Integrated dynamic simulation of a magnetic bearing stage compatible for particle free environment

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Abstract

One of the benefits from active magnetic bearing stages is their multi-degrees-of-freedom motion. When it comes to manufacturing process for semiconductors and display panels, ultra-low contamination may be counted for the first and most important benefit from magnetic bearing stages. We present a new type magnetic bearing stage which is compatible for particle free environment. Since this magnetic bearing stage is designed to be wireless and completely floats in the air or in a vacuum chamber, it is a contamination free device. To properly operate this new type magnetic bearing stage, a full dynamic model has been built to specify its structural dynamics, dynamic motion, and control dynamics. From flexible multi-body simulation an appropriate control algorithm could be identified and implemented in a real system. In this paper, modelling and dynamic simulation result are presented and discussed.

1. A magnetic bearing stage without any connected wires

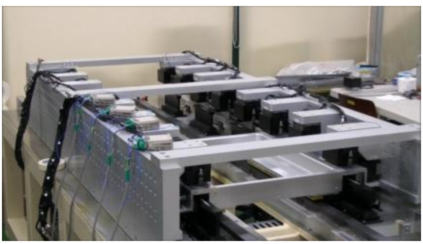

Figure 1: A magnetic bearing stage

Figure 1 shows the developed magnetic bearing stage and Figure 2 depicts its configuration. The magnetic bearing actuators are installed something like streetlamps on a street in vertical and horizontal direction with a 240 mm period along the 2 m frame wall. An eddy current gap sensor is used for each vertical magnetic bearing actuator, but one for two horizontal magnetic bearing actuators. Two linear motor magnet tracks are installed side-by-side underneath the stage while the linear motor cores are located parallel on the frame with a 427 mm period in the feeding direction. When the stage moves, the top and side magnetic bearings respectively in rows, are activated and levitate the stage sequentially according to the stage position in the feeding direction and similarly the linear motor cores are sequentially switched on or off to push the stage to a desired position. All the power consuming parts such as magnetic bearing actuators, linear motor cores, encoder heads are separated from the stage and installed on the frame. There are permanent magnet arrays under the stage, which support approximately 50% out of 72 kg stage weight.

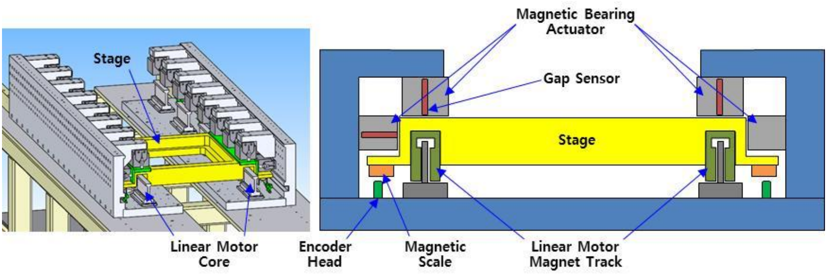

Figure 2: Configuration of the developed magnetic bearing stage

2. An integrated dynamic model

The integrated dynamic model means that the model can describe structural dynamics, dynamic motion, control system, and other physical phenomena such as magnetic force model. To deal with various dynamics in one model, several commercial programs have been used to build a model: HyperMesh, ANSYS, ADAMS, and MATLAB/Simulink.

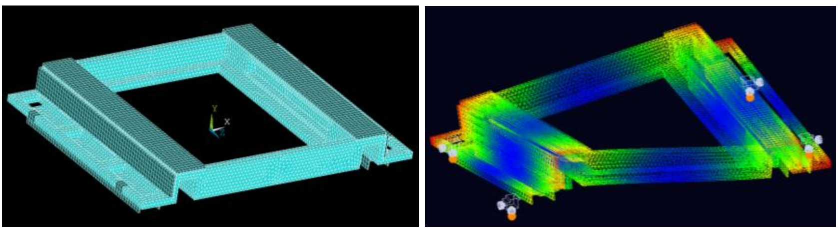

Figure 3: A flexible stage model built by HyperMesh and ANSYS

HyperMesh is used to generates meshes and node numbers on the stage, esapecially uniform hexahedron meshes for the surfaces on which magnetic forces are acting. Through modal analysis, ANSYS generates a flexible structural model of the stage which can be imported to ADAMS in the modal neutral file (MNF) format. The unit magnetic levitating forces are modeled as MFORCE distributed loadcases using an ADAMS tool, mnfload, which adds applied modal loads to existing MNFs.

