Design and Fabrication Of Permanent Magnet DC Generator.

A Project Report

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report entitled **"Design and Fabrication Of Permanent Magnet DC Generator"** is the bonafide work of

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Dedicated To
Our Beloved
Parents And
Teachers

Abstract

ABSTRACT :

Generally, the large wind turbine generators used with grid connected systems have induction generators. They use reactive power from grids and feed the generated power to boost the grid supply. Medium capacity wind turbines use synchronous generators to electrify villages and to provide industrial power supply to remote places. Small capacity wind turbines use Permanent Magnet DC Generators which supply power to microwave stations and illuminating light houses.

We have designed a PMDC generator for meeting the needs of small wind turbines, because there won't be any field copper loss in the PMDC generator.

The PMDC Generator was designed using a Turbo C++ program.
The main results of our design are:

✓ Armature Diameter = 66.012895 mm
✓ Core Length = 80.222945 mm
✓ Number of poles = 2
✓ Number of slots = 20
✓ Number of conductors / slot = 12

The mathematical design so formulated was modified slightly to suit the practical conditions.

After the design of PMDC Generator, the part drawings of the machine were drawn using the AutoCAD Software.

Different local fabricators were approached and a particular fabricator was chosen based on the quotation given and also their expertise.

The PMDC Generator was fabricated using the CAD diagrams. The generator fabricated based on our design was tested successfully.

Acknowledgement

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Contents

CONTENTS

PAGE NO.

CHAPTER

CONTENTS

PAGE NO.

4. ALGORITHM AND FLOW CHART

5. PROGRAM AND RESULT

List Of Figures

LIST OF FIGURES :

PAGE NO.

~*~*~*~*~*~*~*~*~*~*~*~*~

Symbols And Abbreviations

SYMBOLS AND ABBREVATIONS

δ – Current density .

B_{av} – Flux density in tooth.

$B_{av}SC$ – Flux density in stator core.

K_g – Air gap contraction factor.

P_a – Power developed by the armature.

C_o - Output coefficient .

D - Armature diameter.

L - Core length.

τ - Pole pitch.

b - Pole arc.

V_a - Peripheral speed.

K_i - Stacking factor.

L_i - Net iron length.

f - Frequency of flux reversal.

t - Thickness of laminations.

V_m - Maximum voltage between commutator.

B_g - Maximum value of flux density.

I_L - Full load current.

I_b - Current per brush arm.

ϕ - Flux per pole.

A - Number of parallel paths.

Z - Total number of armature conductors.

Y_s - Slot pitch.

S - Number of slots.

Z_s - Number of conductor per slots.

C - Number of coils.

I_s - Current per slot.

I_a - Armature current per parallel path.

A_a - Cross sectional area of conductors required.

W_s - Width of slots.

H_t - Height of slots.

W_t - Teeth width.

$B_{t\,av}$ - Average flux density in teeth over a complete pole pitch.

$B_{t\,m}$ - Maximum flux density within teeth.

D_c - Core depth below slots.

D_i - Internal diameter of armature stampings.

R_a - Resistance of armature winding.

* * *

Introduction

1. INTRODUCTION :

Our project is to design and to fabricate a Permanent magnet DC generator to be used in wind mills.

Permanent magnet DC generator offers some advantage in certain applications.

- ✓ In certain ranges, for very small machines (where the diameter is less than 3.5cm) it is difficult to accommodate the field winding and permanent magnet field is a cheaper alternative.
- ✓ Permanent magnet machines are potentially more efficient because no electrical power is used to provide field flux.
- ✓ Since there is no wound field, permanent magnet machines have fewer electrical connections.

Owing to the above advantages we have decided to design and fabricate the above mentioned PMDC Generator.

* * *

Design
Considerations

2. DESIGN CONSIDERATIONS :

2.1. CHOICE OF SPECIFIC MAGNETIC LOADING :

Choice of the average flux in the air gap in DC machines depends on the following factors :

2.1.1. FLUX DENSITY IN TEETH :

If a high value of flux density is assumed for the air gap, the flux density in the armature teeth also becomes high. The value of the air gap flux density should be so chosen that the flux density at the root of the teeth does not exceed 2.2 Wb/m^2 (Theoretical maximum value). Otherwise the mmf required for the teeth would become excessively large which should mean that the field mmf should be made large.

2.1.2. FREQUENCY :

When the machine rotates, the armature magnetic circuit alternately comes under the influence of north and south poles. If the frequency of the flux reversal is high, iron losses in armature core and teeth will be high. Therefore we should not use a high value of flux density in the air gap of machines which have a high frequency.

2.1.3. SIZE OF THE MACHINE :

As the diameter of the machine increases, width of the tooth also increases permitting an increased value of gap flux density without causing saturation in the machine.

2.2. CHOICE OF AMPERE CONDUCTORS PER METRE :

The following factors affect the choice of ampere conductors per metre.

2.2.1 TEMPERATURE RISE :

A higher value of ampere conductors per metre results in higher temperature rise in the windings. Hence it should be used only in machines which can withstand higher temperature rise. Also the ventilation factor plays a very important role in the

2.2.2. SPEED OF THE MACHINE :

If the speed of the machine is high, the ventilation of the machine will be better and hence greater losses can be dissipated. Thus a higher value of ampere conductors per metre can be selected for high speed machines.

2.2.3. VOLTAGE :

In high voltage machines large space is required for insulation and therefore less space for conductors. This means for a high voltage machine, we must use a small value of ampere conductors per metre.

2.2.4. SIZE OF THE MACHINE :

In large machines it is easier to accommodate many conductors. For a given geometry of armature core, the slot area is proportional to square of armature diameter. Therefore greater the diameter of the machine greater is the value of ampere conductors per metre which can be employed for it.

2.2.5. ARMATURE REACTION

If a high value of ampere conductors per metre is used, the armature mmf becomes high or in other words the armature becomes magnetically stronger. This means that under load conditions there will be greater distortion of field resulting in large reduction in the value of flux. In order to prevent this, field will have to be made stronger. This means that the cost of fabricating the machine would go up.

2.2.6. COMMUTATION

A machine designed with high value of ampere conductors per metre will either have a large number of conductors or small armature diameter.

The machine designed with large number of coils will have a large number of turns in each coil. The inductance of the coils is proportional to the square of the number of turns. Using small armature necessitates deep slots. Deep slots increase the inductance of armature.

Therefore increasing the armature conductors per metre increases armature inductance. The reactance voltage in coils undergoing commutation is directly proportional to the inductance. Reactance voltage delays commutation. Hence a larger

2.3. CHOICE OF THE NUMBER OF POLES :

2.3.1. FREQUENCY :

Frequency of flux reversal increases linearly with the number of poles. The frequency of alteration of flux in DC machines should not be high as it would give rise to excessive iron losses in armature teeth and core. Generally the value of the frequency of flux reversals lies between 25-50 Hz. In certain cases such as DC Turbo generators this is the deciding factor. When we increase the number of poles the dimensions of the machine decreases. But the design is complicated for a large pole machine.

2.3.2. WEIGHT OF IRON PARTS :

YOKE AREA

Flux carried by yoke is inversely proportional to the number of poles. Therefore by using greater number of poles the area of cross section of yoke is proportionally decreased.

ARMATURE CORE AREA

The weight of iron in the core can be decreased by using large number of poles. But the increase in the number of poles would result in higher iron loss in the armature, owing to increased frequency of flux reversals.

2.3.3. WEIGHT OF COPPER :

ARMATURE COPPER :

The portion of conductors responsible for emf production is called active copper. Hence the portion of the conductors embedded in the slots is active copper. The portion of conductor in overhang is called inactive copper. Length of overhang decreases with increase in number of poles. Hence for machines with less number of poles, the length of inactive copper increases and hence the total copper weight

2.3.4. LENGTH OF COMMUTATOR :

The number of brush arms employed is equal to the number of poles in case of machines with lap winding. In machines with wave winding, number of brush arms is two but usually number of brush arms is equal to the number of poles. Length of brushes required in each brush arm is reduced with increase in number of poles. This results in reduction in length of commutator and length of the machine.

2.3.5. LABOUR CHARGES :

Number of conductors increases with the number of poles and hence the number of armature coils increases. As a result number of commutator segments also increases with the number of poles.

Absence of field coils in this machine results in less winding costs.

2.3.6. FLASH OVER :

As the number of poles increases, number of brush arms also increases. Distance between brush arms decreases. Therefore in high voltage machines there is a possibility of flashover between brushes.

2.3.7. DISTORTION OF FIELD :

Armature mmf per pole varies inversely with number of poles. Hence with smaller number of poles, armature mmf per pole increases resulting in distortion of field and reduction in flux under load conditions. Distortion of flux causes poor commutation conditions and sparking, while reduction in flux causes lower emf.

2.4. CHOICE OF CORE LENGTH :

2.4.1. COST :

Manufacturing machines with large core lengths is difficult since the central portion of the core tends to attain a higher temperature rise. Hence ventilating ducts must be provided for very long cores. This increases the manufacturing costs.

2.5. CHOICE OF ARMATURE DIAMETER :

2.5.1. PERIPHERAL SPEED :

The peripheral speed should lie between 15 to 50 m/s, the lower values corresponding to low speed machines. The value of peripheral speed should not normally exceed 30 m/s. If this speed exceeds 30 m/s, the binding wire for the overhang should be extra strong. This is done to prevent the overhang from flying out due to excessive centrifugal force.

2.5.2. POLE PITCH :

The pole pitch may be used as a check for the number of poles. The normal pole pitch values are

Poles	Pole pitch (mm)
2	up to 240
4	240 – 350
6	350 – 450
Above 6	450 – 500

2.6. LENGTH OF AIR GAP :

2.6.1. ARMATURE REACTION :

In order to prevent excessive distortion of field by armature reaction, the field mmf must be made large compared to the armature mmf. A machine designed with large air gap requires large field mmf. Thus the distorting effect of armature reaction can be reduced if the length of air gap is large.

2.6.2. CIRCULATING CURRENTS :

The air gap in the case of multiplier lap wound machines should be long because if it is small a slight irregularity in the air gap would result in large circulating currents.

2.6.3. POLE FACE LOSSES :

If the length of the air gap is made large, the variations in air gap flux density due to slotting are small. Therefore pulsation loss in the pole face decreases if the

2.6.4. NOISE :

Operation of the machine with large air gap is comparatively quiet.

2.6.5. COOLING :

Large air gaps provide better ventilation.

2.6.6. MECHANICAL CONSIDERATIONS :

With small air gaps there is a greater possibility of appreciable unbalanced magnetic pull developing and causing rotor to foul with stator. Therefore air gap should be large enough to avoid this.

2.7. NUMBER OF ARMATURE SLOTS :

The following factors should be considered while selecting the number of armature slots.

2.7.1. MECHANICAL DIFFICULTIES

If a large number of slots are used, the slot pitch becomes smaller and hence width of tooth gets smaller. This may lead to contraction difficulties.

2.7.2. COOLING OF ARMATURE CONDUCTORS :

If a large number of slots are chosen, the number of conductors per slot is less and hence only a few conductors are bunched together. Thus better cooling of armature conductors occur.

2.7.3. FLUX PULSATION :

Flux pulsations (i.e.) changes in air gap flux due to slotting gives rise to eddy current losses in the pole faces and causes magnetic noise. With larger number of slots, the flux pulsations are reduced and therefore there is a reduction in pole face losses and noise in the machine.

2.7.4. COMMUTATION :

Pulsations and oscillations of the flux under the interpoles must be avoided as

2.8. SLOT DIMENSION :

The following points should be considered when fixing the dimensions of the slots.

2.8.1. EXCESSIVE FLUX DENSITY :

The dimensions of the slot should be so chosen that it does accommodate the armature conductors and the insulations without producing excessive flux density in the teeth. Since slots are parallel sided, the teeth are tapered and hence flux density at 1/3 height from root should not exceed 2.2 Wb/m^2.

