DESIGN OF AN ELECTRIC DC MOTOR

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DEDICATION

This work is dedicated to the Almighty God, for giving me the privilege of being among the living souls of today.

I also wish to dedicate this work to my mother for her endless sacrifice in my life and throughout my stay in school.

Declaration

I, Abiola Charles Adekunle declare that this work was done by me and has never been presented elsewhere for the award of degree. I also hereby relinguish the copyright to the Federal University of Technology, Minna.

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Signature and Date

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ACKNOWLEDGEMENT

My sincere gratitude goes to Almighty God for giving me the breath to be amongst the living souls of today and for giving me the strength and courage to complete the program.

I must thank my parent for their parental care without which I would not have been able to pass through the academic system successfully.

I also wish to use this medium to appreciate my supervisor Professor Oria Usifo, my H.O.D Engr.A.G. Raji for his good leading capability in his department. I equally wish to appreciate the effort of Mallam M.B. Doko for his technical support and Parental advice.

Thank you all and God bless you.

ABSTRACT

This project covers the design of an electric DC motor. Understanding to full capacity the basic dimension of a 4.5KW Electric DC motor, its constructional features and the basic components. In Nigeria Today, the use of an Electric Motor cannot be over-emphasized, which ranges from a pulley system, a fork-lift, an electric Blower, A washing machine, grinding machine, etc. with devices such as an Electric DC motor, will boost the technological pattern of Nigeria as she does not have to depend on the developed countries for all forms of technology. Furthermore, an Electric DC motor synchronizes all other forms of technology, as its basic principle operation is used in electric power generation stations. 'Without power Generation, there can be no technology'.

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CHAPTER ONE

1.0 INTRODUCTION:

DC machines are generators that convert mechanical energy to dc electrical energy and DC motors are machines that converts DC electrical energy into mechanical energy. DC machines have a DC output only because a mechanism exists that converts the internal AC voltage to DC voltage.

At the most basic level, electric motors exist to convert electrical energy into mechanical energy. This is done by way of two interacting magnetic fields -- one stationary, and another attached to a part that can move. A number of types of electric motors exist, but most industries use DC motors in some form or another. DC motors have the potential for very high torque capabilities (although this is generally a function of the physical size of the motor), are easy to miniaturize, and can be "throttled" via adjusting their supply voltage. DC motors are also not only the simplest, but the oldest electric motors.

The basic principles of electromagnetic induction were discovered in the early 1800's by Oersted, Gauss, and Faraday. By 1820, Hans Christian Oersted and Andre Marie Ampere had discovered that an electric current produces a magnetic field. The next 15 years saw a flurry of cross-Atlantic experimentation and innovation, leading finally to a simple DC rotary motor. A number of men were involved in the work, so proper credit for the first DC motor is really a function of just how broadly you choose to define the word "motor."

HISTORY

1.111 Michael Faraday (U.K.)

Fabled experimenter Michael Faraday decided to confirm or refute a number of speculations surrounding Oersted's and Ampere's results. Faraday set to work devising an experiment to demonstrate whether or not a current-carrying wire produced a circular magnetic field around it, and in October of 1821 succeeded in demonstrating this.

Faraday took a dish of mercury and placed a fixed magnet in the middle; above this, he dangled a freely moving wire (the free end of the wire was long enough to dip into the mercury). When he connected a battery to form a circuit, the current-carrying wire circled around the magnet. Faraday then reversed the setup, this time with a fixed wire and a dangling magnet again the free part circled around the fixed part. This was the first demonstration of the conversion of electrical energy into motion, and as a result, Faraday is often credited with the invention of the electric motor. Bear in mind, though, that Faraday's electric motor is really just a lab demonstration, as you can't harness it for useful work.

Also note that if you plan on repeating this experiment yourself, you should use salt water (or some similar nontoxic but conductive liquid) for the fluid, rather than mercury. Mercury can be very hazardous to your health, and requires stringent precautions on its use.

1.112 Joseph Henry (U.S.)

It took ten years, but by the summer of 1831 Joseph Henry had improved on Faraday's experimental motor. Henry built a simple device whose moving part was a straight electromagnet rocking on a horizontal axis. Its polarity was reversed automatically by its motion as pairs of wires projecting from its ends made connections alternately with two electrochemical cells. Two vertical permanent magnets alternately attracted and repelled the ends of the electromagnet, making it rock back and forth at 75 cycles per minute.

Henry considered his little machine to be merely a "philosophical toy," but nevertheless believed it was important as the first demonstration of continuous motion produced by magnetic attraction and repulsion. While being more mechanically useful than Faraday's motor, and being the first real use of electromagnets in a motor, it was still by and large a lab experiment.

1.113 William Sturgeon (U.K.)

Just a year after Henry's motor was demonstrated, William Sturgeon invented the commutator, and with it the first rotary electric motor -- in many ways a rotary analogue of Henry's oscillating motor. Sturgeon's motor, while still simple, was the first to provide continuous rotary motion and contained essentially all the elements of a modern DC motor. Note that Sturgeon used horseshoe electromagnets to produce both the moving and stationary magnetic fields (to be specific, he built a shunt wound DC motor).

Electric Motors, are devices used to convert electrical energy into mechanical energy, by electromagnetic means. A machine that converts mechanical energy into electrical energy is called a generator, alternator, or dynamo, and a machine that converts electrical energy into mechanical energy is called a motor.

The magnetic field of a permanent magnet is strong enough to operate only a small practical dynamo or motor. As a result, for large machines, electromagnets are employed. Both motors and generators consist of two basic units, the field, which is the electromagnet with its coils, and the armature, the structure that supports the conductors which cut the magnetic field and carry the induced current in a generator or the exciting current in a motor.

The armature is usually a laminated soft-iron core around which conducting wires are wound in coils.

1.2 TYPES OF DC MOTORS

1. The separately excited DC motor
2. The shunt DC motor
3. The permanent Magnet DC motor
4. The series DC motor
5. The Brushless DC motor

1.2.1 The separately excited DC motor

A separately excited DC motor is a motor whose field circuit is supplied from a separate constant voltage power supply. When the supply voltage to the motor is assumed constant, there is no practical difference in the behaviour of between the separately excited DC motor and the Shunt DC motor.

1.2.2 The shunt DC motor

A shunt DC motor is a motor whose field circuit get its power directly across the armature terminals of the motor. Both motor, the separately excited DC motor and the shunt DC motor are similar in operation, the difference is their source of field power.

The kirchoff's voltage law equation for the circuit of both the separately excited DC motor and the shunt DC motor is given as

$$V_T = E_A + I_A R_A$$

Where V_T is the terminal voltage

E_A is the internal generated voltage of the motor

$I_A$is the Armature current

R_A is the Armature Resistance

1.2.3 The permanent Magnet DC Motor

A permanent-magnet DC(PMDC) motor is a motor whose poles are made of permanent magnet. permanent-magnet DC motor offers a number of benefits compared with shunt DC motors in some application. Since motor do not require an external field circuit, they do not have circuit copper losses which is associated with the shunt DC motors. Again, since no field winding is required, they can be smaller than the corresponding shunt DC motor. permanent-magnet DC motors are especially common in smaller fractional and sub-fractional horse power sizes, this makes up for the disadvantage of space in DC shunt motor

However permanent-magnet DC motor, also have disadvantages. permanent-magnet DC motors cannot produce as high a flux density as an externally supplied DC shunt field, so it therefore has a low torque. It also has the risk of demagnetization. The armature current produced in a DC motor I_A produces a magnetic field on its own which counteracts the magnetic produced by the PMDC motor.

1.2.4 The series DC motor

A series DC motor is a motor whose field windings consist of a relatively few turns connected in series to the armature current circuit. In series motor, the amature current, the field current, and the line current are all thesame. The kirchoff's voltage law equation for this motor is:

$$V_T = E_A + I_A(R_A + R_S)$$

Where R_S is the series field resistance.

1.2.5 BRUSHLESS DC MOTORS(BLDC)

Brushed DC motors have been in commercial use since 1886. BLDC motors, however have only been commercially possible since 1962.

Limitations of brushed DC motors overcome by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and consequent need for servicing, at the cost of potent less rugged and more complex and expensive control electronics.

A BLDC motor has permanent magnets which rotate and a fixed armature, eliminating the problems of connecting current to the moving armature. An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush/commutator system.

BLDC motors offer several advantages over brushed DC motors, including more torque per weight and efficiency, reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, more power, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

The maximum power that can be applied to a BLDC motor is exceptionally high, limited almost exclusively by heat, which can weaken the magnets (Neodymium-iron-boron magnets typically demagnetize at temperatures lower than that of boiling water). A BLDC motor's main disadvantage is higher cost, which arises from two issues. First, BLDC motors require complex electronic speed controllers to run. Brushed DC motors can be regulated by a comparatively simple controller, such as a rheostat (variable resistor). However, this reduces efficiency because power is wasted in the rheostat. Second, some practical uses have not been well developed in the commercial sector. For example, in the Radio Control (RC) hobby, even commercial brushless motors are often hand-wound while brushed motors use armature coils which can be inexpensively machine-wound.

BLDC motors are often more efficient at converting electricity into mechanical power than brushed DC motors. This improvement is largely due to the absence of electrical and friction losses due to brushes. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve. Under high mechanical loads, BLDC motors and high-quality brushed motors are comparable in efficiency.

AC induction motors require induction of magnetic field in the rotor by the rotating field of the stator; this results in the magnetic and electric fields being out of phase. The phase difference requires greater current and current losses to achieve power. ECMs are microprocessor-controlled to keep the stator current in phase with the permanent magnets of the rotor, requiring less current for the same effect and therefore resulting in greater efficiency.

