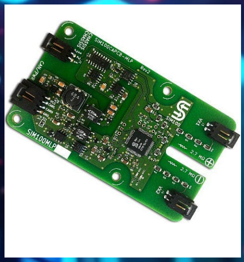
Machine Design LIBRARY

A compendium of technical articles from *Machine Design*

A Guide to Selecting Sensors:
Trends, Features & New Applications


A Guide to Selecting Sensors: Trends, Features & New Applications

CONTENTS

Transforming Engineering with Sensors

REHANA BEGG, Editor-in-Chief, *Machine Design*

As emerging technology trend, so do sensor design trends. From IoT and smart sensor technologies that power industrial automation, to wearable devices that track vital signs, advancements in sensor technologies promise exciting possibilities for engineering new solutions.

Industrial-grade sensors are critical data collection points, enabling devices to interpret and react to their surroundings. Beyond the typical functions to detect, measure, analyze and process characteristics, such as position, length, height and error, these devices play a pivotal role in making products smart and automatic.

Sensor technologies have revolutionized the way manufacturers operate. Smart sensors facilitate IoT integration by facilitating instantaneous connection and sharing of data between devices; AI-powered sensors enable smart decision-making, interpreting data at the point where the data is collected and enabling faster reaction time when changes are detected; and energy-efficient designs ensure that engineering processes are backed up by sustainable practices.

Arguably, a plethora of options available today drives overall equipment effectiveness, improved integration and performance within both products and applications. And as new innovations come to market, we're just beginning to scrape the surface on sensor accuracy and sensitivity.

Yet, to be truly effective, the chosen sensor solution should be matched to the application. The articles in this eBook explore a range of applications and offer some guidance to help enhance production lines, promote safety and boost productivity and profitability.

Courtesy Littelfuse, Inc.

CHAPTER 1:

Selecting the Right Sensor: A Guide for R&D and Electronics Design Engineers

BARRY BRENTS, Field Application Engineer, *Littelfuse*

This article details six essential sensors, along with four necessary questions a design engineer should ask before choosing which ones to use in their next design.

In the R&D and electronics design world, choosing the ideal sensor for your application goes beyond price and availability. Whether you're developing smart home appliances, building automation systems, automotive electronics or industrial equipment, sensors are the critical components ensuring your product functions as intended. When selecting a sensor, engineers must think holistically, considering performance, reliability, customization and the supplier's capabilities.

Following is a breakdown of sensor types, their applications and the key questions every engineer should ask before selecting.

Exploring Sensor Applications

Sensors play a crucial role in various applications, including:

Appliances. From small kitchen gadgets to large home appliances, sensors monitor conditions like temperature, humidity and proximity, ensuring safe and efficient operation.

Building and industrial automation. Sensors enable smart building features such as lighting control, HVAC optimization and security monitoring.

Automotive/electric vehicles (EVs). In modern vehicles, sensors are vital for safety, performance and user experience. They monitor parameters such as speed, tire pressure, battery temperature and proximity for parking assistance. In electric vehicles, sensors play a critical role in battery management and motor control, as well as ensuring efficient energy use, directly impacting vehicle range and safety.

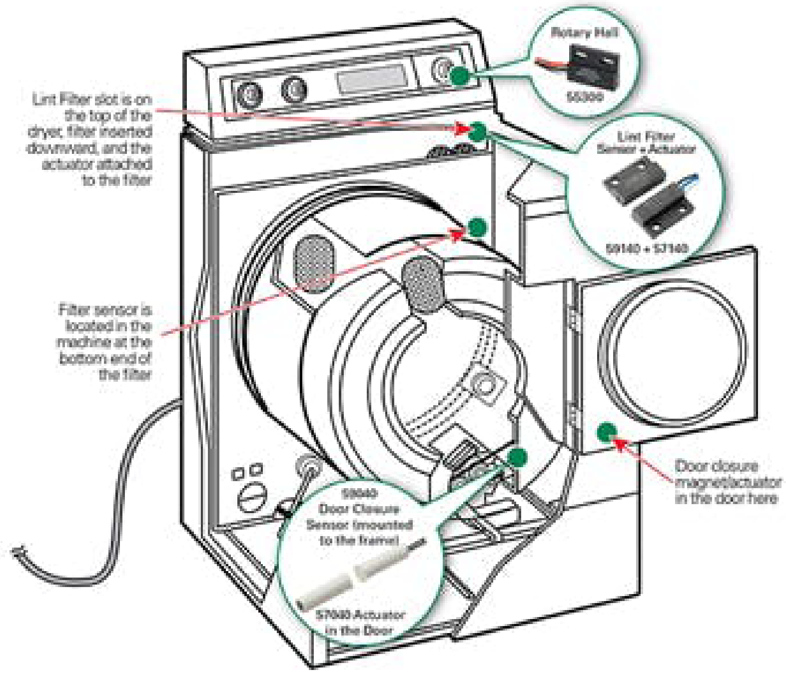
Industrial automation. Sensors are the backbone of automated manufacturing and

READ MORE: An Overview of Proximity Sensors

processing environments. They monitor temperature, pressure, flow rates and machine positioning, ensuring precise control and maintaining safety standards. In robotics, sensors enable navigation, collision avoidance and operational efficiency, driving advancements in smart factories.

A Look at Six Essential Sensor Types

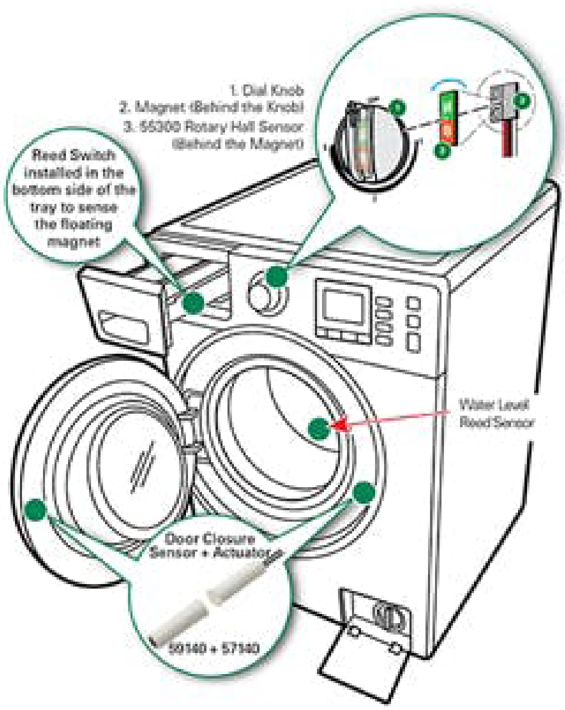
Choosing the right sensor requires understanding the different sensor technologies available. Here's a detailed overview of the six main types used in electronics design. **(see image on page 5)**

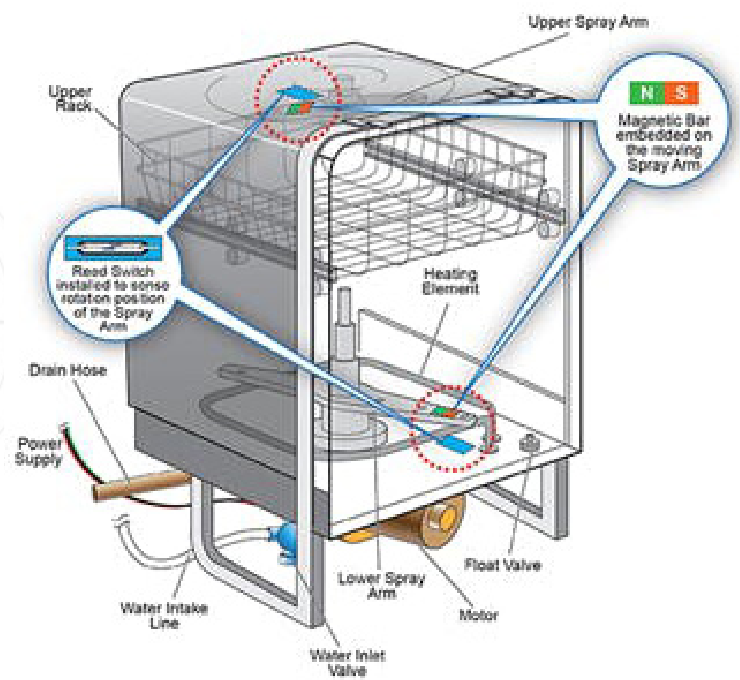


Magnetic Detection Sensors for Proximity, Positioning and Control

Reed switches. Contain two ferromagnetic blades sealed within a glass tube filled with nitrogen gas to prevent oxidation. The sensitivity of a reed switch depends on the blade stiffness, gap and contact overlap. Activated by a permanent magnet or an electromagnet, reed switches operate without requiring external power, making them ideal for battery-powered devices.

Hall effect sensors. Constructed from semiconductor materials, these sensors generate voltage in response to magnetic fields. They require signal conditioning due to their microvolt/millivolt-level outputs, temperature compensation and electromagnetic compatibility (EMC) protection. Hall effect sensors are suitable for proximity detection and





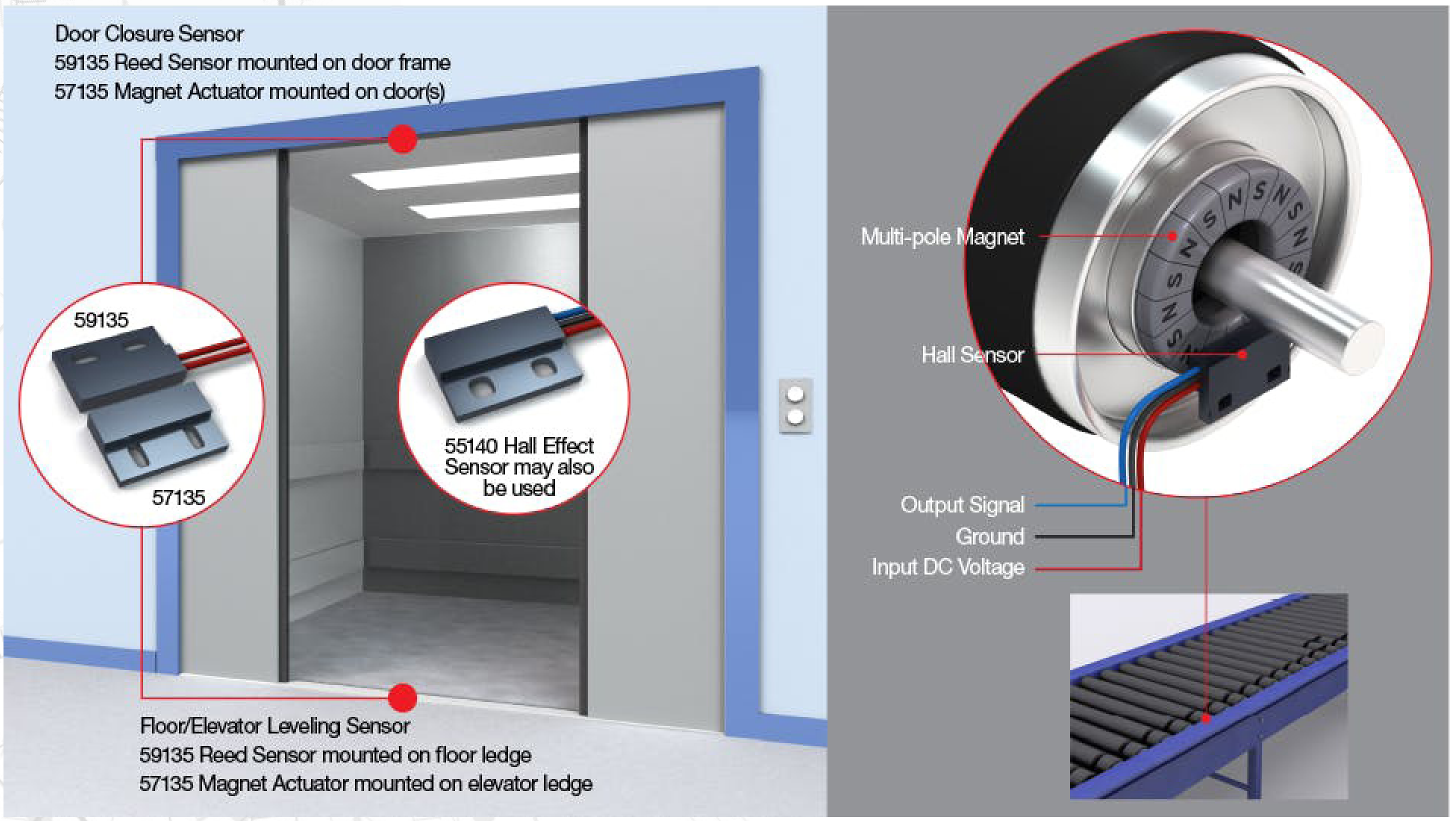
Sensor applications in appliances. Courtesy Littelfuse, Inc.

continuous linear or rotary positioning.

