Fiber optic rotary encoder technology offers EMI immunity for motion control applications in harsh environments—two case studies

The passive nature of fiber optic technology provides a fundamental solution to interference plagued transmission problems.

DENNIS HORWITZ
MICRONOR INC.
Newbury Park, CA.

In many industrial automation or motion control applications, equipment can be exposed to EMI generated by nearby equipment. These noisy electrical environments can induce errors in the communications link between the (rotary or linear) encoder and the system controller. Missing encoder counts can cause the equipment to move to the wrong position or can simply have an adverse effect on the ongoing process. In a manufacturing application, this exposure can lead to out-of-tolerance or defective parts or products. In a test application, EMI can lead to incorrect equipment settings, bad readings, and false results. These encoder communication errors are costly in terms of time lost and money and materials wasted.

By definition, a benign environment is neutral or unthreatening. Examples might be a manufacturing plant, machine shop, or engineering lab operating within a controlled air-conditioned environment or, alternatively, working at a comfortable ambient temperature. In these benign environments, the electronics of conventional encoders are neither thermally stressed (typically operating within the "industrial" electronics range of 0–70°C) nor directly exposed to other adverse elements or conditions (washdown, corrosive chemicals, shock, vibration, etc.). In the majority of these relatively benign applications and conditions, noise problems can be reduced or eliminated by re-routing cables or by upgrading to more expensive, higher performance shielded cabling.

A harsh environment pushes at least one environmental parameter to some extreme. Elements in a harsh environment can include temperature (extreme heat, cold, or cycling), humidity, pressure or vacuum, altitude, shock, or vibration. Other adverse factors might be electrical noise (EMI or RFI); radiation; or wet environments such as wash-down, immersion, or wind-driven rain. Contaminants like sand, dirt, or oil and corrosive agents such as detergents, chemicals, jet fuel, and salt air will compromise a work environment. Needless to say, extremely hazardous or explosive environments pose formidable problems.

Conventional rotary encoders incorporate electronics in which performance diminishes under any or all of these extremes. On the other hand, an all-optical approach can outperform conventional electrical technology. An all-optical encoder features total passivity and electrical isolation—*i.e.*, it cannot generate or be affected by electromagnetic interference and receives input only via fiber optic links. These encoders are also chemically passive and immune to lightning and atmospheric static. Moreover, such encoders operate over a wider range of temperature (-60°C to +150°C and beyond) and are far easier to install. Lightweight cabling replaces heavy and bulky multi-wire harnesses. Another significant installation factor is that remote placement of the encoder is feasible; and with glass fiber, transmissions over very long distances—over 1000 meters or more—are possible.

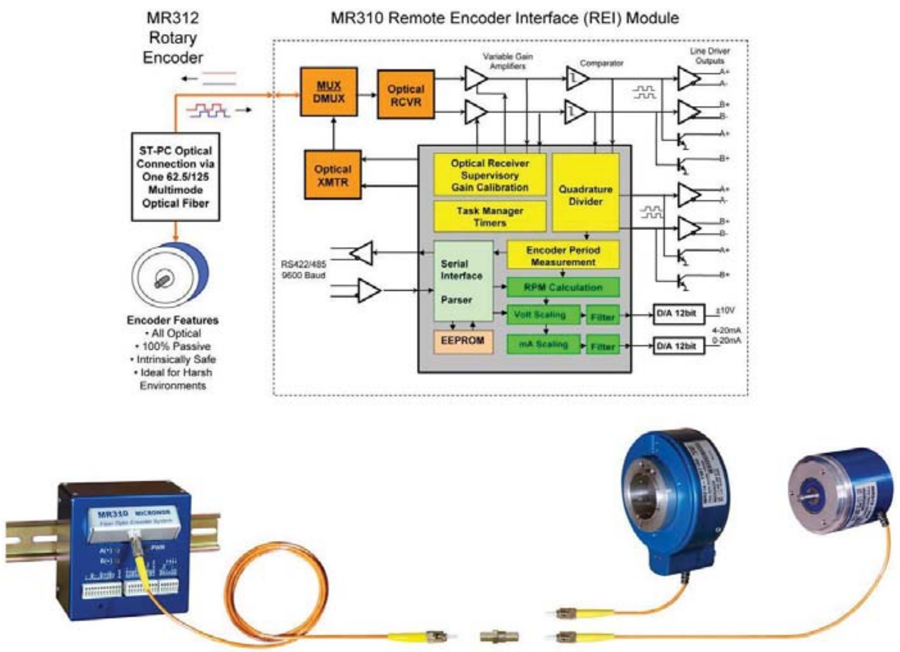

Figure 1. *Block diagram of the Fiber Optic Rotary Encoder (FORE) system.*

THE SOLUTION

An all-optical, totally passive Fiber Optic Rotary Encoder (FORE) using a simplex fiber link has been developed and commercialized. As shown in Figure 1, the FORE system consists of the "passive" encoder, the "active" remote encoder interface (REI) module, and the simplex 62.5/125 multimode fiber link that connects the two. The design incorporates "telecom-proven" wavelength division multiplexing (C-WDM) technology that uses two widely spaced light signals (850 nm and 1300 nm) – corresponding to A and B incremental quadrature signals, respectively. The two light signals are combined (*i.e.*, multiplexed) onto one fiber and transmission is bidirectional. Both the originating light signals transmitted to the encoder and the return signals pass over the same single fiber.

