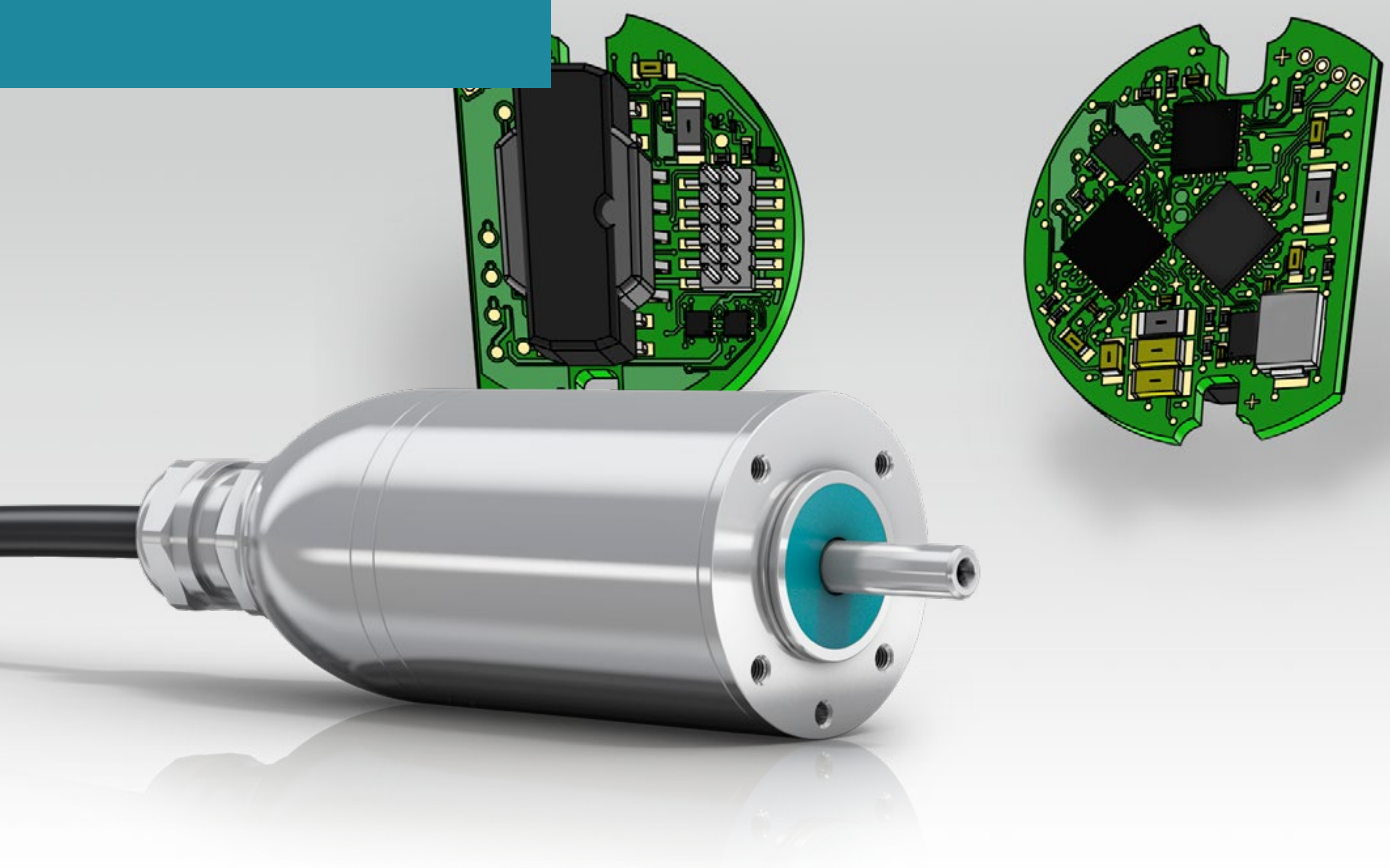
WITTENSTEIN cyber motor

Increasing machine productivity by using an Energy Harvesting multiturn encoder system

Whitepaper



Increasing machine productivity by using an Energy Harvesting multiturn encoder system

Multiturn absolute encoders are used as motor feedback systems in the field of servo drive technology to count and store absolute rotor shaft position over multiple revolutions. In contrast to an incremental encoder or singleturn absolute encoder, no homing is necessary for a multiturn system after power has been lost. This saves time, as the axis does not need to move to a known reference point such as a limit switch. Typically, gear-based or battery-buffered technologies are used for this purpose. Comparatively new on the market are multiturn encoders based on the patented „Energy Harvesting" principle. This whitepaper explains the underlying technology in general, how it is applied in a multiturn encoder system, and what the advantages are of using such a system.

