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Robustness Analysis and Synthesis of a Magnetic Suspension System with Uncertainties

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This thesis deals with the robustness analysis and synthesis of a magnetic suspension system against uncertainties that enters in the feedback form. Robust control theory has been great advances for the design of robust uncertainty-tolerant feedback control systems, and it has developed mathematical tools for the evaluation of stability and performance in the worst case over sets of systems. The magnetic suspension system is one of examples that applied to some physical systems, such as air plane, and so on. For the magnetic suspension system, the characteristic of the magnetic force is extremely complex. Thus, the analysis of this force is too difficult to express the exact behavior of it by mathematical models. The uncertainty is the dominant issue in models used for control system design, and it is important from the above discussion for the controller designer to take account of the uncertainty. Previous researches for the magnetic suspension system have not represented the uncertainty between the physical system and the model, and have dealed with the uncertainties as a disturbance.

Recently, although the researches using robust control have represented the uncertainty with respect to this system, yet the uncertain model is a representation using the unstructured uncertain model. Unstructured uncertainties are easy to deal with mathematically and numerically. Therefore the representation of the uncertainty is conservative. Even though robustness analysis and synthesis are simplified, the result is conservative.

If we allow mathematical complexity to increase, especially when it comes to controller synthesis, structured uncertainties should reduce conservatism. For mathematical complexity, the analysis and synthesis using the structured uncertainty is to be easy by the CAD.

The first contribution of this thesis is the robustness analysis and synthesis of a magnetic suspension system against the structured uncertainty, and the second contribution is discussion that mixed (real/complex) μ reduces conservatism. The structured singular value (μ) can be used to analyze the robustness of the system with respect to the structured uncertainty. We have seen that it may be more natural to model some of the uncertainty with real perturbation. While it is possible to simply treat these perturbations as complex and proceed with the complex μ analysis, the results can be expected to be conservative. These analysis and synthesis are carried out by mixed μ using μ-Analysis and Synthesis Toolbox and MATLAB.

Firstly, a nominal mathematical model with no uncertainty is derived, and the issue of modeling the magnetic suspension system is discussed. We think of mathematical models as our means of analyzing physical reality, and uncertainty is the gap that is left between models and reality, the part of reality that is not account for in our model. Thus it is important to discuss the modeling for building the uncertain model. For the magnetic suspension system, we consider where uncertainties will surely arise in this step. They arise at the linearization of the attraction force, the mass of the iron ball, and the unmodeled dynamics of electromagnetic in the high frequency range. We apply a mathematical model with the structured uncertainty to the magnetic suspension system.

Secondly, we design robust controllers by the μ synthesis against the derived uncertain model, and check the robustness. Furthermore, we design robust controllers against the unstructured uncertain model, since we must make a comparative study of the former and the latter. On the design step, there is a trade-off between allowed perturbations and the desired performance. Through much design giving consideration to these, structured uncertain models can reduce conservatism more than unstructured uncertain models.

Thirdly, several experiments are carried out in order to verify a physical system. First of all, it is most important for these experiments to evaluate the robustness. In these experiments, the uncertainty is caused by moving steady gap between the electromagnet and the iron ball, since it is difficult to supply an iron ball with a disturbance force directly. Moving the gap means varying parameters of the linearization of electromagnetic force and varying the nominal model. It corresponds to the robust stability. In addition to the movement of steady gap, we give suspected-disturbances by adding a voltage signal to a control input signal. It corresponds to the robust performance. In order to check the decrease of conservatism, we consider the behavior of the closed-loop system with designed controllers at the critical point. As a result, we investigate the decrease of conservatism. However, it is necessary to reduce conservatism more, since the controller maybe achieve better robust stability.

Finally, to reduce conservatism more, we discuss that mixed μ synthesis should have a advantages more than complex. Nevertheless some experiments resulted in our improved synthesis being undesirable.

We discuss the uncertainty of the magnetic suspension system, and conclude that the uncertain model with the structured uncertainty reduces conservatism between a physical system and theoretical analysis for this system. Add to these, we will obtain the fact that extremely calculated complex μ can reduce conservatism more than in the case of mixed μ. However, these decrease of conservatism is a slight difference. Therefore, representations of uncertainties as it explicitly capture the behavior of physical systems, leaves some room for consideration. We must also study synthesis that deal with real parameters.