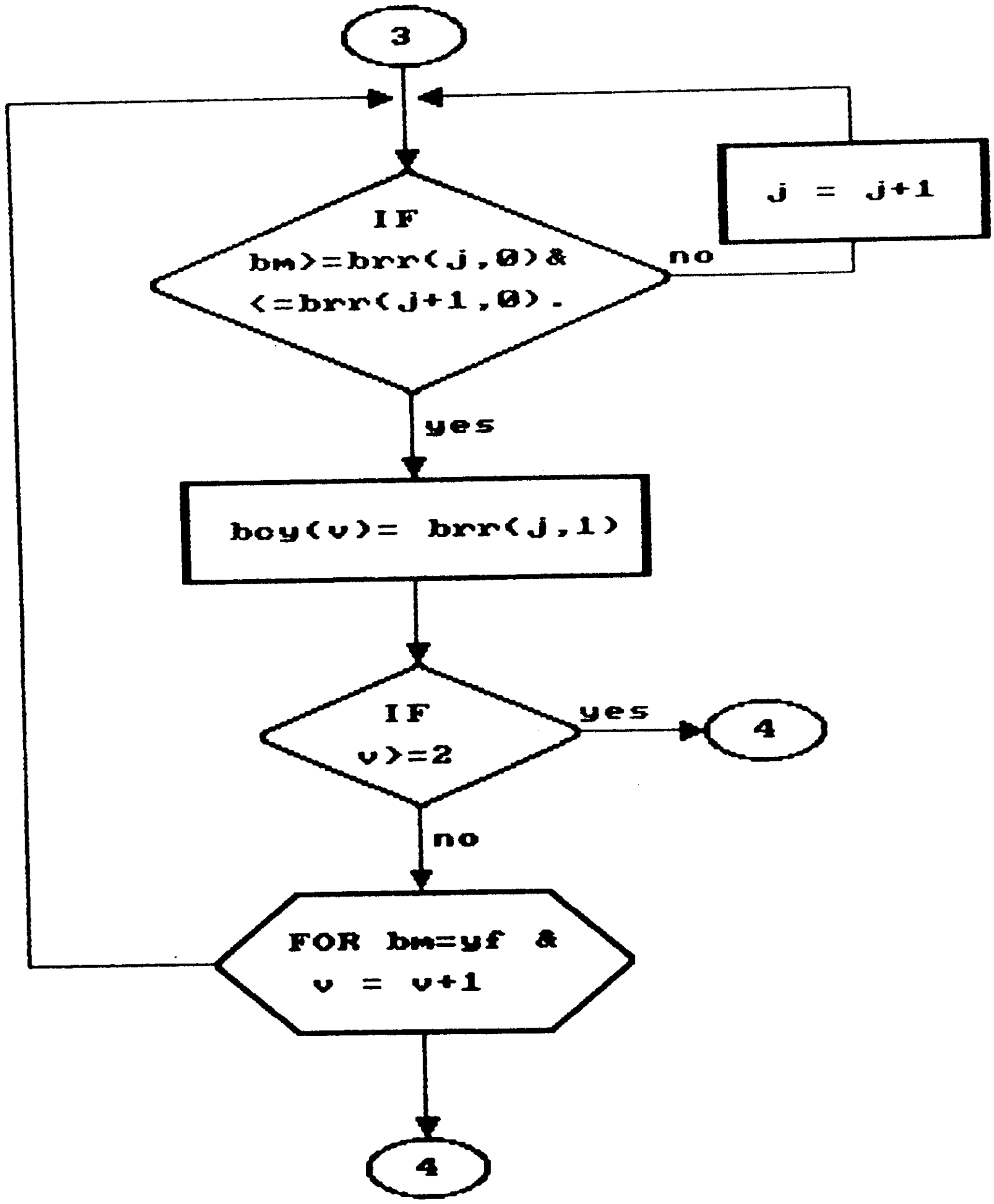
Fig 8.1

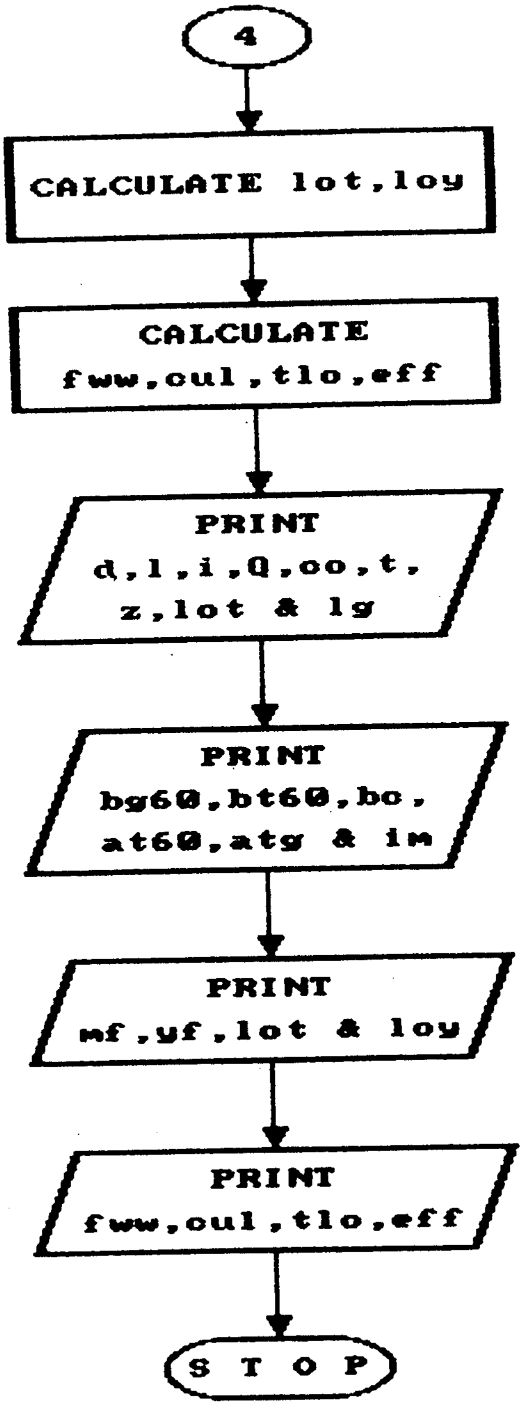
FLOWCHART




1
CALCULATE D & L
FROM L/T RATIO.
CALCULATE t,z,lot
and lg.
CALCULATE
bg60 , atg.
CALCULATE
bt60 , bc.
FOR b1=bc
AND
x =x+1
A
IF
b1>=arr(j,0)
& <=arr(j+1,0)
no
j=j+1
yes
acy(x)=arr(j,1)
2


2
IF
x >=2
yes
no
FOR b1=bc
AND
X = X+1
A
CALCULATE
at60 AND im.
CALCULATE
mf AND yf
FOR bm=mf
AND
v = v+1
3


3
j = j+1
IF
bm>=brr(j,0)&
<=brr(j+1,0).
no
yes
boy(v)= brr(j,1)
IF
v>=2
yes
4
no
FOR bm=yf &
v = v+1
4


