Course Audit

Advanced learning at your desk, at your pace

Understanding motion simulation

PART 2 of 2

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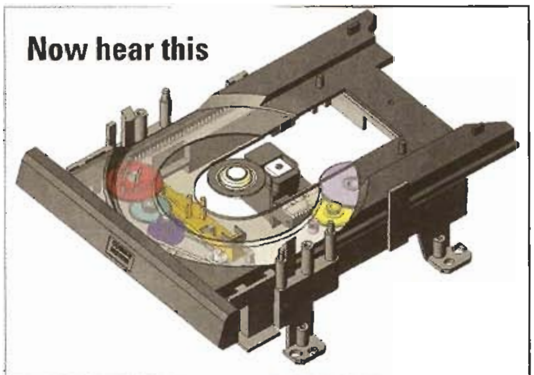
In this installment:

- FEA plus simulation
- Information exports
- Load analysis

Now hear this



A complex CD drive mechanism is easily analyzed by motion simulation.

When computer-aided engineering (CAE) methods became available for design work in the 1980s, finite element analysis (FEA) was the first to be widely adopted. Over the years, it's helped design engineers study the structural performance of new products, and replace costly prototype iterations with inexpensive computer simulations run on CAD models.

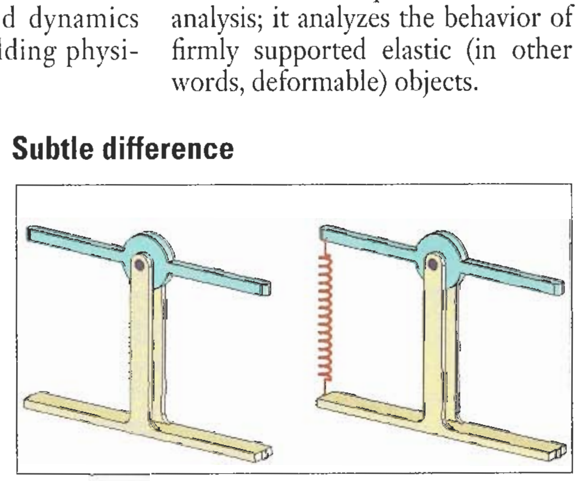
But now, mechanical products are increasingly complex and competition to bring designs quickly to market is more intense than ever. For these reasons, many engineers are using structural performance modeling with FEA as well as kinematics and dynamics simulation before building physical prototypes.

Tool for every job

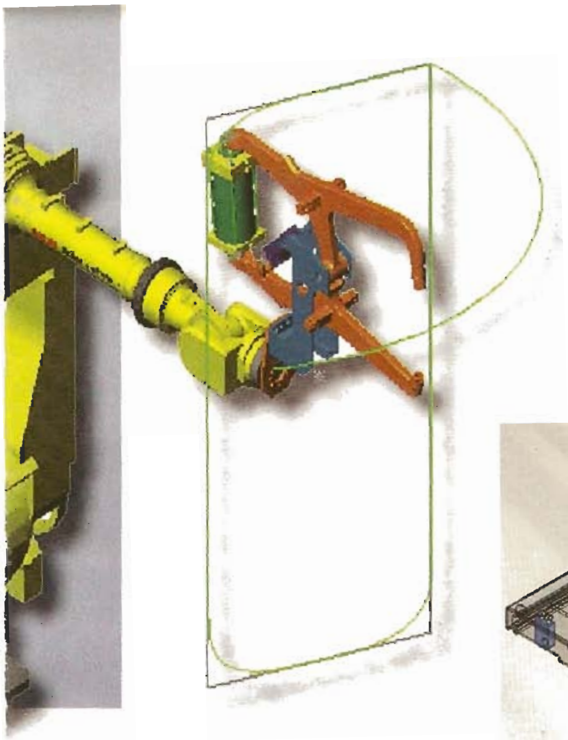
Motion simulation and FEA can also work together in mechanism simulation. To understand how, it helps to understand the fundamental assumptions on which each tool is based.

As we reviewed in the first installment of this series (*see the March 2008 MSD issue online*) FEA is a numerical technique for structural analysis; it analyzes the behavior of firmly supported elastic (in other words, deformable) objects.