Industrial servo motors require a rotary feedback device in order to detect the (real-time) rotor position. This information is required to provide the servo drive with the necessary input for the cascading control loops, such as position, speed, and commutation angle. A singleturn absolute encoder, which only measures the rotor position over one revolution, is often not sufficient. A prime example are servo motor driven ball screw actuators. Being able to detect the absolute position over one motor revolution typically only covers a small percentage of the total linear travel distance. A multiturn encoder on the other hand can cover multiple revolutions, which translates to a longer linear travel distance, often the full stroke length of the ball screw. This difference in detection of the rotor position between a singleturn and multiturn encoder system is not noticeable as long as the system is continuously powered. The information on how many revolutions the motor has traveled can simply be calculated by counting any full (singleturn) revolution which is then stored in the servo drive. The situation is much different if the machine or the encoder loses power. This can have multiple reasons such as en emergency stop, maintenance, or a specific manual setup routine. Without a multiturn encoder system, there is no way of telling if the motor has been moved during that time which invalidates the position information. It is therefore required to conduct a homing procedure in order to avoid errors in the manufacturing process or even collisions caused by the potentially incorrect position value.

The reference or homing signal is typically a limit switch positioned at a defined location, which aligns the real world position with the stored position value once it is reached. This makes the machine design not only more complex by needing additional components, but also decreases productivity as the time needed for homing cannot be used productively. On top of that, some machine designs or processes might require trained personnel to be present during the homing procedure or a homing procedure is simply not possible due to the machine layout.

Reading and saving the position during a power loss therefore requires some sort of energy storage. There are currently two prominent solutions on the market. A mechanical accumulator based on a gear mechanism, similar to a mechanical clock is often used in Europe and the Americas, while battery-based technologies are popular in Asia. Both solutions allow the implementation of a multiturn encoder system, but come with technology specific disadvantages. Manufacturers and users of battery-buffered encoders need to make a decision on the exact location of the battery. Keeping the battery inside the encoder housing means that the battery has to withstand all operating conditions, such as temperature, humidity, dust, oil, etc. This can lead to a significantly reduced lifetime of the battery. Replacing the battery can be a challenge as the encoder might be in hard to reach places, which often means that the most economical solution is to replace the whole feedback system. This can lead to high service costs. Another solution is to place the battery inside a cabinet and further away from the encoder. This allows operating the battery in a controlled environment and increases the lifetime, but requires additional cables from each encoder to the respective battery. Besides the additional costs and efforts of wiring, this solution also leads to a reduced battery life due to the additional losses in the wires. Depending on the combination of wire length, this could lead to a short operational time during a power loss or would require oversizing the batteries. In any case, the multiturn functionality is only available for a limited time. Faulty batteries or broken connections to the encoders are often undetected, as most commercially available servo drives do not have the functionality to monitor those conditions. To minimize a potentially costly failure, frequent preventative maintenance is often the only option.

Service life is also limited with gear-based multiturn encoders. The reason is mechanical wear of the small bearings – often sliding or roller bearings. This is especially noticeable in applications that require high speed or dynamic speed changes as well as start-stop operations, which can all lead to significant stress and shock loads projected onto those bearings. Gear-based encoders are also larger and heavier as the gears need additional space and require a minimum size in order to provide a suitable gear ratio. An input gear that is too small would increase the speed of the first stage over the physical limits. Those size and ratio limitations typically lead to a maximum multiturn resolution of 12 bits.

Suitability of an Energy Harvesting based multiturn encoder

An alternative solution that is trying to overcome all of those drawbacks is the Energy Harvesting multiturn encoder. Energy harvesting is the approach of obtaining (harvesting) electrical energy from the surrounding energy. This technology allows implementing an encoder system that does not require a battery, a wired energy supply, or gears. To achieve this contactless harvesting of energy, those encoders use an electromagnetic principle based on a so-called "Wiegand Wire". This technology is protected by several worldwide patents and requires licensing by the inventors (Dr. Walter Mehnert and Thomas Teil).