In general, manufacturers use brush-type DC motors when low system cost is a priority but brushless motors to fulfil requirements such as maintenance-free operation, high speeds, and operation in explosive environments where sparking could be hazardous.

1.3OBJECTIVE

- To understand the working principle of an electric DC motor
- To design a 4.5KW Electric DC Motor with limited error.

1.4METHODOLOGY:

- Consulting relevant material in the library on an Electric DC motor.
- Getting assistance from the Laboratory Technicians
- Visiting the internet to gather information on an Electric DC motor.
- Using an appropriate computer software in the realization of the project Topic.

1.5 AREA OF APPLICATIONS

- Power tools
- Blowers and pumps
- Machine tools
- Household appliances
- Disc drives
- Positioning in printers and floppy
- Drilling machine

CHAPTER TWO

LITERATURE REVIEW

2.1. THEORY OF AN ELECTRIC DC ROTATION

A simple DC motor has a coil of wire that can rotate in a magnetic field. The current in the coil is supplied via two brushes that make moving contact with a split ring. The coil lies in a steady magnetic field. The forces exerted on the current-carrying wires create a torque on the coil.

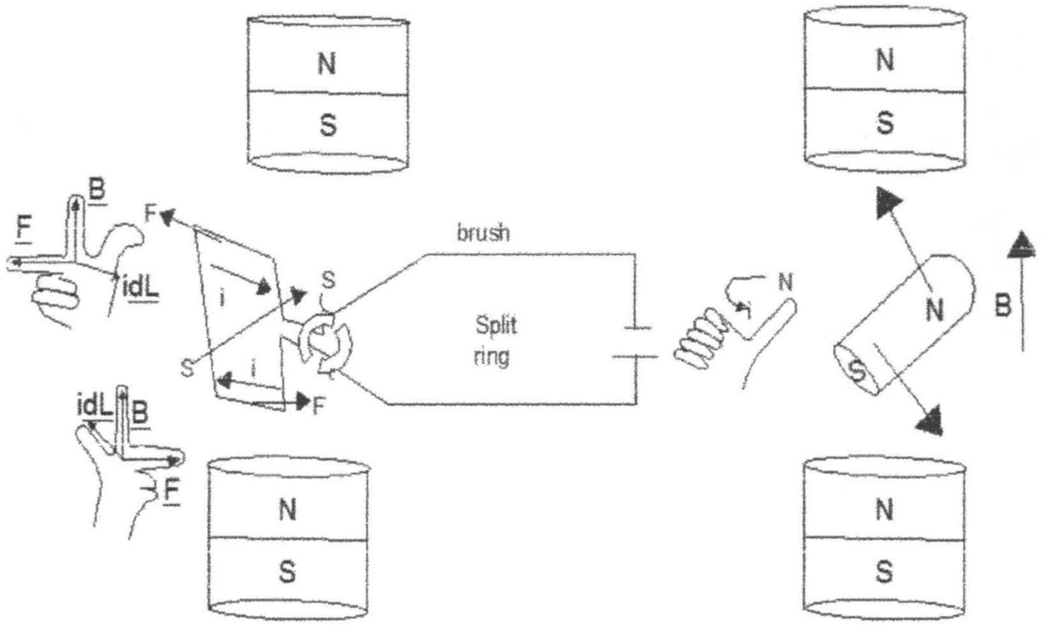

Fig 2.0 Rotation of the motor brushes using fleming's right hand rule

The force F on a wire of length L carrying a current i in a magnetic field B is iLB times the sine of the angle between B and i, which would be 90° if the field were uniformly vertical. The direction of F comes from the right hand rule, as shown here. The two forces shown here are equal and opposite, but they are displaced vertically, so they exert a torque. (The forces on the other two sides of the coil act along the same line and so exert no torque.)

A number of different nmemonics are used to remember the direction of the force. Some use the right hand, some the left. For students who know vector multiplication, it is easy to use the Lorentz force directly: $\underline{\mathbf{F}} = q\,\underline{\mathbf{v}} \times \underline{\mathbf{B}}$, whence $\underline{\mathbf{F}} = i\,\underline{\mathbf{dL}} \times \underline{\mathbf{B}}$.

The coil can also be considered as a magnetic dipole, or a little electromagnet, as indicated by the arrow SN: curl the fingers of your right hand in the direction of the current, and your thumb is the North pole. In the sketch at right, the electromagnet formed by the coil of the rotor is represented as a permanent magnet, and the same torque (North attracts South) is seen to be that acting to align the central magnet.

Note the effect of the brushes on the splitring. When the plane of the rotating coil reaches horizontal, the brushes will break contact (not much is lost, because this is the point of zero torque anyway – the forces act inwards). The angular momentum of the coil carries it past this break point and the current then flows in the opposite direction, which reverses the magnetic dipole. So, after passing the break point, the rotor continues to turn anticlockwise and starts to align in the opposite direction. In the following text, I shall largely use the 'torque on a magnet' picture, but be aware that the use of brushes or of AC current can cause the poles of the electromagnet in question to swap position when the current changes direction.

The torque generated over a cycle varies with the vertical separation of the two forces. It therefore depends on the sine of the angle between the axis of the coil and field. However, because of the split ring, it is always in the same sense. The animation below shows its variation in time, and you can stop it at any stage and check the direction by applying the right hand rule.

Now a DC motor is also a DC generator. Have a look at the next animation. The coil, split ring, brushes and magnet are exactly the same hardware as the motor above, but the coil is being turned, which generates an EMF.

If you use mechanical energy to rotate the coil (N turns, area A) at uniform angular velocity ω in the magnetic field **B**, it will produce a sinusoidal EMF in the coil. EMF (an EMF or electromotive force is almost the same thing as a voltage). Let θ be the angle between **B** and the normal to the coil, so the magnetic flux φ is NAB.cos θ. Faraday's law gives:

$$EMF = -\,d\varphi/dt = -\,(d/dt)\,(NBA \cos\theta)$$

$$= NBA \sin\theta\,(d\theta/dt) = NBA\omega \sin\omega t.$$

The animation above would be called a DC generator. As in the DC motor, the ends of the coil connect to a split ring, whose two halves are contacted by the brushes. Note that the brushes and split ring 'rectify' the EMF produced: the contacts are organised so that the current will always flow in the same direction, because when the coil turns past the dead spot, where the brushes meet the gap in the ring, the connections between the ends of the coil and external terminals are reversed. The EMF here (neglecting the dead spot, which conveniently happens at zero volts) is $|NBA\omega \sin\omega t|$, as sketched.

2.1.1TORQUES IN DC MOTORS

Starting and running torque are the first parameters to consider when sizing electric motors. Starting torque requirements for electric motors can vary from a small percentage of full load to a value several times full-load torque. Starting torque varies because of a change in load conditions or the mechanical nature of the machine, which the electric motor is installed in. The latter could be caused by the lubricant, wear of moving parts, or other reasons.

Electric motors feature torque supplied to the driven machine, which must be more than that required from start to full speed. The greater the electric motor's reserve torque, the more rapid the acceleration.

Electric motor drive systems that use gear reducers have parts that rotate at different speeds. To calculate acceleration torque required for these electric motors, rotating components must be reduced to a common base. The part inertias are usually converted to their equivalent value at the drive shaft. Equivalent inertia $W_2K_2^2$ of the load only is found from:

$$W_2K_2^2 = (W_1K_1^2)(N_1/N_2)^2$$

where $W_1K^2_1$ = load inertia in lb-ft^2, N_1 = load speed in rpm, and N_2 = electric motor speed in rpm.

Electric motors have bodies, which have a straight-line motion are often connected to rotating driving units by rack-and-pinion, cable, or cam mechanisms. For these electric motor parts, the equivalent WK^2 is found from:

$$WK^2 = W(S/2\Pi N)^2$$

where W = load weight, S = translation speed in fpm, Π is pi, and N = rotational speed in rpm.

2.2 USEFUL PARAMETERS IN AN ELECTRIC MOTOR

2.2.1 Electric Motors - Acceleration time:

Acceleration time for electric motors is directly proportional to total inertia and inversely proportional to the electric motor torque. For electric motors with constant acceleration torque, acceleration time is:

where WK^2 = rotational inertia in lb-ft^2, (N_2 - N_1) = the speed difference, and T_x = acceleration torque in lb-ft. For translating bodies, acceleration time is:

where W = weight of the load in lb, (S_2 - S_1) = the translation speed difference, and F_x = translation force in lb.

An approximation method is necessary to find the electric motor's acceleration time if acceleration torque is not linear during speed increase. The quickest method is to break up the speed versus torque curves of the electric motor and the driven machine into segments and calculate acceleration time for each segment. Accurate electric motor acceleration times usually result.

2.2.2. Electric Motors - Power rating:

Electric motors offer the horsepower required to drive a machine, which is typically referred to as electric motor load. The most common equation for power based electric motors on torque and rotational speed is: hp = (torque X rpm)/5,250.

If the electric motor's load is not constant and follows a definite cycle, a horsepower versus time curve for the driven machine is helpful. From this curve both peak and rms the electric motor's horsepower can be determined. Rms load horsepower indicates the necessary continuous electric motor rating. Peak load horsepower is not necessarily an indication of the required electric motor rating. However, when a peak load is maintained for a period of time, electric motors feature a rating, which usually should not be less than peak load horsepower.

2.2.3 Duty cycle in electric motors

Continuous steady-running loads over long periods are demonstrated by fans and blowers. On the other hand, electric motors installed in machines with flywheels may have wide variations in running loads. Often, electric motors use flywheels to supply the energy to do the work, and the electric motor does nothing but restore lost energy to the flywheel. Therefore, choosing the proper electric motor also depends on whether the load is steady, varies, follows a repetitive cycle of variation, or has pulsating torque or shocks.