As the rotary encoder operates, two light signals originate from the "active"REI module, where they have been multiplexed or combined onto a single, multimode glass fiber. With the passive encoder (See cutaway in Figure 2), the light beam containing the "two-color" light signals passes through a slotted disk and a pair of optical filters, which, in turn, separate the two light signals. The light then reflects off a spherical mirror, returning through the filters and disk and back into the fiber where it had originated. The two optical return signals from the encoder are de-multiplexed into two separate light signals (850 nm and 1300 nm) and are converted into conventional A/B incremental electrical outputs. This common signal format can then be connected directly to the sensor/encoder of a PLC (programmable logic controller) or other motion control device. Resolution options range from 100 ppr (pulses per revolution) to 1024 ppr (equal to 0.35 degrees or 21 arc minute resolution. The embedded circuitry within the REI module provides additional features and functions. Its internal processor can also determine shaft position, speed, and direction by counting pulses and measuring phase differences between the optical signals.

In fact, the "active" intelligent REI module includes several additional features and functions. Two analog outputs (4–20 mA and ±10 V) can be separately programmed to represent shaft speed or position. It also features a quasi-multi-turn absolute encoder function via a 24-bit internal counter (depth of 8,388,608 counts plus directional sign). In a 1024-ppr (10-bit) encoder, this function provides the ability to track position over 8,192 turns. Both an external signal input and software command are available to set the initial zero position. Also, a programmable divider function (with independent A/B quadrature outputs) allows resolution to be decreased for special application—eliminating the cost and sourcing of a separate module. and allowing standardization on a single encoder.

Additional REI module features include a built-in test (BIT) and diagnostics function. Using BIT, optical transmission levels can be monitored and the receiver gain adjusted to compensate for degradation and to "warn" the control system of such conditions. Finally, an RS422/RS485 serial I/O interface programs various firmware parameters (analog output mode, scale, divider, zero position point, etc.) and facilitates PC-friendly computer access under software control.

CASE STUDY #1 AERIAL CABLE CARS

The motion of ski lifts, gondolas, and aerial cable cars (see Figure 3) is usually monitored by rotary encoders mounted

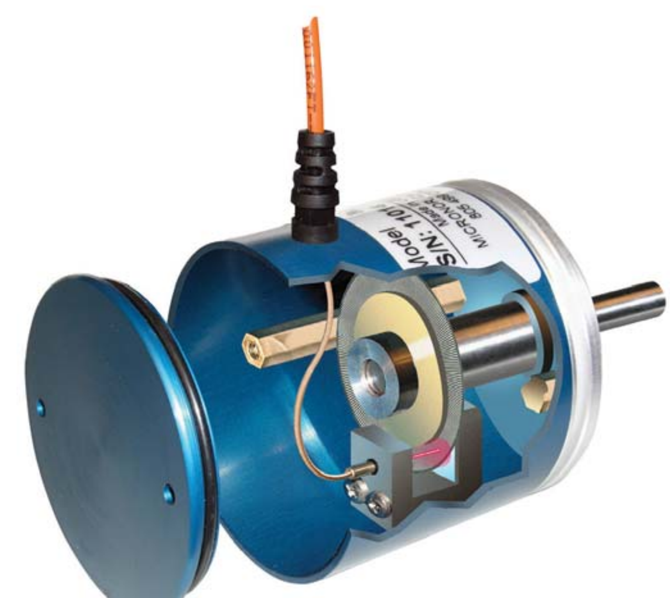

Figure 2. *Cutaway view of the Fiber Optic Encoder.*

Figure 3. *FORE system monitors cable car drive system.*

on high towers at opposite ends of the tramway. These encoders must endure a variety of harsh conditions—the high temperatures of summer, low temperatures of winter, cyclic conditions of day/night, lightning, atmospheric static, wind-driven vibration, and EMI from the large motor drives. Human safety is foremost—followed closely by 24/7 reliability and near-zero maintenance costs.

