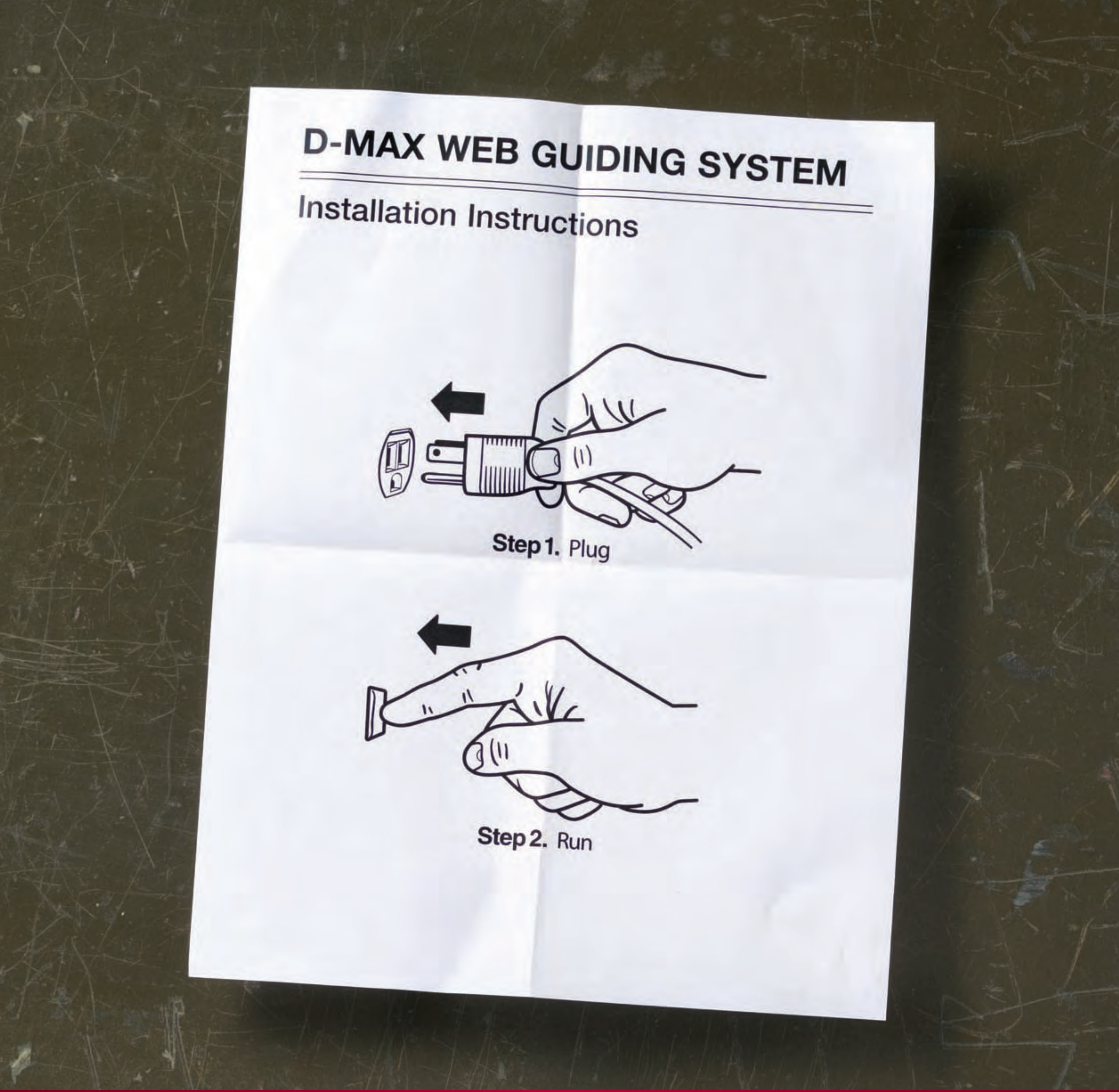

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Sizing web guide actuators

While its components are pretty tough, a web guide's weakest link may be the actuator.

Converters can achieve longer-life spans for web-guiding equipment by correctly sizing the actuators to fit a given processing application.

By Ken Hopcus, Web Handling Applications Engineering Manager, Fife Corp.

What's the best compliment you could ever say about a web guide? There are several answers to this, but the best is, "We put it in and never had to worry about it again."

For a small package, a web guide is quite a complex system. Looking at the web guide's components, sensors and controllers are pretty hard to kill; the likely weakest link is the actuator. If the actuator fails, your worries will soon return.

