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THE ENGINEER'S GUIDE TO DRIVE, CONTROL, AND SENSING TECHNOLOGY

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Keys to controlling web tension

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Controlling web tension with load cells: Part 1 of 3

Many engineers and technicians are unfamiliar with the use of load cells for web tension control. But well-selected load cells improve web applications.

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During manufacturing or converting processes, material is generally pulled off a roll, processed, and rewound — in sections called unwind, intermediate, and rewind zones, respectively. Knowing the unique tension values for each zone is important to making proper process adjustments.

There are several ways to measure and control tension in these zones; some are more sophisticated than others. As we'll see, load cells are the only accurate way to measure web tension. They're important because without accurate tension values, adjustments are inconsistent and may actually reduce throughput or quality.

Basic method: An operator taps on the web and by "feel" tries to determine the amount of tension. With this basic method, tension is adjusted by manually changing brake torques, dancer loads, gear ratios, or motor speeds. The operator continues tapping the web and making adjustments until a satisfactory result is achieved. Because this is a manual process, adjustments take time, and as a result, much wasted product is produced.

Too, there is no consistent way of measuring or altering the tension. Attempts may be made to record settings, but as brake pads and other machine parts wear, the settings produce different tension levels. Temperature changes and inconsistencies in the material also affect tension. Furthermore, different operators have differing opinions on which tension feels right. Product quality is suspect and inconsistent, and this method can even be unsafe. Since tension is unknown, so are the limits to which line speed may be increased. Trying to run at high line speeds may produce stretch or even break the web. Running at low line speeds may be required to produce acceptable product; this greatly limits throughput.

Better method: Load cells are used to measure tension and the value is displayed on an indicator. An operator still manually adjusts the tension. Load cells are added to the rollers (or sheaves and pulleys) in the tension zones to measure the tension and the values are displayed on tension indicators — meters or screen displays. The operator takes the appropriate corrective action to adjust the tension by manually changing brake torque, dancer loads, gear ratios, or motor speeds.

Here, the measure and display of tension is consistent but the control of it is not. Product quality is greatly improved but is somewhat inconsistent. Since the tension is known, so too ar the limits to which the line speed may be increased before the material stretches or web breaks. The line speed may be increased but only to the amount that it can be controlled. Manual intervention by the operator still limits the response time and how tightly the tension values can be controlled. As a result, much wasted product is still produced.

Best method: Load cells are used along with controllers and actuators to automatically measure and adjust web tension. In this setup, load cells are added to the rollers (or sheaves and pulleys) in the tension zones. The load

Definitions

The terms *load cells* and *tension transducers* are used interchangeably to describe a sensor that measures tension in a moving web. The term *load cell* commonly describes weigh-scale sensors that measure the force or load due to the weight of an object. The term has carried over to the web-processing industry, since similar sensors measure the force produced by web tension. *Transducers* transform one type of energy into another. Therefore, a tension transducer is a sensor that measures the force resulting from tension in a web, and transforms it into electrical energy.

cells are connected to a device that displays the tension value and automatically controls the brakes, dancers, gear ratios, or motors. An operator enters the desired tension setting and the appropriate corrective action is performed automatically. The controller may be any closed-loop standalone device, PLC, or programmable drive. They continually compare the tension set point to the actual tension being measured by the load cells and automatically take corrective action to ensure that these values agree. This method provides a consistent means of measuring and controlling tension. Tension control is done automatically and requires minimum operator intervention. Product quality is at its best and consistent. Corrective action takes place immediately. As a result, little wasted product is produced.

Because the tension is known, so too are the limits to which the line speed is increased before the material stretches or web breaks. Also, highly responsive automatic closed-loop tension devices tightly control tension values — so the only limiting factors are control loop response time and actual process limitations.

How they work

Load cells employ strain gages, LVDTs (linear variable differential transformers) or other electromechanical sensing devices.

Consider a strain-gage cartridge-style transducer. The transducer is fastened to the machine frame at one end, and to a roller on the other. Then, the web is wrapped over the roller. Inside each transducer, strain gages are attached to a pair of beams made of spring steel. Referred to as dual beams, they are fixed at one end with the free end connecting to the roller. As tension is applied to the web, the force is transferred from the roller directly to the transducer.

The component of force applied perpendicular to the beam deflects or bends them. This bending (typically 0.002 to 0.004 in.) creates a strain or elongation of the molecules in the beams. The strain gages measure this elongation and generate an electrical signal proportional to the amount of force applied — the web tension value.

To accommodate larger force, beam cross-sectional area can be increased by making it either wider or thicker. The greater the transducer load rating (maximum working force or *MWF*) the larger the beam. So, a transducer with an MWF rating of 150 lb has a beam both wider and thicker than one rated for 25 lb. Overload stops are provided on many cartridge-style transducers, allowing them to accommodate overloads of 150 to 300% of their rating.

Which style?

Selecting a load cell first requires that the proper style be chosen. Different load-cell units are designed for different applications and tension ranges. Several application-specific questions must be answered before choosing.

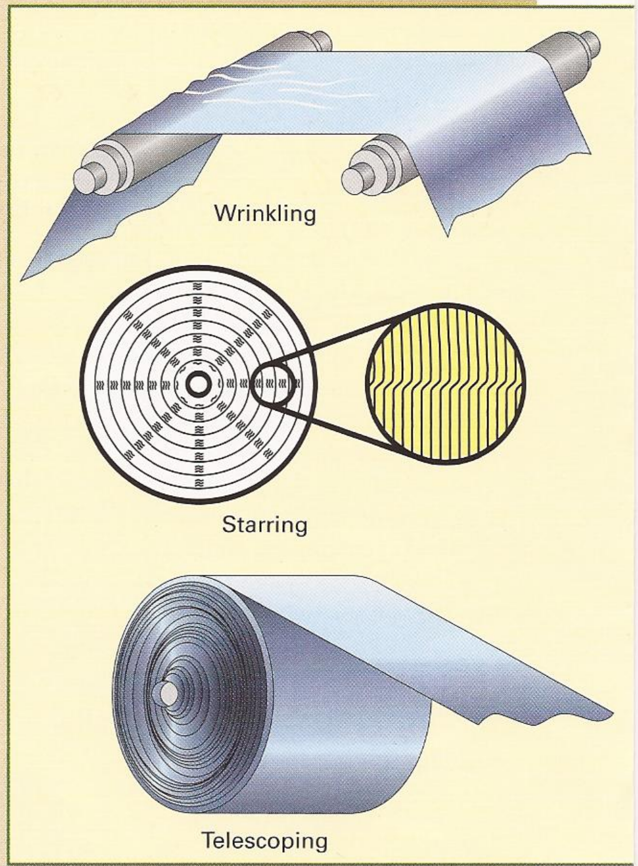
❶ Determine if you have a wide or narrow web. Typically a wide web is over 20 in. wide and utilizes a roller assembly supported on both ends. Some production processes utilizing a wide

What is web tension control?