Subtle difference

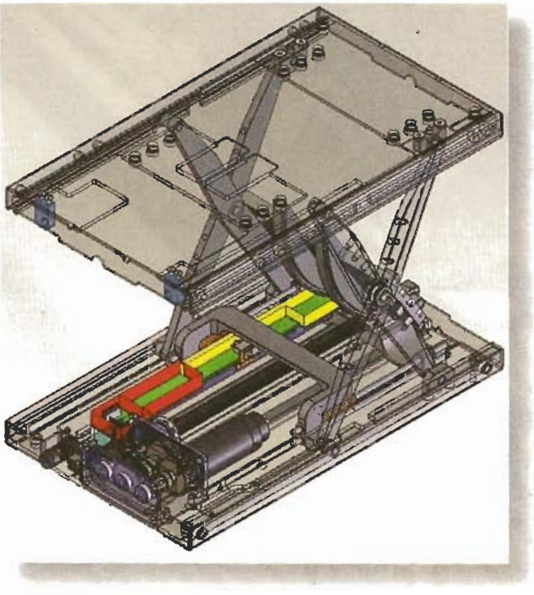


The swing arm at left can move without deformation; thus it is a mechanism. Right, the swing arm in the device is restrained by a spring, so any movement must be accompanied by deformation of the spring; thus it is a structure.



The right robots

This industrial robot created by FANUC Robotics America Inc., Rochester Hills, Mich. FANUC is one of several different sizes. Customers select the right size for their specific application by analyzing robot performance along specified tool paths. Simulation with COSMOSMotion makes that easier.



Cutting down iterations

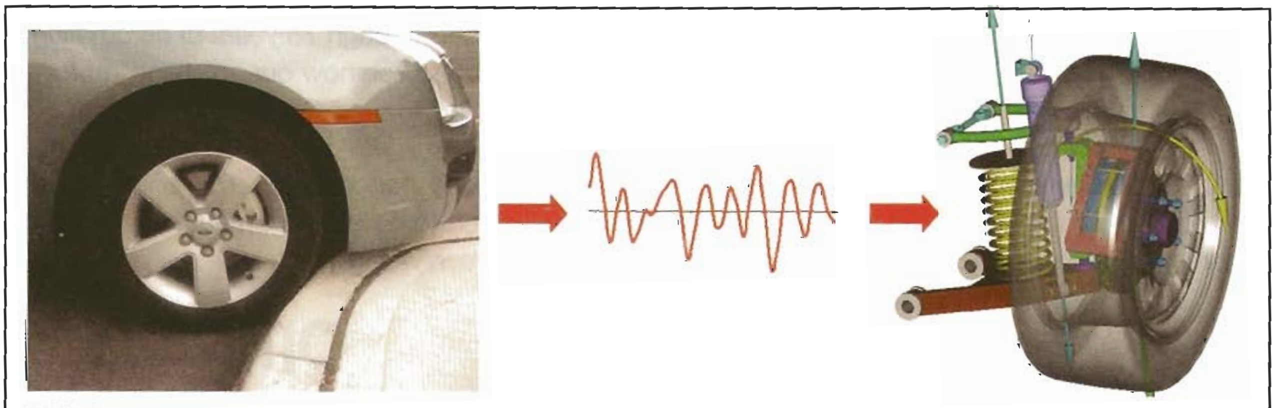
This lifting platform is designed by Syncroness, Westminster, Colo. with SolidWorks, COSMOSMotion, and COSMOSWorks. The product development bureau (which works closely with customers to develop products from exercise equipment to laser systems) optimized the four-bar linkage for the scissors lift in the software as well. The engineering team conducted the motion simulation with little training, and Syncroness credits simulation for quick design iterations and a great visualization tool for customers.

For example, applying static load to a fixed bracket induces a new, deformed shape, which then remains motionless. Application of dynamic load causes the bracket to vibrate about the position of equilibrium. FEA can study displacements, strains, stresses, and vibration of the bracket in both situations.

In contrast, a partially supported object, such as a flywheel hinged on the bracket, can rotate without having to deform. It can also move as a rigid body, which classifies the device as a mechanism rather than as a structure. So, to study its motion, we use motion simulation.

But sometimes the difference between a structure and mechanism isn't obvious. Consider a swing arm mounted to an immovable base by a hinge, with a spring also connecting the arm end and base. The only possible continuous arm motion is vibration about the position of equilibrium, and any arm movement deforms the

Using imported data



Data from test or analytical calculations can be used to define mechanism motion. Here, motion of the control arm is recorded as a function of time as a car drives over a curb. The test data are used to move the suspension assembly model in motion simulation.

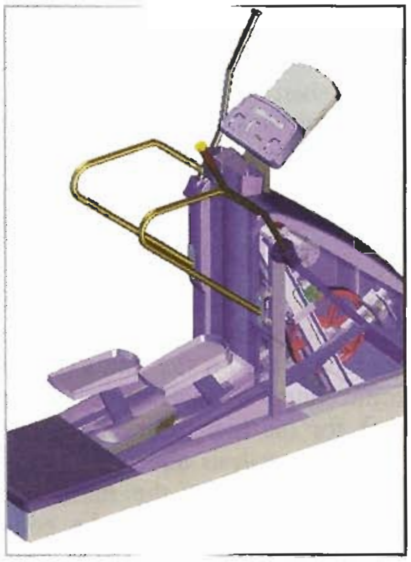
spring, so the device is a structure.

