A Tubular Linear Motor for Micro Robotic Applications

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***Abstract*--** Linear micro motors play an important role in micro robotic systems. Compared to pneumatic or rotary-motor based drives, linear motors show significant advantages in terms of efficiency, thrust control, position accuracy, and system volume [1]. This paper presents the development of a tubular linear interior permanent magnet (TLIPM) motor for the actuation of micro robots. Important design criteria are established based on the results of both analytical and numerical methods. The performance of the micro motor as well as the entire actuation system are analysed and predicted by the finite element analysis (FEA) and kinetic modelling.

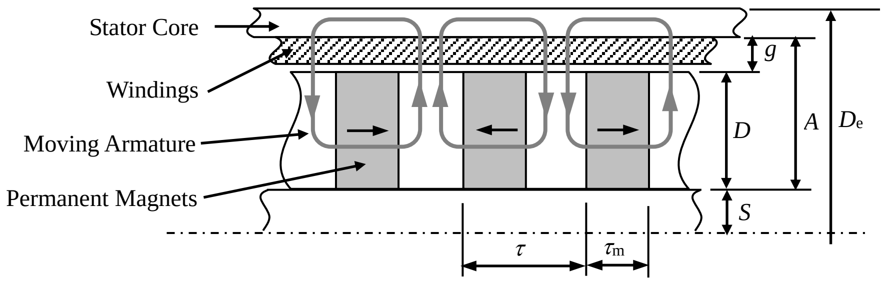

Fig.1 Configuration of the slotless TLIPM micro motor

Fig.1 shows schematically the basic configuration of the proposed TLIPM micro motor. The designed external diameter D_e of the motor is less than 8 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 and armature pole-pieces is the Glassy Metal, an amorphous soft magnetic ribbon material, which features high magnetic permeability and extremely low core loss.

In order to determine the suitable thickness of the permanent magnets 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, it can be derived that ϕ_g will reach its maximum value when $\tau_m = \tau/2$. Further study shows that under the condition of a given motor volume (with fixed values of A and τ), there exists an optimal ratio of g/D to achieve a maximum force or force-to-volume ratio.

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 range of the stator winding, 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. Based on the analysis of the distribution of flux density in the air gap at different armature positions, the produced magnetic force can be predicted. The results can provide an optimal current commutation scheme for the motor controller.

A self-locking mechanism is designed for unidirectional propelling of the actuator. It is a set of titled blade-like legs attached to the linear motor. It can be found that the friction backward is always larger than that of forward [2]. Under a certain condition, the friction backward will always counteract the force which makes the actuator move backwards. Thus, with the mechanism, the actuator is automatically locked in the backward direction and can only move forward.

Kinetic analysis is one of the important issues in the design of an actuation system. The analysis can provide fundamental kinetic performances of the system including forces, velocities and displacements, and improvement can be made to the original design if any of the key performances do not meet the requirements. An accurate kinetic model of the actuation system is essential for a kinetic analysis. The model of an actuation system can only be developed based on a good understanding of both the mechanical and electrical properties of the entire system.

Fig.2 illustrates schematically the mechanical structure of the actuator. A spring is applied between the stator and the armature of the linear motor for the initial relative position restoration and electrical energy saving. A model of the proposed linear actuation system is developed based on the good understanding of both the mechanical and electrical properties of the entire system.

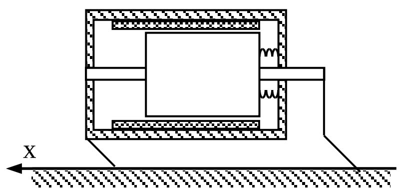

Fig.2 Mechanical system of the linear actuator system

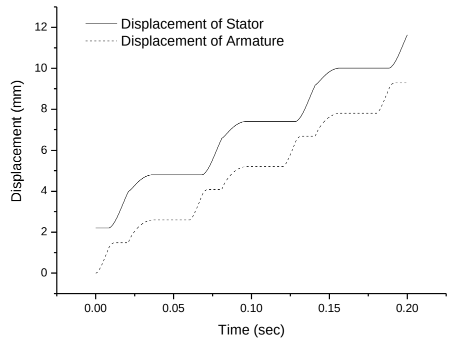

Fig.3 Movement of the linear actuation

The forces in the system include the magnetic force of the linear motor, elastic force of the spring, the frictions between the stator and armature, and the frictions between the legs and supporting surface. The magnetic force can be obtained by previous FE analysis and the other forces are determined by Hooke's Law and Coulomb's law of friction. Therefore, the kinetic state equations can be derived by Newton's Law, while the electrical state equation can be obtained by equivalent circuit of the linear motor. Based on the model derived, the performance of the actuation system can be studied by numerical simulation. A pulsating voltage is applied in the analysis, of which the duty cycle is determined by both the period of the power supply and position of the armature of the linear motor. Fig.3 shows the simulated results of displacement of the system. It is shown that the system can move forward swiftly and the kinetic performance is satisfactory. The performance of the prototype will be tested and compared with the theoretical results. More detailed theoretical and experimental results will be reported in the full paper.

References

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