Web tension control refers to methods used to measure and adjust tension in a moving web. In this context, a web is any material continuously pulled from a roll through some manufacturing process. Tension is the measurable force that stretches or elongates the web. Web tension control methods range from feeling and controlling tension by hand to advanced systems that automatically measure and make adjustments to the process.

Most processes involved in the production or converting of paper, film, plastic, foil, textile, wire, and cable require some form of tension control. It is also necessary on products that require winding onto rolls, printing, coating, laminating, slitting, and extruding. Here we discuss only continuous roll fed (and not sheet-fed) material.

If tension is not properly controlled, wrinkles in the material may result in defective or wasted product, or the outer layers may crush the inner layers, leading to starring, or the inner layers may telescope out resulting in ruined product. When printing on a roll of material, improper tension control results in smeared ink and fuzzy images from poor registration. Applying too much tension may stretch some materials beyond their elastic limit rendering them unusable. In contrast, properly controlling web tension results in higher quality product and produces greater throughput by allowing processes to run at high speeds without sacrificing product quality.



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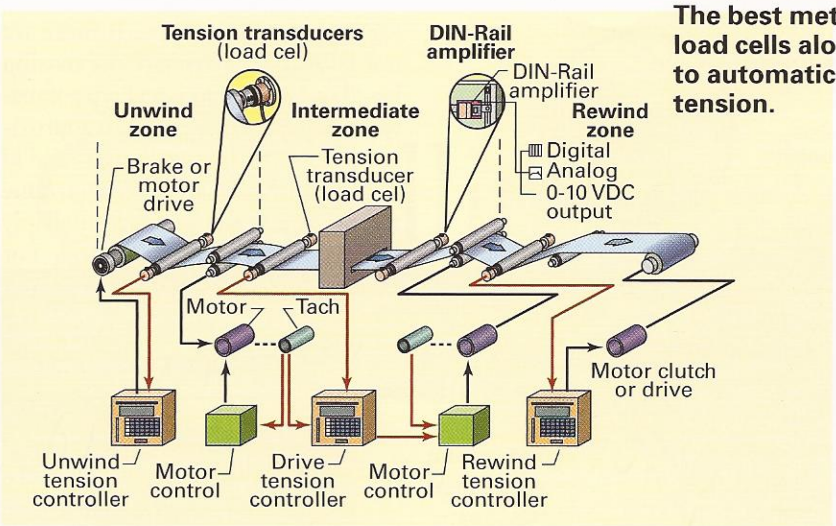


Complete converting system

The best method for web tension is to use load cells along with controllers and actuators to automatically measure and adjust web tension.

web include paper, film, foil, and plastics — and printing and converting of these products with coating, slitting, and laminating. Here, two transducers are required per roller: one mounted at each end of the roller assembly.

Narrow spools for winding cable or wire are typically less than 20 in. wide, and utilize a cantilevered roller or pulley supported at one end by a load cell. Commonly, the outer sleeve rotates on bearings around a center shaft that runs the length of roller assembly. The shaft is held in place on one end and hangs free on the other. The amount of deflection of the shaft due to the overhung tension load limits the practical length of the cantilevered roller to about 20 in. These also accommodate fiber-optic strands, filaments, some hygienic products, and other narrow products that run over a pulley or guide roller.

Standard load cells can often accommodate customer-mounted pulleys to eliminate the expense of integrated rollers. Other styles are designed for specific applications. Only one transducer is required per roller since it supports a cantilevered roller or pulley.

❷ Determine if you have a stationary or rotating shaft roller. Stationary shaft rollers have a shaft that run all the way through the assembly. The outer shell or sleeve is a cylinder that rotates around the shaft on bearings. The shaft does not rotate but remains stationary. Stationary shaft rollers are also referred to as fixed or dead shaft rollers. They're used in many applications because they are relatively easy to manufacture and are readily available.

Narrow-web cantilevered rollers and pulleys generally use stationary shafts. Here, the most suitable transducers are designed so the web can be positioned anywhere along the length of roller face without affecting the ten-

Tension data

Material	Tension, lb/in./mil (1 mil = 0.001 in.)	Paper and laminations	Tension, PLI
Aluminum foils	0.5 to 1.5 (1.0 average)	20# /R - 32.54 gm/m²	0.5 to 1.0
Cellophanes	0.5 to 1.0		
Acetate	0.5	40# /R - 65.08 gm/m²	1.0 to 2.0
Mylar (Polyester)	0.5 to 1.0 (0.75 average)		
Polyethylene	0.25 to 0.30	60# /R - 97.62 gm/m²	1.5 to 3.0
Polystyrene	1.0		
Saran	0.05 to 0.20 (0.10 average)	80# /R - 130.1 gm/m²	2.0 to 4.0
Vinyl	0.05 to 0.20 (0.10 average)		

Substrate	Approximate tension, lb/in.
Mylar, oriented propylene, and polyester	
0.0005in.	0.25
0.001 in.	0.5
0.002 in.	1.0
Cellophane	
0.00075 in.	0.5
0.001 in.	0.75
0.002 in.	1.0
Nylon and cast propylene (non-oriented)	
0.00075 in.	0.15
0.001 in.	0.25
0.002 in.	0.5
Paper	
15 lb/ream (3,000 sq. ft.)	0.5
20 lb/ream	0.75
30 lb/ream	1.0
40 lb/ream	1.5
60 lb/ream	2.0
80 lb/ream	2.5
120 lb/ream	3.5
160 lb/ream	4.5
200 lb/ream	5.5
240 lb/ream	6.5
280 lb/ream	7.5

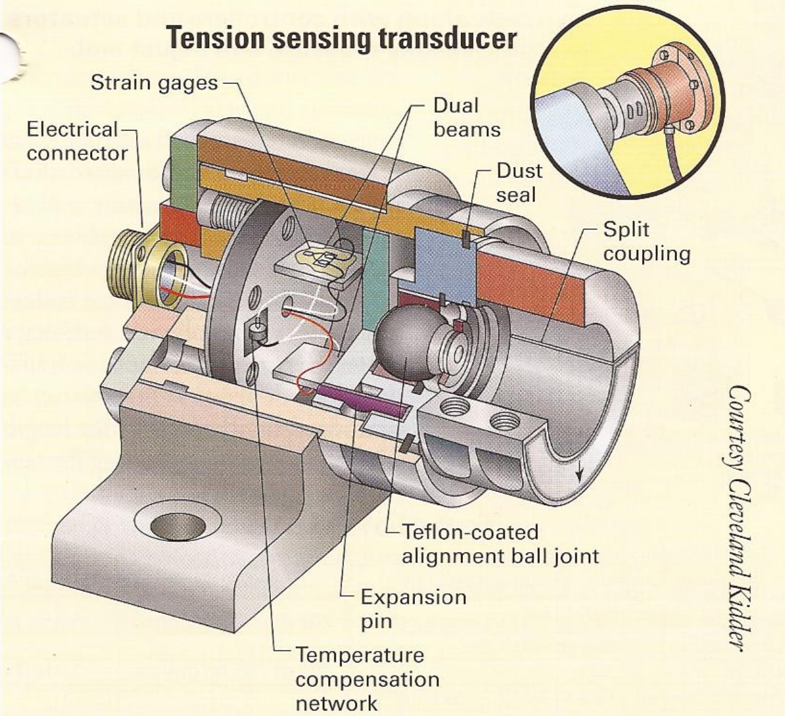
Substrate (1 pt. = 0.001 in.)	Approximate tension, lb/in.
Paperboard	
8 pt.	3.0
12 pt.	4.0
15 pt.	5.0
20 pt.	7.0
25 pt.	9.0
30 pt.	11.0
35 pt.	13.0
45 pt.	15.0
65 pt.	19.0
Laminations	
25-lb. paper/0.0005-in. PE/.00035-in. foil/.001-in. PE	3.0
0.001-in. cello/.0005-in. PE/.001-in. cello	1.5

