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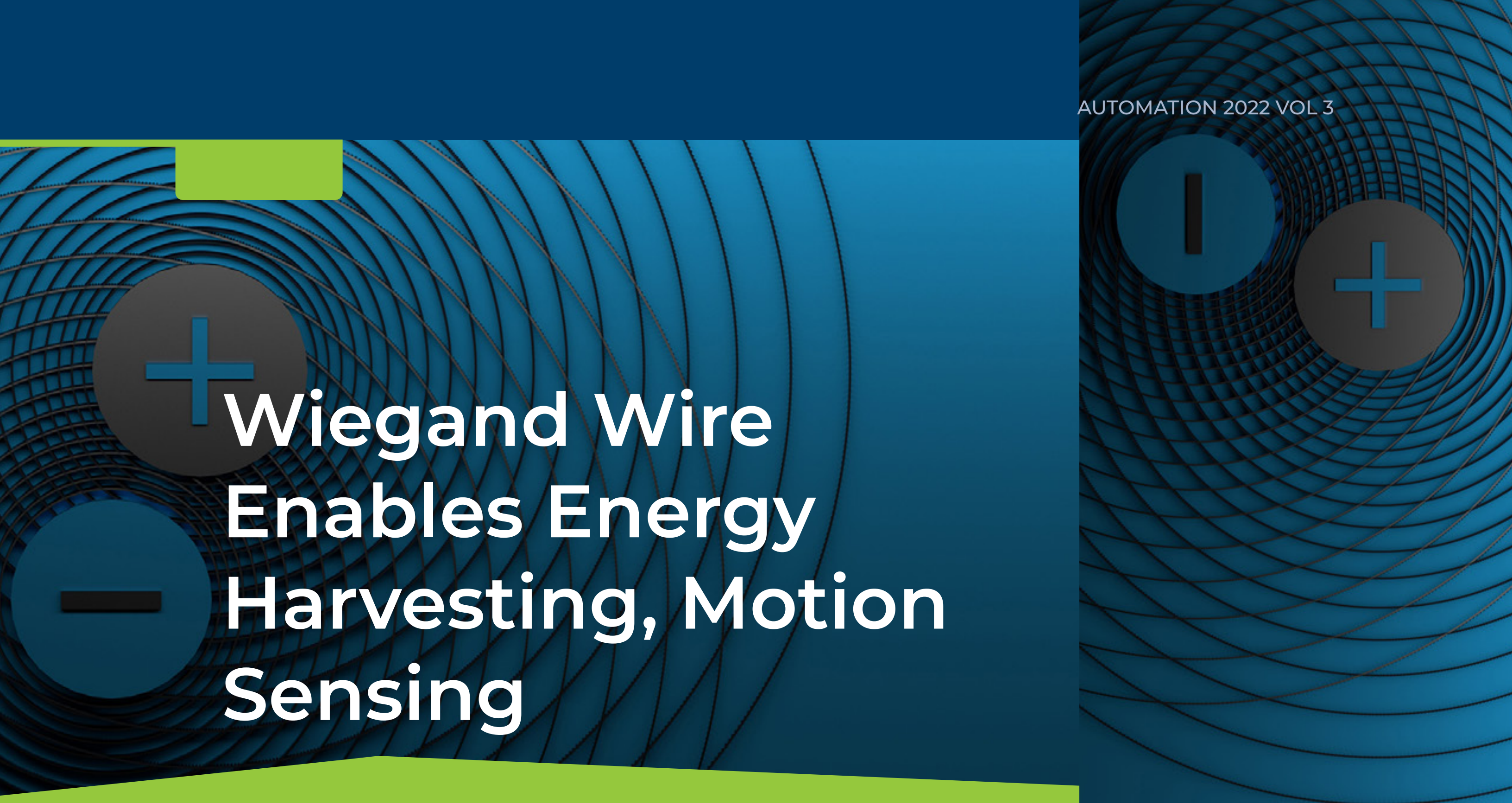

Wiegand Wire Enables Energy Harvesting, Motion Sensing

By manipulating the magnetic properties of Vicalloy wire, devices that can harvest energy and sense motion have been created.

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The “Wiegand effect” was discovered almost 50 years ago and has been used successfully in several specialized applications. However, its full potential for energy harvesting and signal generation has received only limited recognition. With recent enhancements to the energy output from Wiegand devices and the emergence of a new generation of ultra-efficient electronic chips for wireless communications, the technology is showing significant promise, especially in the realm of the Internet of Things (IoT). UBITO, a member of the FRABA Group of technology companies, is leading research and development projects aimed at fulfilling this promise.