4
CALCULATE lot,loy
CALCULATE fww,oul,tlo,eff
PRINT d,l,i,Q,oo,t, z,lot & lg
PRINT bg60,bt60,bo, at60,atg & im
PRINT mf,yf,lot & loy
PRINT fww,oul,tlo,eff
S T O P

PROGRAM

```
#include<stdio.h>
#include<math.h>
#include<stdlib.h>
#include<conio.h>
#include<graphics.h>
main()

{
    int e,ef,k,cho,p,n,ns,j,x,den=7600,choi,v,nu;

      float  pi=3.14285,kw=0.955,kws=0.935,d,l,b,a,xy,dia,dt=1.1,  cd,lmt,rs,
      ro=.021,q,di,fsc,co,ac,fp,t,ts,i,asc,z,lg,yd,lt,lc,at,bg,by,bt,bav,w,ws,kg=1.18,
      bc,bt60,lgc,lg60,atg,b1,at60,im,vt,wt,mf,vy,wy,lmp,atm,wm,fww,cul,ay,ag,
      app,bg60,yf,bm,lot,loy,feff,tlo;

    float acy[2],bcy[2];

    float arr[32][2]=
  {.1,.8,.15,.8,.2,.8,.25,.8,.3,.8,.35,.8,.4,.8,.45,.8,.5,.8,.55,.82,.6,.83,.65,.84,.7,.85,
    .75,.86,.8,.87,.85,.88,.9,.92,.95,.95,1,.99,1.05,1.5,1.1,2.2,1.15,3.5,1.2,5.5,1.25,8.1,
   1.3,8.8,1.35,9.5,1.4,25,1.45,50,1.5,80,1.55,120,1.6,145,1.65,160};

    float brr[46][2]=
    {.9,1.6,.92,1.65,.94,1.75,.96,1.8,.98,1.9,1,2,1.02,2.1,1.04,2.2,1.06,2.3,1.08,
    2.4,1.1,2.5,1.12,2.65,1.14,2.75,1.16,2.9,1.18,3,1.2,3.15,1.22,3.25,1.24,3.4,
      1.26,3.55,1.28,3.65,1.3,3.8,1.32,3.95,1.34,4.1,1.36,4.2,1.38,4.4,1.4,4.55,
      1.42,4.7,1.44,4.85,1.46,5,1.48,5.2,1.5,5.35,1.52,5.55,1.54,5.7,1.56,5.85,
      1.58,6,1.6,6.15,1.62,6.3,1.64,6.5,1.66,6.65,1.68,6.8,1.7,7,1.72,7.2,1.74,
     7.35,1.76,7.55,1.78,7.75,1.8,8};
```

```
int gdriver = DETECT, gmode, errorcode;          /* request auto detection */

initgraph(&gdriver, &gmode, "c:");               /* initialize graphics mode */

errorcode = graphresult();                       /* read result of initialization */

if (errorcode != grOk)                           /* an error occurred */
{
     printf("Graphics error: %s\n", grapherrormsg(errorcode));
     printf("Press any key to halt:");
     getch();
     exit(1);                                    /* return with error code */
 }
 settextstyle(4,0,6);
 outtextxy(0,0,"BRUSHLESS DC MOTOR");
 getch();
 settextstyle(1,0,4);
 outtextxy(20,60,"BY");
 settextstyle(4,0,5);
 outtextxy(60,120,"RAMESH");
 outtextxy(80,180,"RAN");
 outtextxy(100,240,"RAJ");
 outtextxy(120,300,"MALAR");
 settextstyle(1,0,2);
 outtextxy(180,400,"SPONSERED BY ELGI ELECTRICALS");
 getch();
 cleardevice();
 settextstyle(4,0,4);
 outtextxy(50,160,"DESIGN OF BRUSHLESS DC MOTOR ");
 getch();
 closegraph();
clrscr();
printf("\n motor efficency(in %) :");
```

```
scanf("%d",&ef);
printf("\n motor wattage(in watts) :");
scanf("%d",&ws);
printf("\n motor voltage :");
scanf("%d",&e);
printf("\n no. of poles :");
scanf("%d",&p);
printf("\n no. of stator slots :");
scanf("%d",&ns);
printf("\n speed (in rpm) : ");
scanf("%d",&n);
printf("\n ampere conductors:");
scanf("%f",&ac);
printf("\n flux density :");
scanf("%f",&b);
printf("\n width of tooth at 1/3 height  (in meters) :");
scanf("%f",&w);
clrscr();
q=ws*0.736/ef;                         /* i/p kva  */
i=ws/e;                                /*  current */
asc=i/4;                               /* area of stator conductors */
cd=i/asc;                              /* current density */
co=ac*1.1*kw*b*pi*pi/1000;             /* o/p coefficient */
   initgraph(&gdriver, &gmode, "c:");
   settextstyle(4,0,6);
   outtextxy(40,150,"DIAMETER SELECTION");
   getch();
   closegraph();

 printf("\n 1.Good Efficiency  l/τ=1.5 ");
 printf("\n 2.Good Overall Design l/τ=1 ");
 printf("\n 3. Minimum  Cost l/τ= 1.5 to 2 ");
 printf("\n select your choice : ");
```

```
scanf("%d",&nu);
switch(nu)
{
   case 1:
         dia=q*p*60/(1.5*pi*n*co);
         d=pow(dia,.333);
         l=1.5*pi*d/p;
         break;
   case 2:
         dia=q*p*60/(pi*n*co);
         d=pow(dia,.333);
         l=pi*d/p;
         break;
   case 3:
         printf(" enter a value inbetween 1.5 to 2 : ");
         scanf("%f",&xy);
         dia=q*p*60/(xy*pi*n*co);
         d=pow(dia,.333);
         l=xy*pi*d/p;
 }
 fp=b*pi*d*l/p;                      /* flux per pole */
 t=e/(4.44*50*fp*kw);                /* stator turns per phase */
 lmt=(2*l)+(2.3*pi*d/p)+.24;         /* length of meanturn */
 ts=3*2*t;                           /* total stator conductors */
 z=ts/ns;                            /* conductors per slot */
 lt=0.9*l;                           /* net iron length */
 at=ns*w*lt/p;                       /* area of teeth per pole */
 bt=fp/at;                           /* flux density in stator teeth */
 bt60=1.36*bt;                       /* flux density in stator teeth */
 bc=1.1*bt;                          /* flux density in stator core */
 fsc=fp/2;
 ay=fsc/1.2;                         /* area of yoke */
 yd=ay/lt;                           /* yoke depth */
```

```
lmp=(pi*(d+2*dt/100+yd)/(3*p))*100;          /* length of magnetising path */
lg=.2+2*sqrt(d*l);                                      /* air gap length */
lgc=kg*lg;                                    /* effective air gap length */
ag=pi*d*l/4;                                           /* area of air gap */
bg60=1.36*b;                                   /* flux density in air gap */
atg=800000*bg60*lgc/1000;                               /* mmf in air gap */
app=pi*d*l/p;                                                /* area/pole */
if(bt60 && bc >=.1 && bt60 && bc<=1.65)
   {

       for(cho=1;cho<=2;cho++)
        {
          switch(cho)
              {
               case  1: b1=bt60;
                        x=1;