The driving force behind any web guide is its actuator. The actuator needs to generate a force to move the web and the web guide. The actuator must be able to deliver this force at an appropriate speed relative to the web's speed. Just like torque and rpm are used to determine a motor's size, thrust force and speed determine the correct web guide actuator size.

Most of today's web guides are driven by electromechanical actuators (EMAs). An EMA is comprised of a motor and the mechanical elements to convert a motor's torque and rotary motion into force and linear motion. All these conversion elements (the gears, pulleys, belts, screw, and bearings) need to be sized to have good reliability and lifetime.

An actuator needs to move at a rate equal to or greater than the web's lateral error velocity. Typical required actuator speeds based on web line speeds are:

Web Line Speed (fpm)	Max Lateral Velocity ("/sec.)
300	0.38
500	0.50
1,000	0.80
1,400	0.96
3,300	1.56

Thrust is the force the actuator must exert to move the web guide. An actuator's required thrust is found by adding all the force demands including inertia, friction, and gravity.

F(thrust) = F(inertia) + F(friction) + F(gravity)

Inertia is a big component of actuator sizing because web guides are constantly moving and reversing direction. When the web input error changes quickly, the web guide actuator will be asked to do a complete 180, moving from maximum speed in one direction to maximum speed in the opposite direction.

The force to overcome inertia, F(inertia), is determined by the most basic of physics equations: F=ma. The force to accelerate a mass is the mass times acceleration.

The acceleration side of this equation is determined by the top desired speed, shown above, and the desired response time. Response time is specified as the time we want the mass to reach two-thirds the maximum velocity. A standard response system can reach two-thirds of the maximum velocity in 150 ms. A high response system will reach two-thirds of max velocity in 80 ms. The high response system, with its shorter acceleration time, will require approximately twice the force to overcome inertia.

For example, if we are running process at 3,300 fpm, the recommended maximum actuator speed is 1.56"/sec. For a high response system, we want to reach two-thirds of this speed, about 1"/sec., in 80 ms. If we assume linear acceleration, this is 12.5" per second-squared or, in terms of gravity, about 0.03g (where 1g is 386.4"/sec.-squared).

To turn acceleration into a force, we need to determine the mass of the object we are moving. In metric units, this is straightforward because mass and force are commonly calculated in units of kilograms and Newtons, respectively. To find the force (in Newtons) to accelerate a mass, simply multiple the mass (in kilograms) by the acceleration rate (in "/sec.-squared).

In English units, our calculation is less straightforward because we rarely use the English mass unit—the slug. A slug is the weight in pounds of an object divided by the acceleration of gravity (32.2 ft/sec.-squared or 386.4"/sec.-squared). A 32.2-lb. object has a mass of one slug. In either case, metric or English, the F(inertia) will be the mass times the acceleration rate. Another way to view this is the inertial thrust force will be equal to the weight of the object times the ratio of the actuator acceleration rate relative to gravity.

> A conservative COF accounts for the unknown loads and ensures a life of four to five years or more for a web-guide actuator.

Besides the linear inertia of objects, there is rotational inertia associated with the gears, pulleys, belts, and screw in an EMA. If these rotational inertias are large relative to the translation inertia, they should be calculated, but often they are small enough contributor to thrust to be accounted for within the conservative estimate of coefficient of friction (COF).

Overcoming friction

The second term of thrust, F(friction), is the force to overcome all the frictional losses of the web guide. These frictional losses include drag from bearing motion and other real-world drag factors, such as drag from seals, misalignment, lubrication, and contamination.

Frictional forces are usually described as (mass of the object)x(coefficient of friction). The coefficient of friction (COF) is a function of the type of bearing type, whether it is anti-friction bearings (rolling elements) or sliding surfaces. The advertised coefficient of friction of anti-friction bearing is in the range .005 to 0.01, but these ideal values don't account for the real-world drag factors.

These extra drag factors are seldom known and must be either estimated or included by using a conservative COF value. Common conservative COF values are 0.075 to 0.1 for anti-friction bearings and 0.25-0.3 for sliding surfaces, such as greased lubricated steel on bronze or Teflon bushings.

Thrust estimates need to consider gravity if the web guide moves out of the horizontal plane. Sidelay guides are usually installed on horizontal bearings, so this should be zero, but since large winders or unwind stations may weigh thousands of pounds; any error from the horizontal may quickly become significant.

The gravitational thrust component is more common in offset pivot guides and steering guides, which are commonly installed with a non-horizontal component to their motion. A non-horizontal guide's motion will rarely work directly against gravity, tending to move at a gradual angle off horizontal. The force required to overcome the gravitational load will be the (weight of the web guide)x(the sine of the angle, θ, between the guide's line of motion and the horizontal plane).

