MACHINE DESIGN

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Penton

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Relieving tension with electronic gearing

The declining cost of precision motion controls allows economically replacing mechanical drives with electronic versions in web-processing lines.

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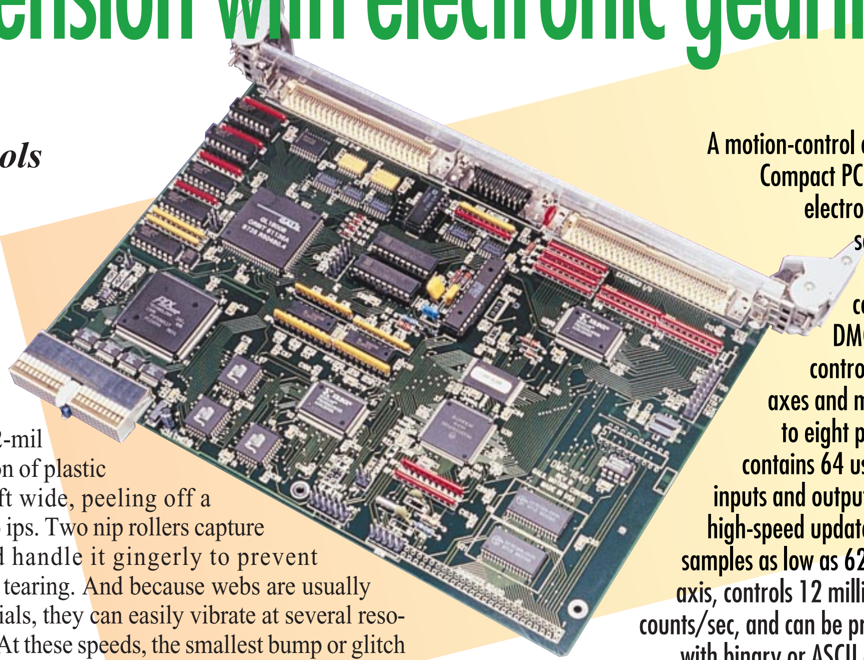


A motion-control card for the Compact PCI bus drives electronic-gearing servomotors in web controls. The DMC-1600 can control up to four axes and multitask up to eight programs. It contains 64 user-selected inputs and outputs, provides high-speed update rates with samples as low as 62.5 μsec per axis, controls 12 million encoder counts/sec, and can be programmed with binary or ASCII commands.

Imagine a 2-mil thick ribbon of plastic wrap, 20-ft wide, peeling off a spool at 36 ips. Two nip rollers capture the web and handle it gingerly to prevent stretching or tearing. And because webs are usually elastic materials, they can easily vibrate at several resonant modes. At these speeds, the smallest bump or glitch in feed rates can spell disaster for the entire web-processing line.

Because the web material adjusts its own tension and provides a critical link between the controlled motor and the tension sensor, the system is unique among motion-control designs. Although web-control systems have been around for decades, most are fraught with niggling mechanical problems. But an advanced technique based on electronic gearing is finding increasing favor in new designs. With the cost of precision drives and controllers continually dropping, it's now more economical to use electronic controls in place of mechanical gears. Electronic systems are programmable, more reliable, and require less maintenance than traditional mechanical systems. Other benefits include quieter, smoother operation, pluggable modules for easy repair, and built-in diagnostics.

The programming capability alone is a major improvement well worth the investment. It lets designers quickly reconfigure a web line using a computer keyboard or human-machine interface keypad. Gone are the days of changing gears and time-consuming setup procedures. Converting a production line is now only a matter of minutes.

MEASURING TENSION

Typically, the four elements of a tension-control system include sensors, motors, amplifiers, and controllers — often just a card plugged into a PC. The most critical input variable, web tension, is usually measured with a spring-loaded dancer arm sensor. The web wraps around the arm and measures tension by sensing the angular position of an attached potentiometer or incremental encoder.

