Replacing line-shaft drives with servos improves productivity and quality

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Converting a single-axis, high-horsepower drive to multiaxis, servo-controlled operation is a cost-effective way to achieve higher productivity and quality, at lower operating costs. This guide to critical axis performance and control considerations helps ensure a successful conversion.

The development of high-performance servo motors and drives is producing an accelerating interest in converting single-axis, high-power (line-shaft) industrial drives to multiple-axis, motion-controlled machines. Such conversions mean that fewer machines are needed to produce a certain product mix with greater speed and with higher quality than previously possible.

The key to a successful conversion centers on the analysis of axis power and control requirements. The removal of a line shaft exposes all the vagaries of each axis point; and, because each axis must stand on its own, it is up to the servo designer to compensate for the dynamics of each axis.

The interaction between the mechanics of the machine and the servo system dictates that a competent servo application engineer must be a part of the conversion team. Too often simplistic assumptions are made based on function of the drive and motor and too little attention given to the basic physics of the system. For example, a dc brush-type servo may lack the performance and flexibility required to ensure acceptable axis performance, whereas a brushless ac servo drive may overcome these deficiencies. Similarly, the real-time performance of the controller must be fast enough to maintain axis coordination and duplicate the performance of the mechanical line shaft.

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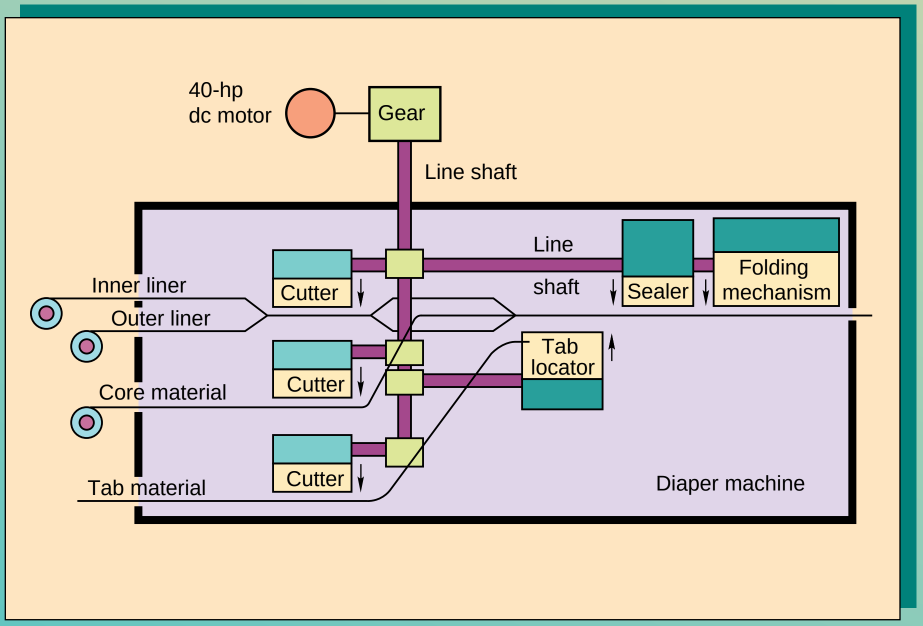
Product changeover, from weeks to hours

The advantages of replacing line shafts with electronic servo drives is illustrated in this simplified example of a diaper-making machine. Originally, the machine incorporated a number of line shafts driving three cutters which trimmed incoming web material to size, a unit for sealing the three-layers of the diaper, an adhesive tab locator, and, finally, a folding unit.

The diaper machine was originally designed as a single-purpose machine. Reconfiguring the machine to produce a diaper of a different size or design meant removing the machine from production, changing gear pinions and shafts, and modifying cams. This process usually took four weeks and then the machine had to be recommissioned.

Redesign of the machine with a high-performance motion controller and servos



Simplified configuration of diaper machine driven by original line-shaft.

Today, with modern brushless drives, servo driver speed-loop bandwidth can be 300 Hz. In addition, controllers can pass information required for axis synchronization with the speed of light through fiber optic cables. This capability insures that machines with an almost unlimited number of axes can be operated with absolute synchronism. Position-loop update times of less than 1 msec are sufficient to maintain position accuracy well above that of the mechanical equivalent. On the surface, such positioning accuracy may seem unreal, but, considering the shaft wind up plus gear and coupling play in a line-shaft system, the newer capabilities are plausible.

Axis torque requirements

Perhaps the most basic consideration in any conversion is to determine how much torque each axis requires. One obvious, but not cost effective, answer is to put the largest servo motor and amplifier available on every axis.

A more precise approach is to instrument each axis with a torque transducer, run the machine in production, and record the real-time loading on each axis. By moving the transducer from axis to axis, data can be taken one axis at a time. Although time consuming and expensive, this method produces accurate results.

The advantage of taking data in real time is two fold. First, the actual loading at every point in the machine cycle can be documented. Second, peak torque and rms torque can be calculated so the smallest servo motor and driver capable of doing the job can be selected.