2.8.2. FLUX PULSATION :

Wide open slots produce greater pulsations of flux in the air gap than slots with narrow openings. Since flux pulsation causes extra iron loss and affects commutation, slots should not be too wide.

2.8.3. EDDY CURRENT LOSS IN CONDUCTORS :

With conductors having large depths the eddy current losses in conductors increases. Therefore depth of conductors should be limited to 19 mm for 25 Hz machines and 15 mm for higher frequencies. The depth of slot in normal large size machines should be limited to such a value that is just sufficient to accommodate a 2 layer winding in which the conductor depth is about 19 mm.

2.8.4. REACTANCE VOLTAGE :

With deep slots, the specific permeance goes up and hence the reactance voltage is high. The reactance voltage retards commutation and hence this is objectionable in non interpolar machines. Therefore in non interpolar machines, ratio of slot depth to slot width is not allowed to exceed 4. For machines with interpoles deeper slots may be used.

2.8.5. MECHANICAL DIFFICULTIES

Due to deep slots, thickness of teeth at the root may become too small in which case flux density at 1/3 height from root may exceed permissible limits. Additional supports have to be provided to teeth at the ventilating ducts.

Design Procedure

3. DESIGN PROCEDURE :

3.1. MAIN DIMENSIONS :

1. Power developed by the armature , $P_a = ((2 + \eta) / (3 * \eta)) * P$ (kW).

2. Output coefficient, $C_o = \pi^2 * B_{av} * ac * 10^{-3}$

3. $P_a = C_o * D^2 * L * n$ (kW).

4. For square pole phase $L = \tau * \psi$

Using the above relation the values of D and L can be separated.

Where,

η = Efficiency

P = Output Power, kiloWatts.

B_{av} = Specific Magnetic Loadings, Weber/ metre ^{2}

ac = Specific Electrical Loadings, Ampere Conductors / metre

τ = Pole Pitch, metre.

D = Armature Diameter, metre.

L = Core Length, metre.

Ψ = Ratio of pole arc to pole pitch.

5. Pole pitch $\tau = \pi * D / p$ metre.

6. Pole arc $b = \Psi * \tau$ metre.

Where,

p = Number of poles.

Assume Stacking Factor $K_i = 0.9$

7. Net iron length $L_i = K_i * L$ metre.

8. Frequency of flux reversals $f = p * N / 120$ (Hz).

Frequency in the range of 25 to 50 Hz is desirable.

CHECK ON THE DESIGN :

1. Peripheral speed $V_a = \pi * D * N / 60$ metre / sec .

2. Maximun voltage between the commutator segments, $V_m = 2 * B_g * L * V_a$ Volts.

Where ,

3. Full load current, $I_L = P / V$ Ampere.

   Current per brush arm, $I_b = I_L * 2 / p$ Ampere.

4. Armature ampere turns per pole $= \pi * D * ac / (2 * p)$

Check if the values are within limits. If not vary the values of the design variables and repeat the calculations till the desired results are obtained.

3.2. DESIGN OF ARMATURE :

3.2.1. NUMBER OF ARMATURE CONDUCTORS :

Assume the armature voltage drop as 3 % of the terminal voltage.

1. Generated emf $E = 1.03 * V$ Volts.
2. Flux per pole, $\phi = B_{av} * \tau * L$ Webers.

Assume Simplex Lap Windings with single turn coils.

3. Number of parallel paths $A = p$.
4. Total number of armature conductors $Z = E * A * 60 / (p * \phi * N)$.

3.2.2. NUMBER OF SLOTS :

GUIDANCE FACTORS :

1. For small machines, the value of the slot pitch lies between 10 to 35 mm.
2. In order to have proper commutation conditions, the number of slots per pole should be between 9 and 16.
3. The number of slots per pole arc should be an integer + ½ in order to reduce flux pulsations.

Based on these factors the number of slots is chosen.

1. Slot pitch $Y_s = \pi * D / S$ metre
2. Number of conductors per slot $Z_s = Z / S$.
3. Number of coils $= Z / 2$.
4. Slot loading $= I_z * Z_s$ Amps

   Check if it is lower than the maximum permissible value of 1500 A.

5. The values of specific loadings actually used are :

$$B_{av} = \phi / (\tau * L) \quad \text{Weber / metre}^2$$

3.2.3. SIZE OF THE ARMATURE CONDUCTORS :

1. Sectional area of armature conductors $A_a = I_z \ / \ \delta$ mm^2

   Where,

   δ = Current density, Ampere / mm^2

   I_z = Current per conductor, Ampere.

2. Current per conductor = Current per parallel path = $I_L \ / \ A$ Ampere.

Assume round conductors.

3. Conductor diameter = $\sqrt{A_a * 4 / \pi}$ mm.

3.2.4. SLOT DIMENSIONS :

1. Slot width W_s = Number of conductors along the width + Space for insulation
2. Depth of the slots H_t = Number of conductors along height + Space for Insulation, metre.
3. Width of the teeth $W_t = Y_s - W_s$ metre
4. Slot pitch at ⅓ height from root $Y_{s⅓} = \pi \ (D - (4 / 3 * Ht)) / S.$ metre.
5. Width of the teeth at ⅓ height from root $W_{t⅓} = Y_{s⅓} - W_s$ metre.
6. Flux density $B_{t⅓} = p * \phi / \ (\psi * S * L_i * W_{t⅓})$ Weber / metre ^{2}

Check if it is lower than the maximum permissible value of 2.2 Weber / metre ^{2}

3.2.5. ARMATURE CORE DEPTH :

Flux in the pole is divided at the armature core and the section of the core carries only half of the useful flux per pole and flux density in the core is assumed as 1.25 Tesla.

1. $\phi_a = \phi / 2$ Webers.
2. Area of the core $A_c = \phi_a / B_{av}$ metre ^{2}
3. Core depth below the slots, $D_c = A_c / L_i$ metre.
4. Internal diameter of the armature stampings $D_i = D - 2 * (H_t + D_c)$ metre.

3.2.6. RESISTANCE, COPPER LOSSES AND WEIGHT OF COPPER :

1. Resistance of the armature winding with ' A ' parallel paths is given by

$$R_a = \rho * l_a * Z / A_a * A^2 \quad \Omega$$

   Where,

   ρ = Specific resistance of copper conductor, Ω- metre.

2. Total length of each conductor = Length of the armature core + Free length per conductor, metre.

3. Free length per conductor $l_f = 14 + 1.15 * \tau$ cm

4. Armature copper losses = $I_a^2 * R_a$ Watts.

Eddy current loss may be assumed as 20 to 25 % of the total armature copper losses.

5. Armature copper losses including eddy current losses = $1.25 * I_a^2 * R_a$ Watts.

6. Volume of copper in armature winding = $A_a * I_a * Z$ cm^3

Density of copper = 8.9 kg / cm^3

7. Total weight of copper in armature winding = 8.9 * Volume of copper in armature winding, kg.

3.2.7. LENGTH OF THE AIRGAP :

1. Armature mmf per pole $AT_a = I_a * Z / (2 * p)$ Ampere.

The mmf required for air gap is assumed to be 0.6 times the armature mmf.

2. Mmf required for the air gap, $AT_g = 0.6 * AT_a$ Ampere.

3. Maximum flux density in the air gap $B_g = B_{av} / \psi$ Tesla.

Assume a gap contraction factor K_g = 1.15

4. Length of the airgap $lg = AT_g / (800000 * B_g * K_g)$ metres.

3.3. DESIGN OF THE POLE :

3.3.1. AXIAL LENGTH :

The axial length of the pole should be less than the armature length, in order to avoid magnetic centreing of the armature.

Assume the axial length of the pole is 1 cm less than the armature length.

1. Axial length of the main pole $Lp = L - 1$ cm.

3.3.2. WIDTH OF THE POLE :

Due to the leakage of the flux, pole flux on full load will be more than useful flux.

Assume i) Leakage factor of 1.1 for the pole.

ii) Working flux density in the pole as 1.6 Weber/ metre ^{2}.

iii) Iron factor for pole as 0.98

1. Gross sectional area of the pole, $A_p = 1.1 * \phi / (1.6 * 0.98)$ metre ^{2}

The width of the pole, W = A / L metre

3.4. DESIGN OF THE YOKE :

Assume flux density in the yoke as 1.5 Weber/ metre^2.

1. Flux in the yoke path $\phi_y = \phi / 2$ Webers.
2. Cross sectional area of the yoke $A_y = \phi_y / 1.5$ metre^2

The axial length of yoke is taken approximately 1.6 times the core length.

3. Axial length of the yoke $L_y = 1.6 * L$ metre.
4. The thickness of the yoke $T_y = A_y / L_y$ metres.
5. The outer diameter of the yoke $D_y = D + 2*l_g + 2*T_y + 2 * H_p$ metre.

3.5. DESIGN OF COMMUTATOR :

Assume the commutator diameter to be 65 % of the armature diameter.

Diameter of the commutator $D_c = D * 0.65$ metre.

DESIGN CHECK :

1. Peripheral speed of the commutator $V_c = \pi * D_c * N / 60$ metre /sec
2. Pitch of the segments, $\beta_c = \pi * D_c * 2 / Z$ metres.

Check if the above values are within limits.

3.6. DESIGN OF BRUSHES :

Electro graphite brushes are used.

The current density in the brushes is assumed to be 0.03 A/mm^2.

1. Current in each brush = $I_b / 2$ Amperes.

The current in each brush must not be more than 70 A.

2. Area of each brush A_b = Current in each brush / δ mm^2

The brushes should cover at least 2.5 segments.

3. Thickness of each brush $t_b = 10 * \beta_c$ mm.
4. Width of each brush $W_b = A_b / t_b$ mm.

Allow 5 mm for clearance between brushes, 10 mm for staggering and 10 mm for end play.

5. Length of the commutator $L_c = 2 * W_b + 25$ mm.

LOSSES AT THE BRUSH :

1. Brush Contact Loss $P_{bc} = 2 * 1 * I_a$ Watts.

The brush pressure used is 20 kN/m^2 and the co-efficient of friction is 0.15

2. Brush Friction Loss $P_{bf} = 0.15 * 20000 * 2 * A_b$ Watts
3. Total loss at the commutator $= P_{bf} + P_{bc}$ Watts

3.7. LOSSES AND EFFICIENCY :

3.7.1. FRICTION AND WINDAGE LOSSES :

1. Brush Friction Loss $P_{bf} = 0.15 * 20000 * 2 * A_b$ Watts

The friction losses and the windage losses are taken as 0.2% of the output.

2. Bearing friction and windage losses = $0.2 / 100 * P$ Watts
3. Total friction and windage losses = P_{bf} +Bearing friction and windage loss W.

3.7.2. IRON LOSSES :

1. Mean width of tooth = $\pi * (D- H_t) / S$ metre.
2. Weight of the armature teeth = $S * L_i *$ Mean width of tooth $* H_t * 7800$ kg
3. Specific iron loss in teeth = $(0.06 * f * B_{tm}^2) + (0.008 * f^2 * B_{tm}^2 * t^2)$ W/kg
4. Iron loss in teeth = Specific iron loss in teeth* Weight of the armature teeth W
5. Weight of the armature core = $\pi * (D - 2*H_t - D_c) * A_c * 7800$ kg
6. Specific iron loss in core = $(0.06 *f * B_{tm}^2) + (0.005 * f^2 * B_{tm}^2 * t^2)$ W/kg
7. Iron loss in core = Specific iron loss in core* Weight of the armature core. W.
8. Total iron loss = Iron loss in core + Iron loss in teeth. Watts.

3.7.3. COPPER LOSSES :

1. Length of mean turn of armature $L_{mt} = 2 * L + 2.5 * \tau + 5 * H_t$ metre
2. Armature copper losses including eddy current losses = $1.25 * I_a^2 * R_a$ Watts.
3. Brush Contact Loss $P_{bc} = 2 * 1 * I_a$ Watts.

3.7.4. EFFICIENCY CALCULATIONS :

Efficiency can be obtained by loss summation.

