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# Design Procedure of A Permanent Magnet D.C. Commutator Motor

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**Abstract**

Electrical machine with electro magnet as excitation system many problems out of which, less efficiency is a major one. Self excited dc machine has to sacrifice some power for excitation system as a result, power available for useful work become less. This problem can be solved to some extent whatever may be the amount , by using permanent magnet for the excitation system of dc machine and there by contributing towards the conservation of conventional energy sources which are alarmingly decrease day by day . Using of permanent magnet in the electrical machine helps in burning of less conventional fossil fuel and contributes indirectly in conservation of air-pollution free environment. With permanent magnet dc motor, the efficiency of the machine also rise up considerably. This paper is an effort to give a computer aided design procedure of permanent magnet dc motor.

**Keywords**: permanent magnet dc motor, yoke, pole pitch, commutator, magnetic loading, electric loading, output coefficient.

## Introduction

It can be stated without any dispute that for the ever developing modern civilization electric motor become an unavoidable part both in industrial product as well as domestic applications. But ever since the growing threat of running out of the conventional energy source used by the mankind by the middle of the next century, the scientists have very desperately engaged themselves for last few decades in molding suitable devices for conservation of different form of conventional energy. Electrical energy, being the most refined form of energy out of its all counterparts, also needs conservation process and one of such process is the construction of electrical motor with better and better efficiency. The application of permanent magnet in electrical machine, or more precisely in electrical motor, can play a vital role in electrical energy conservation process. Because, with permanent magnet excitation system, the energy consumed for field excitation become totally absent and the consumption of fossil fuel reduced to some extent as well as the rate of environmental pollution may decrease.

## 1. PM D.C. commutator Motor

PM dc commutator machines are generally designed in a similar manner to that for any other d.c. commutator machine. The armature of the PM excited machine is similar to the wound field dc machine. So, the armature of PM dc commutator machine is designed by the same rule of winding layout as in general dc shunt motor with constant field excitation. The number of slot and poles, slot geometry, commutator and brush layout, parallel path, winding layout are identical for both type of machines. The determination of air gap flux density and the mechanical design of field structure and stator yoke are different for PM dc commutator machine and wound field dc commutator motor. The permanent magnetic materials are not able to carry high flux density and hence usually the air gap flux density is kept lower than that of counter part wound field motor. This permits the motor to have narrow teeth, enlarged poles, and small air gap length than conventional dc commutator motor.
The field structure and the shape of yoke of PM dc commutator motor depend on the type of permanent magnetic material used. This ultimately determines the overall volume of the motor. With same capacity, the PM dc commutator motor with Samarium cobalt as magnetic material has lesser volume than the one using ferrite as permanent magnetic material.

### 1.2. Calculation of Design of Small D.C. permanent Magnet Motor:

The calculation of small d.c. permanent magnet motor is sub-divided into the following stages-

- i) Determination of the main dimension of the motor.
- ii) Calculation of armature winding.
- iii) Size of armature winding conductor teeth and slot.
- iv) Losses and temperature rise of the armature.
- v) Calculation of size of brush, commutator, losses and temperature rise of commutator.
- vi) Calculation of efficiency.
- vii) Calculation of magnetic system.
    - (a) length of air gap.
    - (b) Size of the yoke.
    - (c) Size of the permanent magnet.

## 2. Determination of main dimension of the small permanent magnet D.C. motor:

### 2.1. Main Dimension:

The armature diameter($D_a$) and armature core length ($L_c$) of rotating machine is called main dimension of the machine.

### 2.2. Loading:

There are two main loadings to a rotating machine viz. (i) magnetic and (ii) electric loading.

**(i) Magnetic loading:**

The total flux around the armature periphery at the air gap is called total magnetic loading.(magnetic loading / area of flux path at the air gap)is named as specific magnetic loading and denoted by Bav.

$$Bav = (P\phi/\pi D_a L_c) = (\phi/\tau L)$$

Where

$P$ = number of poles
$\phi$ = flux per pole
$\tau$ = pole pitch

**(ii) Electric Loading:**

The total number of ampere conductor around the armature periphery is called total electric loading. The ratio of electric loading to armature periphery at the air gap is called specific electric loading and denoted by $A_c$.

$$A_c = I_z Z/\pi D$$

Where

$I_z$ = current in each conductor
Z = number of conductor.

## 3. Output Equation

The output of a machine can be expressed in terms of its main dimension $S_p$ magnetic and $S_p$ electric loading. Power developed by armature in $K_w = P_a$ .

