Motion detection is a valuable resource for improving productivity in many plants. As production speeds increase and more sophisticated assembly lines and conveyor systems are used, there is a greater need to monitor and control conveyor speed. This is particularly true since there are more motors, transmissions and belts that can fail, causing the system to halt. Motion detection can also be used to improve operator safety and equipment performance. Properly applied, motion detection devices can increase uptime and reduce maintenance time and expense.

It is relatively easy to detect the presence or absence of an object on a conveyor, using anything from a photoelectric sensor to a limit switch. However, detecting the object does not necessarily indicate whether the conveyor is operating at the proper speed or delivering the product. The tendency is to assume that the belt or conveyor is operating properly.

The drive system is usually external to the production control system, so a broken drive gear or belt can go undetected and result in serious damage as well as extensive downtime. This problem is not restricted to conveyor systems. Pumps and pistons and other devices that have linear or rotational motion can also jam. It is important to monitor any mechanism involved in the movement of product.

Since most motors operate at a fixed speed, the factors that cause an underspeed condition on a conveyor also make the motors work harder to maintain proper speed. Without detection or correction, the motors may continue to overload until tripped by thermal overload relays in the motor starters. At that point, however, the overload relays and motors require time to cool down before restarting the conveyor – three to five minutes for typical medium-sized motors. Motion detection devices reduce this downtime by signaling an underspeed condition before motor overloads trip, increasing productivity and reducing wear on motors and overloads.

Another feature is the improvement of operator safety. When large equipment is in motion, it generally takes a long time to stop. Large motors may coast for many minutes after the motor is deenergized. In many cases, an operator who is pressed for time may approach this motor or its related mechanisms before they have come to a complete stop. This situation is a major cause of accidents. The solution to this problem is to control access to the hazardous area with a gate. The gate is latched during normal operation by a remote controlled safety interlock switch, such as a Telemecanique XCK J device. Motor speed is monitored by a motion detector, such as Telemecanique’s XSA V. While the machine is moving, the access gate will remain closed and latched. Only when the motion detector senses that the motor or mechanism has slowed to a speed considered safe will the motion detector signal the safety interlock to release the latching mechanism and allow access to the hazardous area. The underspeed detector is used frequently to make the determination of safe access and is called a "zero speed" or "motion" detector.
THE BASICS OF MOTION DETECTION

Motion, or underspeed, detection is based on the principle of counting targets in a predetermined amount of time. In its simplest terms, the procedure involves the following steps:

1. Detecting the presence of one or several targets,
2. Counting them during a known time interval,
3. Comparing the total with a known value corresponding to the preset speed,
4. Signaling the results.

This can also be accomplished with a presence sensor and a device that generates pulses at set time intervals. When an object is detected, pulses are counted until the sensor detects the next object. The number of pulses is compared to a preset number. When the number of pulses counted exceeds the preset figure, a signal is transmitted to indicate underspeed operation. Fewer pulses indicate faster speed.

Another principle, entirely analog, compares the voltage of a constant current charged capacitor with a preset threshold. The presence of a target starts the charging and the next target resets it to zero. When the speed decreases, the time between two targets increases, allowing the voltage across the capacitor to rise. Eventually, it rises above the preset threshold, triggering the underspeed signal.

METHODS OF MOTION DETECTION

There are three basic methods available for detecting motion:

- Using a presence sensor and timer.
- Using a dedicated motion detector with all the electronics in a single unit.
- Using a sensor coupled to a motion detection controller.

Each method has advantages and limitations based on the specific application parameters and needs.

Sensor and Timer

The simplest motion detection systems use presence sensors with timers, such as Telemecanique’s XSC T (left) and XSD T inductive proximity sensors (Figure 1). The timer is interposed between the sensor and the output so that any output signal from the sensor is delayed. The timer is coordinated with the speed at which the target should be moving. This allows a target to move out of the sensing zone before the time delay expires. In this case, no output signal is transmitted so there is no reaction. But if the target remains for too long a time in the sensing zone, the signal indicates an underspeed condition.