Wiegand Effect explained

The Wiegand effect is a physical phenomenon discovered in the 1970s by John Wiegand, an American inventor who found that by repeatedly stretching and twisting a piece of ferromagnetic wire, he could alter its magnetic properties. When a sample of Wiegand wire is exposed to a reversing external magnetic field, it will initially retain its original magnetic state. However, when the strength of the external field reaches a critical threshold, a region of the wire that is magnetically soft will undergo an abrupt reversal of its polarity. This transition takes place within a few microseconds and can be harnessed to induce a pulse of electric current in a fine copper coil wrapped around the wire.

"The mechanical process that produces Wiegand wires creates a combination of magnetically hard and soft layers in the wire, causing the wire to have a high level of magnetic hysteresis."

The electric pulse generated by a Wiegand wire is very brief, but its strength stays nearly constant, regardless of how quickly or slowly the external magnetic field changes. This is what makes the Wiegand effect special: While simple dynamos, which also use electromagnetic induction, are effective at converting rotary motion into electrical energy, their output power varies with rotation speed. When a dynamo is turned slowly, power levels can be too low to be useful. With a Wiegand wire, however, the amount of electrical energy generated with each reversal of the magnetic field remains consistent over a wide range of speeds.

The combination of a short length of Wiegand wire and a surrounding copper coil is referred to as a Wiegand sensor. These are available commercially from UBITO in surface-mountable device (SMD) packaging.

Using energy harvesting power for innovation

"Energy harvesting" refers to technologies that extract energy from the local environment to power electronic devices. Several are available, including photovoltaics (energy from light), thermoelectric and pyroelectric effects (energy from temperature variations), and piezoelectric and electrostatic devices (energy from mechanical motion).

Wiegand sensors are also a good candidate for energy harvesting. In their basic form, these devices produce modest amounts of energy—about 200 nanojoules. However, recent developments have significantly increased energy output from Wiegand devices and opened possibilities for much more ambitious applications.

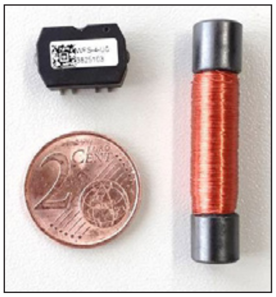

Figure 1. Wiegand harvester (right) and Wiegand sensor (top left).

Building an energy self-sufficient IoT Node.

An R&D program, carried out by a team of researchers at FRABA's technology center and the Rhineland-Westphalia Technical University with support from the German Ministry of Science and Technology, has developed enhanced Wiegand devices that are optimized for power generation. These are called "Wiegand harvesters." The researchers have demonstrated that a set of Wiegand harvesters (figure 1) can generate up to 10 microjoules of energy (approximately 50 times the output from a commercial Wiegand sensor). This was sufficient to energize a low-power ultra-wide-band radio transceiver with a transmission range of 60 meters.

This demonstration points to the feasibility of a new generation of entirely self-powered sensors that would be capable of monitoring a physical action such as a rotary motion or the opening or closing of a door and transmitting a notification signal to a monitoring system through wireless communications. Other condition data such as temperature could also be sent. This type of energy self-sufficient, maintenance-free device could become important components in IoT.

As Christian Fell, FRABA's head of technology development explains: "The vision of the IoT calls for thousands of smart sensors distributed through homes, commercial facilities, and digital factories, collecting data for monitoring, security, and process optimization. If these devices can be made energy self-sufficient, harvesting electricity directly from their surroundings to power both their operation and a wireless communications interface, there will be enormous benefits in terms of simplifying network deployment and reducing maintenance costs, including the cost of installing, checking, and disposing of thousands of backup batteries." The Wiegand effect could provide an excellent power source for remote sensors wherever there are changing magnetic fields present.

Along with an energy source, another key part of a viable IoT node is the communications interface. For their proof-of-concept demonstration, the FRABA-RWTS team used impulse-response, ultra wide band (IR-UWB) technology, based on an SR-1000 UWB transceiver from SPARK Microsystems. This device transmits very short electromagnetic pulses in a 2 to 11 GHz frequency band. Because this technology transmits data in short-duration pulses, it uses less energy than narrow band radio transmitters. This intermittent transmission is also a good fit with the Wiegand effect's characteristic of generating electrical energy with the brief pulses. As noted above, this prototype was able to transmit small data packets over 60 meters in demonstration tests.

