

WHITE PAPER**Energy Harvesting with the Wiegand Effect**

With the growing interest in small distributed sensors and other electronic devices aimed at collecting data for new application, including the “Internet of Things”, more attention is being paid to technologies for energy harvesting. That is, engineers and scientists have been on the lookout for ways to enable stand-alone devices to collect small amounts of energy from the surrounding physical environment to power an isolated electronic circuit. Reducing or eliminating the need for external power sources or batteries make devices more self-sufficient, more reliable, and reduces maintenance requirements. The Wiegand effect is a proven technology for harvesting small amounts of electrical power from mechanical motion.

There are several energy harvesting technologies 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 and efficient,

capable of producing consistent levels of energy, even when the underlying motions occur very slowly.

The Wiegand Effect

The “Wiegand effect” is a physical phenomenon discovered in the 1970’s 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

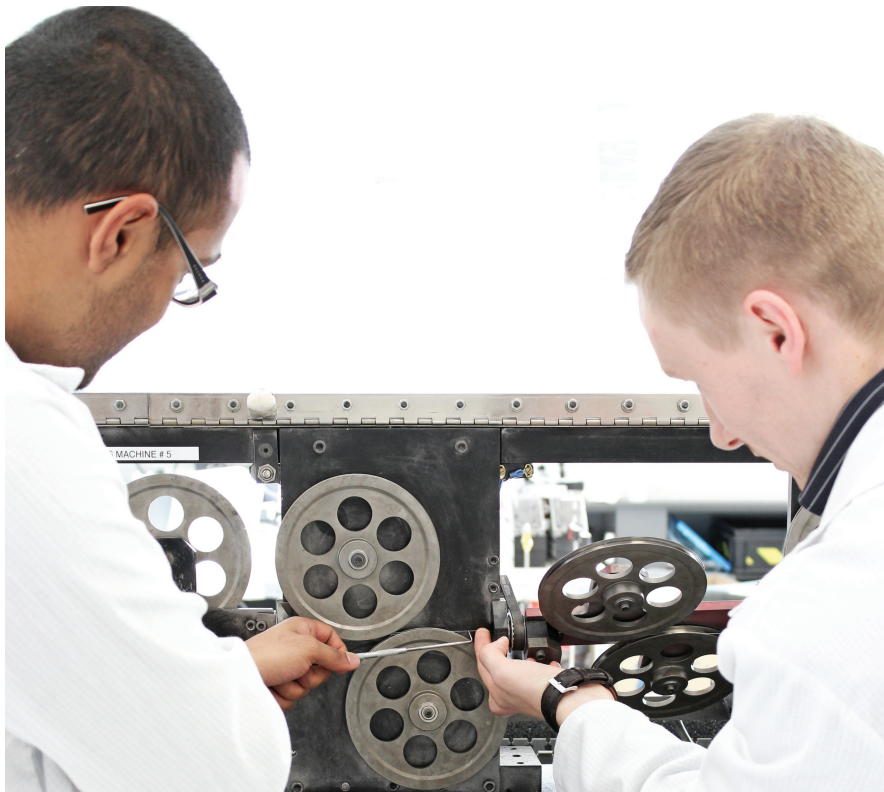
magnetic polarity up to a certain point, then suddenly ‘flip’ to the opposite polarity. This change in magnetic polarity takes place within a few microseconds. This sudden change of magnetic polarity can generate a pulse of current in a copper coil positioned close to the Wiegand wire. The strength and duration of this current pulse is independent of the rate at which the external magnetic field changes. This is what makes the Wiegand effect interesting to engineers: simple dynamos convert rotary motion into electrical energy, but their output power depends on the rotation speed; when the shaft of a dynamo turns very slowly, power levels are too low to be of much use. However, with a Wiegand wire system, the amount of electrical energy generated with each reversal of the magnetic field remains constant, however quickly – or slowly – the magnetic field changes.

“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 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 ‘recipe’ for producing a satisfactory batch of Wiegand wire was determined by John Wiegand and his collaborators through a lot of trial and error. The machine that they developed to produce Wiegand wire features a series of rotating frames that twist, then 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 card reader that contained permanent magnets arranged to cause polarity flips in the Wiegand wires. By detecting these polarity



Wiegand Wire Production



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. While this technology was used successfully for several decades, it has gradually been 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 pulses 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.

The Wiegand effect rotation counter has been used very 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 keeps track of the number of complete turns. The special 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 the Wiegand technology, POSITAL's parent company, FRABA B.V. has taken ownership of 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, consisting of a length of Wiegand wire surrounded by a current-generating copper coil, all packaged in a surface mountable plastic frame.

POSITAL-FRABA anticipates that improvements to the energy harvesting potential of the Wiegand wire system, coupled with improvements in low power electronic chips, will ultimately 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.



WIEGANDSENSOR
POSITAL

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, such as 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 they are exposed to very strong external fields.

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

The Wiegand Cycle

- A. At the beginning of the cycle, the magnetic polarity of the hard outer shell and the 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 afterwards, the combination of the strengthening external field and the reversed polarity of the inner core will cause the magnetic polarity of the outer shell to reverse as well, 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, the core material of the Wiegand wire will flip back to its original polarity. This produces a current surge in the surrounding coil...
- F. ...followed quickly by a reversal of the polarity of the outer core. The wire is now back at State A.