If the appropriate instrumentation is unavailable for this method, an alternate but less accurate approach is available. Each axis is disconnected from the line shaft, and a fish scale is used to pull the axis through enough revolutions to determine the frictional and, possibly, the steady-state process load. The inertia of each section can be calculated and, using a plot of the axis motion during one machine cycle, you can estimate the acceleration and deceleration torque values. At best, this method produces only an estimation of actual axis loading.

Axis dynamics

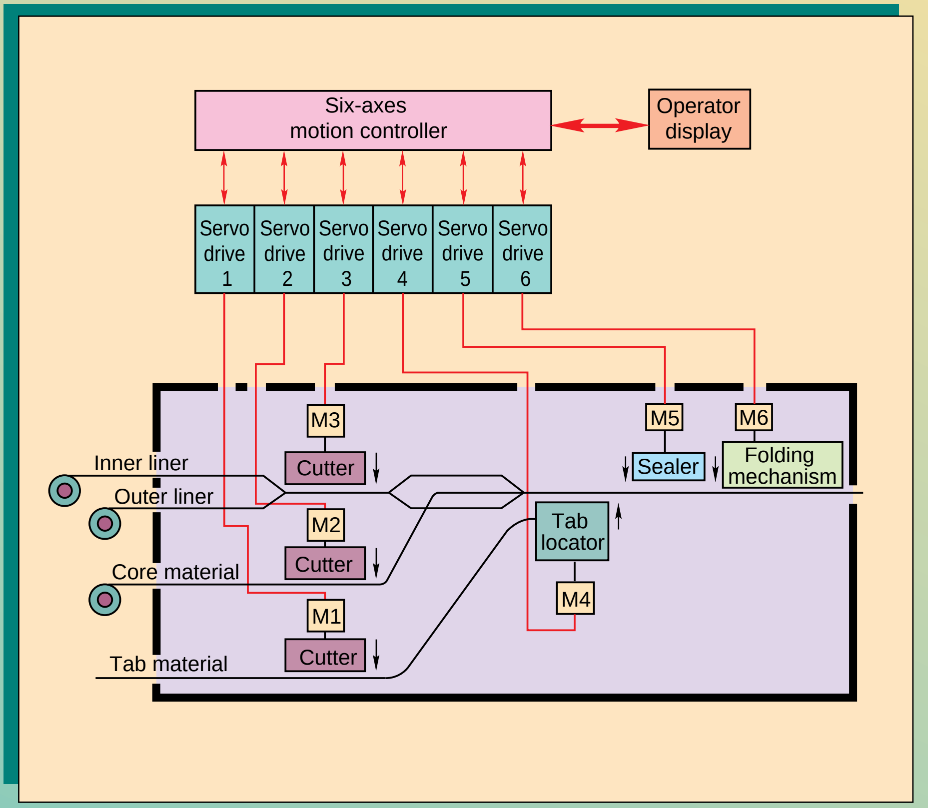
The dynamic performance of each axis is determined not only by frictional and inertial loads, but also by the system spring-mass characteristics.

In a single spring-mass system — represented by a simple motor-shaft-pulley arrangement — the pulley acts as a simple mass and the shaft acts as a spring. As the motor applies torque to the system, the angular position of the pulley will lag behind that of the motor according to magnitude of the mass, magnitude of the torque, and spring constant of the shaft. The longer, or thinner, the shaft, the greater will be the lag between pulley and motor for a given torque.

Natural frequency. These factors also affect the natural frequency of the system. In a simple motor-shaft-pulley system, if the motor is fixed and torque is applied to the pulley then released, the pulley will oscillate at the natural frequency of the system. This frequency depends on the length, thickness, and material of the shaft and the inertia of the pulley.

The natural frequency of an axis has a

driving the various machine units reduced product conversion time from 4 weeks to about 4 hours. In addition, the electronic cams produced motions that could not be produced by the mechanical design thus improving product quality. Also, by means of a menuing system, the entire machine can be set up for a product change by simply entering a product code. And, from prototype production data, it was possible to optimize the size of the motors driving each axis.



Retrofit configuration with high-performance motion controller and servo drives.

profound effect on its performance. If the natural frequency of a machine component is much higher (greater than several hundred hertz) than the frequency of machine operation, it will not interfere with the machine performance. But, when a machine operates at a frequency close to the natural frequency of a component, performance of the component will probably vary from cycle to cycle. Even more important, an increase in machine speed may cause the component to vibrate violently, degrading product quality and producing a machine shut down.

Inertia considerations. In general, servo designs are most easily implemented when the axis inertia is about the same as the servo motor. While some mismatch (up to 10 to 1) can easily be accommodated, often in the real world of production machines the mismatch can reach 100 to 1. When a high value of inertia mismatch is a problem, a judicious choice of gear ratio between the servo motor and load can reduce the inertia mismatch to a more acceptable level.

When a machine is being converted from mechanical to servo-controlled axes, sophisticated digital filters may be necessary to provide axis performance that is consistent with process needs. Sometimes it is necessary to adjust servo amplifier dynamic parameters to minimize or eliminate the effect of an oscillating load due to inertia mismatch. The ability of digital servo amplifiers to accommodate a wide range of adjustment enhances the probability that a setting or filter can be found that will enable the axis to perform optimally. ■