                        break;
               case  2: b1=bc;
                        x=2;
                        break;
               }
          for(j=0;j<=32;j++)
               {
               if(b1>=arr[j][0]  && b1<=arr[j+1][0])
                 {
                acy[x]=arr[j][1];
                 printf("\n \t b1=%f,\t ampere turns/cm :%f ",b1,acy[x]);
                 break;
                   }
                   else
                   continue;

                }
```

```
        }
    }

at60=acy[1]*dt+acy[2]*lmp+atg;                    /* total mmf */
im=.427*p*at60/(t*kws);                           /* magnetising current */
wm=fp*p/(1.7*ns*lt);
atm=ns*wm*lt/p;
vt=atm*lt;                                        /* volume of stator teeth */
wt=vt*den;                                        /* weight of stator teeth */
mf=pi*bt/2;                                       /* maximum flux density in teeth */
vy=ay*lt;                                         /* volume of yoke */
wy=vy*den;                                        /* weight of yoke */
yf=1.1*mf;                                        /* flux density in yoke */

        for(choi=1;choi<=2;choi++)
        {
          switch(choi)
            {
              case 1: bm=mf;
                      v=1;
                      break;
              case 2: bm=yf;
                      v=2;
                      break;
            }
          for(j=0;j<=46;j++)
            {
              if(bm>=brr[j][0]  && bm<=brr[j+1][0])
               {
               bcy[v]=brr[j][1];
          printf("\n \t bm=%f,\t loss/kg in iorn used :%f ",bm,bcy[v]);
               break;
                 }
```

```
                    else
                    continue;
              }
          }
lot=bcy[1]*wt;                                          /* loss in teeth */
loy=bcy[2]*wy;                                          /* loss in yoke */
fww=1.5*ws/100;                                 /* friction and windage loss */
rs=ro*lmt*t/asc;                          /* resistance of winding in ohm */
cul=i*i*rs*3;                                           /* copper loss */
tlo=lot+loy+cul+fww;                              /* total losses in m/c */
feff=ws*100/(ws+tlo);                             /* final efficency in % */
getch();

  initgraph(&gdriver, &gmode, "c:");
  settextstyle(4,0,6);
  outtextxy(55,150,"MOTOR DESIGN FOR");
  getch();
  closegraph();

 printf("\n motor capacity          : %f watts ",ws);
 printf("\n voltage                 : %d volts",e);
 printf("\n current                 : %f amps",i);
 printf("\n input kva               : %f kva",q);
 printf("\n motor efficency         : %d  %", ef);
 printf("\n motor speed             : %d rpm ", n);
 printf("\n no. of poles            : %d ",p);
 printf("\n area of conductor       : %f sq.mm",asc);
 printf("\n no. of slots            : %d",ns);
 printf("\n no.ampere conductors    : %f",ac);
 getch();

   initgraph(&gdriver, &gmode, "c:");
   settextstyle(4,0,6);
```

```
outtextxy(130,150,"ROTOR DESIGN ");
getch();
closegraph();

printf("\n rotor diameter        :%f metres",d);
printf("\n rotor length          :%f metres",l);
printf("\n flux density          :%f webers/sq.m",b);
printf("\n output coefficent     :%f kva/cu.m rps ",co);
printf("\n\n");
getch();

  initgraph(&gdriver, &gmode, "c:");
  settextstyle(4,0,6);
  outtextxy(130,150,"STATOR DESIGN ");
  getch();
  closegraph();
clrscr();
printf("\n length of air gap              :%f mm",lgc);
printf("\n length of mean turn            :%f mm",lmt);
printf("\n stator turns/phase             :%f",t);
printf("\n total stator conductors        :%f",ts);
printf("\n current density                :%f amps/sq.mm",cd);
printf("\n conductors/slot                :%f",z);
printf("\n flux/pole                      :%f webers",fp);
printf("\n flux density in teeth          :%f webers/sq.m",bt60);
printf("\n max flux density in teeth      :%f webers/sq.m",mf);
printf("\n flux density in yoke           :%f webers/sq.m",bc);
printf("\n max flux density in yoke       :%f webers/sq.m",yf);
printf("\n flux density in air gap        :%f webers/sq.m",bg60);
printf("\n mmf in air gap                 :%f ",atg);
printf("\n mmf in yoke                    :%f ",acy[2]*lmp);
printf("\n mmf in teeth                   :%f ",acy[1]*dt);
printf("\n total mmf                      :%f ",at60);
```

```
printf("\n area of teeth        :%f sq.m ",at);
printf("\n area of yoke         :%f sq.m ",ay);
printf("\n area of air gap      :%f sq.m ",ag);
printf("\n area per pole        :%f sq.m ",app);
printf("\n depth of yoke        :%f m",yd);
printf("\n volume of teeth      :%f cu.m ",vt);
printf("\n weight of teeth      :%f kg ",wt);
printf("\n volume of yoke       :%f cu.m ",vy);
printf("\n weight of yoke       :%f kg ",wy);
printf("\n\]n");
getch();

   initgraph(&gdriver, &gmode, "c:");
   settextstyle(4,0,6);
   outtextxy(80,150,"LOSS CALCULATION ");
   getch();
   closegraph();

clrscr();
printf("\n magnetising current          :%f amps",im);
printf("\n loss in teeth                :%f watts",lot);
printf("\n loss in yoke                 :%f watts",loy);
printf("\n friction & windage loss      :%f watts",fww);
printf("\n copper loss                  :%f watts",cul);
printf("\n  total   loss                :%f watts",tlo);
printf("\n finalefficency               :%f %",feff);
getch();
}
```