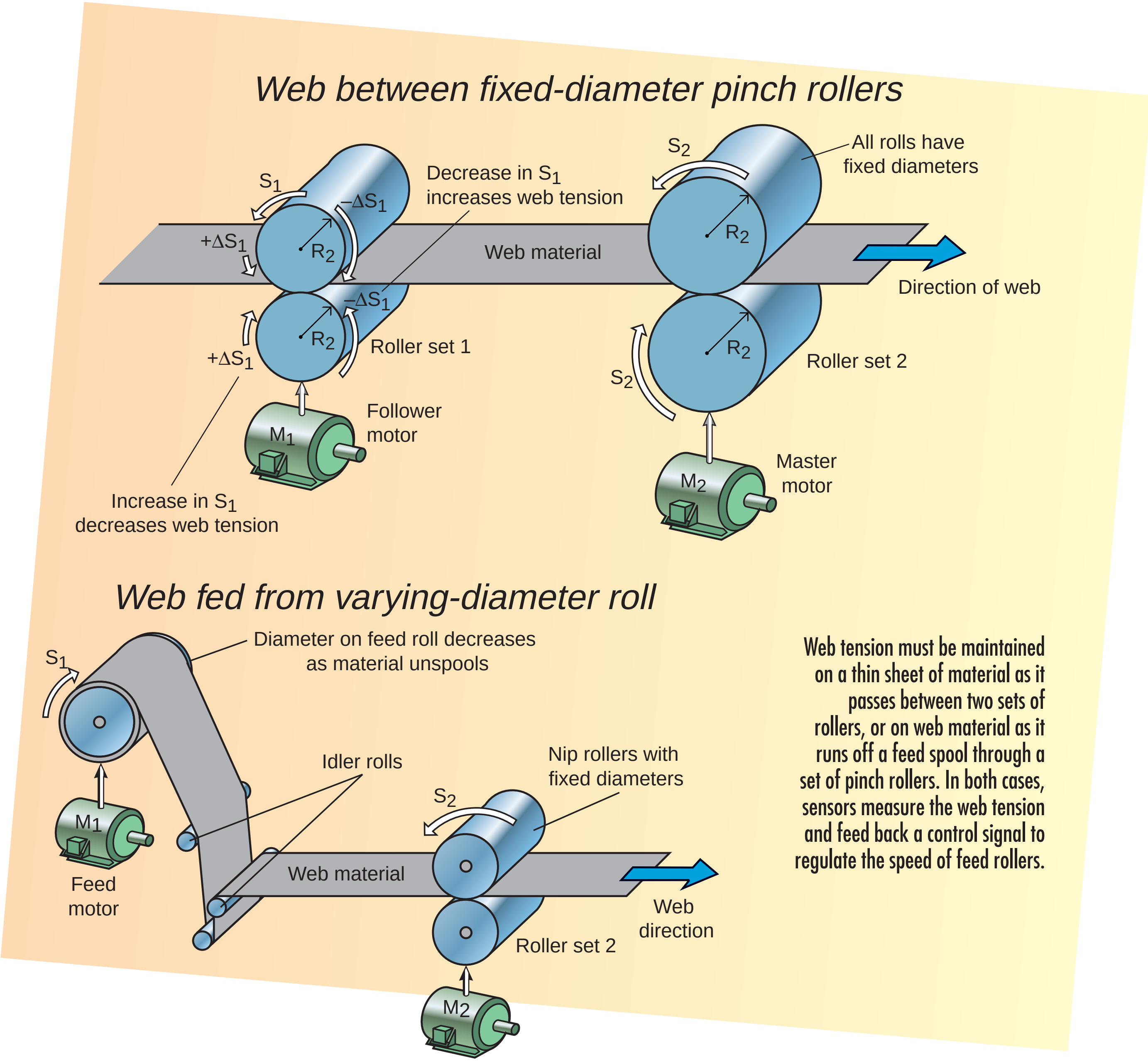
Although dancer arms are common means for measuring tension, load cells provide viable alternatives. Both units contain idlers to generate small displacements that keep in step with the changing tension. Although dancer arms rotate and load cells sense pressure, the load cell's range is typically much smaller than the dancer arm. Thus, the load cell gain — the ratio of the output signal to the input motion — is much higher than for the dancer arm. In many cases, a sensor with high gain provides a tighter, more accurate, and faster responding control system. But for web control, higher gain is not always better. Excessively high sensor gain also effectively increases the control-loop gain and can drive an adequate system unstable. A good rule of thumb is to try a dancer arm first.

