Assortment Of Slot And Pole Relation For A Permanent Magnet Brushless DC Motor

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Abstract*: *Brushless DC motors are permanent magnet motors which are well known for their durability due to simplicity in design and high-speed capability. These types of Permanent motors are limited to few applications such as radiator fans, heater blower fan, water pump, etc. These motors are used for medium power appliances, and for high speed and higher efficiency. For BLDC it is preferable to adopt fractional slot concentrated winding. With the fractional slot concentrated winding for any electrical machine having radial air gap there are many advantages such as reduction in copper, Joule losses are decreased there by improving efficiency. For having a balanced winding the EMF amplitude, shape and relative phase has to be met. This paper presents the possible combinations of slots and poles, winding coefficient which determines the motor performance, winding configuration for a three phase brushless dc motor and design calculations for a particular application.

Index Terms*: *BLDC motor, Efficiency, Winding, Slots, Poles.

I. INTRODUCTION

BLDC is a permanent magnet motor which is well known for its durability due to simplicity in design and because of its high-speed capability. There are two types of BLDC motors; they are inner rotor motor and outer rotor motor. They are more efficient because of the absence of commutator and brushes, it requires less maintenance and smaller in size. They are limited to certain applications only such as radiator fans, heater blower fan, water pump and especially where available volume is less.

Brushless permanent magnet motors have an even number of poles and any number of slots. But one cannot assign any number of slots for the desired number of poles; there are a certain combination of slots and poles which lead to efficient torque production. The motor performance depends on the winding coefficient (i.e. winding coefficient is the performance indicator of a motor). The range of winding coefficient is unity or less than unity [1]. The performance of the machine depends upon winding coefficient. For a BLDC motor fractional slot concentrated winding is preferred. With the concentrated winding, one can reduce the volume of copper required at the end windings; Joule losses are decreased so that the efficiency will be increased [2]. For having a balanced winding, the EMF amplitude, shape and relative phase between all phases (120 degrees electrical) has to be met. The amplitude and shape of the phase back EMF's will be identical if the coils in each phase have the same number of turns and the same coil span and are distributed in the same way around the stator. The back emf of each phase should be 120 degrees electrical.

The limitations of the various papers presented in the literature are they confined to a particular application like Electric Water Pump [5], Centrifuge [7], electric power steering (EPS) [9], kick scooter [10], and applications. But in general there are different types of loads like constant load, varying load and some positioning applications. These loading conditions are not taken into consideration in the literature. In the present paper we proposed a generalized design strategy applicable to various applications along with performance analysis (SPP, SPP/Ph and KW) by considering temperature rise.

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II. DETERMINATION OF WINDING STRUCTURE

A. Selection of Slots for a given number of Poles

Brushless permanent magnet motors have an even number of poles and any number of slots. But one cannot assign any number of slots for the desired number of poles; there are certain combination of slots and poles which lead to efficient torque production. If the slots are not selected properly, then all slots will not be filled with the two coil sides which is an undesirable condition [3]. Initially, the numbers of rotor poles are selected based on the operating speed and the external rotor diameter for a required application. For having high winding factor and higher motor performance, the number of slots should be close to the number of poles. But it is difficult to have a poly-phase structure with some slots equal to a number of poles.

The various combinations of slots and poles for a balanced winding are determined by

$$3k = \frac{S}{HCF(s, 2P)} \tag{2.1}$$

Where s is the number of slots, p is a number of poles and k is any positive integer.

Procedure to check whether the assumed number of slots are satisfied for given poles or not

The given number of poles is 2. Now let the number of slots be 2.

First check for K=1

HCF of (2, 2) =1; Equating the respective values in Equation-1, we have 1≠3.

Similarly, check for any value of K then LHS≠RHS. Hence for 2 poles it is not efficient to have 2 slots.

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Now let us consider that the number of slots be 3.
For k=1;
HCF of (3, 2) =1; Equating the respective values in Equation-1-1 we have 3=3. Hence for 2 poles, one can have 3 slots for having efficient torque production.
The number of slots per pole per phase is given as

$$3k = \frac{S}{HCF(s, 2P)} \quad (2.2)$$

If the number of slots is almost close to number of poles then the motor performance will be more efficient i.e. (s = p±1; s = p±2; s = p±3).
Where SPP is slots per pole per phase and Mph is the number of multiple phases.
In general, one cannot go with all combinations because some combinations will be less efficient. In order to select the best combinations, we have to find the winding coefficient for all the combinations. The value which gives the high factor will be selected.

