No gearbox - no battery!

The new generation of robust multiturn absolute encoders

Lothar Wilhelmy

Multiturn absolute encoders are used in electrical drive engineering to record the *number* of completed turns as well as the position *within* the last turn. The present state of the art is to record the turns mechanically (with a multistage gearbox) or electronically (which requires the aid of a backup battery). Both methods involve disadvantages. But there is a newly patented process that does not require a gearbox or a battery, using instead the energy derived by a micro-generator from even the smallest rotary movements for processing and storage. The technology of these new multiturn absolute encoders is described in detail below.

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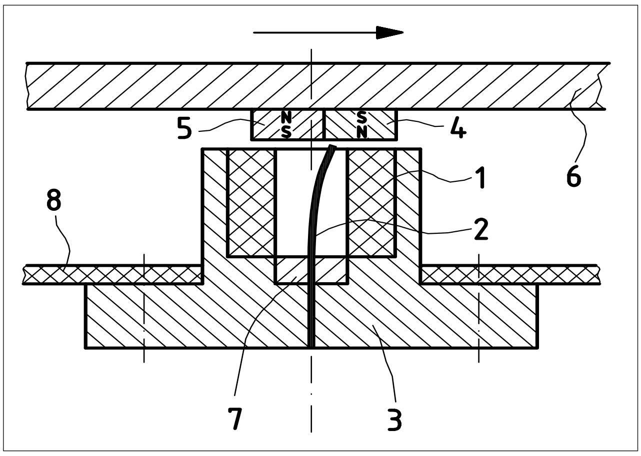
Incremental encoders that produce square-wave or sinusoidal signals are used in great quantities in regulated electrical drives. Since they generate one zero pulse per turn, they can be used not only for speed control, but also for position control, provided that the inverter electronics can process the encoder signals to determine the actual position by recording the number of completed turns (multiturn), as well as the position within a turn (single-turn). This solution assumes that there is no interruption of the supply voltage for the incremental encoder, and that there is no rotation while the supply is disconnected. If this condition is not fulfilled, for instance, if a drive overruns, the emergency stop is triggered, or during manual setting up operations, then a reference run must be made to a known position when the supply voltage has been restored, so that the counting procedure can be reset and restarted.

Multiturn absolute encoders are increasingly being used, to avoid having to carry out such a reference run. *Mechanically*

Highlights of the new absolute encoder generation at a glance:
1. No wearing parts (no gearbox, no battery, ball-bearing life approx. 10^9 turns)
2. High continuous speeds are allowed, even in start-stop operation
3. Versions with solid shaft or (larger) through-bore hollow shaft
4. Rugged construction with high shock-loading capability
5. Insensitive to electromagnetic interference
6. Resolution: single-turn 13-bit, multiturn 16-bit SSI option: 12, 16, 20 or 24-bit
7. Various interfaces: SSI, Profibus-DP, CANopen etc
8. Can be operated in hazardous areas with Ex approval
9. Additional incremental signals with HTL / TTL level as an option
10. Redundant versions as an option



2: The operating principle of the micro-generator, see explanation in text

operated absolute encoders detect and record the number of turns by means of a gearbox. To achieve this, the shaft of the absolute encoder not only carries the encoding disk for the single-turn information on the position of the shaft within a single turn (frequently 8,192 steps = 13 bits) but also gear teeth that engage the first gearwheel of a gearbox. If this first stage of the gearing has a reduction of 16:1, then its coding corresponds to 16 turns. In this way, three stages of gearing can record up to 16^3 = 4,096 turns (12 bits).

Disadvantages of a gearbox + battery solution

However, the gearbox solution suffers from the following disadvantages:

1. High speeds and rapid speed alterations, possibly in conjunction with shock loading effects from braked motors in start-stop operation, limit the operational life of the gearbox.
2. The step-down from a small pinion to a substantially larger first-stage gearwheel hinders the construction of absolute encoders with a *large through-hole* hollow shaft.
3. The number of turns that can be distinguished is normally limited to a 12-bit count.

Electronic absolute encoders eliminate these disadvantages by having a multiturn section that is usually fitted with reed contacts. These reed contacts are activated by rotating magnets (or alternatively: fixed magnets and a rotating blanking plate). The reed contacts are activated in such a way that an ASIC or processor can clearly interpret the direction of rotation from the contact sequence, evaluate this as upwards or downwards count information, and save it in a memory. To do this, these absolute encoders are equipped with batteries to hold up the electronics and the volatile memory if the supply voltage for the electronics is disconnected. In this way, it is possible to implement absolute encoders for high continuous speeds and large-bore hollow shafts, with a count range that is extended beyond the usual 4,096 turns (12-bit count) up to an count range of 65,536 turns (16-bit count).