1. Total Losses = Armature Copper Loss + Brush Contact Loss + Iron Loss + Friction And Windage Losses. Watts.
2. Input Power = P + Total Losses. Watts.

Algorithm And
Flow Chart

4.1. ALGORITHM :

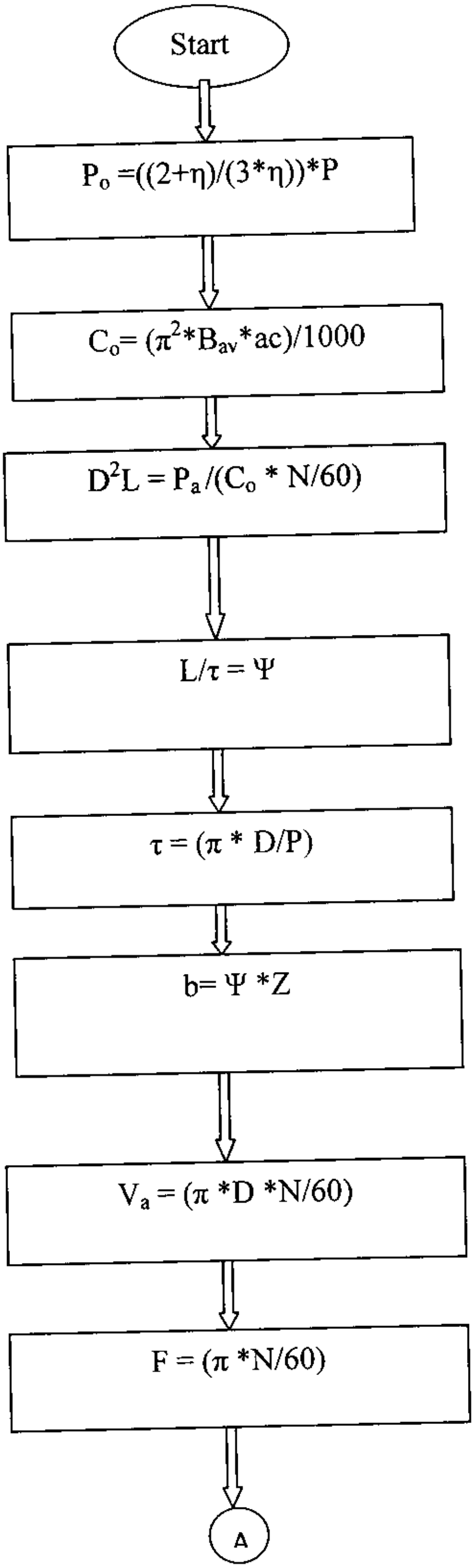
1. The values of power, speed and the terminal voltage of the PMDC generator are decided.
2. The values of the specific loadings are assumed.
3. The numbers of poles are selected such that the frequency of flux reversals lies between 25 to 50 Hz.
4. The main dimensions of PMDC generator are calculated by calculating the power developed by the armature and the output co-efficient.
5. The pole arc, pole pitch and the peripheral speed of the machine are also calculated.
6. The design values are checked with respect to the allowable limits of peripheral speed, maximum voltage between the commutator segments, pole pitch, current per brush arm and the armature ampere turns per pole.
7. Check if the values are within limits. If not vary the values of the design variables and repeat the calculations till the desired results are obtained.
8. The total number of armature conductors are calculated.
9. The values of the specific loadings are modified based on the actual number of armature conductors used.
10. The number of slots is chosen based on the guiding factors for the selection of slots.
11. Then the conductor diameter is calculated by assuming the value of current density.
12. The values of slot pitch, slot width and slot height are calculated.
13. The maximum flux density within the teeth is calculated and is compared with the maximum allowable limit.
14. The design is correct if the values are within the limits. Proceed to next step. Else vary the assumed values and repeat the calculations.
15. The depth of the armature core below the slots and also the length of the air gap are calculated.
16. The armature winding resistance and the armature copper losses are calculated.

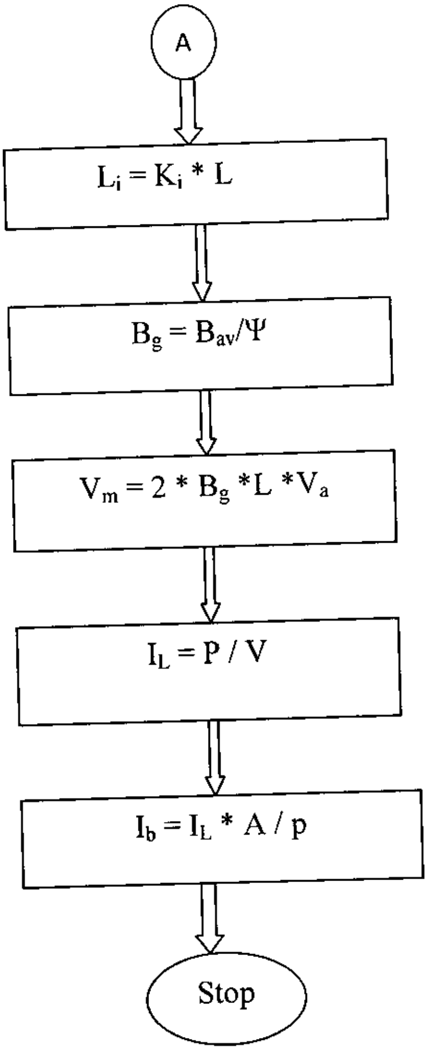
18. The commutator diameter is also calculated and the design is verified by calculating the values of peripheral speed of commutator, number of segments and pitch of the segments.
19. The design is correct if the values are within the limits. Proceed to next step. Else vary the assumed values and repeat the calculations.
20. The brush dimensions are calculated.
21. At last the different losses in the machine such as armature copper loss, iron losses, friction and windage losses and the brush losses are calculated.
22. The full load efficiency of the machine is calculated based on these losses.

* * *

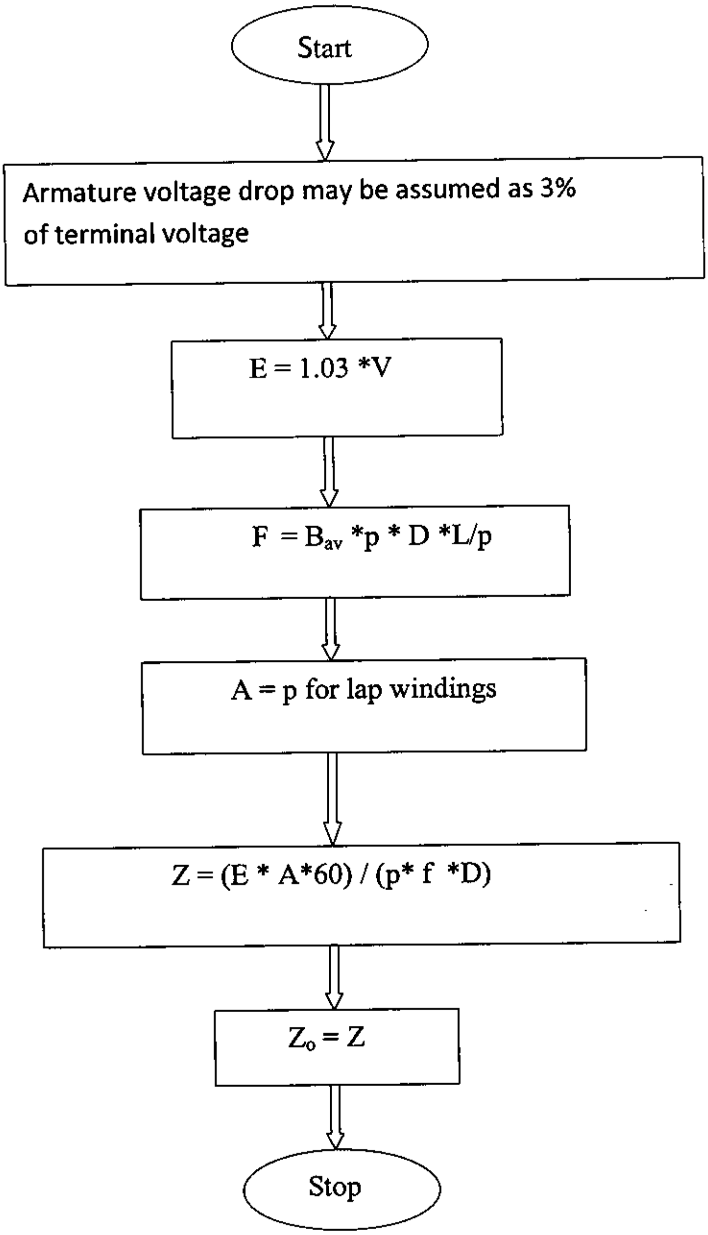
4.2. FLOWCHARTS

4.2.1 MAIN DIMENSIONS

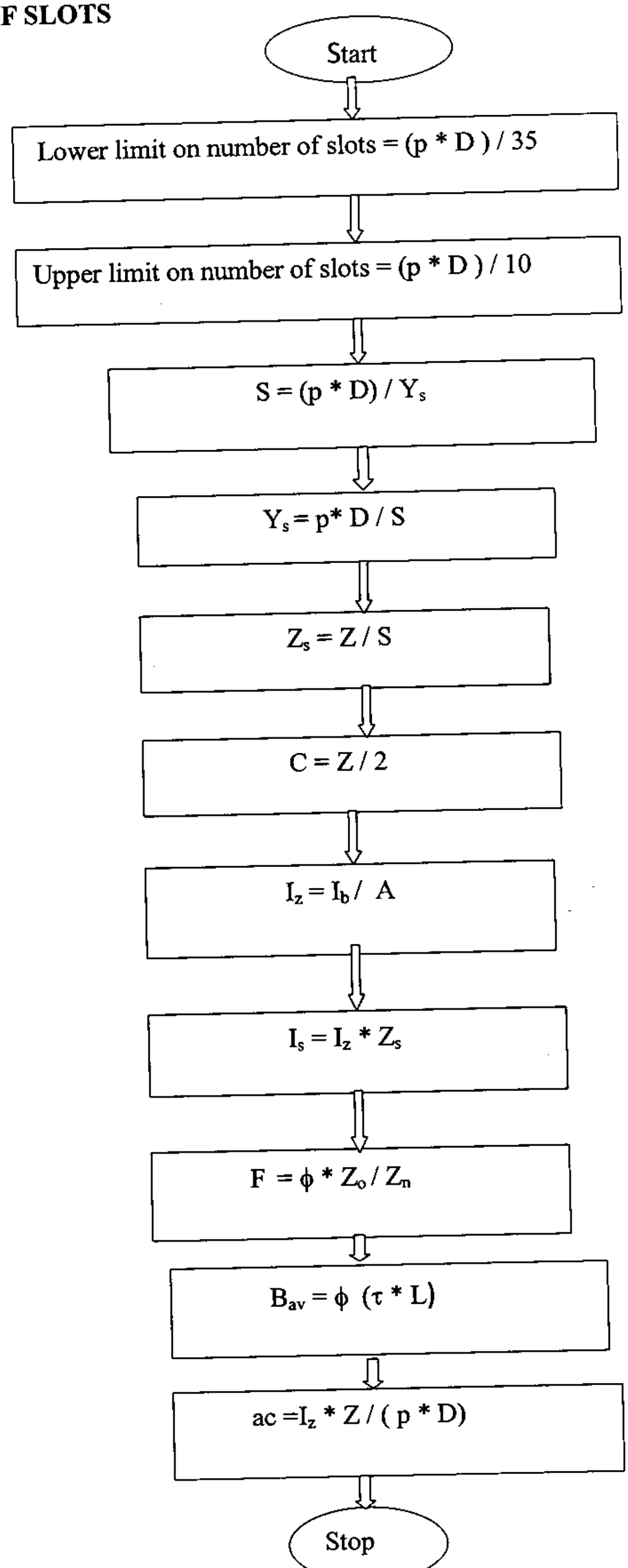



A
L_i = K_i * L
B_g = B_av/Ψ
V_m = 2 * B_g *L *V_a
I_L = P / V
I_b = I_L * A / p
Stop

