Application Note DK9222-0212-0053
Positioning

Increment-precise positioning with position encoders 1 V_{pp}

This application example deals with incremental position encoders for determining the position of drives with sinusoidal output voltages (1 V_{PP}) and the evaluation of the signal by the Beckhoff EL5021 EtherCAT Encoder Interface.

Measuring transducers

Rotary encoders convert mechanical movement sequences (translatory | rotary) into digital voltage values. They are used mainly for the rotary movements of drives, which are subject to permanent positioning or are operated in a closed, controlled system. Rotary encoders usually work according to the principle of the photoelectric scanning of fine gratings and frequently have a round shape. Rotary encoders have no drive of their own, but must be actively and mechanically driven by a shaft.

The accuracy of the returned position is limited by the encoder resolution. For rotary movements the resolution corresponds to the quotient of revolution (360°) and number of segments. It indicates the smallest possible measurable difference between two positions. The more segments, the higher the resolution and the more precise the position information is. This resolution is often sufficient for simple positioning tasks, but a finer resolution is required in order to monitor the synchronism of the axis in addition to its position.

Application Note DK9222-0212-0053
Positioning

Positioning on the basis of the physical encoder resolution

Increase in the position accuracy is possible only with a higher-resolution encoder.

The encoder resolution determines the minimum position difference
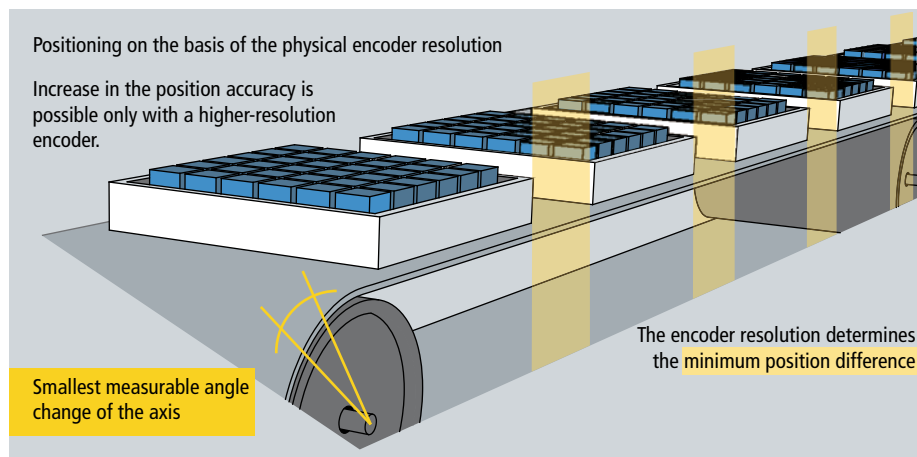
Smallest measurable angle change of the axis

Fig. 1   The accuracy of the returned position is limited by the encoder resolution.

Position detection: absolute or incremental

According to the measuring and evaluation methods, distinction is made between absolute and incremental rotary encoders. Absolute rotary encoders output the momentary absolute position of the measuring system in the form of a unique position value, which is then passed on to the subsequent electronics in binary form. One of the advantages of the absolute encoder is that the position value can be reliably read following a power failure because the value is 'mechanically stored' in the encoder mechanism, e.g. by means of a gear.

The output signals of an incremental encoder always have to be 'counted' by an electronic system and referenced there to a reference point/start signal. Unlike the absolute encoder, the position of the incremental encoder is no longer known to the evaluation electronics following a power failure. For this reason, so-called homing drives to independent position sensors or end positions take place for the purpose of 'zeroing' after switching on.

Distinction is made between one and two-channel position encoders: encoders with only one channel are not suitable for detection of the direction of rotation. With two-channel encoders the direction of rotation can be derived from the phase difference between the two channels (usually called A and B); if necessary, an additional reference pulse (Index C) may be output on an additional channel for each full revolution.

Application Note DK9222-0212-0053
Positioning

Signal type: rectangular or sinusoidal voltages

In the case of incremental encoders, rectangular signals or sinusoidal voltages are output for channels A and B. The sinusoidal voltages are phase-shifted by 90° (also accordingly called sine and cosine) and can be processed by the subsequent electronics in various ways.
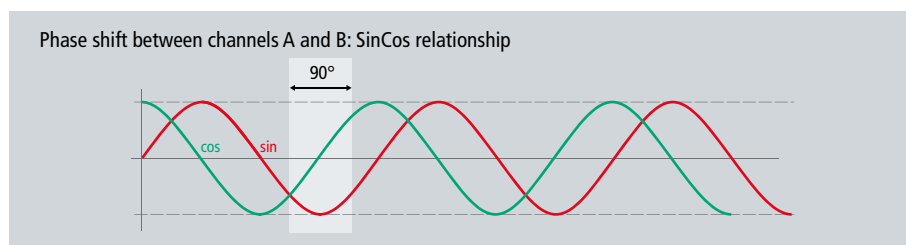

