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WHITEPAPER

ROTARY ENCODERS

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IPF ELECTRONIC

TABLE OF CONTENTS

1 INTRODUCTION

As different as the designations are, as diverse are the areas of application. Encoders, rotary encoders, rotary pulse encoders or angle encoders etc. are used in many industrial sectors for a wide variety of tasks, for example, in machine tools, CNC machines, systems in the wood industry and storage technology, bending machines, conveyor systems, measuring and testing equipment, motors, and, and, and. Whether rotational speed, angle, direction, length, displacement or velocity, the range of applications for encoders and the like is extremely broad. In view of the large selection of potential solutions for a wide variety of applications, this whitepaper deals with a few selected technologies for encoders, their mode of operation and application-specific advantages in the sense of an orientation guide. In this context, however, no claim is made to completeness, as a detailed description of the entire subject would exceed the scope of a whitepaper.

ipf electronic has a broad portfolio of encoders for different applications. The range also includes so-called magnetic position measuring systems, whose functionality and areas of application will also be presented in this whitepaper. The systems were originally developed for the detection of linear movements (position changes), but can also be used to measure rotational movements (angle changes) with the assistance of a measuring wheel.

2 ABSOLUTE ENCODERS AND INCREMENTAL ENCODERS

Rotary encoders can generally be divided into absolute encoders and incremental encoders. Absolute encoders (optical or magnetic) have a one-to-one graduation (one-to-one line graduation or sequence of north and south pole blocks) and do not require initial referencing after switch-on. Therefore, they provide an absolute measured value, with the position or attitude information being output in the form of a digital numerical value that is unique over the entire resolution range of the device.

In connection with absolute encoders and a one-to-one classification, reference is often made to the so-called Gray code. This is a continuous binary code in which the neighboring codes differ in a single digit. The Gray code is used as a method for reliable transmission of digital quantities via analog signal paths. The sequence of a standard Gray code can be generated using a simple rule: starting with 0, all bits are initially 0. Then the least significant bit that can be changed (from 0 to 1 or from 1 to 0) is changed in each case without creating a sequence that already exists. For illustration, the following example of a 4-bit Gray code, where the red digit represents the changed bit in each case:

0000
0001
0011
0010
0110
0111
0101
0100
1100
1101
1111
1110
1010
1011
1001
1000

Sequence of a 4-bit Gray code

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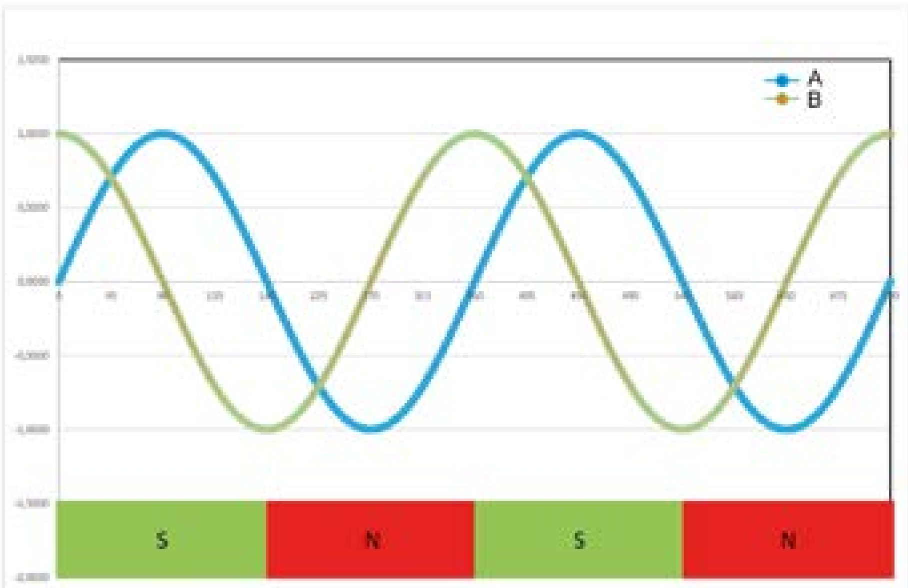
Incremental encoders (optical or magnetic), however, have repeating periodic divisions (line divisions or a continuous sequence of north and south poles with a fixed width). Incremental encoders must therefore be referenced after switch-on because they do not provide unique position information or a unique measured value for position determination.