Where

$$P_a = \text{e.m.f. generated} \times \text{Armature current} \times 10^{-3} \quad [3.1]$$

$$\text{e.m.f. } E = (\phi Z_n P/a) \quad [3.2]$$

$$\text{so, } P_a = (\phi Z_n P/a) I_a \times 10^{-3} = (\phi P \times (I_a Z/a) \times n \times 10^{-3}$$

$$P_a = (\text{total Mag. loading})(\text{total elect. loading}) \times (r.P.S \times 10^{-3}) \quad [3.3]$$

$$Bav = (P\phi/\pi D_a L_c)$$

$$AC = (ac/\pi D_a)$$

Putting equation [3.1] and [3.2] in [3.3]

$$\mathrm{P_a} = \pi D_a L_c Bav \times \pi D_a AC \times n \times 10^{-3} = (\pi^2 BavAc \times 10^{-3})(D_a^2 L_c^n)$$

$$P_a = C_o D_a^2 L_c^n \qquad [3.4]$$

Where

$C_o = \pi^2 BavAc \times 10^{-3}$
= output coefficient of the motor.

## 4. Factor effecting size of the rotating machine:

The size of the rotating machine is affected by (i) speed (ii) output coefficient.

**(i) Speed:**

The volume is inversely proportional to the speed keeping in view the limit of mechanical stress, the speed can be increased to highest practical value and thereby the volume and hence the cost can be decreased.

**(ii) Output Coefficient :**

Higher the output coefficient smaller will be the volume , $C_o$ can be increased by increasing either $Bav$ or AC.

### 4.1. Increase of $Bav$:

The value of $S_p$ magnetic loading depends on

a. Maximum flux density in iron part
b. Magnetizing current
c. Core loss.

To keep the teeth root density within a certain limit, the specific magnetic loading is selected within certain limit. In case of permanent magnet d.c. machine magnetizing current is not required.

The core loss is directly proportional to the flux density in the iron part and hence on the value of specific magnetic loading.

### 4.2. Choice of Specific Electric Loading:

Heat dissipated per unit area of armature surface is proportional to specific electric loading.

Specific electric loading = (Temperature/$\rho\delta C$)

Where

$\rho$ = resistivity of conductor
$\delta$ = current density
$C$ = cooling coefficient

With a better quality insulating material, the higher valued specific electric loading can be used.

With smaller cooling coefficient high specific electric loading can be used.

The ampere conductor per unit length is directly related to the space factor i.e. the ratio of bare conductor area to total slot area. For high voltage this space factor is low which requires a low electric loading with fixed ratio of slot width to slot pitch, fixed current density and fixed slot depth. Moreover, for constant current density and space factor, $S_p$ electric loading is proportional to diameter.

With the increase of $S_p$ electric loading the value of armature reaction m.m.f. becomes high. Commutation is effected by high ampere conductor. Because, with high ampere conductor the number of turns of the coil increases and also the height of the slot. The inductance of the coil and armature increases leading to poor commutation.

**4.3. Selection of Pole:**

Selection of number of poles is done on the basis of the frequency of flux reversal which is given by $= (PN/120)$ , P= number of pole and N = speed in rpm. Selection of frequency of flux reversal for small d.c. machine should be 25Hz to 75Hz in normal case.

**4.4. Selection of type of Winding:**

In two-pole small d.c. machines, the lap and the wave winding are identical. For four-pole machine the choice of type of winding depends on the armature current. For armature current up to 400A, wave winding is preffered. In general for small machines, the wave winding is a normal choice though lap winding can also be used on customers' demand.

**4.5. Selection of Number of pole:**

**(a) Bi-polar Machine:**

For bipolar machine the slot pitch is 0.01 meter to 0.04 meter so that number of slot varies from $(\pi D/0.04)$ to $(\pi D/0.01)$ . The number of slot should be as high as possible to reduce the commotional voltage and should be odd to eliminate cogging torque, but without increasing the labour cost too much.

**(b) Wave Winding:** With the slot pitch from
0.01 Mtr. to 0.04Mtr.,there is a range of number of slots. The selection is done on the basis of the fact that (i) number of pole slots should not be a multiple of pair of poles (ii)number of poles per pole arc should be an integer $(+\frac{1}{2})$ .

**(c) Lap Winding :** In case of lap winding the number of slots should be (i)a multiple of pair of poles and (ii)slots per pole arc is an integer $(+\frac{1}{2})$.