Energy harvesting for self-powered sensors

For small Wiegand sensors, the electrical energy produced with each polarity change, while limited, is sufficient to activate a low-power electronic counter circuit. This form of energy harvesting has been used successfully in more than a million encoders (rotation measurement instruments) built by POSITAL and other manufacturers (figure 2). Because of Wiegand energy harvesting, these encoders' rotation counter systems are entirely self-powered with no need for external power sources or backup batteries, significantly reducing maintenance requirements.

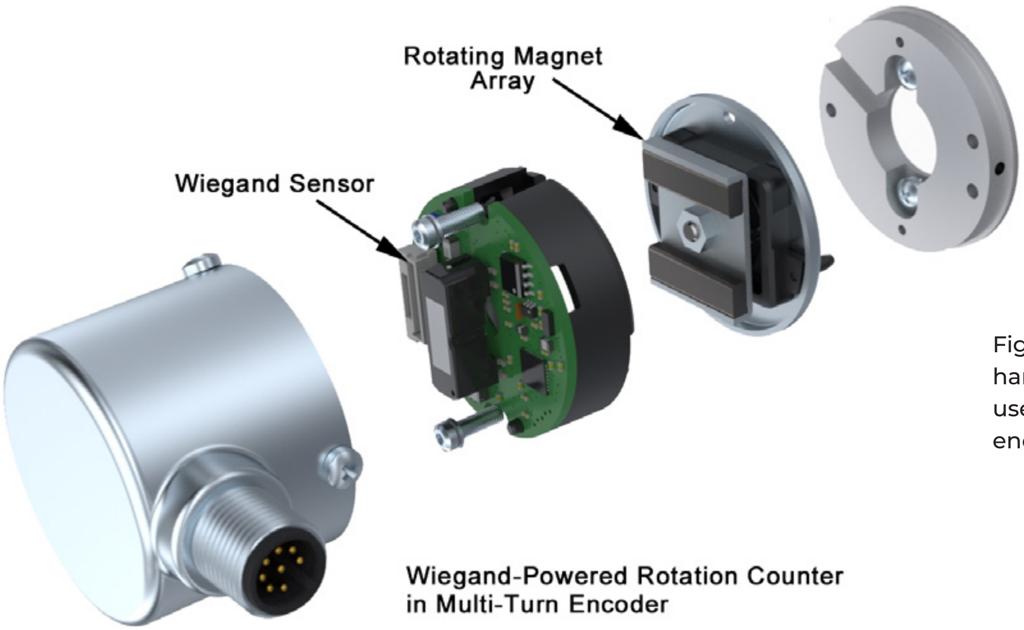

Figure 2. Energy harvesting has been used successfully in encoders.

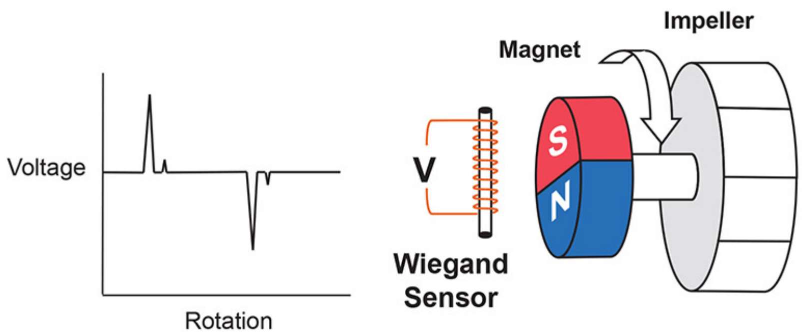

Figure 3. Wiegand sensors for rotation counting in fluid meters.

A similar principle has been used for water or gas meters. Here, a permanent magnet is mounted on the meter's rotating shaft, close to a Wiegand sensor (figure 3). As the shaft turns, the rotation of the magnetic field triggers abrupt polarity reversals in the Wiegand wire, inducing electric current pulses in the copper coil. As the strength and duration of each current pulse is independent of how quickly or slowly the shaft rotates, Wiegand sensors provide much higher signal-to-noise ratios than other analog magnetic sensors (e.g., Hall effect sensors). This ensures that the meter's counter circuit receives clear and unambiguous signals with each rotation of the shaft. Energy from the electrical pulse can also be harnessed to power the rotation counter circuitry, so the counter will keep a reliable record of shaft rotations in the absence of an external energy source.