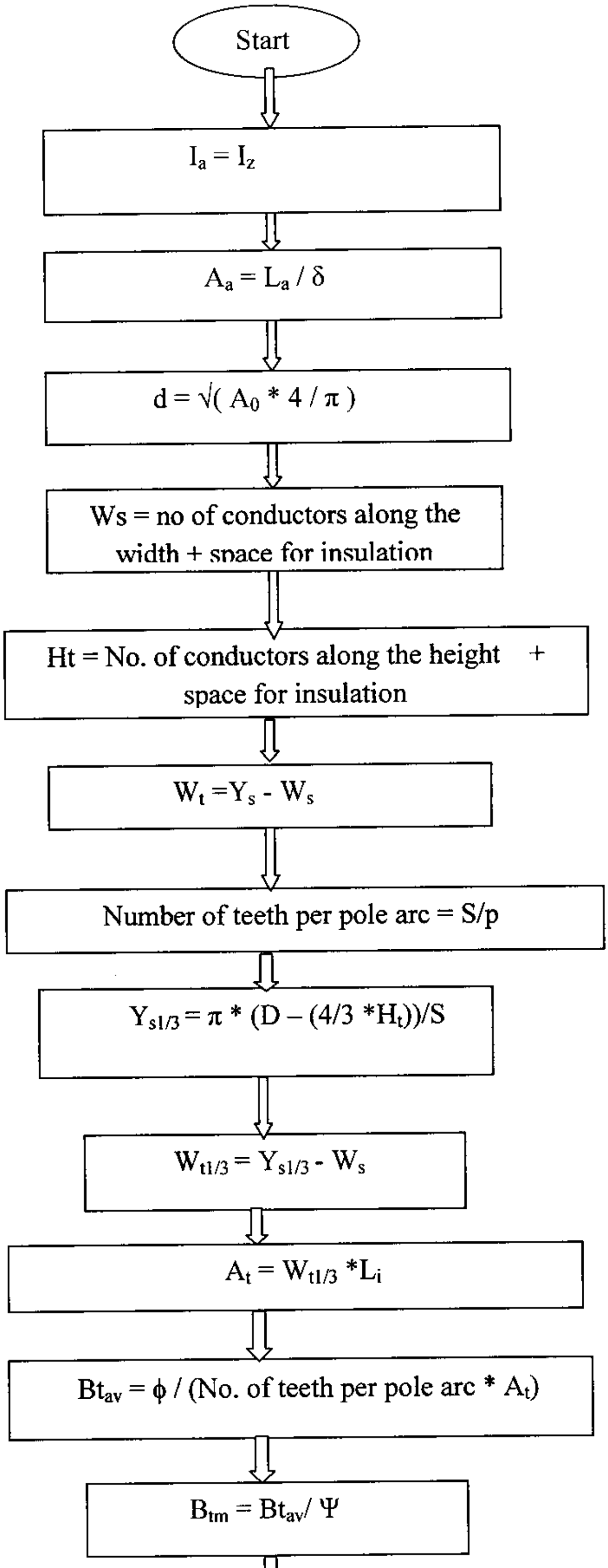
4.2.2. ARMATURE DESIGN



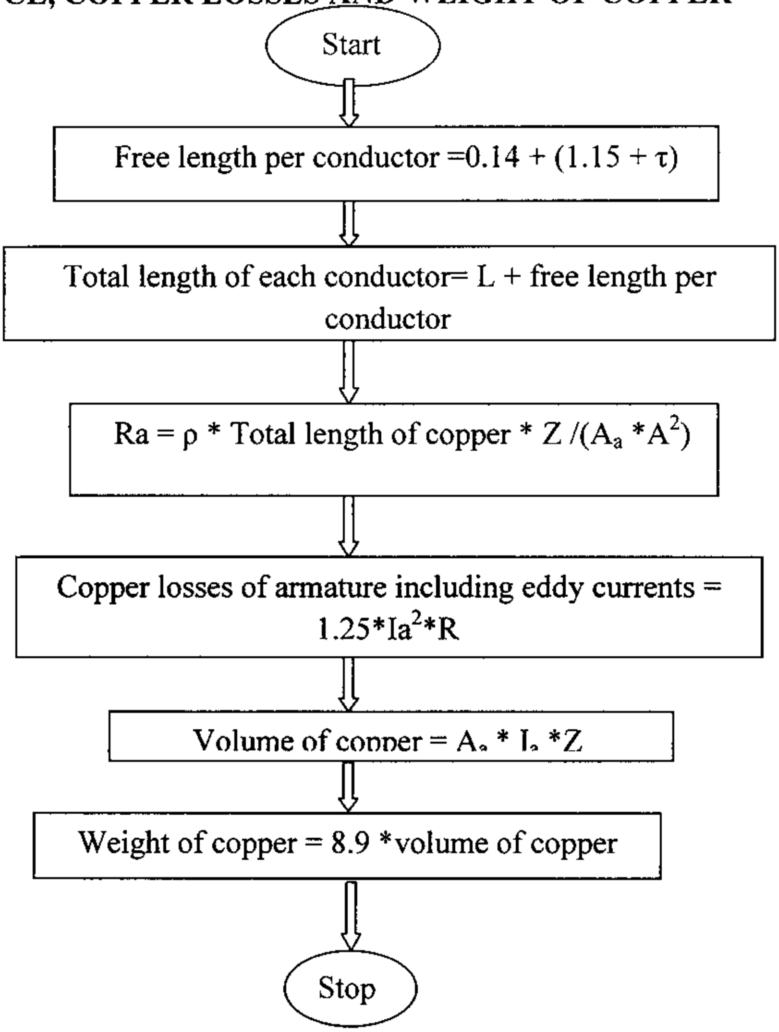
NUMBER OF SLOTS



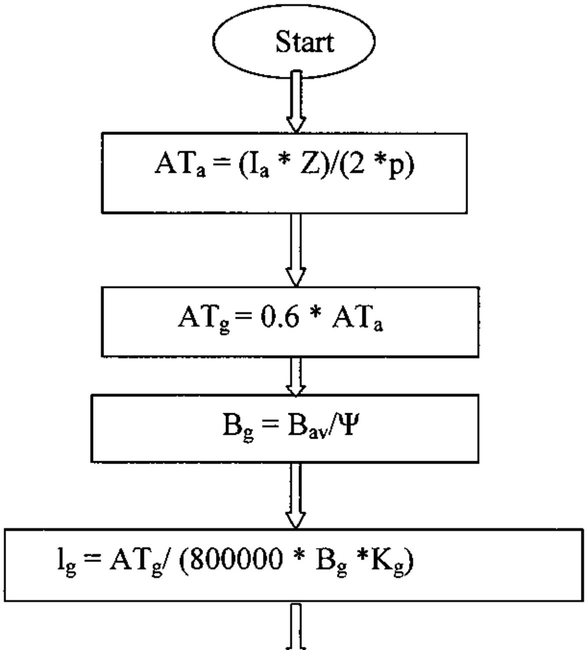
SIZE OF ARMATURE CONDUCTORS



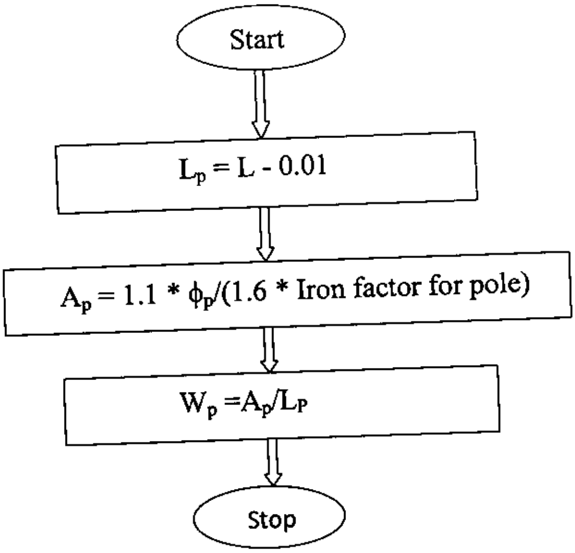
RESISTANCE, COPPER LOSSES AND WEIGHT OF COPPER



