DPS
INDUSTRIAL EQUIPMENT

Image courtesy of LPR Global Inc.

Challenge:
As automation becomes more widespread across many industries, predicting and fine-tuning complex machine behavior is increasingly critical for optimizing performance. International engineering software provider Digital Product Simulation (DPS) was looking to develop a methodology for simulating the interaction of electronic controls with factory hardware.

Solution:
The combined strengths of Abaqus' physical modeling and CATIA Systems' logical modeling helped DPS "co-simulate" the behavior of a gantry robot in a feedback loop of data exchange.

Benefits:
Co-simulation provided DPS with a realistic model of machine behavior that has great potential for use with other large-scale, complex industrial systems.

Automation may be increasingly replacing human labor in many industries, but not even robots can avoid the laws of physics. A robotic gantry crane starts, runs and stops along precisely defined X, Y, and Z coordinate paths, yet the effects of inertia, acceleration, vibration and/or oscillation can still result in performance that is less than ideal.

Simulating this kind of complexity was the aim of a collaboration between global CAD/CAE provider Digital Product Simulation (DPS) and the French mechanical engineering school Supmeca. The school participates in PLACIS ("Collaborative Platform for Systems Engineering"), which is funded by the French National Agency for Research. The PLACIS program supports international Masters of engineering students, teaching systems engineering through a project-based learning approach that often involves industry partners such as DPS.

Christophe Baroux graduated from Supmeca a decade ago and is now technical sales manager for DPS North America. He coordinated a recent academic/industry PLACIS project between DPS and Supmeca and reported the student/engineer team's findings at Dassault Systèmes' inaugural "Science in the Age of Experience 2016" event in Boston.

The team's choice of a gantry crane to demonstrate co-simulation between Dassault Systèmes' Abaqus and CATIA Systems tools was a good one, Baroux feels. "Co-simulation is a very exciting topic, but still a niche subject with not many applications in the real world yet," he says. "Gantry robots are used widely in industrial settings, so we felt our example might be of interest to engineers who are interested in optimizing the performance of complex systems in a number of different fields."

Modeling the complexities of mechatronics

Gantry robots (also called Cartesian or linear robots) are employed for machine tending, materials handling, stacking and palletizing—and are highly valued for their positioning accuracy. Tactics that have been used to improve their productivity include reducing the weight of the robot's end effectors (manipulate-able arms) and/or increasing the speed of operation of the gantry setup. But lighter, flexible robotic arms are more susceptible to swaying while travelling at speed, and they can oscillate for a period of time even after a move is completed. The settling time required for any residual vibration can delay the next step in the operation line, conflicting with the demand for increased productivity.

"A gantry robot is not as simple as it looks," says Baroux. "It's a complex mechatronics challenge because it involves different mechanical aspects that are controlled by integrated electronic systems that implement algorithms within the hardware. We found that the surest route to optimizing real-world performance of something this multifaceted was to combine the core strengths of the physical modeling capabilities of Abaqus with the logical modeling features of CATIA Systems."

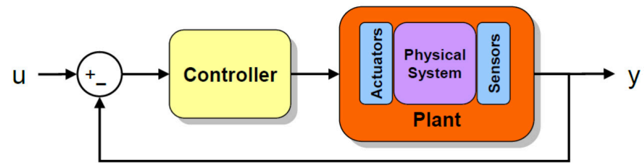

Figure 1. A logical-physical model flow. For the gantry robot project, the physical system modeled with Abaqus includes virtual sensors and actuators in a "Plant" (orange). The sensor data from Abaqus is passed to CATIA Systems (the yellow "Controller"), enabling the controller to compute the actuation needed to drive the physical system towards the desired state. This co-simulation can be repeated in a feedback loop to optimize the performance of the robot.

Adding systems engineering onto core FEA capabilities

DPS' knowledge of both physical and logical modeling runs deep: already established CAD/CAE services providers and longtime users of Abaqus, they became a Dymola reseller after the software was acquired by Dassault Systèmes in 2006 (and renamed CATIA Systems).

Of course Abaqus is the world's technology-leading suite of finite element analysis software for modeling, visualization and best-in-class implicit and explicit dynamics of physical product behavior.

CATIA Systems, on the other hand, provides a graphical interface for building "big-picture," logical models that simulate the behavior of entire systems. The physics of a system are not what is being modeled—the behavior of the system that emerges from the underlying physics is. As an example, you wouldn't simulate the fluid in a hydraulic system, you would model the power and force transmitted by that fluid. In this way, the function of an entire machine—including its powerplant, hydraulics, electronic controls, mechanical actuators and so forth—can all be simulated at once.