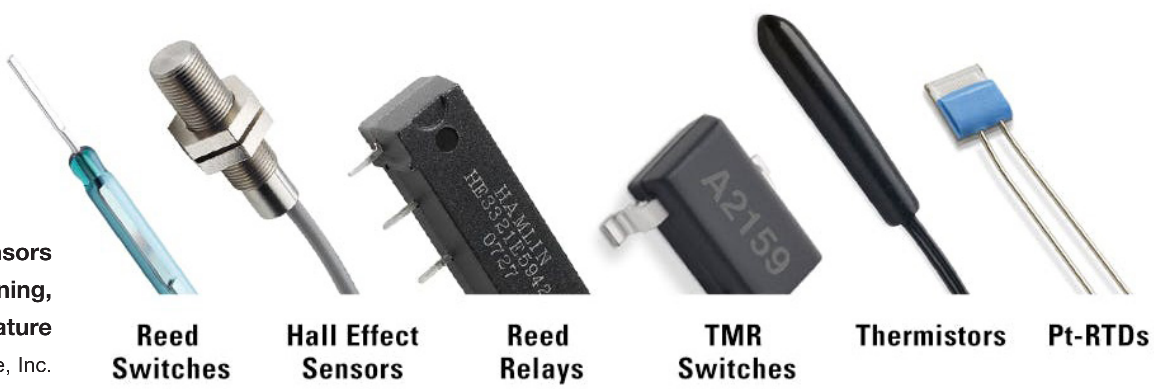
Reed relays. These consist of a reed switch and a control coil, providing galvanic isolation between the control circuit and the load. They offer advantages like high insulation resistance, low contact resistance and long life. Their compact size and high magnetic efficiency make them favorable for low coil drive power applications.

TMR switches. Integrating Tunneling Magneto Resistance (TMR) with CMOS technology, TMR switches offer high sensitivity and ultra-low power consumption. They feature on-chip voltage generators for magnetic sensing, amplifiers, comparators and noise-rejecting Schmitt triggers. Internal temperature compensation allows these sensors to operate across a wide supply voltage range.

Sensor applications in building and industrial automation. Courtesy Littelfuse, Inc.



Commonly used sensors for proximity, positioning, control and temperature sensing. Courtesy Littelfuse, Inc.



[READ MORE: Automate 2024: Balluff Sensors Tackle Everyday Applications and Extreme Environments Alike]

Temperature Sensors

Thermistors. These are thermally sensitive resistors whose resistance changes predictably with temperature. Negative temperature coefficient (NTC) thermistors decrease resistance as temperature rises, while positive temperature coefficient (PTC) thermistors do the opposite. They provide high accuracy over a narrow range (−50°C to 100°C), making them ideal for precise temperature control applications.

Platinum Resistance Temperature Detectors (Pt-RTDs). Featuring near-linear resistance changes across a broad temperature range (−70°C to 500°C), Pt-RTDs are ideal for applications demanding wide-range temperature measurement and control. Their stability and uniform resistance change rate set them apart from other temperature sensors.

Four Critical Questions for Sensor Selection

When selecting sensors, asking the right questions can lead to better performance, reduced development time and enhanced reliability:

1. Does the supplier offer a wide-ranging product line of sensors and other components?

Partnering with a supplier that produces a variety of sensors means you're working with a team that has deep expertise in multiple technologies. This approach can be invaluable when customizing sensors to meet specific requirements. Additionally, sourcing various components from a single supplier simplifies the supply chain, helping to streamline operations and reduce vendor management complexity. A supplier with a broad portfolio is more likely to introduce innovative solutions to give your product a competitive edge.

2. Does the supplier offer application assistance?

Technical support from your supplier can save precious development time. Their expertise can help you select a suitable sensor and ensure you consider essential parameters such as temperature, vibration and electrical noise susceptibility. Supplier application engi-

Custom sensor designers employ simulation software and 3D CAD design tools to create a new design or modify existing standard product packages. Courtesy Littelfuse, Inc.

neers can guide you through installation and usage nuances, potentially identifying issues before they become costly problems in the field.

3. Does the supplier provide custom engineering?

Your design may have unique requirements, such as size constraints, enhanced sensitivity or specific connector types. A supplier with custom engineering capabilities can

"Your design may have unique requirements, such as size constraints, enhanced sensitivity or specific connector types. A supplier with custom engineering capabilities can address these needs by creating a sensor tailored to your application."

Today's manufacturing facilities have the capacity to produce hundreds of millions of sensors and other components.
Courtesy Littelfuse, Inc.

READ MORE: Sensors That Promote More Efficient Industrial Workplaces address these needs by creating a sensor tailored to your application. Suppliers focused solely on standard products may limit your design flexibility and hinder your project's long-term success. Look for manufacturers using advanced tools, such as simulation software and 3D CAD design, to accommodate custom sensor requests efficiently.

4. Does the supplier have the capacity to manage your order requirements?

Supply chain disruptions and long lead times can significantly impact revenue. Ensure your supplier has the manufacturing capacity to meet both your forecasted needs and unexpected large orders. This capability is crucial for maintaining product availability and meeting market demands promptly.

The Advantages of a Capable Sensor Supplier

Working with a supplier that meets these critical criteria may mean a higher upfront cost for the sensor. However, the benefits—such as reduced development time, lower warranty expenses, enhanced product reliability and higher customer satisfaction—can lead to substantial long-term savings. Supplier selection is as vital as sensor selection itself, ultimately contributing to the success of your product in the market.

Final Thoughts

When choosing sensors, price and delivery time are essential, but technical capabilities, customization options, application support and supply chain management can significantly impact the overall product performance and market competitiveness. Make informed decisions to ensure your sensors meet and exceed your project's requirements.

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS

Getty

CHAPTER 2:

Things to Consider When Selecting an Industrial Photoelectric Sensor

ERIC J. HALVORSON, Senior Marketing Technology Manager for Automation and Control, *DigiKey*

This article compares three types of photoelectric sensors—through-beam, retroreflective and diffused—used in industrial applications to detect object presence.

Simply put, sensors are the eyes and ears of industrial automation. Regardless of the application, automation is simply not possible in today's manufacturing process without sensors. There are many different ways in which we measure our environment through sensors. Whether that is vibration, object detection, temperature or humidity, speed, strain or a hundred other different sensing technologies, sensors enable the world of industrial automation. One of the many different sensor technologies available is photoelectric sensors.

Photoelectric sensors are used in industrial applications to detect object presence. There are three types: through-beam, retroreflective and diffused. Depending on the sensor type, they can be used to detect materials such as wood, plastic, metal and glass.

Through-beam sensors utilize a transmitter node and a receiver node. The transmitter will be on one side of the beam, the receiver on the other. These two must be in alignment without obstructing the beam to work. With retroreflective, the sensor contains both the transmitter and receiver in the same unit. The sensor emitter projects the beam to a reflector. The reflector is aligned to reflect the beam back into the receiver.

In a diffused reflective sensor, the sensor again contains both transmitter and receiver in one unit. However, instead of needing a reflector to return the beam to the receiver, the sensor is directed at an object and the light returns to the receiver.

There are advantages and disadvantages to each sensor type. With a through-beam sensor, longer range, reliability and higher accuracy can be achieved. Areas such as wide door openings (e.g., garage doors or wide conveyors) can be monitored. This is due to light only needing to travel in one direction.

Photoelectric sensors are indispensable tools in modern industrial automation, offering reliable and versatile object detection capabilities. Getty

> "Your design may have unique requirements, such as size constraints, enhanced sensitivity or specific connector types. A supplier with custom engineering capabilities can address these needs by creating a sensor tailored to your application."

There are some disadvantages as well. For example, the cost is higher due to the need for multiple components being able to detect through thin, clear objects due to light refraction. With the need for two modules, setup can be more difficult as well. Factors like mounting space requirements, cable management and alignment can prove to be a challenge, depending on the application.

With retroreflective, the cost is lower and setup is easier, having only one module and a reflector. There is no need for additional cabling and power and alignment is easier, but distance becomes shorter. Applications for retroreflective include baggage conveyors at airports, vehicle detection at toll gates and some material handling applications.

The disadvantage of retroreflective photoelectric sensors is the reflector. When the detected object is highly reflective, the sensor may fail to read the object. This can be avoided by adjusting the angles, but it is something to be aware of. With the beam being bi-directional, the detection distance is also shorter.

The diffuse photoelectric sensor is cheaper and there is only one point of installation. However, the detection distance is much shorter. Rather than relying on a reflector to bounce back the beam, the sensor relies on objects passing in front of the beam. The other downside is that depending on the material and color of the object being detected, the sensor may struggle to detect it.

READ MORE: Smart Sensors – A new era for strain gauge-based sensors

Depending on the sensor type, photoelectric sensors can be used to detect materials such as wood, plastic, metal and glass. Getty

What to Consider

When selecting the right photoelectric sensor for your needs, there are several things to review before deciding on one type over another. The following are a few points you should consider:

Location. The sensor's location plays a significant role in the type of sensor technology you can use. What is the detecting range for your application or, to put it simply, how far away from the sensor is the object to be detected? Is there sufficient mounting space for the sensor module and bracket, and is cabling required for power and connectivity? What are the environmental conditions where the sensor(s) will be mounted? What level of ingress protection will the sensors need?

Beam size. Select a sensor with a beam size appropriate for the size of the target you are looking to detect. The target must be big enough to break the beam and trigger detection.

Sensor output. Two-wire sensors and three-wire sensors provide different outputs. In a two-wire sensor configuration, the sensor acts as a switch and will toggle the output on or off. With three-wire configurations, logic is required. In this case, the sensor triggers an event with a connected PLC using sourcing or sinking currents (PNP vs. NPN).

"The disadvantage of retroreflective photoelectric sensors is the reflector. When the detected object is highly reflective, the sensor may fail to read the object. This can be avoided by adjusting the angles, but it is something to be aware of."

Output configuration. You will need to determine whether your sensor application would require a light-on, dark-on, light-off or dark-off configuration. Depending on the configuration needed it will help to select the proper sensor.

The circuit function will help to identify the type of sensor you need. Through-beam, retroreflective and polarized retroreflective sensors are all capable of light-off and dark-off output configurations. In contrast, diffuse reflective sensors are capable of light-on and dark-on configurations.

Excess gain. Excess gain is the measure of the minimum light energy needed to ensure proper triggering of the sensor. When selecting your sensor, you need to ensure there is sufficient excess gain to allow for proper detection. This will be especially important in dirty industrial environments.

When researching your sensor options, most manufacturers will provide an excess gain curve chart for both non-polarized and polarized sensors. These charts will provide maximum distance vs. maximum receiver gain based on a clean environment. There are levels to consider based on the cleanliness of the air in which the sensor will be operating.

Here are some examples to help explain the level of air contamination and how it impacts sensor operation and object detection.

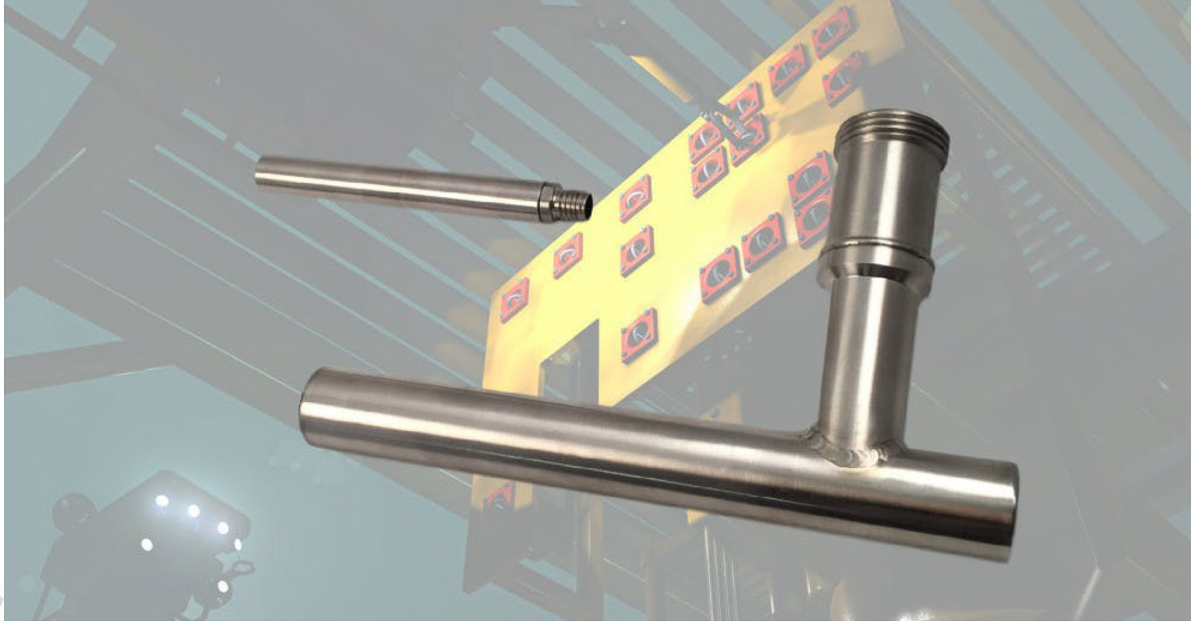
1. *Clean air* — ideal conditions, perfectly clean air
2. *Slightly dirty air* — non-industrial areas
3. *Low contamination* — warehouse, light manufacturing
4. *Moderate contamination* — milling operations
5. *High contamination* — heavy particulate, extreme washdown environments
6. *Extreme contamination* — coal bins

Photoelectric sensors are indispensable tools in modern industrial automation, offering reliable and versatile object detection capabilities. Understanding the nuances of through-beam, retroreflective and diffused sensors is crucial for selecting the optimal solution for specific applications.

By carefully considering factors such as location, beam size, sensor output, output configuration and excess gain, engineers can ensure the successful integration of photoelectric sensors into their automation systems. The judicious choice of these sensors contributes significantly to enhanced efficiency, productivity and quality control in various industrial settings.

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS



CHAPTER 3:

Teaching an Old Sensor New Tricks

MICHAEL MARCIANTE, Applications Engineer, *NewTek Sensor Solutions*

While LVDTs have been around for several decades due to their trademark toughness and reliability, they continue to be adapted with new capabilities to meet today's requirements.

Linear variable differential transformers (LVDTs) have been commercially used for more than 50 years. Originally developed as a laboratory instrument, LVDTs are now utilized in various industries such as computerized manufacturing, military, aerospace, subsea, oil and gas, power generation, packaging, robotics, and research and development for linear position measurement applications.

