Research Paper

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Optimization of Pmbldc Motor

Engineering

KEYWORDS : SUBERMISIBLE MOTOR, PMBLDC MOTOR, Speed, air gap magnetic flux density, efficiency

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ABSTRACT

Thispaper deals with a method of design of permanent magnet brushless dc machine (BDCM), primarily aimed for subermisible motor applications. The design variables such as airgap flux density, slot electric loading, stacking factor, coil fill factor, end turn coil factor, magnet fraction, slot fraction, flux density in the stator back iron, etc., are used in design process. The simplified design equations for trapezoidal back emf motor of rating 45w, 2900 rpm, 12 V(D.C.) radial flux surface mounted BDCM are obtained. Since the motor is for high current and low voltage application so water cooling is used

Introduction

A. Definition (Brushless dc motor)

"A motor having stator (armature) windings and a permanent-magent (PM) or salient-pole soft-iron rotor. The stator windings are supplied from a solid-state switches, which are controlled by rotor shaft position sensors and logic. In the absence of a regulator, the motor speed is approximately proportional to the primary d.c. voltage." **(A. Kusko, Fellow, IEEE S.M. Peeran, Member, IEEE)**

B. Early history of PM Excitation systems:-

The first PM excitation systems were applied to electrical machines as **early as the 19th century**, e.g., J. Henry (1831), H. Pixii (1832), W. Ritchie (1833), F. Watkins (1835), T. Davenport (1837), M. H. Jacobi (1839).

Of course, the use of very poor quality hard magnetic materials (steel or tungsten steel) soon discouraged their use in favour of electromagnetic excitation systems. ***The invention of Alnico in 1932 revived PM excitation systems;*** however, its application was limited to small and fractional horsepower d.c. commutator machines.

C. Theoretical Aspects of PMBLDCM :-

Brushless motor drives fall into the ***two principal classes*** of sinusoidally excited & square wave (trapezoidally excited) motors.

The equivalent block diagram of a commutatorless d.c. motor:-

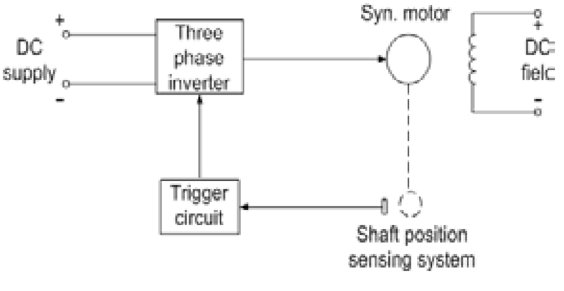

Fig-2: Brushless DC motor

Only two phase windings out of three conduct current simultaneously. Such a control scheme or electronic commutation is functionally equivalent to the mechanical commutation in d.c. motors. So the motors with square wave excitation are called d.c. brushless motors.

PM d.c. brushless and a.c. syn. Motor designs are practically the same: with a polyphase stator and PMs located on the rotor. The only difference is in the control and shape of the excitation voltage: an ac synchronous motor is fed with more or less sinusoidal waveforms which in turn produce a rotating magneticfield.

In **PM d.c. brushless motors** the armature current has a shape of a square (trapezoidal) waveform, ***only two phase windings (for Y connection) conduct the current at the same time*** and the switching pattern is synchronized with the rotor angular position **(electronic commutation).**

II SELECTION OF PMBLDC MOTOR

Therefore, we **select** brushless d.c.motor with permanent-magent for submersible pump application.

Due to their ***high efficiency and power density***, ***high speed permanent magnet*** brushless machines are emerging as a key technology for applications as spindle drives, compressors, ***pumps,*** gas turbine micro-generators, and electrical hybrid vehicle traction systems.

Permanent magnet synchronous machine is a good candidate for most of the future industrial applications due to their distinct advantages over induction machine. They are usually more efficient because of fact that the field excitation losses are eliminated. In additional , copper losses in general are reduced in PM machines compared to conventional machines.

In other words, due to lower losses, heating of the PM machines will be less, which can result either run the machine at lower temperatures or to increase the shaft power so that the maximum allowable temperature has been reached.