A Wiegand wire consists of a Vicalloy material (a cobalt-iron-vanadium alloy) produced by cold forming and final annealing. The results is a wire with a soft magnetic core and a hard magnetic outer layer (see figure 1, left). This means that the magnetic coercivity of the outside shell is much larger than that of the inner core. This high coercivity shell will therefore retain an external magnetic field even when the field's original source is removed and will not change its magnetic polarity as easily as the core. If an external magnetic field, e.g. created by a permanent magnet, is now brought near the wire, it is excluded from the inner core by the high coercivity outer shell until a threshold is reached. Once the field is strong enough to overcome the threshold, the polarity in the core will suddenly reverse to line up with the polarity of the external magnetic field. Once the external field is strong enough, the shell will also change its magnetic polarity. This fast switching of magnetic polarity, also called Barkhausen effect, can be used to induce a voltage in a pick-up coil that is wound around the Wiegand wire (see figure 1, right).

To use the Wiegand effect in an encoder, a diametrically poled permanent magnet is mounted on the rotor shaft. The Wiegand sensor (assembly of Wiegand wire and coil) is mounted so that rotation of the magnet results in a changing magnetic field in the sensor. The electrical energy induced by the Wiegand sensor is stored with a capacitor. The subsequent sensor circuit increments or decrements the counter value depending on the direction of rotation and saves it inside electronic memory. Since the Wiegand sensor system cannot detect direction of rotation, an additional magnetic sensor (usually a Hall sensor) is needed for this purpose. FRAM (ferroelectric random access memory) is typically the memory of choice, as it requires very little energy for read and write operations, allows write access to individual memory locations and is non-volatile. A dedicated circuit is in charge of those operations. Whenever a motion is triggering a Wiegand pulse, the circuit detects the state of the Hall sensor, reads the count value from memory, increments or decrements it, and stores the new counter value in memory again. This all runs fully autonomously and without any external power supply by purely utilizing the kinetic energy of the rotating rotor shaft. Once electrical power is restored again, the encoder will read the stored counter value from FRAM to calculate the current absolute multiturn position.

Figure 2 shows a schematic of a Wiegand sensor as it is used in rotary encoders.

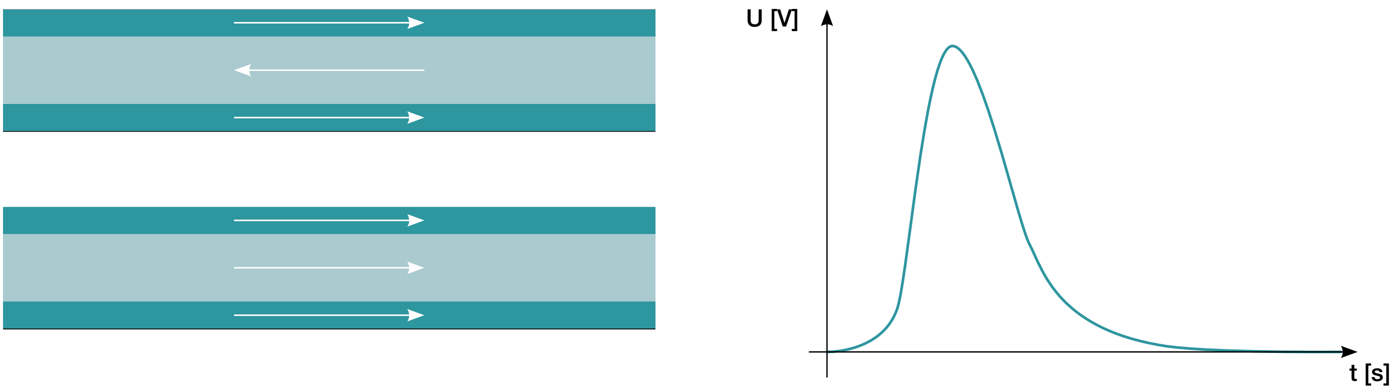


Figure 1: Wiegand wire with opposite (top) and like (bottom) magnetization of sheath and core (left); electrical pulse of a Wiegand wire (right)