CONTROL METHODS

The tension of the web between two sets of rolls is always under control. Accepted practice dictates that one roll-drive motor be made independent or a master. The other drive motor is called a follower, driven by a controller which senses tension and varies the motor speed. For instance, as the follower feeds the web to the controlled section, its speed increases to relax tension or decreases to increase tension.

In spite of the relative simplicity of web-control systems, their design can become particularly involved under certain conditions:

- Precise tension requirements call for tension variations within a very narrow range and a highly accurate position-control system.
- When devices with narrow ranges of motion such as



Web tension must be maintained on a thin sheet of material as it passes between two sets of rollers, or on web material as it runs off a feed spool through a set of pinch rollers. In both cases, sensors measure the web tension and feed back a control signal to regulate the speed of feed rollers.

load cells measure tension, the position range of the motor decreases significantly.

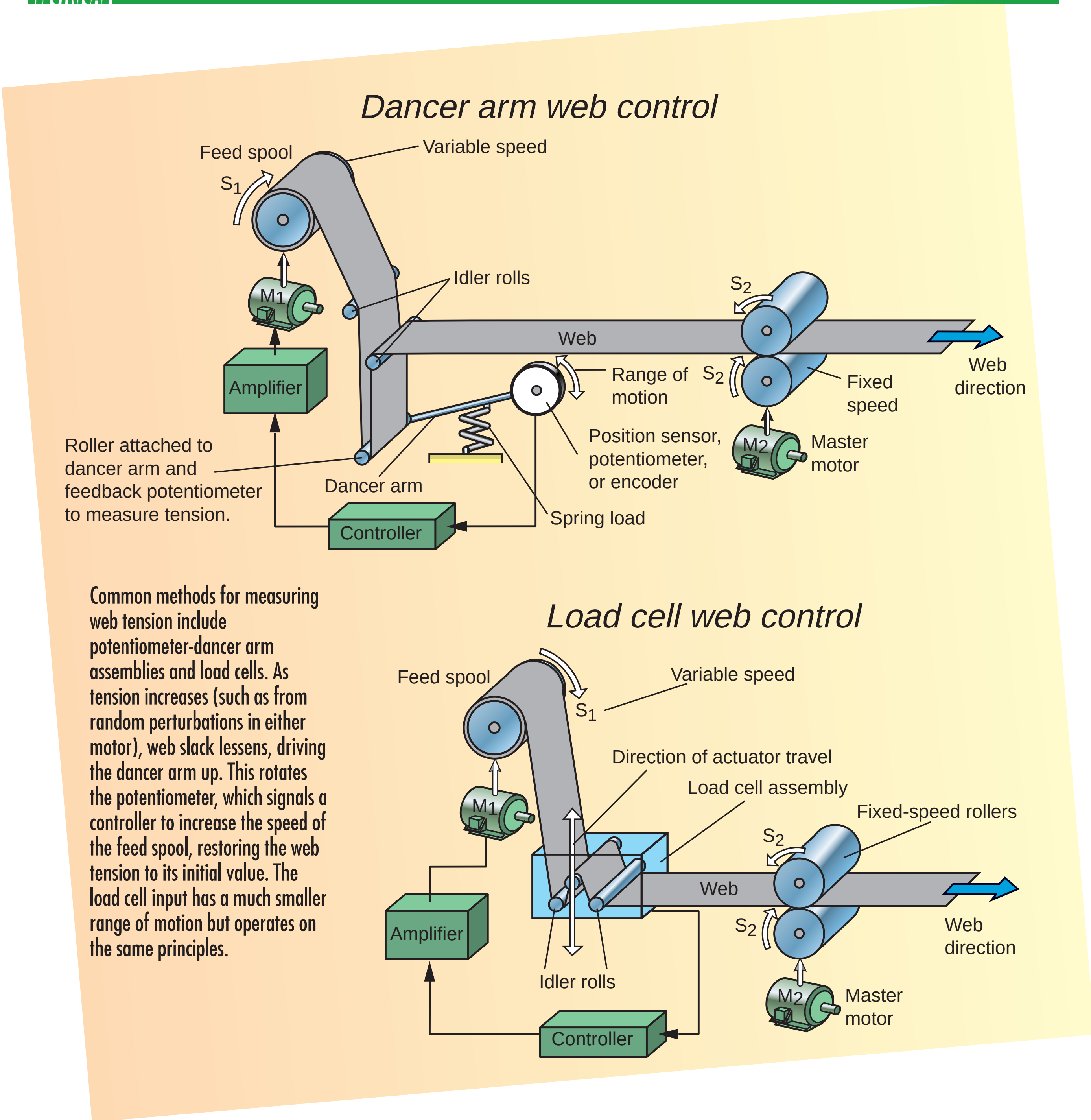
• Flexible webs tend to stretch making motor and load-sensor positions drop out of sync. They then behave as though connected by a rubber shaft, and the soft coupling generates a resonance mode that can drive the system unstable. However, placing the sensor as close as possible to the controlled motor minimizes the effect. As the web between the motor and sensor becomes shorter, flexibility decreases. Unfortunately, no method has been found to completely eliminate this problem.

