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Challanges in Controller Design for Active Magnetic Bearings Dealing with Shocks

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1. Introduction

The benefits of active magnetic bearings (AMBs) are being implemented across many industries. As the confidence of the engineering sectors in them grows, AMBs find homes in increasingly challenging environments. One such environment is onboard vehicles that can become subject to shocks, such as turbulence in air or sea. Shocks can also arise from sudden changes in the load, such as in spindle motors that stabilize cutters. Shocks inherently pose the risk of compromising the dynamic performance capabilities and reducing the operational life of machinery. Shocks also expose an inherent weakness of linearized controllers as they can push the rotor away from the region in which the linearisation holds. Designing an AMB with shocks in mind further exposes this weakness, because it is desirable to use the entire gap as a buffer zone to give the coils time to respond to demand. Furthermore, using high currents is desirable to counteract shock forces thus magnetic saturation becomes a key concern. The well known issues of model inaccuracies in AMBs become more severe in non-linear regions thus requiring robust control.

In order to design an AMB that is resilient to shocks, without over sizing the electromagnet in comparison to steady state needs, the design must account for the nonlinear behaviors across the air gap as well as current. In response to these requirements a nonlinear controller is used. Sliding-mode control has been chosen as a control candidate because it is quick to act and adept at dealing with disturbances as well as model inaccuracies.

This paper will explore heuristic and analytical methods of non-linear simulations with a primary focus on assessing ways the impact of shocks can be mitigated through the control law as well as power electronics design. Any mechanical improvements, such as AMB topologies, are outside the scope of this paper.

2. Simulation Challenges

The mechanical understanding of AMBs tends to start out with the assumption along the lines of:

$$f(i,g) = \alpha\frac{i^2}{g^2} \quad , \quad \alpha = \sqrt{\frac{N^2\mu_0 Ag}{4}} \tag{1}$$

Where N is the number of turns of the coil, μ_0 the magnetic constant, Ag the surface area of the electromagnet, i the current in the coils of the electromagnet and g the gap between the electromagnet and target.

However, this relationship can break down at the higher flux densities caused by high currents and narrow gaps which can be shown through partially validated simulation data in fig. 1 below.

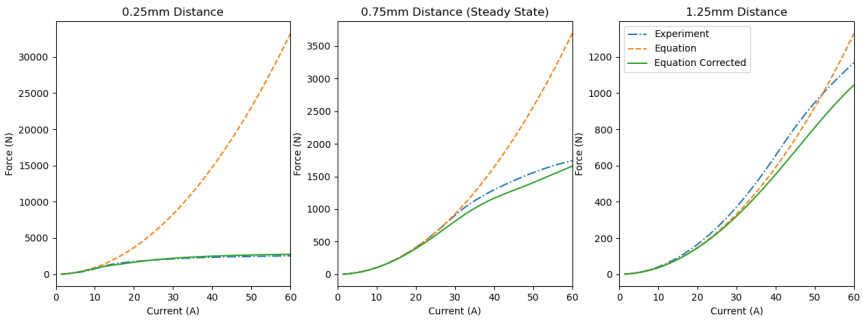

Fig. 1 Force on Rotor from Electromagnet at 3 Gaps Swept Through Current Range

The dash-dot blue line is data obtained from a FEA simulation and partially confirmed experimentally, the orange line is the typical force equation assumptions, and the solid green line is the corrected equation to account for saturation.

As can be seen above, the equation has been heuristically modified through the inclusion of a Michaelis–Menten hyperbolic function to approximate the effect of magnetic saturation to a reasonable effect.

3. Controller Validation

As proposed, the slide mode controller is used. The exact control law is still under active development but a candidate exists. Initially, the controllers robustness is put to the test through assessing its performance with a large mismatch between the strength of opposing coils. Fig. 2 below shows close to no impact on the performance of the controller despite the large mismatch in coil output.

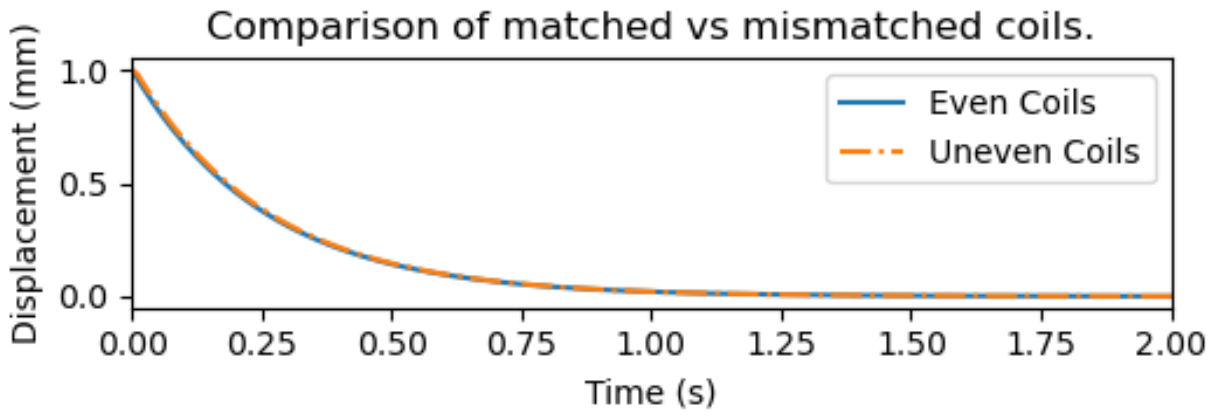

Fig. 2 Displacement Error Correction

The blue solid line is having two electromagnets perfectly matched, the dash-dot orange line is top coil outputting 20% more and the bottom 20% less force than expected.

4. Conclusion

The preliminary investigation into nonlinear effects relevant to the full gap span of the AMB shows they are a significant concerns regarding the saturation effect which strongly dissuades the use of linear controllers if they are to operate within the entire region of the air gap. Additionally the viability of slide-mode control is shown under a large coil mismatch representative of overall parameter variations. By verifying these underlying assumptions the path for shock resilient research has been laid on solid foundations.

5. Future Work

The work on analyzing the impact of the shock and control strategies which can aid in responding is still being carried out in the preliminary stages. Such work includes the design of various sliding manifolds as well as overall controller topologies such as cascaded sliding-mode controllers. High level overview of power electronics strategies, such as temporary overloading of coils will also be examined. Additionally the effect of hysteresis needs to be examined to gain better understanding of temporal behavior of nonlinearities. Observer design or alternative ways of detecting the shock itself will also be paramount to the success of any control strategy. Noise immunity is of particular concerns to not cause unnecessary errors in steady state. These will be examined in separate experiments and then implemented in the simulation.

There is development of a full degree of freedom AMB test jig, which will be used to verify the simulation performance and subsequently the actual performance of the controller and power electronics in response to shock and disturbances.