Driving machine tool evolution

From speeds of thousands of rpms with micron positioning to adaptive control, ac drives continue to push machine tool capabilities forward.

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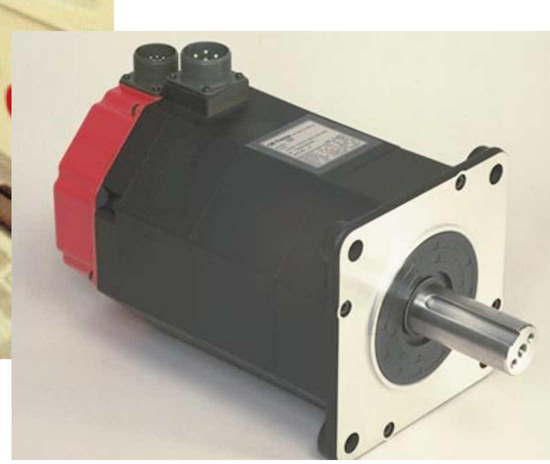

With the latest developments in ac drives, be they servos or spindle drives, designers are developing machine tools that deliver faster, more precise motions than ever before.

Are you up to speed on all the changes in digital ac drives and the latest advances they have brought to machine tools? Some may have escaped notice as the rapid pace of development enables designers to leap over the incremental improvements of the past.

Today's machine tools rely primarily on two distinct classes of ac drives; feed drives (or servos) and spindle drives.

The latest servos offer:

- Four quadrant operation
- Current loop bandwidth of 5,000 rad/sec or more
- Velocity loop bandwidth of 600 rad/sec or more
- Smooth torque (no ripple) even at low speeds
- High static and dynamic stiffness in closed position loops

The latest spindle drives offer:

- Maximum speeds to 40,000 rpm, controllable to zero rpm in contouring mode
- Orientation of the cutting tool with a four-factor increase in rigidity
- Recovery from load changes 33% faster than earlier designs

The digital age

Such improvements are the result of the latest developments in digital control, including feed forward control, friction compensation, absolute feedback, and adaptive control.

Feed forward - that is, feeding the position command into the velocity loop - provides position loop gain control while moving. (Feed forward increases the apparent gain after a valid command to move. It does not affect stability at standstill.) By increasing the feed forward gain, you can reduce following error (lag), which otherwise would be large during high-speed machining. Lag is directly proportional to the gain and inversely proportional to the feedrate. So, it's possible to have near infinite gain with zero lag. Increasing feed forward reduces the following error, letting machine tools cut truer circles and, with look ahead and feedrate change control, cut sharper corners with minimal shock to the machine.

Friction compensation corrects for poor performance from components, such as sticky slides. Friction, servo delay, and backlash can cause flats or other imperfections at the quadrant points where the servo must reverse direction. Compensation functions correct these conditions.

All machines have some friction. The few with a lot require high torque motors. Otherwise, once movement starts, any overtravel in the axis can result in oscillation. Servos are ideal for controlling torque buildup and preventing such overshoot.

The machine may also have a resonance at a low enough frequency to cause vibrations during operation. A notch filter will suppress a fixed resonance. Other feedback functions suppress such sources of vibration as compliance in the lead screw. Plus, the drive can monitor cutting loads and feeds, and initiate alarms for conditions such as a broken tool.

Precise digital control reduces stresses to the machine without sacrificing response. Linear acceleration and deceleration control grants the fastest ramps for a given torque, reaching speed in 30 msec or less with a low inertia motor. Bell curve acceleration imparts a softer start when a machine can't tolerate faster speed changes.

In tapping, the feed amount of the z-axis for one rotation of the spindle should equal the pitch of the tap. Precise digital control and accurate feedback controls the spindle rotation and z-axis feed so that they are always synchronous. This permits rigid tapping at speeds up to 4,000 rpm.

Digital control and improved feedback techniques let the same spindle controller and motor handle contouring. Therefore, axis resolutions can reach 0.001 degree, at spindle speeds to 200 rpm for contouring and 25,000 rpm for velocity control.