For example, electric motors that run continuously in fans and blowers for hours or days may be selected on the basis of continuous load. But electric motors located in devices like automatically controlled compressors and pumps start a number of times per hour. And electric motors in some machine tools start and stop many times per minute.

Duty cycle is a fixed repetitive load pattern over a given period of time which is expressed as the ratio of on-time to cycle period. When operating cycle is such that electric motors operate at idle or a reduced load for more than 25% of the time, duty cycle becomes a factor in sizing electric motors. Also, energy required to start electric motors (that is, accelerating the inertia of the electric motor as well as the driven load) is much higher than for steady-state operation, so frequent starting could overheat the electric motor.

For most electric motors (except squirrel-cage electric motors during acceleration and plugging) current is almost directly proportional to developed torque. At constant speed, torque is proportional to horsepower. For accelerating loads and overloads on electric motors that have considerable droop, equivalent horsepower is used as the load factor. The next step in sizing the electric motor is to examine the electric motor's performance curves to see if the electric motor has enough starting torque to overcome machine static friction, to accelerate the load to full running speed, and to handle maximum overload.

2.2.4 Electric Motors - Service factors:

A change in NEMA standards for electric motor service factors and temperature rise has been brought about because of better insulation used on electric motors. For instance, a 1.15 service factor -- once standard for all open electric motors -- is no longer standard for electric motors above 200 hp.

Increases in electric motor temperature are measured by the resistance method in the temperature rise table. Electric motors feature a nameplate temperature rise, which is always expressed for the maximum allowable load. That is, if the electric motor has a service factor greater than unity, the nameplate temperature rise is expressed for the overload. Two Class-B insulated electric motors having 1.15 and 1.25 service factors will, therefore, each be rated for a 90°C rise. But the second electric motor will have to be larger than the first in order to dissipate the additional heat it generates at 125% load.

Electric motors feature a service factor, which indicates how much over the nameplate rating any given electric motor can be driven without overheating. NEMA Standard MGI-143 defines service factor of an ac motor as "...a multiplier which, when applied to the rated horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the service factor..." In other words, multiplying the electric motor's nameplate horsepower by the service factor tells how much electric motors can be overloaded without overheating. Generally, electric motor service factors:

- Handle a known overload, which is occasional.

- Provide a factor of safety where the environment or service condition is not well defined, especially for general-purpose electric motors.
- Obtain cooler-than-normal electric motor operation at rated load, thus lengthening insulation life.

2.2.5 Electric Motors - Efficiency:

Small universal electric motors have an efficiency of about 30%, while 95% efficiencies are common for three-phase machines. In less-efficient electric motors, the amount of power wasted can be reduced by more careful application and improved electric motor design.

Electric motor's feature an efficiency level, which also depends on actual electric motor load versus rated load, being greatest near rated load and falling off rapidly for under and overload conditions.

2.2.6 Back EMF

Just as putting voltage across a wire in a magnetic field can generate motion, moving a wire through a magnetic field can generate voltage. This means that as a DC motor's rotor spins, it generates voltage -- the output voltage is known as back EMF. Because of back EMF, a spark is created at the commutator as a motor's brushes switch from contact to contact. Meanwhile, back EMF can damage sensitive circuits when a motor is stopped suddenly.

2.2.7 Noise (ripple) on power lines

A number of things will cause a DC motor to put noise on its power lines: commutation noise (a function of brush / commutator design & construction), roughness in bearings (via back EMF), and gearing roughness (via back EMF, if the motor is part of a gearmotor) are three big contributors.

Even without these avoidable factors, any electric motor will put noise on its power lines by virtue of the fact that its current draw is not constant throughout its motion. Going back to our example two-pole motor, its current draw will be a function of the angle between its rotor coil and field magnets:

