The analysis of a novel transverse-flux linear oscillating actuator

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Abstract —This paper presented a successful design of a novel single-phase transverse-flux linear oscillating actuator (TLOA) with moving magnet, which can achieve high stability short reciprocating movement. Compared with available construction of LOA with moving magnet, the biggest advantage is easy to stack the stator iron which is similar to rotary motor. After its construction and operational principle are introduced, the thrust force is studied based on FEM model. Then some optimal parameters of structure are deduced. The predicted results are validated by experiment of prototype.

I. INTRODUCTION

The short-stroke reciprocating motion is required by a lot of small equipments such as air compressor, air condition, refrigerator and so on, so single-phase linear oscillating actuators (LOA) is adopted[1-2]. Among LOA's different types, permanent-magnet (PM) LOAs with moving magnet are particularly attractive due to their inherent high operation frequency and force capability. For example, LG of Korea developed this kind LOA to apply in a refrigerator [3-4]. Although its performance is fine, both inner and outer stator irons are difficult to be made because the lamination is stacked along radial direction or made by special soft magnetic composition material. In order to overcome this disadvantage, this paper presented a transverse-flux linear oscillating actuator (TLOA) which has similar stator lamination of normal rotate motor. Due to transverse-flux construction, it also has high thrust force density.

II. CONSTRUCTION AND OPERATIONAL PRINCIPLE

The presented TLOA is shown in Fig.1. It has two symmetrical outer stators which are same to rotate brushless motor with Ns=2p=6, which lamination is easy to be made. The inner stator is also used lamination and made in the same way. The six poles of PMs are fixed alternately on non-ferromagnetic bracket. The prototype is shown in Fig.2.

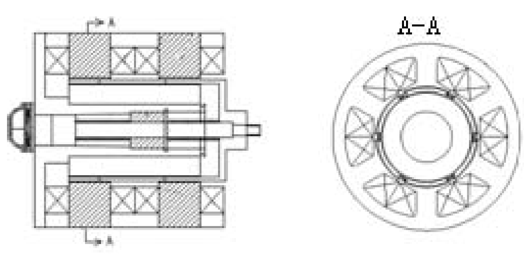


Fig. 1. Configuration of TLOA with moving magnet

When TLOA is static, the positions of permanent magnet are shown in Fig.1. If two windings are supplied with current by requirement, TLOA will produce the thrust force and let the mover oscillate. The operating frequency depends on the current frequency. When the operation frequency is equal to the system resonance frequency, TLOA has highest efficiency. Due to this TLOA with lower mover mass, its resonance frequency is much high.

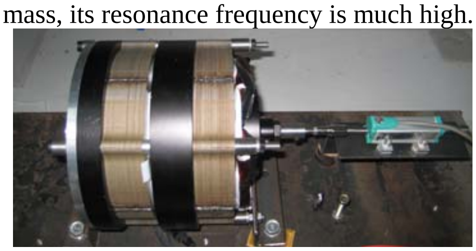


Fig. 2. The prototype photo of TLOA

Based on analytical method, the thrust force and back-EMF are expressed as follows

$$F_e = 2B_{av}N_1\tau \times i = k_i i \qquad (1)$$

$$E_0 = 2B_{av}N_1\tau \times v = k_i v \qquad (2)$$

Where B_{av} is average air gap flux density, N_s is one stator serial turns, K_i is the coefficient, τ is pole pitch. Apparently, the thrust force and back-EMF have same coefficient which depends on actuator construction parameter and air gap flux density. Therefore B_{av} and N_1 should be increased as possible in order to obtain high thrust force.

III. FINITE ELEMENT ANALYSIS

In order to analysis the air gap flux density and get optimal design, a 3D model is erected. The model only includes one pole pitch of stator on considering the symmetry. Based on the model, the air gap flux density B_g with different current is analyzed when mover in different positions. Fig.3 shows air gap flux density B_g with displacement s=0 and current i=2A. The B_g of left stator is decreased and that of right stator is increased due to input current, then the mover runs towards right. Along with the mover running, the B_g of right stator increases more.

In addition, the structure parameter of permanent magnet including length L_m, height h_m, pole arc ratio $\alpha_p = \tau_{pm}/\tau$ and split ratio $\alpha_s = R_s/R_r$ are optimized. Fig.4 shows predicted thrust force. Apparently, this prototype can produce thrust force over than 100N with current 2A. The thrust force linearly increases along with α_p until α_p =0.7, and then the increasing degree lowers. Therefore the optimal α_p is near 0.7.