B. Determination of Winding Coefficient

The winding coefficient is the ratio of a fundamental component of magnetic flux embraced by a coil to the total magnetic flux per pole. It is denoted as K_w. This coefficient is used for determining the efficient winding armature of a motor. It is the performance indicator of a motor. The range of Winding coefficient is unity or less then unity [4]. Coefficient must be near to unity to maximize the no-load emf amplitude with the lowest number of turns. If the winding coefficient is nearer to unity then the motor yields better performance

In order to determine the winding coefficient, initially, the ratio of number of slots to the number of poles is considered. From the winding coefficient versus slots per pole plot, one can determine the corresponding winding factor value for the ratio of number of slots to the number of poles.

Winding Co-efficient (K_w) = K_d * K_p (2.3)

Where K_d is distribution factor and K_p is pitch factor

Let the distribution factor K_d=1. The value of K_P is selected on the basis of ratio of slots to pole ratio.

Case (i): For number of slots > number of poles

$$K_P = Cos \frac{\left(180 - \frac{180}{\frac{S}{P}}\right)}{2} \quad (2.4)$$

Case (ii): For number of slots < number of poles

$$K_P = Cos \frac{\left(\frac{180}{\frac{S}{P}} - 180\right)}{2} \quad (2.5)$$

Case (iii): For number of slots = number of poles

The value of K_p is zero.

From fig. 2.1, one can observe that the structure which offers the best winding coefficients have number of slots close to the number of poles. Generalized way of determining the slots for having higher winding coefficient is s=p±1; s=p±2; s=p±3.

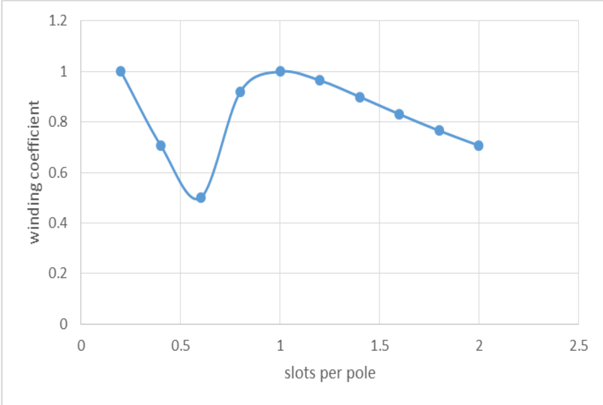

Fig. 2.1. Variation of winding coefficient with slots per pole

C. Winding Configuration

After selecting number of slots, poles and winding coefficient is to be fixed for the winding configuration. For a BLDC motor fractional slot concentrated winding is generally preferred. With the concentrated winding one can reduce the volume of copper required at the end windings, joule losses are decreased there by improving the efficiency. For having a balanced winding, the EMF amplitude, shape and relative phase between all phases (120 degrees electrical) has to be met [5]. The amplitude and shape of the phase back EMF's will be identical if the coils in each phase have the same number of turns and the same coil span and are distributed in the same way around the stator [6]. The back emf of each phase should be 120 degrees electrical [7].

The winding configuration involves the following steps:
Step 1: The SPP (slots per pole per phase) is reduced to a fraction of two non-divisible Integers x and y.
Step 2: For determining the layers (i.e. first and second layer) take two values namely 0's and 1's.
Step 3: From the ratio of (x/y), Integer 'y' has 0's and 1's where the number of 1's is equal to the integer 'x'.
Step 4: Then initial repeatable sequence of 0's and 1's are composed.
Step 5: Then this sequence arranged in an optimal way.
Step 6: Then this optimal repeatable sequence is reproduced for x times.
Step 7: Then the general phase sequence AC'BA'CB' is assigned to the whole sequence. First of all phase A is Obtained then after 120ºE phase B is taken followed by phase c 120º E from phase B. Then it said to have relative phase sequence, for having a proper balanced winding. The A', B' and C' are for return Conductors. The A' will 180ºE to the A phase. Similarly B' and C' are 180ºE to B and C phase respectively.
Step 8: The conductors associated to 1's are chosen for first layer of the winding.
Step 9: Then the second layer is obtained by reproducing and shifting the initial layer by a tooth or slot width.