2.3THE WORKING PRINCIPLE OF A DC MOTOR

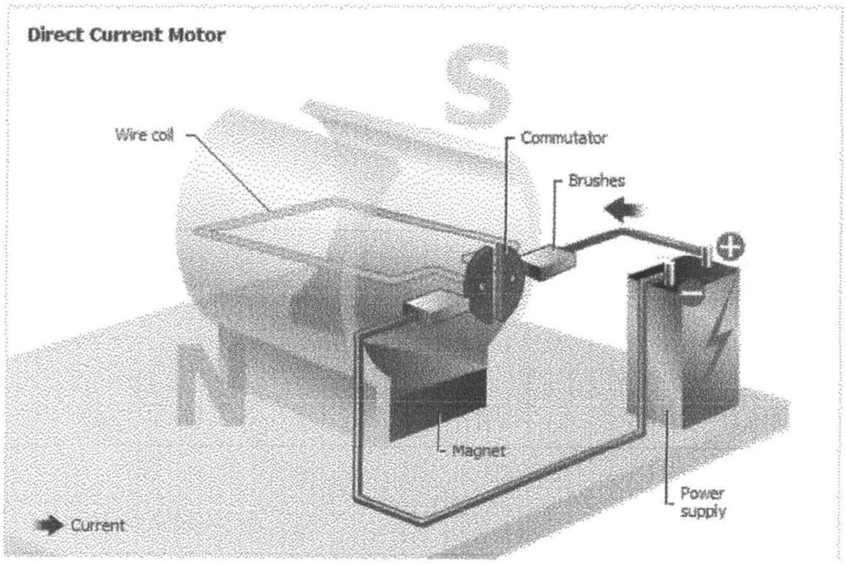

Fig2.1 A DC motor

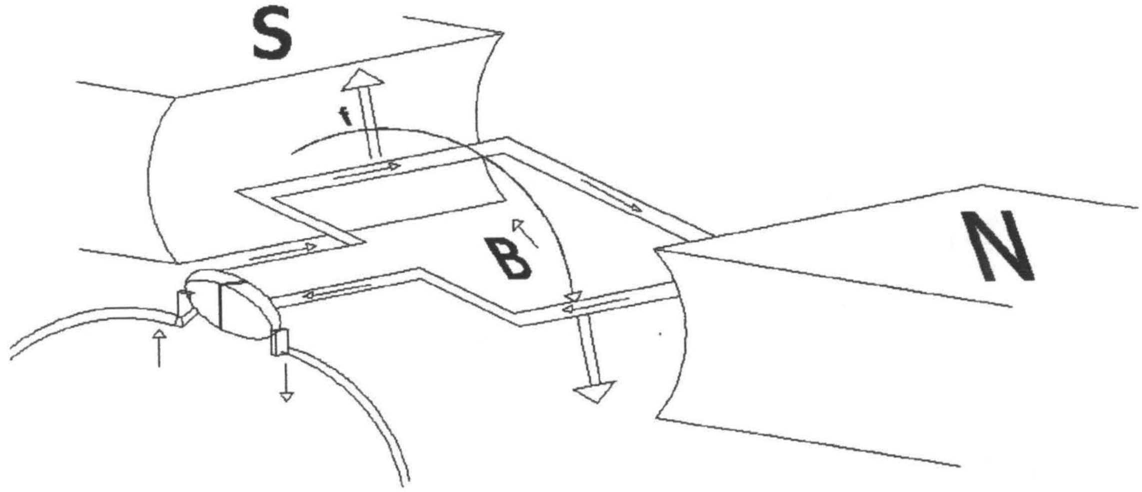

Fig 2.2 A DC motor Operation

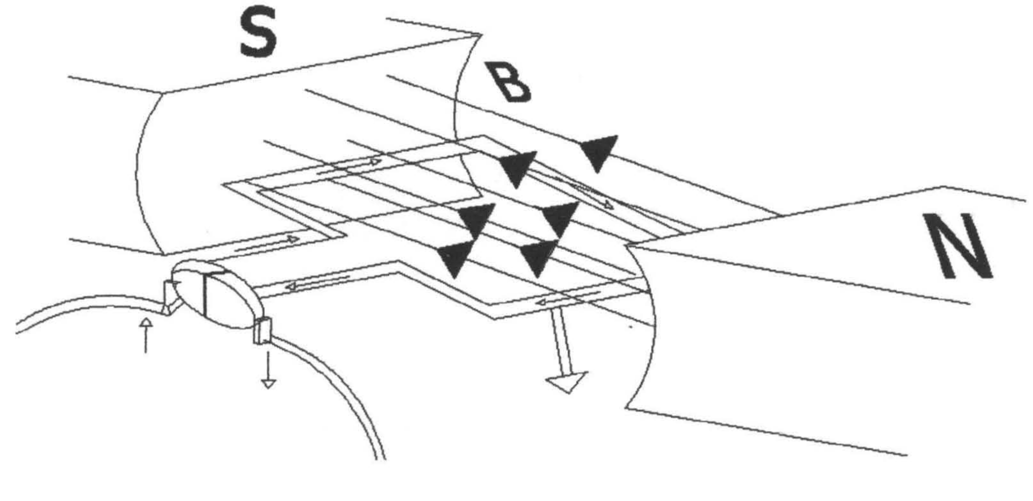

Fig 2.4 magnetic field in a DC motor

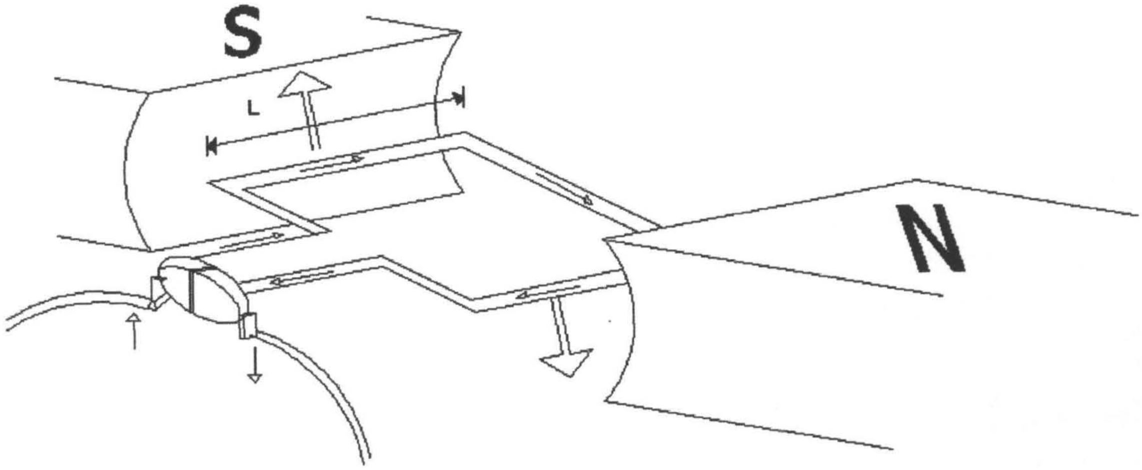

Fig 2.5 force in a DC motor

A simple DC motor has a coil of wire that can rotate in a magnetic field. The current in the coil is supplied via two brushes that make moving contact with a split ring. The coil lies in a steady magnetic field. The forces exerted on the current-carrying wires create a torque on the coil.

If an armature revolves between two stationary field poles (North and south pole) , the current in the armature moves in one direction during half of each revolution and in the other direction during the other half. To produce a steady flow of unidirectional, or direct, current from such a device, it is necessary to provide a means of reversing the current flow outside the motor once during each revolution. In older machines this reversal is accomplished by means of a commutator, a split metal ring mounted on the shaft of the armature. The two halves of the ring are insulated from each other and serve as the terminals of the armature coil. Fixed brushes of metal or carbon are held against the commutator as it revolves, connecting the coil electrically to external wires. As the armature turns, each brush is in contact alternately with the halves of the commutator, changing position at the moment when the current in the armature coil reverses its direction. Thus there is a flow of unidirectional current in the outside circuit to which the generator is connected. In some newer machines this reversal is accomplished using power electronic devices, for example, diode rectifiers.

Because the speed of rotation controls the flow of current in the armature, special devices must be used for starting DC motors. When the armature is at rest, it has virtually no resistance, and if the normal working voltage is applied, a large current will flow, which may damage the commutator or the armature windings. The usual means of preventing such damage is the use of a starting resistance in series with the armature to lower the current until the motor begins to develop an adequate back voltage. As the motor picks up speed, the resistance is gradually reduced, either manually or automatically.

The speed at which a DC motor operates depends on the strength of the magnetic field acting on the armature, as well as on the armature current. The stronger the field, the slower is the rate of rotation needed to generate a back voltage large enough to counteract the applied voltage. For this reason the speed of DC motors can be controlled by varying the field current.

In any electric motor, operation is based on simple electromagnetism. A current-carrying conductor generates a magnetic field; when this is then placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field. As you are well aware of from playing with magnets as a kid, opposite (North and South) polarities attract, while like polarities (North and North, South and South) repel. The internal configuration of a DC motor is designed to harness the magnetic interaction between a current-carrying conductor and an external magnetic field to generate rotational motion.

Observing a simple 2-pole DC electric motor (here red represents a magnet or winding with a "North" polarization, while green represents a magnet or winding with a "South" polarization).

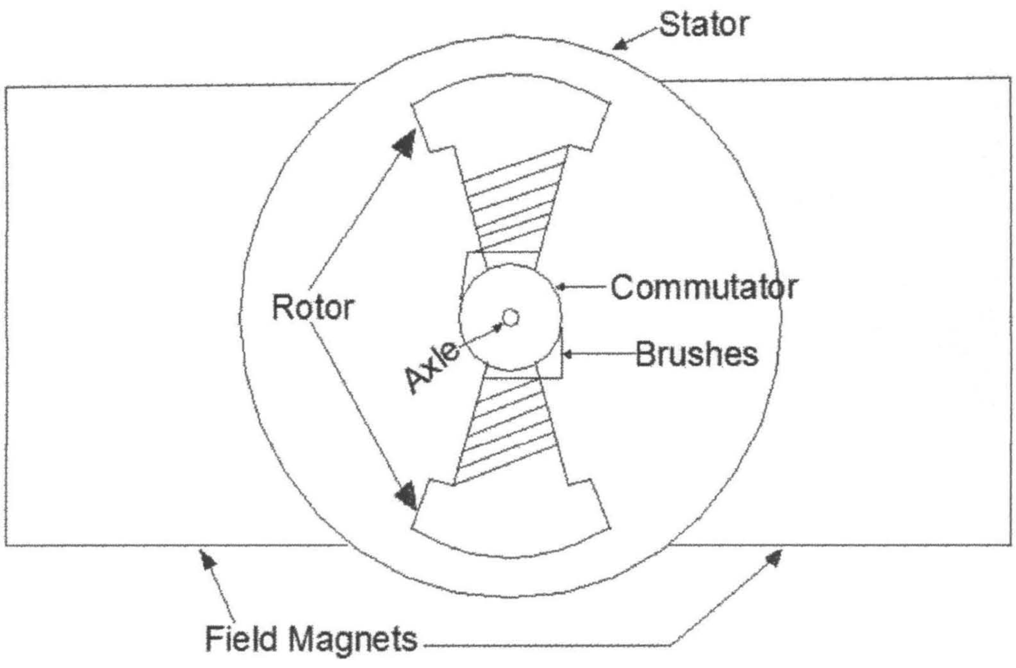

Fig 2.7 a DC motor schematics diagram

Every DC motor has six basic parts -- axle, rotor (a.k.a., armature), stator, commutator, field magnet(s), and brushes. In most common DC motors, the external magnetic field is produced by high-strength permanent magnets. The stator is the stationary part of the motor -- this includes the motor casing, as well as two or more permanent magnet pole pieces. The rotor (together with the axle and attached commutator) rotate with respect to the stator. The rotor consists of windings (generally on a core), the windings being electrically connected to the commutator. The above diagram shows a common motor layout -- with the rotor inside the stator (field) magnets.

The geometry of the brushes, commutator contacts, and rotor windings are such that when power is applied, the polarities of the energized winding and the stator magnet(s) are misaligned, and the rotor will rotate until it is almost aligned with the stator's field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts, and energize the next winding. Given our example two-pole motor, the rotation reverses the direction of current through the rotor winding, leading to a "flip" of the rotor's magnetic field, driving it to continue rotating.

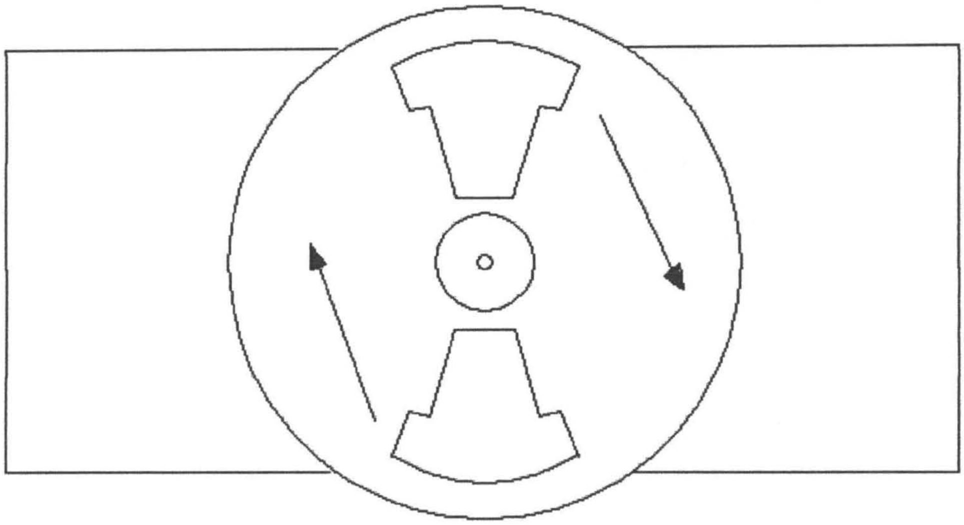

Fig2.8 a two pole motor

In real life, though, DC motors will always have more than two poles (three is a very common number). In particular, this avoids "dead spots" in the commutator. You can imagine how with our example two-pole motor, if the rotor is exactly at the middle of its rotation (perfectly aligned with the field magnets), it will get "stuck" there. Meanwhile, with a two-pole motor, there is a moment where the commutator shorts out the power supply (i.e., both brushes touch both commutator contacts simultaneously). This would be bad for the power supply, waste energy, and damage motor components as well. Yet another disadvantage of such a simple motor is that it would exhibit a high amount of torque "ripple" (the amount of torque it could produce is cyclic with the position of the rotor).