2.1 OPERATING PRINCIPLE OF OPTICAL AND MAGNETIC ENCODERS

Rotary encoders or angle of rotation encoders detect rotational movements and convert them into evaluable digital output signals for processing in a control system (PLC). Rotary encoders from ipf electronic operate according to the principle of optical scanning. For this purpose, they have a pulse disc on which, depending on the encoder, there is a one-to-one (absolute) or repeating (incremental) graduation. This is scanned by an optical system and converted into encoder-specific output signals (multiturn, RS422, etc.) by integrated electronics.

The operation of magnetic encoders is comparable to optical systems. Instead of a pulse disk, however, a magnetic rotary encoder consists of a magnetized disk on which, depending on the device, there is a graduation with repeating north and south poles (incremental) with a fixed width or a one-to-one graduation (absolute), which to a certain extent consists of north and south pole „blocks“. Incremental magnetic rotary encoders record the field strength and field direction when the disk rotates, which in turn results in analog sine or cosine signals that are converted by the signal conditioning circuits into two square-wave signals offset by 90°.

The operation of incremental magnetic systems is independent of whether it is a solution for the detection of linear or rotational movements. Therefore, Fig. 1 shows as an example a linear measurement system with alternating north and south poles on a magnetic tape, where the sensors are the same for both fields of application. In this context, there are solutions with sensor elements that generate both signals as well as systems with two single sensors.



Output signals of the sensor elements in an incremental magnetic linear measurement system, with a division of the magnetic tape from repeating north and south poles with fixed width. The detection of field strength (A) and field direction (B) results in sine and cosine signals, respectively, which are converted into two rectangular signals offset by 90°.

2.2 ONE-, TWO- AND THREE-CHANNEL INCREMENTAL ENCODERS

Among incremental encoders there are single, dual and triple channel solutions. Single-channel encoders operate with a single output signal ''A''. They are usually used for length and speed measurements, i.e. in applications in which no detection of the direction of rotation is required. Dual-channel rotary encoders provide two ''A'' and ''B'' signals offset by 90° to each other, whose phase relationship is evaluated via electronics. In this way, the direction of rotation can be determined on the basis of a rising or falling edge, e.g. for monitoring motors. In addition to the ''A'' and ''B'' signals, three-channel encoders provide a so-called zero pulse (''Z'' signal). This signal consists of a single, factory-set pulse that is output at exactly the same position on the pulse disc each time an incremental encoder is rotated. The zero pulse is therefore a kind of fixed reference point which, among other things, may be required for a reference run, e.g. to obtain the initial position of a drive shaft.

3 PARAMETERIZABLE ENCODERS

All incremental encoders have one thing in common: They must be designed ex works for the number of pulses required for a later application with a correspondingly specified line pitch. This means that a separate incremental encoder is required for each number of graduations. Industrial sectors with a high demand for encoders for different tasks, for which different resolutions are sometimes required, therefore need a separate device for each field of application with corresponding stocking of all required variants. The incremental encoders of the **VD58982x** series from ipf electronic, however, can be parameterized directly on site with a PC and therefore flexibly set to the required number of pulses (between 1 and 65536 pulses) per revolution.

3.1 FREE CHOICE OF SIGNAL HEIGHT

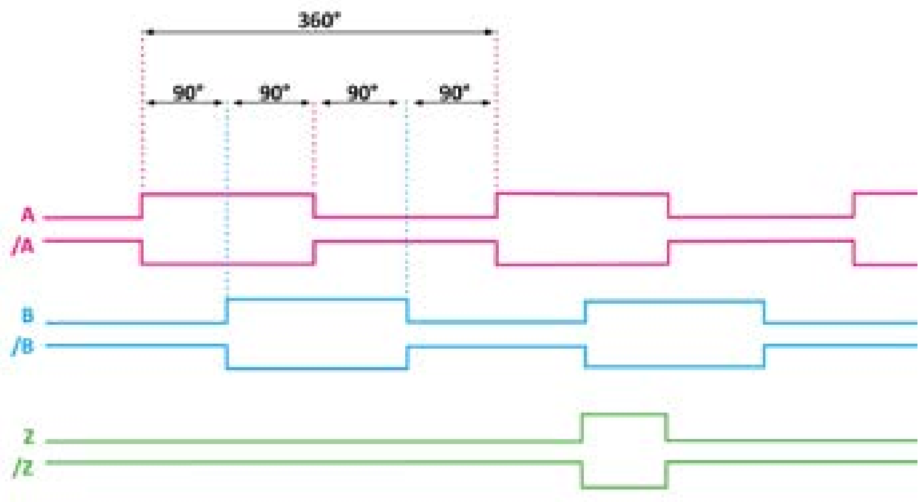
The parameterization software for the encoders can also be used to select the signal level for evaluation on an industrial controller (HTL level) or a PC (TTL level). A high voltage is defined as high level, while a low voltage is called low level. With the HTL level, the signal level corresponds to the applied supply voltage of 8 to 30V. Voltages <8V, on the other hand, are identified as ''Low''. For the TTL level, a signal <0.8V is considered ''Low'' and a signal >2V is considered ''High''. TTL levels have their origin in computer technology, as microcontrollers usually operate with a supply voltage of 5V, while classic industrial controllers require a supply voltage of 24V (HTL level).