Because such a large, logical model is much less computationally dense than, say, a finely meshed FEA one, it can be run across any timespan desired. "Logical models enable you to study global behavior over whatever time cycle you are interested in," says Baroux. "Depending on the inertia in the system, and what it is doing, this can vary from seconds to hours to months. With CATIA Systems added to our toolkit we became able to significantly expand the scope of our capabilities."

Broadened design engineering capabilities bring in more business

As DPS' design engineering knowhow widened with its toolkit, the company began winning more industrial jobs on such large systems as nuclear power plants—predicting, for example, the clogging of steam pipes over a year or more. They also contributed to Dassault Systèmes' "Ice Dream" project, which imagined months of towing an iceberg from the Arctic Ocean to provide fresh water to the Canary Islands (DPS' analysis predicted that more than 60% of the iceberg would survive the trip).

Then, with their expertise established in both FEA and systems modeling, DPS started to investigate bringing those two worlds together with co-simulation. "When the opportunity to participate in the PLACIS project arose, we realized that a mechatronics system like a gantry robot was well suited to demonstrating our logical-physical modeling methodology with Abaqus and CATIA Systems," says Baroux. "This robot challenge was certainly on a smaller scale than an entire power plant, but it does provide a clear example of how co-simulation can help optimize systems behavior."

The gantry robot challenge

The PLACIS project team's goals were to minimize the vibration of a one-axis gantry robot arm as it moved and to increase the precision of the arm's positioning. The modeling approach was simplified by the team, who pursued their studies with a wireframe 2D model mainly for simulation runtime reasons. The group created a 2D Abaqus model of the gantry robot (Figure 2), with a 2-meter long arm moving along an 8- by 4-meter horizontal frame. Friction behavior was added to the connection between the arm and the frame and the arm had one translational degree of freedom.

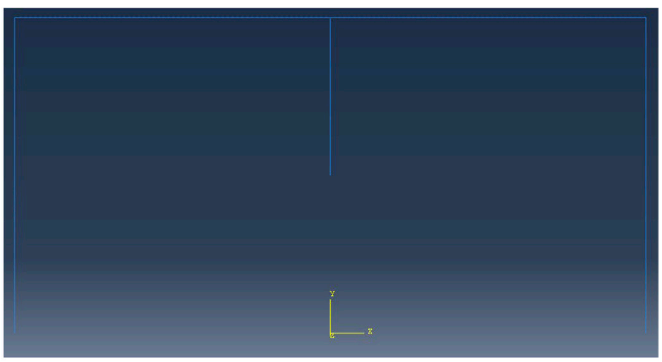

Figure 2. 2D Abaqus model of the gantry robot.

Virtual sensors were positioned to measure the displacement and velocity (the outputs) of the top node of the arm. Then a concentrated force, driven through a virtual actuator (the input), was applied to the same node.

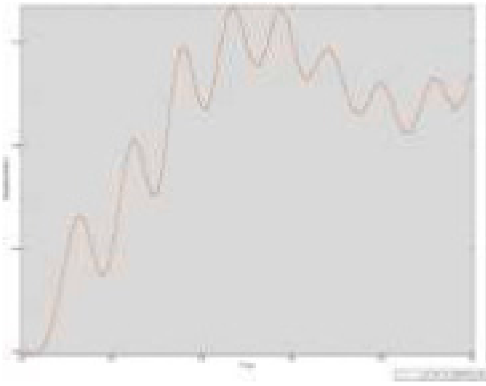

Figure 3. Displacement of the robot arm when an instantaneous force is applied.

As Figure 3 shows, when the simulation was run, vibration in the arm was clearly visible when an instantaneous force was applied. Now the task was to couple this Abaqus model with a CATIA Systems model to find a good control set that would minimize the arm's vibration.