So since most small DC motors are of a three-pole design

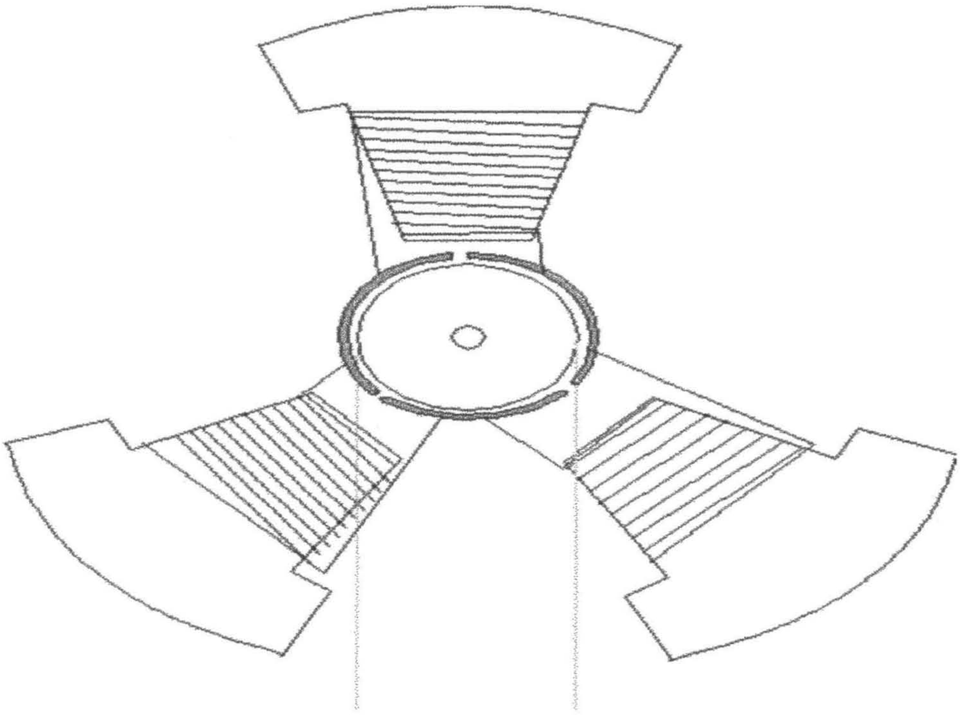

Fig2.8 A DC motor with 3-phase design

It was noticed that a few things from this -- namely, one pole is fully energized at a time (but two others are "partially" energized). As each brush transitions from one commutator contact to the next, one coil's field will rapidly collapse, as the next coil's field will rapidly charge up (this occurs within a few microsecond). We'll see more about the effects of this later, but in the meantime you can see that this is a direct result of the coil windings' series wiring:

2.4 CONSTRUCTIONAL COMPONENT

For an Electric DC Motor, the main component commonly used in industrial and domestic applications are;

- Rotor
- Stator
- Enclosure

The stator and rotor do the work, and the enclosure protects the stator and rotor.

2.4.1 THE ROTOR

The **rotor** is the non-stationary part of a rotary electric motor, which rotates because the wires and magnetic field of the motor are arranged so that a torque is developed about the rotor's axis. In some designs, the rotor can act to serve as the motor's armature, across which the input voltage is supplied. The stationary part of an electric motor is the stator.

2.4.2 The Stator

The stator consists of wound poles that carry the supply current to induce a magnetic field that penetrates the rotor. In a very simple motor, there would be a single projecting piece of the stator for each pole, with windings around it; in fact, to optimize the distribution of the magnetic field, the windings are distributed in many slots located around the stator, but the magnetic field still has the same number of north-south alternations. The number of 'poles' can vary between motor types but the poles are always in pairs (i.e. 2, 4, 6, etc.).

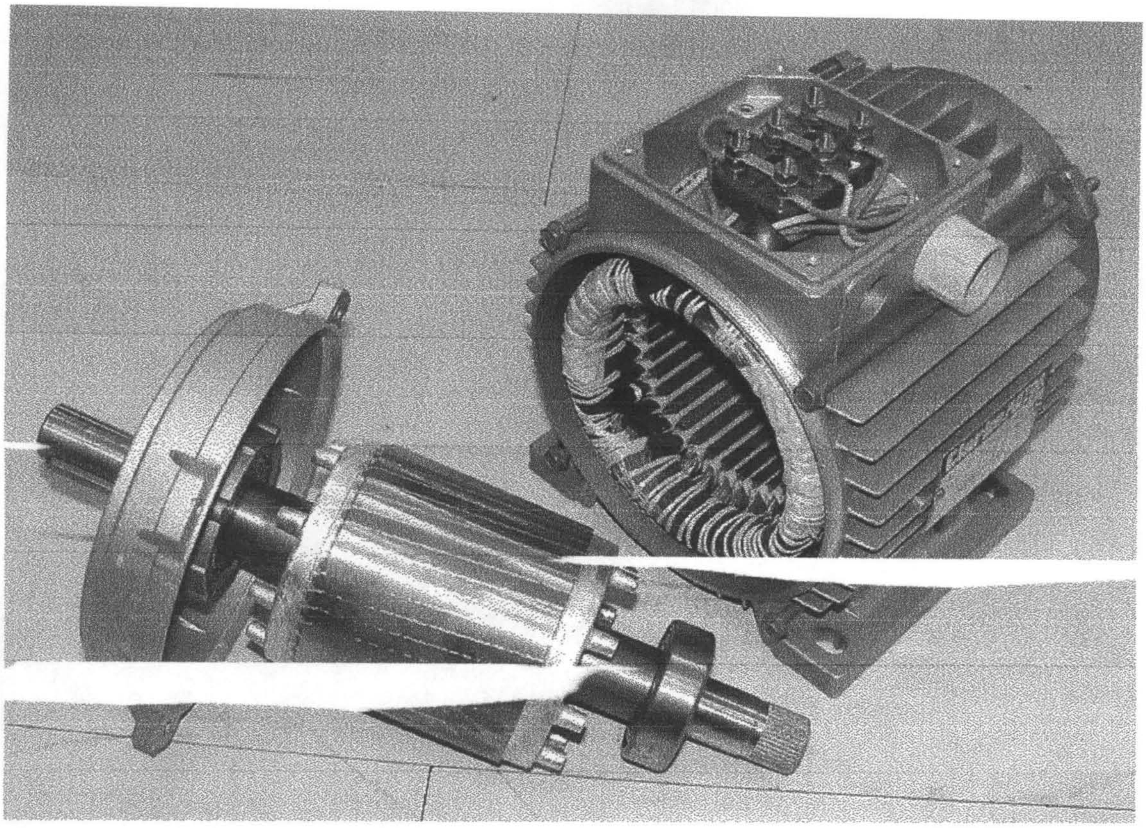

Fig2.9 The stator(on right) and rotor(left)

2.5 Armature:

The purpose of the armature is toprovide the energy conversion in aDC machine.In a DC motor, the armature isrotated by an external mechanicalforce, such as a steam turbine.This rotation induces a voltage andcurrentflowinthe armature.Thus, the armature convertsmechanical energy to electricalenergy.In a DC motor, the armaturereceives voltage from an outsideelectrical sourceand convertselectrical energy into mechanicalenergy in the form of torque.The armature is typically a soft iron drum mounted on the motor shaft, with the armature conductors set axially into the surface of the drum. Also mounted on the armature shaft are the commutator segments, to which the armature conductors are connected. The armature shaft is mounted in ball bearings at each end, the bearings being held in the ends of the motor casing.

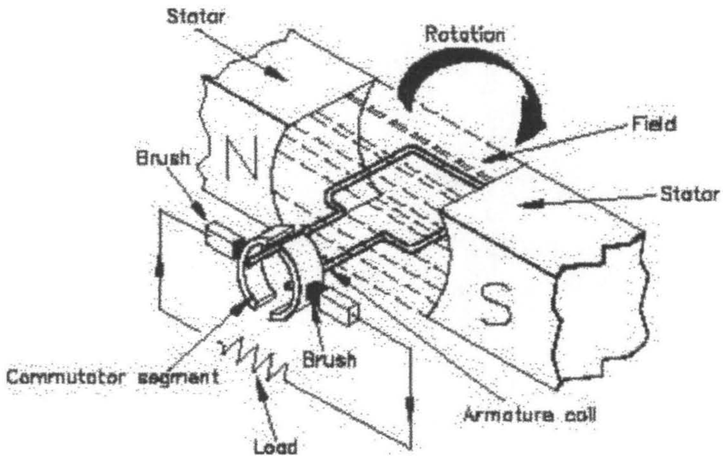

Fig 2.10 The Armature

2.5.1 Electric DC rotor:

RotorThe purpose of the rotor is to provide the rotating element in a DC machine.In a DC generator, the rotor is the component that is rotated by an external force. In a DCmotor, the rotor is the component that turns a piece of equipment. In both types of DCmachines, the rotor is the armature.