Fig. 2:   SinCos relationship

A full revolution of the shaft (360°) is represented by a complete sine period. The output voltage of the encoder depends on the manufacturer, but is usually an output level of one volt peak-to-peak (1 V_{PP}). The designation Vpp stands for the voltage level from the lowest point to the highest point of the amplitude. By adding the suffix 'peak-to-peak', the given voltage is detached from the reference 0 V or 'ground' and can be referenced to any offset.
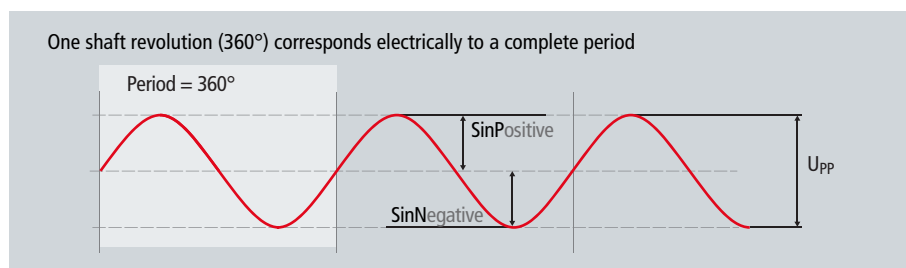

Fig. 3   By adding the suffix 'peak-to-peak', the given voltage is detached from the reference 0 V or 'ground' and can be referenced to any offset.

In order to avoid interference on the signal lines, however, the GND-referenced sine or cosine signals are not transmitted, but rather their respective floating differential signals Sin_{Diff} or Cos_{Diff} are. The differential signals are thus composed of the signal and the inverted signal (complementary signal) ($Sin_{Diff} = Sin_{Pos} - Sin_{Neg}$). The output signal of the sensor is the peak amplitude value of the differential signal with a level of 1 V_{PP} and corresponds to twice the signal voltage (see fig. 4).

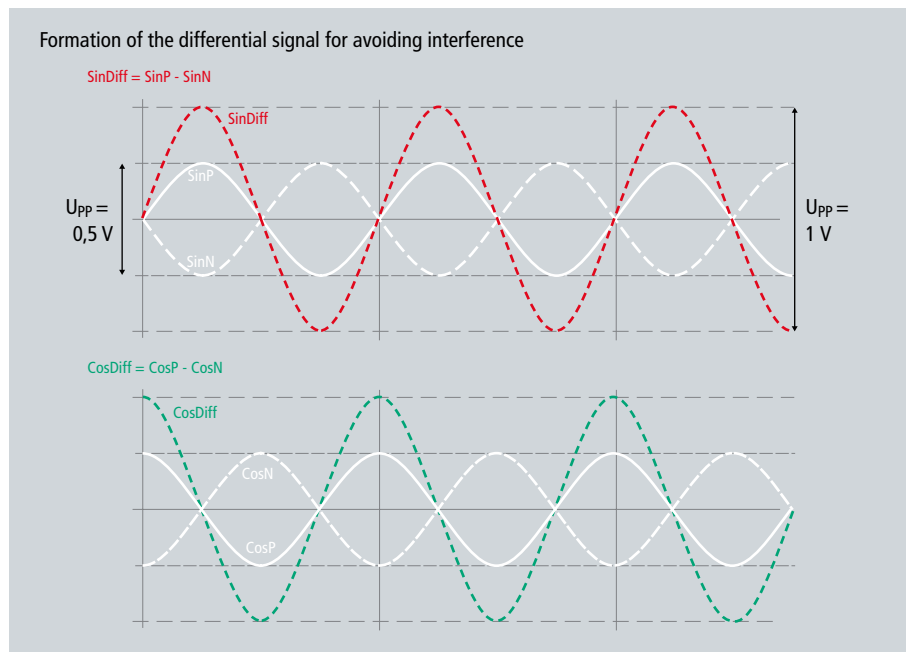**Application Note DK9222-0212-0053**

Positioning

Fig. 4   Composition of the differential signals

Other possible voltage levels of SinCos encoders extend from the mV range up to several volts. Encoders with a current interface typically have a level of 11 μA_{pp} with a 1 kOhm load. Also typical in incremental encoders are rectangular output signals with 5 V TTL or also 30 V HTL, which in turn are not floating, but referenced to ground.