Note: When these substrates are coated with polyethylene, nylon, polypropylene, EVA, EAA and EEA, add the following tension values to the values listed above for the substrate only.

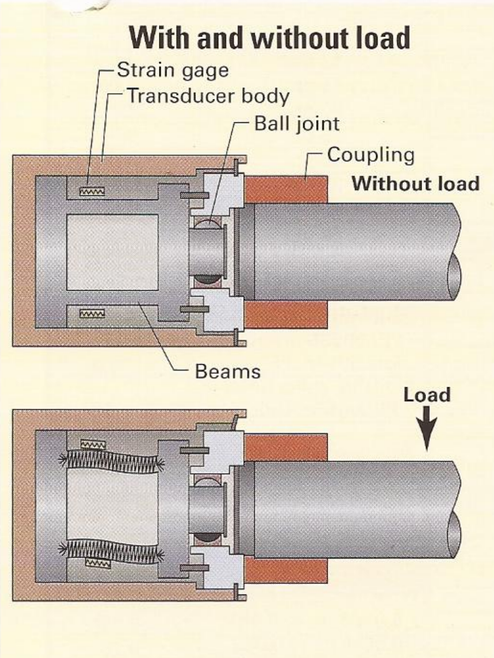
Coating thickness	Approximate tension, lb/in.
0.0005 in. to 0.001	0.12
0.0011 in. to 0.002	0.25

Copper wire

AWG	Tension	AWG	Tension
8	30.0 lb	20	5.0 lb
10	20.0 lb	24	4.5 lb
12	12.0 lb	30	1.25 lb
14	9.0 lb	36	0.25 lb
16	6.0 lb	40	0.1 lb



The transducer is first fastened to the machine frame at one end and to a roller on the other end. Then, the web is wrapped over the roller. Inside each transducer, strain gages have been attached to a pair of beams made of spring steel.



The component of force applied perpendicular to the beam deflects or bends them. This bending creates a strain or elongation of the molecules in the beams.

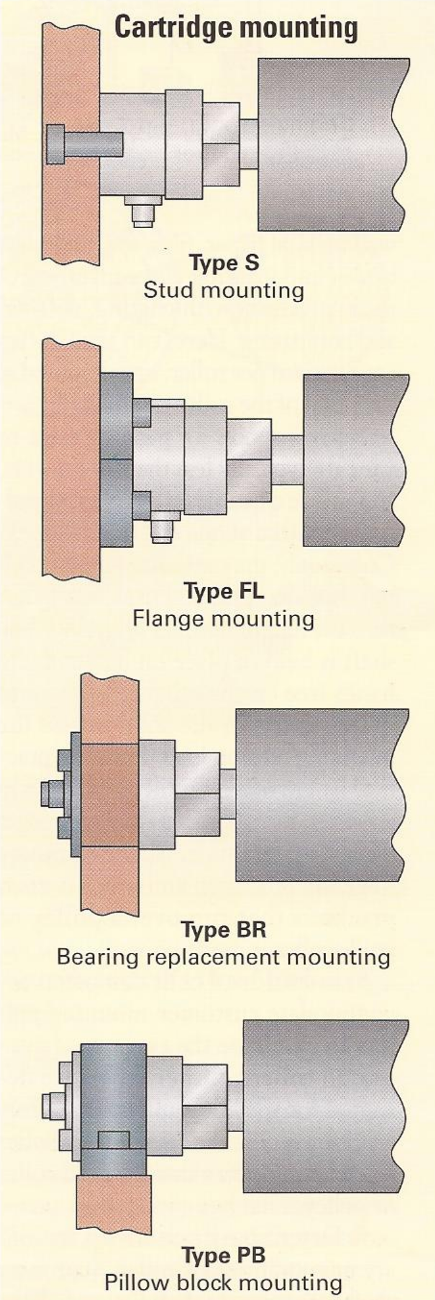
sion measurement.

Cartridge-style and slim cell transducers are most suitable for wide web rollers with stationary shafts. The former comes with flange and pillow mounting kits. Low-profile designs, on the other hand, can be mounted inside or outside machine frames. Under pillow block loads, load cells with bearings are most suitable.

Rotating shaft rollers are designed so that the shaft is part of the rotating assembly. The outer shell or sleeve is integral to the shaft; there are no bearings in the assembly, and the shaft rotates.

Rotating shaft rollers are generally utilized for very high speed requirements, since they exhibit higher resonant frequencies than stationary shaft rollers. Large diameter roller construction (with typically large loads) favors rotating shaft rollers with pillow block bearings.

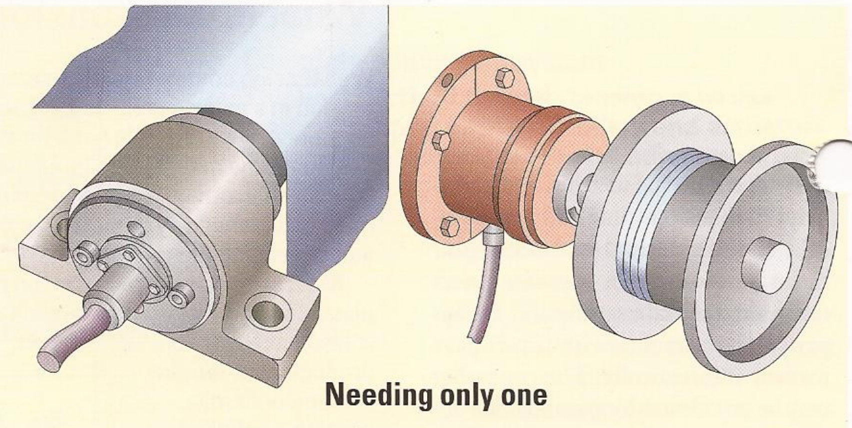
❸ Determine the proper tension. Many times, process or production engineers have a good idea of what running tensions should be. If these are not known, approximate the tension based on the thickness and type of material. Charts can be used to approximate tensions. Tension is measured in lb per lineal inch, *PLI*. To determine the tension in the material, multiply the PLI by the width of the web. For example, nylon or cast propylene four



Cartridge-style load cells can be mounted in a number of ways, making them convenient for a myriad of applications.

mils thick requires approximately 1 PLI of tension: 0.25 lb/in./mil x 4 mil = 1 lb/in. To run a 60-in. wide web of propylene, a typical tension of 60 lb. is required: 1 lb/in. x 60 in. = 60 lb. To estimate load requirements for wide web transducers, use the running tension value. Ensure that the transducer you are considering is designed for this load.

