control design

ESSENTIALS OF ROBUST LINEAR POSITION SENSORS

A Control Design Essentials Guide, by the editors of *Control Design*

About the Control Design Essentials Series

The mission of the Control Design Essentials series is to provide industrial machinery designers with an up-to-date, top-level understanding of a range of key machine automation topics. Our intent is to present essential engineering concepts in a practical, non-commercial fashion, together with a review of the latest technology and marketplace drivers—all in a form factor well suited for onscreen consumption. Check in at ControlDesign.com/Essentials for other installments in the series.

—The Control Design Editorial Team

STATE-OF-THE-ART LINEAR POSITION SENSORS

While the industrial controllers provide the brains of automated machines and the cylinders and actuators provide the muscle, the sensors help to optimize performance, reliability and precision control, with the proper technology. Automated machines and mobile equipment demand it.

The technology in linear-position sensors enables users to develop higher-quality machines that are more efficient. Designers can take advantage of sensor capabilities, such as addressing the needs of the Industrial Internet of Things (IIoT) and Industry 4.0. Industrial Ethernet and IO-Link drive seamless integration of these smart sensors, adding to the data and information available, which aids functional understanding and control of a machine.

Not only are Industry 4.0, IIoT and other communications options necessary to future-proof an application, but these smart linear-position sensors must also be properly specified to provide robust operation well into the future. To do this, careful consideration of temperature, shock and vibration, as well as mechanical installation, must also be addressed. Applying the technology and ensuring product specifications meet requirements will keep your linear position sensors smart and working robustly well into the 21st century.

SENSORS MAKE THE CONNECTION

When it comes to the IIoT, Industry 4.0 and Smart Manufacturing, they all share a common vision to improve manufacturing through connected devices. However, when connecting to a linear-position sensor or any smart sensor, it isn't just about field setup and programming; to monitor the sensor's output, connections need advanced diagnostics and data logging, as well. With the IIoT, the challenge is determining which information is most valuable and deciding on the best way to provide this information to the user.

If you are going to connect the sensor, it must provide actionable information for rapid troubleshooting to minimize downtime, schedule maintenance and predict future failures.

In addition to analog and pulse and direction signals, there are many industrial Ethernet options available to make the connection to linear-position sensors to provide more information. A popular machine-to-machine, or device, communications protocol to move data and information around the plant floor is OPC UA. In IIoT applications, OPC UA servers, such as a sensor or compressor, can host a few or many data points. OPC UA clients can find the OPC UA servers, understand how to talk to them and request the server send specific data. It ties higher-level systems to controllers, HMIs and sensors creating real-world usable data and information.

Keep in mind that the need for data varies. A linear-sensor absolute position variable has a high priority, and diagnostics or statistics would have a low priority. To address this, some smart sensors have two data paths, real-time Ethernet I/O separate from communication over power line (COPL)

When using COPL in a linear-position sensor, it allows data and information to be collected independently of the I/O protocol used to monitor the sensor for control purposes. Without affecting real-time operation, advanced diagnostics and data logging are possible. Logging of operational statistics, such as total distance, total cycles and time above temperature, may be available. Violations, such as input voltage, temperature or shock events, may also be available. Status and error logging, such as sensor LED status, errors in measurement and communication and power cycle count, provide additional diagnostics and statistics.

To keep control and information separate, the sensors can use COPL to connect to a WLAN server. This Web-server device powers the sensor and can be accessed using Wi-Fi via a Web browser on a PC or mobile device such as a smartphone or tablet. The sensors can provide this extensive monitoring capability without affecting real-time control.

MODERN COMMUNICATION

There are numerous applications in machine automation where accurate position information is required to make control decisions in real time. Historically, an analog signal, such as voltage or current, or a fieldbus network such as DeviceNet, CANbus or Profibus was used. Now, control systems are moving beyond these methods to industrial Ethernet.