While advancements in manufacturing, electronic circuitry and construction materials have extended LVDT performance in a wider range of environments and applications over the years, the fundamental principles of its operation and key attributes such as dependability, toughness, sensitivity, accuracy, zero mechanical friction and long service life have remained unchanged. It is these trademark characteristics that have kept LVDTs relevant over the years and in demand by many industries.

What is an LVDT?

An LVDT is an electromechanical transducer that measures movements as small as ±0.010 in. (±0.254 mm) to ±10 in. (±254 mm) or longer in some cases. It converts linear motion into corresponding electric signals, which can be interpreted by operations and control systems.

In composition, LVDTs include two basic parts:

1. A housing containing a single primary winding coupled to two secondary windings S1 and S2.
2. A movable core mechanically linked to the measured object.

READ MORE: Six Ways LVDTs Support Position Measurement in IoT Industrial Applications

The housing and core rely on magnetic coupling and have no contact. Typically, the LVDT housing is fixed to a stationary reference point, and the measured object is mechanically linked to the movable LVDT core. As the core moves, the change in magnetic coupling between each secondary coil S1 and S2 produces an output proportional to the position of the measured part. The LVDT's raw output can then be interpreted by a signal conditioner, which delivers an analog or digital output to a meter or logic controller. (**See Figure 1**)

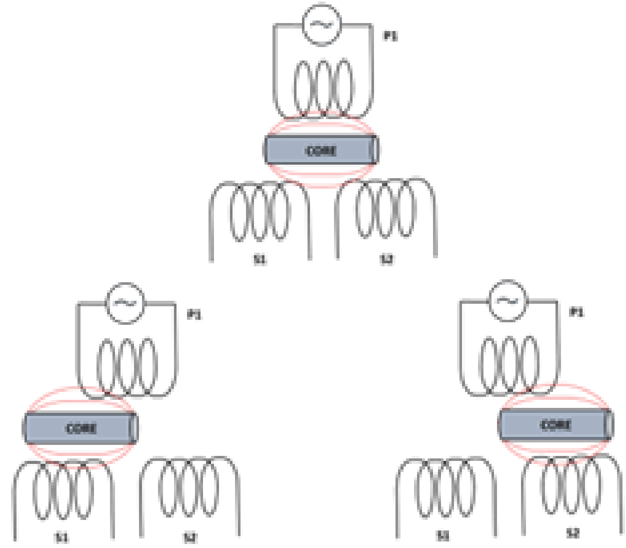


Figure 1. As the core moves over S1, the voltage output of S1 increases. As the core moves over S2, the output of S2 increases. The value of (S1 S2) and (S2 – S1) becomes a linear function of the core position.
NewTek Sensor Solutions

Initially, LVDTs required external excitation from a signal conditioner to produce a digital output. However, modern LVDTs can now be built with internal signal conditioning modules, eliminating the need for external modulation, while still maintaining some beneficial characteristics of an AC-operated LVDT. AC units are still desirable in many applications with temperature extremes as they are not limited by the temperature limits of the internal electronics.

Why LVDTs Remain Popular

LVDTs possess many traits that make them a "tried-and-true" technology for many applications.

- **They are extremely rugged and durable.** This has made LVDTs popular for decades in heavy industrial production applications such as paper mills as well as power generation stations.
- **LVDTs are sensitive to very slight changes in position on the submicron level.** Resolution is limited only by the signal conditioner. Precise feedback on infinitesimal movement is necessary for the optimal performance of different automated processes and measuring parameters for dimensional quality, TIR and thermal expansion.
- The frictionless operation of an LVDT provides for near-infinite mechanical life. They are reliable over millions of cycles, which is critical for installations with inaccessible or unattended locations, or when replacing equipment or instrumentation is expensive and cumbersome. They also eliminate the threat of stiction errors with stationary surfaces.
- **LVDTs are sometimes the only type of position sensor that works for a given application.** For example, LVDTs are preferred in harsh environments like underwater and space and other areas with extreme environments. The absence of onboard electronics in AC-operated versions can tolerate high levels of moisture, chemicals, shock,

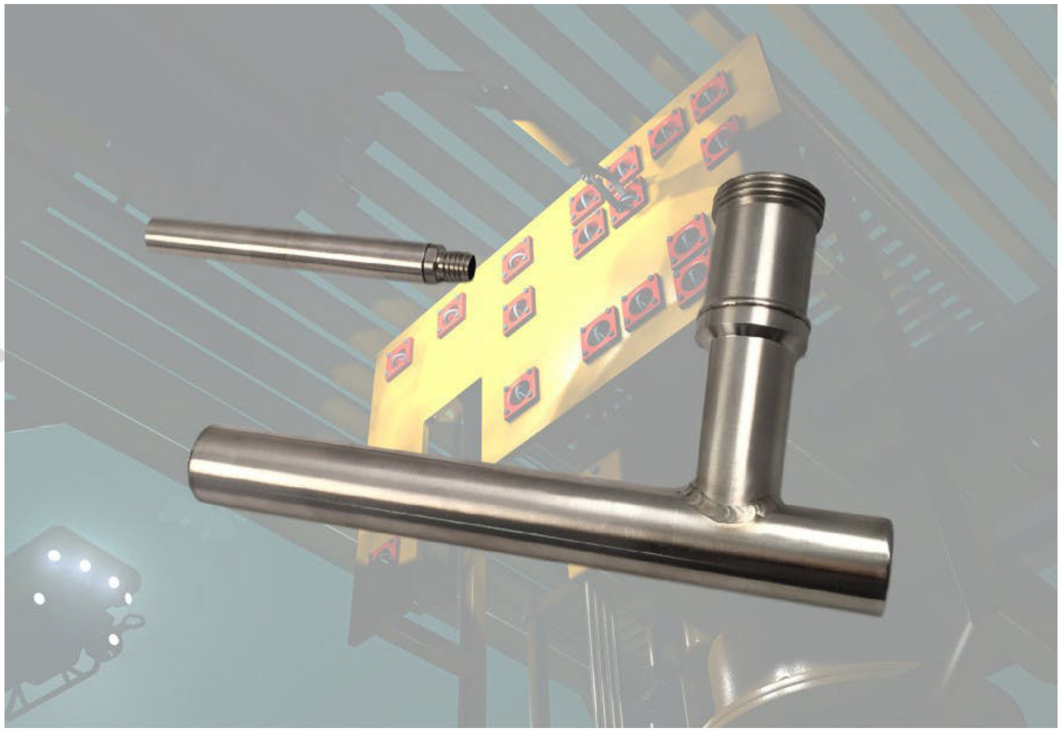


Figure 2: The higher content of nickel, chromium and molybdenum in the alloys used by NewTek to encase the LVDT assembly extends the corrosion resistance of its Submersible Position Sensors.

vibration and extreme temperatures without affecting performance or life.

Modern LVDTs

LVDTs have been updated to make them more energy efficient, compatible with control systems and easier to fit into tight installations while offering greater performance characteristics.

Higher pressures. The use of high-strength alloys now allows LVDTs to be hermetically sealed to pressures of 20,000 psi, making them suitable deep subsea environments, downhole use near cutting tools for oil exploration and other extreme high-pressure applications such as pressure test vessels and hydraulic actuators. They serve as ideal replacements for load cells, pots and magnetostrictive sensors in underwater use. (**See Figure 2**)

Higher temperatures. New higher-temperature materials and ceramics enable LVDTs to operate at temperatures exceeding 1,000°F, making them suitable for applications with rugged environments such as power plants, engine control systems and autoclaves.

Radiation resistance. When LVDTs are now constructed using radiation-tolerant and hardened materials so they can operate in nuclear power plants, aircraft, submarines and other applications with radiation exposure. (**See Figure 3**)

Greater reliability. LVDTs can be constructed with special alloys such as Monel, Inconel, Hastelloy and Titanium to extend their reliability when operating in challenging environments like seawater, corrosive acids as well as high/low temperatures and pressures.

Exotic alloys such as those that contain cobalt, nickel and chromium can deliver even

Figure 3: Radiation Resistant LVDTs provide critical position measurements in autoclaves, particle accelerators, nuclear power plants, submarines, spacecraft and other applications with radiation exposure. Constructed of radiation-tolerant and hardened materials, these AC-operated linear position sensors operate continuously in demanding radiation environments without failure or decay.

LVDTs are sometimes the only type of position sensor that works for a given application. For example, LVDTs are preferred in harsh environments like underwater and space and other areas with extreme environments. The absence of onboard electronics in AC-operated versions can tolerate high levels of moisture, chemicals, shock, vibration and extreme temperatures without affecting performance or life.

higher performance from LVDTs where comparable technologies will not survive. For instance, a higher content of nickel, chromium and molybdenum extends chemical resistance to seawater in depths to 10,000 ft and external pressures of ~5000 psi.

LVDT construction materials are chosen based on parameters such as corrosion, pressure, and magnetic properties across the operating temperature range.

Convenient DC and digital outputs. PCBs with microelectronic processors allow for custom analog voltage, current and digital outputs directly from an LVDT or a remote-mounted signal conditioner. Digital outputs are critical for monitoring different assets in factory automation, especially as the industry moves to the IoT, smart factories and intelligent automation.

DC and digital outputs also offer convenience and higher reliability for laboratories to immediately process results with different third-party software. It also enables data to be saved in the clouds or shared with different partners.

Low power consumption. Modern LVDTs operate on lower voltages at 2.5 kHz – 10

READ MORE: New Uses for Linear Variable Differential Transformers (LVDTs)

Figure 4: Vented LVDT sensors equalize pressure inside and outside the LVDT to operate reliably in temperature extremes of –65°F to +400°F and operating pressures of 30,000 psi. Offering a lightweight, low-mass core and a compact 3/8-in. diameter, these miniature AC-operated position sensors are ideal for high-response dynamic measurement.

kHz, making them resistive to noise created by electrical equipment and radio frequencies. They also consume much less power than legacy LVDTs that run on 120 V and 60 Hz that draw a lot of current. The lessened power consumption is critical in structural monitoring applications where measurements are made infrequently and paired with battery-powered electronics.

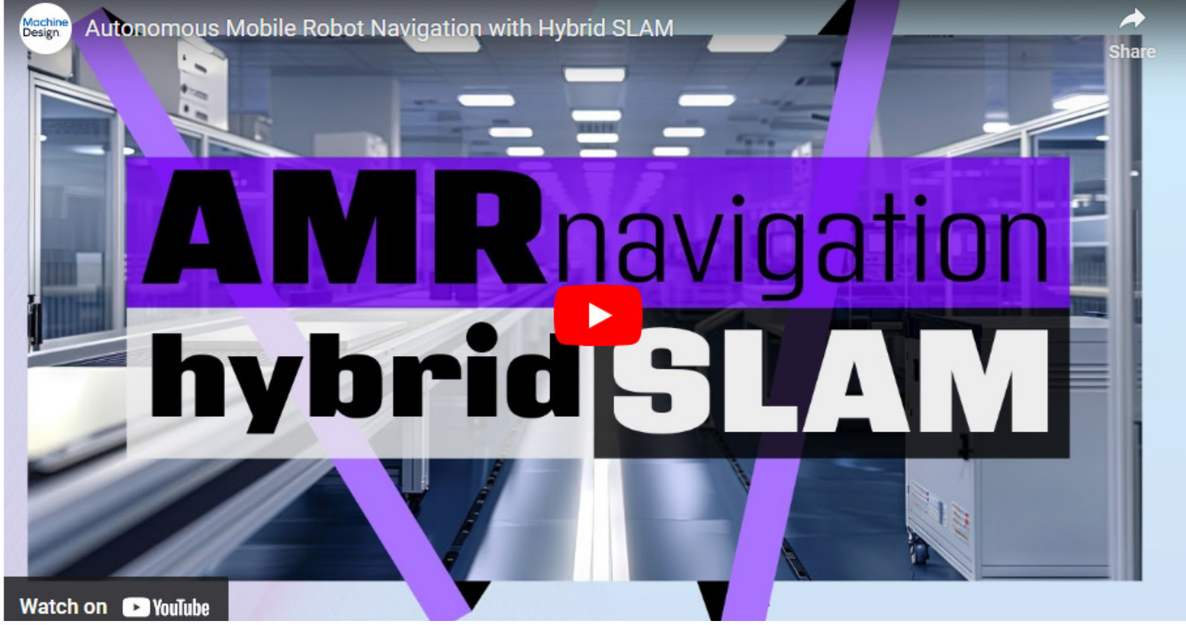
Smaller units. Computer-controlled winding machines allow for new coil designs previously not practical when LVDTs were wound by hand. This means LVDTs can be made smaller and lighter than ever before. Smaller, lighter LVDTs are of particular importance for spacecraft, robotics and where space is at a premium.

Vented. LVDTs can be designed with vented holes in the housing to equalize pressure inside and outside the unit to withstand a combination of high pressure, temperature, shock and vibration. Vented LVDT position sensors are ideal for high response dynamic measurement such as plastic injection molding machines, automatic inspection equipment as well as different robotic applications requiring displacement feedback to ensure proper machinery operation. (**See Figure 4**)

While LVDTs may have been around for a long time, many characteristics and operating benefits are just as relevant now as they were 50 years ago. The optimization of LVDTs with new performance and physical characteristics addresses even more modern applications, making them a cost-effective and more reliable choice than other sensor technologies on the market today.

to view this article online, ☞ click here

☞ BACK TO TABLE OF CONTENTS



CHAPTER 4:

Optimizing Autonomous Mobile Robot Navigation with a Hybrid SLAM Technique

REHANA BEGG, Editor-in-Chief, *Machine Design*

Thira Robotics designs feature-rich autonomous mobile robots guided by LiDAR and a special tape to stay in line. The AMRs are good to go on oily and rough terrain.

