Optimal Design of High Precision Planar Actuator with Halbach Magnet Array

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Abstract — An analytical method is presented to optimize the dimensions of a high precision planar actuator. As the distribution of the stator current have different contributions to the driving force but the heat loss due to these currents are same. It is reasonable to optimize the depth of the stator current sheet. The minimal of the heat loss and the maximal of the force density is proposed as the design objectives. Two analytical expressions are established to reveal the relationship between the design objectives and the electromechanical parameters. This design method is general to other coreless electrical motors or actuators because the basic principle of optimization is the same.

I. Introduction

The planar actuator shown in Fig.1 is designed for high precision instruments such as wafer steppers and surface profilometers [1]. Thus the optimal design of this actuator focuses on two goals. One of the objectives, also the most important objective, is to reduce the heat loss in order to avoid the deformation of the mechanical system. The other objective is to improve the force and energy density, because these instruments are usually small.

II. Structure and Basic Module

The planar actuator is consisted of four linear motors and each linear motor has a mover with Halbach magnet array and a multi-phase stator covered by armature coils. The multi-phase can be 2, 3, 4,…, or more phases. To simplify the analysis the linear motors can be divided into basic building modules shown in Fig. 2. Each basic module has one pair of stator and mover parts. The dimension optimization of basic module can be easily extended to the whole actuator because of the symmetry [2].

III. Ideas of the Optimal Design

The key to reduce the heat loss is to explore the heat sources, and then to optimize the related parts. The heat loss of this kind of actuator has three sources: the copper loss of the stator windings, the iron loss in PM mover, and eddy current loss in aluminum plate of the stator. The latter two kinds of losses are almost zero because the special structure and the constituent materials which will be discussed in the full paper. The copper loss which is generated by the stator current then is the major part of the heat losses. However, the magnetic field due to PM mover decays exponentially with the distance from the mover surface, thus the stator current in different depth produces different driving force but the loss contribution is the same. That is, with a certain mover dimension, the proper depth of the stator current sheet must be optimized.

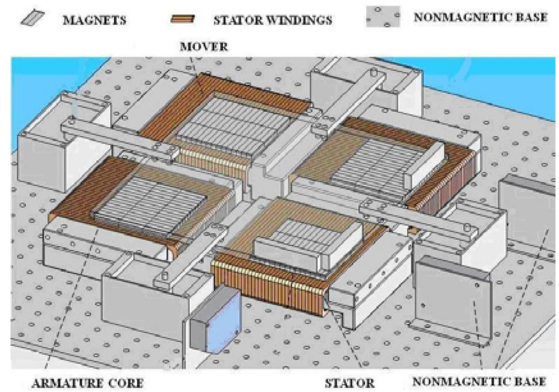

Fig. 1. Tri-dimensional view of the electromagnetic planar actuator

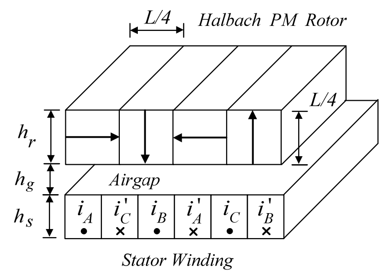

Fig. 2. Basic building module of the actuator

IV. Conclusions

An analytical expression, which is related to several electrical parameters and mechanical dimensions, to determine the copper loss with unit driving force is derived. This expression helps to choose the proper dimensions of the actuator. Fig. 3(a) shows the copper loss of an actuator basic module related to the depth of the stator and mover. Fig. 3(b) presents the graph of the copper loss of an actuator basic module with variable stator depth and several invariable mover dimensions. It is easily observed that an optimal ratio (stator depth / mover depth) about 0.7 to 1.1 is obtained.

To achieve the second optimal objective, another analytical expression is established to reveal the relationship between force density and electromechanical parameters. From the numerical calculation the optimal ratio about 1.1 to 1.8 is obtained, which is shown in Fig. 4(a), (b).