❹ Determine space and mounting requirements. Slim transducers are better for tight spaces. Again, cartridge-style transducers offer a variety of mounting options — stud mount, bearing replacement, flange mount, and PB mount. Also check the roller shaft diameters that the load cell can accommodate. A split bushing may be required to accommodate smaller shaft diameters. You may need to turn down the ends of the roller shaft if it is larger than the load cell can accept.

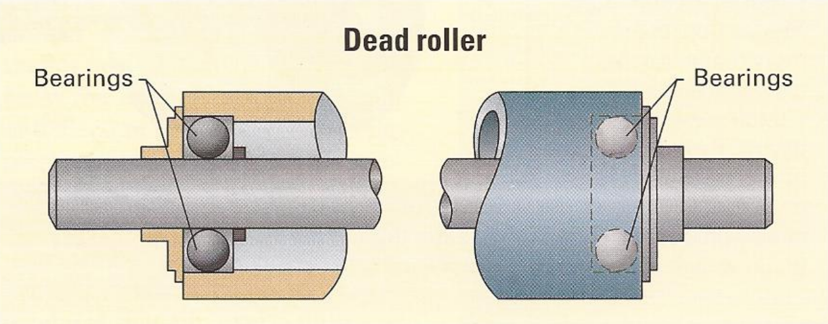


Left: On narrow webs, rollers are typically cantilevered — and the setup requires only one load cell. Right: Lines that spool wire or cable often run over pulleys. Again, only one cell (at the support) is needed.

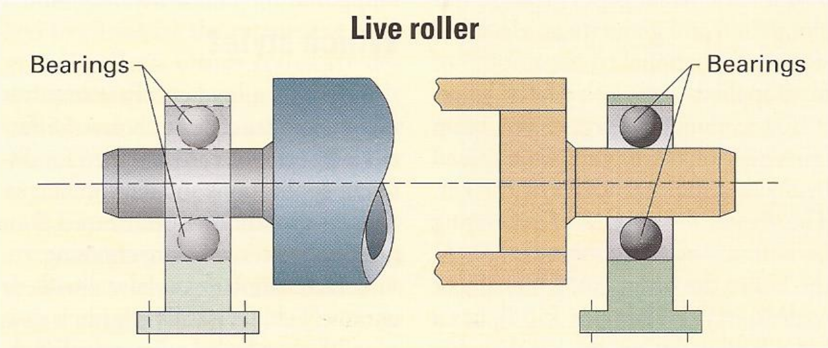
❺ Determine environmental restrictions. Wet environments may require a corrosive and water resisting design. Chemical environments may require stainless steel or special coatings. Ensure that the transducer you are considering meets these requirements. In what temperature ranges will the load cell operate? Many load cells are temperature compensated so that the output does not change by more than 0.02% per °F from 0° to 200°F. Does the application require operation in a special atmosphere or vacuum? Special transducers are available for use in very high temperatures, special atmospheres, and vacuums.

❻ Select the proper load cell style. Review the load cell's data sheet and selection guide, and any other available information, and consult with your supplier for recommendations and tips on mounting and orientation for optimum performance. This is useful in determining the parameters required for sizing load cells to the proper load rating, which is the next step.

Stay tuned for the next installment of this series. For more information, visit cmccontrols.com.



On stationary rollers, the shaft stays put while an outer sleeve rotates around the shaft on bearings.



Rotating shaft rollers are designed so that the entire shaft is part of the spinning assembly.

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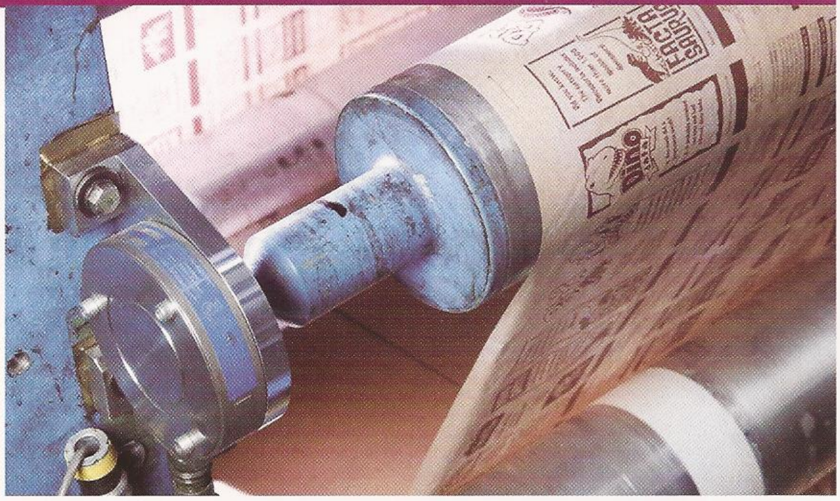
Controlling web tension with load cells: Part 2 of 3

The more you know about selecting and sizing load cells, the better your chance for success in your web tension application.



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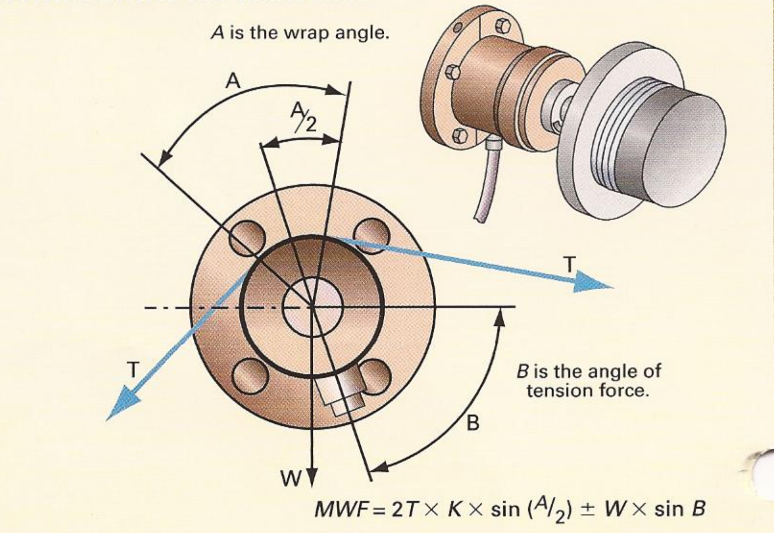
When spools or webs of continuous paper, wire, cloth, or plastic are manufactured and converted, the material is typically pulled off a roll, processed, and rewound — in unwind, intermediate, and rewind zones. Knowing the unique tension values for each is important for making proper process adjustments and maintaining throughput and quality.