Wiegand-based event triggering also has been used for tachometers for rail cars and other equipment. For this application, the Wiegand sensor is located near two magnets with the opposite polarity. The presence of a large ferromagnetic (iron) body nearby can neutralize the effect of one of these magnets so the magnetic field at the Wiegand sensor is dominated by the other magnet (N-S in figure 4). As the ferromagnetic body rotates, it neutralizes the

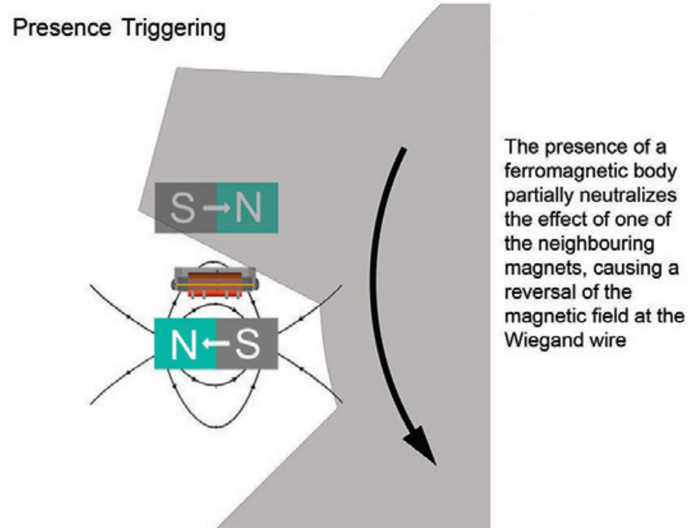

Figure 4. The presence of a large ferromagnetic (iron) body nearby can neutralize the effect of one of these magnets so the magnetic field at the Wiegand sensor is dominated by the other magnet.

other stationary magnet, reversing the field (S-N) and triggering a polarity flip in the Wiegand wire (figure 5). The benefit of Wiegand technology in this application is that it operates reliably over a wide range of rotation speeds. Moreover, with no mechanical contact between the sensor and the moving component, there is no wear, and the systems have service lifetimes of billions of operating cycles.

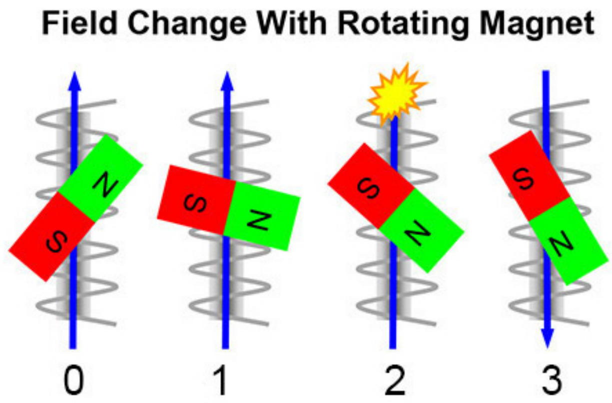

Figure 5. As the ferromagnetic body rotates, it neutralizes the other stationary magnet, reversing the field (S-N) and triggering a polarity flip in the Wiegand wire.

The Wiegand cycle

The mechanical process that produces Wiegand wires creates a combination of magnetically hard and soft layers in the wire, causing the wire to have a high level of magnetic hysteresis (figure 6).

As the external magnetic field changes, the Wiegand wire will at first retain its initial polarity (Point A in figure 6). However, when the strength of the external field reaches a critical threshold, the polarity of the magnetically soft zone of the Wiegand wire suddenly reverses (Point B). As the external field continues to strengthen, the

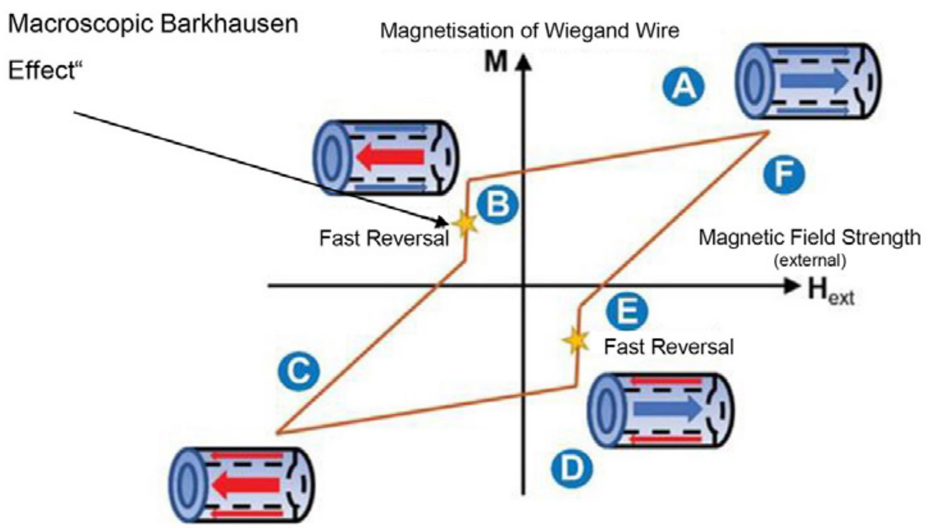

Figure 6. The mechanical process that produces Wiegand wires creates a combination of magnetically hard and soft layers in the wire, causing the wire to have a high level of magnetic hysteresis.