Parameterizable incremental encoders: **VD589820** with 6mm solid shaft, **VD589821** with 10mm solid shaft and **VD589822** with 12mm hollow shaft (from left).

3.2 MORE CONFIGURATION OPTIONS

In addition to the direction of rotation (CW=Clockwise/CCW=Counterclockwise), i.e. the selection of the direction in which the positive count is to take place, the position of a reference signal (zero pulse) in the range from 0° to 360° on the pulse disc can also be freely specified for the parameterizable encoders. Compared to conventional encoders, users thus remain completely flexible in their configuration. Even the width of the reference signal is adjustable, with the Z signal being present for either a quarter turn (Z 90°) or a half turn (Z 180°) and thus being "High". Furthermore, it is possible to invert the output signals (complementary signal) (A-nA / B-nB / Z-nZ) for parameterizable encoders. Here, a signal inversion of A, B and Z takes place, so that e.g. a rising edge A (High) becomes a falling edge A (Low). The same applies to B and Z.

With the assistance of inverted signals, plausibility tests can be carried out, for example, in order to identify faults on signal lines. In general, however, such complementary signals serve to increase the resolution and thus the measuring accuracy of an incremental encoder, because a so-called 4-fold evaluation is then possible, in which both the rising and falling edges are counted.



Inverted signals of a parameterizable encoder. A 4-fold evaluation of the A and B signals as well as their complementary signals increases the resolution and thus the measuring accuracy.

3.3 TIME SAVING DURING START-UP

All previously set parameters of the **VD58982x** encoders can also be saved and transferred to the new encoder when a device is replaced. This eliminates the need for renewed parameterization, saving considerable time during commissioning. Machine builders and system integrators in particular can benefit from the solutions, as they no longer need to stock a variety of different encoders for different tasks.

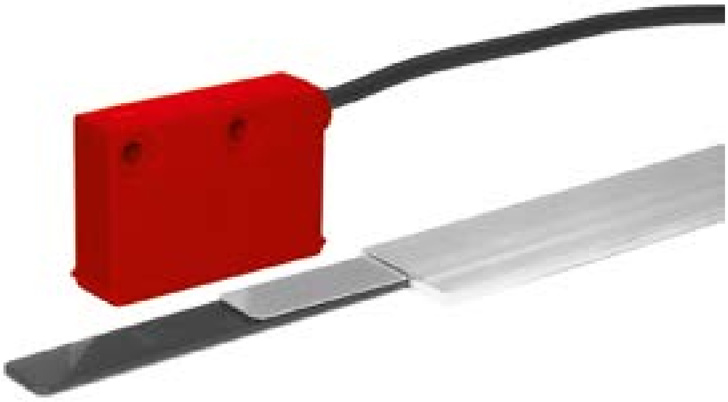
4 MAGNETIC ENCODERS

The **MD420020** and **MD420021** magnetic rotary encoders (angle sensors) from ipf electronic are two-part systems consisting of an encoder (magnet) and a sensor. Depending on how the encoder is rotated in an application, the direction of the magnetic field lines changes with respect to the sensor. The stationary installed sensor detects these directional changes in the field lines, which allows the exact position of the encoder to the sensor to be determined. For this purpose, the analog output supplies an angle-proportional signal of 4...20mA or 1...10V in the rotation angle range from 0° to 360°. The compact, wear-free angle sensors are ideal for integration into existing machine assemblies to record angles of rotation. The separate mounting of encoder and sensor opens up many variable mounting options. The angle sensors from ipf electronic in IP67 are very robust, insensitive to contamination and designed for an operating temperature range of-40°C to +85°C. The systems therefore always work reliably even under the most adverse environmental conditions. Another decisive advantage: Since the **MD420020** and **MD420021** are absolute measuring systems, they do not need to be calibrated or referenced before commissioning and are therefore ready for immediate use.

Magnetic encoders (here the **MD420020**) are absolute encoders and therefore do not have to be referenced after commissioning.

