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Modular magnetic levitation planar motors for long-stroke motion and full rotation

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Abstract

As the magnetic levitation planar motor is mostly designed for a single specific application, the parameters of the motor should be re-optimized once the requirement changed. A novel modular planar motor is proposed in this paper, which can target specific market niches by scaling the parameters of the modules in several dimensions and then by adding or substituting the modules. Then the structure of two basic modules, the magnet module and the coil module, are designed to guarantee the independence, extensibility and commonality of the modules. To make the module installation simple and efficient, a novel assembly method for the magnet array is proposed according to the analysis of the force between modules with a magnetic charge mode firstly. Subsequently, a thermal network model is built to assess the heat dissipation capability of the structure of the coil module. Finally, finite element method simulation and measurement are used to verify the proposed assembly method for the magnet array and the cooling structure of the coil module, respectively. The results of FEs and the experiment data validate the analysis and design.

Keywords: Modular magnetic levitation planar motor, magnet module, coil module, cooling system, magnet array assembly

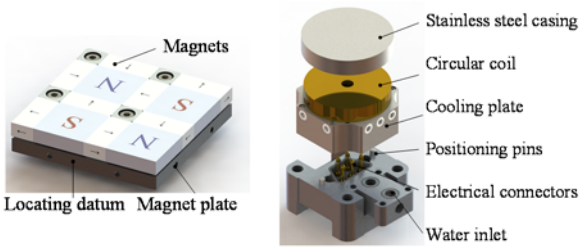
1. Introduction

The ironless magnetic levitation planar motor has been adopted for high-end applications such as the lithography tools for nanometre accuracy as its better dynamic performance. However, the stacked linear motors are still the preferred choice for other equipment in Integrate Circuit (IC) manufacturing for micrometre accuracy. Compared with the stacked linear motors, the planar motor can be more advantaged especially in both large-stroke movement along the x-and y-axis and full rotation around the z-axis, as mechanical support such as linear guideways or air bearing is not essential. Limits for universal applications of planar motors lie in the design complexity and the cost. Firstly, the planar motor are designed for applications with a specific load and acceleration requirement [1]. The parameters should be re-optimized if the performance specifications change. Secondly, the optimized parameter values of the planar motor are diverse, which makes the cost very high. What's more, the force between magnets makes the assembly of the magnet array difficult.

To solve the problem above, this paper proposes a modular magnetic levitation planar motor (MMLPM). Firstly, the definition of the MMLPM is presented and the criteria of motor design for diverse applications is described. Then the structure of two basic modules, the magnet module and the coil module is designed with the requirement of extensibility and independency. To make the module installation simple and efficient, a novel assembly method for the magnet array is proposed firstly. Subsequently, the heat dissipation capability of the coil module structure is analysed with a thermal network model. Finally, finite element method simulation (FEMs) and measurement are used to verify the proposed assembly method for magnet array and the cooling structure of coil modules, respectively.

2. Definition of the MMLPM

The MMLPM is a moving-magnet planar motor composed of magnet modules and coil modules, and can target specific market niches by scaling the parameters of the modules in several dimensions and then adding or substituting the modules. The magnet module includes 12 magnets and one magnet plate, as shown in Figure 1(a). The magnets are glued on the magnet plate and the whole magnet module can be mounted with screws. The four side faces of the magnet plate are the locating datum for assembly. Several magnet modules can constitute a two dimensional quasi-Halbach array. The coil module comprises one circle coil, cooling system, temperature sensor and standard location interface. The structure of the coil module is shown in Figure 1(b). The circular coil is adopted for motion along axes and full rotation around the z-axis. Figure 1(b) indicates that the module contains the interfaces of positioning, electrical connection, which are designed for independence, extensibility, and commonality. The coil module is powered by a linear amplifier and is switched during the movement of the translator. The coil is cooled by a cooling system, which is composed by the stainless steel (SS) casing, cooling plate and the water channel.



(a) Magnet module (b) Coil module

Figure 1. Structure of modules

Several product platforms of the MMLPM can be built by scaling the parameters of the modules into several dimensions. Then MMLPMs targeting specific market niches can be designed by only changing the account of modules, and the modules are chosen from the product platforms. For example, planar motors with different loads or accelerations can be realized by adding or substituting the magnet modules, as shown in Figure2 (a). Similarly, planar motors for diverse requirements for strokes can be obtained by varying the number of the coil modules, as shown in Figure2 (b).

