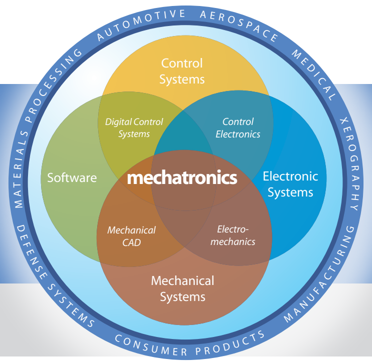
UBM Electronics DesignNews EDN

MECHATRONICS IN DESIGN



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

Never Start a Fight

Good advice for life and for mechanical design.

MOST ENGINEERS HAVE TAKEN a course on design of machines and machine elements. What is usually missing from these courses is the insight expert machine designers have from years of practice. Guiding principles, e.g., 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 (*Exact Constraint Design: Machine Design Using Kinematic Principles*, D. Blanding, 1999). J. Skakoon's *The Elements of Mechanical Design* is an invaluable reference and was the source for much of this article.

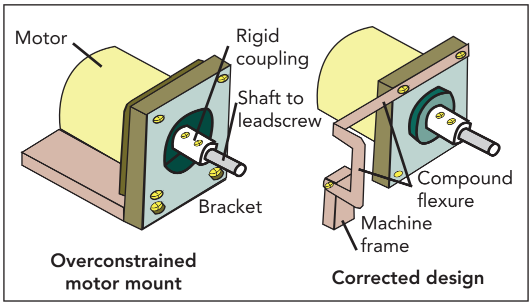
Precision machines are essential elements of an industrial society. A precision machine is an integrated system that relies on the attributes of one component to augment the weaknesses of another component. Characteristic to all precision systems is the high level of determinacy required. Predictable and reproducible behavior is a key quality that can only be achieved when mechanics and control systems are carefully designed and robust to disturbances. To achieve excellent and predictable behavior, the mechanisms need to be, among other things, exactly constrained. Exact constraint means applying just enough constraints to define a position or motion — no more, no less. Advantages of exactly-constrained designs compared to overconstrained designs are: no binding, no play, repeatable position, no internal stress, lose-tolerance parts, easy assembly, and robustness to wear and environment.

A three-dimensional object has six degrees of freedom (i.e., the degree of freedom is the number of independent coordinates needed to completely 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 are needed, you will start a fight between these places. This is overconstraint. As an example, three bearings on one shaft do not work. It is not luck you need in trying to fit the shaft through three bearings, it's sympathy — it won't go!

The design of quality precision machines depends primarily on the ability of the engineer to predict how the machine will perform before it is built. The most important factors affecting the quality of a machine are the accuracy, precision (repeatability), and resolution of its components and the manner in which they are combined. Simply put, 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 detailed your story is. Designing a machine that has good accuracy, precision, and resolution is not a black art.

Kevin C. Craig, Ph.D., Robert C. Greenheck Chair in Engineering Design & Professor of Mechanical Engineering, College of Engineering, Marquette University.

Consider the use of linear drives for scanning, which often consist of a motor attached to a leadscrew, which in turn drives the scanning carriage. A first design (figure left) showed a cyclic error in the linear motion. More accurate machining, better part alignment, and a more expensive leadscrew were all tried, with no success. A constraint analysis then showed that the design was overconstrained. With the motor rigidly attached to the leadscrew, the motor requires only a single constraint, i.e., prevent rotation of its housing. The compound flexure (figure right) eliminated the problem, and the expensive leadscrew, accurate machining, and assembly steps were unnecessary.



Overconstrained motor mount

Corrected design

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. **DN**