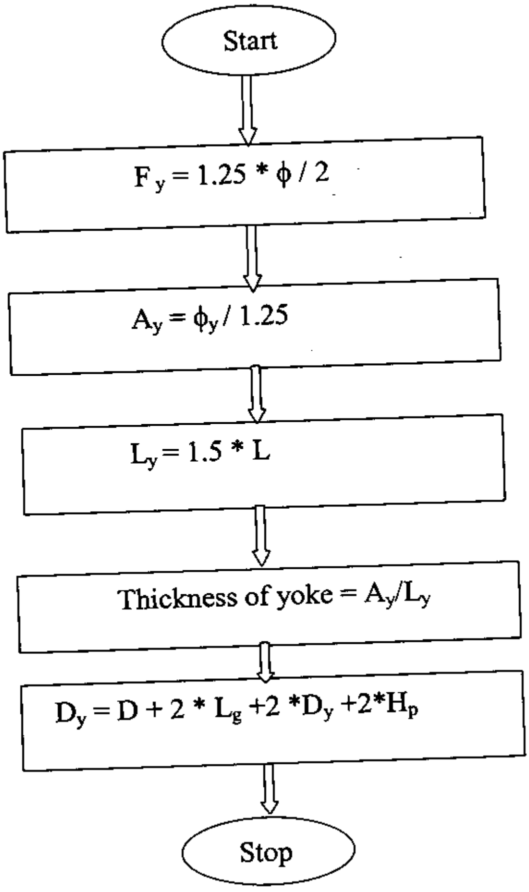
LENGTH OF AIR GAP



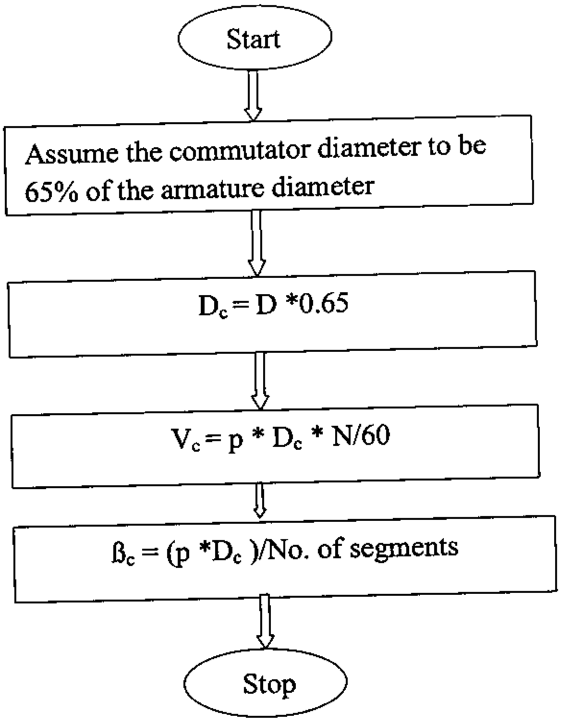
4.2.3. DIMENSION OF POLE



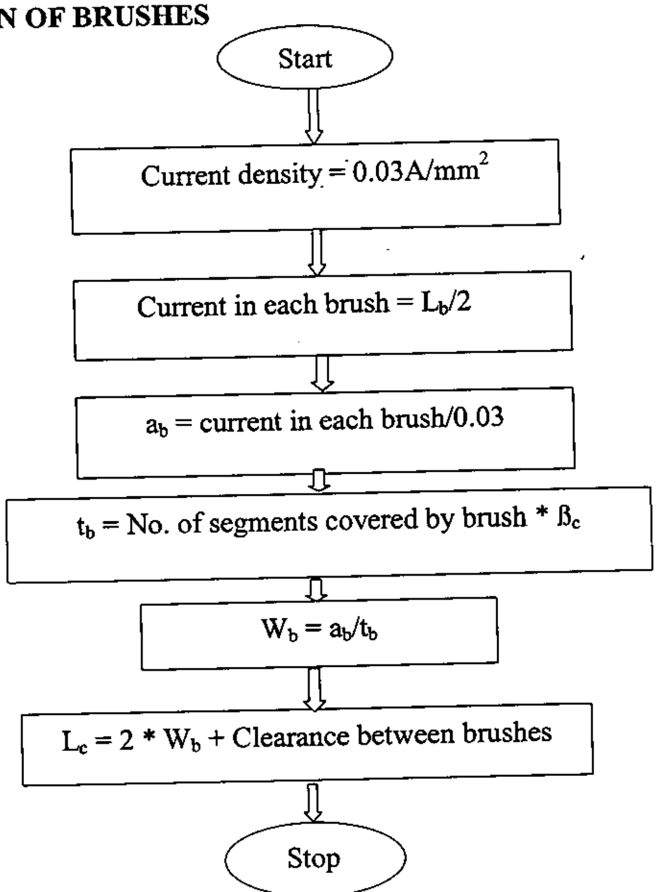
4.2.4. DIMENSIONS OF YOKE



4.2.5. DESIGN OF COMMUTATOR

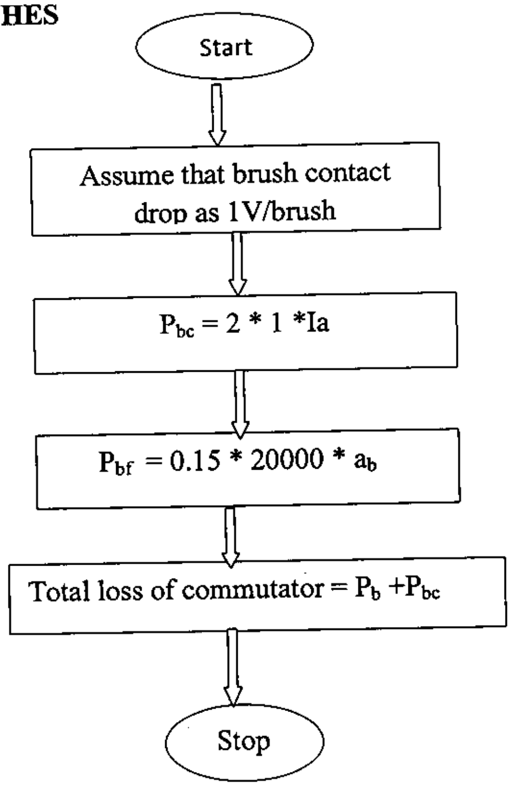


4.2.6. DESIGN OF BRUSHES

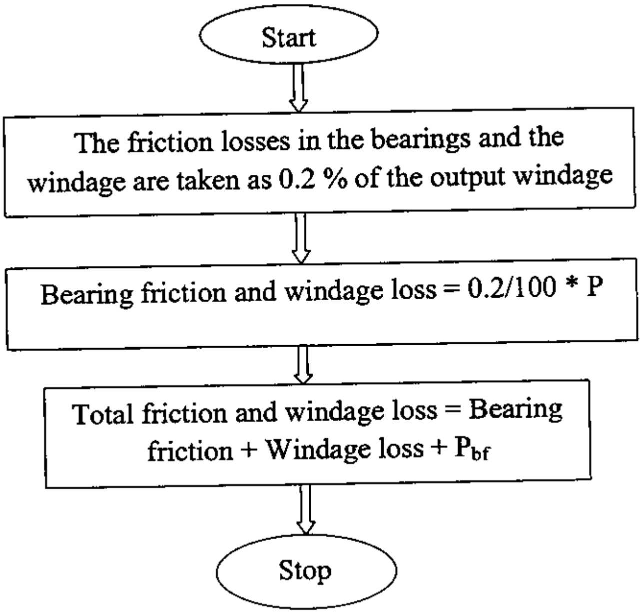


4.2.7. LOSSES AND EFFICIENCY CALCULATIONS :

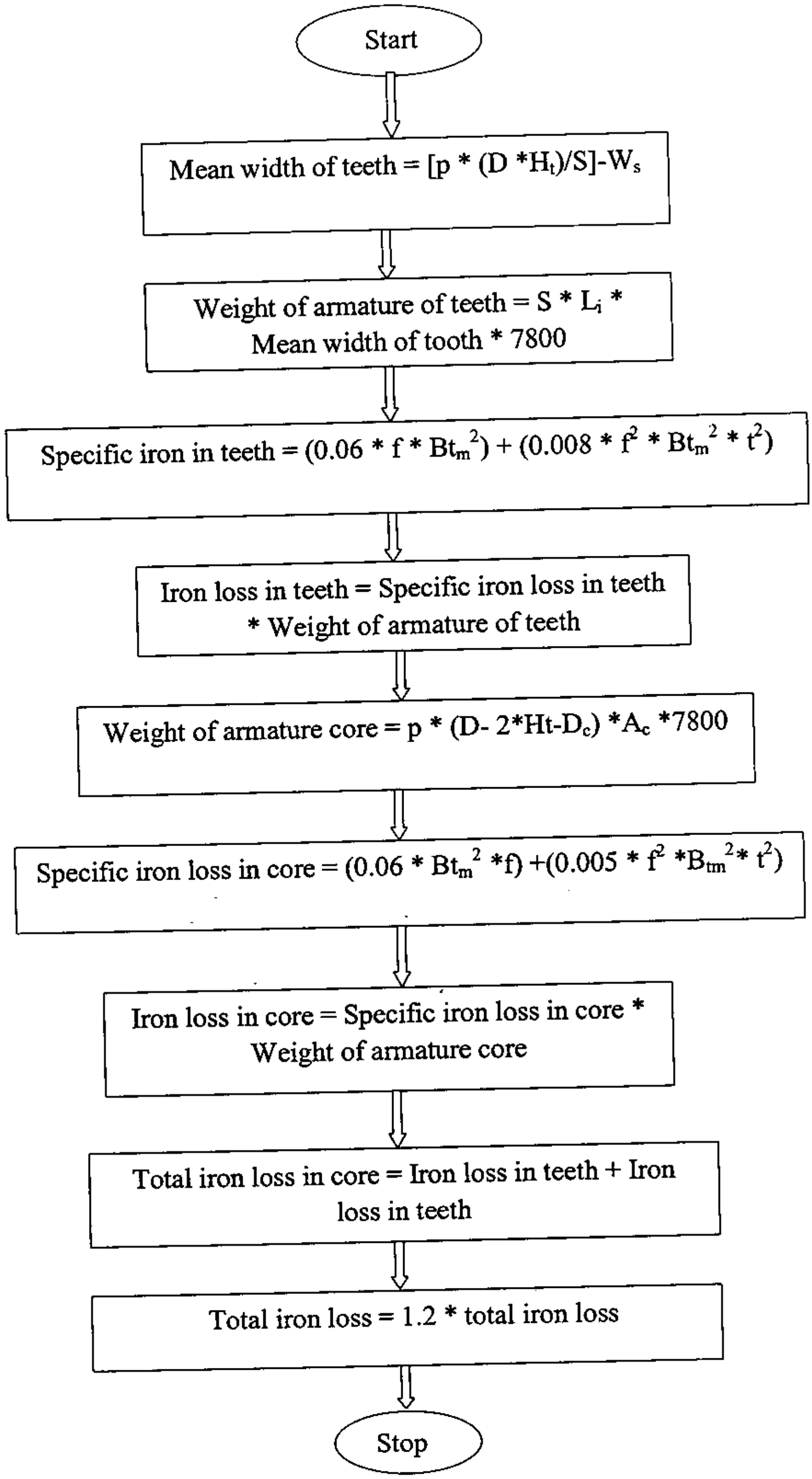
LOSSES AT THE BRUSHES



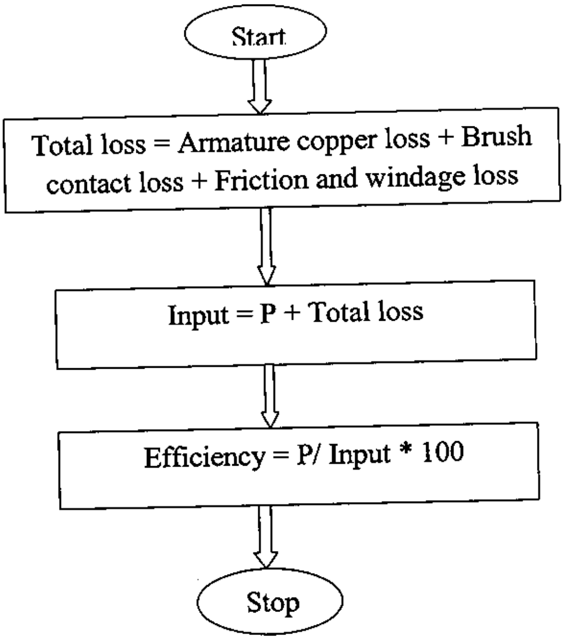
FRICTION AND WINDAGE LOSS



IRON LOSSES


Start
Mean width of teeth = [p * (D *H_t)/S]-W_s
Weight of armature of teeth = S * L_i * Mean width of tooth * 7800
Specific iron in teeth = (0.06 * f * Bt_m^2) + (0.008 * f^2 * Bt_m^2 * t^2)
Iron loss in teeth = Specific iron loss in teeth * Weight of armature of teeth
Weight of armature core = p * (D- 2*Ht-D_c) *A_c *7800
Specific iron loss in core = (0.06 * Bt_m^2 *f) +(0.005 * f^2 *B_{tm}^2* t^2)
Iron loss in core = Specific iron loss in core * Weight of armature core
Total iron loss in core = Iron loss in teeth + Iron loss in teeth
Total iron loss = 1.2 * total iron loss
Stop

EFFICIENCY


Start
Total loss = Armature copper loss + Brush contact loss + Friction and windage loss
Input = P + Total loss
Efficiency = P/ Input * 100
Stop