There are several ways to measure and control tension; as we discovered in the last installment of this series (*see the February 2007 issue at motionsystemdesign.com*) load cells are the most accurate. But selecting and sizing the right transducer for an application does require careful attention to detail; designers must fully understand their application and then formulate a basic equation for each transducer to be installed. As always, it's recommended that designers consult with suppliers before submitting orders. Sometimes, after evaluating requirements, they can recommend machine design improvements or alternatives.

The importance of sizing

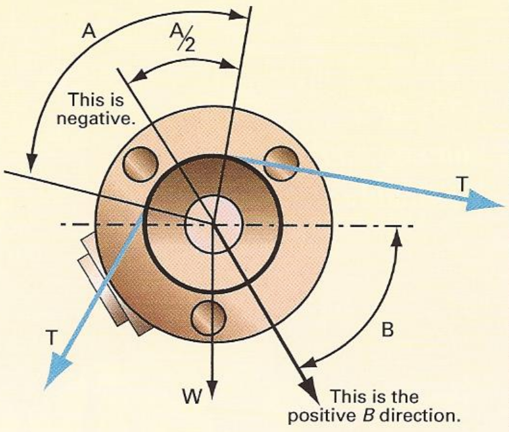
Load cells (also called tension transducers) are electromechanical devices that have inherent design limitations. If the tension or force on them is too high, the electromechanical elements become overstressed and fail. If the force is too low, the signal output may be too small to

With cantilever load cell



The point where the web touches the roller as it enters and exits the wrap is the *tangent.* Draw a radius from the circle center, perpendicular to each tangent at entry and exit. These lines define angle *A,* which is the wrap angle.

Slim design



$$MWF = T \times K\sin(A/2) \pm W/2 \times \sin B$$

With this design, the tension overload factor *K* is 1.2 for most applications.

measure. So, because of these restrictions, load cells are manufactured with a range of maximum working force (*MWF*) ratings. The goal for a designer making use of load cells in a system is to select *MWF* ratings that meet *tension range* requirements without overstressing electromechanical elements.

What is tension range? It is the ratio of the maximum running tension to minimum running tension. For example, the range of a system with a maximum running tension of 80 lb and a minimum of 20 lb is 4:1. In fact, transducers for applications in which the tension range is 4:1 can be sized for a larger load and still produce a significant signal during low-tension operation. On the other hand, if the required tension range is wide (10:1 to 40:1) the *MWF* rating must be as small as possible, with the load cell's rating closely matching maximum tension requirements. This ensures that there is enough range remaining to provide sufficient measurement during the system's low-tension operation.

The formulas for *MWF* depend on the transducer design itself, but the range over which transducers can operate depends upon three things: transducer design, machine design, and how they are applied. So, factoring parameters into the formulas returns the *MWF* required by a specific application.

Force exerted on a transducer depends upon the magnitude and orientation of the web's wrap angle, as well as the actual tension in the material. So to design a web-monitoring system, the first step is to obtain the values for tension, roller weight, and a sketch of the web path.

The *MWF* calculation defines force on individual load cells. Select transducers with load ratings that meet or exceed calculated *MWF*.

Applying sizing formulas

How does a designer best determine the wrap angle and angle of tension force? Web wraps around rollers, and transducers measure the force exerted on rollers by the moving web's tension. So assume we have roller mounted with a contained cartridge-style load cell. To use one example: For cartridge-style load cells, the maximum working force exerted on the transducers is then calculated:

$$MWF = \frac{2TK\sin(A/2) \pm W \times \sin B}{2}$$

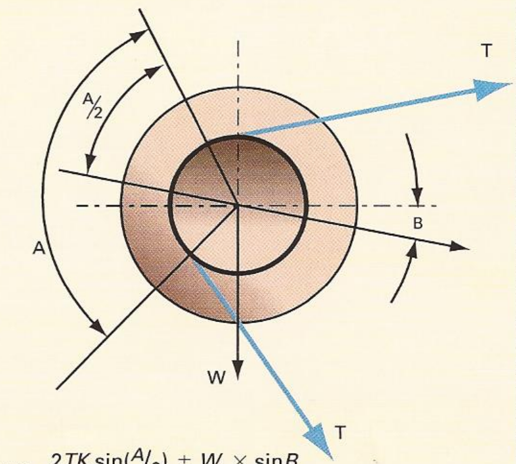
where T = Maximum total tension
K = Transient tension overload factor (normally 1.4 to 2.0)
A = Wrap angle
B = Angle of tension force
W = Weight of roller, lb

The next step is to make a sketch that shows where the web enters and exits as it wraps around the roller. The point at which the web touches the roller as it enters and exits the wrap is referred to as the tangent. Draw a radius from the center of the circle and perpendicular to each tangent at entry and exit: These lines define angle A, which is the wrap angle. Then, draw a line that bisects angle A. The angle that this line makes with the horizontal is angle B — the angle of tension force. If B is below the horizontal, assume a positive value in the calculation; if angle B is above the horizontal, use a negative value.

The next step is to determine the maximum tension T and the minimum tension for your process. If this is not known, consult a transducer supplier. They often offer charts that indicate typical tensions for various materials.

Finally, weigh your design's rollers

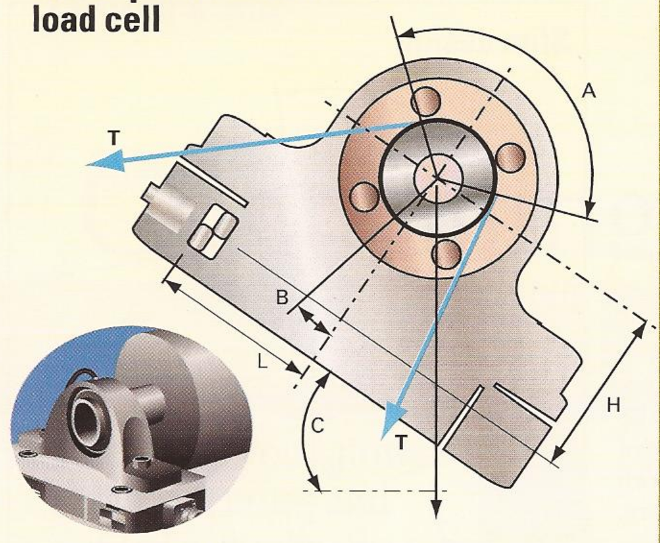
Cartridge transducer



$$MWF = \frac{2TK\sin(A/2) \pm W \times \sin B}{2}$$

Course audit

Under pillow block load cell



$$MWF = \frac{(2KT\sin(A/2))(H\sin B + L\cos B) \pm W(L\cos B - H\sin C)}{2L}$$

Forces exerted on a load cell depend on the wrap angle's magnitude and orientation, as well as actual tension in the material.

or calculate their weight to determine *W* and establish *K*. The latter is a safety factor that accounts for transient tension overloads; a value of 1.4 to 2.0 is typical, depending on the application. Plug these values into the equation for *MWF* exerted on each transducer — and then select a transducer rating that exceeds that *MWF*.