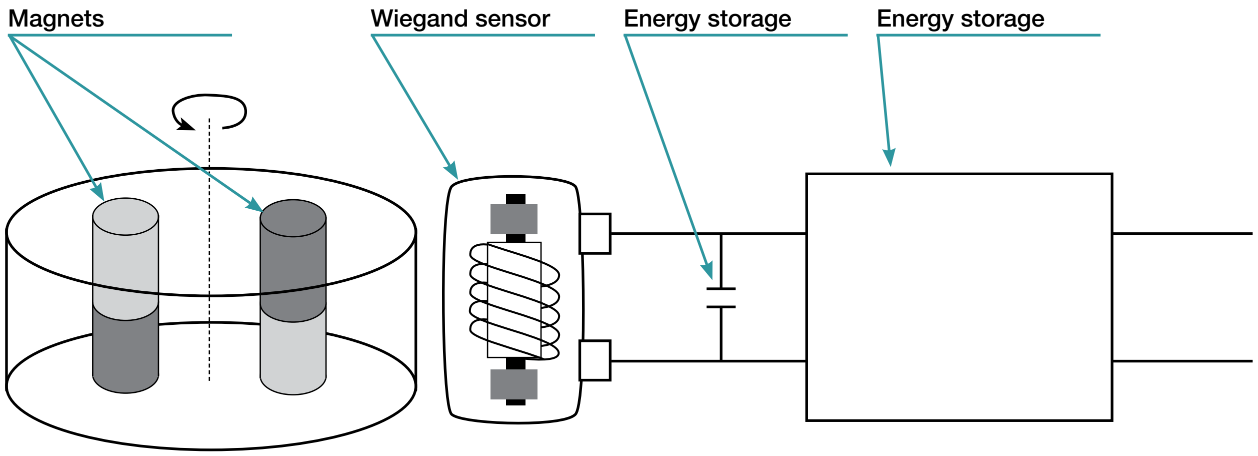


Figure 2: Schematic illustration of a Wiegand sensor in a rotary encoder

The feature that sets this solution apart from other multiturn encoder options is the fact that re-magnetization energy and the associated induced voltage pulses are always available, which means that the multiturn functionality is also available without any external power supply. However, the user has to ensure that the magnet cannot be re-magnetized by external influences. Those influences could be strong external magnetic fields, a ferromagnetic environment or ferromagnetic debris (e.g. iron dust). Since the system is not able to distinguish whether the pulses are generated by encoder movements or by interfering fields, it is necessary to protect the system against interfering external magnetic influences, which can be common in certain applications. Otherwise, the technology is very robust against failures. The Wiegand sensors principle is almost fully independent of the rate of change of the magnetic field and therefore does not rely on the rotary speed of the shaft. The converted electric energy is released abruptly and consistently and therefore allows to reliably powering the electronic circuit for the required time interval. The principle is independent of the direction of rotation or any additional electrical energy. This is very important for a backup system that is incrementally counting from a known absolute position in case of a power loss, but cannot detect the absolute position directly. Incremental systems always entail the risk of experiencing counting errors, which can accumulate over time and can only be corrected by moving to a known reference position. However, the respective technologies have advanced a lot over the last couple of years so that counting errors do not occur if the encoder is designed properly and the system is used in permissible ambient conditions.

Table 1 shows the advantages and disadvantages of the individual functional principles of a multiturn encoder once again at a glance:

	Gearbox	Battery	Energy Harvesting
Multiturn function principle	Absolute coded system via miniature gearbox	Absolute counting system with a volatile memory	Absolute counting system with a non-volatile memory
Power supply	None	With battery	With Wiegand sensor
Installation space	Comparatively large, limited possibilities of miniaturization	Comparatively low, but additional space requirement for battery	Comparatively low
Resolution	Usually limited to 12 bit	No limitation	No limitation
Restricted operating conditions	High speeds limit the service life due to mechanical wear	Permitted operating temperatures are usually limited to +85°C due to negative influence on battery life	Shielding from magnetic interference fields necessary

Table 1: Comparison of operating principles for multiturn encoders

Case study: Small servo motor cyber® dynamic line with multiturn encoder from WITTENSTEIN cyber motor

