I. INTRODUCTION

Using electric magnetic suspension, magnetic levitation (MagLev) systems have been widely applied in various industries for their great characteristics such as non-contact, noise free, cleanliness, high speed transportation, and so on.

Especially, superconducting-hybrid electro-magnetic suspension (SH-EMS) is increasingly receiving attention in industries for their great characteristics such as non-contact, noise free, cleanliness, high speed transportation, and so on.

The advantages of the proposed method
1) Easiness to design and understand the control method because of transforming the conventional controller to modern optimal controller.
2) Consideration for robust performances and stability to deal with the propulsion disturbance force by FEM analysis and the proposed inner feedback compensator.
3) Applicability of additional input-to-output properties, inherited by the two degree-of-freedom approach

II. STRUCTURE AND FEM ANALYSIS OF SH-EMS

SH-EMS Model Equation

\[ x_1(t) = x_2(t) \]

\[ \dot{x}_2(t) = g + \frac{\mu A}{4M} N_{SC} S_C \frac{N(t)}{N_{ref}} + 1 + \frac{1}{M} F_d(t) \]

where \( x_1(t) \) : the gap position error \( z(t) - z_{ref} \)

\( F_d(t) \) : the disturbance force.

III. PROPOSED ROBUST CONTROL

Solving a convex optimization problem

\[ \begin{align*}
\text{minimize} & \quad J = \int \left( \sum \alpha_{1st} \dot{z}(t) + \sum \alpha_{2nd} (\dot{z}(t) - \dot{z}_{des}) \right) dt \\
\text{subject to} & \quad \alpha_{1st} \leq \alpha_{1st}^{des}, \\
& \quad \alpha_{2nd} \leq \alpha_{2nd}^{des}, \\
& \quad 0 \leq \lambda \leq 1
\end{align*} \]

where \( \alpha_{1st}, \alpha_{2nd}, \alpha_{3rd} \) are weighting factors to regulate the importance of the system specifications. And \( \alpha_{des}, \dot{z}_{des} \) are the desired time domain specifications such as overshoot, rise time, and settling time.

\( \beta_{1st}, \beta_{2nd}, \beta_{3rd} \) are the systems responses, obtained from the design performance of the envelop curve.

IV. SIMULATION RESULTS

![Image of simulation results]

V. CONCLUSIONS

The novel robust air-gap controller with inner feedback loop for SH-MagLev systems is proposed, formulating a convex combination set to envelope the performance limitation satisfying the time-domain specifications.

The derived LMI approach to design the proposed controller is applicable to consider extended performances with respect to the input-output relation, using LMI optimization.

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Table 1. PARAMETERS OF THE MAGLEV SYSTEMS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Coil Turns</td>
<td>730 turns</td>
</tr>
<tr>
<td>N_{SC}</td>
<td>Superconductor Coil Tuns</td>
<td>100 turns</td>
</tr>
<tr>
<td>A</td>
<td>Pole Area of Coil</td>
<td>0.005 (m²)</td>
</tr>
<tr>
<td>g</td>
<td>Gravitational Constant</td>
<td>9.80665 (m/s²)</td>
</tr>
<tr>
<td>M</td>
<td>Mass of the Levitated Vehicle</td>
<td>50 (kg)</td>
</tr>
<tr>
<td>e(t)</td>
<td>Applied Voltage</td>
<td>50 (Volt)</td>
</tr>
<tr>
<td>i(t)</td>
<td>Current of Coil</td>
<td>3.6 (Amp)</td>
</tr>
<tr>
<td>i_{SC}</td>
<td>Current of Superconductor</td>
<td>3.6 (Amp)</td>
</tr>
<tr>
<td>z(t)</td>
<td>Gap Position</td>
<td>0 (m)</td>
</tr>
<tr>
<td>z_{ref}</td>
<td>Desired Gap Reference</td>
<td>0.005 (m)</td>
</tr>
</tbody>
</table>

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