Reviewing the thrust force and its components:
F(thrust) = F(inertia) + F(friction) + F(gravity)
F(inertia) = ma = (weight/gravity) * acceleration
F(friction) = weight*cosθ*COF
F(gravity) = weight*sinθ

Combining these equations, the required thrust is:
F(thrust) = [(weight/gravity)*acceleration] + [weight*cosθ*COF] + [weight*sinθ]
OR
F(thrust) = (weight) * [(acceleration/gravity)+(cosθ*COF)+(sinθ)]

If the load moves horizontally, θ = 0, the cosθ = 1, the sinθ = 0, and the equation becomes:
F(thrust) = weight * [(acceleration/gravity)+(COF)]
(Note: COF is the conservative value that incorporates internal drag and inertia.)

We can substitute in a couple more relationships. We know the value for Earth's gravity and the guide's acceleration is the change in velocity, v, over a response time, t,
g(gravity) = 386.4"/sec.-squared
acceleration = v/t

So now the thrust equation looks like this:
F(thrust) = weight * [(v/tg)+(COF)]

In the earlier calculation of acceleration, the v/tg term was found to be a low 0.03. Even if this term was three times larger, 0.10, it's clear that the estimated coefficient of friction, especially our conservative value ranging from 0.075 to 0.30, often determines more than half of the required thrust.

With the maximum velocity and thrust calculated, the web guide designer can start the design process, selecting motor size and drive transmission geometry. The next step is selection of individual components to meet the transmission geometry and making decisions on a cost and reliability basis. If inexpensive parts are selected, the cost of the system will be lower, but the lifetime costs of the guide, including parts, labor, and production downtime, will be higher.

Each component's life is calculated using what is known as the L10 life. This is the time in which 90% of a given component will reach failure. All the rotational components, including the belts, gears, bearings, screw/nut assembly and motor, have a known life under the predicted running conditions. The two most important components on this list are the screw and nut.

If the low advertised coefficient of friction is used to calculate thrust, the actuator will be undersized and the screw and nut assembly will have a shorter than expected service life. Using the more conservative coefficient of friction values, the unknown loads are accounted for and the life is in an acceptable range, typically 4 to 5 years or more. The result is a savings in lifetime maintenance and downtime cost by the web guide user.

For any application, whatever your process speeds or the size of your equipment, you can trust that a knowledgeable web guide supplier can design, build, and select the right actuator for your application. The right actuator will ensure the accuracy and reliability you expect from your web guide system and keep your worries from becoming reality. You weren't worried were you?

Finding the right sensor

Making the correct choice in web-guide sensors is a combination of knowing what you need and what a sensor can do.

By John Plumb, Senior Systems Engineer, Fife Corp.

The sensor is the eye of the automatic web guide. As you stand and watch a moving web, sensing the position of the material doesn't seem like a difficult task, but think about the different challenges that a web sensor may face.

Could you provide proportional feedback to motion of a couple of thousandths of an inch? Could you watch the web in a harsh environment? Could you watch both edges at once? Could you watch the web in that small, hard-to-get-to place? If you were the right web guide sensor, you could.

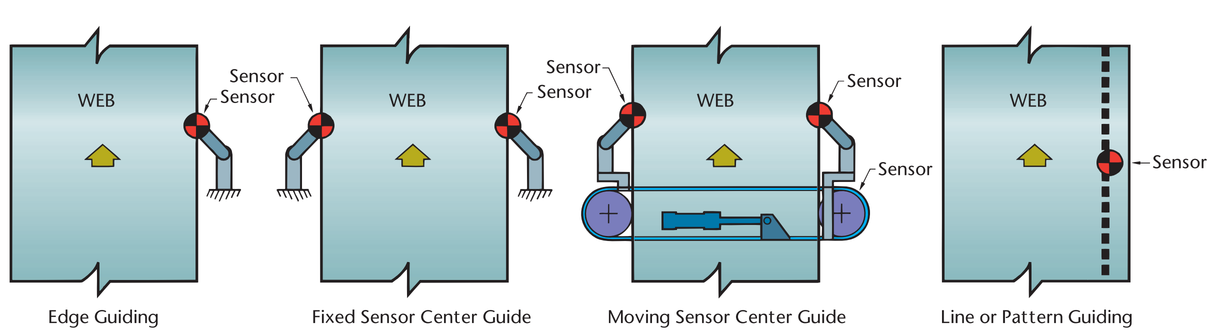
Finding the right sensor is a combination of knowing what you need and what a web guide sensor can do.

What do you need to detect?