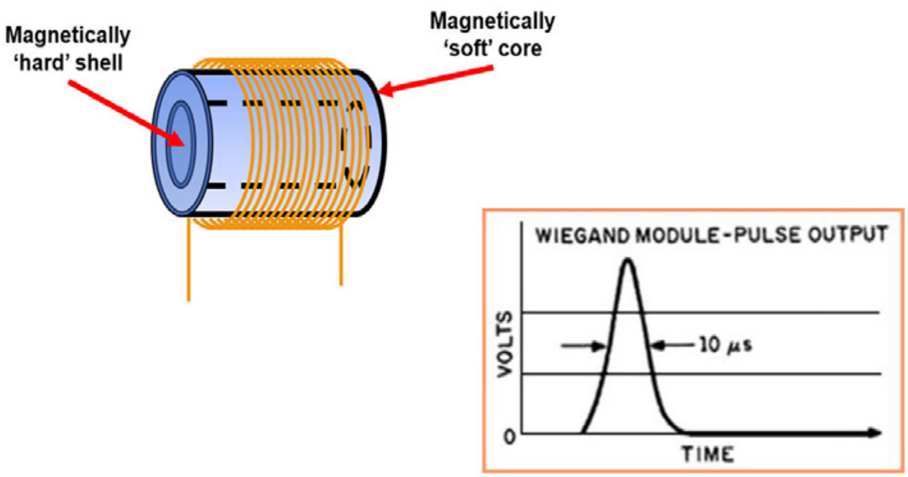

Figure 7. Rapid changes in the magnetic polarity of the wire core induce short pulses of electrical current in the fine copper coil wrapped around the Wiegand wire.

magnetically hard zone will also reverse its polarity, so the whole wire reaches a new magnetic state (Point C). When the external field changes back toward its original polarity, a sudden reversal of the soft material will occur again (Points D, E). The wire will eventually return to its earlier state (Points F, A). These rapid changes in the magnetic polarity of the wire core induce short pulses of electrical current in the fine copper coil wrapped around the Wiegand wire (figure 7).

Manufacturing Wiegand wire

Wiegand wire is produced through a process that involves annealing a spool of Vicalloy wire (an alloy of vanadium, iron, and cobalt), then simultaneously stretching and twisting the wire. This aggressive cold working alters the crystalline structure of the metal and creates two regions—an inner core and outer shell—with significantly different levels of magnetic coercivity. (Coercivity is a property of ferromagnetic materials that defines how easily the material can be magnetized by an external magnetic field. Magnetically soft materials, such as mild steel, have low coercivity and change their magnetic state easily. Magnetically hard material, such as the alloys used to make permanent magnets, will retain their magnetic state unless they are exposed to very strong external fields.) The interaction of these two regions causes the wire to have a high level of magnetic hysteresis.

The "recipe" for producing a satisfactory batch of Wiegand wire was determined by John Wiegand and his collaborators through trial and error. The machine they developed to produce Wiegand wire features a series of rotating frames that stretch, twist, and then untwist the wire at various rates. This machinery was acquired by FRABA, along with John Wiegand's lab notes. Since then, research carried out by FRABA and its partners has automated this process and optimized it for quality and consitency (figure 8).

Figure 8. Research carried out by FRABA and its partners has automated this process and optimized it for quality and consitency.

Looking ahead

Wiegand technology has a strong track record, with proven successes in niche applications such as fluid metering and rotary encoders. It also has significant potential for more advanced uses, both as a sensor for detecting mechanical motions and as an energy harvesting device for self-contained electronic devices. The advantages of Wiegand technology include consistent performance over a wide range of operating speeds and long-term reliability, since the underlying physical phenomenon is completely non-contacting.

R&D carried out by FRABA's UBITO business unit is enhancing the energy output from Wiegand generators and creating possibilities for a new generation of self-contained, zero-maintenance wireless sensors designed to operate as nodes on emerging IoT.

ABOUT THE AUTHOR

Tobias Best (tobias.best@fraba.com) is based in the FRABA Group's Asia Pacific Headquarters in Singapore. Best has been promoting Weigand sensor technology for UBITO globally since 2017.