2.5.2 The field winding:

Field windings The field windings are attached to the inside of the yoke and form two poles fitting closely around the armature with a running clearance.A series winding usually consists of a small number of turns of large size wire. With this winding, the motor can produce high starting and overload torque. This design is not used for applications with light loads or no load conditions. Series motors should be avoided in applications where they are likely to lose there load because of their tendency to "run away" under no-load conditions. The types of winding are further divided into:

- Lap winding
- Wave winding
- The frog-leg winding

2.5.2.1: The lap winding:

This is the simplest type of winding construction used in modern dc machines. A simplex lap winding is a rotor winding consisting of coils containing one or more turns of wire with the ends of each coil coming out at adjacent commutator segments. If the end of the coil is connected to the segment after the segment that the beginning of the coil is connected to, the winding is a progressive lap winding. In lap winding, there are as many parallel current paths through the machine as there are poles on the machine

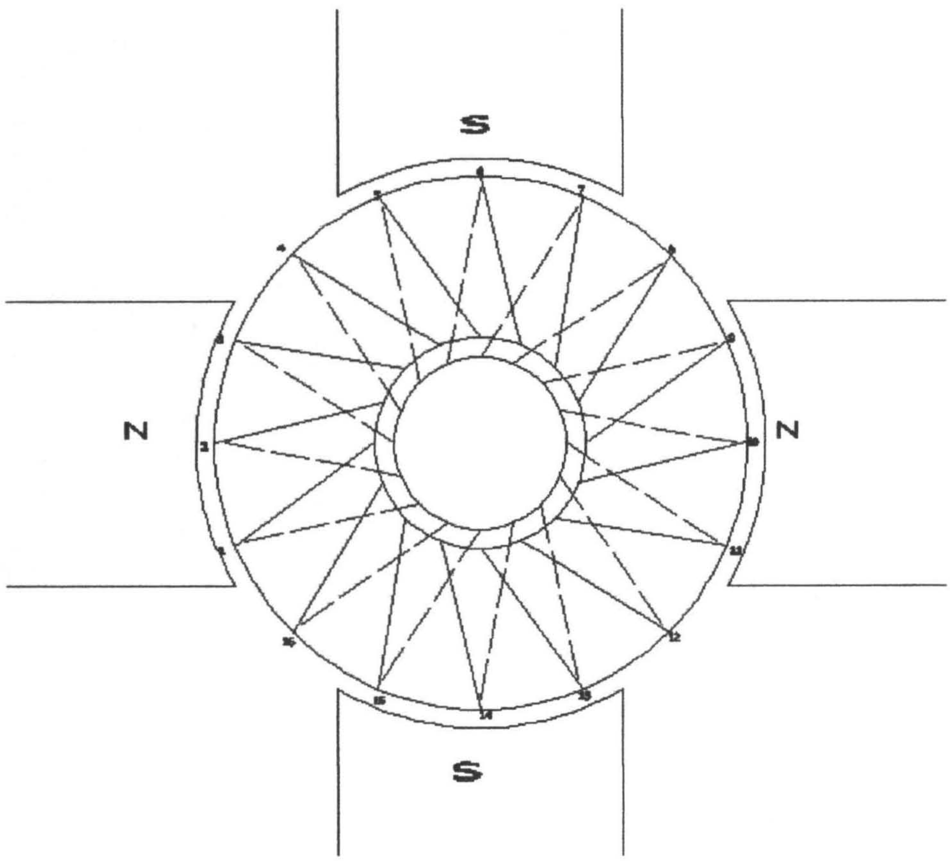

Fig 2.11 A four pole lap-wound dc motor

2.5.2.2 The wave winding:

This is an alternative way to connect the rotor coils to the commutator segments. In a wave winding, every rotor coils connects back to the to a commutator segments adjacent to the beginning of the first coil. It therefore contains two coils between the adjacent commutator segments has a side under each pole face, all output voltages are the sum of the effect of every pole, and there can be no voltage imbalances

2.8.3 Mechanical losses

These losses are due to friction and windage.

(i) friction loss e.g., bearing friction, brush friction etc.

(ii) windage loss i.e., air friction of rotating armature.

These losses depend upon the speed of the machine. But for a given speed, they are practically constant.

Iron losses and mechanical losses together are called stray losses.

2.8.4 Constant and Variable Losses

The losses in a DC. generator (or DC. motor) may be sub-divided into

(i)constant losses (ii) variable losses.

2.8.4.1 Constant losses

Those losses in a DC. generator which remain constant at all loads are known as constant losses. The constant losses in a DC. generator are:

(a) iron losses

(b) mechanical losses

(c) shunt field losses

2.8.4.2 Variable losses

Those losses in a DC generator which vary with load are called variable losses.

The variable losses in a DC. generator are:

(a) Copper loss in armature winding ($I_a^2 R_a$)

(b) Copper loss in series field winding ($I_{se}^2 R_{se}$)

Total losses = Constant losses + Variable losses

Field copper (Cu) loss is constant for shunt and compound generators.

CHAPTER THREE

3.1. DESIGN SPECIFICATION

Power = 4.5KW

Speed = 2,400 rev/min

Efficiency = 80%

Number of poles = 6

Voltage = 220V

3.2. MAIN DIMENSIONS

The main dimension in the construction of a DC motor will be inferred from the specification above.

Using the relationship;

$$D^2L = \frac{w}{\pi \times B_{avg} \times n \times 10^{-3}} \text{--3.2.1}$$

Where w = power input - (series field loses + armature copper losses)

B_{avg}= average flux density in air gap

n= number of poles = 6

D = separation diameter

L= length.

Power input = $\frac{power\ output}{Efficiency}$

$= \frac{4500}{0.8}$

=5,625watt

Series field losses = 0.2% of 4500watt = 9w

Armature Copper losses = I^2R losses in the Armature

$= \frac{1}{2}$ total loss

$= {}^1/_2$ (5625-4500)

$= \frac{1}{2} \times 1125 = 562.5$w

since the motor is to operate on maximum efficiency, on full load,

$$w = 5625 - (10 + 562.5)$$

$w = 5052.5$watt

For large machines like the DC electric motors, the flux density (B) is taken to be 10,000 gauss.

The maximum flux density in the air gap (Bg) is deduced from a graph of loading constant for DC machines

Bg= 9,500gauss

The average flux density in air gap over the pole pitch is given be

$B_{av} = Bg \times k_f$-----------------------------------4.2.2

k_f= field form factor = 0.72 for large machine like DC electric motor.

B_{av}= 9500× 0.72

= 6840 line per sq cm ≈ 6840 $gauss$

The armature strength (q) can be deduced from the graph of loading constant

$$q = 35{,}000$$

$$R_{ps} = \frac{2400}{60} = 40rev/sec$$

$$D^2L = \frac{w}{\pi^2 \times B_{av}q \times n \times 10^{-3}}$$

$$= \frac{5052.5}{3.142^2 \times 6840 \times 35000 \times 40 \times 10^{-3}}$$

$$= 0.534 \times 10^{-4}m^3$$

Separation of diameter and length =

Core length = pole arc

$= \frac{\alpha\pi D}{2P}$

Where $\alpha = ratio\ pole \frac{are}{pole}\ pitch$

For non-interpole motors like the D.C Electric Motors, the ratio may be taken as high as 0.75 for large machines

$$L = \frac{0.75 \times 3.14 \times D}{6}$$

L= 0.3925D

$$D^2L = 0.534 \times 10^{-4}m^3$$

$$\equiv 0.3925D^3 = 0.534 \times 10^{-4} \times 10^9$$

$$D = \sqrt[3]{\frac{0.534 \times 10^{-4}}{0.3925}}$$

$$D = 53mm = 5.3cm$$

$$L = 0.3925 \times 53 = 20.8mm$$

$$\boldsymbol{L = 21mm \approx 2.1cm.}$$

3.3 DETERMINATION OF MEAN E.M.F INDUCED PER CONDUCTOR

Mean E.M.F. $= B_{av}LV \times 10^{-8}$---3.3.1

B_{av}previously calculated = 6840gauss

Peripheral speed $V = \pi D R_{ps}$

$$L = 2.1cm, D = 5.3cm$$

$$v = 3.14 \times 5.3 \times 40$$

$$= 665.7cm/sec$$

Hence the average EMF

$$= B_{av} \times L \times V \times 10^{-8}$$

$$= 6840 \times 2.1 \times 665.7 \times 10^{-8} = 0.0956V \approx 0.1V.$$

Therefore to calculate the B_{av},

$2P\phi = B_{av} \times \pi DL$ --4.3.2

$$2P\phi = 6840 \times 3.14 \times 5.3 \times 2.1$$

$$= 0.239 \times 10^{6}$$

The mean EMF therefore becomes

$$= 2P\phi \times R_{ps} \times 10^{-8}$$

$$= 0.239 \times 10^{6} \times 40 \times 10^{-8}$$

$$= 0.0956V \approx 0.1V.$$

3.4 THE NUMBER OF CONDUCTORS IN SERIES ON THE ARMATURE

On full load, the EMF induced in the armature winding exceeds the terminal voltage by an amount equal to the sum of the voltage drop in the armature windings, the interpole winding, the series windings and the contact drop at the brushes.

Drop allowed= $2\%\ of\ EMF$---4.4.1

EMF=220V

$$\frac{2}{100} \times 220 = 4.4V$$

$Zs = \frac{E \times 10^{8}}{2P\phi \times R_{ps}}$---4.4.2

$$\frac{(220 + 4.4) \times 10^{8}}{0.239 \times 10^{6} \times 40} = 2347\ conductors \approx \mathbf{2400 conductors}$$

3.5 THE NUMBER OF SLOTS

The DC electric motor is a Lap wound machine. The number of slots chosen in the electric motor depends on 3 factors

- The diameter
- The number of poles
- The number of conductors

$$number\ of\ slots = \frac{no\ of\ conductors}{no\ of\ poles} + 1$$

$$= \frac{2400}{6} + 1$$

$$= 401\ slots$$

$slot\ patch = \frac{\pi D}{no\ of\ slots}$ ---4.5.1

$$= \frac{3.14 \times 5.3}{401} = 0.04cm$$

3.5.1 DESIGN OF THE SLOT

The slot depth is chosen usually of considerable importance. The depth determines the number of copper that can be accommodated and the total loading of a machine. The slot should just be large enough to accommodate the winding and the insulation. The maximum permissible slot depth is limited from reactance of the armature coils. The slot depth and width can be determined from the following dimensions.