Program And
Result

5.1. PROGRAM :

```
#include <iostream.h>
#include <conio.h>
#include <math.h>
#define pi 3.141592654
#define P 0.100
#define N 2000
#define eta 0.95
#define Bav 0.45
#define ac 2000
#define Ki 0.9
#define p 2
#define Kf 0.78
#define V 30
#define del 4.5
#define BavAC 1.25
#define Spres 0.000000021 // Specific resistance of copper in ohm-m.

void disp();
double Pa,Co,D,L,Li,tow,prod,val1,f,Vm,b,Bg,Va,IL,Ib,ATpp,O,E,A,Iz,Is,Z,Zs;
double c,S,u,C,sp,Aa,Ia,d,d1,id,BavM,acM,Ws,Wt,NTPa,Ht,Aw,Ah,Ys,Db3,At,Ysb3;
double Btm,Oa,Ac,Dc,Di,lf,la,Ra,CuA,WtCu,Vola,Lp,Ap,Wp,ATa,ATg,lg,Oy,Ay,Ly;
double Ty, Pbc,Pbf,Lcom,Lwindage;
double Cdia,Cpit,CpBS,BapS,BpS,Btav,Wtb3,t,Vc,Ipb,Ab,Lc,;
double Tfw,Hp,Dy,MWt,SILt,SILc,TIL,ILc,ILt,Wtt,Wtc,Lmt,Input,TLoss,Eff;
int Zc,Zo,Zn,Sl,Su,Tb,Wb;

void main()
{
clrscr();
cout << "\n Design of " << P << " kW " << V << " Volts, " << N << " rpm.,
Permanent Magnet DC Generator ";
```

```
cout << "\n MAIN DIMENSIONS : ";
cout << "\n Specific Loadings : " ;
cout << "\n Bav = " << Bav << " Weber/m^2 ";
cout << "\n ac  = " << ac << " Ampere Conductors / m ";
Pa = ( (2 + eta ) / ( 3 * eta ) ) * P;
cout << "\n Power developed by the armature Pa =  " << (Pa * 1000) << " W ";
Co = ( pi * pi * Bav * ac ) / 1000;
cout << "\n Output Coefficient =  " << Co;
prod = Pa / ( Co * N / 60 );
val1 = ( prod * p ) / ( Kf * pi );
D = pow ( val1, 0.333 );
cout << "\n\n Armature Diameter = " << (D * 1000) << " mm ";
L = prod / ( D * D );
cout << "\n Core Length      = " << (L * 1000) << " mm ";
cout << "\n Number of poles = " << p ;
tow = ( pi * D / p );
cout <<"\n Pole Pitch = " << (tow*1000) << " mm ";
b = (Kf * tow);
cout<< "\n Pole Arc = " << (b*1000) << " mm " ;
Va = ( pi * D * N / 60 );
cout << "\n Peripheral Speed  = " << Va << " m/s ";
cout << "\n Assume Stacking Factor as " << Ki;
Li = Ki * L;
cout << "\n Net iron length = " << (Li*1000) << " mm ";
f = ( p * N / 120 );
cout << "\n Frequency of flux reversals = " << f << " Hz ";
t = 0.35;
cout << "\n The thickness of lamination used for the machine = " << t << " mm ";

cout << "\n\n CHECK ON THE DESIGN : ";
cout << "\n   i) Peripheral Speed =  " << Va << " m/s ";
cout << "\n  ii) Maximum Voltage Between The Commutator Segments Vm : ";
cout << "\n\t Type of winding : Simple Lap With Single Turn Coils ";
```

```
cout  << "\n\t Maximum value of flux density Bg =  " << Bg << " Weber/m^2 ";
Vm = 2 * Bg * L * Va;
cout << "\n\t Maximum Voltage Between The Commutator Segments Vm = " << Vm
<< " Volts ";
cout << "\n iii) Pole Pitch = " << (tow * 1000) << " mm ";
IL = ( P * 1000 ) / V;
cout << "\n\t Full load current = " << IL << " Amps.";
Ib = IL * 2 / p;
cout << "\n iv) Current per brush arm = " << Ib << " Amps. ";
ATpp = ( pi * D * ac ) / ( 2 * p ) ;
cout << "\n v) Armature ampere turns per pole = " << ATpp;

cout << "\n\n ARMATURE DESIGN ";
cout << "\n NUMBER OF ARMATURE CONDUCTORS : ";
cout << "\n Armature voltage drop may be assumed as 3 % of the terminal voltage. ";
E = 1.03 * V;
O = Bav * pi * D * L / p;
cout << "\n Flux per pole = " << (O*1000) << " mWb ";
A = p;
cout << "\n Number of parrallel paths A = " << A;
Z = ( E * A * 60 ) / ( p * O * N );
cout << "\n The total number of armature conductors = " << Z ;
Zo = Z;

cout << "\n\n NUMBER OF SLOTS : " ;
Sl = ( pi * D * 1000 ) / 35;
Su = ( pi * D * 1000 ) / 10;
cout << "\n Guiding factors for the selection of slots are : ";
cout << "\n   i) Number of slots lies between " << Sl << " and " << Su << " . ";
Sl = 9 * p ;
Su = 16 * p;
cout << "\n  ii) For proper commutation : " << Sl << " and " << Su << " . ";
cout << "\n iii) To reduce flux pulsations : Slots per pole arc = Integer + 1/2  " ;
```

```
cout << "\n Enter the number of slots : " ;
cin >> S ;
Ys = pi * D * 1000 / S ;
cout << "\n Slot pitch = " << Ys << " mm ";
Zs = Z / S;
cout << "\n Number of conductors per slot = " << Zs ;
cout << "\n Enter the number of conductors per slot = " ;
cin >> Zs;
cout << "\n\n Number of conductors per slot = " << Zs ;
cout << "\n Enter their arrangement along width and height : ";

cin >> Aw >> Ah;
cout << "\n Number of slots = " << S ;
Z = Zs * S;
cout << "\n The total number of armature conductors = " << Z ;
Zn = Z;
C = Z / 2 ;
cout << "\n Using single turn coils, Number of coils = " << C;

Iz = Ib / A;
Is = Iz * Zs;
cout << "\n The total current per slot = " << Is << " Amps. ";
cout << "\n Check if the above value is satisfactory! ";

O = O * Zo / Zn;
cout << "\n Modified value of flux per pole = " << (O*1000) << " mWb ";
cout << "\n The values of specific loadings actually used are : " ;
BavM = O / ( tow * L ) ;
acM = Iz * Z / ( pi * D);
cout << "\n \t Bav = " << BavM << " Weber/m^2 ";
cout << "\n \t ac  = " << acM << " A/m ";

        "\n SIZE OF ARMATURE CONDUCTOR : ";
```

```
cout << "\n Armature current per parallel path = " << Ia << " Amps ";
cout << "\n Assume a current density of " << del << " Amps/mm^2 ";
Aa = Ia / del;
cout << "\n Cross sectional area of the conductor required = " << Aa << " mm^2 ";
cout << "\n Assume round conductors! ";
d1 = Aa * 4 / pi;
d = sqrt ( d1 );
cout << "\n Conductor diameter = " << d << " mm ";
cout << "\n Assume Enameled round copper conductors. " ;
cout << "\n Enter the value of insulated conductor diameter = ";
cin >> id;
d1 = d;
d = id;
Ws = ( Aw * d ) + 2;

cout << "\n\n SLOT DIMENSIONS :";
cout << "\n Width of the slot = " << Ws << " mm ";
Ht = ( Ah + 2 ) * d ;
cout << "\n Height of the slot = " << Ht << " mm ";
Wt = Ys - Ws;
cout << "\n Teeth width = " << Wt << " mm ";
NTPa = S / p;
Db3 =  D - ( 2/3 * Ht / 1000 * 2);
Ysb3 = pi * Db3 / S;
Wtb3 = Ysb3 - Ws / 1000;
At = Wtb3 * Li;
Btav = O / ( NTPa * At );
cout << "\n Average flux density in the teeth over a complete pole pitch = " << Btav
<< " Wb/m^2 ";
Btm = Btav / Kf;
cout << "\n The maximum flux density within the teeth = " << Btm << " Wb/m^2 ";
cout << "\n Check if Bt max <= 2.2 Weber/m^2. ";
        "\n\n ARMATURE CORE DEPTH :";
```

```
cout << "\n Flux in the pole is divided at the armature core and the section of the core
carries only half of the useful flux per pole.";
Oa = O / 2;
Ac = Ca / BavAC;
Dc = Ac / Li;
cout << "\n Core depth below the slots = " << (Dc*1000) << " mm ";
Di = D - 2 * ( Ht / 1000 + Dc ) ;
cout << "\n Internal diameter of the armature stampings = " << (Di*1000) << " mm ";

cout << "\n\n RESISTANCE, COPPER LOSSES AND WEIGHT OF COPPER : ";
lf = 0.14 + ( 1.15 * tow );
la = L + lf;
Ra = Spres * la * Z / ( 2 * Aa / 1000000 * A * A );
cout << "\n   i) Resistance of the armature winding             = " << Ra << " ohms ";
CuA = 1.25 * Ia * Ia * Ra;
cout << "\n  ii) Armature copper losses including eddy current losses   = " << CuA <<
" Watts ";
Vola = Aa * la * Z ;
WtCu = 8.9 * Vola / 1000;
cout << "\n iii) Total weight of copper in the armature winding        = " << WtCu << "
kg ";

cout << "\n\n LENGTH OF THE AIRGAP : " ;
ATa = ( Ia * Z ) / ( 2 * p );
ATg = 0.6 * ATa;
Bg = O / ( Kf * tow * L );
cout << "\n Flux density in the airgap = " << Bg << " Weber/m^2 ";
cout << "\n Assume the gap contraction factor as 1.15 ";
lg = ATg / ( 0.796 * Bg * 1.15 * 1000 );
cout << "\n\n Length of the air gap = " << lg << " mm ";
getch();
```

```
cout << "\n\n DIMENSIONS OF THE POLE : ";
cout << "\n i) AXIAL LENGTH : ";
cout << "\n    The axial length of the pole should be less than the armature length, in
order to avoid magnetic centering of the armature.\n    Assume the axial length of the
pole is 1 cm less than the armature length.";
Lp = L - 0.01;
cout << "\n The axial length of the pole = " << (Lp*1000) << " mm ";

cout << "\n\n ii) WIDTH OF THE POLE : ";
cout << "\n    Due to the leakage of the flux, pole flux on full load will be more than
useful flux. \n Assume i) Leakage factor of 1.1 for the pole. \n\t ii) Working flux
density in the pole as 1.9 Wb/m^2. \n\t iii) Iron factor for pole as 0.98 ";
Ap = 1.1 * O / ( 1.6 * 0.98 );
Wp = Ap / Lp ;
cout << "\n The width of the pole = " <<  (Wp*1000) << " mm ";
Hp = 0.01;
cout << "\n\n iii) Height of the pole = " << (Hp*1000) << " mm ";
cout << "\n iii) Pole arc = " << (b*1000) << " mm ";

cout << "\n\n DIMENSIONS OF THE YOKE : " ;
cout << "\n Assume flux density in the yoke as 1.5 Weber/m^2. ";
Oy = O / 2 ;
Ay = Oy / 1.5;
Ly = 1.6 * L;
cout << "\n The axial length of yoke is taken approximately 1.6 times core length. ";
cout << "\n The axial length of the yoke = " << (Ly*1000) << " mm ";
Ty = Ay / Ly;
cout << "\n The thickness of the yoke = " << (Ty*1000) << " mm ";

Dy = D + (2*lg/1000) + 2*Ty + 2 * Hp;
cout << "\n\n The outer diameter of the yoke = " << (Dy*1000) << " mm ";

cout << "\n\n COMMUTATOR AND BRUSH DESIGN : " ;
```

```
Cdia = D * 0.65;
cout << "\n Diameter of the commutator = " << Cdia << " m";


cout << "\n\n Design Check : " ;
Vc = pi * Cdia * N / 60;
cout << "\n   i) Peripheral speed of the commutator = " << Vc << " m/s ";
cout << "\n  ii) Number of segments                = " << C ;
Cpit = ( pi * Cdia * 2 ) / Z ;
cout << "\n iii) Pitch of the segments                    = " << (Cpit*1000) << " mm ";


cout << "\n\n BRUSHES : " ;
cout << "\n Electro graphite brushes are used. \n The current density in the brushes is
0.03 A/mm^2. ";
Ipb = Ib / 2;
cout << "\n Current in each brush = " << Ipb << " Amps.";
cout << "\n The current in each brush must not be more than 70 A. ";
Ab = Ipb / 0.03;
cout << "\n Area of each brush = " << Ab << " mm^2 ";
cout << "\n The brushes should cover at least 2.5 segments.";
Tb = 10 * Cpit * 1000;
cout << "\n\n Thickness of each brush = " << Tb << " mm ";
Wb = Ab / Tb ;
cout << "\n Width of each brush = " << Wb << " mm ";
Ab = Wb * Tb ;
cout << "\n Area of each brush used = " << Ab << " mm^2";
cout << "\n\n Allow 5 mm for clearance between brushes, 10 mm for staggering and
10 mm for   end play. ";
Lc = 2 * Wb + 25 ;
cout << "\n Length of the commutator = " << Lc << " mm ";
getch();


cout << "\n\n\n LOSSES AT THE BRUSH ";
cout << "\n   The brush contact drop is assumed as 1 V per brush ";
```

```
cout << "\n Brush Contact Loss Pbc    = " << Pbc << " Watts ";
cout << "\n The brush pressure used is 20 kN/m^2 and the co-efficient of friction is
0.15 ";
Pbf = 0.15 * 20000 * 2 * Ab / 1000000;
cout << "\n Brush Friction Loss Pbf    = " << Pbf << " Watts ";
Lcom = Pbf + Pbc;
cout << "\n Total loss at the commutator = " << Lcom << " Watts ";

cout << "\n\n LOSSES AND EFFICIENCY " ;
cout << "\n\n   i) FRICTION AND WINDAGE LOSSES : ";
cout << "\n Brush Friction Loss Pbf    = " << Pbf << " Watts ";
cout << "\n The friction losses in the bearings and the windage losses are taken as
0.2% of the output. ";
Lwindage = 0.2 / 100 * P;
cout << "\n Bearing friction and windage losses = " << Lwindage << " Watts ";
Tfw = Lwindage + Pbf;
cout << "\n Total friction and windage losses = " << Tfw << " Watts ";
cout << "\n\n  ii) IRON LOSSES : ";
MWt = pi * ( D*1000 - Ht ) / S;
cout << "\n Mean width of tooth = " << MWt << " mm ";
Wtt = S * Li * MWt/1000 * Ht/1000 * 7800;
cout << "\n Weight of the armature teeth = " << Wtt << " kg ";
cout << "\n Flux density in teeth at 1/3 height from root is " << Btm << " Wb/m^2.";
SILt = ( 0.06 * f * Btm * Btm ) + ( 0.008 * f * f * Btm * Btm * t * t );
cout << "\n Specific iron loss in teeth = " << SILt << " Watts/kg ";
ILt = SILt * Wtt;
cout << "\n Iron loss in teeth = " << ILt << " Watts. ";

Wtc = pi * ( D - 2*Ht/1000 - Dc ) * Ac * 7800;
cout << "\n Weight of the armature core = " << Wtc << " kg ";
SILc = ( 0.06 * f * Btm * Btm ) + ( 0.005 * f * f * Btm * Btm * t * t );
cout << "\n Specific iron loss in core = " << SILc << " Watts/kg ";
```

```
TIL = ILc + ILt;
cout << "\n Total iron loss = " << TIL << " Watts ";
cout << "\n Allow an additional 20% for loss caused by ripples in the motor supply
waveform";
TIL = 1.2 * TIL;
cout << "\n Total iron loss = " << TIL << " Watts ";

cout << "\n\n iii) COPPER LOSSES : " ;
Lmt = 2 * L + 2.5 * tow + 5 * Ht/1000;
cout << "\n Length of mean turn of armature = " << Lmt << " m ";
cout << "\n Resistance of the armature winding                    = " << Ra << " ohms ";
cout << "\n Armature copper losses including eddy current losses   = " << CuA << "
Watts ";
cout << "\n Brush Contact Loss Pbc    = " << Pbc << " Watts ";



cout << "\n\n EFFICIENCY CALCULATIONS ";
cout << "\n Efficiency can be obtained by loss summation.";
cout << "\n Armature Copper Loss             = " << CuA << " Watts ";
cout << "\n Brush Contact Loss               = " << Pbc << " Watts ";
cout << "\n Iron Loss                   = " << TIL << " Watts ";
cout << "\n Friction And Windage Losses      = " << Tfw << " Watts ";
TLoss = CuA + Pbc + TIL + Tfw;
Input = (P * 1000) + TLoss;
cout << "\n\n Total Losses = " << TLoss << " Watts ";
cout << "\n\n Input Power  = " << Input << " Watts ";
Eff = P * 1000 / Input * 100;
cout << "\n\n Efficiency at full load = " << Eff << " % ";

getch();
disp();
getch();
}
```

```
void disp()
{
clrscr();
cout << "\n \t\t DESIGN SHEET ";
cout << "\n\n Rating - " << P << " kW \t\t Voltage - " << V << " V ";
cout << "\n Speed  - " << N << " r.p.m. \t\t Type - PMDC ";

cout << "\n\n MAIN DIMENSIONS ";
cout << "\n  1. Output                              P       " << P << " kW ";
cout << "\n  2. Armature Power                      Pa      " << Pa << " kW ";
cout << "\n  3. Speed                               N       " << N << " rpm";
cout << "\n  4. Armature Peripheral Speed                   Va      " << V << " m/s";
cout << "\n  5. Output Co-efficient                 Co      " << Co;
cout << "\n  6. Specific Magnetic Loading                   Bav     " << BavM << "Wb/m^2";
cout << "\n  7. Specific Electric Loading            ac     " << ac << " A/m ";
cout << "\n  8. Armature Diameter                           D       " << (D*1000) << " mm";
cout << "\n  9. Gross Core Length                           L       " << (L*1000) << " mm ";
cout << "\n 10. Net Iron Length                             Li      " << (Li*1000) << " mm";
cout << "\n 11. Frequency of flux reversals           f     " << f << " Hz ";
cout << "\n 12. Pole pitch                          T       " << (tow*1000) << " mm ";
cout << "\n 13. Pole Arc                                    b        " << (b*1000) << " mm" ;

cout << "\n\n ARMATURE  ";
cout << "\n  1. Winding                                             Simplex Lap ";
cout << "\n  2. Number of parallel paths                    A       2 ";
cout << "\n  3. Number of slots                             S       " << S;
cout << "\n  4. Conductors per slot                 Zs      " << Zs;
cout << "\n  5. Conductor : Area                            a        " << Aa << " mm^2";
cout << "\n       Bare conductor diameter        d      " << d1 << " mm";
cout << "\n       Insulated conductor diameter   id      " << id << " mm ";
cout << "\n  6. Current density                             del      " << del << " A/mm^2 ";
cout << "\n  7. Length of the mean turn                     Lmt      " << Lmt << " m ";
cout << "\n  8. Slot pitch                         Ys       " << Ys << " mm ";
```

```
cout << "\n              Depth              Ht      " << Ht << " mm ";
cout << "\n 10. Core Depth below the slots          Dc      " << (Dc*1000) << "mm";
cout << "\n 11. Length of the Airgap           lg      " << lg << " mm ";
cout << "\n 13. Resistance                   Ra      " << Ra << " ohms ";

cout << "\n\n FIELD ";
cout << "\n 1. Number of poles                     p        " << p;
cout << "\n 2. Pole arc                            Pa      " << (Pa*1000) << " mm ";
cout << "\n 3. Pole Size : Length                          " << (Lp*1000) << " mm ";
cout << "\n             Width                      " << (Wp*1000) << " mm ";
cout << "\n             Height             " << (Hp*1000) << " mm ";
cout << "\n 4. Outer diameter of the yoke          Dy     " << (Dy*1000) << " mm ";
cout << "\n 5. Length of the yoke                  Ly      " << (Ly*1000) << " mm ";
cout << "\n 6. Shaft Diameter                              " << (Di*1000) << " mm ";
getch();
clrscr();

cout << "\n\n EFFICIENCY ";
cout << "\n 1. Armature Copper Loss                        " << CuA << " Watts ";
cout << "\n 2. Brush Contact Loss                          " << Pbc << " Watts ";
cout << "\n 3. Iron Loss                           " << TIL << " Watts ";
cout << "\n 4. Friction And Windage Losses                 " << Tfw << " Watts ";
cout << "\n 5. Total losses                        " << TLoss << " Watts ";
cout << "\n 6. Efficiency                                  " << Eff << " % ";


}
```