An improved design approach, however, may overcome some of the major drawbacks inherent in these systems. It commands the follower motor to run in what's called coarse and fine motion modes. Closed-loop control handles fine positioning, and other means such as electronic gearing controls coarse positioning — the major portion of the motion profile.

To illustrate, consider a system where the web moves between two rollers of fixed and equal diameters. Commanding the follower motor to pace the master at a one-to-one ratio provides coarse control.

However, fine control adds (or subtracts) incremental motion occasionally to correct for inaccuracies in roller dimensions and to respond to random disturbances. Because the range of fine motion control is relatively small, it requires comparatively low gain, which decidedly simplifies the loop design.

Gear ratios also play a critical part in accurately controlling motion. For example, the web moves from a feed roll with varying diameter to a nip roller with a fixed diameter. In this case, the gear ratio between the two motors varies continuously, and it's necessary to estimate the value. Both master and follower motors contain position sensors which provide a simple method for estimating these gear ratios. The ratio comes from periodically measuring the positions of the two motors and comparing their incremental differences. The tension-sensor output compares to the commanded tension or setpoint, and their difference, *E*, is called the tension error.



Common methods for measuring web tension include potentiometer-dancer arm assemblies and load cells. As tension increases (such as from random perturbations in either motor), web slack lessens, driving the dancer arm up. This rotates the potentiometer, which signals a controller to increase the speed of the feed spool, restoring the web tension to its initial value. The load cell input has a much smaller range of motion but operates on the same principles.

The objective of superimposing the fine motion component is to drive E to zero.

For example, adding velocity factors to fine control increases or decreases the velocity of the follower motor by an amount proportional to E. Most systems can tolerate a large ratio between the speed increase and E for fast response. But when it's too large, the system can become unstable.

Yet another approach changes the gear ratio in proportion to E. Although this method appears to equal the first, it's less effective because it works over a smaller range, and the error is proportional to the speed of the master motor. However, in extreme cases such as when the master motor stops, no error signal appears, and the controller cannot make a correction. Because of this, the added-speed method is preferred over simple gear-ratio changing for most applications.

DESIGN EXAMPLE

Consider a system that uses a 6-in.-diameter master nip roller and a 12-in. follower-roller motor. Also, assume that servomotors and encoders having 4,000 counts/turn resolution control the feed follower and nip rollers. The master advances the web 200 in. at a constant 24 ips, and the acceleration or deceleration rates are 40 in./sec^2. The velocity of the follower motor must then maintain the commanded tension.