However, this type of encoder also has disadvantages:

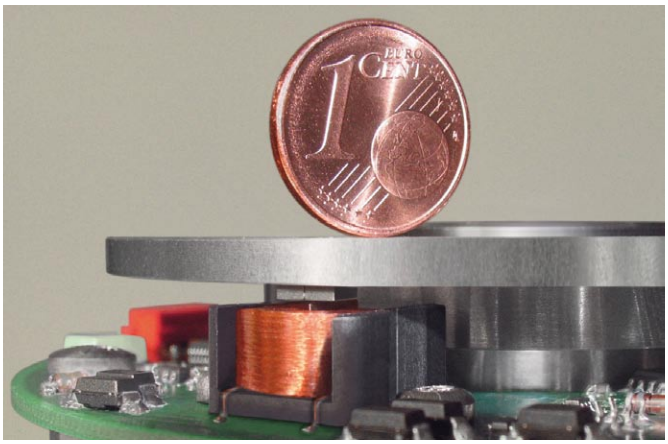
1. The battery for operating the processor and holding up the memory for the count information only has a limited operating life, especially at enhanced temperatures or for lengthy operation of the encoder *without* an external supply.
2. The reed contacts may be activated by shock, such as that caused by braked motors, thus leading to erroneous count pulses.
3. Absolute encoders with a battery can only be used with restrictions *in* ***Ex*** *areas* .

Absolute encoders with micro-generator

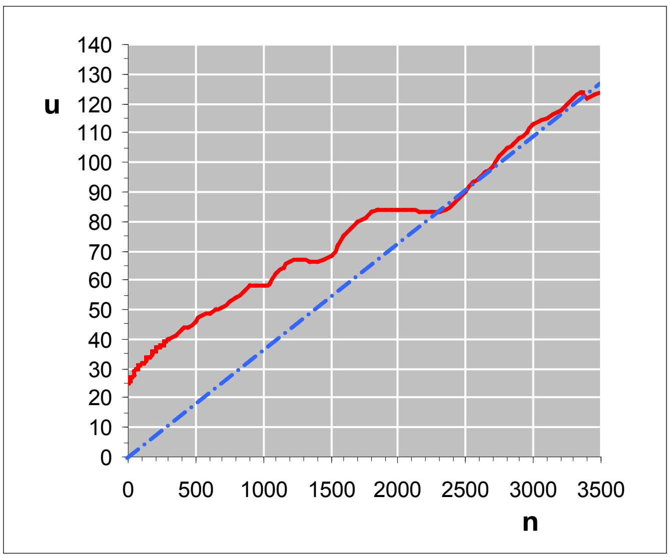
Baumer Hübner – always a specialist for HeavyDuty encoders – took up the challenge of developing absolute encoders that did *not* require gearboxes or batteries, thus avoiding the above-mentioned disadvantages and opening up new fields of application for these encoders that were previously excluded. The core of this new generation of multiturn absolute encoders is a micro-generator that derives the energy required for electronic processing and non-volatile storage directly from the rotational motion of the drive. The patented method is distinguished by simple construction, robustness, freedom from wear, insensitivity to magnetic fields, and a wide operating temperature range. A further advantage is that it is possible to make an optimum adjustment of the amplitude and duration of the generated voltage pulses to suit the requirements of the electronic counting and memory circuitry. This is a significant difference to other methods for voltage generation described in the patent literature, such as those involving Wiegand wires or switched reed contacts – methods that, because of the low levels of energy generated, have, up to now, not led to practically applicable devices that can stand up to tough industrial operating conditions.

Operating principle of the micro-generator

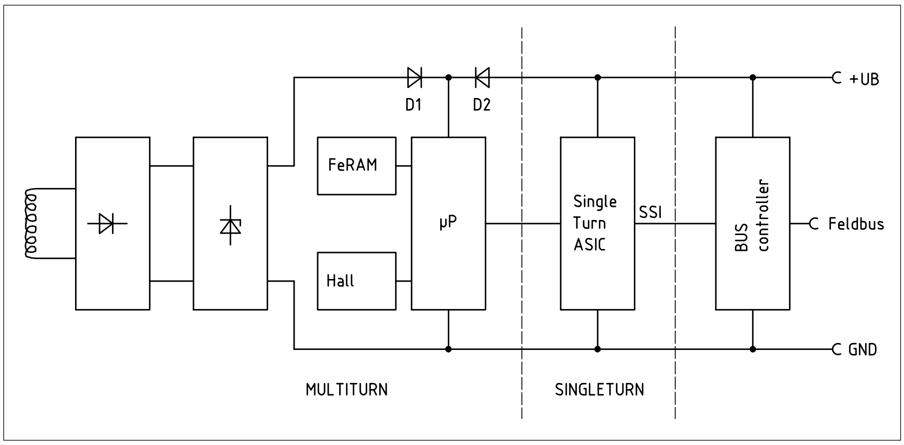
The operating principle of the micro-generator is illustrated in **Fig. 2**. This shows a coil (1) that surrounds a rust-resistant magnetizable leaf spring (2). The spring is embedded in a plastic carrier (3),