	Slot Depth	Slot Width
Bare Copper	6.1mm	1.2mm
Mica Wrap	0.7mm	0.3mm
Allowance for slack	0.2mm	0.1mm
Total	7mm	1.6mm

3.6 ARMATURE CURRENT

$P = VI$ -------------------------3.6.1

$$I = {}^{P}/_{V}$$

$$I = \frac{5000}{220} = 22.73A$$

3.7 THE DIMENSION OF THE ARMATURE CONDUCTOR

$$A_c = area\ required$$

$= \frac{1}{2} \times \emptyset \times \frac{10^6}{B}$ --3.7.1

Where $2P\phi = 0.239 \times 10^6$

$$\phi = \frac{0.239 \times 10^6}{2} = 39833.3\ lines$$

$$= 0.0398 \times 10^6 lines$$

$\frac{1}{2} \times \frac{0.0398 \times 10^6}{10000}$ =1.99sq cm

The necessary core depth below slots

$$d_c = \frac{A_c}{C} = \frac{1.99}{6} = 0.33cm$$

3.7 THE LENGHT OF THE ARMATURE CONDUCTOR

For large machines, with no allowance for spacing of coils, and for a slot width equal to 40% of the slot pitch at the root of teeth.

$I_s = 14 + P_p/\cos\theta$ ---4.7.1

$$sin\theta = \frac{slot\ width}{slot\ pitch}$$

$$slot\ width = 0.4 \times slot\ pitch$$

$\theta = 23.5^0, cos\theta = 0.92,$

$$I_s = 14 + P_p/0.92$$

$$I_s = 14 + 1.09P_p$$

$where P_p = pole\ pitch = \frac{\pi d}{2p}$----------------------------------4.7.2

$$\frac{3.14 \times 5.3}{6} = 2.77cm$$

$$I_s = 14 + 1.09(2.77)$$

$$I_s = 17.0cm.$$

because each lamination is very thin, the resistance to current flowing through the width of a lamination is also quite large. Thus laminating a core increases the core resistance which decreases the eddy current and hence the eddy current loss.

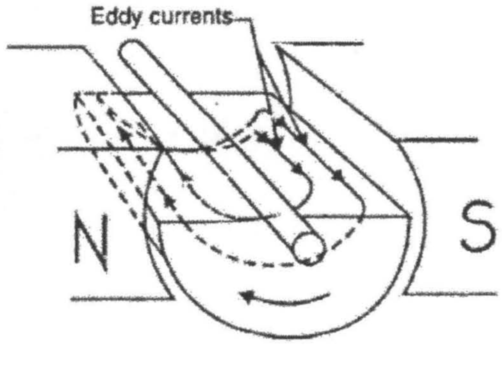

Fig 2.15circulating current in a core

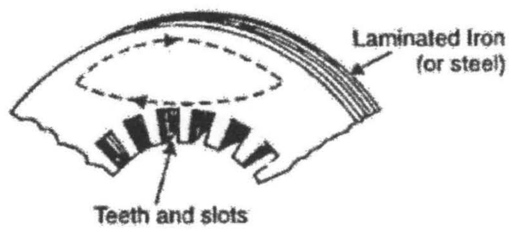

Fig 2.16 laminated core

Thus, the eddy current loss is calculated as:

$$\text{Eddy current loss, } P_e = K_e B_{max}^2 f^2 t^2 V \quad \text{watts}$$

where K_e = Constant depending upon the electrical resistance of core and system of units used

B_{max} = Maximum flux density in Wb/m2

f = Frequency of magnetic reversals in Hz

t = Thickness of lamination in m

V = Volume of core in m^3

It may be noted that eddy current loss depends upon the square of lamination thickness. For this reason, lamination thickness should be kept as small as possible.

3.8 THE OVERHANG OF THE WINDING(L_o)

$$L_o = 7 + \ tan\theta P_p/2$$

$$L_o = 7 + tan\theta 23.5° \left[\frac{2.77}{2}\right]$$

$$= 7 + 0.435(1.385)$$

$$L_o = \mathbf{7.60}\boldsymbol{cm}.$$

3.9 WEIGHT OF COPPER IN THE ARMATURE WINDING

The total length of the conductor L_a

$L_a = L + L_s$--3.9.1

$L_a = 2.1 + \ 17.0$

$L_a = 19.1$cm

For complete winding,

$L_a = Z_a l_a$ − − − − − − − − − − − − − −4.9.2

$$= 2400 \times 19.1$$

$$L_a = 45840cm$$

The volume $V_a = L_a A_a$

$$A_a = \frac{I_a(armature\ current)}{a(current\ density)}$$

For large strap wound machine, $a = 4.5A/mm^2$

$$A_a = \frac{22.73}{4.5} = 5.05cm^2$$

$$V_a = 45840 \times 5.05$$

$$= 231492$$

The density of copper is 8.9gm per Cc

Therefore, the weight of copper is

$$8.9 \times (\sqrt{a} \times 10^{-3})kg$$

$$= 2060.3Kg$$

3.10 THE RESISTANCE OF THE WINDING

$r_a = \ell \frac{L_a}{A_a} \times \frac{1}{(2p)^2}$---------------------------------------3.10.1

$$\ell = specific\ resistance\ of\ copper = 1.7 \times 10^{-6}\Omega$$

$$r_a = 1.7 \times 10^{-6} \times \frac{45840}{5.05} \times \frac{1}{6^2}$$

$$= 4.286 \times 10^{-4}\ \Omega$$

3.10.1 FREQUENCY

This is the product of $\frac{1}{2}$ of the number of poles and speed per R_{ps}

$$R_{ps} = \frac{1000}{60}$$

$$= \frac{1}{2} \times 6 \times \frac{1000}{60}$$

$$= 3 \times 16.66 = 49.98 rev/sec.$$

3.11 THE OUTPUT

Fundamental Output Relation

The total work done in one complete revolution of a DC machine is the product of Total electric loading and the total magnetic loading

$\omega = 2P\phi \times Z_a I_a \times 10^8 watt/sec$----------------------------------3.11.1

$$Z_a C = total\ electric\ loading$$

$$2P\emptyset = total\ magnetic\ loading$$

$$\omega = 2 \times 3 \times 0.0398 \times 10^6 \times 22.73 \times 2400 \times 10^{-8}$$

$$\omega = 130.27 watt/sec.$$

The output coefficient

This is the product of the EMF and the armature current divided by the product of the speed of the armature, the length and the square of the diameter.

$C_o = \frac{EI_a \times 10^{-3}}{R_{pm} \times D^2 L}$---3.11.1

3.12 THE FIELD SYSYTEM

In DC motor, the larger the ratio adopted for $\mathbf{F_f}$ /$\mathbf{F_a}$the greater the amount that the field strength can be reduced and the speed increases without risk of flashing over.

$$F_a = Z_a I_a / 4p$$

$$= \frac{22.73(2400)}{4 \times 3} = 4546 Amps.$$

In large DC machines like the electric Motor, the ratio $^{F_f}/_{F_a}$ is 1.2

The ratio $^{F_f}/_{F_a} = 1.2$--4.12.1

$$F_f = 1.2 \times F_a$$

$$F_f = 1.2 \times 4546 = 5455.2$$

3.13 NUMBER OF TURNS

This is given by dividing the ampere-turns by the current

$F_f = IN$--3.13.1

$$N = \frac{F_f}{I}$$

$$N = \frac{5455.2}{22.73} = 240 \; ampre \; turn$$

3.14 MEAN LENGTH OF TURN

The pole laminations are secured by steel rivets between two end plates each 3cm thick.

The mean length of one turn will be

$$2 \times (20.5 + 33 + \pi \times 6)$$

$$\approx 145cm.$$

3.15 THE SECTIONAL AREA OF POLE

The pole being used for the electric motor is the laminated type. The flux density is taken to 10,000 lines per sq cm.

The pole flux on full load is

$$\lambda \times useful\ flux(\emptyset)$$

$$where\ \emptyset = 0.0398 \times 10^6$$

$$\lambda = lag\ or\ lead\ factor = 1.2$$

Pole flux on full load$= 1.2 \times 0.0398$

$$= 0.048mega\ lines$$

For a working flux density of 10000 lines per sq cm. The area required

$$= \frac{0.048 \times 10^6}{10,000} = 4.8sq\ cm$$

Taking an iron factor of 0.95, the gross sectional area of the pole becomes

$$\frac{4.8}{0.95} = 5.05sq\ cm.$$

3.16 POLE LENGTH AND BREADTH

To permit end play and avoid magnetic centering of the armature, the axial pole length may be taken a little less than the core length, 2mm is appropriate.

The pole length = $21mm - 2mm = 19mm$

Winding= $19mm - 4mm = 15mm$

The breadth now becomes

$$B = \frac{Area}{Lenght} = \frac{50.5}{19} = 2.66mm$$

Conductor section $\alpha = \frac{space\ factor \times h \times \omega}{N}$

$$\frac{0.6 \times 15 \times \omega}{240}$$

$$\alpha = 0.0375\omega$$

$$where\ w = width$$

$$w = 2.66 + 4$$

$$= 6.66mm$$

Therefore,

$$\alpha = 0.0375(6.66)$$

$$\alpha = 0.25mm^2$$

3.17 THE YOKE

The yoke is usually made of cast steel the normal value of flux density on full load is $12{,}000 gauss(1.2wb/mm^2)$. On full load leakage coefficient for the yoke is 0.8, so that for the $4.5KW$ DC electric Motor. The flux in the yoke becomes

$$\emptyset_y - 0.8 \times 0.048 = 0.0384 megaline$$

$$Area = \frac{\frac{1}{2} \times 0.0384 \times 10^6}{12000}$$

$$A_y = 1.6mm^2$$

The flux density of the yoke with a leakage factor of 0.8

$$B_y = \frac{0.048 \times 10^6 \times 0.8}{2 \times 1.6} = 12000\ lines/Km^2$$

3.18 THE AIR GAP

The effective area of the Air gap is $A_g = K_f P_p L$---------------------4.18.1

$$K_f = field\ form\ factor = 0.72$$

$$P_p = pole\ pitch = 2.77cm$$

$$L = 21mm = 2.1cm$$

$$A_g = 0.72 \times 2.1 \times 2.77$$

$$= 4.188cm^2$$

Flux density of the Air gap B_g

$$B_g = \frac{\emptyset \times 10^6}{A_g} = \frac{0.048 \times 10^6}{4.188}$$

$$= 8118.4 lines$$

3.19DESIGN OF THE COMMUTATOR

Taking 2.5cm as a normal distance between the spindles foe a 220V, 6 pole machine like the DC electric Motor.