In conclusion, the two design objectives are satisfied simultaneously when the optimal ratio approximately equals to 1.1. This optimal design method can be easily extended to other kinds of coreless electrical motors or actuators, because the basic principle of optimization is the same.

In addition, a general design method of this kind of actuator using step by step design process will present in the full paper. This method provides a general and easy way to achieve special performance of this actuator.

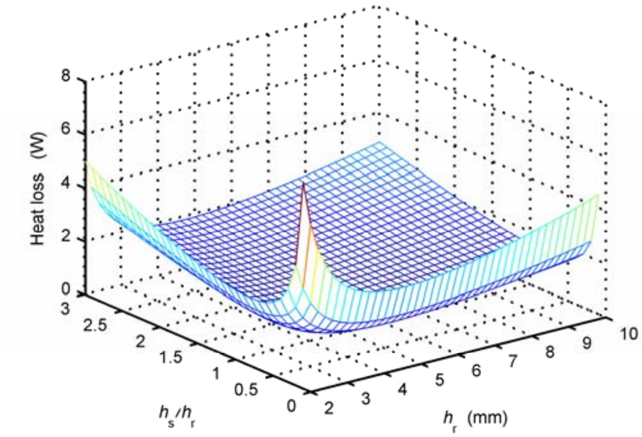

Fig. 3(a) Heat loss vs. depth of stator current sheet and depth of mover,

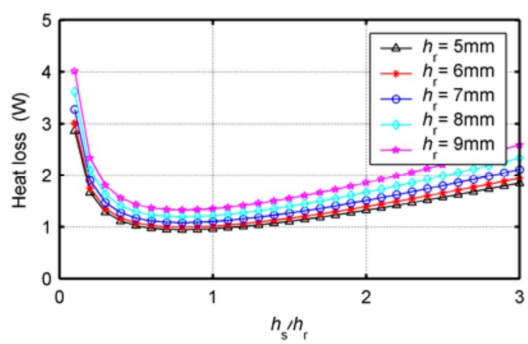

Fig. 3(b) Graph of the heat loss vs. the depth ratio (stator current sheet depth / mover depth)

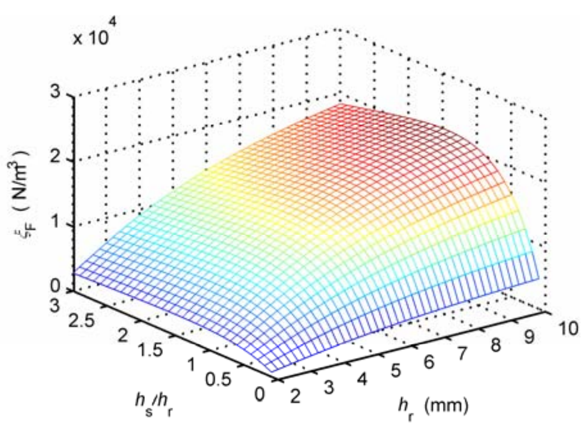

Fig. 4(a) Force density vs. depth of stator current sheet and depth of mover

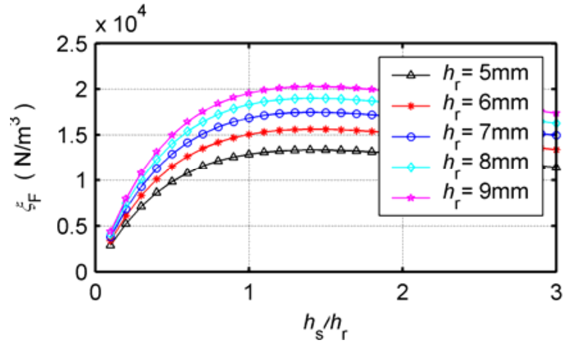

Fig. 4(b) Graph of the force density vs. the depth ratio (stator current sheet depth / mover depth)

V. REFERENCES

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