The thrust force has two components. One is called detent force F_d which is caused by permanent magnet and stator iron. The other one is called electromagnetic force F_e

which is produced by supply current. Fig.5 shows these two components. F_d is very small during effective stroke and its average value is zero, which make F_e is not symmetrical during positive and negative displacement. It increases very quickly if the mover is out of design stroke. The main component F_c can keep constant as long as the mover operates in effective stroke.

The relationship between thrust force and different permanent magnet length L_m is shown in Fig.6. Permanent magnet L_m does not affect the thrust force without considering two ends, but affect the stroke *s*. That is to say, L_m is not only decided by two stator distance L_{ss}, but also affected by stroke *s*.. In order to guarantee constant thrust force during whole stroke, two design rules are deduced from magnetic field analysis. One is the stator stack length L_s should be over than *s*. The other is L_m should be between (L_{ss}+ 2*s*) and (L_{ss}+2L_s- 2*s*). To this TLOA, the available range of L_m is 55mm～75mm，so the prototype is chosen 63mm.

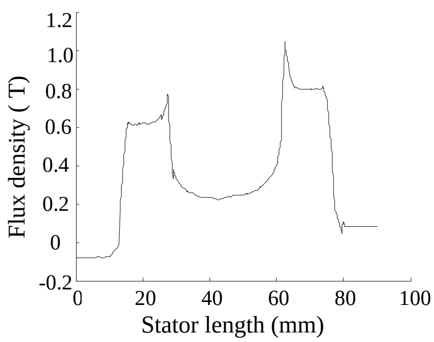


Fig.3. The air gap flux density distribution with *s*=0, *i*=2A

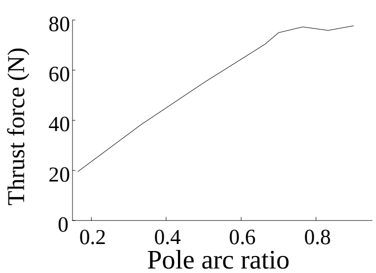


Fig. 4. The thrust curve under different α_p

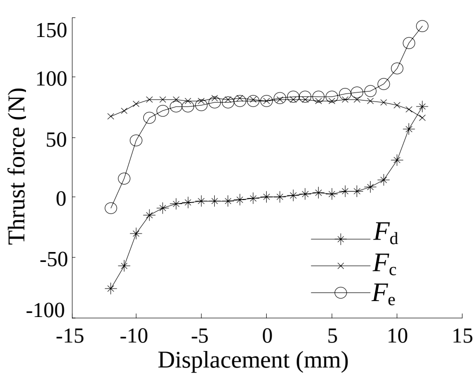


Fig. 5. Two components of thrust force

Fig.7 shows the static thrust force of FEM and experiment. The predicted FEM result is only a little bit lower than prototype measurement. The error increases with supply current which is caused by ignoring the iron loss in FEM model. The thrust force also linearly increases along with supply current, which is coincided with equation (1). The coefficient K_i is equal to 80.

The mass of mover is 0.7kg with aluminium bracket. With two springs of rate *K*=12.5N/mm, the resonant frequency is measured 30.5Hz at no load which is much higher than LOA with moving-iron or moving both iron and magnet. If the spring rate is increased and the mass of non-ferromagnetic bracket is lowered, the resonant frequency can be improved to the requirement value of refrigerator compressor.

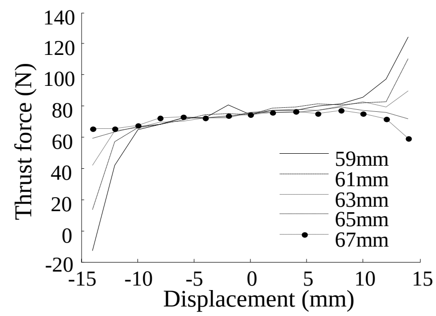
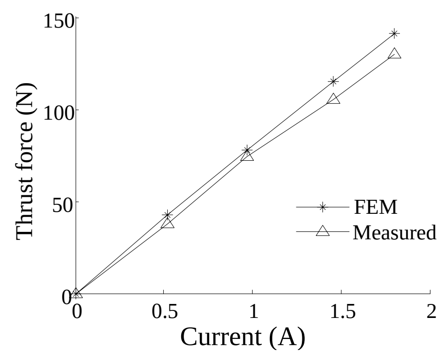


Fig. 6. The thrust force curve with different PM length L_m

Fig. 7. The thrust force curve with different current



IV. CONCLUSION

The presented TLOA with moving magnet has similar stator as rotate motor which is easy to be stacked. By FEM model, the thrust is analyzed and the parameters are optimized. Since its rotor only includes permanent magnets and a light non-ferromagnetic bracket, its resonant frequency is high. Therefore, it will have good applications in refrigerator compressor.

V. REFERENCES

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