The performance data of an encoder are usually of the order of 100 to 10,000 SinCos periods for each revolution. The rotary movement of the shaft is thus defined by multiple position information, from which the subsequent electronics perform a coarse determination of the position in the first step by counting the pulses or half-waves. In the second step the two momentary amplitude values of channels A and B (Sin_{Diff} and Cos_{Diff}) are mathematically referenced to each other by linear interpolation. As a result, the current angular position of the amplitude curve (0 to 360°) inside a half-wave is also available. Thus a higher positional resolution is achieved with SinCos signals in comparison with rectangular TTL signals. This form of pulse multiplication allows the mechanical resolution of the rotary encoder to be maximised, so that sufficient information is available for the determination of the position even for very slow movements. Common interpolation rates are often around 4 to 8 bits.

Application Note DK9222-0212-0053

Positioning

Evaluation of the signal quality on the oscilloscope – Lissajous figures

In order to visually evaluate the signal quality, both output signals can be displayed on an oscilloscope as an XY display. In this representation the Sin_{Diff} and Cos_{Diff} signals produce a Lissajous figure; in the ideal case an even, round graph appears in the centre of the display. Recognisable deviations in the shape and position of the circle provide an indication of the signal quality and the alignment of the encoder. The size of the circle corresponds to the amplitude of the output signals.

Compared to the standard circle at 1 V_{pp}, a larger circle indicates a gain error (blue). Offset errors are indicated by an off-centre position of the circle (green), while ellipsoidal graphs represent a phase error (red).
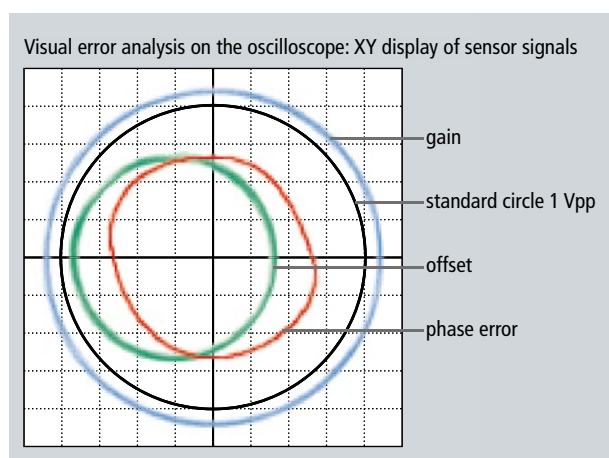
Visual error analysis on the oscilloscope: XY display of sensor signals

— gain

— standard circle 1 Vpp

— offset

— phase error

Fig. 5   Lissajous circle for the analysis of SinCos signals on an oscilloscope

Practical example | Exact positioning in real-time even at low feeding speed

With higher interpolation rates and higher positional resolution, the more precise the NC positioning will be. However, the computing time required for interpolation in the evaluation unit imposes limits on the principle at high velocities. The Beckhoff EL5021 1-channel SinCos encoder interface offers a dynamic, frequency-dependent interpolation rate for the maximisation of the encoder resolution in such applications. For dynamic adaptation to the current velocity therefore, the position is calculated with a high resolution, e.g. 13 bit, at low velocities or at a standstill, and only with a lower resolution, e.g. 8 bit, at higher velocities.

Application Note DK9222-0212-0053
Positioning

Positioning with EL5021 encoder interface

More detailed angle specifica-
tion through interpolation

Significantly improved
minimum position difference

Increase in the position accuracy
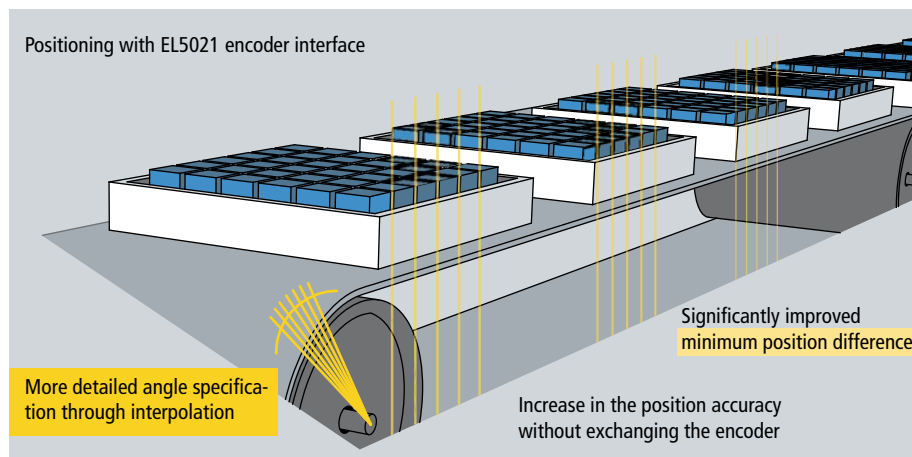without exchanging the encoder