The use of PM brushless motors has become a ***more attractive option*** than induction motors.

III METHODOLOGY

- A. Design Three-Phase Inverters
- B. Design of Stator & Rotor (PMBLDC Motor) :-
- Assume basic design considerations.
- 1) Sizing procedure and main dimensions:-
- Select type of permanent magnets (SmCo).
- Select properties of permanent magnets (Br, Hc).
- Assume the air gap magnetic flux density (Bmg), stator line current density (Am), no-load EMF to phase voltage ratio (ε) .
- Find the output coefficient (i.e. $D^2$1inLi value).
- Find the estimated volume of PMs & actual volume of PMs.
- Find the no. armature turns per phase (N1), no of slots, type of winding and the current density in armature winding (Ja).

2) Motor Efficiency (η):-

- Find armature winding resistance & armature winding losses.
- Find the flat-topped value of the current in the armature phase winding according to equation Ia(sq).
- Calculate the stator slot pitch (t1), the width of stator tooth (c1t), the magnetic flux density in stator teeth (B1t), the height of the stator yoke (h1y) & the magnetic flux

density in the stator yoke (B1y).

- Calculate the mass of the stator teeth & yoke and the stator core losses due to harmonic.
- Find friction & windage losses.
- Finally find motor efficiency (η).

IV DESIGN CALCULATION

Rating of PMBLDC Motor :-

1) D.C. Voltage :- 12 V
2) Power :- 45 W
3) Speed :- 2900 R.P.M

A. Sizing procedure & Main dimensions :-

The rated armature current

$Ia = Pout \ \% \ (3V1\eta cos\varnothing)$

$= 45 \ \% \ [3\times(12/\sqrt{3})\times0.75]$

$= 2.88$ A

The product $\eta cos\varnothing$ at rated load should be minimum 0.75.

The output coefficient **is,**

$\sigma = 0.5\ {}^2\pi kw1\ Am\ Bmg\ \eta\ cos\varnothing$

where kw1 (Wdg coefficient) = 0.96

$\eta\ cos\varnothing = 0.75$ (Assumed)

$\sigma = 0.5^2\ \pi\times o.96\times12{,}000\times0.75\times0.75$

$= 31{,}978$ Vas/m^3

The no-load EMF to phase voltage ratio has been assumed $\epsilon = 0.83$. Thus the product

$D^2 1inLi = Pout\ \epsilon/\ \sigma ns = (45\times0.83)/31978\times50 = 2.34\times10^{-5}\ m^3$ …(1)

Assuming $\alpha i = o.4$ the effective pole arc coefficient is

$bp = \alpha i = 0.4\times\pi D1in/2p = 0.628\ D1in$

Round poles: - Under these conditions it is possible to use round pole with square pole shoes. Therefore,

Length of pole = Width of pole shoes

$Li = bp$

$= 0.628\ D1in$

Take this value in equ. 1,

$D^2 1in\times0.628\ D1in = 2.43\times10^{-5}\ m^3$

$D^3 1in = 3.726\times10^{-5}$

$D1in = 0.0334\ m = 33.41\ mm \approx 33mm$ &

$Li = 0.628\times33 = 20.724 \approx 21mm$

stator diameter D1in = 33 mm ,

the effective stator length Li = 21 mm

The no. of armature turns per phase can be roughly chosen on the basis of the assumed line current density & armature current,

$N1 = Amp\ \%\ (m1\sqrt{2}\ Ia)$

$= 12{,}000\times1\times0.0518/(3\ \sqrt{2}\times2.88)$

$= 50.90 \approx 52.$

Total no of stator slots $S = 3ptq = 3\times2\times2 = 12$,

where, slot/pole/phase (q) = 2 & pt = total no of poles

Total no of stator conductors = 6 N1 = 6×52 = 312.

Conductors per slot (Zs) = 312 % 12 = 26.

A double layer winding (lap wdg with diamond coils) located in 12 stator (armature) slots. Two parallel conductors with their diameter da = 0.5 mm have been chosen.

B. Motor efficiency(η):-

τ The value of length of mean turn of the armature is,

$Lmts = 2Li+2.5+0.06kv+0.2$

where2.5 +0.06kv+0.2 represent length of overhang.