In contrast, the same device without a spring is a mechanism, because the swing arm can rotate freely. Whether it spins about the hinge or oscillates about a position of equilibrium, no part of the device has to deform during the arm movement.

For the version with the spring, FEA can analyze arm vibration, and even calculate strains and stresses in spring and other components treated as elastic bodies. For the version without the spring, motion simulation returns joint reactions and inertial forces that act upon each link of the mechanism. But how can the two tools be used together?

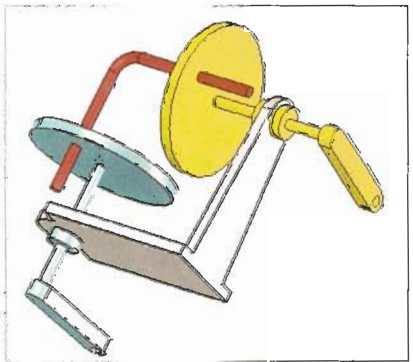
Motion simulation results supply input data — required for accurate FEA structural analysis. It's actually quite easy, because motion simulation always calculates these factors, whether or not it's followed by FEA. Joint reactions and inertial forces are, by definition, in balance, and mechanism components subjected to a balanced set of loads can be submitted to FEA and treated by the analysis program as structures.

Healthy design



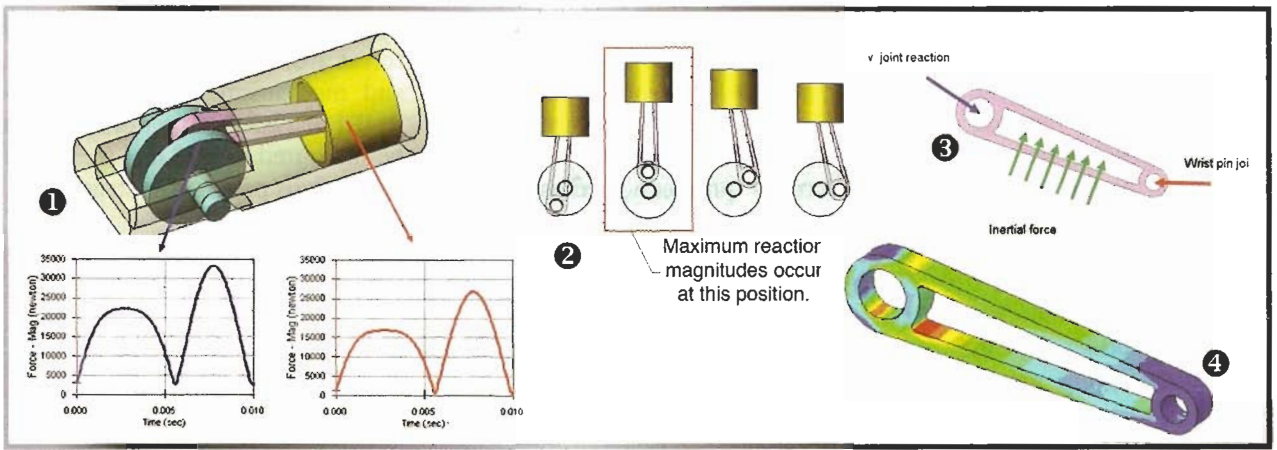
Simulation optimizes steps and trajectories, and calculates user-generated power on an exercise machine.

Impossible by hand



Even a simple 3D mechanism is difficult to analyze by hand, but presents no problem for motion simulation.

Connecting rod example



❶ Motion simulation finds reactions on both ends of the connecting rod: the large diameter end, which is the crank throw end, is attached to the crank shaft, and the small diameter end or wrist pin end, is attached to the piston by a wrist pin. Simulation also finds inertial forces acting on the connecting rod. These inertial forces are not negligible in fast-moving mechanisms. Plotted are reactions during one full turn.

❷ Forces — reactions on both ends and inertial forces — acting on the connecting rod may be determined for any number of crankshaft mechanism positions.

❸ According to the d'Alembert principle, joint reactions are in balance with inertial forces. The connecting rod is thus in equilibrium as if it were a structure.

❹ The connecting rod is presented to FEA as a structure so that stresses can be calculated.

Engineers can transfer that data from motion simulation to FEA manually, but the best results are generated if the motion simulation software can export results to FEA automatically.

When used this way, motion simulation and FEA perform coupled simulation: This defines FEA loads automatically, and eliminates the guesswork and possible errors common of manual setup.