It's best to perform the calculation for the minimum tension value as well, because then resulting values predict force output at the lowest tension. If you find that it is a small percentage of the transducer rating (less than 1/20 or 1/40 the rating or so) you may need to increase wrap angle, reorient the web wrap, or reduce the roller weight to achieve a usable measurement at low tension.

Case in point

In one application for printer R. Donnelley & Sons, Chicago, two transducers are used on each tension roller, one on each side. For one new printer design, initial calculations indicated that the main draw rollers (which are extremely important for maintaining steady tension on the entire web) were too heavy to take full advantage of load cell capabilities. The output signal wasn't strong enough to achieve optimum performance. So, the printer decided to upgrade the entire system, replacing existing rollers with much lighter composite versions. The result: Load-cell resolution improved significantly and boosted overall closed-looped system performance.

Stay tuned for the final installment of this series. For more information, visit cmccontrols.com.

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Controlling web tension with load cells: Part 3 of 3

The more you know about selecting and sizing load cells, the better your chance for success in your web tension application.

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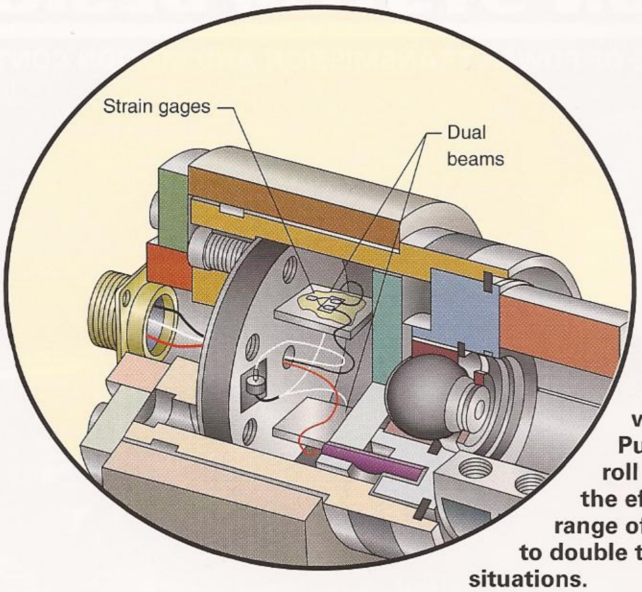


Many strain gages are bipolar, so they produce signal if the beam is deflected down or up. The signal can also be offset or zeroed with the electronics. Pulling against the roll weight can extend the effective measuring range of the transducer up, to double the rating in some situations.

When webs of continuous paper, wire, cloth, or plastic are manufactured, the material is typically pulled off a roll, processed, and rewound in unwind, intermediate, and rewind zones. Knowing the unique tension values for each is important for maintaining throughput and quality.

There are several ways to measure and control tension; as we discovered in the last installments of this series (*see the February and June 2007 issues at motionsystemdesign.com*) selecting and sizing the right transducer for an application requires careful attention to detail. Let's now discuss how orientation and size affects the performance of these sensors.

Get the most from load cells

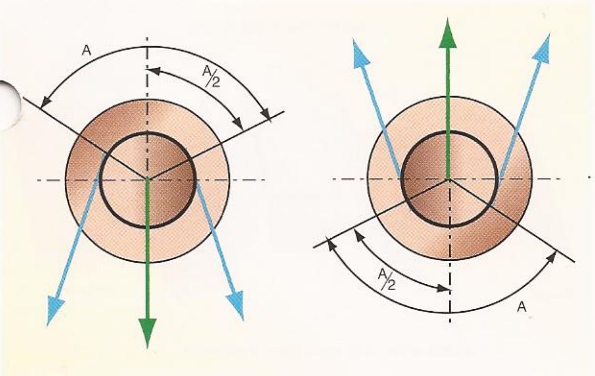
Assume we're using a cartridge-style transducer. (The formulas for other styles may be different so the specifics may change, but the principles for application are the same.) First things first: Load cells must be oriented properly. This is because the force exerted on the roller by tension in the material must bend the transducer beam to produce measurements. The force from tension in the material always points along the bisector of the angle of wrap. The bisector is the line that splits the angle in half, also called the angle of tension force. If the bisector of the wrap angle is vertical and the material pulls down on the roller, this force points straight down. If the bisector of the wrap angle is vertical and the material is pulling up on the roller, the force points straight up. Pulling horizontally on the roller is often used to negate the effect of the roller weight on the transducer.

There is an arrow on the coupling face of our example cartridge transducer. Installation instructions require that the transducer body be rotated so that the arrow is in line with the bisector of the wrap angle. When oriented this way, force is always perpendicular to the beam. So the beam undergoes maximum bending/deflection, which makes for a larger output measurement signal. For this reason, under a given tension and wrap angle, no other orientation yields stronger measurements. If the transducer is not installed to align with the bisector of the wrap angle, measurement power is diminished.

Generally, eyeballing is sufficie[illegible] to achieve proper alignment. The re[illegible]sultant signal output is a function of the sin of the included angle between the direction of the force and beam surface. 5° of misalignment results in less than a 1% decrease in signal strength. Being 15° off results in only a 4% drop.

Consider roller weight

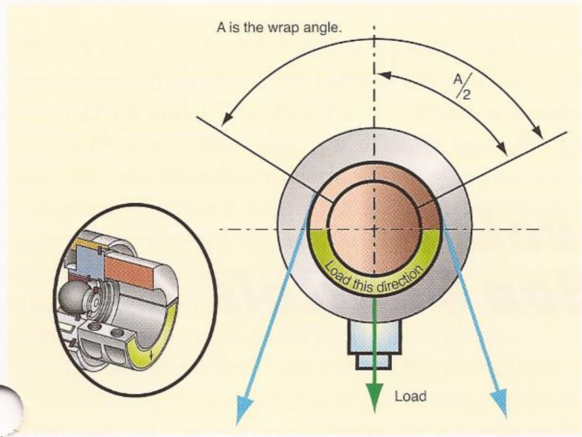
Keep in mind that load cells not only measure force due to material tension, but also that from roller mass. The force measured by the transducer due to the mass of the roller is called *tare weight*. It's a function of the roller mass and orientation of the transducer with respect to gravitational force. Gravity always pulls a mass toward the earth — so force due to gravity (weight) points vertically downward and bends (or deflects) the transducer beam most when it is perpendicular to it. As part of calibration, tare weight is zeroed so that only the signal due to tensi[illegible] is measured. This is accomplished by



Pulling orientation

Note the arrow on the coupling face of this cartridge-style transducer. Pulling up on the roll extends the transducer's range.