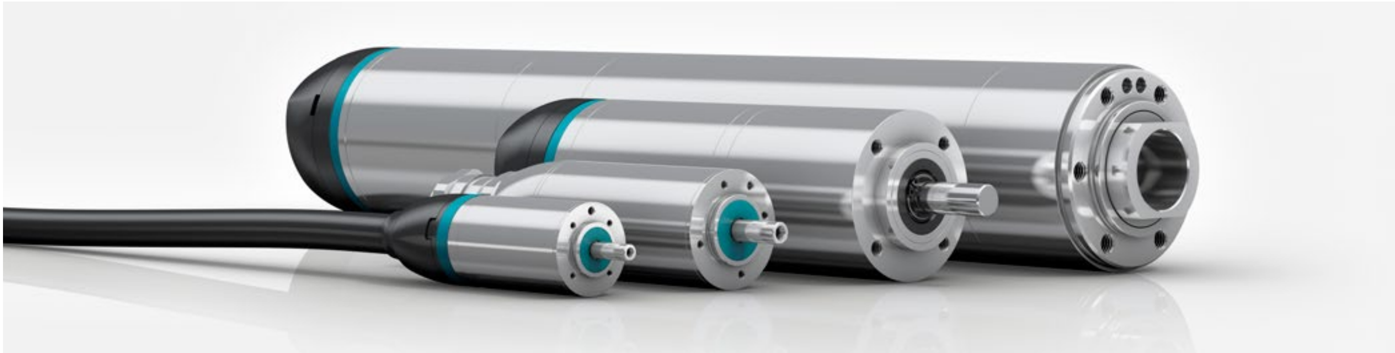


Figure 3: Industrial small servo motors of the cyber® dynamic line in sizes 17, 22, 32 and 40 mm

A multiturn encoder developed by WITTENSTEIN cyber motor based on the energy harvesting principle is used in the cyber® dynamic line product family. These are small servo motors suitable for industrial applications with a power range below 500 watts (see figure 3).

In order to achieve multiturn functionality for those motors, the encoder must meet the following requirements:

- Kit for integration into the existing geometry of cyber® dynamic line motors in sizes 32 and 40 mm (max. outer diameter of the encoder board of 27 mm)
- Maintenance-free and energy self-sufficient solution for permanent storage of the absolute position (even when there is no power supply)
- Resolution of position measurement (singleturn) ≥ 12 bit
- System accuracy ≤ 1°
- Resolution of the revolutions (multiturn) ≥ 12 bit
- Permissible speed range: 0-12.000 rpm
- Permissible angular acceleration: $9.5x10^6$ rad/s^2
- Extended operating temperatures: -40 to 125 °C (due to the use in a synchronous servo motor with a maximum winding temperature of 120°C)
- Permissible vibration: 10 Hz-150 Hz, 5 g
- Permissible shock: semi-sinusoidal, 50 g, 11 ms
- Mounting tolerance due to mounting tolerances and shaft expansions during operation
- Digital interface based on BISS-C

An encoder that met all the above requirements did not exist on the market, so WITTENSTEIN cyber motor developed the encoder module independently. The first challenge was the miniaturization of the functional principle into an encoder module, which is suitable for installation in the specific servomotors in frame size 32 and 40 mm. The result of the development is shown in figure 4.

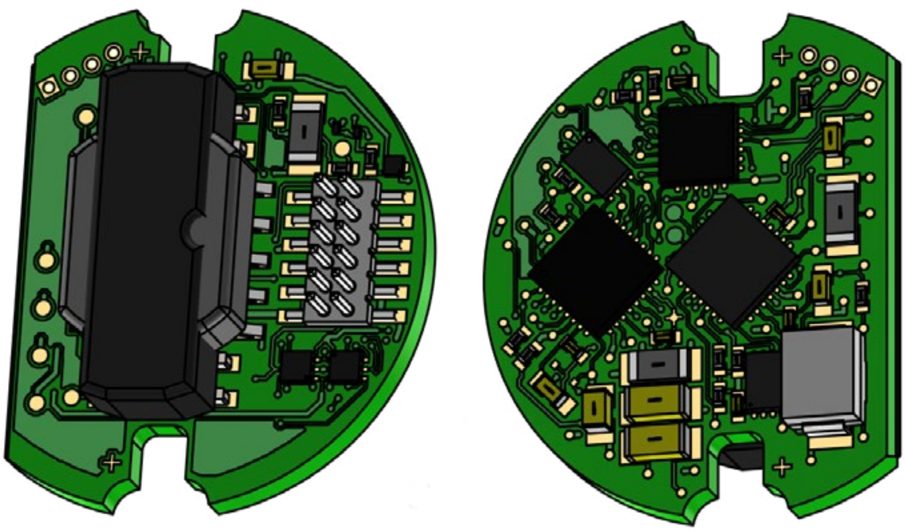
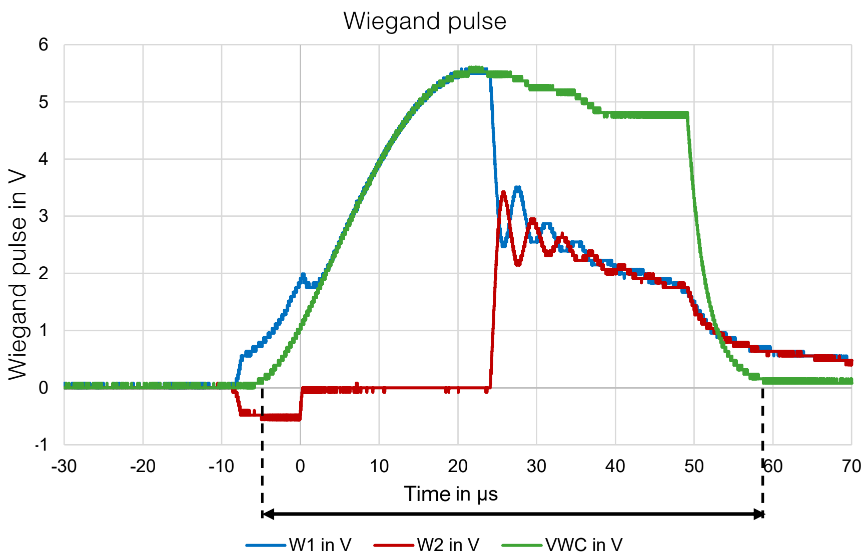


