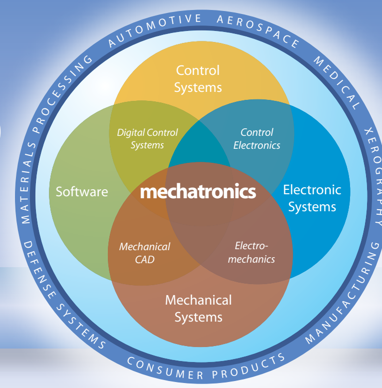
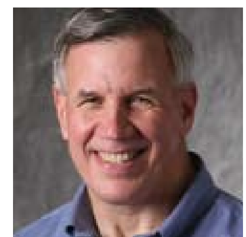
MECHATRONICS IN DESIGN

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



The Other Side of Resonance



BY KEVIN CRAIG

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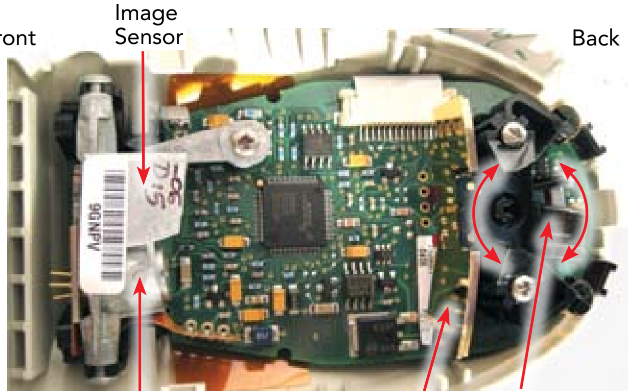
We all want our ideas and work to resonate with others. Resonance in engineering mostly has a negative connotation — something to be avoided. Of course, without resonance we wouldn't have radio, television, music or swings on playgrounds, but mostly resonance brings to mind its dark side — it can cause a bridge to collapse or a helicopter to fall apart. Resonance requires three conditions: a system with a natural frequency, a forcing function applied at the natural frequency and in phase with velocity and a lack of energy loss. Let's look beyond the dark side of this mystifying physical phenomenon and identify ways to exploit resonance to achieve energy efficiency, a challenge we all face in our work as mechatronics engineers. Two examples come to mind.

Oscillating mirrors are used in handheld bar code scanners to reflect laser light out and collect reflected light from the barcode (see figure, below). They use less power, have less moving mass, fit in a smaller space and survive shocks and drops better than rotating polygon mirrors, which are used in fixed scanners. It is important to reduce the energy required to oscillate mirrors at the required frequency and also produce wide oscillation angles. To accomplish these objectives, the system, essentially a torsional spring-mass-damper system, is driven into resonance by a solenoid. The solenoid has two coils: one to sense frequency of oscillation and another to drive the system. The system has no inherent failure mechanism, as there are no bearings and hence no friction. As the mechanical stresses in the flexing member of the system are kept below a threshold, fatigue failure is avoided. The result of this design is extreme reliability.

For the second example, I turned to my long-time colleague and friend Dr. Fred Stolfi, a mechatronics professor at Columbia University in New York City. Stolfi has more than 25 years design experience from Smith Corona, Philips and Xerox, and so his mechatronics' courses show how to solve real-world multidisciplinary system design problems, focusing on general techniques which can be applied in a wide variety of product areas. While at Philips, Stolfi and his team designed a satellite cryogenic Stirling-cycle refrigerator for NASA Goddard Space Flight Center. For long life, the refrigerator employed magnetic bearings to support the moving shafts. The Stirling cycle consists of two elements. The displacer shuttles the helium working gas from the cold tip to the compression section. When the gas is in the compression section, the piston compresses the gas and rejects heat. When the gas is in the cold tip, the piston expands the gas and absorbs heat. The piston and displacer therefore oscillate at the same frequency but with a phase shift. The nominal operating temperature of the refrigerator was 65K (-343F).

To get the high efficiency needed for satellite operation, the piston was operated at its natural frequency — in resonance. The mass of the piston resonated on the gas spring formed by compressing the gas with the piston face. In this way, the linear piston motor only had to compensate for losses and did not have to accelerate and decelerate the mass every cycle. For closed-loop control, the piston and displacer used linear variable differential transformers (LVDTs) to measure linear position. For resonance, the frequency of the cycle was adjusted in a phased locked loop so the piston velocity and force were in phase. A second-phase locked loop was used to control the displacer relative to the piston.

With today's energy crisis, mechanical efficiency on earth is as important as mechanical efficiency in a satellite. Similar techniques can be employed to make terrestrial systems use less energy to operate.



Bar code scanner oscillating mirror.

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