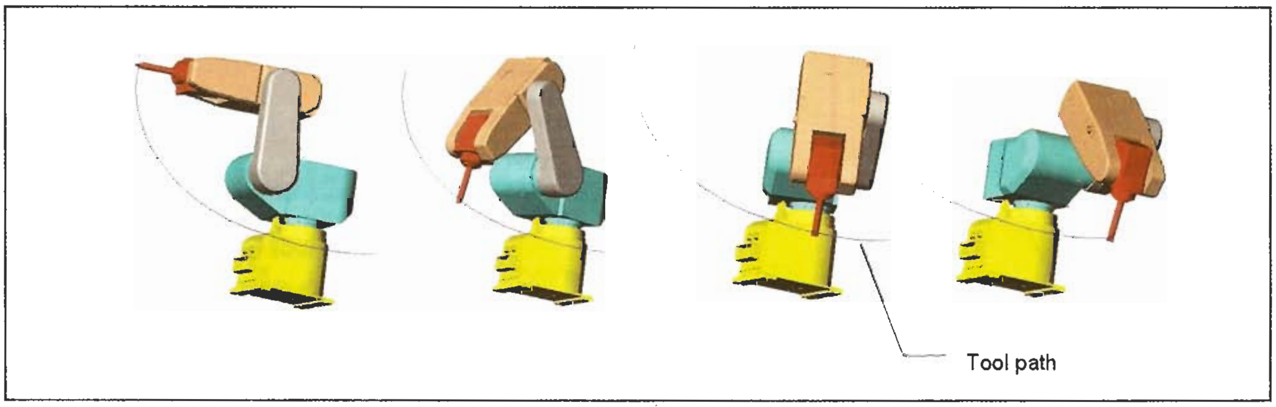
To combine motion simulation and FEA:

1. Use motion simulation to find displacements, velocities, accelerations, joint reactions, and inertial forces acting on all components within the range of motion selected for study. In this step, all the mechanism links are treated as rigid bodies.

2. Find the mechanism position that corresponds to the highest reaction loads on the joints of the connecting rod. Analysts most often look for the highest reactions because the analysis under the maximum loads shows the maximum stresses experienced by the connecting rod.

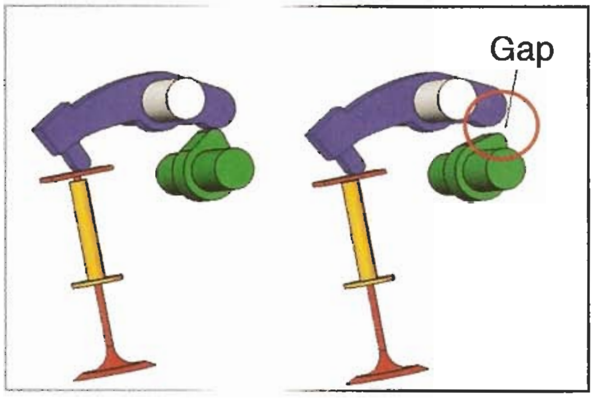
3. Transfer those reaction loads, along with the inertial load from

Virtual verification



Simulated movement of an industrial robot through several positions makes it possible to create a tool path without physical tests.

Impact analysis



Impact and contact can be simulated, for example, to study a gap that may form between a cam and follower (rocker) in a valve lifting mechanism.

the CAD assembly to the connecting rod CAD model.

4. The loads that act on the connecting rod isolated from the assembly consist of joint reactions and inertial forces. According to the d'Alembert principle, these loads are in balance, making it possible to treat the connecting rod as a structure under a static load.

5. A connecting rod subjected to a balanced set of static loads is assigned elastic material properties and submitted to FEA for structural static analysis. FEA performs structural analysis to find deformations, strains, and stresses.

Motion simulation and test

Motion simulation can import time history data from a test, so existing mechanism motion can be easily reproduced and fully analyzed using inexpensive computer models rather than time-consuming and expensive tests. Similarly, mechanisms can be analyzed under input defined by an analytical function.

For example, in the case of a car suspension, motion simulation answers typical questions: How soon after a wheel hits a curb will suspension oscillation die out? What is the required damping in the strut? What stresses are induced in the control arms and its bushings?

Integrated software

Both motion simulation and FEA use CAD assembly models for analysis. A common, integrated software environment for all three tools facilitates the data exchange among CAD, motion simulation, and FEA. Why?

Integration eliminates the need for cumbersome data transfer via neutral file formats, typical to standalone applications. In addition, the use of motion simulation integrated with CAD (and not interfaced with it) greatly reduces the effort required to set up motion simulation models.

Another timesaving aspect is that material properties and CAD assembly mates can be reused when creating a motion simulation model. Motion trajectories, which are results of motion simulation, can be turned back into CAD geometry. This, however, is only possible in an integrated software environment. Additionally, integration with CAD eliminates the need to maintain a database for motion simulation models by storing simulation model data and results together with CAD assembly models. Finally, any CAD changes are fully associative with simulation and FEA models.

We hoped you enjoyed this series. For more information, visit solidworks.com. To access the first part of this series, visit motionsystemdesign.com.