PROGRAM OUTPUT

```
motor efficency(in %) :70

motor wattage(in watts) :140

motor voltage :110

no. of poles :2

no. of stator slots :36

speed (in rpm) : 3000

ampere conductors:4600

flux density :0.5

width of tooth at 1/3 height  (in meters) :0.0078

1.Good Efficiency  l/g=1.5

2.Good Overall Design l/g=1

3. Minimum  Cost l/g= 1.5 to 2

select your choice : 2

        b1=0.781966,    ampere turns/cm :0.860000

        b1=0.632472,    ampere turns/cm :0.830000

        bm=0.903530,    loss/kg in iorn used :1.600000

        bm=0.993883,    loss/kg in iorn used :1.900000


motorcapacity               : 140.002136 watts

voltage                     : 110 volts

current                     :1.272747 amps

input kva                   : 1.472022 kva

motor efficency             : 70  %

motor speed                 : 3000 rpm
```

no. of poles	: 2
area of conductor	:Ø.318187 sq.mm
no. of slots	:36
no.ampere conductors	:46ØØ.ØØØØØØ
rotor diameter	:Ø.Ø92469 metres ✓
rotor length	:Ø.1453Ø8 metres ✓
flux density	:Ø.5ØØØØØ webers/sq.m
output coefficent	:23.865536 kva/cu.m rps
length of air gap	:Ø.5Ø9561 mm
length of mean turn	:Ø.864823 mm
stator turns/phase	:49.146122
total stator conductors	:294.87674Ø
current density	:4.ØØØØØØ amps/sq.mm
conductors/slot	:8.191Ø21
flux/pole	:Ø.Ø1Ø557 webers
flux density in teeth	:Ø.781966 webers/sq.m
max flux density in teeth	:Ø.9Ø353Ø webers/sq.m
flux density in yoke	:Ø.632472 webers/sq.m
max flux density in yoke	:Ø.993883 webers/sq.m
flux density in air gap	:Ø.68ØØØØ webers/sq.m
mmf in yoke	:6.439Ø16
mmf in teeth	:Ø.946ØØØ
total mmf	:284.586Ø29
area of teeth	:Ø.Ø18361 sq.m

area of yoke	:0.004399 sq.m
area of air gap	:0.010557 sq.m
area per pole	:0.021114 sq.m
depth of yoke	:0.033636 m
volume of teeth	:0.000812 cu.m
weight of teeth	:6.172241 kg
volume of yoke	:0.000575 cu.m
weight of yoke	:4.372004 kg
magnetising current	:5.288964 amps
loss in teeth	:9.875586 watts
loss in yoke	:8.306808 watts
friction & windage loss	:2.100032 watts
copper loss	:13.631981 watts
total loss	:33.914406 watts
finalefficency	:80.499611 %

CHAPTER 8

DETERMINATION OF PERFORMANCE

8.1 TEST RESULTS

NO LOAD TEST

VOLTAGE volts	CURRENT amps	SPEED RPM
10	0.3	50
20	0.3	130
30	0.3	320
40	0.3	460
60	0.3	650
80	0.3	780
95	0.3	1110
110	0.3	1460

PREDETERMINATION OF EFFICIENCY

I_L AMPS	$I_a = I_L$ AMPS	$W_{CU} = I_a^2 R_a$ WATTS	W_O WATTS	I/P=V I_L WATTS	TOTAL LOSS $W_{CU} + W_O$ WATTS	O/P=I/P - TOTAL LOSS WATTS	$\eta = \frac{O/P}{I/P} * 100$ (%)
2	2	11.12	32.74	220	43.86	176.14	80.06
3	3	25.02	32.74	330	57.76	272.24	82.49
4	4	44.48	32.74	440	77.22	362.78	82.45
5	5	69.50	32.74	550	102.24	447.76	81.41
6	6	100.08	32.74	660	132.82	527.18	79.87
7	7	136.22	32.74	770	168.96	551.04	76.53
8	8	177.92	32.74	880	210.66	669.34	76.06
9	9	225.18	32.74	990	257.92	732.08	73.94