Rough terrain navigation, seamless interface and collaboration with workers, fleet navigation systems, interoperability with other systems...The checklist of must-have features for autonomous mobile robots (AMRs) has grown steadily over recent years, not least for their demand and ability to independently interact with their environments.

But when it comes to navigating spaces that are dirty, oily or have uneven and bumpy floors, AMRs can be constrained by their environment and have ways to go.

Thira Robotics, a South Korean designer and developer of self-driving logistics robots hopes to solve these unmet needs with a patented technology that allows its fleet of AMRs to drive over oily and imperfect roads and imperfect surfaces.

"The main market differentiator for Thira's technology involves two main characteristics," according to Shawn O'Farrell, automation technical lead at Disher, a Zeeland, Mich.-based integrator and engineering solutions provider. "The first is uneven floors, broken surfaces, oily floors and wet floors. They have patented technology that will go over all those surfaces.

"The second technology that they're bringing to market is 'Hybrid SLAM' technology," he continued. "What's interesting about it is the traditional AMR will perform SLAM LiDAR, scanning the environment and navigating to fixed locations. In this case, with this new technology, we get high precision only when it's needed, and we use a special tape that allows you to apply it to any surface on the floor."

READ MORE: FMCW LiDAR Gives the Gift of Sight

What is Hybrid LiDAR?

LiDAR SLAM stands for Light Detection and Ranging Simultaneous Localization and Mapping. A LiDAR-SLAM system uses a laser sensor to generate a 3D map of the environment. LiDAR is used to measure the distance to an object by sending a light pulse, bounces it off the object to the sensor and records time of flight (ToF). Positioning and location calculations are performed at a remarkable rate, making the level of precision on these devices accurate.

Thira Robotics has developed proprietary LiDAR and vision sensors, which the company dubbed “Hybrid SLAM.” The combination of laser scanner-based 2D LiDAR and a camera are the basis for improved autonomous navigation.

Additionally, Thira AMRs utilize the proprietary reflector tape to improve precision. This capability allows the AMR to build a map, localize the AMR in that vicinity and map out unknown areas/obstacles to determine the optimal path to travel in accomplishing tasks.

“The tape can be applied to any surface on the floor,” explained O’Farrell. “It only fluoresces with UV. This technology allows us to not only get high precision, but to do it with far less expense than traditional magnetic tape or other technologies that do line following. That will change the market.”

Target Industries: Material Handling, Inventory Management and Healthcare

During a booth demo at Automate 2024, O’Farrell demonstrated how the AMRs steadily navigated oily and imperfect or undulating surfaces. The L200 is designed to lift a cart at a low ground clearance, and the SML System ensures steady lifting of heavy loads. The L300 model in stainless steel targets the food & beverage and pharmaceuticals industries.

“When you need a washdown, clean-room situation, this robot will handle all the hard tasks within that space,” said O’Farrell. “It has a three-point suspension and is really targeted at large food manufacturers.”

AMR advancements are changing the way industries operate in fundamental ways. In one case study, Thira Robotics had a client—Parker, a leading motion and control technologies company—that needed to automate the transportation of products in its production facilities and needed a solution that could handle wet and slippery floors.

For this project, Thira Robotics specified the L200 AMR, which could lift heavy cart loads at low ground clearances, and would be rugged enough to handle water drains, damaged floors and braille blocks. The fleet was further augmented with Thira Robotics’ proprietary AWG shock-absorber system, which absorbs shocks over bumps (of up to 30 cm) for further stabilized driving.

O’Farrell also showcased the L300 model, which is made of stainless steel and has a three-point suspension. It is targeted at large food manufacturers and pharmaceutical markets. He noted that Disher has a variety of clients in the United States that require this solution and is now partnering with Thira Robotics to bring the technology to the U.S.

Their AMRs are designed for “any manufacturer that needs to singulate packages, skids, dunnage, totes, you name it,” said O’Farrell, who has a background in machine automation and holds a bachelor of science in manufacturing systems engineering from Kettering University. “It’s a wonderful product that is different in a way that it executes its motion.”

READ MORE: 4D LiDAR Sensors on a Chip

Filling Manufacturing Gaps Through Game-Changing Technology and Collaboration

According to O'Farrell, Thira Robotics adapted technology from construction trades, applied it directly to the manufacturing sector and it has resulted in a game-changing AMR solution for Disher's clients.

"[The technology] solves the really significant problem in the U.S. for labor shortages and the need to do automation in brownfields really well when it comes to material handling and product delivery," he said. "It just tied together, and it was a good synergy between South Korea and the U.S."

"[Adapting technology, such as the Hybrid SLAM technique,] solves the really significant problem in the U.S. for labor shortages and the need to do automation in brownfields really well when it comes to material handling and product delivery," O'Farrell said. "It just tied together, and it was a good synergy between South Korea and the U.S."

Also present at the booth was Suzy Im, managing partner at BDMT Global (Boston), who helps global technical leaders and innovators broker go-to-market plans and grow global business operations for clients, including Thira Robotics. She pointed out that there are many reasons U.S. manufacturing has slowed down for the past 20 years. "But now they're trying to catch up," Im said.

Manufacturers are focusing on adopting more automation and seeking out collaboration opportunities "so that they can get to where they should be and get to a lot faster," she said.

For both O'Farrell and Im, this is where collaboration opportunities come into play. "This is a time where we collaborate as much as possible and recognize there's a market gap so that we can overcome with a solution that we don't have to build from scratch," said Im. "By collaborating we can get there faster."

READ MORE: Rockwell Automation Acquires Clearpath Robotics: Accelerating AMR Deployments

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS

CHAPTER 5:

The Role of Advanced Sensors in Propellant Technology

SHARON SPIELMAN, Technical Editor, *Machine Design*

Unlocking the complex interactions within combustion systems aims to pave the way for safer, more efficient defense applications. Element U.S. Space & Defense and Texas Tech's Mechanical Engineering Department are collaborating to achieve this goal.

To understand the dynamics of combustion, sophisticated sensor systems are used to provide data on thermal dynamics, energy transfers and combustion processes.

Machine Design spoke with Dr. John Granier, chief engineer of munitions and energetics at Element U.S. Space & Defense, along with Dr. Michelle Pantoya, J.W. Wright Regents Chair in mechanical engineering and professor at Texas Tech, about their collaboration on this research. In the above video, we learn that effective development of propellants requires high accuracy in measurement techniques.

The sensor systems employed by Element and Texas Tech use advanced principles of physics to capture critical details about combustion. By applying technologies that quantify light intensity emission across multiple wavelengths, Pantoya noted, they get insights into how thermal energy moves through a system. Granier said that one of the main changes since his days as a student at Texas Tech is the high-speed camera. “This is allowing us to get almost...a thousand times more data than we could have gotten 20 years ago,” he added.

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS

ID 327403500 © Aung Thurein Tun | Dreamstime.com

CHAPTER 6:

Powering the Skies: The Critical Sensor Requirements for Advancing Air Mobility

DARREN MAGAS, Senior Product Manager Aerospace Business,
Sensata Technologies

Sensor technology companies are leveling up sensor capabilities that best support advanced air mobility capabilities.

Advanced air mobility (AAM) is reshaping industries that have defined human progress for decades. Consider aerospace and automotive. At the heart of the industries' transformation lies electrification, which has become the driving force behind the revolution in air travel. This shift doesn't just impact vehicles—it extends to every corner of the supply chain, encouraging suppliers and manufacturers to embrace innovation that makes air travel safer, cleaner and more efficient.

Today's traditional aircraft contribute nearly 3% of global emissions, proving the urgent need for a greener alternative. At the same time, rapid urbanization has heightened the demand for solutions to reduce traffic congestion. Advanced air mobility—fueled by breakthroughs in battery and fuel cell technologies—seeks to address both challenges by reducing carbon footprints and providing a sustainable alternative for urban and regional transportation.

But as this exciting future unfolds, the success of AAM depends on more than just propulsion systems and flight designs. To achieve truly transformative outcomes, the aerospace industry must ensure next-generation sensor technologies are developed and deployed. These sensors are the "eyes and ears" of the aircraft, delivering the critical data needed for autonomous flight, collision avoidance, air traffic management and even passenger comfort.

The question now is: What must the aerospace industry do to equip itself with the right sensors to support the development of advanced air mobility?

Electric aircraft use similar components to electric vehicles but have some unique requirements when it comes to component weight, safety and system design. Flight range and payload capacity are directly tied to weight, prompting engineers to make intricate changes to remove even a tenth of a pound from systems and components. Electric aircraft typically have many more electric motors and battery modules or fuel cells, all cross-tied to prevent total loss of electric propulsion in case of failure, which needs additional electrical safety components.

Additionally, the systems and components need to function reliably at high voltage and power (up to 450A and 1,000 Vdc) over a long lifespan. Finally, they must operate under extreme temperatures (−55°C to +85°C), at altitudes from 10,000 to 35,000 ft, and withstand high levels of vibration and shock.

This article will address the product requirements and solutions for high-voltage system circuit protection, isolation monitoring for safety and electric propulsion unit efficiency using example within Sensata Technologies' portfolio:

High voltage system protection. For high voltage-high power systems, commutation functions are managed by high voltage contactors. These devices handle switching during startup and shutdown and provide short circuit protection. They are often paired with a pyrofuse switch, which can quickly disconnect the battery in a short circuit event.

Sensata Electrified Flight (SELF) contactors offer a lightweight solution with a ceramic to metal brazed header for a hermetic seal that is ideal for EVTOL applications. These contactors are rated from 12 Vdc to 1,000 Vdc, with continuous current ratings up to 600, and meet the DO-160 aerospace standard. The SELF pyrofuse switch provides a fast disconnect time of less than 1 millisecond, with a maximum breaking capacity of 1,000 Vdc, 16 kA, and a continuous current carry rating of 500 amps.

Sensata electrified flight contactor Courtesy Sensata Technologies

Isolation monitoring for safety. The Insulation Monitoring Device (IMD) operates effectively even with active batteries experiencing large voltage variations. It detects all leakage sources, including multiple simultaneous symmetrical and asymmetrical faults, and resistive paths between the chassis and battery points with the same potential.

The IMD continuously monitors and uses an algorithm for high noise rejection, estimating new isolation resistance values twice per second. In case of an insulation fault, it identifies the fault's relative position to the battery terminals and measures capacitance from each terminal to the chassis. The IMD's enhanced performance demonstrates Sensata's capability in addressing complex current and voltage measurement challenges.

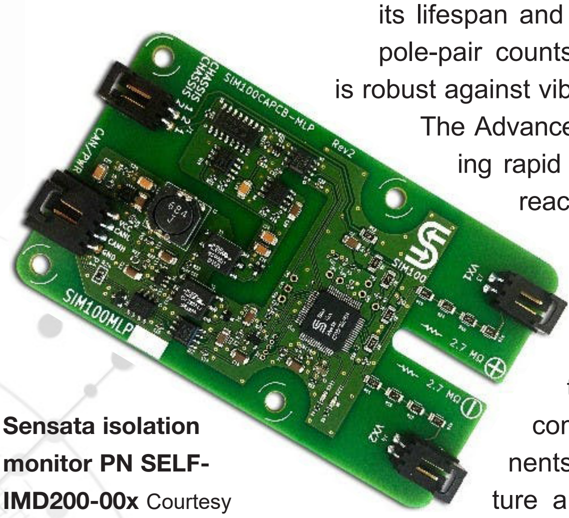
Electric propulsion unit efficiency. The adoption of electric motors (e-motors) in aircraft such as UAM, AAM and eVTOL has created an immediate demand for accurate, low-profile position sensors that achieve efficiency similar to axial flux e-motors. Axial flux e-motors feature a gap between the rotor and stator, with the direction of magnetic flux parallel to the axis of rotation.

[WEBINAR: Optimizing Sensor Technologies: Expert Insights for Design Engineers in Three Key Industries]

Sensata electrified flight pyrofuse switch Courtesy Sensata Technologies

In contrast, conventional e-motor magnets are radially oriented. Radial flux e-motors require non-grain-oriented steel due to their two-dimensional magnetic flux path. However, axial flux e-motors benefit from a unidirectional magnetic flux path, allowing the use of grain-oriented electrical steel, which has higher permeability and reduces iron losses, thereby increasing motor efficiency.

To ensure optimal efficiency of the axial flux motor, knowing the rotor's positional accuracy is crucial. Sensata's SELF-EDP rotary position sensor offers a revolutionary solution compared to traditional resolvers. Unlike resolvers, which are heavier, have a higher profile, and require off-board electronics, the SELF-EDP sensor is lightweight, low-profile, magnet-free and can have a built-in redundant channel. It provides accuracy of ≤±1 deg. over its lifespan and is adaptable to custom motor diameters, pole-pair counts, and mounting positions. Additionally, it is robust against vibration, dust, humidity, oil and wear debris.



Sensata isolation monitor PN SELF-IMD200-00x Courtesy Sensata Technologies

The Advanced Air Mobility (AAM) market is experiencing rapid growth, with production rates expected to reach thousands of aircraft per year. In addition to sensor technologies, charging infrastructure will play a pivotal role in this transformation.

Sensata Technologies is addressing these infrastructure needs through its comprehensive range of high voltage components, including Dynapower charging infrastructure and a broader Contactor portfolio. These components and systems will play a vital role in enhancing eVTOL performance.

Traditional aircraft produce 3% of global emissions. At the same time, population growth in large cities is creating demand for transportation methods to relieve congestion. Over the last decade, advances in battery and fuel cell technology are enabling the advanced aircraft air mobility revolution. This movement aims to reduce the aircraft emissions, address congestion in large cities, and create more cost effective regional air transportation.