5.2. RESULTS OF PROGRAM :

Design of 0.1 kW 30 Volts, 2000 rpm., Permanent Magnet DC Generator.

```
DESIGN DETAILS
MAIN DIMENSIONS :
Specific Loadings :
        Bav     = 0.45 Weber/m^2
        ac      = 2000 Ampere Conductors / m
Power developed by the armature Pa =  103.508772 W
Output Coefficient    =  8.882644
Armature Diameter             = 66.012895 mm
Core Length                   = 80.222945 mm
Number of poles               = 2
Pole Pitch                    = 103.692813 mm
Pole Arc                      = 80.880394 mm
Peripheral Speed              = 6.912854 m/s
Assume Stacking Factor as 0.9
Net iron length               = 72.20065 mm
Frequency of flux reversals   = 33 Hz
The thickness of lamination used for the machine = 0.35 mm

CHECK ON THE DESIGN :
 i) Peripheral Speed                  =  6.912854 m/s
 ii) Maximum Voltage Between The Commutator Segments Vm :
      Type of winding                      : Simple Lap With Single Turn Coils
      Maximum value of flux density Bg     =  0.576923 Weber/m^2
      Maximum Voltage Between The Commutator Segments Vm = 0.639888 Volts
iii) Pole Pitch = 103.692813 mm
      Full load current               = 3.333333 Amps.
iv) Current per brush arm             = 3.333333 Amps.
v) Armature ampere turns per pole     = 103.692813
```

```
ARMATURE DESIGN
NUMBER OF ARMATURE CONDUCTORS :
Armature voltage drop may be assumed as 3 % of the terminal voltage.
Flux per pole = 3.743344 mWb
Number of parallel paths A = 2
The total number of armature conductors = 247.639527

NUMBER OF SLOTS :
Guiding factors for the selection of slots are :
 i) Number of slots lies between 5 and 20 .
 ii) For proper commutation : 18 and 32 .
iii) To reduce flux pulsations : Slots per pole arc = Integer + 1/2 .
Enter the number of slots : 20

Slot pitch = 10.369281 mm
Number of conductors per slot = 12.381976
Enter the number of conductors per slot = 12

Number of conductors per slot = 12
Enter their arrangement along width and height : 4    3

Number of slots = 20
The total number of armature conductors      = 240
Using single turn coils, Number of coils     = 120
The total current per slot                   = 20 Amps.
Check if the above value is satisfactory!

Modified value of flux per pole              = 3.852525 mWb
The values of specific loadings actually used are :
        Bav    = 0.463125 Weber/m^2
        ac     = 1928.773988 A/m
```

```
SIZE OF ARMATURE CONDUCTOR :
Armature current per parallel path         = 2.466667 Amps
Assume a current density of 4.5 Amps/mm^2
Cross sectional area of conductor required  = 0.548148 mm^2

Assume round conductors!
Conductor diameter                          = 0.835418 mm

Assume Enameled round copper conductors.
Enter the value of insulated conductor diameter = 0.914

SLOT DIMENSIONS :
Width of the slot      = 5.656 mm
Height of the slot     = 4.57 mm
Teeth width            = 4.713281 mm

Average flux density in the teeth over a complete pole pitch = 1.13209 Wb/m^2
The maximum flux density within the teeth = 1.451398 Weber/m^2
Check if Bt max <= 2.2 Weber/m^2.

ARMATURE CORE DEPTH :
Flux in the pole is divided at the armature core and the section of the core
carries only half of the useful flux per pole.
Core depth below the slots                  = 21.343437 mm
Internal diameter of the armature stampings = 14.18602 mm

RESISTANCE, COPPER LOSSES AND WEIGHT OF COPPER :
 i) Resistance of the armature winding                       = 0.390161 ohms
 ii) Armature copper losses including eddy current losses   = 2.967389 Watts
iii) Total weight of copper in the armature winding         = 0.397466 kg

LENGTH OF THE AIRGAP :
Flux density in the air gap    = 0.59375 Weber/m^2
Assume the gap contraction factor as 1.15
```

DIMENSIONS OF THE POLE :

i) AXIAL LENGTH :

The axial length of the pole should be less than the armature length, in order to avoid magnetic centering of the armature.

Assume the axial length of the pole is 1 cm less than the armature length.

The axial length of the pole = 70.222945 mm

ii) WIDTH OF THE POLE :

Due to the leakage of the flux, pole flux on full load will be more than useful flux.

Assume i) Leakage factor of 1.1 for the pole.
ii) Working flux density in the pole as 1.9 Wb/m^2.
iii) Iron factor for pole as 0.98

The width of the pole = 32.410031 mm

iii) Height of the pole= 10 mm

iv) Pole arc = 80.880394 mm

DIMENSIONS OF THE YOKE :

Assume flux density in the yoke as 1.5 Weber/m^2.

The axial length of yoke is taken approximately 1.6 times the core length.

The axial length of the yoke = 128.356712 mm
The thickness of the yoke = 10.004736 mm
The outer diameter of the yoke = 106.349127 mm

COMMUTATOR AND BRUSH DESIGN :

Assume the commutator diameter to be 65 % of the armature diameter.

