A study on the optimal design of BLDC Slot-less PM motor using Response Surface Method

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Background

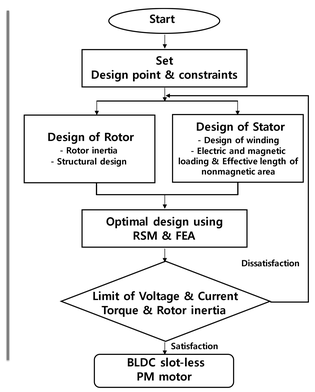
Permanent magnet (PM) motors, which are capable of precise control with wide operation range and high power density, are widely used in various industrial fields such as automobile, aerospace, homeappliance, defense industry and so on. Especially, because slot-less motor has no teeth and their corresponding slots, it has a variety of electromagnetic and structural advantages compared to the slotted motor. In this paper, the electromagnetic characteristics of the BLDC slot-less PM motor are analyzed by Finite Elements Analysis(FEA). Furthermore, the optimal design of BLDC slot-less PM motor is conducted with Response Surface Method(RSM) and 3-Dimensional FEA(3-D FEA) to satisfy the requirements of a driving motor of guided weapon

Conclusion

- ❖ BLDC slot-less PM motor for driving a wing of guided weapon is designed using FEA and RSM
- ❖ Satisfy the required electromagnetic output characteristics within the design constraints
- ❖ Reduce the inertia of the rotor to have the rapid response for forward and reverse rotation
- ❖ Verify the effectiveness of the study in this paper by the experimental tests with the prototype

Introduction

- ❖ Slot-less PM motor has no teeth and their corresponding slots, it has considerable advantages compared to the slotted motor.
  - * No cogging torque * Compact design * Low iron loss
  - * Smooth motor running even at low speed
  - * Less vibrations and audible noise
  - * No saturation effects in the iron core
  - * Uniform output characteristics and so on
- ❖ In this paper, BLDC slot-less PM motor for driving a wing of guided weapon is designed using FEA and RSM to not only satisfy the required electromagnetic output characteristics within the design constraints but also reduce the inertia of the rotor.
- ❖ Finally, the validity of the design method and output characteristics of the BLDC slot-less PM motor is verified through the experimental tests with the prototype.



❖ **Specification & Constraint of design**

* Required Torque at the rated speed : over 20 [mNm]
* Required Inertia of rotor : under 3 [gcm^2]

Content	Value	Unit
Rated Speed	5,000	rpm
Torque	over 20	mNm
Voltage	24	V_{dc}
Limit of current	1.2	A_{peak}
Size	22Φ ×32	mm

EQUATIONS

❖ **Calculation of rotor inertia**

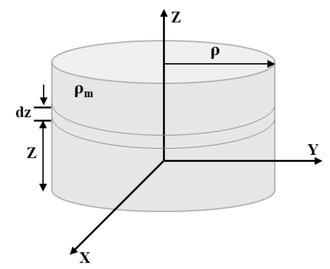
$$dm = \rho_m (d\rho)(\rho d\varphi)(dz) = \rho_m \rho d\rho d\varphi dz$$

$$dI = \rho^2 dm = \rho_m \rho^3 d\rho d\varphi dz$$

$$I = \int dI = \int_0^h \int_0^{2\pi} \int_0^r \rho_m \rho^3 d\rho d\varphi dz$$

$$= \rho_m \int_0^r \rho^3 d\rho \int_0^{2\pi} d\varphi \int_0^h dz = \frac{M}{\pi r^2 h} \frac{r^4}{4} 2\pi h$$

$$= \frac{1}{2} M r^2 [kg \cdot m^2]$$



❖ **Calculation of magnetic torque**

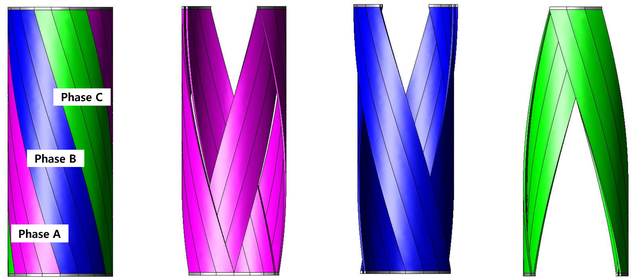
$$T = \left(\frac{\pi}{4} k_w \hat{B}_{g1} ac \cos\beta \right) D_g^2 L_{stk} [Nm]$$

Design of BLDC Slot-less PM motor

Design of winding

❖ **Design of winding for BLDC slot-less PM motor**

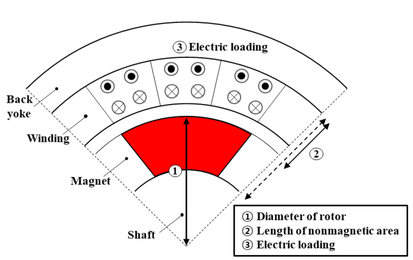
* Faulhaber (called skewed-winding), rhombic and diamond winding are the typical winding methods of the slot-less motor.
* The winding of the stator is designed with the skewed-winding (Skew angle: 90 deg)

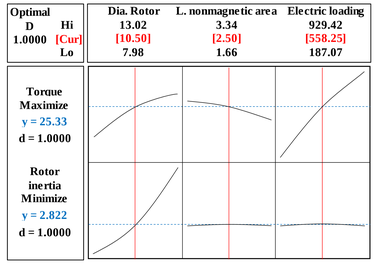


Optimal design with RSM

❖ Optimal design of BLDC slot-less PM motor with RSM

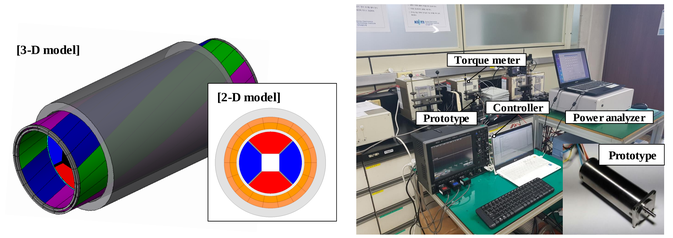
* The objective functions of RSM :
  (1) Average torque (over 20mNm) (2) Rotor inertia (under 3gcm^2)
* Design parameters : (1) Dia. rotor (2) Length of nonmagnetic area (3) Electric loading
* Result : Dia.rotor 10.5 [mm], Length of nonmagnetic area 2.5 [mm],
  Electric loading 558 [Ampere conductor]





Final model of slot-less motor

❖ **Final model of BLDC slot-less PM motor**



Content	Value	Unit
Rated Speed	5,000	rpm
No-load back EMF	7.02	V
Load torque	25	mNm
Torque constant	38.12	mNm/A

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