INSTRUCTIONS
Control and dynamic system simulator gives a chance to system designers to estimate what kind of dynamic performance can be achieved from design parameters and selected devices without doing real experiments. Initially our simulator was built only with common Simulink blocks to model dynamic components in control systems of machinery equipment. To cover a number of commercial mechanical and electrical parts, a set of database for motors, drives, bearings, etc. was also developed and included in our simulator. To describe 6 degrees-of-freedom motion of a moving table, the equations of motion can be derived from Figure 1 by Lagrangian equation.

FIGURE 1. General moving table model supported by 4 corner linear guide blocks.

Even though a state-space representation of the 6 d.o.f. equations of motion of the moving table in Simulink is handy, the derivation is lengthy and complicated when it is assumed that sensor and motor locations are arbitrary and there are four horizontal and four vertical spring-damper rollers at each corner of the table as shown in the figure. The situation gets worse when mechanical models of multi-axis machine tools need to be built. Furthermore the maintenance and expandability of the equations of motion are quite poor. Thus, the equations of motion represented by common Simulink blocks were dropped out from our simulator and mechanical parts were modeled by SimMechanics blocks. Designers can model the multibody system using blocks representing bodies, joints, constraints, and force elements without deriving the equations of motion for the complete mechanical system. Using SimMechanics, we successfully extend the capability of our simulator to handle multi-axis machine tools. As a demonstration, we present a dynamic model and simulation result of a 4-axis machine tool in this paper.

A 4-AXIS MACHINE TOOLS AND ITS MODEL
Figure 2 shows the 4-axis machine tools and its solid model. All axes in the 4-axis machine tool have hydrostatic bearings. The C-axis is driven by a direct drive motor and other axes adopt linear motors.

FIGURE 2. A 4-axis machine tools and its mechanical.

To make the moving table have 6 d.o.f. motion, a mechanical guide block in the vertical direction is modeled as shown in Figure 3 using an in-plane joint, a prismatic joint, a spherical joint, and a spring-damper. Note that a moving table has eight sets of blocks shown in Figure 3: four sets for the vertical direction and additional four sets for the horizontal direction. A busing joint is used to model a rotational axis. The bushing joint has three translational and three rotational degrees and it allows unconstrained, combined 3D translation and rotation.

FIGURE 3. Linear guide model using SimMechanics blocks.
When a linear axis modeled by SimMechanics blocks, was compared with the equations of motion represented by a state-space block, it was found that the outputs from two models produced less than 0.01% difference in their values in our test. The SimMechanics model for the 4-axis machine tool's mechanical moving parts is shown at Figure 4. As expected, the Z-axis is stacked on top of the X-axis and the C-axis is on the Y-axis. Other configurations of multi-axis machine tools can be easily modeled in this way. Simple copy-and-paste can produce different multi-axis machine tool models.

FIGURE 4. Mechanical system model for the 4-axis machine tool using SimMechanics blocks.

Other model blocks for motors, motor drives, and a controller are connected to the SimMechanics multi-axis mechanical model. The whole model of the 4-axis machine tool was simulated and some of its outputs are shown in Figure 5. In Figure 5, the output from the X-axis was compared with the measured experimental data. The simulation results matches well with the experimental data. The circular response consisted of X- and Y-axis motions shows good agreement between the simulation and the experiment.

CONCLUSIONS
We presented a model and simulation results of a 4-axis machine tool. The complete multi-axis mechanical parts were modeled using blocks representing joints and constraints from SimMechanics and other parts are modeled by common Simulink block. Simulation and experimental results showed good matches. The physical modeling approach for multi-axis machine tools is expandable to other configurations with ease of use.

REFERENCES