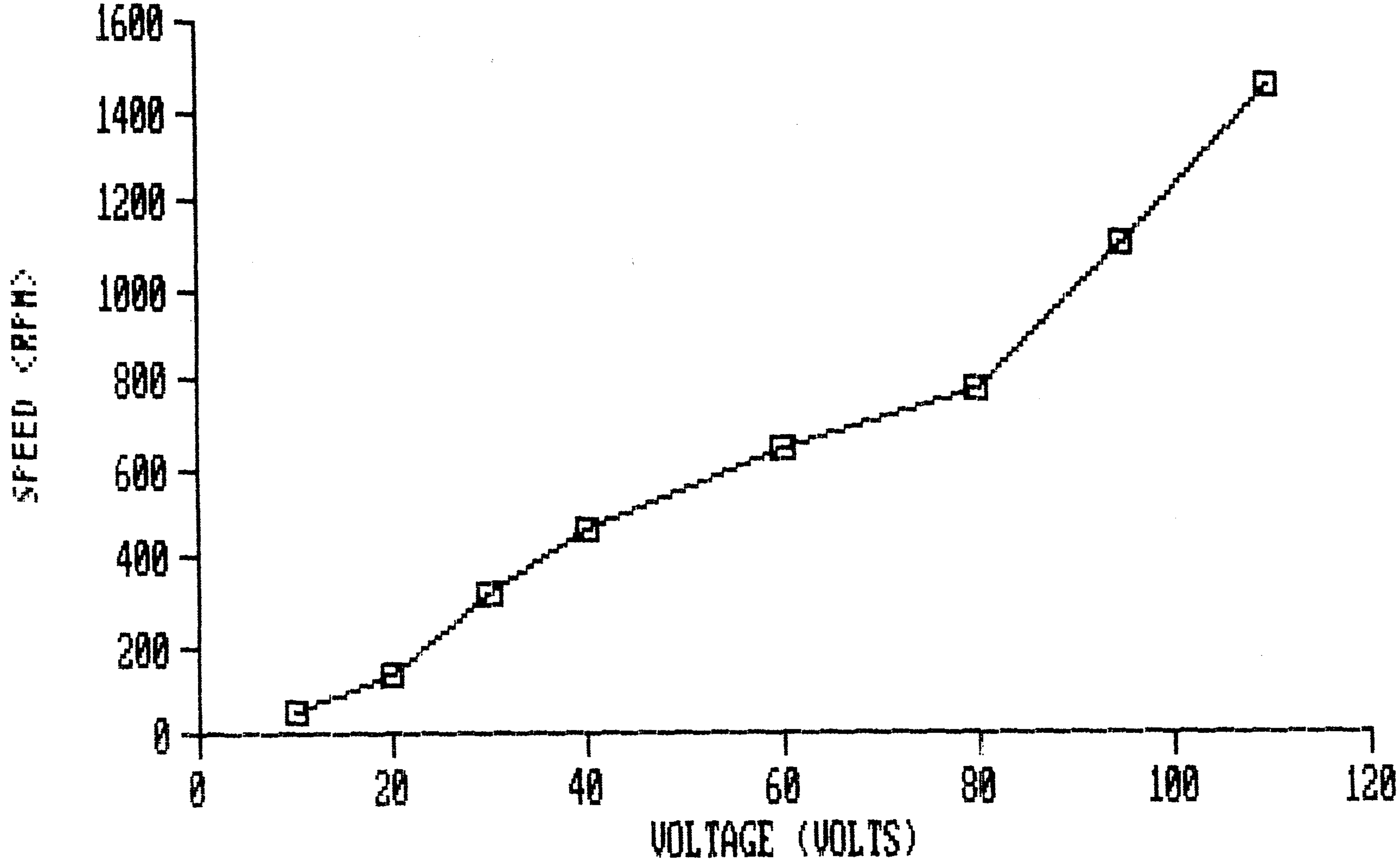
8.2 APPLICATIONS

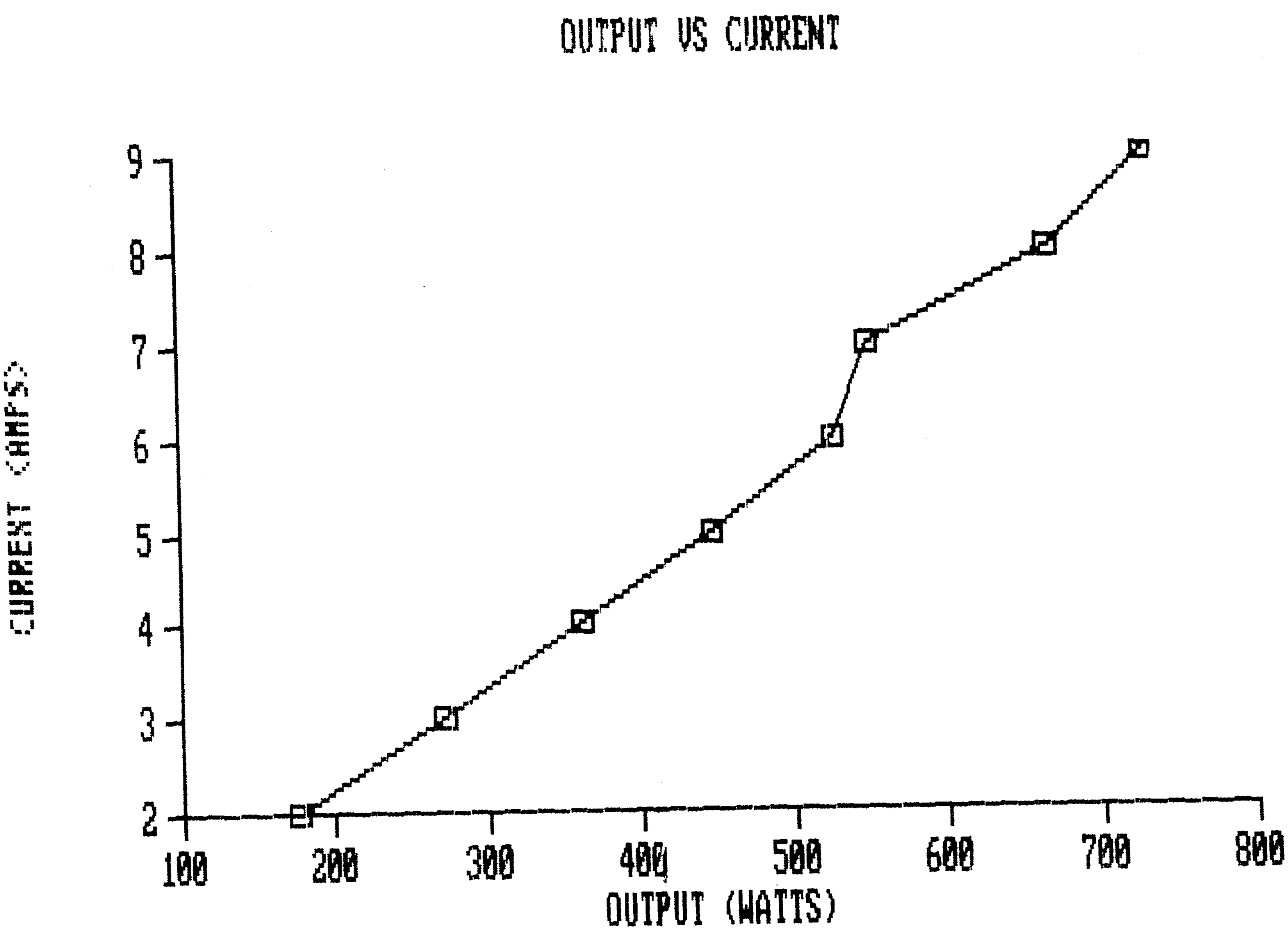
As in a stepping motor. The frequency of exciting the phase windings determines the speed of brushless DC motors. The torque can be controlled by adjusting

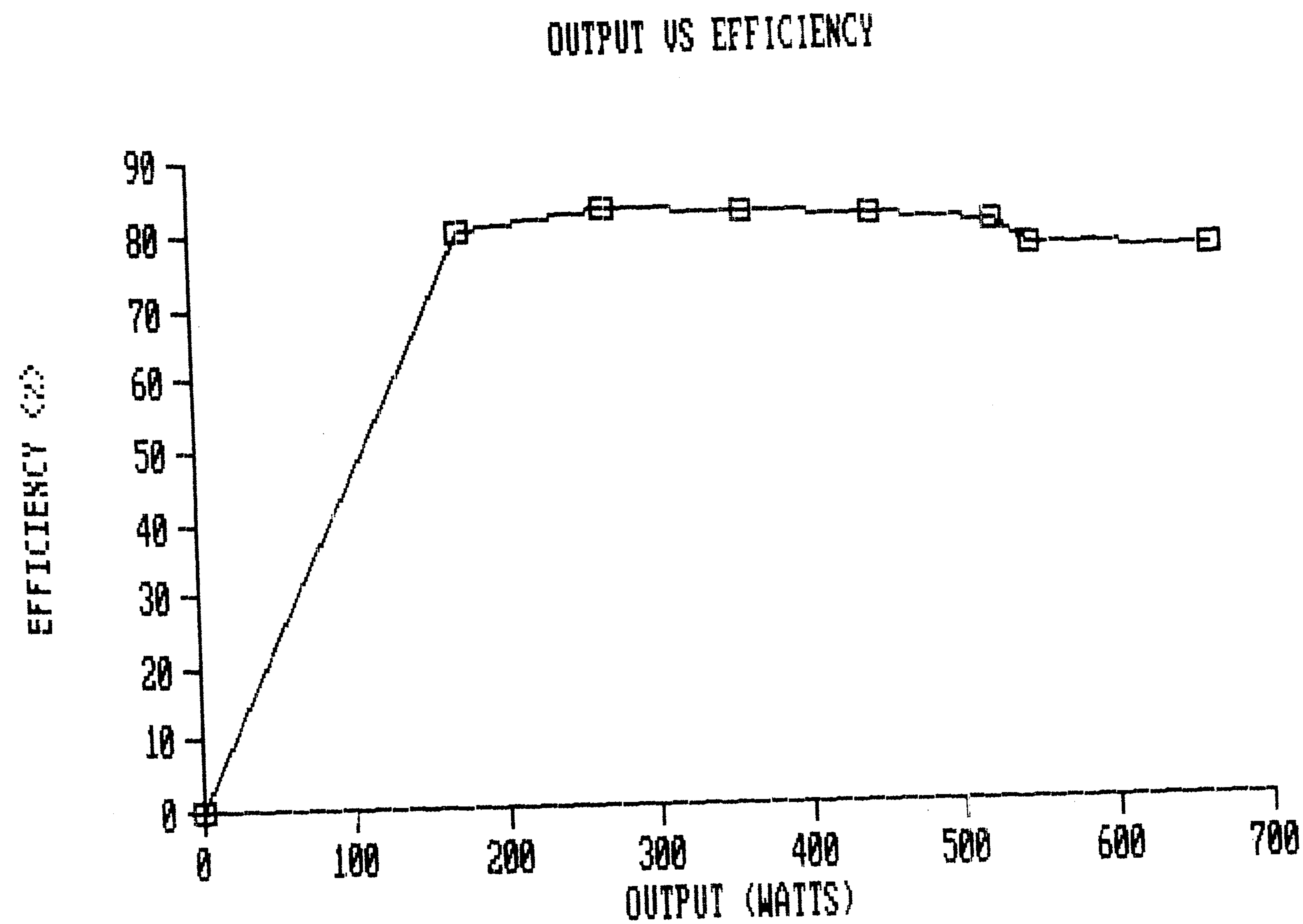
- The amplitude of phase-winding currents
- The angle between the rotor-magnetic axis and the excited phase winding.

