DEVELOPMENT OF A SLOTLESS TUBULAR LINEAR INTERIOR PERMANENT MAGNET MICRO MOTOR FOR ROBOTIC APPLICATIONS

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Introduction

Compared to pneumatic or rotary-motor based drives, linear motors show a significant advantage in terms of efficiency, thrust control, position accuracy, and system volume [1]. In addition, permanent magnets are used in the linear motors, obtaining high force-to-volume ratios and high drive performance. This paper presents the development of a slotless tubular linear interior permanent magnet (TLIPM) micro motor for drive application in micro robots. Important design criteria are established based on the results of both analytical and numerical methods. The flux density distribution in the air gap, the electromagnetic force, and the motor inductance etc. are analysed and predicted by the finite element analysis (FEA).

Motor Configuration Design

Fig.1 shows the basic configuration of the proposed TLIPM micro motor. The designed external diameter D_e of the motor is 7 mm. Due to the small external diameter, the slotless structure is selected for simplicity in construction and a better performance. The material of the permanent magnets used in this micro motor is NdFeB, and the material for the stator core is the Glassy Metal, an amorphous soft magnetic ribbon material, which features high permeability and extremely low core loss.

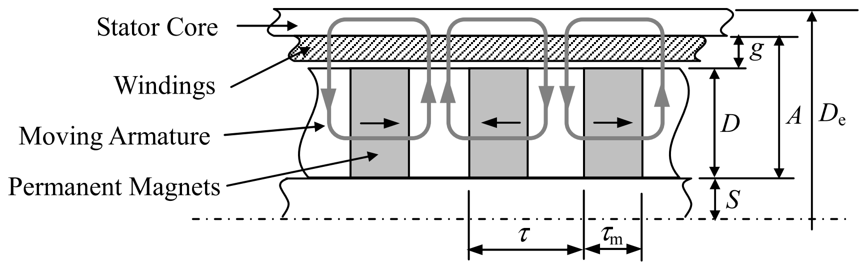

Fig.1 Configuration of the slotless TLIPM micro motor

In order to determine the suitable thickness of the PMs and the diameter of the moving armature, an analytical analysis is firstly performed. Under the assumption of infinite permeability of the iron core and ignoring the leakage flux, the magnetic flux in the air gap produced by the PM can be expressed as:

$$\phi_g = \mu_0 \pi H_c \tau_m / (4g/(2D+2S+g)(\tau-\tau_m) + \tau_m / D(D+2S)) \qquad (1)$$

where H_c is the coercive force of the PM material. From (1), it can be derived that ϕ_g will reach its maximum value when $\tau_m = \tau/2$. Based on the criteria, the produced electromagnetic force can be obtained by $F = BIL$. Further study shows that under the condition of a given motor volume (fixed values of A and τ), there exists an optimal ratio of g/D to achieve a maximum force or force-to-volume ratio. A 2D FE analysis considering the non-linear magnetic property of the iron core is also performed to verify the analytical results.

Flux Density and Force

Since the moving armature of the micro motor is deliberately designed shorter than the stator so that it can move back and forth within the stator, the distribution of the resultant flux density in the air gap varies with the position of the armature. Consequently, the produced electromagnetic force is also a function of the position of the armature. A 2D FE model is established to analyse the flux density in the air gap and the force is predicted under different armature positions. The results can provide an optimal current commutation scheme for the motor controller. Fig.2 shows the motor force at different armature positions.

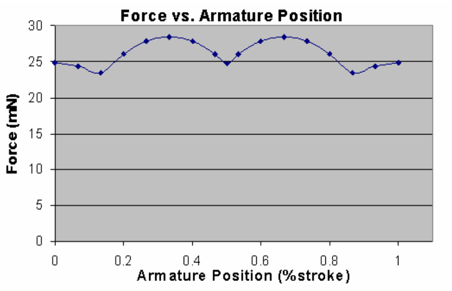

Fig.2 Motor force vs. armature positions

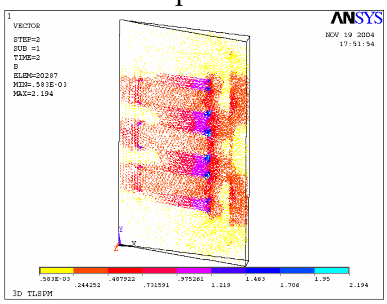

Fig.3 3D FE model of TLIPM with flux density distribution

Stator Winding Inductance

The stator winding inductance is one of the most important parameters for motor modelling, performance simulation and controller design. The energy method is used for computing the inductance. However, due to the tubular structure, it is difficult to use 2D FEA to calculate the stored magnetic energy, especially in non-linear case. Thus, a 3D FE model is applied to find out the magnetic energy generated by the stator phase current. During the analysis, both non-linear and saturation effects are considered to improve the accuracy of calculation.

Conclusion

The numerical simulation of the motor and its drive system shows satisfactory performance. Two prototypes of the motor are being constructed. Their parameters and performance will be tested and compared with the theoretical results. More detailed theoretical and experimental results will be reported in the full paper.

References

[1] N. Bianchi, S. Bolognani, F. Tonel, “Design Consideration for a Tubular Linear PM Servo Motor”, EPE Journal, Vol.11, No.3, Aug. 2001, pp.41-47