Fig. 6   Improved positioning capability using the EL5021 encoder interface

If an encoder with a division of 1,000 signal periods per revolution is used, the EL5021 supplies a resolution of 1,000 x 256 = 256,000 units at the lowest interpolation rate (8-bit | 256-fold) in order to represent a movement distance of 1 mm per revolution. The movement distance of 1 mm is thus determined with an accuracy of 1/256,000 mm. With an average interpolation rate of 10 bit, position determination with an accuracy of 1/1,024,000 mm is possible with the identical measuring device. At the maximum possible interpolation level of 13 bit, the movement distance can be determined with an accuracy of 1/8,192,000 mm, which corresponds to an increase in accuracy by a factor of 35 using identical hardware.

EL5021 1-channel Sin/Cos Encoder Interface (1 V$_{PP}$)

A typical area of application for interpolated incremental encoder signals is in high-resolution feedback systems for positioning in real-time. The EL5021 SinCos encoder interface serves to directly connect a position encoder (5 V DC) to the higher-level EtherCAT fieldbus. The sinusoidal output signal 1 V$_{pp}$ is conditioned, interpolated and made available as a 32 bit value, so that a single signal period can be used for positioning with a resolution of up to 13 bit. The EL5021 continuously measures both differential analog signals (channel A and B) and calculates a positional value from them. The positional value consists of the number of periods (period counter) and the current position within the period (period portion). In addition, the reference mark is also output in 32 bit width. The current counter value and the value of the reference mark can be read permanently. The maximum permissible input frequency for the measuring signal inputs is 250 kHz. The EL5021 corrects offset, gain and phase errors and also makes diagnostic values available with the process date, for example, exceeding the max. frequency limit of the valid resolution range, or an insufficient voltage level of the input signal.

Pulse multiplication by interpolation

A special feature of the EL5021 encoder interface is the dynamic, frequency-dependent interpolation rate for the maximisation of the encoder resolution for positioning in real-time. The determination of the period portion with a resolution of 8 to 13 bit corresponds to 256 to 8192 graduations within one sine period. Minima and maxima in the upper and lower frequency

Application Note DK9222-0212-0053
Positioning

bands specified by the user enable the automatic adjustment of the interpolation rate to the frequency of the input signal. The interpolation width reduces automatically as the frequency or the movement velocity increases. If the signal frequency drops again, the interpolation rate is automatically increased up to the maximum desired rate. 13 bit is the theoretical maximum desired resolution with which the signal is output at a standstill or with slow movement. Conversely, if the maximum period resolution is set to 12 bit, 6 bit period resolution will still be achieved at the typical maximum input frequency of 80 KHz and thus result in fast movement.

Velocity-dependent interpolation stages of the EL5021

35-fold

8-fold

4-fold

8 bit   10 bit   13 bit

velocity

The EL5021 automatically extends the interpolation width as velocity decreases.

Positioning accuracy in the lower velocity range can be increased by a factor of 35 without exchanging the encoder.
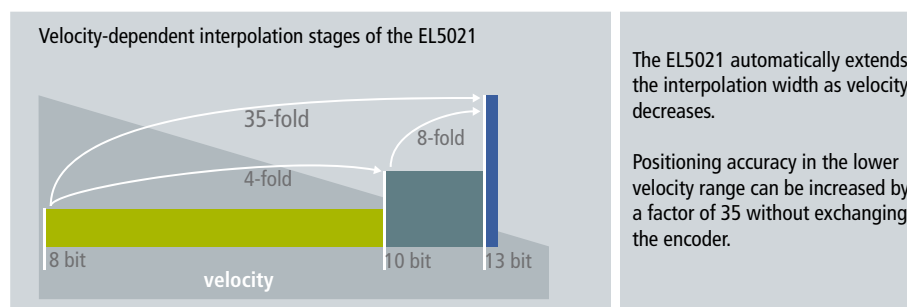
Fig. 7   Velocity-dependent interpolation stages of the EL5021

– 1-channel SinCos encoder interface 1 V$_{PP}$ **www.beckhoff.com/EL5021**
– EtherCAT **www.beckhoff.com/EtherCAT**