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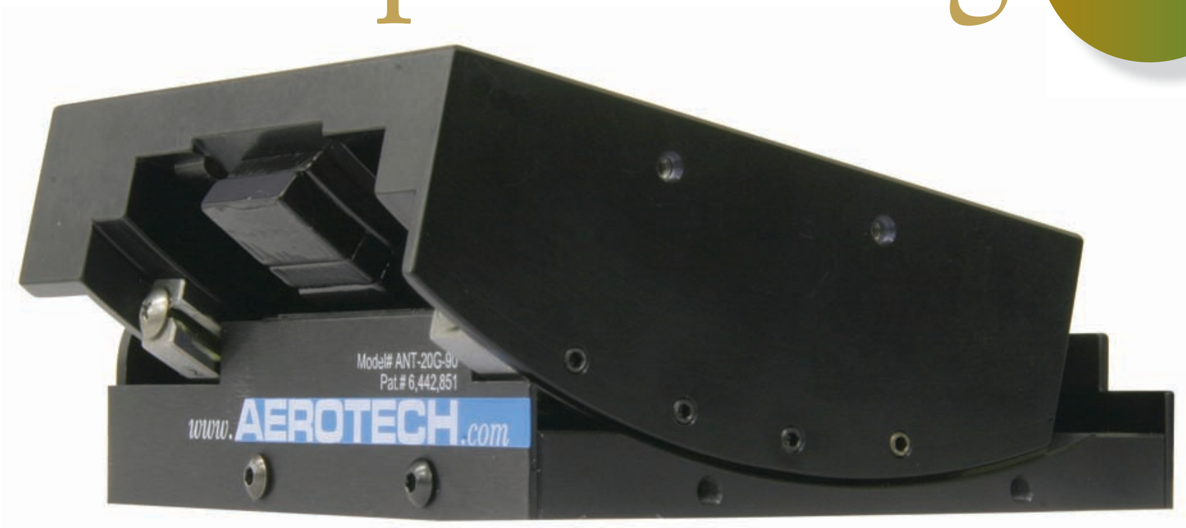
Microportioning Meets Mechatronics

NEW TECHNOLOGY VIDEO SHORTS, engineeringTV.com

Micropositioning meets



This goniometer includes an actuator with integral motor. Height and performance requirements called for a low profile direct-drive motor system, which meant embedding a custom linear motor directly into the stage base.

Mechatronics, with its multidisciplinary engineering approach integrating electrical, control, software, and mechanical elements, is well matched to the design of complex micropositioning devices.

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Compared to traditional methods, the mechatronic design approach is more of a holistic approach to product design, where the tradeoffs between different functional components (software, hardware, user interface, etc.) are carefully considered for their impact on overall performance. The goal of the process is to arrive at an optimal solution at the conclusion of product design. Mechatronic principles have been successfully deployed in numerous applications such as hard drives, robotic manipulators, temperature control, and automotive systems. Here we consider mechatronics in micropositioning stages.

Micropositioning defined

The term "micropositioning" has different meanings that are largely defined by the context of the application. In this discussion, we are talking about actuators capable of motion in the micron to submicron region. This requires that the actuator is capable of achieving submicron repeatability and accuracy. These types of products are widely used to manufacture fiber optic devices, laser ablation processes, and semiconductor, hard drive, and metrology systems.

The application of mechatronic design principles is critical to the successful implementation of such micropositioning devices and systems. When every micron matters, each design element must be carefully considered for its contribution to overall system error, as a single "bad" choice can easily exceed the total system error budget.

Mechanical subsystem design

One would expect that a device designed to move at the micron level with corresponding accuracy and repeatability would necessarily be small in size. However, there are actuators with travel in the range of hundreds of millimeters that are quite capable of being classified as micropositioning devices. The size of the load (mass, dimensions, inertia) and the environment (cleanliness or atmospheric composition) add to the challenge, narrowing design parameters even further as they relate to material and bearing selection. These design selections are also guided by their impact on system response.

The mechatronic aspect of mechanical subsystem design comes into play when considering the interaction between software, control, and electronics. In some applications, it may be necessary to integrate the control and power stages into the mechanical subsystem itself. To minimize overall footprint, for example, it may be necessary to integrate a custom motor assembly into the moving stage.