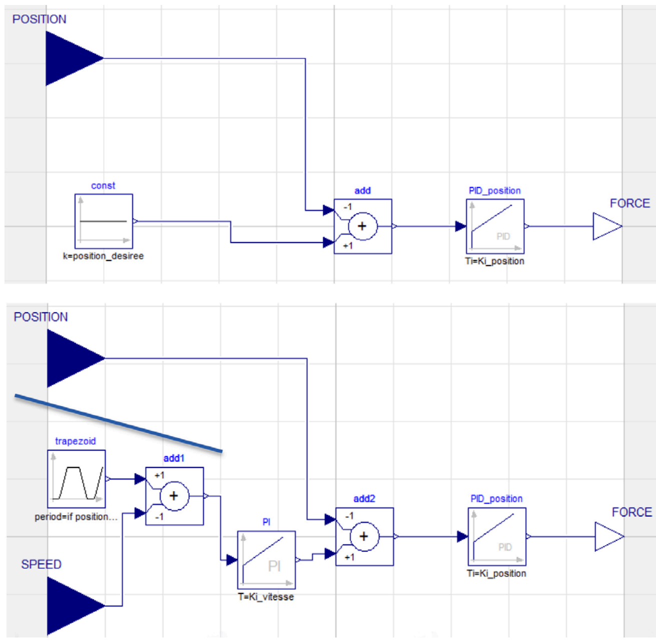

Figure 4. Control models in the CATIA Systems environment.

The CATIA Systems model was created with two inputs from the Abaqus model—displacement and velocity—and one output: force amplitude. The model was set up using two different controllers (Figure 4)—one that acted only on position and another that acted on both position and velocity—enabling more accurate computation and correction of any errors between the desired and current states of the Abaqus model. Position response was compared with a reference value to compute the right force to apply on the arm, while velocity and force were limited so as to model what might occur in a real-world system.

With the Abaqus and CATIA Systems models established, the co-simulation could be run in a feedback loop of data exchange to tweak the controllers' parameters until they reached values that would minimize the gantry robot's vibration as well as increase the positioning accuracy of its arm. This "tweaking" can be accomplished via a PID (Proportional-Integrator-Derivator) technique or, alternatively, by integrating the co-simulation with Isight/SEE, to achieve a more robust parameter set. "This is one of the key capabilities of Isight," says Baroux. "You can integrate your co-simulation in an optimization loop within the Isight environment to automate the tweaking of the controller and reach your desired target."

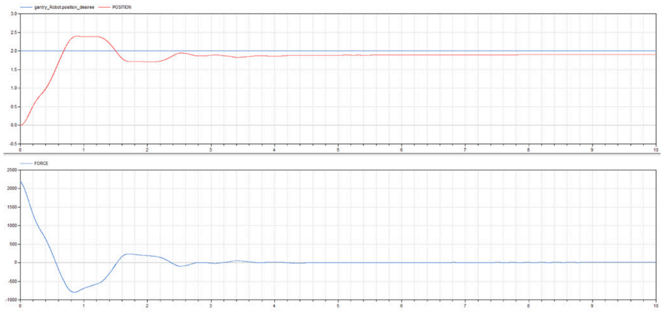

Figure 5. First co-simulation results: The upper graph shows the evolution of the arm's positioning compared with the desired position. The lower graph shows how the effort applied in Abaqus (computed within CATIA Systems) evolves throughout the co-simulation process; notice that this effort is too high at the beginning which implies that adjustments need to be made on the controller to improve this phenomenon.

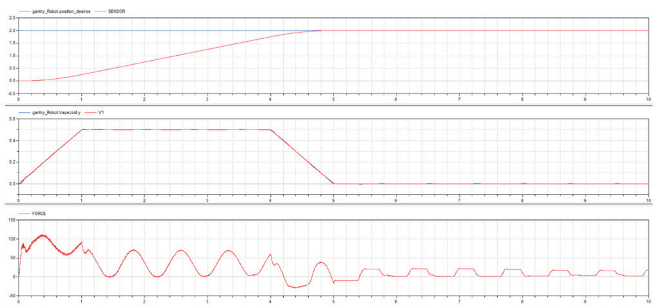

Figure 6. Second co-simulation results: The two upper graphs plot the evolution of, respectively, the arm's positioning and the arm's velocity throughout the co-simulation process. Note that the desired target is reached almost perfectly without any overshoot. The third graph plots the effort evolution, which is much more realistic compared to the first results shown in Figure 6.

As seen in Figures 5 (an early run when the controller was not yet optimized) and 6 (a final run), the end result was much improved control over the gantry robot arm's behavior.

"This Abaqus-CATIA Systems co-simulation technique is very useful when your control model has an influence on your physical model's accuracy," says Baroux. "Abaqus is well suited to handle any detailed simulation, and combining it with CATIA Systems' dynamic visual modeling provides an easy and convenient way to verify and validate the control part."

Baroux feels that co-simulation has tremendous potential to enhance the efficiency and accuracy of the overall design process, particularly when modeling large, complex systems. "Our investment in the software has definitely paid off," he says. "You do need to be rigorous if you want to use this approach because every project includes collaboration between different groups of people. The emergence of innovation platforms like **3D**EXPERIENCE is helping democratize the application of systems modeling and co-simulation, making them more accessible to non-analysts."

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