Physically it's the same Ethernet found in corporate IT systems that connects computers, servers and peripherals, but these are not deterministic applications. In industrial applications, latency is not tolerated, and responses must be deterministic. While requirements vary in linear-position sensor applications, industrial controllers need consistent delivery times for the control data. This requires industrial Ethernet and a related industrial protocol.

The sensors are now connecting to the controller using industrial Ethernet with popular protocols such as EtherNet/IP, Profinet, EtherCAT and Ethernet Powerlink. In most cases, standard Ethernet hardware and topologies, such as ring, star and point-to-point, are used. Each protocol has differences in how network traffic is switched along with the timing required for deterministic purposes.

An example of this is EtherNet/IP, an open standard administrated by Open DeviceNet Vendors Association (ODVA), which uses explicit and implicit messaging. Basically, explicit messaging provides client-server type of information, such as diagnostic and configuration data where speed is not vital. Implicit messaging uses user datagram protocol (UDP), optimized for time-critical applications, such as real-time control. It is suitable for use in a controller to capture and pass real-time data to and from sensors and actuators.

Linear-position sensors have benefited from the popularity of Ethernet connectivity. Many fully support and are keeping pace with industrial Ethernet protocols allowing designers to integrate the sensors and other components on a single, cost-effective network that is simple to integrate. Sensors should work with these modern communication methods providing control functions, as well as configuration and diagnostics. And it does it using fewer cables, while capable of being single-fault tolerant, and it often eliminates costly interface cards.

Another solution to IIoT connectivity is IO-Link. It works with most fieldbus and industrial Ethernet networks by using an IO-Link Master that becomes a remote I/O node. Most IO-Link devices and sensors can identify and configure themselves. It's a simple plug-and-play, standard, unshielded three-wire connection to a sensor. Once connected, it allows monitoring of devices and continuous diagnostics, data logging and error detection. It makes it easy to configure linear-position sensors and provides diagnostic information such as broken wires and communication failures.

SURVIVE THE HEAT

Important to any linear position sensor application is the long-term, robust operation of the device without need for repair or replacement, so specifying the proper sensor is important. Failures can be expensive, and high temperatures can often be the cause. Preventing these high temperatures for affecting system performance must also be considered.

High temperatures will reduce a sensor's performance and operational longevity. A common problem when using a position sensor in an extreme environment is sensor drift. This can cause poor performance in the form of measurement error. Sensors may include an algorithm to compensate for these temperature effects.

Unfortunately, high temperature does not just affect the transducer or magnetostrictive sensing element, it also can affect the electronic circuitry connected to it, which provides the signal processing. The internal semiconductor components can be sensitive to the heat and reduce the mean time to failure (MTTF). While the MTTF in a sensor's datasheet is for an ambient temperature of 25 °C, for example, this value is significantly reduced as the device approaches its maximum temperature. Heat will make it fail more quickly. Some quote a rule of thumb that the MTTF is reduced by half for every 10 °C rise over its optimal temperature level. Just because a sensor is rated to operate up to 85 °C doesn't mean it should be. Cooler is better. Some sensors may use higher-temperature-spec semiconductors to reduce this problem, but it can add cost.

Linear-position measurement must be repeatable and reliable. To reduce the risk of measurement errors and failures, the sensor element and electronics can be enclosed in a sealed housing or cylinder that can then be cooled to a more appropriate operating temperature. While this can protect the sensor from damage due to high temperature, a better option is to remove the electronics from exposure to the heat source. This is common in extreme environments such as steel mils.

In these extreme applications, the sensing element can be hardened to survive the extended temperature range. Redundant sensors elements with completely separate measurement systems in the same device could also be used. In this case, each sensor element would have its own power, electronics and output signal.

There are linear-position sensors available that can perform reliably and repeatably in high-temperature environments. Careful selection is required to achieve appropriate lifespan with minimal maintenance required.

