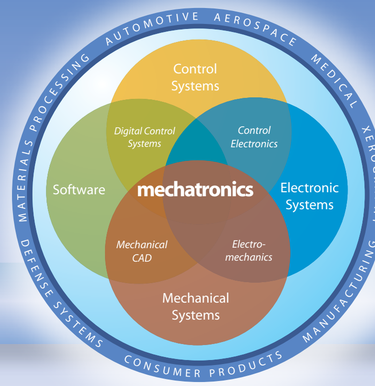
MECHATRONICS IN DESIGN

FRESH IDEAS ON INTEGRATING MECHANICAL SYSTEMS, ELECTRONICS, CONTROL SYSTEMS AND SOFTWARE IN DESIGN



Compliance in Mechatronic Motion Systems: Friend or Foe?

BY KEVIN CRAIG

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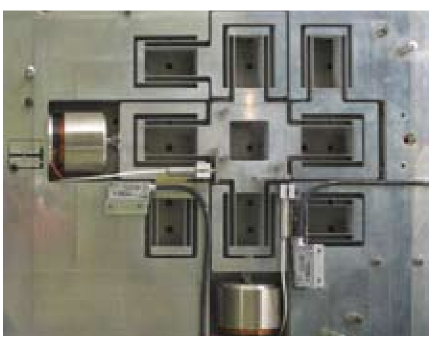
Resonance and anti-resonance are mystifying phenomena. Resonance, and its destructive potential, always brings to mind the Tacoma Narrows Bridge Disaster in 1940 (http://rbi.ims.ca/5726-521). Anti-resonance brings to mind tuned mass-damper systems on upper floors that quiet lively buildings excited by the wind. As the wind buffets the building, it stays still as the mass-damper system oscillates. But I can't help remembering the frustration of a colleague when he said he hit an anti-resonance with his students since he could put in infinite effort, but the output seems to be zero or something close.



Two-Axis Flexure Bearing (S. Awtar).

When you push a child on a swing and your pushes are in phase with the velocity of the child, you add energy to the child's motion. This energy accumulates and, with small damping, a very energetic oscillation results. Your shoves are in resonance with the oscillation — the natural frequency — of the child on the swing. At this frequency, the energy in the system freely flows back-and-forth between kinetic and potential energy and the system behaves like an energy reservoir. The Tacoma Narrows Bridge collapse was a consequence of this effect as wind vortices rocked the bridge at its natural frequency to destruction. At an anti-resonant frequency, the system behaves like an energy sink as energy being applied by the input is completely trapped in the energy storage elements of a sub-portion of the original system such that no output can ever be detected at the point of measurement. Energy from the wind applied to a building is trapped in the mass-damper subsystem, so it moves while the building remains stationary.

This is all very interesting, but what does this have to do with mechatronic motion systems? Plenty! To get insight into this subject, I turned to one of the leading experts on compliant mechanisms, Professor Shorya Awtar, who teaches mechatronics at the University of Michigan at Ann Arbor. The discussion was both illuminating and exciting. His basic message was that there are no free lunches in design — there is always a trade-off. The best path to good design is to become aware of these trade-offs, assess the effects of these trade-offs through modeling and analysis and then make an intelligent choice based on what you need. Compliance is always present in real systems. It can be parasitic and degrade motion, but it also can be used to significantly enhance motion quality. The difficulty arises when it is not modeled effectively or is simply ignored.

A goal for mechatronic motion systems is high motion quality — high resolution, precision, accuracy and speed — as well as robustness to system changes. In an ideal world, machine components would be rigid, machining and assembly imperfections or tolerances would be non-existent and there would be no friction or backlash to overcome. Incorporating compliance into a system design can significantly enhance motion quality and it can do so in three ways. To eliminate friction and backlash in a load-bearing situation, a designer might use a magnetic bearing or an air bearing, where there is no contact. Both are very complicated, high-maintenance systems. A flexure bearing provides both load bearing and motion guidance, albeit small motion, while eliminating friction and backlash (see picture of S. Awtar's two-axis flexure bearing, above left). It is designed to have an optimal distribution of rigidity and compliance. Secondly, in motion transmission, flexible couplings are used to accommodate misalignments inherent to the design or due to manufacturing and assembly tolerances, while eliminating friction and backlash. And lastly, when fixing two components together, flexible clamps provide similar benefits.

Designs in nature often exploit compliance, while man-made designs often avoid compliance. As long as the compliance in the system design is captured in the model, high-quality motion and robustness can be achieved with the aid of compliance — a friend! Compliance is a foe when it is not understood and accounted for in the system design. Ignoring inherent compliance or avoiding using compliance to one's advantage makes compliance a foe!

For more information, check out Kevin Craig's mechatronics' webcast on compliance at http://rbi.ims.ca/5726-520.