Figure 1 XSC T and XSD T Inductive Proximity Sensors
This basic method of motion detection works fairly well in controlled applications and is relatively inexpensive to implement. This system is limited because it only detects underspeed conditions. It does not reliably detect stoppage in the line, because it does not send a signal if the stoppage occurs between two targets. There are many applications where these limitations are acceptable.

Generally, preset detection times of up to 10 or 20 seconds are available in this type of system (while usually applied to linear motion detection, these times correspond to about 6 and 3 rpm, respectively, with only one target per rotation). This method requires a timed interlock to allow for start-up; otherwise, the device will continually signal an underspeed condition until the line reaches threshold speed. Another limitation with this system is a difficulty in proper detection of large objects following one another at close range and smaller objects sparsely spaced.

Telemecanique’s XSA V self-contained motion detector switch incorporates all the necessary electronics (sensor, timer and comparator) for rotational speed detection in a single housing (see Figure 2). It is specifically designed for rotational speed detection (see Figure 3). While other sensors signal the presence of a target, the dedicated motion detection device only provides signals related to target speed from its normally closed output. The output stays closed as long as the speed is above the preset value. It opens in an underspeed condition.

![Figure 2 XSA V Self-Contained Motion Detector Switch](image)

For rotational speed control on a grain feeder (Figure 3), one XSA V switch (left) monitors underspeed conditions to protect the motor, while a second device at the end of the transmission system detects conditions such as a broken conveyor.

![Figure 3 Rotational Speed Control using XSA V Sensor](image)
The speed ranges of the XSA V devices are greater than those attainable in the previous category of devices. Two types currently available have operating frequencies ranging from 6 to 150 pulses per minute and 120 to 3,000 pulses per minute, respectively, adjustable by potentiometers on the units. The pulses per minute correspond to the rotation speed of the shaft multiplied by the number of targets (see page 6).

The low speed threshold range (6 to 150 pulses per minute) is used typically for "zero speed" detection. With several targets on a motor shaft, a speed of under 10 to 15 pulses (targets) per minute is considered acceptable in most cases. The high speed range (120 to 3,000 pulses per minute), is generally used in jamming and early transmission failure detection applications.

The self-contained device is an inductive proximity sensor, which provides accurate, inexpensive detection of metal targets in applications where detecting an underspeed condition is critical. Current technology allows the device to be encased in a standard 30 or 18 mm tubular housing, which is easily mounted. It also has a built-in 9-second time delay to compensate for conveyor start-up. A 3-second time delay version is available for less inertial mechanisms. Because the motion detector is self-contained, it eliminates the need for additional logic interlocks. In PLC applications where the timing can be performed by the software and control devices are not powered down when the motor stops, the built-in power up delay is not required. Zero delay versions are available for applications of this sort or if delays longer than 9 seconds at start are required.

This device, like any inductive sensor, is limited to applications involving metal targets. In addition, it only signals underspeed conditions and is limited to use with fairly large targets (30 x 30 mm or 18 x 18 mm standard). The maximum number of pulses per minute should also be considered. If the maximum speed is exceeded under normal conditions, the sensor does not have time to sense the target and falsely indicates an underspeed condition. The maximum speed values of the XSA V motion detector cover most industrial applications.

When application parameters preclude the use of the first two motion detection solutions or dictate the need for maximum capability, a presence sensor can be coupled to Telemecanique’s SX2 DV motion detection controller (Figure 4). The controller performs the electronic functions of comparison and switching of the output circuit to signal over- or underspeed conditions.
The SX2 DV unit provides a variety of advantages, including a wider range of operating frequencies from 2.2 pulses per minute up to 6,000 pulses per minute, and a built-in time delay variable from zero to 15 seconds. It is also possible to interlock with an external signal to allow for longer start-up times. The device has two potentiometers to adjust thresholds for over- or underspeed detection.

The ability to use almost any sensor with this system provides the user with maximum flexibility. For example, where inductive sensors have limitations with temperature, shielded fiber optic extensions of photoelectric sensors are well-suited for high temperature applications. In an application that requires detecting nonmetallic objects, such as plastic bottles, a capacitive sensor can be used in conjunction with the motion detection controller.