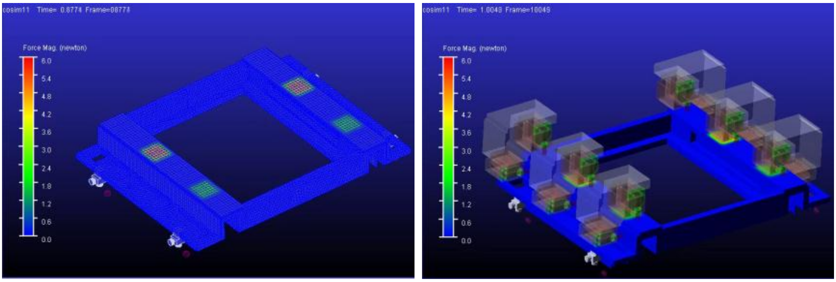

Figure 4: Magnetic forces acting on the stage model in ADAMS

When the stage moves, the position of the magnetic actuator continuously changes with respect to the stage. If the built-in MFORCE function in ADAMS is used, it shows discrete node-to-node translation of magnetic forces on the stage. To make the transition smooth, a user-written subroutine is prepared to determine which MFORCE loadcases are activated and how to interpolate them for continuous translation of magnetic force along the surface of the stage. The strength of magnetic forces is computed in MATLAB/Simulink control block and sent back to ADAMS.

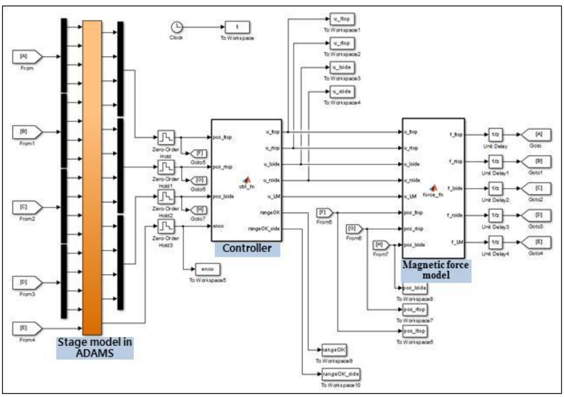

Figure 5: Controller and magnetic force model represented by MATLAB/Simulink

During co-simulation, MATLAB/Simulink takes care of the control system and a magnetic force model, and ADAMS runs the mechanical flexible body model of the stage. The integrators on both MATLAB and ADAMS run in parallel and they exchange data as specified by a 10 kHz sampling rate. MATLAB/Simulink, using output sensor values from ADAMS, runs a control algorithm and calculates the magnetic forces and sends them back to ADAMS.

3. Conclusion

For the simplicity reason in real-time implementation, PD control with a position dependent feed-forward is chosen among several control approaches and found to be sufficient as a control algorithm for the developed magnetic bearing stage. Figure 6 shows simulation results. The left plot shows the vertical position of the centre of mass of the stage when the stage is levitated vertically about 1 mm from the rest position and moves at 500 mm/sec in the feeding direction. The plot in the right shows the gap sensor signal values of the top magnetic bearing actuators. The gap sensors are activated as the stage locates in valid sensing areas. Simulation reveals that there is no problematic flexible structural mode to be dealt with by the controller and it is very important to properly regulate the activation timing for the magnetic bearing actuators. The simulation results were verified through the experiments and the experimental results will be reported soon.

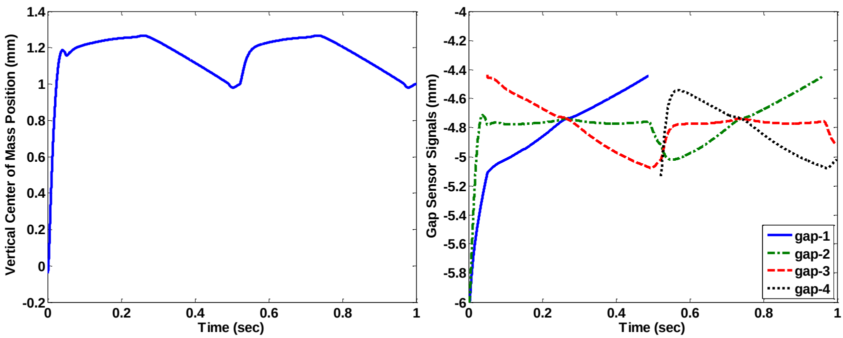

Figure 6: Simulation results: vertical center of mass position of the stage (left) and sequential gap sensor signals (right) when the stage moves at 500 mm/sec

References:

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