Diameter of the commutator = 0.042908 m

Design Check :

i) Peripheral speed of the commutator = 4.493355 m/s
ii) Number of segments = 120

BRUSHES :

Electro graphite brushes are used.

The current density in the brushes is 0.03 A/mm^2.

Current in each brush = 1.666667 Amps.

The current in each brush must not be more than 70 A.

Area of each brush = 55.555556 mm^2

The brushes should cover at least 2.5 segments.

Thickness of each brush = 11 mm

Width of each brush = 5 mm

Area of each brush used = 55 mm^2

Allow 5 mm for clearance between brushes, 10 mm for staggering and 10 mm for end play.

Length of the commutator = 35 mm

LOSSES AT THE BRUSH

The brush contact drop is assumed as 1 V per brush.

Brush Contact Loss Pbc = 4.933333 Watts

The brush pressure used is 20 kN/m^2 and the co-efficient of friction is 0.15

Brush Friction Loss Pbf = 0.33 Watts

Total loss at the commutator = 5.263333 Watts

LOSSES AND EFFICIENCY

i) FRICTION AND WINDAGE LOSSES :

Brush Friction Loss Pbf = 0.33 Watts

The friction losses in the bearings and the windage losses are taken as 0.2% of the output.

Bearing friction and windage losses = 0.0002 Watts

Total friction and windage losses = 0.3302 Watts

ii) IRON LOSSES :

Mean width of tooth = 9.651427 mm

Weight of the armature teeth = 0.496791 kg

Flux density in teeth at 1/3 height from root is 1.451398 Wb/m^2.

Specific iron loss in teeth = 6.419137 Watts/kg

Iron loss in teeth = 3.188967 Watts.

Weight of the armature core = 1.341648 kg

Specific iron loss in core = 5.576078 Watts/kg

Iron loss in core = 7.481132 Watts.

Total iron loss = 10.6701 Watts

Allow an additional 20% for loss caused by ripples in the motor supply waveform

Total iron loss = 12.80412 Watts

iii) COPPER LOSSES :

Length of mean turn of armature = 0.442528 m

Resistance of the armature winding = 0.390161 ohms

Armature copper losses including eddy current losses = 2.967389 Watts

Brush Contact Loss Pbc = 4.933333 Watts

EFFICIENCY CALCULATIONS

Efficiency can be obtained by loss summation.

Armature Copper Loss = 2.967389 Watts

Brush Contact Loss = 4.933333 Watts

Iron Loss = 12.80412 Watts

Friction And Windage Losses = 0.3302 Watts

Total Losses = 21.035042 Watts

Input P = 121.035042 Watts

DESIGN SHEET

Rating - 0.1 kW

Speed - 2000 r.p.m.

Voltage - 30 V

Type - PMDC

MAIN DIMENSIONS

1. Output	P	0.1 kW
2. Armature Power	Pa	0.103509 kW
3. Speed	N	2000 rpm
4. Armature Peripheral Speed	Va	30 m/s
5. Output Co-efficient	Co	8.882644
6. Specific Magnetic Loading	Bav	0.463125 Wb / m^2
7. Specific Electric Loading	ac	2000 A/m
8. Armature Diameter	D	66.012895 mm
9. Gross Core Length	L	80.222945 mm
10. Net Iron Length	Li	72.20065 mm
11. Frequency of flux reversals	f	33 Hz
12. Pole pitch	T	103.692813 mm
13. Pole Arc	b	80.880394 mm

ARMATURE

1. Winding		Simplex Lap
2. Number of parallel paths	A	2
3. Number of slots	S	20
4. Conductors per slot	Zs	12
5. Conductor : Area	a	0.548148 mm^2
Bare conductor diameter	d	0.835418 mm
Insulated conductor diameter	id	0.914 mm
6. Current density	del	4.5 A/mm^2
7. Length of the mean turn	Lmt	0.442528 m
8. Slot pitch	Ys	10.369281 mm
9. Slot Size : Width	Ws	5.656 mm

10. Core Depth below the slots	Dc	21.343437 mm
11. Length of the air gap	lg	0.16338 mm
13. Resistance	Ra	0.390161 ohms

FIELD

1. Number of poles	p	2
2. Pole arc	Pa	103.508772 mm
3. Pole Size : Length		70.222945 mm
Width		32.410031 mm
Height		10 mm
4. Outer diameter of the yoke	Dy	106.349127 mm
5. Length of the yoke	Ly	128.356712 mm
6. Shaft Diameter		14.18602 mm

EFFICIENCY

1. Armature Copper Loss	2.967389 Watts
2. Brush Contact Loss	4.933333 Watts
3. Iron Loss	12.80412 Watts
4. Friction And Windage Losses	0.3302 Watts
5. Total losses	21.035042 Watts
6. Efficiency	82.620701 %

* * *

CAD Drawing

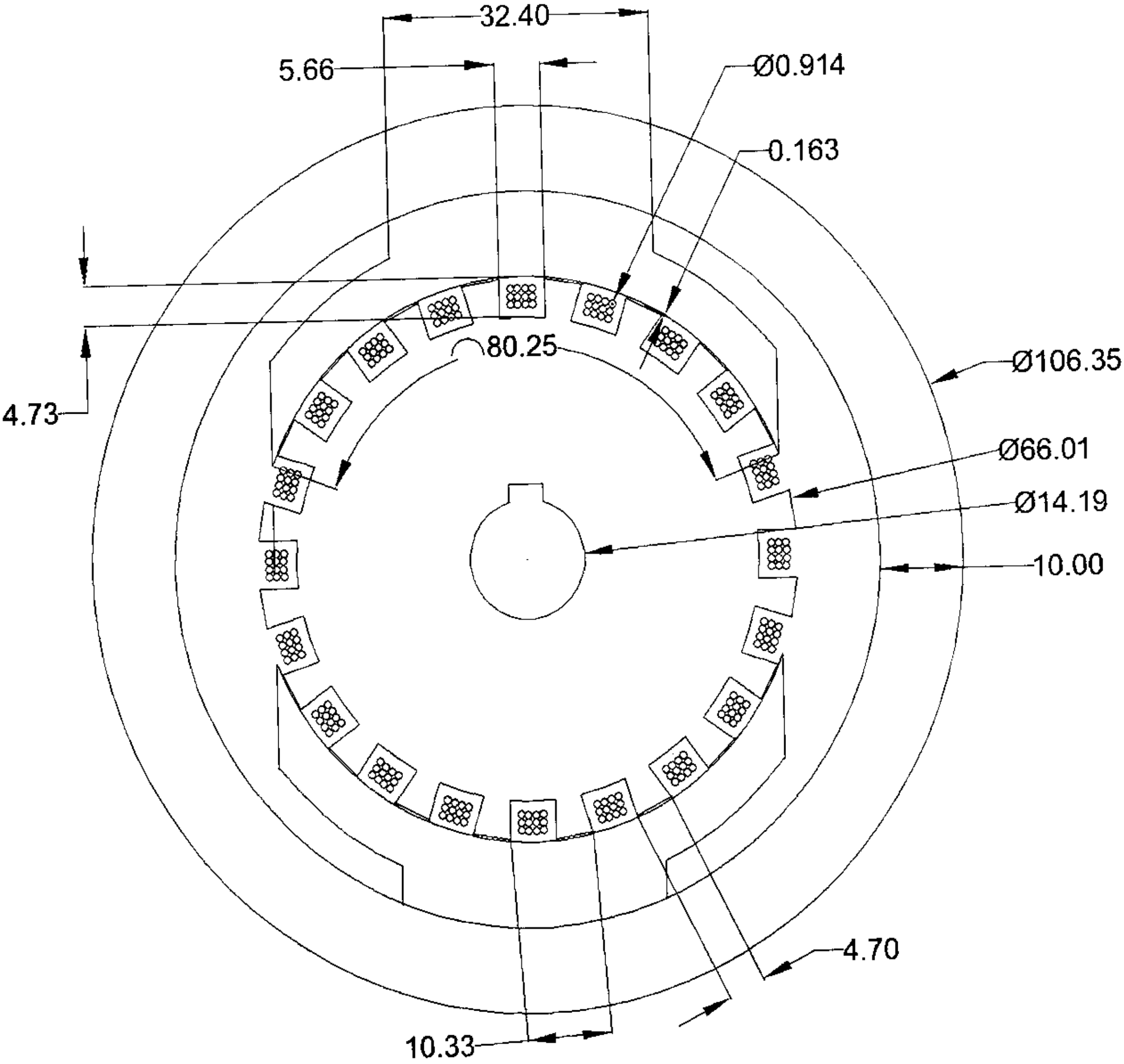


Fig.1. CAD DRAWING.

Diagrams

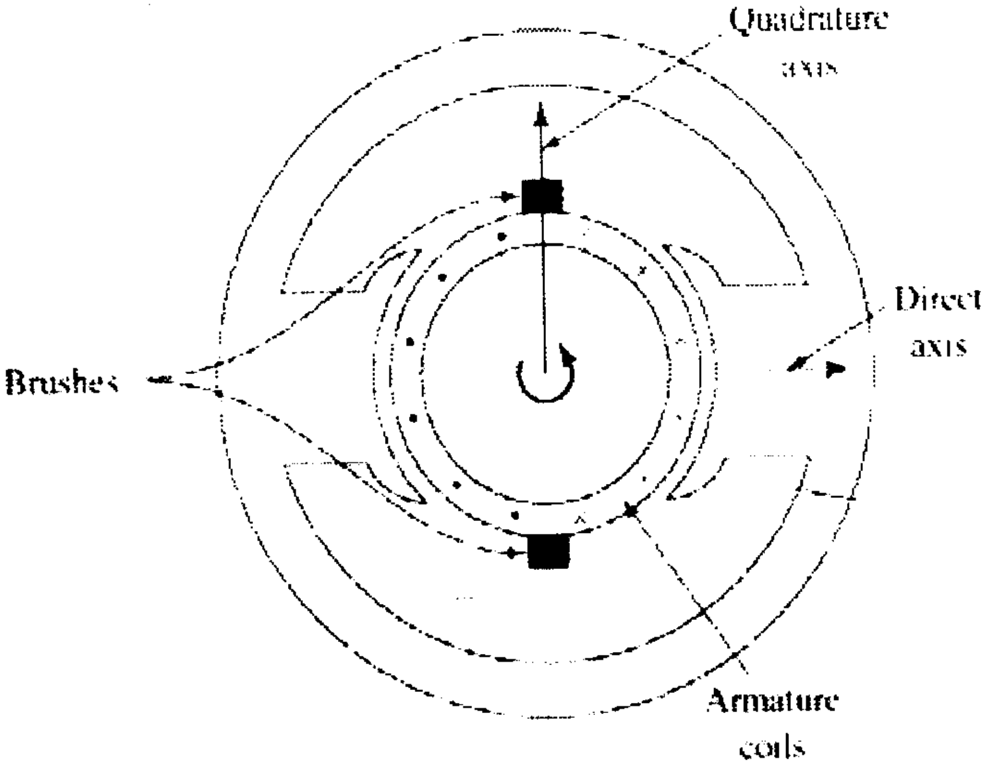


Fig.2. CROSS-SECTIONAL VIEW OF PMDC.

Fig 3. OUR PROJECT SETUP

Conclusion

6. CONCLUSION :

The design of a permanent magnet dc generator was under taken in this project which involved the following parts.

i) Selection of the capacity of the machine required for specific application.

ii) The voltage output level.

So after selecting these specific values, we have used the mathematical equations for the design available in the reference books. We have also used the C++ program to make the calculations easy. One thing we have observed from this design is that there exist deviations from the practical values.

We have assumed the values of specific loadings and number of poles as given in " Electrical Machine Design " by A.K.Sawhney and " Design Of Electrical Machines (D.C. & A.C.) " , by Dr. V.N.Mittle. In this design we were able to see the advantages of C++ programming in quickly arriving at the calculated values.

Thus we were able to design and fabricate a Permanent Magnet DC Generator to a satisfactory level and test the same successfully.

* * *

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