The circumference is given by

$$6 \times 2.5 = 15cm.$$

$$diameter = \frac{circumference}{\pi} = \frac{15}{3.142} = 4.77cm$$

$$peripheral\ speed = 3.14 \times 4.77 \times 16.66$$

$$= 249.5cm/sec.$$

Number of segment can be chosen to be the same as the number of slots in the armature

$$numberof\ segment = 401$$

3.20 THE BRUSHES

At normal full load, carbon brushes of medium hardness can be used for the DC electric Motor. The density can be put at $25A/in^2$

$$the\ current\ per\ brush\ arm = 22.73A$$

$$Total\ sectional\ area\ of\ the\ brush\ blocks\ per\ spindle = \frac{22.73}{25} = 0.91in^2$$

$$= 2.889cm^2$$

The DC electric motor uses 4 brushes, two positive and 2 negative.

CHAPTER FOUR

DISCUSSION OF RESULT

DESIGN SPECIFICATION

Power = 4.5KW

Speed = 2,400 rev/min

Efficiency = 80%

Number of poles = 6

Voltage = 220V

Bg= 9,500gauss

k_f= field form factor = 0.72

loading constant $q = 35{,}000$

4.1 Result Of Main Dimension

PARAMETERS	ABBREVIATION	VALUE
average flux density in air gap	B_{avg}	$6840\ gauss$
number of poles	n	**6**
separation diameter	D	$5.3cm$
Length	L	$20.8mm$

Power input	P_{in}	5,625watt
Speed	S_p	2,400 rev/min
$pole\ pitch$	P_p	$2.77 cm$

4.2 Result From The Calculation Of Main EMF In The Conductor

PARAMETERS	ABBREVIATION	VALUE
Peripheral speed	v	$665.7 cm/sec$
Mean E.M.F.	E_{mean}	$0.0956V$
$Average\ flux\ density$	B_{av}	6840

4.3 Result From The Calculation Of Number Of Conductors

PARAMETERS	ABBREVIATION	VALUE
$number\ of\ conductors$	Zs	**2400**
voltage Drop allowed	V_{drop}	$4.4V$

4.4 Results From Calculation Of The Number Of Slots

PARAMETERS	ABBREVIATION	VALUE
$no\ of\ conductors$	Z_s	**2400**
$no\ of\ poles$	N_p	**6**
$number\ of\ slots$	N_{slots}	401
$slot\ patch$	P_{slots}	$0.04cm$
$Total\ Slot\ depth$	D_{slots}	7mm
$Total\ slot\ Width$	W_{slots}	$1.6mm$

4.5 Result From Armature Current Calculation

PARAMETERS	ABBREVIATION	VALUE
$output\ power$	P_{out}	$4500watt$
$Applied\ voltage$	V	$220v$
$Amature\ current$	I_A	$22.73A$

4.6 Result From Armature Conductor Calculations

PARAMETERS	ABBREVIATION	VALUE
area required	A_c	1.99sq cm
Total Flux	$\emptyset$	0.239
core depth	d_c	$0.33cm$

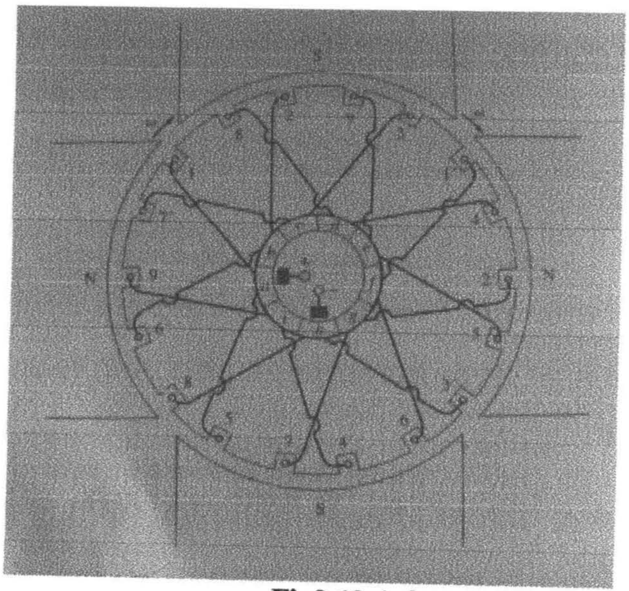

Fig2.12 A four-pole wave wound DC machine

2.5.2.3 The frog leg winding

This consist of the lap and the wave winding combined together. The name is gotten from the shape of how the coil looks

2.6The bearing:

The bearing is a friction reducing mechanical device that is mounted on the rotor shaft and housed in the motor casing. Bearings, mounted on the shaft, support the rotor and allowit to turn. And the bearings are usually two in number, one in front and the other at the back of the shaft. The positioning of the bearing also determines whether the rotor will be at the middle of the stator or not. So the proper positioning of the bearing is necessary so that the rotor will not be brushing the stator.

Resistance of winding	r_a	$4.286 \times 10^{-4}\,\Omega$

Results From The Calculations Of Output Relationship

PARAMETERS	ABBREVIATION	VALUE
frequency of rotation	f	$49.98 rev/sec.$
total electric loading	$Z_a C$	0.0398×10^6
total magnetic loading	$2P\emptyset$	2400×10^{-8}
field coefficient	F_a	$4546 Amps.$

Results From Length Of Turns In The Armature Winding

$Iron\ factor\ 0.95$

$lag\ or\ lead\ factor\ 1.2$

PARAMETERS	ABBREVIATION	VALUE
Number of turns	N	$240\ ampre\ turn$
mean lenght of turns	$\boldsymbol{L_{mean}}$	$145cm$
pole flux on full load	$\boldsymbol{\emptyset_{load}}$	$0.048 mega\ lines$
pole sectional Area	$\boldsymbol{P_{Area}}$	$5.05 sq\ cm.$
Conductor section	α	$0.25 mm^2$
Area of the yoke	Y_{area}	$1.6 mm^2$
flux density of yoke	B_y	$12000\ lines/Km^2$

Results From The Air Gap Calculations

$$K_f = field\ form\ factor = 0.72$$

PARAMETERS	ABBREVIATION	VALUE
$effective\ area\ of\ air\ gap$	A_g	$4.188cm^2$
Flux density of the Air gap	B_g	$8118.4lines$

Results From The Design Of The Commutator

PARAMETERS	ABBREVIATION	VALUE
$diameter$	$\boldsymbol{d}$	$4.77cm$
$peripheral\ speed$	P_s	$249.5cm/sec.$
Total sectional area of brush	B_t	$0.91in^2$
$the\ current\ per\ brush\ arm$	$B_{b}/_{a}$	$22.73A$

4.6 Result From Armature Conductor Calculations

PARAMETERS	ABBREVIATION	VALUE
area required	A_c	1.99sq cm
Total Flux	$\emptyset$	0.239
core depth	d_c	$0.33cm$
pole pitch	P_p	$2.77cm$
lenght of armature conductor	L_s	$17.0cm$

Results From The Armature Winding Calculation

wound machine constant $a = 4.5A/mm^2$

PARAMETERS	ABBREVIATION	VALUE
Winding Over – hang	L_o	**$7.60cm$**
total lenght of the conductor	L_a	19.1cm
Armature impeedance	Z_a	2400
Armature current	I_a	19.1
Area of winding	A_a	$5.05cm^2$
Volume of winding	V_a	$231492cm^3$
Weight of copper	W_c	$2060.3Kg$

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CHAPTER FIVE

CONCLUSION.

- An **electric motor** uses electrical energy to produce mechanical energy, very typically through the interaction of magnetic field and current carrying conductors.
- An electric DC motor is designed to run on DC electric power.
- So far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source, so they are not purely DC machines.

Result Obtained

- In order to build a 4500W power, 2,400rev/min speed, efficiency of 80%, 220V voltage, using 6 poles,
- An Average power input of 5,625watt will be required, a total loss of 1,123watt is expected, an average flux density of 6840gauss is required.
- 2,347 conductors will be needed for the DC motor, 401 slots, 23.73A armature current, 0.33cm core depth, 17.0cm length of armature conductor, 240 ampere-turn of conductor.

Recommendations

- The copper loss in a DC electric motor can be minimized by using Aluminium coil which has more conductivity and less loss.

- There should be a speed control mechanism attached to a DC motor to reduces the possibility of insulation break down especially when the motor is operating on full load.

4.8 LIMITATIONS

- The power loss and other losses in an Electric DC motor is considerably large compared to the useful power.
- It takes a lot of space, considering the dimensions and the number of turns of the winding.
- It takes in a large current to start therefore cannot be implemented using micro controllers.

4.9 Remedy

- ✓ Research is still on, in the implementation of motor coils using solid state devices.
- ✓ To reduces the amount of current drawn by the motor, a special motor starter is being implemented which is beyond the scope of this work.
- ✓ Effect of copper loss can be minimized by using conductors of large diameters in order to reduce to reduce the resistance per unit length of the conducting winding