$Lmts = 2\times0.021+2.5\times0.0518+0.06\times0.012+0.2$

$= 0.3772$ m

The cross section of the armature conductor,

$sa = \pi\times d^2\ \%\ 4 = \pi\times0.5^2\%4 = 0.1963$ mm.

The ***skin effect*** in the stator winding wound with a round conductor of small diameter can be ***neglected***. Thus,the armature winding resistance at 75°c,

$R1 = R1dc = (N1/a)\ \rho\ Lmts/sa$

where $\rho = 0.021$ for copper at 75°c.

$= (52/2)\times0.021\times(0.3772/0.1963)$

$= 1.0355\ \Omega$

C. ***The flat-topped value of the current*** in the armature phase winding,

$Ia(sq) = \sqrt{(3/2)}\ Ia = \sqrt{(3/2)}\times2.88 = 3.527$ A.

The losses in the three-phase wdg ***due to 120° square wave current*** are **(star connection),**

Δ **Pa** = 2 R1dc $[Ia(sq)]^2$ = **8.58 w.**

The armature winding losses (***Neglecting skin-effect***),

Δ **Pa** = m1R1dc Ia^2 = **8.58 w.**

[With both equations we get same losses]

The stator slot pitch,

$t1 = \pi D1in\ /\ S = \pi\times33/12 = 8.639$ mm

The width of the stator tooth

$c1t = \pi\ (D1in+2h14+b12)\ \%\ z1 - b12$

$= \pi\ (33+2\times0.7+3.0)\ \%\ 12 - 3.0$

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$= 6.79$ mm

D. magnetic flux density in the **stator teeth**,

$B1t = (Bmg \times t1) \% (c1tki)$

where ki = stacking coefficient = 0.96

$B1t = 0.75 \times 8.639 \% (6.79 \times 0.96)$

$= 0.994$ T

The height of stator tooth

$h1t = 0.5b11+h11+h12+0.5b12+h14$

$= 0.5 \times 4.8 + 9.5 + 0.4 + 0.5 \times 3.0 + 0.7$

$= 14.5$ mm

Stator core: - The value of depth of core (dc) can be calculated by assuming a suitable value of density Bc. The value of flux density in the armature core lies between 1.0 to 1.2 wb/m^2.(Here Bc = 1.2 wb/m^2)

Depth of armature core $dc = \Phi / (2Li\ Bc)$

$dc = 3.263 \times 10^{-4}/(2 \times 0.021 \times 1.2)$

$= 6.475$mm

Outer diameter os stator

$D1out = D1in + 2(dc + h1t)$

$= 33+2(6.475+14.5)$

$= 74.95$mm

The height of stator yoke,

$h1y = 0.5(D1out - D1in) - h1t$

$= 0.5(74.95-33)-14.5$

$= 6.475$ mm

The excitation flux (square-wave flux)

$\Phi f\ (sq) = Bmg \times bp \times Li$

$= 0.75 \times 0.021 \times 0.021$

$= 3.31 \times 10^{-4}$ Wb

E. The magnetic flux density in the **stator yoke**,

$B1y = \Phi f_{(sq)} / (2h1yLiki)$

$= 3.31 \times 10^{-4} / (2 \times 6.475 \times 10^{-4} \times 0.021 \times 0.96)$

$= 1.2688$ T

The mass of the stator teeth,

$m1t = 7700c1th1tLikiz1$

$= 7700 \times 6.79 \times 10^{-3} \times 0.0145 \times 0.021 \times 0.96 \times 12$

$= 0.283$ kg

The mass of the stator yoke,

$m1y = 7700\pi\ (D1out-h1y)\ h1yLiki$

$= 7700\pi\ (0.07495-6.475 \times 10^{-3})6.475 \times 10^{-3} \times 0.021 \times 0.96$

$= 0.216$ kg

F. ***The stator core losses due to fundamental harmonic,***

$[\Delta PFe]\ n=1 = p1/50\ (f/50)^{4/3}\ [kadtB^2 1tm1t + kadyB^2 1ym1y]$

where, kadt =1.7 to 2.0 for teeth =1.7 (assumed)

kady = 2.4 to 4.0 for yoke = 2.4 (assumed)