SHOCK, VIBRATION, DEBRIS AND WEAR

Shock and vibration are two additional factors that can reduce a position sensor's lifespan. Specifications for shock, such as IEC 60068-2-27, typically define the survivability of a single shock event. Although there may be momentary measurement inaccuracies and errors, the device recovers from the event and resumes normal operation. However, in some applications, the vibration may be present during normal operation, and the sensor should operate under continuous, sinusoidal events. Some position sensors, such as optical encoders, fail due to high vibration, so be sure the sensor specification meets the expected range of vibration frequencies.

Some linear-position sensors such as potentiometers, LVDTs and magnetostrictive linear displacement transducers offer robust and reliable solutions in these harsh environments.

While the potentiometer may have wear issues due to friction at the wiper, or the LVDT may need frequent calibration due to changing linearity, all can handle shock and vibration; and some, such as magnetostrictive, handle it better than others.

There are many options for linear-position sensing using a variety of technologies. However, the application may place demands on the sensors that may cause conventional techniques to fail. Potentiometers and electromechanical sensors may have a shorter lifespan due to the wear and tear of continuous operation or a high number of cycles. Optical sensors, such as encoders, may not tolerate dirt and debris, requiring frequent cleaning.

While measurement performance for the application is likely the top concern, it's important to not overlook selecting a sensor that can handle the environment it is operating in. Vibration, dirt and debris may require a sealed, noncontact way to measure position. An example of this is position measurement based on a magnetostrictive sensing mechanism. This measurement method does not need moving parts other than a magnet moving over a ferromagnetic material (magnetostrictive sensing element) so there is no mechanical stress. The advantage is an extended sensor lifespan, especially in applications with significant vibration and debris, and high cycle rates.

MECHANICALLY FLEXIBLE

The specifications, signal performance and electrical integration are often top concerns for a control system designer, but when position sensing, measurement and movement are involved, mechanical design and physical configuration are also important.

As with any sensor, there are installations and applications that are problematic. A sensor's mechanical configuration and issues due to harsh environments can make it difficult to specify a solution. Exposure to high temperatures and continual shock and other factors such as electromagnetic interference and corrosive materials can impact device performance and damage the sensor. Even the mechanical linkage to a sensor such as an encoder can damage the sensor due to moment loads on the shaft.

Understand the basic mechanical components of a linear-position sensor and how it fits into a machine before addressing these problems. The sensor's purpose is to measure the linear displacement between two points, usually along a straight line. The result of the measurement is communicated as an analog or digital signal to a controller or human operator for various purposes.

The main components in most linear-positioning systems are:

1. sensing element
2. electronics
3. controller or software
4. actuator

The sensing element may be a rod or extrusion along the measured linear path or be mounted to one. It may also be a lead screw operating an encoder. The electronics convert the sensed displacement between points into a linear measurement. The controller or software creates usable, scaled data from the measurement and makes decisions based on its value. The actuator is the device that converts a source of energy, such as an electric motor or a pneumatic or hydraulic cylinder, into linear motion.

A mechanical design can provide solutions that protect the sensing element and electronics to help to reduce sensor problems related to temperature, vibration and shock. Two solutions include detachable electronics and a redundant design to help to improve reliability in extreme environments. A third solution is to consider embeddable products.

A simple option to improve the reliability of a sensor is to fully embed it along with the electronics in a pneumatic or hydraulic cylinder. It has become a common standard in mobile hydraulics and is appropriate in harsh industrial applications.

In industrial machine applications it may be preferred to install the sensor electronics externally for easy replacement if needed. However, some machine designs may benefit from the space savings and temperature protection embedded sensors provide. The hydraulic oil may be lower than ambient temperatures around the sensor.

These embedded solutions, with an encapsulated sensing element and electronics, often use simple interfaces, such as an analog signal. The more advanced interfaces, such as industrial Ethernet, often required a mechanical change, where the electronics are physically separate from the sensing element and the harsh environment.

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