3: Micro-generator with magnet pairs



4: The off-load voltage generated by the micro-generator, as a function of the speed



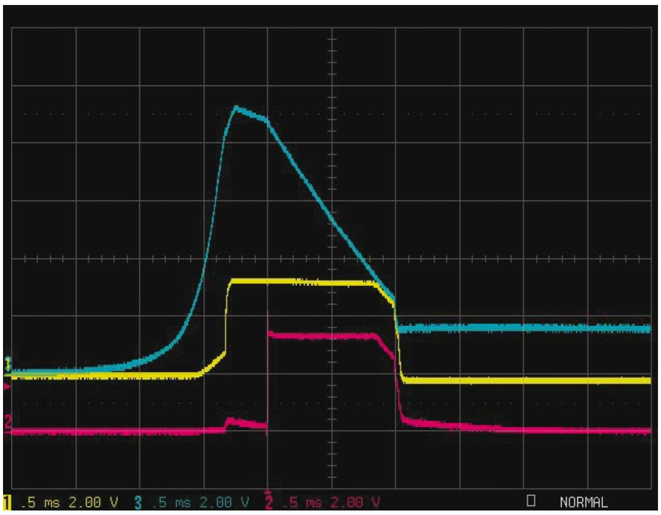
5: Block diagram of the new multiturn absolute encoders

and cobalt-samarium magnet pairs of opposing polarity (4 and 5) run past the spring with a close spacing. The magnets are fixed underneath a rotating disk (6) that rotates together with the shaft of the absolute encoder. If the disk moves in the direction shown by the arrow and the magnets approach the spring from the left, then the magnetic reluctance causes the spring to be moved by the magnet (4) in the direction of rotation, until the spring tension overcomes the pull of the magnet. At this moment, the spring snaps back, whereby it is also caught and accelerated by the magnet (5). This causes a very fast change of the magnetic flux in the spring, which, following the relationship **u ~ dΦ / dt**, generates a strong voltage pulse in the coil surrounding the spring.

Fig. 3 shows the micro-generator, with the spring projec-ting slightly from the coil and a pair of magnets just above the spring. The overall length of the micro-generator (including the disk with the magnets) is 20 mm. The spring exhibits a self-resonant frequency that would result in an increased amplitude if resonance was achieved. It is therefore surrounded by a temperature-stable damping material (7) above the injection molding in the plastic carrier (3). This ensures that the spring never vibrates more than about ± 1 mm, regardless of operating conditions. The damping material also provides acoustic damping and protects the spring from being kinked.

As simple as the operating principle of this micro-generator may appear, its development took up a lot of time. Starting from the voltage pulse that was required for the processing and storage of the count information, and the restricted space that was available, the spring had to be optimized for length, width, thickness, hardness and compliance, in an interaction with the 3-dimensional variability of the magnet pairs. Detailed work was necessary to apportion the length of the spring between the freely vibrating, damped and clamped sections. Additional variables to be considered were the Shore hardness of the damping material and the dimensioning of the coil for the number of turns, wire cross-section and dimensions.

The micro-generator provides voltage pulses from zero speed right up to the maximum speed. At maximum speed, the rapid motion of the magnet pairs past the spring would by itself be sufficient to generate the voltage, as can be seen in the rising curve of voltage against speed u(n) in **Fig. 4**. If the disk with the magnet pairs (4 and 5) now moves in the opposite direction, then the spring is first moved by the magnet (5) and then jumps back towards the magnet (4). This now generates a voltage pulse with the opposite polarity.



6: Voltage curves: blue: Voltage at the input to the voltage regulator; yellow: Voltage at the output from the voltage regulator; red: Voltage at the control output of the processor

The voltage pulses from the coil are now rectified (**Fig. 5**) and limited to a maximum of 12 V. They are then regulated down to the voltage required for the attached electronic circuitry by a fast, low-drop voltage regulator. The voltage regulator switches into the active state when the voltage at its input goes above a minimum value. The oscillogram in **Fig. 6** shows this voltage (blue) and the output voltage from the regulator (yellow).