$\Delta\ [PFe]\ n=1 = 2.4(50/50)^{4/3}\ [1.7 \times 0.994^2 \times 0.183 +$

$2.4 \times 1.268^2 \times 0.216]$

$= 2.738$ w

Losses for nonsinusoidal current,

$$\Delta PFe = \sum_{n=1}^{n=13} P1Fen = |\Delta P1Fe|n=1 \sum_{n=1}^{n=13} (v1n/v1r)^2\ n^{-0\cdot 7}$$

Only harmonics n= 5,7,11 &13 will be included. The higher harmonic stator core losses can approximately be evaluated on the assumption that the rms value of the fundamental harmonic voltage V1,1≈ V1 = 12 v and higher harmonics rms voltage are,

$V1,5 \approx 12/5 = 2.4$ v, $V1,7 \approx 12/7 = 1.71$ v,

$V1,11 \approx 12/11 = 1.09$ v, $V1,13 \approx 12/13 = 0.92$ v

$\Delta\ PFe = 2.738[(12/12)\ 1^{-0\cdot 7} + (2.4/12)\ 5^{-0\cdot 7} + (1.71/12)\ 7^{-0\cdot 7}$

$+ (1.09/12)\ 11^{-0\cdot 7} + (0.92/12)\ 13^{-0\cdot 7}]$

$= 3.097$ w

G. ***Friction & windage loss*** :- This loss depends upon type of construction, speed and rating of machine and varies between 0.2 to 0.8 per-cent of rating,

$\Delta PF+w = 0.3/100 \times 45 = 0.135$ w

Total loss $= \Delta Pa + \Delta PFe + \Delta PF+w = 11.453$ w

H. Efficiency (η) = output/Input

where Input = o/p + total loss

$= 45+11.453$

$= 56.453$ w

η **= 45/56.45 ≈ 80%**

Similary we find 4 pole,

η **= 45/57.721 = 77.96 ≈ 78%**

V. Design Sheet:-

Sr. No.	Quantity	Symbol	Value
1	Output	---	45 w
2	Connection	---	Y

Sr. No.	Quantity	Symbol	Value	
3	Speed	ns	50 r.p.s	
4	Inner diameter of the stator	D_{1in}	33 mm	
5	Outer diameter of the stator	D_{1out}	74.95 mm	
6	Effective length of the stator core	L_i	21 mm	
7	Stacking factor for stator core	k_i	0.96	
8	Number of turns per phase	N_1	52	
9	Number of poles	p_t	2	4
10	Number of stator slots	z_1	12	24
11	Slots per pole per phase	q	2	2
12	Height of permanent magnet	h_M	5.0 mm	5.0 mm
13	Width of permanent magnet	w_M	10 mm	50 mm
14	Length of permanent magnet	l_M	21 mm	21 mm
15	Diameter of stator conductor	d_a	0.5 mm	
16	Air gap magnetic flux density	B_{mg}	0.75 T	
17	Coercive force	Hc	700 kA/m	
18	Width of pole shoe	b_p	21 mm	
19	Thickness of pole shoe	d_p	1.0 mm	
20	Magnet materials	---	SmCo	
21	Efficiency	η	80 %	78 %

V CONCLUSIONS

The aim of the optimization procedure is to minimize the cost of the active material of the motor, while ensuring a rated power and high efficiency. It is proposed to optimize a PM motor using the PBIL with RSM. The PBIL does not optimize the performance characteristics directly, but uses polynomial fits of the performance characteristics of the motor, created using RSM.

The motor's characteristics are calculated using FEM and classical machine theory for a number of combinations of input parameters. Fig. shows the logic sequence followed by the control program. The output characteristics and input parameters are used to fit polynomial equations of second order to every output characteristic. These polynomials are used as objective functions and constraints in the PBIL optimization.

The following simplifications are made for the FEM:(a) the end leakage reactance is calculated using classical theory since it would be very difficult to calculate using a two-dimensional FEM; (b) the induced EMF and inductive reactance are assumed constant throghout the load range, and equal to the value obtained at rated current; (c) the model is independent of rotor position.

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