Transducer mounting orientation



Installation requires that the transducer body be rotated so that the arrow is in line with the bisector of the wrap angle.

various means with electronic amplifiers or controllers, either automatically or by adjusting a potentiometer.

If the output signal due to the tare weight is too great, less of the total transducer output signal can be utilized for measuring the tension force. This is especially important to consider when roll weight is large in comparison to required tension. As a general rule of thumb, tare weight should be no greater than two-thirds of the transducer load rating *MWF*. This preserves enough signal to measure tension load.

There are exceptions to this — say, if the tension range is small, 2:1 or 4:1. But for a large tension range (20 or 30:1) tare weight must be reduced to zero or used to extend the transducer range, by working in the opposite direction of the load. In other words, either the roller weight must be reduced or the web path changed so that the transducer can be oriented differently. One option is to use rollers of aluminum or composite material to reduce their weight.

Make weight work for you

The tare weight term $\pm W \sin(B)/2$ is gravitational force exerted on the transducer beam by roller mass. Angle B is the angle between the horizontal and the bisector of the wrap angle. So, B is always between 0° and 90°.

When B is exactly 90° it means that force is either pulling straight up or down on the roller. The sin of 90° is 1, so with $B = 90°$ tare weight is $\pm W/2$ — half the weight of the roller, as there are two transducers supporting the roller. When tension pulls down on a roller, tare weight $W/2$ acts in the same direction as the tension force, and is positive. It adds to the tension force to increase total load on the transducer.

By setting the web to pull up on the transducer, you can make roller weight work for you. Here, tare weight $W/2$ acts in the opposite direction of the tension force and is negative. It's subtracted from tension force to decrease the total load on the transducer. For example, assume maximum tension in the material is 50 lb, roller weight is 60 lb, and wrap angle is 180°. With a cartridge-style transducer, if force is pulling straight down, *MWF* is 80 lb per transducer. (50 lb is the force due to the tension and 30 lb is the tare weight.) You'll have to select a transducer that meets or exceeds an 80-lb rating for this application.

On the other hand, if the web path is changed so that force is pulling straight up, *MWF* is 20 lb per transducer. 50 lb is the force due to the tension and 30 lb is the opposing tare weight — which is subtracted. Pulling up on the roll allows a lower *MWF* rating, for higher transducer output and sensitivity. One caveat: Though a transducer with a 20-lb rating meets the minimum *MWF* rating in this situation, it is not enough to support the 30-lb tare weight. So, a transducer with a rating greater than 30 lb must be selected.

That said, by pulling up instead of down on the roll, reduced transducer size increases sensitivity, cuts costs, and increases the ability to measure lower tensions — and expands the range of measurable tensions. How? A transducer with a lower *MWF* force rating is more sensitive to lighter loads than one with a higher *MWF* rating. That's why the recommended orientation for most applications is a 180° wrap angle, pulling straight up on the roller.

When B is 0° force pulls horizontally on the roller. The sin of 0° is 0, so $B = 0°$ yields a tare weight of zero. In other words, pulling horizontally against the roller negates any effects of roller weight.

Horizontal setting exercise

For the same application we just explored, calculate *MWF* when the material is pulling horizontally against the roller. Ignore the safety factor by making $K = 1$. Maximum working force is 5 lb (the force due to the tension) and 0 lb is the tare weight. Now assume the closest transducer rating that meets or exceeds this *MWF* is 25 lb. Output signal is only that due to tension force. So, only 20% (5 lb) of the available transducer output signal (good to 25 lb) is being utilized for the maximum tension measurement — but there is no output due to the roller weight. This means that everything being measured is actual tension signal.

This technique improves the measurements of small signals when roll weight is appreciably larger than the tension. Note that transducer *MWF* rating should not be less than the weight it might support. Otherwise, you could damage it by overloading, or find yourself unable to zero out the roller weight with the electronics.

Something else to consider: Even though the tare weight is zero, the transducer is subjected to the weight of the roller while it is being installed and rotated into position.

Make wrap angle work for you

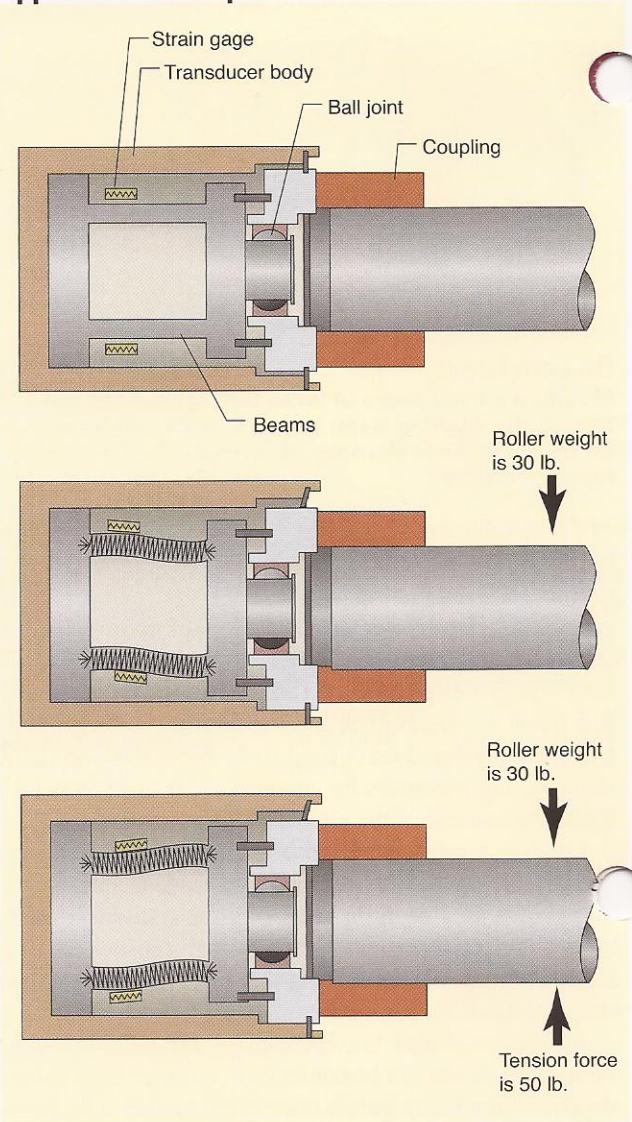
The force due to tension and wrap angle is part of the sizing formula. As we reviewed in previous installments, the term $2T \times \sin(A/2)/2$ is the force exerted by the tension in the material as it wraps around the roller. (The term is divided by two because there are two transducers supporting this roller, and they divide the total load.) Tension T pulls in opposite directions, away from the roller, and this puts double the load (or $2T$) on the roller. The portion of tension that is transmitted to the roller and the transducer is dependent upon the amount of wrap around the roller. Wrap angle is the angle between where the web first touches the roller as it enters, and where it last touches as it exits.