**4.6. Number of Coils and Turns per Coil:**

The minimum number coils is given by

$$C_{min} = (EP/15)$$

Where,
E= induced voltage and P is the number of poles. The turns per coil is $T_c = Z/2C_{min}$ .

For wave winding the total number of coil is so chosen that $coil/slot$ is an integer and should not be multiple of pair of poles.
For lap winding $coil/slot$ is an integer and should be multiple of pair of poles.

**4.7. Slot Area:**
To calculate slot area the following points should be considered carefully
i. Current density
ii. Height/width ratio.
The flux density in the core and teeth (particularly at the teeth root)and the copper loss depend on the area of the slot and current density.

**4.8 Temperature Rise:**
Temperature rise depends on the class of insulation. For F class insulation the temperature rise may be allowed up to $100^0$C for totally enclosed machine.

## 5. Choice of Permanent Magnet:

A permanent magnet with high maximum energy product is generally selected. The operating point or operating flux density is chosen in the vicinity of the maximum energy product. The armature is designed for a small air gap flux density corresponding to operating flux density of the permanent magnet.

## 6. Commutator and Brush:

The number of commutator segment is equal to number of coils or segment. The minimum number of segments is (E×P/15) where E = induced voltage, P = number of poles. The diameter of the commutator is generally lies between 0.6 to 0.8 of armature diameter. For small machine this value can be extended up to 0.9 . The peripheral speed can exceed up to 30mtr/sec.

The commutator bar segment pitch or thickness of the commutator should not generally be less than 4mm. for factional lop machine this value can be lowered up to 2.5m. length of the commutator depends upon the space required by the brushes and upon the surface required to dissipate heat generated by commutator loss.

The number of brush spindles are equal to number of poles. The number of brushes in each spindle are such that brush current does exceed 70 amp. Each brush spindle current is equal to ($2I_a/\rho$) thickness of the brush is (Number of coils/number of slot)-1 commutator bar pitch.

Temperature rise of the commutator is calculated by calculating total loss in the commutator and brush. There are generally two loss – Brush contact and Brush fictional loss.

Temperature Rise= (Total loss/ dissipating area × heat transfer coefficient)

$\theta = (P_c + P_F)/(\pi \times D_c \times C_L \times F_c)$

$\theta$ =Temperature rise in degree centigrade

$P_c$ =Brush contact loss in watt

$P_F$ =Brush friction loss in watt

$D_c$ =Commutator length in mtr.

$F_c$ =Heat transfer coefficient in W/m$^2$ $^0$C

Commutator temperature rise can be allowed up to $155^0$C

## 7. Design of Permanent Magnet:

The choice of the permanent magnet depends on the cost factor, availability, mechanical design (hardness and strength requirements), available spaces in magnetic circuit and magnetic and electrical performance specification of the circuit.

After selection of the type and shape of magnet, a suitable magnet length is assumed and estimate total mmf that can be delivered by the magnet. Armature demagnetizing mmf is estimated by considering necessary brush shift angle.

The total field mmf is found out and the air gap mmf is considered as 65% to 70% of the total field mmf. The air gap length is calculated and is to be checked if it is within 1.5% of the pole pitch.If this limit is exceeded, the magnet length is reassumed and the process is repeated. It is to be noted that the operating flux density of the magnet is at the maximum energy point or very near to the maximum energy point to keep the volume of the magnet minimum.

## 8. Design of Yoke:

The dimension of yoke is determined by the value of flux carried by the yoke. The yoke carries half of the total flux. The flux density of yoke for permanent magnet machine is normally taken as 0.8 wb/m$^2$. The cross-sectional area and length of the yoke is estimated and finally the height of the yoke is found out.

## Conclusion

PM dc motor is excitation loss free and hence some amount of contribution is given to the conservation of energy as well as air pollution control by the out put power /volume is high and better dynamic performance is available with this motor. Construction and maintenance is also simple. The majority of PM dc motor with slotted rotor use Ferrite PM..Barium and strontium Ferrite PM dc motor are going to be used extensively in Auto mobile sector. With the advent of rare earth PM material like Samarium cobalt, Nedium iron boron, the brushless PM motor become more efficient than Induction motor. In servo mechanism also maintenance free brush-less PM dc motor replace the conventional servo motor. In Germany PM Brushless motor upto 1KW is already designed .It is well accepted fact that there are always some losses associated with energy conversion process from any energy to electrical energy .These losses plays an important role in determining the cost of electrical machine in general and motor particularly. Here lies the relevancy of Permanent Magnet Motor which save at least some amount of energy or rather conserve some amount of fossil fuel indirectly for future generation.

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