5 MAGNETIC DISPLACEMENT ENCODERS

Displacement sensors (incremental encoders) from ipf electronic measure distances and directions or directions of rotation and angle changes. Since, strictly speaking, these are not encoders in the classic sense, these solutions are subsumed under ''linear measurement system'' in ipf electronic's product selector. A linear measurement system consists of a probe (sensor) and a magnetic tape. The sensor travels contactlessly over the magnetic tape, on which north and south poles with precisely defined pole widths alternate in the longitudinal direction.



Magnetic displacement sensors such as the **MW100400** travel contactlessly over a magnetic tape for displacement measurement.

When scanning the different magnetic poles, two sinusoidal signals are generated and converted into digital square-wave signals or pulses by the sensor's electronics to obtain high-resolution displacement information for further processing via a counter or a controller. Magnetic displacement encoder systems are very easy to mount, allow a flexible design for the respective application due to the available magnetic tapes in lengths up to 75 meters, withstand a high initial acceleration if required and are absolutely wear-free with high accuracy (resolution linear 0.1mm with 4-fold evaluation).

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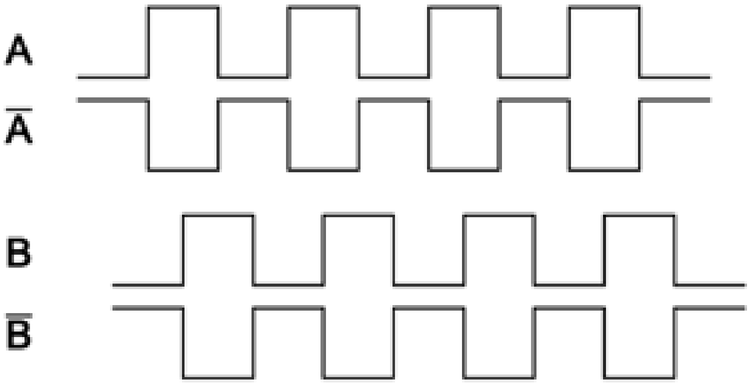
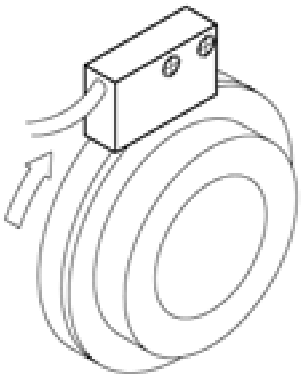


Signal images of a magnetic displacement encoder with inverted signals for a 4-fold evaluation.

With the help of measuring wheels or magnetic rings, the solutions from ipf electronic also become very robust, open magnetic encoder systems, e.g. with the AM000051 (Ø 50mm), which delivers a maximum of 2048 pulses per revolution with a 4-fold evaluation. In addition, simple angle measurements can also be realized with the solutions. The accuracy of a system, taking into account the respective magnetic tape length "L" in meters, is ±(0.1 + 0.01 x L)mm.



With measuring wheels or magnetic rings, the magnetic position encoders become robust, open encoder systems

If higher requirements have to be met, a measuring system of the MW11 series (resolution 10µm, accuracy 50µm) with a magnetic tape **AM000059** is suitable. Like the magnetic sensors, the magnetic displacement sensors or the encoder systems realized with a magnetic ring are insensitive to dirt, oils, moisture and vibrations. They are therefore not only suitable for a wide range of applications, but are also recommended for the simple retrofitting of existing machines and systems, among other things, due to their easy, flexible handling.

6 APPLICATION EXAMPLE

A concrete application example will be used to show how versatile magnetic displacement measuring systems from ipf electronic can be used, e.g. in special machines for processing precious and semi-precious stones as well as synthetic stones.

6.1 OWN SPECIAL MACHINE CONSTRUCTION

Edelsteinmanufaktur (Gemstone manufactory) Herbert Stephan KG, located in Frauenberg not far from Idar-Oberstein, is one of the largest companies in the region for processing precious and semi-precious stones as well as synthetic stones and describes itself as a high-tech manufactory. For good reason, because there are basically no standard solutions for machine processing of gemstones. For this reason, Herbert Stephan KG develops its own machines, including in-house software programming for the control systems. In the meantime, there are well over 100 special machines.

6.2 FILIGREE SHAPES WITH ULTRASONIC

One of the core competences of Herbert Stepan KG is the engraving of shapes, motifs or patterns by means of ultrasonic technology and negative matrices in synthetic and genuine gemstones. The solution developed specifically for this purpose enables machine production in larger quantities at competitive prices. More than 50 such ultrasonic machines are now in use. The production process: A negative die is soldered onto an ultrasonic head and then the corresponding shape is machined into a stone with this tool using high vibrations and boron carbide as an abrasive emulsion. In this way, for example, motifs can be produced that cannot normally be ground. In addition, the process is also used to press recesses into stones for gold inlays, among other things.