Sensata SELF-EDP-00x Courtesy Sensata Technologies

to view this article online, ☞ *click here*

☞ **BACK TO TABLE OF CONTENTS**

Sonair

CHAPTER 7:

New 3D Ultrasonic Sensor Technology Dramatically Reduces Costs and Improves Safety for Mobile Robot Developers

KNUT SANDVEN, CEO, *Sonair*

A new category of sensing technology transforms mobile robot vision from 2D to 3D, improves safety performance and provides 50-80% cost savings compared to traditional, LiDAR-based systems and sensor packages.

A new class of sensor technology dubbed ADAR (acoustic ranging and detection) enhances autonomous mobile robot (AMR) safety while offering 50-80% cost savings compared to traditional, LiDAR-based systems.

AMRs are seeing increased adoption worldwide due to their effectiveness across multiple material handling applications and spurred by labor shortages across the manufacturing, logistics and warehouse sectors. In fact, the global mobile robot market grew by 27% in 2023 to reach $4.5 billion, according to leading market analyst firm Interact Analysis.

As AMRs find their way into more facilities, it is critical to ensure that these versatile robots can safely navigate around objects and people to the level described in the EN/ISO 13849/SIL2 machine safety standard. A typical sensor package for an AMR today includes LiDARs and depth cameras. This combination of sensors is expensive and computationally intensive to operate.

ADAR, the foundation for the Sonair 3D ultrasonic sensor, is the first sensor technology to use ultrasound in the air to give robots safe spatial awareness in 3D. Decades in the making, and leveraging a patented design developed at the world-renowned MiNaLab sensor and nanotechnology research center in Norway, Sonair provides distance and

READ MORE: Next-Generation Vision Sensors for Autonomous Fleets

direction to all objects in a 180 × 180 field-of-view (FOV).

To understand Sonair's benefits versus traditional sensor combinations, we'll look at the well-established pros and cons of traditional AMR sensor technologies. Before doing so, it's important to note that you can't directly compare Sonair software output (the "point cloud"), point by point with the output of LiDAR systems.

As a 3D ultrasonic sensor, Sonair works very differently, enabling it to provide safe, fast and effective obstacle detection using fewer data points—consuming less energy and making lower demands on computational resources while delivering the most crucial value: seeing objects that laser and camera technologies struggle to see.

Sonair, a new sensor category, is designed to both enhance safety and reduce cost compared to available solutions. Sonair

Pros and Cons of LiDAR Technology

LiDAR technology alone accounts for an estimated 30% of the hardware cost for an AMR. LiDAR sensors are used for real-time 2D mapping, obstacle detection and navigation. Normally, AMRs incorporate safety-certified 2D LiDARs.

LiDAR works by emitting directed laser beams and measuring the time it takes for the beam to return after hitting an object. This enables the creation of a map of the robot's 2D surroundings in a straight horizontal plane. If the LiDAR is mounted on a standard AMR, it would typically only see the legs of someone standing in front of it, in a single plane. High-resolution LiDAR creates millions of data points, which ensures detailed sensing in the LiDAR plane, but is also a drag on battery power and computational resources.

LiDAR typically provides a 360-deg. FOV, but the robot itself will shield the FOV, so one sensor in each horizontal corner is typically used (two in total), and with openings in the robot chassis to ensure 360-deg. FOV is obtained. Today, AMRs need to be built around the LiDAR to allow it enough viewing angle and to protect the sensitive scanners from harm.

3D LiDARs are expensive, with a typical system costing around $12,000, and they are not safety certified. (Safety certified 2D LiDARs can cost anywhere from USD $1,500 to $5,000, and non-safety certified 2D LiDARs cost less than $100.)

LiDAR can struggle in dusty environments as the particles interfere with laser beams resulting in inaccurate distance readings and sometimes, failure to detect obstacles altogether. LiDAR is also heavily dependent on having a direct line-of-sight, which can result in detection failures in dynamic environments. Reflective surfaces, such as mirrors and some metals can also interfere with LiDAR performance, leading to inaccurate distance measurements.

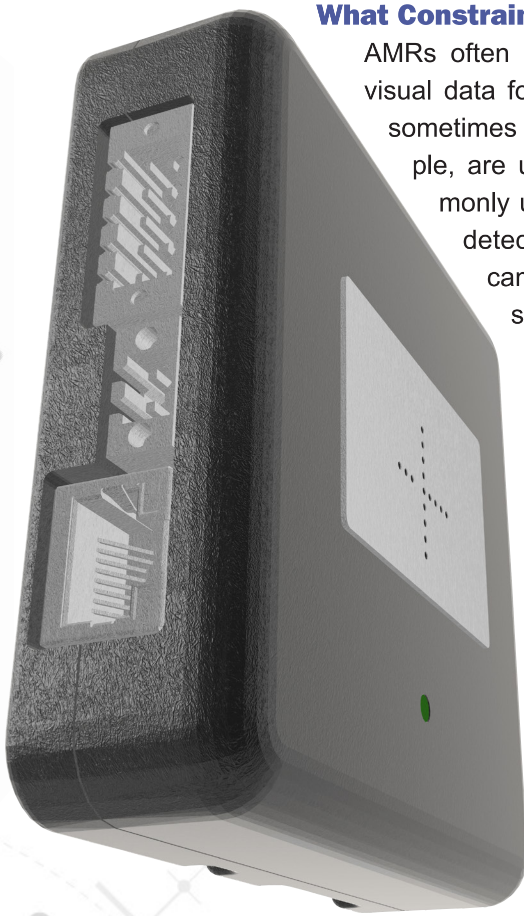
What Constraints do Cameras Pose?

AMRs often incorporate front-facing cameras to provide visual data for object recognition, obstacle detection and sometimes visual navigation. RGB cameras, for example, are used to provide color images and are commonly used in conjunction with AI models for object detection and classification. Meanwhile, depth cameras measure depth and are used to understand the AMR's environment in 3D.

Using cameras for obstacle detection in robotics faces challenges due to limited FOV. As a result, AMRs typically incorporate a combination of several cameras, which drives up cost and complexity. In addition, camera-based systems—even those with AI capabilities—do not qualify for safety on their own.

Cameras are also sensitive to lighting conditions, which affects performance in low light or when glare is present. In addition, environmental factors such as rain, fog and occlusions further complicate detection, and transparent or reflective surfaces can confuse cameras. Additionally, cameras often struggle with small or distant objects and object classification can lead to false positives or negatives, reducing system reliability.

Moreover, depth perception is limited, especially with monocular cameras, while stereo setups require complex calibration. AMRs typically incorporate non-safety certified low-cost depth cameras. And when you do gather useful camera data, processing that data is computationally expensive, leading to potential latency and higher energy consumption.



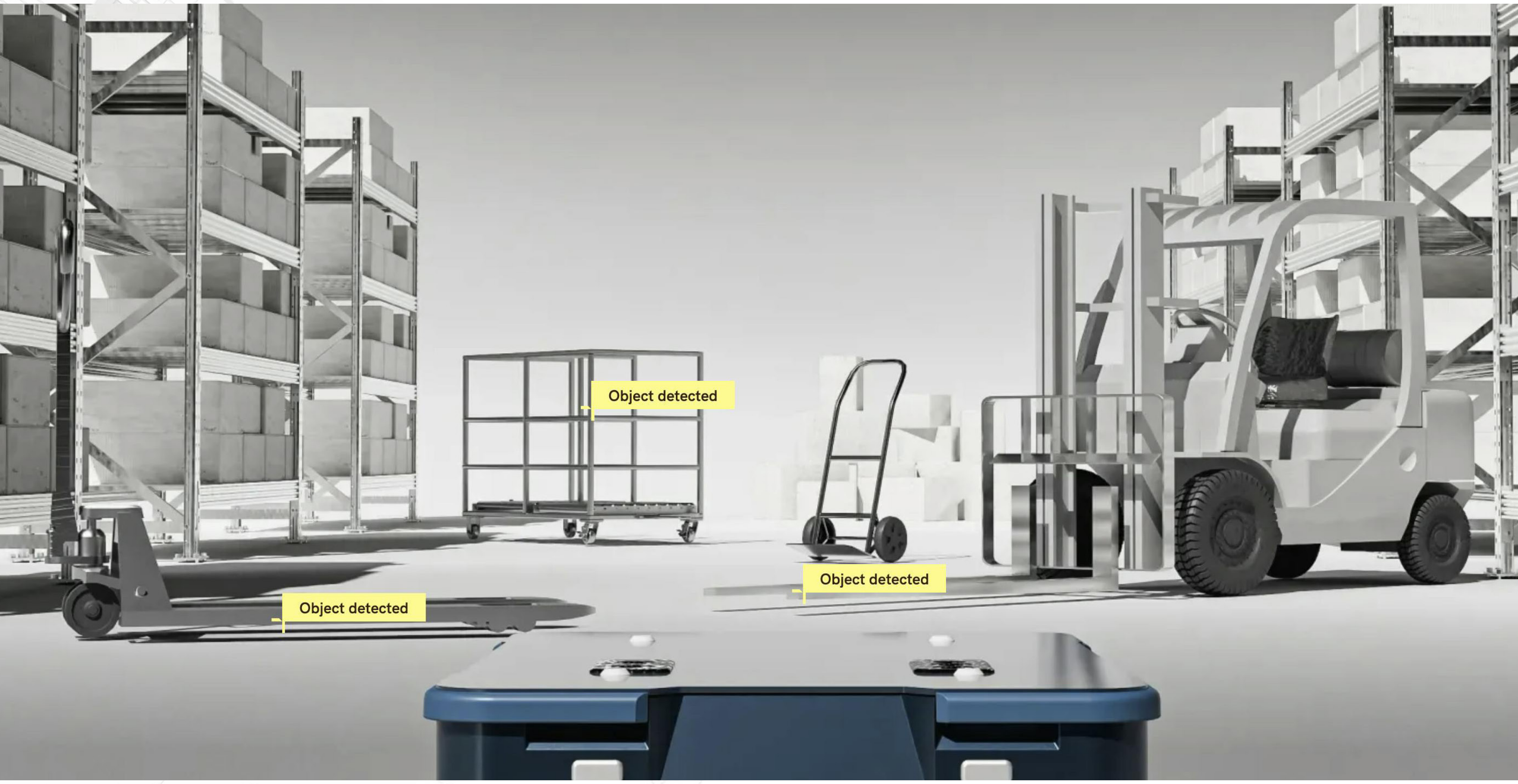
ADAR (acoustic ranging and detection) is the basis for the Sonair 3D ultrasonic sensor, which uses ultrasound in the air to give robots safe spatial awareness in 3D.
Sonair

1D Ultrasonic Sensors Have Limitations

Simple, 1D ultrasonic sensor technology is probably best known in its "parking sensor" form. Most cars today have coin-sized circles on their front and back bumpers to help the car measure the distance to objects and help the driver avoid them when parking or moving slowly.

This technology is used on AMRs for obstacle detection at close range, particularly in situations where precise, immediate feedback is needed, like when avoiding nearby objects. These sensors emit sound waves and measure the time it takes for the echoes to return, determining the distance to nearby objects.

READ MORE: Emergent Technologies That Improve Productivity and Flexibility



Autonomous mobile robots (AMRs) depend on a variety of laser and camera sensors, for safety, object detection and navigation. The Sonair 3D ultrasonic sensor is a newcomer in this category. Sonair

Typically, 1D ultrasonic sensors are distributed around the AMR's body, often near the base to achieve 360-deg. coverage. However, these sensors cannot provide directional information, a severe limitation when it comes to safety and effective obstacle detection.

How ADAR Provides a Safety Shield

Sonair, based on ADAR, is a new sensor category designed to both enhance safety and reduce cost compared to the sensor combinations we've looked at so far.

Sonair is a 3D ultrasonic obstacle detection sensor that provides a "safety shield" around a robot. The new sensor operates by emitting a burst of ultrasound and then analyzing the signals received by an array of receivers. This gives a 3D view of the area in front of the robot, up to a range of five meters.

The innovation is made possible by the integration of piezoelectric actuation in MEMS (micro electromechanical system). The MEMS transducers, made of silicon, have an acoustic impedance which is well matched to air and, above all, they are of millimeter size.

Unlike commercially available transducers, these miniaturized transducers can be placed in an array with a separation corresponding to half an ultrasonic pulse wavelength. This opens for image reconstruction of the full volume in front of the array. This allows

READ MORE: FMCW LiDAR Gives the Gift of Sight

Sonair to both send directional ultrasound and determine the direction the ultrasound is coming from.

The imaging method is called beamforming, which uses well-established techniques deployed in medical ultrasound, SONAR and RADAR systems.

3D-based safety sensors are designed to overcome the limitations of 2D LiDAR, which only senses in a 2D plane. 2D safety planes can miss important safety information such as people leaning towards the robot, garage doors, cables hanging from the roof and objects lying on the floor below the LiDAR mount height.

Direct comparisons between the "resolution" of ADAR and LiDAR are not meaningful, because the two systems use information from the sensor in completely different ways. Sonair uses only a few points per object to accurately detect the object in 3D. Combined with a camera, the image information from the camera is used to define the extent of the object. Moreover, when combined with either a camera or a cheap, non-safety certified LiDAR, Sonair can also be used for effective navigation and scene understanding.

The Sonair 3D ultrasonic sensor is not commercially available yet, but Sonair, the company behind this new category of mobile robot sensors, has launched a global early access program that a wide range of warehouse AMR manufacturers, automotive OEMs, and healthcare and cleaning robotics companies have been quick to sign up to.