Think about thermal expansion

When motors or power electronics are integrated directly into a device, it introduces a heat source that can reduce positioning accuracy due to thermal growth. The following table shows the thermal expansion in microns over 1 m of material length for a 1° C rise in temperature. Based on the expansion coefficient, a 100-mm long aluminum actuator will expand 2.4 µm for each 1° C temperature increase. Note that integral power electronics and motors have the potential to raise the temperature much greater than that.

THERMAL EXPANSION

Material	Microns of expansion (per m length, per °C rise)
Aluminum	24
Brass	19
Copper	17
Iron	12
Steel	13
Platinum	9
Tungsten	4.3
Gold	14
Silver	18

In applications where extreme accuracy is required over a range of operating temperatures, the control subsystem must be capable of measuring or calculating the temperature rise and adjusting accordingly to stay within the allotted error budget. Alternatively, different materials with a lower coefficient of thermal expansion could be considered for the actuator to limit growth. However, it's important to remember that material selection has implications for actuator stiffness, which can influence the control architecture and processor type.

Consider control subsystems

There's more to micropositioning, of course, than micron-level movements. Parameters of importance include specifications for move and settle time (step response), maximum operating speed, and throughput-related specs. The design and interaction of both the control and mechanical system ultimately define the operating envelope of the complete system.

A good first order approximation is that the wider the system bandwidth, the better system performance will be in terms of settling times and peak position errors. That's because mechanical systems exhibit resonant modes or frequencies about which they tend to oscillate. These resonant modes must be outside the system bandwidth and sufficiently attenuated so they're not excited by stage motion.

In keeping with mechatronic design principles, required system bandwidth is estimated early in the design process based on performance criteria. Bandwidth estimates are used not only to guide the mechanical system design by defining a limit on the lowest allowable system resonance, but also to define the control structure. A finite element analysis (FEA) of the mechanical structure can provide estimates on

Mechatronic design considerations

In the case of the goniometer micropositioning device, the following mechatronic principles guided product design:

- Analysis of tradeoff between control complexity and actuator complexity, low stiffness/high control complexity versus high stiffness/low control effort
- Review of thermal effects caused by the integration of electronic devices into the mechanical subassembly
- Design for manufacturability and serviceability of mechatronic assembly; cost-effective packaging of mechanical, motor, and control elements
- Human interface aspects, user programming, software and firmware maintenance, connectivity

the values of the system's primary resonant modes.

This information is then used to define the control requirements in terms of servo update rate, control structure (PID/state space), and the number and order of filters required. Based on the servo update rate, servo algorithm, and number of filters specified, it's possible to estimate the number of operations per second required to implement the control algorithm, which helps define the processor type (microcontroller, DSP, or microprocessor) as well as operating speed.

System simulation

Beyond FEA analysis, which provides information on the mechanical subsystem's frequency response, a mechatronics design approach can derive great benefit from full system simulation. Items in the control loop such as processor word width, sensor resolution, power stage, control algorithm, and the mechanical system can be modeled and simulated to verify expected performance. Operational parameters can be varied to attain desired performance levels or identify unexpected problems well in advance of completion of a functional prototype.

Meaningful mechatronics

As devices become increasingly complex and development timelines are reduced to shorten ROI and bring products to market sooner, the advantages of a mechatronics-based system design approach become ever more apparent. Micropositioning applications, in general, are well suited to the mechatronics design approach, as all the core technologies are present with significant interaction between them.

The processes applied in mechatronics are not new. Taken together, they represent a "best practices" approach that has been applied by groups of individuals with specializations in different engineering disciplines for many years. What's new is the recognition of the value of this capability at the university level. Many universities now have mechatronics-based programs that provide engineers with exposure to mechanical, electrical, software, and control systems concepts with sufficient depth of knowledge in each discipline to understand the synergistic relationship between them.

Ron Rekowski is director of product management for Aerotech's laser and medical group. To learn more, visit www.aerotech.com. For more information regarding mechatronic design, visit www.motionsystemdesign.com.