Brushless DC motors are, therefore, able to display a wide variety of operating characteristics. As these characteristics can be controlled easily and the price of electronics controllers are falling sharply, brushless DC motors find increasing applications in drives previously dominated by conventional DC motors. Typical applications of these motors include turn-table, drives for record players, hard-disks drives for computers, low-cost instruments, small fans, for cooling electronic equipments etc. Brushless DC motors of somewhat higher ratings find applications in air craft and satellite systems.

VOLTAGE VS SPEED




OUTPUT VS CURRENT
CURRENT (AMPS)
9
8
7
6
5
4
3
2
100
200
300
400
500
600
700
800
OUTPUT (WATTS)


OUTPUT VS EFFICIENCY
EFFICIENCY (%)
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
OUTPUT (WATTS)

CHAPTER 9

CONCLUSION

A brushless DC motor of 140 watts i.e., 0.18 hp has been designed and fabricated in this project. The test results of this motor is found satisfactory.

This motor is being commercialised in developed countries. The cost of this motor is comparatively higher than the conventional DC motors.

These motors may perhaps be considered for use in traction systems in future. The electronic commutation process can be improved using micro-controller systems or by using linear brushless DC IC controller mc 33032, p60.

REFERENCES

1 A.K.Sawhney, **"A course in electrical machine design"**, Dhanpat rai & sons, 1990.

2 J.B.Gupta, **"Theory and performance of Electrical machines"**, S.K. Kataria and Sons, New Delhi, 1944

3 Percoman, **"DC Motors Speed Controls Servo Systems"**, Electro - craft corporation, U.S.A. 1977

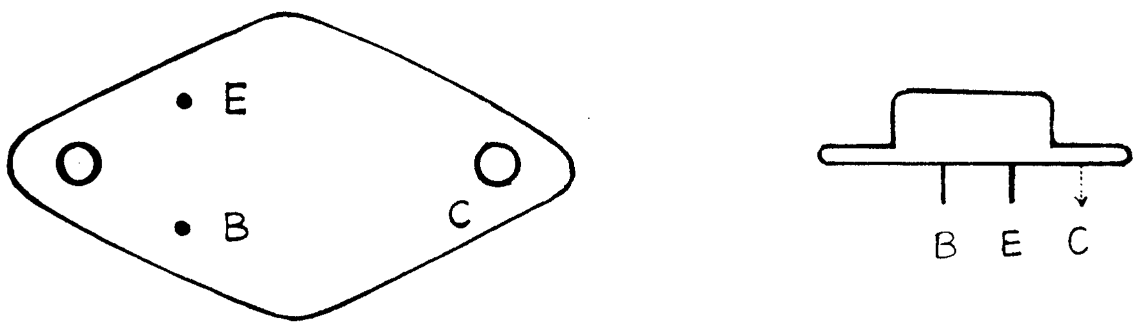
4 Ram Gopal and Agarwal, **"Teach yourself C"**, Khanna Publications.

5 **"Permanent Magnet Manual"**, International General Electric Company (India) Pvt. Ltd., Nirmal, Nariman Point, Bombay

APPENDIX

PIN DIAGRAM OF TRANSISTOR USED.

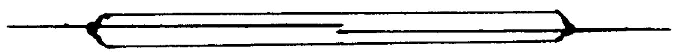
POWER TRANSISTOR 2N6251



TYPE : Si -NPN.

RATING : 200/300 VOLTS, 10 AMPS, 175 WATTS.

REED SWITCH



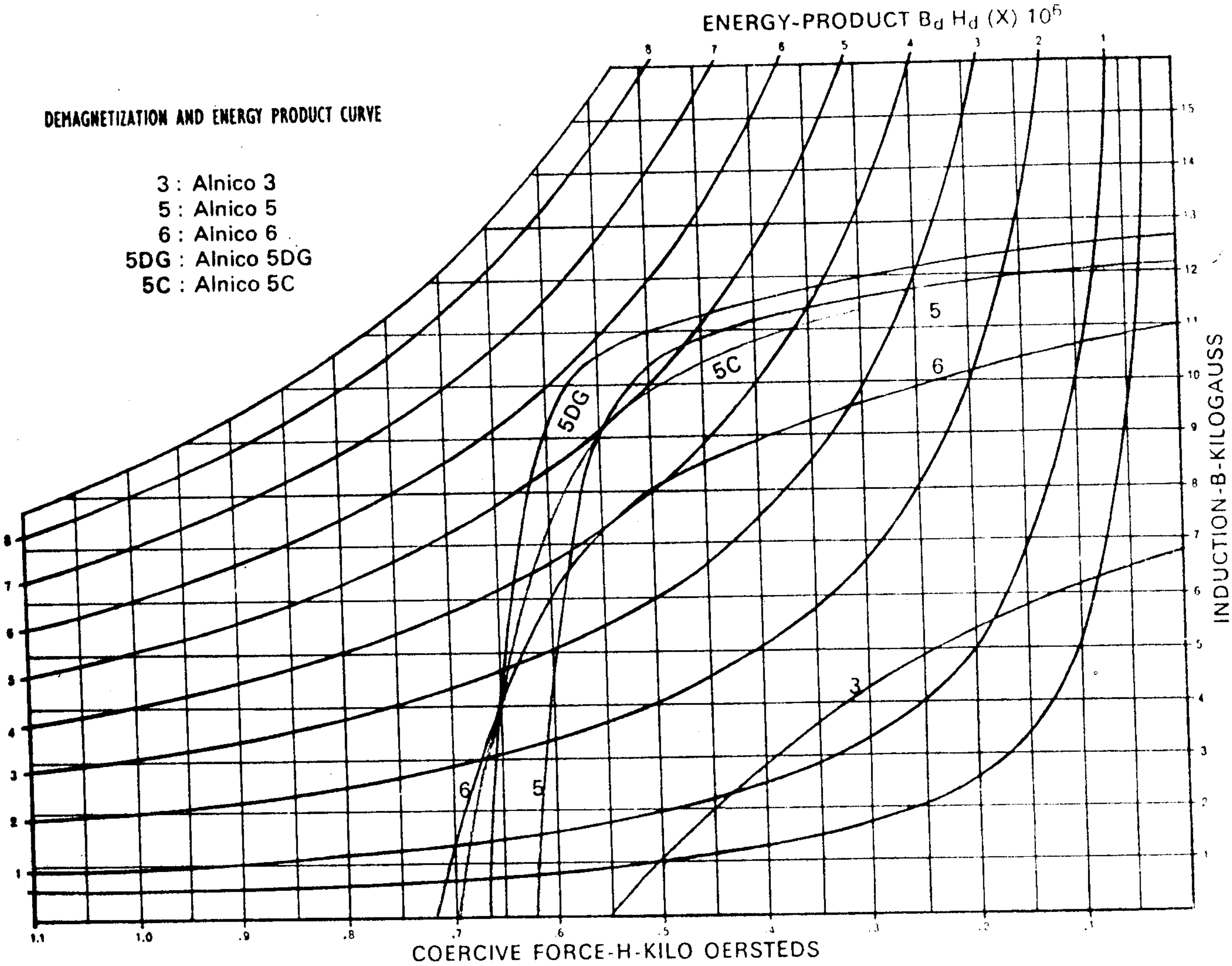
RATING : 2 AMPS.