Unambiguous positioning with Hall sensors

The board (8) with the micro-generator and the turns counter is fitted with Hall sensors that are activated by powerful permanent magnets which are also mounted on the underside of the rotating disk (6). The Hall sensors are activated in advance of the magnets, before the micro-generator produces the voltage pulse. The code pattern produced by the Hall sensors depends on the polarity of the magnets and thus on the angular position of the disk. In this way, unambiguous position detection is assured within a turn, even in the presence of possible extraneous fields.

The voltage step at the regulator starts the oscillator for the processor (μP in Fig. 5). Its control output produces a logic *high* to signal the end of initialization and the start of the processor program (red), Fig. 6. First of all, the processor reads out the non-volatile FeRAM, i. e. the momentary state of the turns counter and the last signal from the Hall sensors referring to the angular position of the disk. The processor uses this information to decide whether the drive shaft has made a rotation, and whether an upwards or a downwards count pulse should be stored in the FeRAM. The entire procedure from initialization of the oscillator to storing the value is completed in around 500 μsec. Although the angular position of the disk is evaluated 3 times per turn, even at 6,000 rpm there is an interval of 3.3 msec available, so that it would be possible to register turns at considerably higher speeds.

Even when the program has been run, the micro-generator still provides enough energy (Fig. 6) for the processor to restart its program cycle and check the Hall sensors again. However, since the Hall sensors are not providing any new information, there is thus a repeated checking and confirmation of the information already evaluated, but no new value is stored. This reserve of energy is used up to some extent at higher temperatures, at which the processor functions more slowly.

In normal circumstances, the absolute encoder is fed from an external supply voltage and the processor continuously receives its voltage through diode D2.

7: The new absolute encoders are also available with a large-bore hollow shaft

The processor continually evaluates the information from the Hall sensors until it detects a change, whereupon it makes a decision about the next count pulse. In normal operation the non-volatile FeRAM registers up to 65,536 turns (16-bit count), and can be expanded ex-factory to up to 16,777,216 turns (24-bits) if required for SSI. Unlike other non-volatile memories, the FeRAM is not subject to any limitation on the number of read/write cycles.

Various interfaces can be implemented

Development of the micro-generator and the multiturn electronics progressed hand-in-hand as far as electrical and mechanical requirements were concerned, and data exchange between multiturn and single-turn sections had to be taken into account in addition to the requirements for the turns counter. When the supply voltage is switched on, and every time the zero mark on the code disk appears, the single-turn section instructs the processor via the data cable (Fig. 5) to report the present state of the number of turns and the latest position of the Hall sensors, so that it can synchronize the single-turn and multiturn information and combine them into an absolute position word.

For encoders with an SSI output, the absolute position word can be read out directly through the SSI. It is, however, also possible (as indicated in Fig. 5), to activate a BUS controller that carries out the conversion to the widespread BUS interface PROFIBUS-DP or CANopen. Other interfaces, e.g. for EtherCAT and BISS, are in development.

The SSI encoders are programmed from a PC with the aid of the Interface-Box HEAG 182. It is possible to set up: rotational direction, zeroing (reset), presetting the position, Gray or binary code, readout and reset of an error status message. Encoders with a Profibus-DP and CANopen interface have addresses set by coding switches from 1 to 99, and are programmed through the corresponding BUS. Here it is easy to set up the parameters for rotational direction, presetting the position, resolution per turn and overall resolution. As an option, additional 1024 or 2048 incremental pulses per turn (HTL or TTL signal levels) are available for speed control.

8: Absolute encoders on the drives of stage sets

Available with solid or hollow shafts, in various frame sizes

As an option, the new absolute encoders are also available in a *redundant* version. In this case, the single-turn code disk is sensed with two separate optical systems, and the multiturn board is fitted with two micro-generators each with its own electronic evaluation and memory circuits. Furthermore, the redundant systems can also be fitted with *different* BUS interfaces.

The absolute encoders undergo temperature and continuous operation tests, as well as tests for shocks and electromagnetic influences arising from standstill braking. The **title picture** shows the new generation of HeavyDuty absolute encoders with a *solid* shaft and EURO-flange B 10. **Fig. 7 and 8** show *hollow* shaft versions, whereby the diameter of the hollow shaft is practically unlimited. The latter is of importance for large magnetic absolute encoders that do not have their own bearings, such as on torque motors. The absolute encoders are also produced as purely single-turn encoders. Other sizes, including small, robust encoders with a 60 mm housing diameter, are being developed. In these, the micro-generator is not necessarily axially aligned, but can also be radially aligned.

The non-contacting micro-generator can advantageously be applied for further tasks, such as a pure turns counter (without a single-turn section), as a position sensor that generates voltage pulses if positions are overridden (with a polarity that depends on the direction of motion) or generally as a battery-free signaling device.

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