Figure 4: Multiturn encoder module for integration into the cyber® dynamic line motor family



Legend:

- W1 / W2 = Voltage potential of the Wiegand wire connections
- VWC = Induced Wiegand voltage

Figure 5: Resulting Wiegand pulse from WITTENSTEIN measurements

After designing the module for the given space, the encoder function was verified. It quickly became apparent that the implementation of the simple principle of using Energy Harvesting based on a Wiegand sensor could become very complex when considering the multitude of moving parameters. After a detailed parameter influence analysis, the following important factors were identified:

- Axial distance between encoder magnetic surface and Wiegand sensor
- Encoder magnet quality
- Quality of Wiegand wire
- Nonlinearity as a function of operating temperature
- Influence of shielding and flux guide plates

With the help of an iterative improvement process, the encoder module was optimized with regard to the various influencing factors. The height of the induced Wiegand pulse served as a decisive quality characteristic of the encoder. Figure 5 shows an example of the resultant Wiegand pulse from the measurements by WITTENSTEIN.

To ensure an error-free and stable multiturn encoder system, the encoder was verified and validated in the installed state. In addition to the actual reliability and system tests, intensive environmental tests (including temperature-cycling tests, EMC tests, and shock and vibration tests) were conducted.

Summary

In summary, the Energy Harvesting principle can be used to realize miniaturized, maintenance-free and energy self-sufficient multiturn encoders. This solution overcomes the disadvantages of traditional multiturn encoder solutions, such as dependence on an electrical power supply, the comparatively large installation space, or the limited operating life. The principle of Energy Harvesting works independently of the speed of a rotary movement, the direction of rotation and any additional electrical energy. Due to the magnetic principle of action, the device has to be shielded from magnetic interference field. The energy harvesting principle has allowed WITTENSTEIN cyber motor to develop a miniaturized multiturn encoder module that can be integrated in the highly dynamic and industrial-grade small servo motors and actuators in the cyber® dynamic line. This gives machine and plant engineers new freedom in machine design and increases machine productivity by eliminating the need for a reference run when starting up the drive axes.

Further links

Website: WITTENSTEIN cyber motor GmbH

Microsite: The new generation of the small servo drive system

WITTENSTEIN | cyber motor

WITTENSTEIN cyber motor GmbH · Walter-Wittenstein-Straße 1 · 97999 Igersheim · Germany
Tel. +49 7931 493-15800 · info@wittenstein-cyber-motor.de

WITTENSTEIN Inc. · 1249 Humbracht Circle · Bartlett, IL 60103 · USA
Tel. +1 630 540 5300 · info.cyber-motor@wittenstein-us.com

WITTENSTEIN S.P.A. · Via Giosuè Carducci 125 · 20099 Sesto San Giovanni MI · Italy
Tel. +39 02 241357-1 · info@wittenstein.it

WITTENSTEIN Co., Ltd. · 2-6-6 Shibadaimon Minato-ku · 105-0012 Tokyo · Japan
Tel. +81 3 6680 2835 · sales@wittenstein.jp

WITTENSTEIN (Hangzhou) Co., Ltd. · No. 355 Tianmushan West Road · 311122 Hangzhou · China
Tel. +86 571 8869 5852 / 5851 · info@wittenstein.cn

WITTENSTEIN – one with the future

www.wittenstein.de

Whitepaper_Increasing Machine Productivity by using an
Energy Harvesting Multiturn Encoder System_2021_I_EN