The tension sensor in this case comprises a load cell with an output signal ranging between 0 and 10 V with the design center at 4 V. A

Master motor program

PROGRAM	INTERPRETATION
#RUN	Label
PRY = 424400	Distance
SPY = 50928	Speed
ACY = 84800	Acceleration
DCY = 84800	Deceleration
BGY	Start *Y* motion
EN	End program

This program starts with the label #RUN to identify it. It proceeds with the parameters of the distance, speed, acceleration and deceleration of Y, and commands the start of motion with the BGY command. The interpretation comments are only for explanation and are not a part of the program.

Modified speed program

INSTRUCTION	INTERPRETATION
#TENSION	Label
JGX = 0	Initial jog speed = 0
ACX = 100000	Acceleration of *X*
DCX = 100000	Deceleration of *X*
BGX	Start X mode
#TLOOP	Label
E = @ AN [1] - 4	Calculate tension error
JGX = E * 20	Set correction speed
JP #TLOOP	Repeat loop
EN	End program

The #TENSION program performs the fine-speed adjustments needed to keep the tension constant. After the label, the program sets the *X*-axis in the jog mode with zero initial speed. Tension control is done by an algorithm that starts with the label #TLOOP. The first step calculates *E*, the error in tension, which equals the difference between the tension, represented by the analog signal @AN[1], and the desired set point, 4. To eliminate the tension error, the program increases the *X*-motor speed by an amount of 20 *E*, which is directly proportional to the error *E*.

Gear ratio program

INSTRUCTION	INTERPRETATION
#GEAR	Label
GAY	Set Y as gearing master
GRX = 0.5	Initial gear ratio of 0.5
XP = _TPX	Starting *X* position
YP = _TPY	Starting *Y* position
#LOOP	Label
P = YP +1000	Define next position target
MF, P	Wait for Y motor to reach P.
X =_TPX	Measure *X* position
Y = _TPY	Measure *Y* position
DX = X - XP	Calculate increment DX
DY = Y- YP	Calculate increment DY
G = DX/DY	Calculate gear ratio G
GRX = G	Upgrade gear ratio
XP = X	Update previous *X* position
YP = Y	Update previous *Y* position
JP#LOOP	Repeat the process
EN	End program

This program sets the Y-motor as the master and the X-motor as a follower with an initial following gear ratio of 0.5. As the following ratio varies with the roll diameter, the program estimates the varying gear ratio and updates it. A simple method for estimating the gear ratio determines the position increments DX and DY of the two motors, and then calculates the gear ratio, G, as DY/DX.

single controller card plugged into a desktop computer handles the *X*-axis follower motor and the *Y*-axis master motor, with the tension feedback signal connected to the analog input terminal. Three programs running simultaneously in the controller card direct the master motor, estimate and update the gear ratio, and fine-tune the tension.

Master-motor control theory is straight forward. The circumference of the 6-in. roll is 6π in. And with an encoder resolution of 40,000 counts/turn, each inch equals 2,122 counts. Accordingly, 200 in. of travel produces 424,400 counts, a velocity of 24 ips generates 50,928 counts/sec, and an acceleration of 40 in./sec^2 equals 84,800 counts/ sec^2. The #RUN program for the master motor is shown in the "Master Motor Program" table.

The second program, #GEAR, commands the *X*-axis to follow the master-*Y* axis in gearing mode. Because the initial 12-in.-diameter feed roll is twice the diameter of the nip roller, the initial gearing ratio is 0.5. The algorithm monitors the position of the *X* and *Y* motors for every 1,000 counts of *Y*. It then calculates the corresponding position increments *DX* and *DY*, and estimates the gear ratio as *DX/DY*. This is illustrated by the program in the "Gear Ratio Program" table.

Finally, the third program, #TENSION, in the *Modified Speed Program*, monitors the tension signal and subtracts a 4-V set-point value to calculate the tension error *E*. It adds a speed of 20*E* to the *X* motion, where the proportionality factor of 20 was found to be the optimal value. ■

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