Previous tramway controls used conventional optical rotary encoders, as well as early generation fiber optic encoders. Conventional encoders with internal electronics exhibited sensitivity and reliability problems arising from seasonal temperature extremes and daily day/night cycling. They were still susceptible to lightning-induced failures despite deployment of lightning arrestors and surge suppressors. Finally, these conventional encoders required long, heavy copper cable runs that made for awkward installation and support, and the extensive lengths in themselves made EMI pickup likely.

First generation FOREs using Plastic Optical Fiber (POF) were an improvement. The all-optical, passive design (albeit with four fibers) offered immunity to EMI and lightning as well as improved reliability. Still, these early optical encoders suffered from some technical limitations. Although fiber optics is superior to copper as a transmission medium, POF is considerably lossy and consequently out-distanced versus glass fiber (8 meters versus 1000s of meters). POF technology supports a more limited operating temperature range (typically -40°C to +85°C) than glass, and the four-fiber connection made installation and maintenance somewhat problematic. This final complication arose because each light signal and direction in these early encoders employed a separate fiber.

The new-generation FORE with glass fiber and WDM technology has demonstrated many advantages over the prior solutions. As noted above, they provide more reliable operation over temperature. The POF encoder's limited link length proved an impractical working distance as encoders need to be placed higher and farther away from the system controllers. Furthermore, the "glass" encoders proved to be simpler to install and support thanks to their single-fiber design.

CASE STUDY #2: FIBER OPTIC ANEMOMETER FOR MINES

In this application, a coal mining operation needed to monitor air velocity of its underground ventilation system. Because of the potential presence of explosive fumes, the ideal solution needed to be totally passive with no potential for electrical arcing. The goal was to achieve a real-time measure of air velocity unaffected by EMI emanating from nearby pumps, compressors, drills, and other heavy mining equipment. The sensor also had to be able to operate from nearly 1000 feet below the surface and to transmit to a remote monitor above ground.

As shown in Figure 4, the solution was to affix a fan blade to the FORE. During a one-day mine closure for annual systems maintenance, the FORE/fan blade was installed underground and was linked topside via a 1000-foot optical fiber link. One of the REI modules analog outputs was programmed to monitor speed in RPMs (revolutions/minute) and was calibrated to represent air velocity in feet/minute. The fiber optic link insured that the signal transmission of the encoder

Continued on page 54

Figure 4. *Demonstration of the fiber optic "anemometer" proof-of-concept for measuring air velociy in underground mines.*

was unaffected by the electromagnetic emissions of various mining equipment along its path.

CONCLUSION

The convergence of telecom-proven WDM technology and optical rotary encoders has produced an EMI-immune fiber optic-based rotary sensor solution applicable to a wide range of harsh, hazardous test and remote sensing applications. The FORE is a rotary sensor innovation that is completely passive (no remote power connections required), EMI immune, and intrinsically safe. It can support remote sensor-controller links in excess of 1000 meters via the simple installation of just one glass "wire."

For EMC-challenged plant environments and other situations in which equipment must be operated in harsh environments, the FORE ensures reliable machine, process and actuator positioning, feedback, and control. The intrinsically safe, electrically isolated FORE is also a logical choice for hazardous or explosive environments.

In EMC test facilities such as anechoic chambers, using FORE ensures that its "copperless" encoder cable links will not affect the measurement setup or process. This feature is especially critical for the precision measurements necessary for electronic warfare system and radar signature evaluations. The absence of electromagnetic emissions also creates a "stealth" attribute valuable to military, aerospace, and homeland security applications. Medical applications can also benefit from a FORE built from materials "transparent" to MRI diagnostic systems.

While many applications attempt to mitigate EMC and EMI issues via special (and sometimes very expensive) shielding, cabling, surge suppressors, packaging, and other design techniques, the passive nature of fiber optic technology provides a fundamental solution to interference-plagued transmission problems. It is true that fiber optic sensor technology generally presents a cost premium over conventional electrical/copper sensor technology. However, when the added cost of protecting conventional sensors (safety barriers, lightning arrestors, surge suppressors, etc.) are factored into design decisions along with the knowledge that some field failures will still occur despite these expensive precautions, the FORE offers a highly-reliable solution with lowest life cycle costs in EMC-sensitive, harsh, or hazardous environments.

Dennis Horwitz *received his M.S.E.E. from UCLA and has over 25 years' experience in R&D, sales, and marketing of fiber optic test equipment and components. He was co-founder of two successful startups in fiber optic test and measurement—Photodyne, Inc and Rifocs Corp. He is actively involved in fiber optic standards committees serving a range of vertical markets (ARINC for airlines, IEC for general international standards, ISA for industrial automation, SAE for automotive and aerospace, and TIA for North American telecommunications). He is currently co-owner and VP-Sales & Marketing for Micronor, Inc., serving the industrial automation and motion control markets and specializing in solutions for harsh and hazardous environments.* ■

MORE ON OUR WEBSITE