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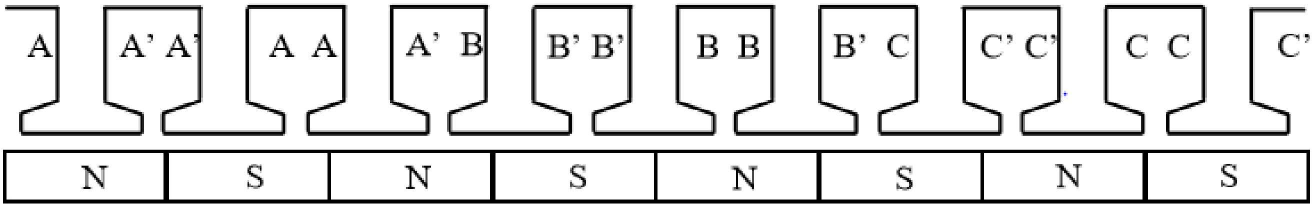
D. Determination of concentrated winding of a three phase machine with 27 slots and 24 poles

Step 1: -	S_{pp} =27/ (3*24) = 3/8
Step 2: -	Initial repeatable sequence: **0 0 0 0 0 1 1 1**
Step 3: -	Optimal repeatable sequence: **1 0 0 1 0 0 1 0**
Step 4: -	**1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0**
Step 5: -	**A C’ B A’ C B’ A C’ B A’ C B’ A C’ B A’ C B’ A C’ B A’ C B’**
Step 6: -	**A A’ A B B’ B C C’ C**
Step 7: -	**A’ A A’ B’ B B’ C’ C C’**
Step 8: -	



III. PERFORMANCE ANALYSIS

The possible SPP, SPP/Ph and K_W combinations of various number of poles and number of slots have been analyzed for a Particular motor. The possibility of the combinations along with the design parameters like SPP, SPP/Ph and K_W are presented in table 3.1.

Table 3.1: Performance analysis of BLDC machine for various slots and poles combinations

P/S	**2**	**6**	**12**	**24**	**32**	**40**	**48**	**Remarks**
3	1.5 0.5 0.866	Not Possible	Not possible	Not possible	0.09375 0.03125 0.866	0.075 0.025 0.866	Not possible	SPP SPP/Ph K_W
9	4.5 1.5 0.365	1.5 0.5 0.866	0.75 0.25 0.866	0.375 0.125 0.866	0.28125 0.09375 0.6427	0.225 0.075 0.6427	0.1875 0.0625 0.866	SPP SPP/Ph K_W
18	9 3 0.132	3 1 0.5	1.5 0.5 0.866	0.75 0.25 0.866	0.5625 0.1875 0.328	0.45 0.15 0.328	0.375 0.125 0.866	SPP SPP/Ph K_W
27	13.5 4.5 0.116	4.5 1.5 0.365	2.25 0.75 0.617	1.125 0.375 0.945	0.84375 0.28125 0.902	0.675 0.225 0.727	0.5625 0.1875 0.328	SPP SPP/Ph K_W
33	16.5 5.5 0.095	Not possible	Not possible	Not possible	1.031 0.34375 0.9988	Not possible	0.6875 0.229 0.7557	SPP SPP/Ph K_W
42	21 7 0.0747	Not possible	Not possible	Not possible	1.3125 0.4375 0.9308	1.05 0.35 0.953	Not possible	SPP SPP/Ph K_W
54	27 9 0.058	9 3 0.132	4.5 1.5 0.365	2.25 0.75 0.6427	1.6875 0.5625 0.802	1.35 0.45 0.878	1.125 0.375 0.945	SPP SPP/Ph K_W

IV.CONCLUSION

This paper presents the design and performance data of machine for the direct-drive propulsion system. The machine has been specifically designed to meet the requirements. From the above analysis the different numbers of slots and poles combinations are determined. If the number of slots is almost close to number of poles then the motor performance will be more efficient i.e. (s = p±1; s = p±2; s = p±3). The Winding coefficient is the performance indicator of a motor. If the winding coefficient is nearer to unity then the motor yields better performance. The range of winding coefficient is 1 or less than 1. In general for a BLDC motor one can prefer fractional slot concentrated winding. In order to have balanced winding the EMF amplitude, shape and relative phase of all phases must be met.

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