Optimizing reciprocating motion

Reciprocating motion is found in cutting, pumping, and positioning applications everywhere. Here are some ways to improve the performance of these cycling systems.

Elisabeth Eitel
Senior Editor

Think of reciprocating motion, and cams — those kings of kinematic linkages — may come to mind. For good reason: Cams have been the traditional gold standard for reciprocating motion since the dawn of industrialization. Even today, modern varieties (designed with software for sophisticated speed and acceleration motion curves) can outpace fluid power and electrical systems on response time. In fact, when a fixed system is acceptable, cams can be the best way to maximize cycles.

"Historically, reciprocal motion has been generated by rotary devices (steam or gasoline engines and electric motors) turning a crank or a cam, or indirectly by turning a shaft," explains Phil Hollingsworth, director of engineering at California Linear Devices, Carlsbad, Calif. However, as he points out: "In these mechanical systems, reciprocal motion is by necessity repetitive in its motion profile, repeating once per cycle. Adjustments to the motion profile can be very time consuming and costly. And due to the inertia of such a system, speed changes can typically only be achieved over the course of several cycles."

So if a system needs to perform varying functions over its life, electronically adjusted systems are more suitable. *Electronic cam* output, as with mechanical cams, is a function of some measured position. However, motion is delivered by synchronized motors driven by (re-programmable) controllers — an approach free of the wear and inflexibility problems of mechanical types.

"With electronic servo-driven actuators, motion profiles can be varied every cycle based on inputs provided by the machine," Hollingsworth adds. Programmable motion control profiles allow stroke lengths, speed, acceleration, and dwell times to be varied for every stroke, or altered occasionally as needed — very versatile. "Change-over in product can be as easy as directing the controller to use different programmed parameters."

Direct driving

In reciprocating applications that need maximum responsiveness, linear-motor actuators generate propulsion power without inertia-creating leadscrews, gears, couplings, or drive motors. The resulting low inertia, coupled with high drive forces, produces acceleration and speed for at least twice the bandwidth of alternative positioners. This means they excel in applications involving repetitive short-distance, forward-and-reverse motion. "And this isn't brute-force reciprocating motion — actuator load positioning is under continuous feedback control for repeatability to within a few microns," says Stan Froud for Copley Controls Corp., Canton, Mass.

"Some linear motors are very re-

Reciprocating examples

Two common examples of reciprocating motion are conveyor diverters and flying dies.

On **conveyor diverters,** smooth-reversing actuators rapidly push packages from one conveyer to another without damaging or throwing them in an uncontrolled manner. "The smooth accurate motion lets conveyers run at higher speeds," Hollingsworth says.

On **flying dies,** actuators accelerate dies — for example, up to the speed of a vinyl-siding extrusion line. The die can then cut the siding to an accurate length at higher speeds than other technologies allow.

"Sometimes, however, reciprocating motion can imply fixed travel with no ability to adjust travel distance," says Froud. "On the other hand, pick-and-place applications involve back-and-forth motion with a travel distance variable under computer command at every move. So in that sense, certain actuators can be too sophisticated for use in simpler reciprocating motion." Here, reciprocating motion is best achieved with a simple rotary motor driving a crankshaft, in turn, producing a fixed-distance, back-and-forth action.

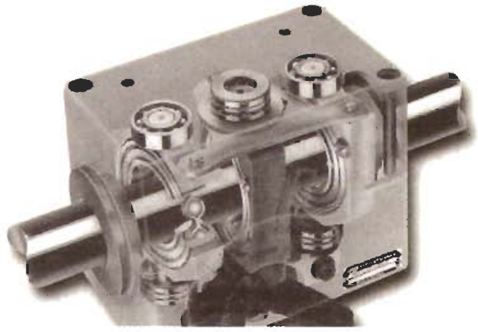
Other examples of reciprocating motion include piston pumps and compressors, roller pressure and tensioning systems, material testing devices, and insertion machines.

sponsive," agrees Hollingsworth, "possessing high bandwidth expressed as very high acceleration rates with *S*-curved motion profiles." This type of profile can be called on to increase machine throughput without shaking things to pieces.

"These *S*-curve motion profiles are different than trapezoidal motion profiles, which have constant acceleration and deceleration and produce a bump on starting and stopping," says Jim Woodward, applications manager at Copley Controls Corp. (The bump is called *jerk* and is the rate-of-change of acceleration.) In trapezoidal moves, the jerk is theoretically infinite because acceleration and deceleration begin instantly and remain constant. "In contrast, *S*-curve profiles ramp up the acceleration/deceleration, controlling jerk, and producing programmably soft starting and stopping. They are great for eliminating noise, wear on machinery, and handling parts that are either fragile or which might fall

Backlash

Backlash is a particularly harmful consequence of reciprocating systems. It imparts shock to loads and actuators, damaging product and limiting equipment life. "To minimize this effect, motion is often slowed, which in turn slows the entire machine — and throughput," says Hollingsworth. "By contrast, direct-drive linear motors are inherently



Rolling-ring drives allow relatively inexpensive single-direction motors to control variable-speed bi-directional linear motion axes over adjustable strokes.

off of machinery when it starts or stops too quickly," Woodward adds.

Doing away with programming

On the other hand, for many reciprocating linear motion processes — slitting, traversing, coating, spraying — mechanical designs such as rolling-ring drive systems eliminate the need for programming and electronics. How? "Rolling-ring drives are mechanically controlled devices, so travel direction and speed are not dependent on drive motor speed or rotational direction. As a result, a variable-speed bidirectional linear motion process may be accomplished using a relatively inexpensive single-direction motor with a simple on/off switch," explains Bob Eisele of Amacoil, Inc., Aston, Pa.

The inner race of a rolling ring bearing is machined to form a sort of ridge — the apex of which remains in constant point contact with the drive shaft — even during reversal. This eliminates backlash during linear motion. Pivoting the bearings from left to right at the end of each stroke causes the drive nut to change direction — without requiring reversal of the rotational direction of the shaft or motor. In repetitive, back-and-forth linear motion applications (where a nozzle, guide, or other tool moves through strokes) this eliminates the need for an electronic control system and therefore simplifies operation.

For more info, log on to amacoil.com, calinear.com, copleycontrols.com, or e-mail the editor, Elisabeth Eitel, at eeitel@penton.com.

free of backlash," he adds. The moving member connects directly to the stationary member through a relatively stiff magnetic field, and the entire mechanism can be programmed to have very smooth starts and stops — much like cam motion, but without the limitations of follower liftoff. Smooth starts and stops also improve machine life and are gentle on transported loads.