In low speed applications, a limit switch or magnetic proximity switch can be used. If the mounting space is limited or the targets are small (e.g., 2 mm), smaller sensors or fiber optic extensions can be used. In hazardous locations, a NAMUR inductive proximity sensor or other appropriate device can be used with an intrinsically-safe relay, providing transistor output to the motion detection controller.

While two devices are needed in this method of motion detection, the advantages are versatility and accuracy of sensing. This solution is also the most costly of the three alternatives.

Table 1 highlights the pertinent details of the three motion detection alternatives.

<table>
<thead>
<tr>
<th>Sensor with Time Delay</th>
<th>Self-Contained</th>
<th>Sensor and Motion Detection Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensing Principle</td>
<td>Inductive, Photoelectric</td>
<td>Inductive</td>
</tr>
<tr>
<td>Min. # of Components</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Function</td>
<td>Underspeed</td>
<td>Underspeed</td>
</tr>
<tr>
<td>Speed Range</td>
<td>Low (0.2 to 30 pulses per minute)</td>
<td>High (6 to 3,000 pulses per minute)</td>
</tr>
<tr>
<td>Advantages</td>
<td>• Simplicity</td>
<td>• Simplicity</td>
</tr>
<tr>
<td></td>
<td>• Cost</td>
<td>• Start up delay, fixed</td>
</tr>
<tr>
<td></td>
<td>• Symmetrical configuration</td>
<td>• Cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Output reflects speed only</td>
</tr>
<tr>
<td>Limitations</td>
<td>• No start up delay</td>
<td>• Metal targets</td>
</tr>
<tr>
<td></td>
<td>• Metal or reflective objects (targets only)</td>
<td>• Large size sensor (30 mm, 18 mm dia.)</td>
</tr>
<tr>
<td></td>
<td>• Interlocking is cumbersome</td>
<td>• Limited to large targets (min. 18 x 18 mm)</td>
</tr>
<tr>
<td></td>
<td>• Range</td>
<td>• Hazardous environment</td>
</tr>
<tr>
<td>Applications</td>
<td>• Continuous detection of objects on conveyors</td>
<td>• Conveyor lines</td>
</tr>
<tr>
<td>Comments:</td>
<td>– More suited for detecting jamming of objects on a conveyor line</td>
<td>• Feeders</td>
</tr>
<tr>
<td></td>
<td>– Detects object only; will not reliably detect a stoppage on the line</td>
<td>• Fans &amp; Blowers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pumps</td>
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<td></td>
<td></td>
<td>• Grinders &amp; Crushers</td>
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<tr>
<td></td>
<td></td>
<td>• Blenders &amp; Mixers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cotton gins</td>
</tr>
<tr>
<td></td>
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<td>• Saws</td>
</tr>
</tbody>
</table>

Table 1 Motion Detection Methods
APPLICATION TIPS

Target Selection

It is relatively simple to select or design targets, especially for rotational applications. For transmission chains (including conveyors), the best approach generally is to position the detection device at the last conveyor roller in the drive system (the farthest roller put into motion by a single motor). A good target for speed detection is a cam or gear on the roller shaft (Figure 5, left). If this is not available, you must fabricate and mount a target. The design considerations include the number of targets needed as well as target size and material.

![Figure 5 Using Roller Shafts and Gears as Targets](image)

Number of Targets

To determine the number of targets required for accurate detection, use the formula:

\[ n = m \times N \]

Where:

- \( n \) = the speed threshold (number of pulses per minute),
- \( m \) = the number of targets needed, and
- \( N \) = the speed in rotations per minute.

In this situation, “\( N \)” is a known value, because it relates to the speed of the mechanism. Enter the number of pulses per minute “\( n \)” from the sensor specification. Then, solve for “\( m \)”, the number of targets needed.