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS

metsen

CHAPTER 8:

Q&A: Advanced Sensor Technologies Promote Safer, More Efficient Manufacturing Processes

JEREMY COHEN, Managing Editor, *Machine Design*

Metsen's Vaibhav Modi explains why sensors backed by custom software benefit continuous casting processes across industries.

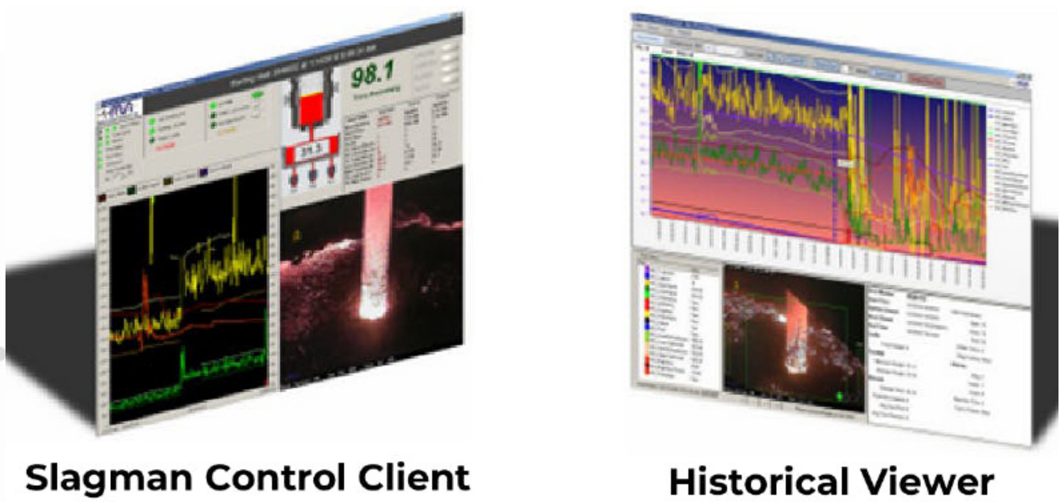
Advances in sensor technology have transformed manufacturing processes across various industries by enhancing precision, efficiency and safety. Sensors measure and monitor typical parameters like temperature, pressure and humidity. Industrial manufacturers also use them in more advanced applications like measuring vibrations, chemical compositions and capturing real-time data for better control of production processes.

Sensor technology helps manufacturers detect process deviations and anomalies as soon as they occur, minimizing waste and rework. They facilitate predictive maintenance, which reduces downtime. Advanced sensor systems also improve workplace safety by monitoring environmental conditions and detecting hazardous situations promptly.

With the emergence of Industry 4.0 and its focus on leveraging robots and smart machines to optimize performance, manufacturers need sensor systems designed to support automation. IoT, artificial intelligence and big data are common themes within the industrial automation mix. These and other developments are paving the way for future innovations in smart manufacturing and the new Industry 5.0 initiatives that are gaining momentum, which focus on the human aspect of technology applications.

In this Q&A, Vaibhav Modi, technical sales representative for Metallurgical Sensors Inc (Metsen), provides insights on some manufacturing processes benefiting from advanced sensor technologies. He also talks about trends impacting emerging and future industrial sensor systems.

READ MORE: Automate 2024: Balluff Sensors Tackle Everyday Applications and Extreme Environments Alike



Vhaibav Modi noted that "software sits at the heart of the sensor system's effectiveness." It is responsible for collecting, integrating and visualizing data in real time. Metsen

***Machine Design:* What kinds of industrial sensors does Metsen design and implement?**

Vaibhav Modi: Metsen designs and implements extreme vision camera systems for harsh environments; vibration and optical slag detection systems to identify the waste matter in molten metal; endoscopes for checking smelting furnace conditions; a system for high-precision rhomboidity measurement of billets, blooms and bars; and hydroweigh systems for molten metal weight measurement in the ladle and bucket. Each system involves advanced sensor technologies customized for the customer's primary need.

***MD:* What industrial manufacturing processes benefit from Metsen's sensor systems?**

VM: Metsen's core sensor solutions benefit continuous casting processes in steel mills, smelter operations in metal processing plants, automotive, food and beverage, pharmaceutical, pulp and paper, oil and gas, aggregates, robotics and general surveillance environments. They are used by companies globally.

For example, within the automotive production assembly environment, many sensor technologies are used for everything from precision welding and painting to safety performance testing before vehicles are delivered to customers. Industries with highly noxious encapsulated environments—such as petrochemicals, aggregates, food and beverage, and pharmaceuticals—can also benefit from integrating sensor technologies that allow safer process monitoring.

***MD:* Are there any universal issues or challenges that advanced sensor systems address across the process industries?**

VM: All industries are united by three common objectives: safety and compliance, energy efficiency and process optimization, driven by best-in-class quality control. Advanced

READ MORE: 5 Reasons Metallurgy is Essential in Material Selection for Harsh Environments

sensor systems uniquely address each objective. Sensors backed by custom software designed to monitor environmental conditions can ensure compliance with safety regulations. When hazardous conditions emerge, alerts are generated to ensure safe working conditions for employees.

Regarding energy efficiency, sensors can monitor energy consumption in manufacturing processes, analyzing energy usage patterns. This allows manufacturers to implement energy efficiency strategies, reducing costs and minimizing environmental impact. As for process optimization, analytics from sensor data can identify inefficiencies or bottlenecks in the process, allowing manufacturers to fine-tune operations, improve workflows and enhance overall efficiency.

Quality control sensors provide real-time data for continuous product quality monitoring. With the right sensor system in place, deviations from set standards can be promptly identified for immediate corrective actions to maintain best-in-class quality standards throughout production.

***MD*: Can you share a success story or a specific project using your sensor technology to improve existing machine operations?**

VM: Major global companies in the iron and steel processing environment use our Slagman vibration slag detector (VSD) system to improve the safety and life of the steelmaking tundish, improve the quality of the yield they produce and reduce downtime. In the steel industry, downtime can cost as much as $10,000 per hour, so if advanced sensor systems can help save as little as 15 seconds off a critical process, more than $100K can be saved each month by not having to slow down the machines.

A large steel company had a caster producing high-quality billets focused on improving tundish life. The average tundish permanent (safety) lining life was 150 heats. A better refractory was tested, which increased the life to 250 heats. After implementing the VSD system, the life of the lining increased to 1,000 heats and the average tundish working-lining life doubled. Despite tundish slag decanting practices, there were two to three tundish breakouts (or hotspots) per month. After implementing the VSD system, tundish breakout was reduced to zero and the tundish decanting practice ceased. Zero breakouts are the safety goal of every steel mill operation.

The tundish drain-down design target in another steel plant was 4,536 kg (about 10,000.16 lb), but production averaged 5,443kg - 6,803kg (11,999.74 lb – 14,998.05 lb), even with tundish slag decanting practices. After implementing the VSD system, a significant drain-down average of 2,722kg (about 6000.98 lb) was achieved, and decanting ceased. Previously, the production crew used 90 to 95 tundishes on average per month with a throughput of 500 to 520 heats.

After implementing the VSD system, the caster reduced tundish consumption to an average of 65 per month and increased throughput from 600 to 630 heats monthly. The return on investment (ROI) was less than one month from start to finish and the safety benefits were an added value. Since each manufacturing environment has different criteria

[READ MORE: Sensors That Promote More Efficient Industrial Workplaces]

[READ MORE: Emergent Technologies That Improve Productivity and Flexibility]

for improving production and quality, we consult with customers to design sensor systems to meet their unique needs and customize the system to fit their process.

MD: **What R&D innovations are you developing to advance sensors for greater machine efficiency?**
VM: The companies we talk to and work with daily are pushing the implementation of new technologies, such as automation, artificial intelligence and cloud-based solutions for data storage. Metsen is innovating its EVCam series of extreme vision systems by using artificial intelligence in many ways, such as enabling the capability to learn from the images and data collected through the software.

Our systems can also be implemented with cloud technology and, as we move into Industry 5.0, we continue to embrace the interaction and collaboration between humans and technology. These kinds of developments we see taking shape will impact the development of industrial sensor systems.

MD: **Is there anything else our audience of mechanical and design engineers should know about advanced sensor technologies?**
VM: Software sits at the heart of the sensor system's effectiveness, collecting, integrating and visualizing data in real time, so ensure the system you choose is designed to fully integrate with your plant's production processes. Also, keep predictive maintenance in mind, which requires analytics to monitor equipment performance continuously. Maintenance can be scheduled proactively by detecting early signs of wear or potential failures based on sensor data patterns, minimizing costly unplanned downtime and repairs.

Finally, work with a team of highly skilled professionals who can provide you with top-notch customer service support from start to finish and provide continued support utilizing a remote monitoring management system.

to view this article online, ☞ *click here*

☞ **BACK TO TABLE OF CONTENTS**

CHAPTER 9:

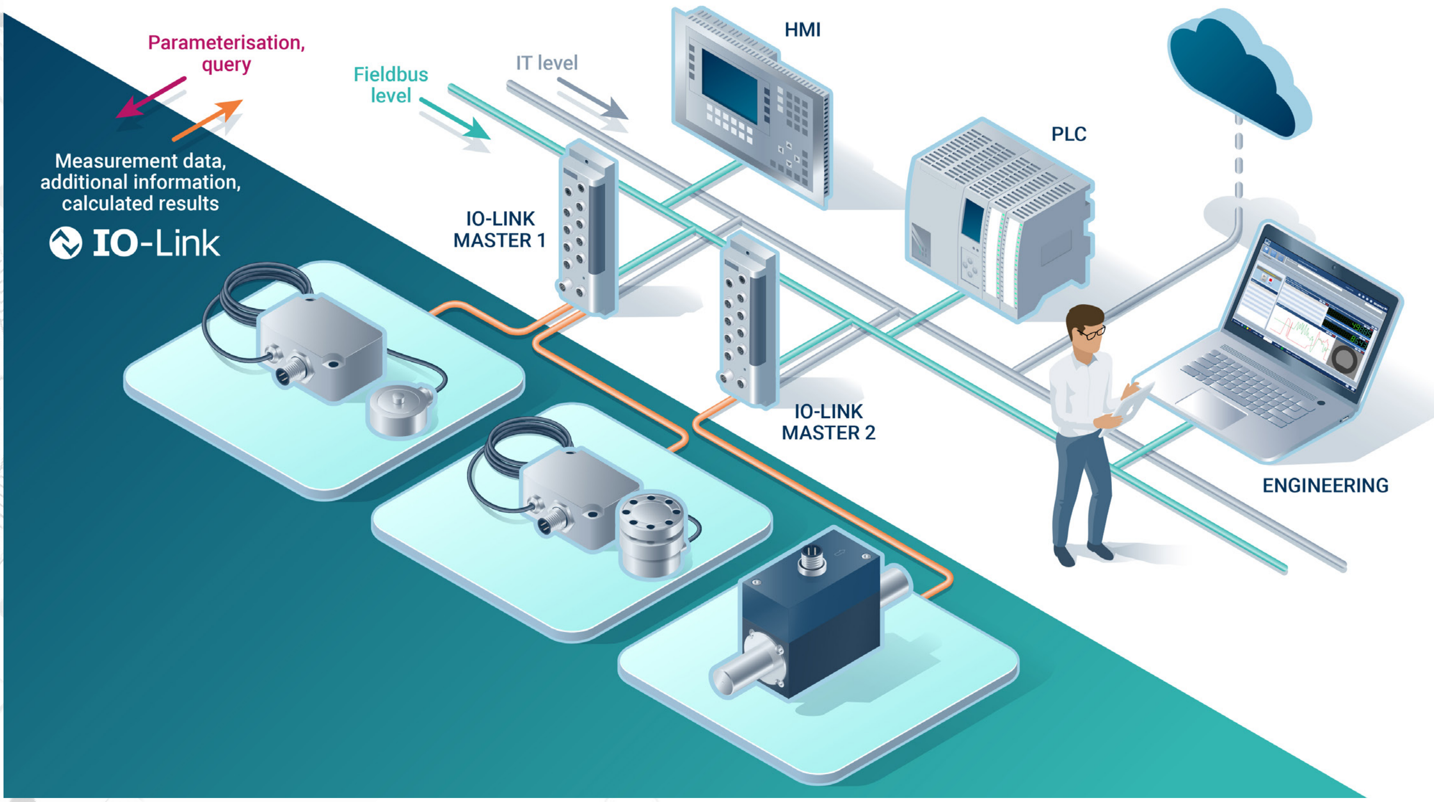
Smart Sensors: IO-Link Enables New Era for Strain Gauge Sensors

JEREMY COHEN, Managing Editor, *Machine Design*

IO-Link-enabled smart sensors are emerging as a leading technology for field-level applications, offering a future-proof solution that seamlessly integrates with both new and existing machine architectures.

The digitalization of sensors for mechanical quantities represents the future in modern production and testing technology. Decentralized intelligence, data economy, failure-proof setup and efficient operation all go hand-in-hand with increased accuracy and greatly improved reliability in operation. Smart sensors with an IO-Link interface are set to be the predominant technological solution for sensors in the field-level, providing a future proofed solution that integrates with new and existing machine architectures in an easy, flexible and cost-efficient way.

READ MORE: High-Sensitivity Wide-Range Strain Gauge Mixes Graphene and Silicone-Rubber Matrix



Machine Design connected with Martin Schütz, product manager, Smart Sensors, Hottinger Brüel & Kjær, to help navigate the interface between smart sensors and IO-Link.

***Machine Design:* In which applications are strain gauge-based sensors typically used?**
Martin Schütz: Strain gauge-based sensors are used in a wide variety of industrial and testing applications and fall into three main categories: force transducers, load cells and torque transducers. Measuring these mechanical quantities (force, load, torque) is at the heart of many mechanical processes in machines and production lines or in end-of-line testing applications. Typical applications are force joining processes; check weighing and torque measurements in end-of-line production; and testing and monitoring applications—just to mention a few.