The portion of tension transmitted through the wrap angle is $\sin(A/2)$ and its maximum value is one — which occurs when angle A is 180° — $\sin(180°/2) = \sin(90°) = 1$. The largest amount of tension is transmitted to the roller when the wrap angle is 180°. (Think about it: When A is 0° there is no wrap around the roller and the tension force is zero.) So, for typical applications, and especially for low tension, make the wrap angle as large as possible. This produces the greatest tension force giving more signal output resulting in a better measurement.

Many machine designers use a minimum of 30° of wrap as a general rule of thumb. A wrap angle of 30° transmits 25% of the line tension to the transducer. This is still a significant value, so the signal will be manageable. In most cases, this also gives enough wrap to ensure that the material stays in contact with the roller surface. There is another reason for the 30° rule. Particularly with light material running at low tension and at high speeds, air may blow under the material and cause it to rise and lose contact with the roller surface.

In fact, transducers are applied at much lower angles of wrap, but these applications require scrutiny to ensure proper performance. For some applications it is desirable to slightly decrease the wrap angle, to use a smaller transducer with a smaller *MWF* rating. This is generally the approach when large tension ranges are required. In this case, we want to use the entire transducer output signal in order to get maximum resolution.

Application example

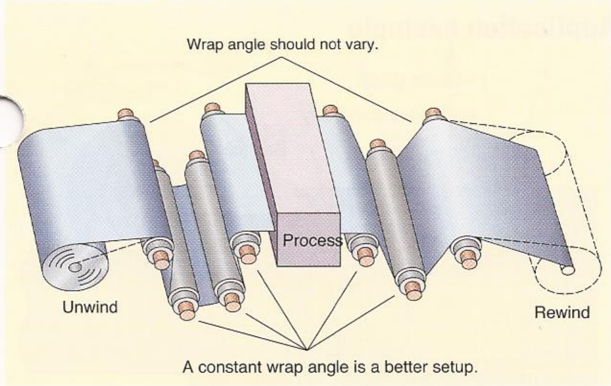


If the web path is changed so that force is pulling straight up, *MWF* is 20 lb per transducer. 50 lb is the force due to the tension and 30 lb is the opposing tare weight — which is subtracted. But although a transducer with a 20-lb rating meets the minimum *MWF* rating in this situation, it is not enough to support the 30 lb of tare weight.

Maintain a fixed angle of wrap throughout the process. Otherwise, if the angle of wrap varies, the tension force on the transducer changes. This results in inaccurate measurements. Only use transducers on rollers where the wrap angle is fixed.

Safety factor: Use judiciously

A safety factor K is assigned to ensure that the *MWF* rating of the transducer is high enough to protect it from transient overloads. Overload conditions may damage the transducers, and some transducers are rated for high overloads than others. A typical overload rating is 150% of



Be consistent

Maintain a fixed angle of wrap throughout the process. If the angle of wrap varies, the tension force on the transducer changes. This results in inaccurate measurements.

MWF. A value for *K* of 1.4 to 2 is typically used for these transducers, which effectively extends the overload protection to 210% and 300%. But it is not always necessary to assign a *K* value greater that 1; it depends upon the application and the transducer overload rating. Some overload limits reach 500% and even 1,000%. If the maximum tension value is conservative, and the machine has tight controls, the *K* value doesn't need to be large. Making the *K* value too big may make for an oversized transducer, which limits the low end of the effective tension range.

Of course, undersized and overloaded transducers may become damaged. But when a large tension range is required (say, 20:1 or 40:1) oversizing the transducer limits its low-end performance. When a small tension range is required (2:1 to 4:1) oversizing the transducers gives it extra protection.

Be realistic about tension control and tension range. How well tension can be controlled (and over what range) depends upon many factors not related to load cells. Some of these factors are the mechanical design of the machine, mechanical wear of the components, line speed, and the mechanical and electrical system response. All systems have natural resonant frequencies that limit their ability to be controlled and to respond to corrective changes.

Controlling tension above a 20:1 or 30:1 range with acceptable tolerances is extremely difficult. In fact, some system integrators won't even accept jobs specifying a tension range over 10:1. For this reason, although load cell signal output is linear all the way down to zero, try not to exceed a 40:1 tension range from an individual load cell. These applications require special attention. (Steps can be taken to extend the measuring range such as routing the web over an idler roller to change the wrap angle.) But many applications require much less range than this — 4:1 to 8:1.

Bandwidth and response

These two quantities quantify a system's capability to react to command changes. Bandwidth for any system is the maximum frequency at which a system can be excited and still remain stable. The value of this bandwidth is less than the natural frequency of a system. For example, in a mechanical system, the natural frequency of a mass attached to a spring is expressed:

w = square root of k/m

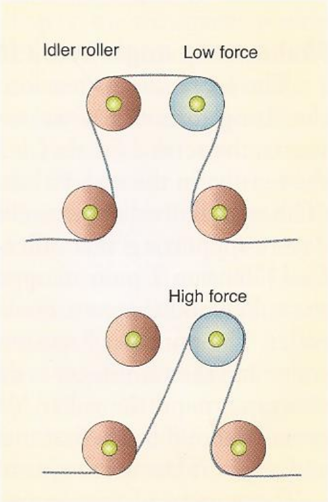
where w = natural frequency

k = spring stiffness, N/m, and

m = the inertial mass, kg.

If this type of system is excited at its natural frequency, the system oscillates uncontrollably and becomes unstable. Well, electrical systems operate in a similar manner. For a servo system, bandwidth is the frequency of small signal change (10% or less) that, applied to the input, reduces output to 0.707 (-3 dB) of input. Servo bandwidth is expressed in Hertz (cycles per second) and radians per second. To convert from Hz to rad/sec, multiply the Hz value by 2π. For example, a hypothetical servo system has a bandwidth of 100 Hz. This can also be expressed as 628 rad/sec.

Influence of wrap angle



Larger wrap angle results in a higher force on the sensing roller.

Response time indicates the time (in seconds or milliseconds) for output to reach the speed or position commanded by a small input change. For slightly underdampened systems — and most servo systems fall into this category — response time is approximately three times the reciprocal of the bandwidth when expressed in rad/sec. To illustrate: A servo with a 100-Hz (628-rad/sec) bandwidth has a response time of 3(1/628) = 0.005 sec. Thus, the servo reaches the full value of a small input change in 5 msec.

Typically, for small input changes, ac brushless servo drives have a bandwidth of 100 Hz and response times of 0.005 sec. For systems where a large change (more than 10%) is required, system response must usually be added to acceleration time because of load inertia, maximum accelerating current, and other factors.

To learn more about using load cells for web tension control, visit the archives of motionsystemdesign.com, and scroll to the February and June 2007 issues to read Part I and Part II of this article series, or visit cmccontrols.com.