Using the ultrasonic head and a soldered-on negative die, the appropriate shape is carved into a stone using high vibrations and boron carbide.

A decisive parameter during machining is the most precise and accurately positioned advance of the tool to the workpiece. In the past, a cable pull system was used for this purpose, but it repeatedly caused problems due to both the process-related vibrations in the 22kHz range and the boron carbide used during machining. Not only was the system susceptible to wear and contamination, but it was also inaccurate because the predefined parameters, e.g. the zero position of the tool feed, kept changing. As a result, the wire-draw system had to be recalibrated more frequently, sometimes even during the production of a production batch. In search of an alternative, the company turned to ipf electronic because they had already been working with the sensor specialist from the Sauerland region in some areas for some time. With an incrementally operating magnetic linear measurement system, ipf electronic finally had a solution that met the decisive requirements, especially in terms of precision and reliability.

6.3 MAGNETIC LINEAR MEASUREMENT SYSTEM INSTEAD OF CABLE PULL

Essentially, the linear measurement system consists of a **MW110430** sensor as probe head with a very high resolution of 10µm and the **WY050100** pulse monitor. As already described above, the sensor in magnetic displacement measuring systems usually travels contactlessly via a magnetic tape. On the special machine of the gemstone manufactory, however, the sensor is permanently mounted on the machine, while the magnetic tape, which is attached to the tool advance and protected by an additional stainless steel tape, moves over the sensor.

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The sensor is permanently mounted on the machine, while the magnetic tape, which is attached to the mold drive and protected by an additional stainless steel band, moves over the sensor. Thus, the sensor connection cable is not subject to wear.

This solution ensures that the connection cable for the sensor is not subject to wear due to the movements of the tool slide. The magnetic tape contains alternating north and south poles with a precisely arranged pole width of 5mm, which generate a sine/cosine oscillation when scanned in the sensor. The sensor converts these oscillations into two square-wave pulses offset by 90 degrees. The resulting four signal edges can be used via the pulse monitor to determine and visualize the distance covered by the tool advance or the desired depth of the negative die as well as its direction of movement.

6.4 EXACT ADVANCE DUE TO HIGH RESOLUTION

Since the stones are sometimes only two to three millimeters thick and the machining depths are sometimes in the hundredths of a millimeter, the advance must work extremely precisely. The sensor's high resolution of 0.01mm delivers this precision. Furthermore, because the advance is very slow and the process generates strong vibrations at the same time, it is also necessary to record the square-wave pulses at the highest possible sampling rate. Here, too, the input frequency or sampling rate of the pulse monitor of 250kHz compared to the ultrasonic frequency of the tool of 22kHz means that one is definitely on the safe side, especially since the system processes the pulses very cleanly due to the high resolution even when the tool slide is retracted manually.

Before beginning processing, the tool advance must be exactly in the zero position in order to precisely maintain the presettings for engraving. After machining, but also partly for checking during initial machining, the tool slide with the die is retracted by hand. The linear measurement system ensures that the die is exactly back in the zero or start position when it is subsequently re-started or at the beginning of a new production run. With the cable pull system, however, this position could be lost during rapid retraction of the die slide, so that readjustment was necessary.

6.5 CLEAR VISUALIZATION OF THE CURRENT DIMENSIONS

The pulse monitor visualizes the respective current measure for the advance with green digits. The display changes to red when the set value for the depth of the die is reached.

The impulse monitor, designed as a front panel device, is parameterized via the integrated touch panel. It is preset so that the display visualizes the respective current dimensions in green while the machine is in operation. After reaching the set value, the machine switches off and the display changes to red so that the employee responsible for the machine can immediately see when the processing of a stone has been completed.

The special machines enable extremely delicate work, such as this turtle made of jade. (Photo: Herbert Stephan KG)

6.6 ESTABLISHED STANDARD

According to the maintenance manager of Herbert Stephan KG for electrical installations, ipf electronic's solution is superior to conventional displacement measuring systems because it not only meets the required high accuracies, but also operates without contact and is thus insensitive to mechanical loads and vibrations. Even contamination from the boron carbide now no longer impairs the production process. In the meantime, the incremental linear measurement system from ipf electronic has established itself as the standard for the ultrasonic machines of the gemstone manufactory, with all machines successively being equipped with the solution.

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