Maglev summer project - note

Martin Brønstad, Jørn Deila, Jørgen Dyrskog

martin.bronstad@ntnu.no, jodeila@stud.ntnu.no, jorgen.dyrskog@ntnu.no

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1 Introduction

This note is meant to document some of the simulation and modelling work done during our maglev summer project. See the model description paper for more details on the system model. Model description and simulation framework were provided by Hans A. Engmark, *hans.a.engmark@ntnu.no*.

2 Modelling

We wanted to confirm the assumed polarization of the magnets of $J = 1.22$. To do this we measured the flux produced by each magnet with a hall effect sensor. The polarization J were then found by inserting $I = Kl$ in equation 1b in the model description and solving for K.

2.1 Permanent magnets

Measured flux $B = 0.064$T with sensor in position $s = \begin{bmatrix} 0 & 0 & 0.025 \end{bmatrix}^T$ relative to the magnet center. These values yield $J = 1.1$, which seemed reasonable for a magnet of grade N35. The measurements also corresponded well with results from magnetic field calculators.

2.2 Levitating manget

Measured flux $B = 0.0544$T with sensor in position $s = \begin{bmatrix} 0 & 0 & 0.0125 \end{bmatrix}^T$ relative to the magnet center. These values yield $J = 0.8$. This is quite a bit lower than expected. The field strengt should have been about 0.09T according to a magnetic field calculator (assuming a magnet grade of N38). Several measurements with different sensors yielded the same result. The measured value was used in simulations and the designed system should work for the current levitating magnet, but the discrepancy in values might be useful to keep in mind should one wish to replace the levitating magnet in the future.

2.3 Solenoids

We opted to model and use the solenoids from the analog system. The flux were measured while applying a current to one solenoid. Sensor were placed in $s = \begin{bmatrix} 0 & 0 & 0.005 \end{bmatrix}^T$ relative to the solenoid center. With $I = 0.9$A, $B = 0.0448$T. With $I = 1.5$A, $B = 0.0640$T. Simulation of the same conditions yielded $B = 0.0226$T and $B = 0.0377$T respectively. This is most likely caused by the solenoids having a relative permeability $\mu > 1$. Our solution was to increase the number of windings to 1050, which seemingly made the simulations behave more accurately in our use case. This might not be the best solution for more extensive simulation and model based control however, and should perhaps be looked further into in the future.

3 Simulations

The provided simulation framework was used to look at different configurations of the system, and used in combination with electrical design and other practical considerations to decide the final setup. This section covers the parameters and simulation results of the final system setup.

3.1 Parameters

Permanent magnets	
x[m]	$\frac{0.004}{\sqrt{2}}\begin{bmatrix}1 & -1 & -1 & 1\end{bmatrix}$
y[m]	$\frac{0.004}{\sqrt{2}}\begin{bmatrix}1 & 1 & -1 & -1\end{bmatrix}$
z[m]	$\frac{l}{2}\begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}$
l[m]	0.01
r[m]	0.01
J[T]	1.1
Levitating magnet	
m[kg]	0.075
l[m]	0.005
r[m]	0.025
J[T]	-0.8
Solenoids	
x[m]	$0.02\begin{bmatrix}1 & 0 & -1 & 0\end{bmatrix}$
y[m]	$0.02\begin{bmatrix}0 & 1 & 0 & -1\end{bmatrix}$
z[m]	$\frac{l}{2}\begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}$
l[m]	0.02
r[m]	0.01
nw	1050

Table 1: Simulation parameters

3.2 Z-graph

The system in its unforced state will have a z-graph as shown in figure 1. The vertical equilibrium point is then in $\eta_{eq} = \begin{bmatrix}0 & 0 & 0.037\end{bmatrix}^T$

3.3 Solenoids

As a measure of the solenoids ability to influence the position of the levitating magnet the force in x-direction was plotted as shown in figure 2. The levitating magnet is moved along the x-axis with a height equal to the vertical equilibrium. The blue plot shows the unforced system, and red shows the case where $u = \begin{bmatrix}-0.8 & 0 & 0.8 & 0\end{bmatrix}^T$. Depending on the control structure, the solenoids at max actuation should in theory be able to stabilize the magnet within $x = \pm 0.006$ of the origin at $z_{eq} = 0.037$.