Web Material Properties: What is your web? Converting processes involve many different materials, including paper, foils, wovens, nonwovens, and an unlimited variety of laminated or coated materials. To the sensor, it's not the material, but the material properties that are important. Does your web reflect or block light? Does your web block ultrasonic energy in the air? Does the density of your web restrict airflow through it?

Edge, Center or Line Guiding: Do you want to detect your web's edge, center, or a feature on your web's surface? Most web guides work off the transition at the web's edge. This is sufficient for many applications, especially if

Figure 1. Sensor Configurations for Web Guiding Systems



your web width is consistent and your operators are conscientious enough to move the sensor for product width changes. If you have larger width changes and want to guide relative to the center of the web or measure the web width, the web guide needs to detect both edges using either a pair of edge sensors or a full-width "curtain" system (See Figure 1).

Edge or Line Quality: What is the quality of your edges or the surface feature you want to detect? For edges, are they sharp or ragged? For surface features, are they visually distinct? Continuous or intermittent? Do you have step changes in the edge position at splices, especially if you have width changes?

Irregular web edges may cause the sensor signal to be too noisy, causing sudden actuation movements and poor performance. Sensors that are able to see a larger sample of the edge can average out the web edge variations. Center guiding, which detects and averages both edges, may also smooth the signal from measuring ragged edges. Advanced sensing or signal processing can also compensate for ragged edges or line quality, such as changing the dead band or averaging the signal over time.

At high line speeds, line or edge variations may pass so fast that the guide system will not respond to them. Some camera-based systems can be programmed to ignore certain features.

Physical Constraints: What physical constraints do you have? Does the sensor have to fit into a tight location? Does the web edge flutter? How much does the web plane change, especially considering an offset pivot or steering-guide exit span twisting?

What would happen if the web touched the sensor? Is your web sticky, abrasive, or wet? Does your web scratch or tear easily?

Environment: What is the environment at the detection point? Is the web in a challenging environment such as extreme hot oven, a hazardous atmosphere (solvents), a vacuum process (no convective cooling for electronic components), or a dusty location?

Range and Resolution: What is range of lateral position you need to detect? What is your edge position variation from lateral motion and width variation? Do you want your web guide to automatically adjust for width changes or have your operators manually reposition the sensor?

How fine of resolution do you need? In general, a wider sensing range will decrease sensing resolution. For example, a camera- or light-based sensor with a linear array of 1,000 pixels or elements sensor can differentiate 0.001" if the range is 1", but the resolution will drop by three times if the sensing range is increased to 3" without an increase in pixels or sensing elements.

Did you count the number of question marks in this discussion? Yes, quite a few. Taking the time to answer as many of these questions as possible will help in selecting which of the many standard of customized web sensor designs will be best for you application.

Options: How do sensors differ?

This section should help you to understand the variety of standard and customized sensors available to meet your needs.

Mode of Sensing: The most common sensing modes are pneumatic, ultrasonic, and optical.

Pneumatic sensors are the grandfather of web guide sensors, often paired with hydraulic actuation and a pneumohydraulic logic controller. With their remote or purged electrical components, pneumohydraulic systems have long been the favorite for intrinsically safe or hot processes.

Infrared sensors are best for opaque webs (opaque in the wavelength of the sensor). Infrared sensors can detect visibly clear webs if they have enough absorption at key infrared wavelengths. Analog infrared sensors are affected by dust or other contamination (which can be reduced with an air nozzles cleaning option).

Ultrasonic sensors are best for clear or transparent webs, but may have trouble sensing light non-woven or mesh webs.

Linearity and Proportional Feedback: Web sensors are not on/off devices. For accurate web control, the sensor must provide a linear proportional feedback of web position. A proportional signal, from low to high output as the web moves through the sensing range of the sensor, is the first component of a tunable, accurate, and stable guiding control loop.

Center vs. Width Sensing: There are two options to upgrade from edge sensing and an assumed web center to a system that automatically detects the center:

1. Wide sensing range fixed sensors – In this system two fixed sensors are used to detect the position of each edge. A typical sensor will have a 6"-plus sensing range to detect and center a web with width changes of up to 12".

2. Web-seeking edge sensors – The mechanical alternative to wide range fixed sensors uses two sensor actuators to "find" the web. Two sensors are mounted on synchronized actuators. Initially outboard of the web, when the guide goes into run mode, the two sensors move inward, finding one edge, then the other.

