Eindhoven University of Technology

MASTER

Thermo-Mechanical Design of a Stator for a Planar Motor

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Award date:
2024

Link to publication

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Summary

This thesis describes the conceptual thermo-mechanical design of a modular stator for a planar motor used in a six-degree-of-freedom positioning stage. The intended application of the motion stage is for the inspection of wafers. The considered planar motor is of the moving magnet type. This thesis focuses on the cooling and mechanical fixation of the coils in the stator. The design is made modular in the sense that sets of three coils can be interchanged without much effort.

Due to the thermal expansion of this fixation structure and the frame of the stator, the coils are displaced. This displacement introduces disturbance forces on the mover. This effect should be minimized, which can be done through compensation when temperature fields are known, or by limiting the actual displacements by selecting correct materials and a smart mechanical design. A second design challenge is a result of the required vacuum compatibility of the stage. This results in a large pressure difference and these large loads.

An analysis is provided on the sensitivity of the disturbance forces for coil displacements. The process sensitivity is determined by assuming a feedback controller. Together with the required tracking error, the maximum allowed disturbance force is determined. This is then translated into a maximum coil displacement. Power is dissipated in the coils through Ohmic losses. This dissipation is analyzed using a certain motion path. This analysis is done on the stator, module, and coil level.

The key factor of the selected concept is to have an individual vacuum barrier for each module. The vacuum boundary wraps around each module, thereby making the interchange of modules time-efficient. The coils are fixed to a ceramic plate, resulting in a non-magnetic, insulating, and stiff fixation with low thermal expansion and high thermal conductivity. The coils are actively cooled using a laminar flow of coolant over the bottom of said ceramic plate. This flow is guided by a cooling housing.

The concept is thermally analyzed with a lumped parameter model of a 2D section of the module. Simplifying the 3D module to a 2D section is valid, and this is verified with an experiment. The thermal model models the heat flow from the three coils through the ceramic plate into coolant. It also models radiation into the vacuum chamber. The flow characteristics are separately analyzed, and the model for this is coupled to the lumped parameter model.

The performance of the stage is determined in terms of tracking performance and the maximum heat a single module can dissipate. The tracking performance depends on the velocity of the mover. At a maximum scanning velocity of 2 m/s, a tracking error of 11 nm is expected. The maximum acceleration depends on the motion path since high acceleration leads to more dissipation. If the motion path consists of long strokes, the duty cycle of each module reduces, giving the module time to cool down. If the motion path results in a mean dissipation of 330 W for any module, this path can be sustained indefinitely. Higher dissipation values limit the duration this motion path can be used. For semi-stationary acceleration of the mover in the center of a single module, an acceleration of 16.4 $\mathrm{m/s^2}$ can be sustained indefinitely. Higher accelerations are possible, but for a limited duration. If the motion path is such that the mover does not stay above a single module, the acceleration is not limited by the thermal performance of the module.

In conclusion, the main goal and requirements of designing a modular, cost-effective thermo-mechanical design of such a stator are met. Further analysis regarding the magnetics, fixation of the coils, and the sensitivity to disturbance forces is recommended.