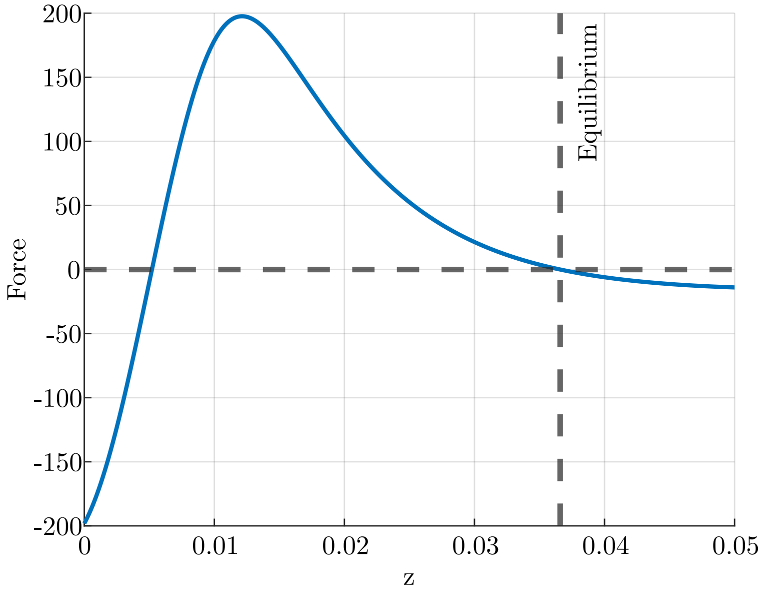

Figure 1: Forces on levitating magnet in z-direction.

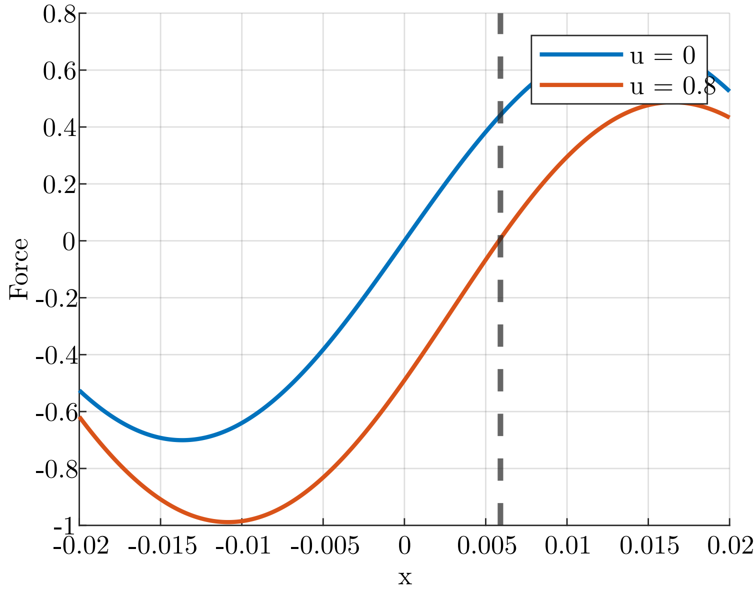

Figure 2: Forces on levitating magnet in x-direction with and without solenoid actuation.

3.4 Sensor placement

In addition to the 3-axis hall effect sensor in the middle of the platform, we wanted the opportunity to place two other 3-axis sensors off-center to improve the observability of the system. It is desirable to put these sensors in positions where the changing magnetic field of the solenoids cancel out to minimize the measurement disturbance. Given a control structure where opposing solenoids use inverted currents, that is $u = \begin{bmatrix} u_x & u_y & -u_x & -u_y \end{bmatrix}$. These positions were found to be in $x = \pm 0.0186$, $y = \pm 0.0186$, as shown in figure 3.

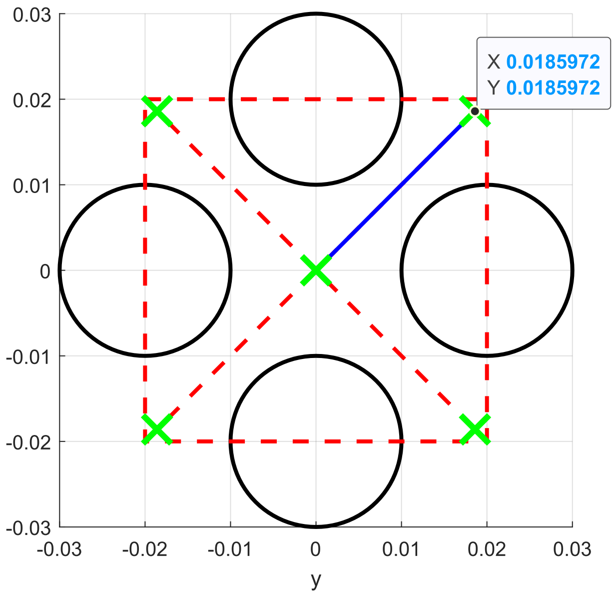

Figure 3: Desirable sensor positions shown in green