***MD:* How do smart sensors evolve from the traditional measurement chain?**
MS: Traditionally strain-gauge based sensors must be set up in a measurement chain, consisting of a passive sensor, high-quality, double-shielded cabling and an amplifier with the required output signal—that is, analogue (V, mA), serial Bus (Profibus, CAN) or industrial Ethernet (Profinet, Ethernet/IP, EtherCAT, etc.). With the new line of smart sensors, we integrate the sensing element, the amplifier and a microprocessor as well as a communication interface into one single unit.

[READ MORE: What's the Difference Between Stress-Strain Curves and Stiffness-Strain Curves?]

MD: **What are key benefits of integrating electronics into the sensor?**
MS: With this approach, we can achieve higher sensor accuracy due to the internal linearization functionality and the possibility of compensating temperature influences on the sensor. With integrated, domain-specific algorithms offering statistical functions such as min/max value tracking, limit switches, a check-weighing algorithm or power calculation, engineers achieve the results needed for their underlying process rather than having to implement these by themselves in the PLC program.

Another groundbreaking advancement is the implementation of a sensor health monitoring feature, which allows the sensors to continuously track the applied load or temperature and compare with the sensor-specific limits. If these limits are overrun, the sensor sends out an alarm event notifying the PLC and higher-level applications about the issue.

MD: **Why choose IO-Link as the communication interface?**
MS: There are many advantages to the IO-Link interface, and I want to highlight a couple of them. IO-Link unifies the sensor connector and cabling to a single standard allowing for simplification of sensor and actuator setup in the field-level. IO-Link was invented to be integrated into any common fieldbus environment, which is why there are IO-Link masters available for all common industrial Ethernet protocols.

READ MORE: Sensors That Promote More Efficient Industrial Workplaces

***MD:* How does this solution benefit system architects designing state-of-the-art machines and processes?**
MS: This is a huge advantage in terms of system design and overall machine architecture because engineers can now design sensor and actuator setups in their machines without having to change a big part of the setup when switching the overarching PLC solution. Furthermore, with IO-Link standardized backup protocols and system setup and parametrization, procedures can be defined for all IO-Link sensors in a machine. This means a huge efficiency benefit in servicing and machine setup.

***MD:* How is an overall cost-efficiency benefit achieved with this solution?**
MS: Overall, the cost efficiency benefits can be divided into three categories. Firstly, due to the higher accuracy of sensors with integrated signal processing, applications benefit from using a single sensor for wider measurement ranges without having to buy multiple sensors with different measurement ranges to fit the application.

Secondly, the integrated amplifier and standardized cables and connectors reduce the initial hardware costs. Leveraging the integrated domain-specific algorithms for process control applications such as force limit detection or check weighing also allows for decentralization and means fewer engineering hours in programming these algorithms.

Lastly, the IO-Link protocol standard allows for a standardized sensor setup, which is failsafe, fast and efficient and is the same for all IO-Link sensors. No more different approaches are required—one parametrization solution works for all. This means that less special training is required for system setup and maintenance staff, which results in an overall gain in total cost of ownership (TCO).

to view this article online, ☞ *click here*

☞ BACK TO TABLE OF CONTENTS

ID 14338456 © Tebnad | Dreamstime.com

CHAPTER 10:

Applying Low-Noise Solid-State Relays to Limit EMI: A Comprehensive Guide

JESUS MIRANDA, Product Manager, Crydom Solid State Relays, *Sensata Technologies*

A comprehensive look at low-noise solid-state relays and ways to limit electromagnetic interference.

Electromagnetic interference (EMI) is a pervasive challenge in the realm of modern electronics, influencing the performance, reliability and compliance of numerous devices. As industries continue to push the boundaries of electronic innovation, the need to mitigate EMI becomes increasingly critical. Solid-state relays (SSRs) offer unique advantages over traditional electromechanical relays (EMRs), but also present distinct challenges related to EMI.

This comprehensive guide explores the application of specialized low-noise SSRs to limit EMI, delving into their features, benefits and specific use cases.

The Role of Solid-State Relays (SSRs)

In a traditional EMR, a low-power circuit energizes a coil, creating a magnetic field which then physically closes the contacts and allows the high-power circuit to flow. Solid-state relays are electronic switching devices that use semiconductor components to switch on or off when an external voltage is applied.

Unlike EMRs, SSRs have no moving parts, which provides several benefits:

- **Increased reliability**. With no mechanical parts to wear out, SSRs typically have a longer lifespan. SSRs are known to last for millions of operations while EMRs often last in the range of 100,000-500,000 operations or slightly above when heavily derated. Obviously, the life expectancy of EMRs depends on the quality of materials and can be further increased at an additional cost. A frequent practice to increase life expectancy

READ MORE: Teaching an Old Sensor New Tricks

of EMRs is oversizing the ratings of the contacts, which in turn increases cost of the part as well.

- **Faster switching speeds.** SSRs can switch much faster than EMRs, which is crucial for many modern applications. Instantaneous turn-on solid state relays and contactors respond to a control signal in less than 100 μs.
- **Shock and vibration resistant.** Because they are not reliant on any moving components, solid state switching solutions are not susceptible to erratic or unreliable operation when operating under tough environments.
- **Silent operation.** Solid state switching solutions make no acoustical noise when the output contacts change state. This is highly desirable in many commercial and medical applications.
- **No arcing.** SSRs generate no sparks arcs when opening or closing, and do not bounce electrically or mechanically, making them well-suited for hazardous environments.

One of the drawbacks of SSRs is driven by their nature as a semiconductor—specifically in terms of heat. When the SSR is on, resistance within the circuit causes power dissipation and heat build-up, which—depending on the application—may necessitate the inclusion of a heat sink, thus increasing the size of the solution. Many SSRs are sold with integral heat sinks, which helps reduce the complexity in managing heat dissipation across a specific application.

The fast-switching nature of SSRs can also generate high-frequency noise, contributing to EMI. This is where specialized low-noise SSRs come into play.

Understanding EMI and its Impact

EMI is the disturbance generated by an external source that affects an electrical circuit. This interference can degrade the performance of the circuit, lead to data loss or cause total device failure.

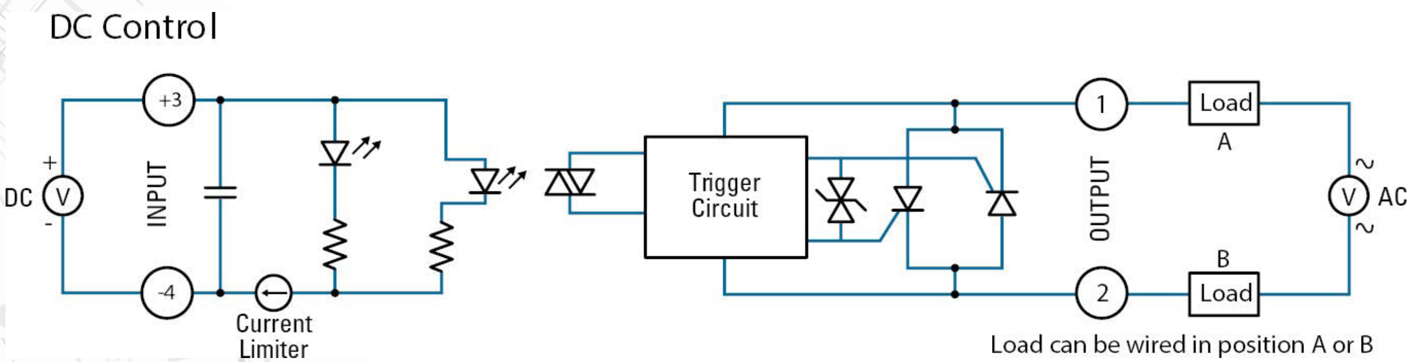
EMI can originate from various sources, including power lines, radio transmitters and even other electronic devices. In industrial settings, the consequences of EMI can be particularly severe, affecting precision machinery, communication systems and sensitive medical equipment.

Key Features of Low-Noise SSRs

To mitigate the EMI generated by fast switching, low-noise SSRs incorporate a variety of approaches, such as shielding and filtering. But the circuit design itself plays a significant role.

First, using relays with a silicon-controlled rectifier (SCR) output is an initial step in looking to minimize EMI. But when looking to meet standards such as IEC 60947-4-3, additional steps may be needed.

SSRs with zero-crossing detection are designed to deliver lower noise levels for resistive loads. This feature allows the relay to switch at the point where the AC voltage waveform crosses zero volts. Switching at this point eliminates inrush current and voltage spikes, significantly reducing EMI. For inductive loads, so-called random-switching SSRs are preferred. When the switch is activated, they switch instantly, rather than waiting for the AC supply to reach zero.



The author explained that SCR-based relays have the advantage of a faster dv/dt characteristic when compared with a triac relay. Sensata's LN series of relays is an example that incorporates a low noise trigger circuit.

SCR-based relays also have the advantage of a faster dv/dt characteristic when compared with a triac relay—especially when the relay is not activated. By way of comparison, SCRs have a dv/dt of around 500 volts/microsecond (volts/µs)—compared to 10 volts/µs for a triac—and will not conduct after the zero-crossing point. Because the components are also spread wider within the device, they will generally deliver slightly better heat dissipation.

An example of these types of SSRs can be seen in Sensata's LN series of relays, which incorporate a low noise trigger circuit designed to help use of additional EMI filter.

The LN Series offers ratings up to 75 Amps at 528VAC in standard panel mountable hockey-puck style device with Integrated input/output overvoltage protection. It is also available with standoffs for PCB mounting if needed, and is UL recognized and TUV certified.

Some key applications where the LN series has been well-suited include commercial ovens, household appliances and medical equipment.

Sensata Technologies' LN Series offers ratings up to 75 Amps at 528 Vac in a standard panel mountable device with integrated input/output overvoltage protection.

Benefits of Low-Noise SSRs

The implementation of low-noise SSRs offers several benefits across various industries where EMI is most challenging, such as medical devices, telecommunications or industrial automation equipment.

While more expensive than EMRs, solid state relays deliver the wear-free operation needed in today's digital electronic landscape. By reducing EMI, these SSRs also ensure that sensitive electronic equipment operates more reliably and efficiently and potentially deliver an extended lifespan as impacts on components are minimized.

Using low-noise SSRs can also help reduce or eliminate the need for an external filter, reducing cost, design complexity and space.

The application of specialized low-noise solid-state relays is a critical strategy for limiting EMI in various electronic systems. By incorporating features such as snubber circuits, zero-crossing detection and advanced shielding, these relays help ensure the reliable and efficient operation of sensitive equipment. As industries continue to demand higher performance and stricter compliance with EMI standards, low-noise SSRs will play an increasingly significant role in the design and implementation of modern electronic systems.

to view this article online, ☞ *click here*

☞ **BACK TO TABLE OF CONTENTS**

ID 14338456 © Tebnad | Dreamstime.com

CHAPTER 11:

Inventors Manipulate Light and Optics to Solve Everyday Problems

REHANA BEGG, Editor-in-Chief, *Machine Design*

An inventor banks on optical systems, design and prototyping and manufacturing services to solve problems. In the accompanying video, a patented light sensor plays a central role in finding the edge of the tape.

Countless light technologies used in everyday life are taken for granted.

But that changes when one speaks to John Ellis, a serial inventor, who often brings real-world challenges to his team of primarily physicists to figure out solutions.

"That could be anything from light emitting from a streetlight, which must make a particular pattern on the ground to meet a transportation standard or a camera that's looking at boxes moving on a conveyor belt and trying to read bar codes or dimensional information," Ellis said.

His Massachusetts-based company, Optics for Hire, provides contract optical systems, design and prototyping and manufacturing services. "It's just a very wide range of applications, but it always involves sending light, which could be in any wavelength or collecting light," explained Ellis. "We're designing the lenses that collect that light or send light, the mechanics that hold those lenses, and then electronics to process the light or move motors or drive lasers."

For the most part, solutions revolve around optical engineering, spanning the gamut of products. As a simple example, there's a "little optic" installed inside Mattel's Barbie doll, and for a more complex example, look to the $100,000 microscopes that Argonne National Lab uses to look at scintillators.

Licensing Technology as a Revenue Stream

Over the past few years Optics for Hire has developed its own products and started licensing its technology to create commercial solutions.

"One of those products was a little toy that has spinning fan blades, that has animation on it," said Ellis. "Our engineers figured out how to make the animation work based on the timing of the fan blade spinning, and each fan blade had a bunch of little LEDs. You can see these at any kind of retail outlet—Walmart, Target, Walgreens—and our customer, who uses this technology has then licensed it to Disney and Marvel and other companies and put animation of the Frozen movies or Jurassic Park movies on it. So that was a little technology that we licensed and got a feeling for the potential of licensing. That has sold many millions of units."

Solving Everyday Problems with Basic Sensor Technology

A natural tinkerer, Ellis is apt to find solutions to everyday niggling problems. A case in point was not knowing whether his kids' hockey skates needed sharpening. Ellis took his query to the office and worked with his engineering team to figure out a solution.

"We came up with a sensor that would use a camera to look at the edge of a hockey skate and determine whether that skate needed to be sharpened again," he said.

The blade sharpening project was soon nixed because Ellis realized the cost of manufacturing the product would outweigh the value added. Instead, he moved on to solving the problem of knowing when to sharpen knives.

"Most people, when they're sharpening their knives at home, don't have any feedback methods—it's all subjective," explained Ellis. "How well does it cut a tomato? Is it cutting paper easily or not easily?"

