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Robust Decoupling Control for Magnetic Bearing using H_∞ Loop Shaping Design Procedure

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A magnetic bearing has undesirable interaction between the vertical motion and the horizontal motion by gyroscope effect at high rotational speed. An approximate decoupling control design for the interaction of a magnetic bearing is considered by using the Hadamard weighted loop shaping design procedure, and the usefulness of this approach is evaluated from simulations in this thesis.

A Multivariable system often has interaction between inputs and outputs. The interaction give rise to inherent problems of a multivariable control design. Decoupling control is a method to cancel the interaction between inputs and outputs in a multivariable system. Recently, van Diggelen and Glover provide a procedure to achieve an approximate decoupling control, called the Hadamard weighted H_∞ Frobenius synthesis. This procedure achieves an approximate decoupling by using the hadamard weights. They also provide the Hadamard weighted loop shaping design procedure. The procedure is based on the Hadamard weighted H_∞ Frobenius synthesis and the loop shaping design procedure (LSDP). One of the advantage of this procedure is to achieve approximate decoupling by using the hadamard weights.

A magnetic bearing has several excellent advantages such that: a rotor can spinning at high speed, frictionless, low losses, *etc.* because of without any contact. Therefore considerable number of studies have been made for a magnetic bearing. Although feedback control is indispensable for a magnetic bearing, since it is essentially an unstable system. For feedback control is required a mathematical model, however it contains several uncertainties, because of parameter errors, unmodeled dynamics *etc.* Therefore, we should be better to consider the robust stability for these uncertainties. The LSDP is well known a method to design a robust controller for these uncertainties. Fujita *et al.*, apply the

LSDP to a magnetic bearing, and they obtain good robust stability for these uncertainty. On the other hand, a magnetic bearing has undesirable interaction between the vertical motion and the horizontal motion by gyroscope effect at high rotational speed, Mohamed and Emad show that the interaction by gyroscope effect have a great effect on the stability of a magnetic bearing. Therefore decoupling control is required at high rotational speed for a magnetic bearing, although few studies of this problem on decoupling control has been made.

In this thesis, we consider an approximate decoupling control design for the magnetic bearing which has interaction between the vertical motion and the horizontal motion by gyroscope effect using the Hadamard weighted loop shaping design procedure. And the usefulness of this approach is evaluated from simulations.

This thesis is organized as follows. In chapter 2, the relative gain array number (RGA-number), the Hadamard weighted loop shaping design procedure, the Hadamard weighted H_∞ Frobenius synthesis and the LSDP are introduced. The RGA-number can be used to measure large of interaction in a multivariable system.

In chapter 3, the mathematical model of the magnetic bearing is derived, and parameters of the magnetic bearing are introduced. We discussed what interaction is had by the magnetic bearing, and we show that the interaction by gyroscope effect is proportional to the rotational speed of a rotor. Therefore the interaction by gyroscope effect should be cancel when the magnetic bearing is required high control performance at high rotational speed. In this thesis, applying the magnetic bearing to a machine tool spindle is considered, and the control objective is to suppress the interaction between the vertical motion and the horizontal motion at high rotational speed against disturbance to a rotor.

In chapter 4, we design robust decoupling controllers for the magnetic bearing using the Hadamard weighted loop shaping design procedure. Hadamard weights are design variables which the designer can vary to trade off robust stability with performance. In this thesis, we design three controllers about three hadamard weights, in order to investigate the effect of hadamard weights for robust stability and performance. Although this procedure produced extremely high order controller, in this case, these controllers are 1188 degree. A lower order controller is normally preferred high order controllers for some reasons: they are easier to understand, computationally less, *etc.* If we consider applying the controllers to real magnetic bearing, degree of controllers must be less than 40, since the performance of computer, *etc.* Therefore we reduce the degree of controllers to 36 using the balanced truncation.

In chapter 5, in order to the usefulness of this approach is evaluated, two simulations are conducted as follows:

- we give step disturbance forces to the rotor, in order to confirm the control objective is achieved.
- we perturb the rotational speed 10000[rpm] to 20000[rpm], in order to confirm the robust performance.

These simulation results show that the control objective is achieved by suitable hadamard weights. Moreover performance and robust stability are inspected by the RGA-number and stability margin. These results show that large hadamard weights suppress the RGA-number, that is to say achieve approximate decoupling control, although the increase of hadamard weights give rise to deterioration of stability margin. And we compared the Hadamard weighted loop shaping design procedure with the LSDP. Consequently, it is appear that in view of decoupling control, the Hadamard weighted loop shaping design procedure obtain better control performance than LSDP. Although the stability margin of Hadamard weighted loop shaping design procedure is slightly less than that of LSDP.

It should be concluded, from what has been said above, that the Hadamard weighted loop shaping design procedure is effective for the magnetic bearing which is required good accurate at high rotational speed(for example machine tool spindles) or rotor is fat and short.