Achieving Energy Harvesting with the Wiegand Effect

Generating energy from mechanical motion has potential for new generation of sensors.

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With the growing interest in small distributed sensors and other electronic devices aimed at collecting data for new applications—including the Internet of Things (IoT)—more attention is being paid to technologies for energy harvesting. Engineers and scientists are looking for ways to enable stand-alone devices that collect small amounts of energy from the surrounding physical environment, to power a tiny electronic circuit.

Several energy harvesting technologies are in use today. Thermocouple effects, for example, can be harnessed to provide electrical energy (although these require strong temperature gradients in the region of the device to provide significant power levels). Piezoelectric transduction, electromagnetic induction, and capacitive energy harvesting all rely on conversion of mechanical energy from a vibrating component into electrical energy. The Wiegand effect is another energy harvesting technology that generates electrical energy from mechanical motion, in this case, rotations or oscillating motions. Wiegand effect energy harvesting is reliable, efficient, and capable of producing consistent levels of energy, even when the underlying motions occur very slowly.

The Wiegand Effect

The "Wiegand effect" was first discovered in the 1970s by John Wiegand, a German-American musician and inventor who became interested in the use of magnetic effects in audio equipment.

Wiegand found that when a specially prepared piece of ferromagnetic alloy (the Wiegand wire) is subject to a reversing external magnetic field, it will retain its magnetic polarity up to a certain point, then suddenly 'flip' to the opposite polarity. This change in magnetic polarity occurs within a few microseconds. This sudden change of magnetic polarity can generate a pulse of current in a copper coil positioned close to the Wiegand wire. The strength and duration of this current pulse is independent of the rate at which the external magnetic field changes. For more information, see the sidebar, "Inside the Wiegand Effect."

"Wiegand wire" is produced through a process involving the annealing of a Vicalloy spool wire (an alloy of vanadium, iron, and cobalt), then simultaneously stretching and twisting the wire to form a strain-hardened outer layer on the wire, surrounding a soft inner core. The wire is then aged under controlled conditions to stabilize its crystalline structure. The machine they developed to produce Wiegand wire features a series of rotating frames that twist and un-twist the wire at various rates (Figure 1).

Figure 1: The machine used to produce Wiegand wire features a series of rotating frames that twist and un-twist the wire at various rates.

Application of the Wiegand Effect

An early commercial application of the Wiegand effect was with access cards for security systems. Several short lengths of Wiegand wire were embedded side-by-side in the plastic body of each card. The spacing between these pieces of wire would be unique for each card manufactured. In use, a card would be swiped through a reader that contained permanent magnets arranged to cause polarity flips in the Wiegand wires. By detecting these polarity reversals, the device could read the coded number built into the card (based on the wire spacing) and decide whether the card holder should be granted access. This technology has been gradually replaced by newer RFID technology.

Energy Harvesting from Rotary Motion

Another main application for the Wiegand effect has been to provide power for rotation counters in water and gas meters, and the multi-turn rotary encoders used in industrial motion control applications. When the Wiegand effect is used for rotation counters, a short (15 mm) length of Wiegand wire is located next to a permanent magnet mounted on a rotating shaft. As the magnetic field rotates, the magnetic polarity of the wire segment flips twice for each full turn (N-S to S-N, then S-N to N-S). These polarity changes generate current pulses in a fine copper wire wrapped around the section of Wiegand wire. The current pules energy created with each polarity change (almost 200 nanojoules per pulse) is sufficient to energize a low-power counter circuit that records the rotation count.

Figure 2: Wiegand modules comprise a length of Wigand wire surrounded by a current-generating copper coil, all packaged in a surface mountable plastic frame.

The Wiegand effect rotation counter has been used successfully by POSITAL-FRABA, a manufacturer of industrial encoders (rotation sensors). Here, a set of Hall-effect sensors measure the angular position of the shaft-mounted magnet within each rotation, while the Wiegand wire powered rotation counter tracks the number of complete turns. The advantage of this arrangement is that the rotation counter is, in effect, self-powered. The instrument will maintain a reliable rotation count, even if motion occurs when external system power is unavailable. The counter system doesn't need backup batteries, improving reliability and reducing maintenance requirements.

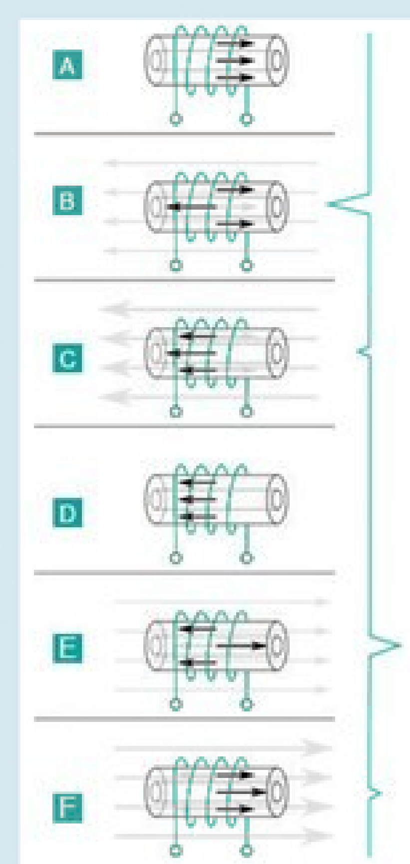
Based on the success of this application or Wiegand technology, POSITAL's parent company, FRABA B.V, has taken ownership on three of the existing wire producing machines and undertaken an extensive R&D program aimed at improving the reliability of the manufacturing process and increasing the energy output of the devices. Wiegand modules are available for commercial sale, comprising a length of Wigand wire surrounded by a current-generating copper coil, all packaged in a surface mountable plastic frame (Figure 2).

POSITAL-FRABA anticipates that improvements to the energy harvesting potential of the Wiegand wire system, coupled with improvements in low power electronic chips, will lead to fully self-powered sensors. Add in the possibility of wireless data communications, and we are approaching the ideal of stand-alone sensors that won't require wired connections for power or data communications. Such sensors would open the door to an enormous range of exciting applications.

Inside the Wiegand Effect

Ferromagnetic materials—such as alloys of iron, nickel, and cobalt—can be magnetized by external magnetic fields. The ease with which a material changes its magnetic polarity depends on a material property termed 'coercivity.' Magnetically soft materials, like the mild steel used for transformer cores, 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 exposed to very strong external fields.

The mechanical processing used to produce Wigand wires creates a magnetically hard outer layer on the wire surrounding a relatively soft core.



The Wiegand Cycle

A. At the cycle's beginning, the magnetic polarity of the hard outer shell and softer inner core are the same.

B. When the wire is exposed to a moderate external field in the opposite direction, the hard outer layer of the wire shields the softer core, so both retain their original magnetic polarity. However, when the strength of the external field reaches a critical threshold, the influence of this shielding effect is overwhelmed, and the polarity of the magnetically softer material at the core of the wire will suddenly reverse. This sudden change in polarity creates a current pulse in the coil surrounding the wire.

C. Soon afterward, the combination of the strengthening external field and reversed polarity of the inner core will cause the magnetic polarity of the outer shell to reverse, generating a second, smaller current pulse.

D. As the external field diminishes, the wire retains its new polarity.

E. When the external field (now reversed) reaches the critical threshold, core material of the Wiegand wire will flip back to its original polarity. This produces a current surge in the surrounding code, E, followed quickly by a reversal of the polarity to the outer core. The wire is now back at state A. ECN