For example, if you want to detect a shaft speed of 3 rotations per minute and the minimum sensor speed threshold is 6 pulses per minute, then:

\[ m = \frac{n}{N} = \frac{6}{3} = 2 \]

In this example, a minimum of 2 targets will be needed to detect 3 rpm. In applications with very low shaft speeds, this formula helps determine if targets must be added to meet the minimum operating frequency of the sensor. Also, in these applications it is sometimes preferable to install more targets to reduce fault detection time. In this example, using 4 targets would change the pulses per minute to 12.
In typical conveyor applications with higher shaft speeds, the formula helps match the appropriate sensor and number of targets to the need. First determine the speed in rotations per minute (N), using a tachometer or other device. Next, select a detection method and device(s) with the appropriate range of operating frequencies in pulses per minute (n). Then, work with the formula to determine the optimum number of targets and resulting operating frequency.

For example, if a conveyor has a shaft speed of 600 rpm, a self-contained motion detector with operating frequencies from 120 to 3,000 pulses per minute could be recommended, using from 1 to 5 targets (5 x 600 = 3,000). Since it is easier to incorporate an even number of targets than an odd number, the choice is to use either two or four targets. If two targets are used, the operating frequency is 1,200 pulses per minute; for four targets, it is 2,400 pulses per minute.

An even number of balanced targets is best for accurate speed detection when the target is mounted on a shaft. This ensures symmetry (on/off time ratio remains constant). Mechanical symmetry is important, since it also reduces shaft wear.

**Target Size**

Generally, target size should be no smaller than the surface size of the sensor face. It is important to consider the sensing speed capability of the detection device selected. While the standard targets recommended for sensors can be used in motion detection applications, the target in motion should be considered to be smaller than it actually is because, while it is in motion, the target is in the sensing area for a short period of time. For maximum accuracy, use a larger target than the standard size listed for the sensor. To further improve accuracy, position the sensor as close to the target as possible. This keeps the target in the sensor’s detection zone for a longer time.

It is possible to construct a standard target that covers a wide speed range and is suitable for use with most Telemecanique sensors. The target should be made from steel and rectangular in shape (200 mm x 90 mm x 2 mm). Mount the target symmetrically across the end of the rotating shaft (Figure 6). Next, position the sensing face of the detector on a radius of 80 mm from the horizontal axis of the shaft. The piece then acts as two diametrically opposed targets.

**Figure 6** Standard Target Dimensions (mm)

Size is more critical at higher operation speeds, because the sensor must respond quickly. A good inductive device reacts in about 1 millisecond. The same is true for most photoelectrics, but some respond as fast as 5 microseconds. The additional cost of these faster devices must be weighed against the benefits they provide in sensing capability and flexibility, particularly in high-speed applications.
Target Material

- Use caution when fabricating a target such as a gear tooth arrangement so that the target cams are far enough away from the sensor to distinguish the target from the background. It is best to place the sensor parallel to the axis to reduce background influences. Additionally, metallic targets can be placed on nonmetallic material to reduce background influences.

- Magnetic tape or other magnetic material can be used as a target, and a Telemecanique SG magnetic switch used for sensing.

- Where it is difficult to position a sensing device close to a target, a photoelectric sensor with fiber optic extensions can be coupled with the system and reflective tape used on the targets.

- Using fiber optic extensions is a good solution for motion detection in hazardous environments. Another method in these applications is to use one of Telemecanique’s NAMUR inductive proximity sensors with an NY2 intrinsically safe relay and a solid state output to provide the speed required.

- If it is impossible to mount a target on a shaft, another solution is to print marks on it or attach colored paper to it, and use a Telemecanique XUR, XUM or XUV color mark detection sensor in conjunction with the motion detection controller.

CONCLUSION

You should consider the benefits of applying the motion detection principles described in this publication to existing as well as new systems. The demand for increased uptime, productivity and increased operator safety supports the use of control techniques that detect possible problems before they cause damage or stop production.

Application parameters dictate which method of motion detection is best, as well as the selection of target size, material and location. Properly applied, a motion detection system is an important part of automated production and material handling systems.

For further information, contact your local Square D/Telemecanique sales office.