Absolute position feedback, which is in wide use in the automotive industry, eliminates machine re-referencing following a power loss. This reduces downtime.

Once referenced, the absolute encoder tracks all motion even during power off. On power up, the control reads the machine position and updates the position registers. Absolute encoders typically have a range of up to 5,000 inches.

Ac advances

Four-quadrant operation, current-loop bandwidths to 5,000 rad/sec, and other capabilities of digital ac drives would not be possible if it weren't for the development of SCRs in the 1960's. They made the first electric dc drives practical. Then in the 1970's, transistor improvements and pulse-width modulation technology produced the first high-performance dc electric drives.

In the 1980's, electronic advances in literally all component areas made it possible to combine ac drives with three-phase ac motors. After developments in control techniques enabled balanced three-phase current operation, ac drives rivaled dc versions in performance.

Today's ac motors have no commutation limits. Compared to dc motors, this gives them a wider operating zone with higher acceleration torques and more useful torque at high speeds. With a correspondingly lower inertia, because they are typically 20% smaller than dc versions, they have faster acceleration and deceleration. Most ac drives run directly off a 230-V, three-phase ac supply, eliminating special transformers. The net result is performance equivalent to or better than a dc system and increased drive reliability.

By any other name . . .

Designations and terminology associated with commercial ac drives can be confusing. Some labels are synonymous, such as *sinusoidal synchronous ac* or *permanent magnet ac*. Both apply to a motor with permanent magnets built into the rotor. The magnets supply the field flux, which interacts with a flux produced by a three-phase stator winding and a three-phase sine wave current for torque generation.

Brushless dc or *electrically commutated dc* (ECM) usually refers to motors that are similar to synchronous but with a pulsed dc current in the form of a trapezoid. *Asynchronous ac* motors are the ac squirrel-cage induction types. They usually incorporate special winding and stator slot techniques for reduced losses and better performance.

Most machine-tool servo applications use sinusoidal synchronous ac motors because they offer smooth operation at low speed. Spindle applications use asynchronous ac motors because they are better at high speeds.

An asynchronous ac motor control usually provides constant torque up to base speed. Then it uses flux-vector techniques, producing an effect similar to field weakening in a dc motor, for constant horsepower to maximum speed. This speed may be as much as 30 times base speed.

Adaptive control may finally have arrived with digital drives. Talked about since the 1950's, it's being implemented in high-speed digital systems as self-tuning or reference-type control.

Self-tuning calculates system parameters and adjusts the control to accommodate them. Reference control, on the other hand, compares the actual system response, such as cutting torque, to a reference model and adjusts the system to respond like the model.

Adaptive control may be as simple as a regulator that tunes itself to a new motor or as complex as a control algorithm dynamically responding to load disturbances. The techniques are math intensive but are possible because of today's high-speed microprocessors.

One example is a form of reference-type adaptive control that accommodates fluctuations in machining conditions. During operation, the drive is continually tuned to reflect changes.

When dealing with resonances, almost all systems are self-compensating at some velocity and torque due to compliance from the motor shaft and coupling. But this effect is of little help in a practical sense because resonance frequency varies with each application. An adjustable filter, however, will track and cancel it.

As desirable as these results are, though, the real payoff is in the system approach to optimize machine performance and overcome limitations. This has led to the 90's advant of an all digital integrated system.

Making the connection

One problem often encountered with digital systems, is that unlike analog systems, there is no single digital standard. Thus, in most commercial systems, velocity and current loops are digital, while command input is a ±10 Vdc analog signal. Some drives offer a digital input option, as it's required to interface with CNC drives, but these are often proprietary.

So drives go from one extreme, intelligent, to the other, servo amplifier. Intelligent drives operate from a position command and close the position, velocity, and current loops in the servo drive. Some also generate more profiles, store programs, and execute diagnostic routines. With servo amplifiers, on the other hand, CNCs close the loops, producing digital PWM signals that serve as amplifier inputs.

Each approach has advantages and disadvantages. For mult-axis machine tool applications, the servo amplifier system is usually best. ●

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