Multi-objective Optimization of Linear Proportional Solenoid Actuator

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Abstract **─** This paper employed a multi-objective Genetic Algorithm (GA) process to optimize the structure parameters of Linear Proportional Solenoid (LPS). And designed objectives include magnitude of static push force, stability of push force with displacement in working range and push force to mass ratio. A two-dimensional finite element analysis model is presented to reduce the large calculation time generated by GA process. The optimization process result of LPS shape parameters is obtained and the optimal LPS is manufactured. Through using a high-precision measuring device in the static push force test, a comparison result between conventional shape and optimal shape shows that the proposed optimization strategy is feasible.

Index Terms **─** Genetic algorithm, linear proportional solenoid, multi-objective.

I. INTRODUCTION

Electro Magnetic Actuators as the core component are widely employed in vehicle suspension system and engine, Inverter Compressor and many other pneumatic/hydraulic control systems. Meanwhile, due to the simple structure, high reliability, low cost and long stroke, Linear Proportional Solenoid (LPS) is the most essential electro-magnetic actuator. This paper aims to optimize the LPS used in proportional control valve. Generally, the optimization strategies of LPS are usually implemented by shifting the shape parameters [1-2]. With the improvement of computing power, the iterative algorithm become a growing interest of computational electromagnetics field, especially in industrial application. Plavec and Wu considered the dynamic performance as an important object of on/off Electro-magnetic actuators optimization [3-4]. Since the volume of Electro-magnetic actuators is an important condition, five main shape parameters are optimized to obtain the maximum electro-magnetic force in a specific valve volume [5].

In this paper, a shape design optimization process of LPS is presented by GA and finite element analysis method.

II. SIMULATION STRUCTURE

Generally, three-dimensional model can obtain a high accuracy magnetostatic simulation result. The three-dimensional simulation model and geometry structure definition of LPS is shown in Fig. 1. For reducing the computation time, it is necessary to employed a two-dimensional simulation model instead of three-dimensional model. Assuming that the magnetic flux density in soft magnetic material yoke is not fully saturated, the cubic three-dimensional structure LPS can be simplified by a two-dimensional axial symmetry shape model. In this two-dimensional model, we proposed a hypothesis that the yoke of simulation model has an equivalent radial cross-sectional area with actual LPS and the definitions of shape parameters are shown in Fig. 2.

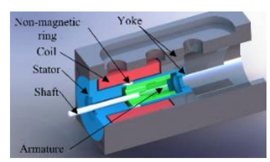

Fig. 1. Geometry structure definition of LPS three-dimensional simulation model.

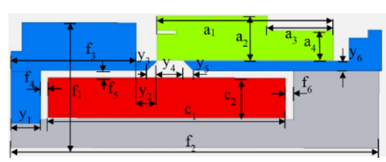

Fig. 2. Simplified LPS simulation two-dimensional model and design parameters.

III. MULTI-OBJECTIVE OPTIMIZATION METHOD

LPS shape optimization is a multi-objective issue, it focused on push force output efficiency, magnitude and stability of static push force in working stroke. To solve this optimization issue, a genetic algorithm tool is employed to obtain optimal shape parameters and a

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finite element model is established to calculate the magnetostatic force at each sampling position in working stroke. All these work are accomplished by ANSYS MAXWELL. And the following equation (1) shows the optimization fitness function:

$$\begin{aligned} fitness &= (F_{ex} - F_{AVG}) / F_{ex} \\ &+ F_D / F_{AVG} + (K_{ex} - F/m) / K_{ex} \end{aligned} . \tag{1}$$

Equation (1) include: average electromagnetic force-F_{AVG}, standard deviation of static electromagnetic force-F_D and average electromagnetic force to mass ratio of moving parts-*F/m*. In this paper, F_{AVG} is calculated by the average push forces of each sampling position in working stroke. It is used to evaluate the excitation force performance in coil rated current. And F_{ex}=170N is the expectation average force. F_D is used to evaluate the deviation degree of the push force at each sampling position. *F/m* represents the push force output efficiency. K_{ex}=1.8 N/g is the expectation force to mass ratio.

A genetic algorithm, which is 100 population size and 49 generations, is employed to solve this optimization problem and obtain the optimal shape design parameters. The iteration result is shown in Fig. 3. And the shape design parameter array can be defined by P{a1, a2, a3, a4, y1, y2, y3, y4, y5, y6, c1, c2}. The conventional shape design parameter array is {31.4, 7.40, 16.9, 3.55, 5.50, 3.70, 3.10, 3.90, 0.83, 2.30, 42.80, 8.20}, and the optimal shape design parameter array is {32.3, 7.65, 4.70, 5.15, 5.50, 3.75, 3.11, 4.12, 1.06, 2.32, 43.48, 7.36}. The unit of shape parameter is millimeter.

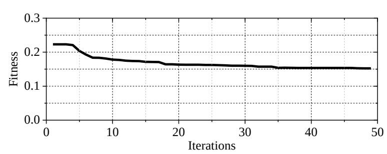

Fig. 3. Multi-objective GA optimization iteration result of LPS shape parameters.

IV. RESULT

LPS's static performance test device are shown in Fig. 4. For actual usage, the working stroke start from 3mm point and stop to 0.4mm. This paper measured several static posh force versus displacement curve in different coil excitation current, and the test result is shown in Fig. 5. In all excitation current, the optimal shape LPS shows the advantage of push force magnitude.

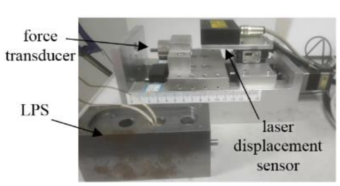

Fig. 4. Static performance test device of LPS and manufactured optimal shape LPS.

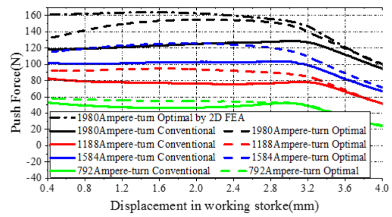

Fig. 5. Static push force measurement in specific coil exciting current.

V. CONCLUSION

Above all, a multi-objective GA optimization process of LPS is presented and the optimal shape design parameters in this process is manufactured. By the comparison of optimal LPS and conventional LPS in rated excitation current, average electromagnetic force is improved by 21.8%. Therefore, the above results can verify the validation of proposed optimization strategy.

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