MADE OF GLASS COVER AND MAGNETICALLY OPERATED METAL STRIP.

LENGTH : 7 CM.

DIAMETER : 4 mm.

Typical Alnico III, V, VDG & VI Demagnetising Curves are shown below :



Magnetic Characteristics — Alnico Magnets

	Alnico III	Alnico V	Alnico VDG	Alnico VI	Alnico VC
Remanence Br. (Gauss)	6500--7000	12000—12500	12400—12800	10800—11500	11500—12500
Coercivity Hc (Oersted)	450—540	600—630	640—680	690—720	650—700
(BH) Max (Mega Gauss Oersted)	1.2—1.4	5—5.5	5.7—6.2	4—4.5	5—5.5
Working point B (Gauss)	4000	9800	10400	8000	9000
Working point H (Oersted)	320	510	560	530	550
Reversible permeability	4.3	4.3	4.3	4.3	4.3
Minimum magnetising force (Amp turns/cm)	2000	2500	2500	2500	2500

Reversible Temperature Coefficient of Residual Induction is 0.02% per degree centigrade.

Physical Characteristics

	Alnico III	Alnico V	Alnico VDG	Alnico VI	Alnico VC
Density gm/cc	6.9	7.3	7.3	7.3	7.3
Curie point C	760	870	870	870	870
Rockwell hardness	C—45	C—50	C—50	C—50	C—50
Coefficient of thermal Expansion per C X-10	13	11.6	11.4	11.4	11.6
Resistivity (Micro ohms per cm/cm²) at 25 C	60	47	47	47	47

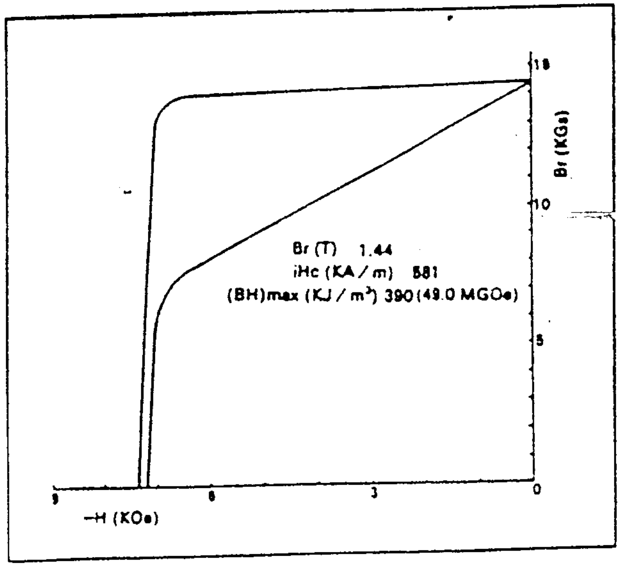
Note : 1) The properties listed are average values and are applicable to simple geometric shapes like cylindrical and rectangular.

2) Alnico V, VDG, VC, VI are anisotropic while Alnico III is isotropic.

3) Alnico VDG can be usefully produced in limited shapes and sizes.

4) Magnets offered by us comply with ISS 6077 (Part I) — 1971.

** Permanent Magnets **



Dongbo International Ltd.

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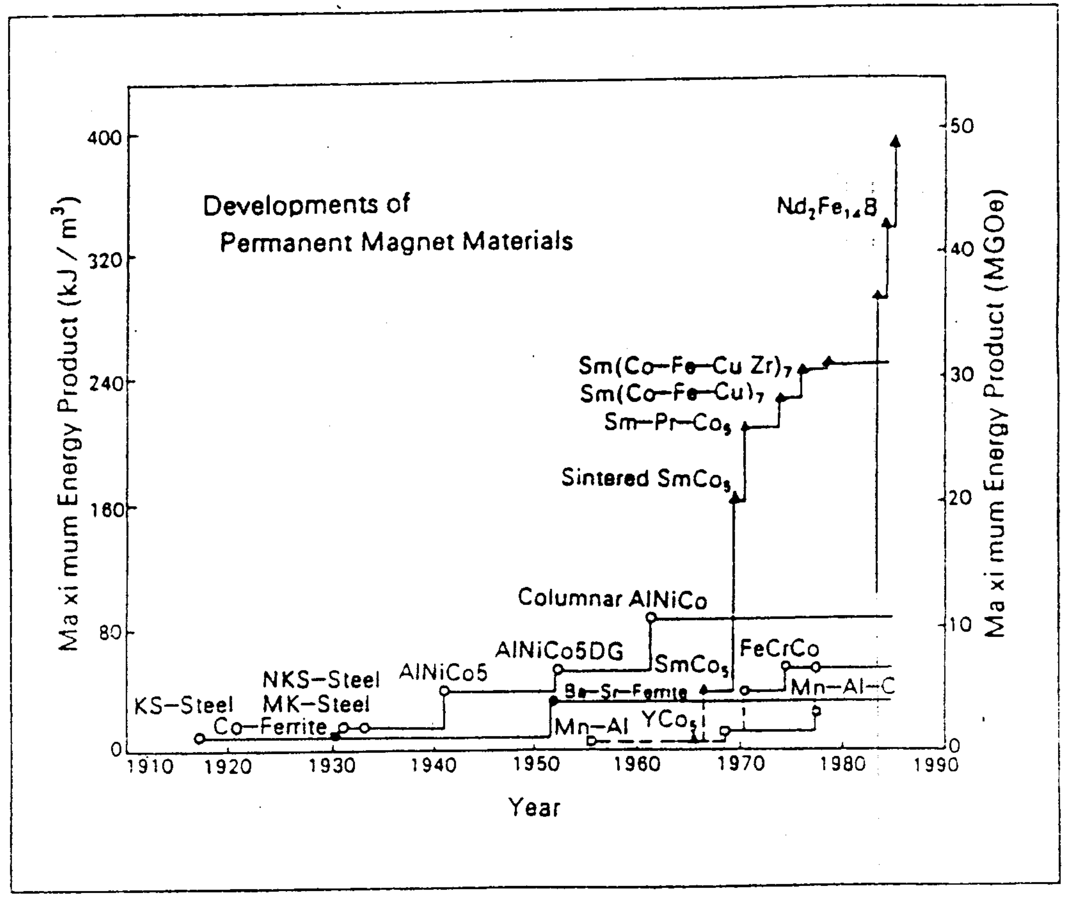