(a) MMLPMs for different loads or accelerations

(b) MMLPMs for different stokes

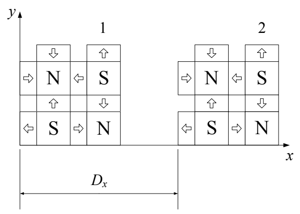
Figure 2. Design criteria for MMLPMs

3. Novel assembly method for magnet array

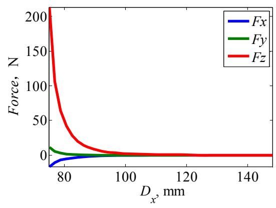
As shown in Figure 1(a), the structure of the magnet module is independent and generic. However, the force between magnet modules is large and will make the assembly of the magnet array difficult. As the MMLPM meets the diverse needs by changing the number of the modules, it's critical to make the assembly process more efficient. The force between two magnets can be modelled with a magnetic charge model and the force between two magnet modules is described with

$$\vec{F}_{module} = \sum_{m=1}^{12}\sum_{n=1}^{12}\vec{F}_{mn} \quad (4)$$

where $\vec{F}_{mn}$ is the force of two magnets and can be found in [2]. The force between two magnet modules varies with the distance of the modules (Figure 3). It indicates that a large repulsion force in the z-axis exists between two neighbouring modules. An iron plate is utilized to overcome it, which is located in the zone with strong magnetic field of the module to be assembled (Figure 4). Design the gap H_i between the iron plate and the module to make the attraction force equal to the repulsion force.

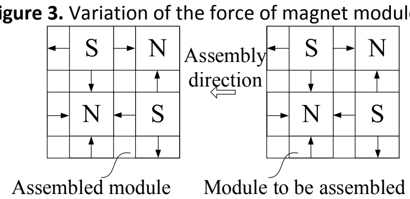


(a) Distance of two modules

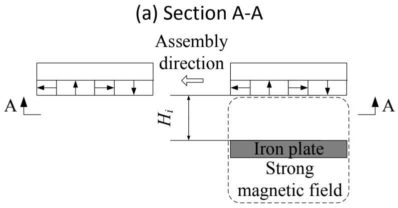


(b) Force of two modules

Figure 3. Variation of the force of magnet modules



(a) Section A-A



(b) Main view

Figure 4. Novel assembly method for magnet array

4. Structure of the coil module

Planar motors with circular coils need more power supply than motors with rectangular coils [1]. The heat dissipation capacity of the cooling system in the coil module should be assessed. Although the cooling system is independent, the cooling water can flow through the module along the channel (Figure 5). The temperature of the cooling water through modules is assumed constant at 20°C. Then a thermal network model is used to analyse the heat flows in the coli module as shown in Figure 6(a).

The result of the analysis indicates that most of the heat in the coil is removed by the water through the cooling plate and the SS casing (Figure 6(b)).

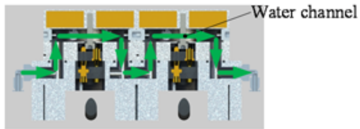
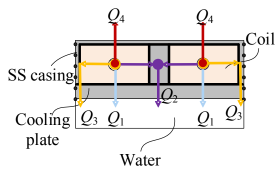
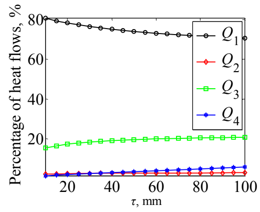


Figure 5. Structure of coil module



(a)2D cross-section



(b) Heat flows analysis

Figure 6. Thermal model analysis

5. Simulation and measurement

The force exerted on the module to be mounted (Figure 4) is calculated with finite element method simulation (FEMs) software. The force remains below zero in the z-axis and about zeros in both *x*- and *y*- axis (Figure 7). Especially, the force in the *z*- axis becomes zero at the final location, which facilitates positioning and fastening of the module.

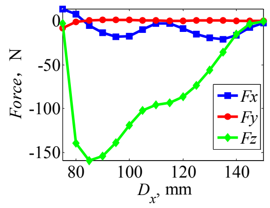
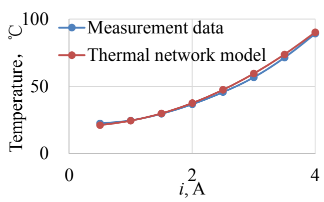
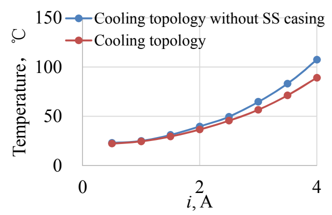


Figure 7. Force on the module to be assembly

The thermal network model is verified by measurement, and the temperature of the top of the coil module is measured by a thermal imaging camera (FLIR A325). The measurement data in Figure 10 (a) is in good agreement with the calculated temperature by the thermal network model. In addition, a lower temperature rise is obtained with the proposed cooling system, which is mostly achieved by the SS casing.



(a) Validation of the model



(b) Comparison of the cooling system

Figure 8. Validation and comparison of the cooling system

Conclusion

A modular magnetic levitation planar motor is proposed to reduce difficulties in the motor design for diverse applications. The structure of the modules are designed for extensibility, independence and commonality. A novel assembly method for magnet modules and a new cooling system of coli modules are proposed and are verified by FEMs and experiment respectively.

References

[1] Rovers J M. M, J W Jansen and E A Lomonova 2013 *IEEE Trans. Magn.* **49** 5730-5741.

[2] Rovers J M M, J W Jansen, E A Lomonova and M J C Ronde 2009 *IEEE Trans. Magn.* **45** 4372-4375.