Chapter 5

Conclusion

This laster chapter gives a short summary on what has been done in the present work followed by an outlook which focuses on the future work possible in the field of adaptive control for a rotor suspended by active magnetic bearings.

5.1 Summary

The main topic of the present work is the development of state space adaptive control for a rigid rotor suspended by active magnetic bearings. Therefore, the specific objectives were the modelling of a rotor bearing system, the derivation of a linear discrete time model for a chosen point of operation, the search for a proper algorithm which can cope with parameter changes of the controlled system, and the proof of the performance by means of simulation.

To start with, an experimental setup and the rotor model was presented with a rigid rotor suspended by two active magnetic bearings with four axes of control. Non-conservative cross-coupling forces, simulating a system change, were applied to the rotor in a given plane along the rotor axis. For simulation purposes a comprehensive nonlinear model including a rigid rotor, position and current sensors, analogue to digital converters, digital signal processor, digital to analogue converters, switching power amplifiers with pulse width modulators and magnetic actuators was established. Then, a linear continuous time model has been derived from the nonlinear model for a point of operation. For the sake of simplification, an internal current control loop was designed for the point of operation in order to reduce the order of the resulting linear system. Under these assumptions the magnetic actuator can be treated as a negative spring regarding the rotor position, and as a gain regarding the control current. From there a continuous time state space model for the rotor bearing system was derived and transformed into a discrete time state space model with its matrices in controller canonical form.

The estimation algorithm and the controller design were based on the state space model in controller canonical form. The prediction error algorithm was applied to an innovations model derived from the state space model in order to identify the model parameters under on-line conditions. In this algorithm a state space model and all states have to be calculated after each sampling time interval. To provide numerical stability, a special implementation of this algorithm was used. Additionally, an effective algorithm was proposed to detect system parameter changes in order to start the adaptation process.

In order to justify the application of a linear state space controller for the position control loop of the rotor bearing system, a control current loop was tested by means of simulation with respect to its bandwidth. Using a PI-controller for this task the position stiffness and the current gain derived from the nonlinear model could be confirmed. Additionally, the bandwidth of the current control loop covers the frequency band for the position control loop. This loop was investigated by both step responses and responses to additional disturbances.

Adaptive control was performed via the design of a pole placement controller with and without integrative feedback based on the identified state space model. Simulations proofed the successful operation of the proposed algorithms. The sudden appearance of destabilising non-conservative cross-coupling forces was assumed in order to change the parameters of the system. The simulation results showed that the proposed identification algorithm can cope with parameter changes and the entire system can be stabilised even for high values of non-conservative stiffness coefficients.

5.2 Outlook

Since the adaptive control concept has been extensively investigated by means of simulation, an implementation within a real system is desirable. However, some numerical problems will be involved with that implementation for two reasons.

Firstly, the adaptive control concept includes a large number of matrix operations. The advantage is, that the computation time can be expected to be constant, because no iterations are involved with it. This was a primary constraint for the choice of the state space adaptation algorithm. Still, it will be a challenge for a digital controller to carry out all computation within a sample period of $100\,\mu$s.

Secondly, within a simulation there are no limitations on the computation accuracy. In a digital signal processor one is limited to a system accuracy, which can deteriorate the performance.

Once the control concept is implemented for a real application, all design parameters of the adaptive control algorithm can be tuned, e.g. the initial covariance or the forgetting factor. If this is done, a stable state space control loop is the result which guarantees a certain closed loop performance over a wide range of plant parameters. Moreover, the control concept can be applied to other open loop unstable MIMO-systems.