鐵氧體永磁技術參數
Technical Data of Ferrite Magnets

牌號 Grade	最大磁能積 Max. Energy Product (BH) max		剩磁 Remanence Br		矯頑力 Coercivity H_{CB}		溫度範圍 Temperature Range
	kJ/m³	MGOe	mT	G	kA/m	Oe	℃
Y 10T	6.4~9.6	0.8~1.2	≥200	≥2000	128~160	1600~2000	
Y 15	14.3~17.5	1.8~2.2	280~360	2800~3600	128~192	1600~2400	
Y 20	18.3~21.5	2.3~2.7	320~380	3200~3800	128~192	1600~2400	
Y 25	22.3~25.5	2.8~3.2	350~350	3500~3900	152~208	1900~2600	
Y 30	26.3~29.5	3.3~3.7	380~420	3800~4200	160~216	2000~2700	
Y 35	30.3~33.4	3.8~4.2	400~440	4000~4400	176~224	2200~2800	−40~+85℃
Y 15H	≥17.5	≥2.2	≥310	≥3100	232~248	2900~3100	
Y 20H	≥21.5	≥2.7	≥340	≥3400	248~264	3100~3300	
Y 25BH	23.9~27.1	3.0~3.4	360~390	3600~3900	176~216	2200~2700	
Y 30BH	27.1~30.3	3.4~3.8	380~400	3800~1000	224~240	2800~3000	

SI單位與 CGS 單位換算公式

The following relations serve to convert the CGS units to the SI units

$$1\ \mathrm{Oe} = \frac{10^3}{4\pi}\ \mathrm{A/m} \quad (安/米)$$

$$1\ \mathrm{G} = 0.1\ \mathrm{mT} \quad (毫特斯拉)$$

$$1\ \mathrm{GOe} = \frac{1}{4\pi} \times 10^{-1}\ \mathrm{J/m^3} \quad (焦耳/米^3)$$

鐵氧體永磁的參考性能
The Phisical Parameters of Ferrite Magnets

表 3

材料牌號 Grade	電阻率 Specific Electrical Resistance P (Ω·cm)	比重 Density d (g/cm³)	居里點 Curie Temperature	回復磁導率 Permieability Reversible μrec	剩磁溫度系數 Br Temperature Coefficient αBr (%/℃)	線膨脹系數 r Coefficient of linear Expansion (10^{-6}/℃)
Y 10T	10^4~10^8	4.0~4.9	450 450	1.05~1.3	−0.18~−0.20	+9~15
Y 15	10^4~10^8	4.5~5.1	~460 450	1.05~1.3	−0.18~−0.20	+9~15
Y 20	10^4~10^8	4.5~5.1	~460 450	1.05~1.3	−0.18~−0.20	+9~15
Y 25	10^4~10^8	4.5~5.1	~460 450	1.05~1.3	−0.18~−0.20	+9~15
Y 30	10^4~10^8	4.5~5.1	~460 450	1.05~1.3	−0.18~−0.20	+9~15
Y 35	10^4~10^8	4.5~5.1	~460	1.05~1.3	−0.18~−0.20	+9~15
Y 15H	10^4~10^8	4.5~5.0	460	1.05~1.3	−0.18~−0.20	+9~15
Y 20H	10^4~10^8	4.5~5.0	460	1.05~1.3	−0.18~−0.20	+9~15
Y 25BH	10^4~10^8	4.5~5.0	460	1.05~1.3	−0.18~−0.20	+9~15
Y 30BH	10^4~10^8	4.5~5.0	460	1.05~1.3	−0.18~−0.20	+9~15

鑄造鋁鎳鈷永磁技術参數
The Principle Technical Data of Cast Al-Ni-Co Magnets

序號 No.	牌號 Grade	最大磁能積 Max. Energy Product (BH) max kJ/m³ (MGOe)	剩磁 Remanence Br mT (G)	矯頑力 Coercivity H_{CB} kA/m (Oe)	矯頑力 Coercivity H_{CJ} kA/m (Oe)	相對回復磁導率 Reversible Permeability μrec	密度 Density D x10³ kg/m³ (g/cm³)
		最小值 Not less than :				典型值 Typical Value	
①	LN 9	9.0 (1.13)	680 (6800)	30 (380)	32 (400)	6.0~7.0	6.9 (6.9)
②	LN10	9.6 (1.20)	600 (6000)	40 (500)	43 (540)	4.5~5.5	6.9 (6.9)
③	LNG12	12.0 (1.50)	700 (7000)	40 (500)	43 (540)	6.0~7.0	7.0 (7.0)
④	LNG16	16.0 (2.00)	780 (7800)	52 (650)	54 (680)	5.0~6.0	7.0 (7.0)
⑤	LNG34	34.0 (4.30)	1200 (12000)	44 (550)	45 (560)	4.0~5.0	7.3 (7.3)
⑥	LNG37	37.0 (4.63)	1200 (12000)	48 (600)	49 (610)	3.0~4.5	7.3 (7.3)
⑦	LNG40	40.0 (5.00)	1250 (12500)	48 (600)	49 (610)	2.5~4.0	7.3 (7.3)
⑧	LNG44	44.0 (5.50)	1250 (12500)	52 (650)	53 (660)	2.5~4.0	7.3 (7.3)
⑨	LNG52	52.0 (6.50)	1300 (13000)	56 (700)	57 (710)	1.5~3.0	7.3 (7.3)
⑩	LNGT28	28.0 (3.50)	1000 (10000)	58 (720)	59 (740)	3.5~5.5	7.3 (7.3)
⑪	LNGT32	32.0 (4.00)	800 (8000)	100 (1250)	102 (1280)	2.0~3.0	7.3 (7.3)
⑫	LNGT38	38.0 (4.75)	800 (8000)	110 (1380)	112 (1400)	1.5~2.5	7.3 (7.3)
⑬	LNGT60	60.0 (7.50)	900 (9000)	110 (1380)	112 (1400)	1.5~2.5	7.3 (7.3)
⑭	LNGT72	72.0 (9.00)	1050 (10500)	112 (1400)	114 (1430)	1.5~2.5	7.3 (7.3)
⑮	LNGT36J	36.0 (4.50)	700 (7000)	140 (1750)	148 (1850)	1.5~2.5	7.3 (7.3)