The outcome of his team's effort was an optical system sold by the Farberware brand. The knife-sharpening system could be used with electric or any kind of knife sharpener and would signal the sharpness level with the aid of a light. A green light indicated the knife was sharp, a yellow light meant it needed more sharpening, and a red light signalled the knife was dull and needed sharpening.

"It gives you that feedback that is based not on some subjective method, but actual data about how light was scattering off the edge of it," explained Ellis. "This was an indication of thickness of the blade, which then was negative sharpness of the blade."

John Ellis, founder of Optics for Hire, credits a light sensor as the science behind the RollRanger, a device that helps one find the edge of the roll of tape. Optics for Hire

Patented Sensor Finds the Edge of Your Tape

When Ellis was frustrated with the annoying task of peeling back the tape at the edge of a roll, his natural inclination was to find a better way. "I couldn't find the edge," he said. "Even with my glasses, I would stare at the roll of tape, and I would feel around for it. I could never figure out where it was. And then, even if I did eventually start to figure out where it was, it would tear as I was ripping it off the edge. It was just annoying enough that I had a conversation with our team about whether there was a way that you could optically sense the edge of a roller tape—and you must do it very inexpensively."

His team came up with a system known as the RollRanger, which doesn't use optics at all. "It's a lot more like a phonograph record with a little pin," described Ellis. "If you can imagine an old phonograph record, the pin was going around and going up in those pits around the track to play the music."

A patented sensor moves along the roll of tape until the "pin" reaches the edge of the tape. An LED indicator light comes on as the pin senses the edge. A scraper forms part of the design and can be used to uniformly lift the tape. "Because we all have a lot of better things to do with our day than get frustrated with rolls of tape," quipped Ellis.

The RollRanger is for sale on Amazon and through retailers.

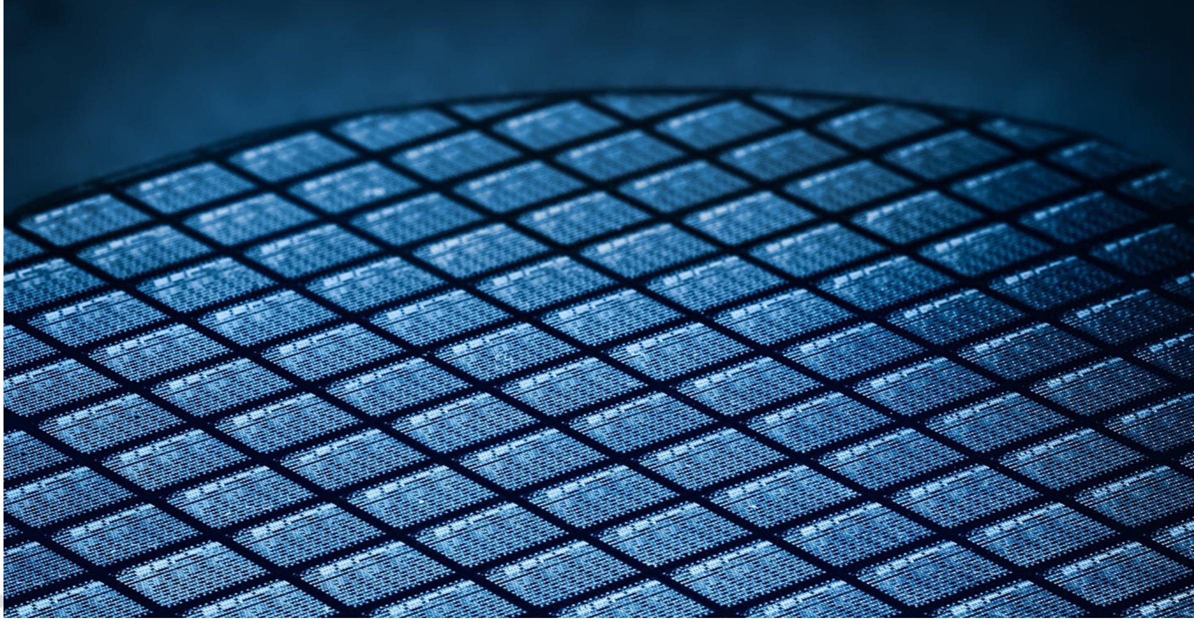
"It's been a lot of fun to learn about selling consumer products and getting the price point right and getting the packaging right and getting the marketing messages correct," said Ellis. "This is really precision mechanics. You have to know how to create a spring just the right way. You have to know about manufacturing and injection molding to make a product work properly. The skills that we have from optical engineering are applicable to lots of different things. Some are really important problems, and some are not so important, but annoying enough to want to solve."

Part 2: Behind the Optical Solutions that Help Detect Malaria and Treat Brain Cancer

Part 3: Ask the Inventor: What Room Does AI Leave for Inventing New Solutions?

to view this article online, ☞ click here

☞ **BACK TO TABLE OF CONTENTS**



Sigma-Netics

CHAPTER 12:

Custom Pressure Transducer Delivers High-Temperature Accuracy

SEAN GREGORY, Director, Engineering Applications & Sales, *Sigma-Netics*

Sigma-Netics designed a sensor for the demanding performance requirements of a semiconductor application. Discover how they balanced thermal performance with package size.

Designing high-performance pressure transducers can be a technical balancing act. While it's relatively simple to design an accurate low range transducer with high output sensitivity, it is difficult to couple that with low thermal errors at extreme temperatures. Add in additional requirements—like a smaller form factor or lower mass—and the design challenge becomes even more difficult.

Basic physics limits many pressure transducer design and performance combinations that tend to be mutually exclusive in commodity sensors, including low-range accuracy, thermal performance and size. Striking a balance between these attributes is possible but requires a significant amount of custom engineering along with a deep understanding of pressure transducer components and calibration strategies. Traditional sensing technologies offer a few of these options in combination, but not all.

For example, bonded gauge sensors offer high accuracy at low pressures with excellent thermal performance and survivability, but they sacrifice size, requiring a significant strain field and room to bond. MEMS sensors offer high accuracy at low pressure ranges, high signal output and small size, but they perform poorly or even fail to survive at extreme temperatures, typically limited to under 200°F. Exceptions exist but can then be cost-prohibitive.

For a glimpse at what's possible when a sensor is designed for demanding performance requirements, rather than bought as-is from a catalog, consider a model we recently created for a semiconductor application. This customized 0-100 PSIA sensor measures

READ MORE: High-Precision Motion Components Drive Advances in Semiconductor Production

pressure as part of a semiconductor gas flow monitoring and control system. Performance requirements included an accuracy of 0.35% FSO TEB, frequent excursions to temperatures as high as 428°F and a high output signal of 100 mV.

Designed for flush-mount installation within the gas flow system, the sensor also needed to be small, with just a 12.7-millimeter (mm) diameter and 13.5-mm height. Conventional COTS solutions could not meet these application requirements.

The Problems With Accuracy, Heat and Size

Achieving this level of accuracy is not an issue for high-performance pressure transducers. Most of our off-the-shelf pressure transducers, for instance, offer a standard accuracy of 0.25% FSO static accuracy (not TEB) and can optionally reach accuracies better than 0.1% FSO static accuracy for operating temperature ranges between −65° and +250°F. (See sidebar for more on our commercial off-the-shelf sensors.)

High temperatures, however, affect the sensor's circuitry and strain gauges, introducing errors that reduce accuracy across the entire span. A typical high-temperature sensor operating at 428°F could exhibit a thermal error as high as 2.0% with standard thermal compensation techniques. Many off-the-shelf high-temperature models can't achieve 428°F at all—at least not for long-term exposure—without limiting output options or requiring thermal isolation methods that increase the final product's complexity.

Our new sensor design, by contrast, has a total error of 0.35% FSO TEB across a wide temperature range—from room temperature to 428°F. That total error includes linearity, hysteresis, repeatability and thermal effects on zero and span.

With this sensor, the combined features of low-range accuracy and high-temperature thermal performance don't come at the expense of package size, where the three requirements tend to compete. Nor does it require traditional thermal wells or standoff tubes that require extra room within the sensor location.

In high-temperature applications, it is usually necessary to protect against heat either by using a standoff tube to "bleed" the temperature, adding mass to use as a heat sink or separating the electronics module to isolate the components that can't tolerate high temperatures. Similarly, internal space is required to allow for the additional thermal compensation sensors. In addition, with low-range sensors, diaphragm thickness is limited by the outer diameter of the sensors: traditional diaphragm or beam designs yield to machine tooling pressures before desired thicknesses are reached, and media-isolated designs require complex geometries, further impacting the size, mass and number of internal components.

How It's Done

Pushing the envelope on the compact low-range sensor's thermal performance while minimizing its package size did not come down to an individual technical breakthrough. Instead, the improvements are rooted in careful application of known, but difficult, sensor design, manufacturing and calibration methods.

In particular, we paid close attention to materials used throughout the sensor, avoiding lower melting-point solders in favor of gold, using proprietary bonding techniques and selecting only heat-tolerant materials throughout the sensor. Likewise, we selected high-temperature electrical components for the signal conditioning circuitry.

Sigma-Netics

To ensure total error band accuracy across such a wide thermal range, we took the extra step of thermally matching the sensor's individual strain gauges. Thermal matching boils down to a time-consuming process of identifying resistors with a similar Temperature Coefficient of Resistance (TCR)—and then creating the Wheatstone Bridge circuitry using these matched resistors. This technique reduces one of the key causes of thermal error: strain gauge performance variability. Strain gauges in a single lot "move" differently from one another as temperatures change due to variations in material conditions, starting resistance and TCR. Our process reduces this critical source of thermal performance uncertainty, allowing traditional techniques to further enhance performance.

Rather than thermally matching the strain gauges, the standard practice in the sensor industry is to compensate for the differences in strain gauge TCR with additional resistors or through a digital compensation board. These compensation methods include well-known active and passive measures that would not have allowed us to meet the 0.35% FSO TEB accuracy specification at high temperatures without adding size or additional components or impacting the sensor's operating temperature capabilities.

The Value of Custom Designs

While engineered for a specialized semiconductor application, this high-temperature low-range sensor does highlight the value of custom sensors for all difficult applications. The same design, manufacturing and calibration principles can be tailored to the requirements of other applications whose thermal performance, accuracy and package space requirements are not well-served by commodity sensors — including space exploration, aircraft, subsea vehicles, downhole oil and gas, high-temperature process industries, and more.

This article was submitted by Sean Gregory, director, Engineering Applications & Sales at Sigma-Netics.

READ MORE: Twisting and Bending a Layer of Semiconductor Materials in an LED Boosts its Efficiency

READ MORE: The Semiconductor Race is On!

Extreme Ingress Protection

Although some applications call for a custom design starting with a blank sheet of paper, you can still meet many challenging application requirements with the right commercial-off-the-shelf (COTS) unit. For example, some of the following transducers can withstand radiation, fatigue and submersion in underwater vehicles and high pressures in excess of 30,000 PSI:

The SST 64X-RT radiation-tolerant mV/V pressure transducer features custom ATP, NDE, traceability and low mass for installations with limited space.

The SST 144 high-pressure, fatigue-rated transducer can handle pressures in excess of 100,000 PSI. Units are available with extended temperature compensation ranges, high-level analog and digital outputs, and ±0.25-percent FSO accuracy.

The SST 44X multi-purpose aerospace pressure transducer features shunt calibration, multi-temperature thermal sensor characterization and cryogenic options. Its all-welded, customizable design is ideal for all applications.

The SST 44X-M miniaturized aerospace pressure transducer is a low-mass, highly accurate unit weighing in at less than 90 grams. Units feature a ¾-inch outer diameter, pressure ranges up to 10,000 PSI and a variety of wetted material options.

The SST 74X-UV submersible vehicle depth transducer is a compact, 90-gram model with shallow diaphragm sensors and a configurable flange design for outboard or inboard bulkhead installation. Units include an all-welded hermetic construction that resists shock and vibration.

With their ruggedized design, these pressure transducers meet the requirements of demanding industrial and aerospace applications—including deep space missions. Other notable features include combined temperature and pressure measurement, remote electronics modules, wide standard temperature ranges (−65° to +250°F) and more.

In particular, we paid close attention to materials used throughout the sensor, avoiding lower melting-point solders in favor of gold, using proprietary bonding techniques and selecting only heat-tolerant materials throughout the sensor. Likewise, we selected high-temperature electrical components for the signal conditioning circuitry.

To ensure total error band accuracy across such a wide thermal range, we took the extra step of thermally matching the sensor's individual strain gauges. Thermal matching boils down to a time-consuming process of identifying resistors with a similar Temperature Coefficient of Resistance (TCR)—and then creating the Wheatstone Bridge circuitry using these matched resistors.

This technique reduces one of the key causes of thermal error: strain gauge performance variability. Strain gauges in a single lot "move" differently from one another as temperatures change due to variations in material conditions, starting resistance and TCR. Our process reduces this critical source of thermal performance uncertainty, allowing traditional techniques to further enhance the performance.

Rather than thermally matching the strain gauges, the standard practice in the sensor industry is to compensate for the differences in strain gauge TCR with additional resistors or through a digital compensation board. These compensation methods include well-known active and passive measures that would not have allowed us to meet the 0.35% FSO TEB accuracy specification at high temperatures without adding size or additional components, or impacting the sensor's operating temperature capabilities.

The Value of Custom Designs

While engineered for a specialized semiconductor application, this high-temperature low-range sensor does highlight the value of custom sensors for all difficult applications. The same design, manufacturing and calibration principles can be tailored to the requirements of other applications whose thermal performance, accuracy and package space requirements are not well-served by commodity sensors—including space exploration, aircraft, subsea vehicles, downhole oil and gas, high-temperature process industries and more.

to view this article online, ☞ *click here*

☞ **BACK TO TABLE OF CONTENTS**