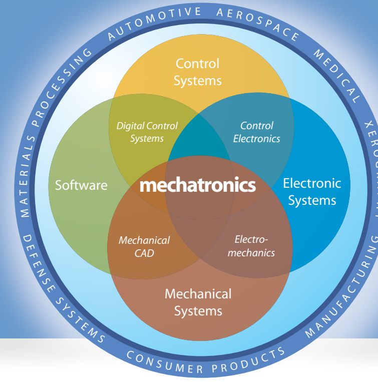

No fighting

In life and in mechanical design, keep the peace.

Most engineers have taken a course on the design of machines and machine elements. These courses, however, often overlook the insight that expert machine designers have gleaned from years of practice. Guiding principles—for example, keep complexity intrinsic, keep functions independent, improve designs with self-help, and plan load paths in assemblies—are not well-publicized. One of the most important guiding principles is exact-constraint design, and **references 1** and **2** provide material on that topic, with **Reference 2** serving as the source for much of this column.

Precision machines are essential elements of an industrial society. A precision machine is an integrated system that relies on the attributes of one component to augment the weaknesses of another component. Characteristic to all precision systems is the high level of determinacy they require. Predictable and reproducible behavior is a key quality that only carefully designed, robust mechanics and control systems can achieve. To achieve excellent and predictable behavior, the mechanisms require, among other things, exact constraint—just enough constraint to define a position or motion. Unlike overconstrained designs, exactly constrained designs boast a repeatable position, easy assembly, and robustness to wear and environment. They have no binding, no play, no internal stress, and no loose-tolerance parts.

A 3-D object has six degrees of freedom—the number of independent coordinates necessary to describe a system's motion—three translations and three rotations. Selectively constrain these degrees of freedom to obtain the desired motion or structure. If you rigidly constrain a component at more places than necessary—by, for example, placing three bearings on one shaft—these places will "fight" with each other.

The design of high-quality precision machines depends primarily on an engineer's ability to predict how the machine will perform before he builds it. The most important factors affecting the quality of a machine are its accuracy; its precision, or repeatability; and the resolution of its components and the manner in which they are combined. Accuracy is the ability to tell the truth, precision is the ability to tell the same story over and over again, and resolution is how much detail the story has. Designing a machine that has good accuracy, precision, and resolution is not a black art.

Consider the use of linear drives for scanning. They often comprise a motor attached to a lead screw, which in turn drives the scanning carriage. A first design shows a cyclic error in linear motion (**Figure 1a**). Trying more accurate machining, better part alignment, and a more expensive lead screw yields no success. A constraint analysis shows that the design is overconstrained. The motor attaches rigidly to the lead screw, so the motor requires only one constraint: to prevent the rotation of its housing. The compound flexure eliminates the problem by eliminating the need for an expensive lead screw, accurate machining, and assembly steps (**Figure 1b**).

Understanding how to transform basic physical principles into working concepts with predictable behavior is the key to achieving high accuracy, high speed, and high reliability. EDN

Kevin C Craig, PhD, is the Robert C Greenheck chairman in engineering design and a professor of mechanical engineering at Marquette University's College of Engineering. For more mechatronic news, visit mechatronicszone.com.

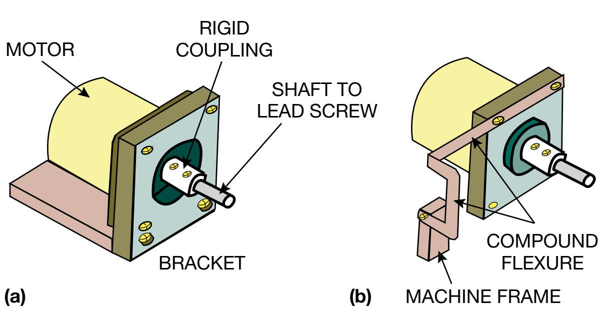

Figure 1 A first design shows a cyclic error in linear motion (a). A constraint analysis shows that the design is overconstrained. The compound flexure eliminates the problem by eliminating the need for an expensive lead screw, accurate machining, and assembly steps (b).

REFERENCES

1 Blanding, Douglass L, *Exact Constraint: Machine Design using Kinematic Principles*, ASME Press, 1999.

2 Skakoon, James G, *The Elements of Mechanical Design*, ASME Press, 2008, ISBN: 978-0-7918-0267-0.