Analog vs. Digital: Most sensors are analog, providing a signal proportional to how much of the emitted media (whether pneumatic, optical, or ultrasonic) reaches the receiver. If the web is partially transparent to the media, some of the media will pass through the web and add to the off-web signal. If web transparency varies product to product (again, whether pneumatic, optical or ultrasonic transparency), the system must be recalibrated to guide to the same sensor target line.

Some sensors are digital, such as camera systems or optical array sensors. Digital sensors detect the web with a row of small individual receiver elements or pixels in discrete lanes spread over the sensing range. Advanced image processing algorithms identify all the lateral transitions in the web, so with a strong contrast, the system can guide off the web's edge, the transition from coated to uncoated web, or a printed line or pattern on the web.

Sensor Performance: Good sensor performance results from several features. A good web sensor is:

* Insensitive to any ambient signals near the sensor, such as general airflow and other sources of light or ultrasonics.

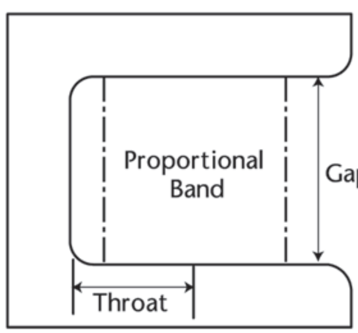
* Insensitive or auto-compensating over time or temperature changes. Maximum operating temperatures are limited by the electronic components in the sensor.

* Resistant to contamination appropriate to the application. Ultrasonic sensors that are properly sealed will be partially resistant to loose contamination. Digital sensors should include internal logic to ignore small amounts of contamination.

* Able to minimize the effects of web plane changes. (Some optical sensors, such as surface pattern sensors, rely on reflected light and are more sensitive to sensor-to-web variations).

Sensor Geometry: Most sensors detect the web by comparing a transmission through the web vs. open atmosphere.

Figure 2. Sensor Geometry



A U-shaped sensor is the most common form factor for web guide sensors. The two-sided design is used to different advantages depending on the mode of sensing. The U-shaped design allows each jaw to house laterally registered emitter and receiver elements. The U-shape design could also allow measurement from both sides or include a mirror on one side to double measured signal strength with two passes through the web.

The two-sided U-shaped sensor also has some limitations (See Figure 2). The gap is the opening distance between the two sides and limits the web plane deviations without contact. The throat is the distance from the sensing centerline to the base of the "U" and determines the maximum lateral shift without contact. The proportional band is the linear portion of the sensing range (See Figure 2).

The sensor gap needs to be larger than the maximum web thickness plus the maximum plane change. Web plane change may be cause by web edge flutter or bagginess, but is also normal at the exit of offset pivot and steering guides. If the web drags on the sensor, the web or sensor may be damaged. To reduce web plane changes in the sensor gap a fixed web support bar or roller can be mounted next to the sensor, making it possible to use a smaller gap sensor.

The sensor throat should be deep enough to prevent the web edge from striking the back of the sensor.

With analog sensors, narrow sensing ranges are generally more accurate. Wide sensing range sensors are recommended if the guide structure is loose or flexible.

Specialty Sensors: Beyond standard optical, ultrasonic, and pneumatic sensors, there are several sensing modes or sensor designs used for specific applications. These sensors are an example of how a good sensor supplier will innovate to solve any web sensing challenge.

- *Line Array Camera* – The most advanced and versatile optical sensors use line array receivers to increase resolution and apply digital processing to compensate for changing surface patterns or contamination.
- *Laser Curtain Sensor* – Used for both width measurement and center guiding, a laser curtain sensing system can have extremely large gaps and sensing range.
- *Ragged Edge Sensor* – As mentioned above, either sensor design or signal processing can reduce the noisy signal of a ragged edge or line.
- *Fiber Optics Sensor* – Optical sensors can be placed in hazardous, vacuum, or constricted locations by using fiber optics to remotely locate the emitting and receiving electronics.
- *Raised Feature Sensor* – For example, an optical sensor can detect the raised tufts in a carpet as it goes over a roller, guiding off the raised tuft edge rather than the actual carpet edge.
- *Capacitance or Inductance Sensor* – Metallic webs or strips can be sensed by capacitance or inductance.
- *Mechanical Paddle or Finger Sensor* – A flag or paddle that rests against the web edge. Obviously a contacting sensor is not good for thin or delicate webs, but they work well for thick belts (e.g. conveyor belts) and may be the only way to sense "open" webs (such as netting).

Choosing a web guide sensor is more than just "pneumatic, optical, or ultrasonic" or "edge vs. center." For any new product or process challenge, an experienced web guide supplier will help you answer these questions and show which sensor provides the best solution. No matter the application, there is a sensor waiting to be your eyes in the web-guiding process. ■