HEIDENHAIN

Technical Information

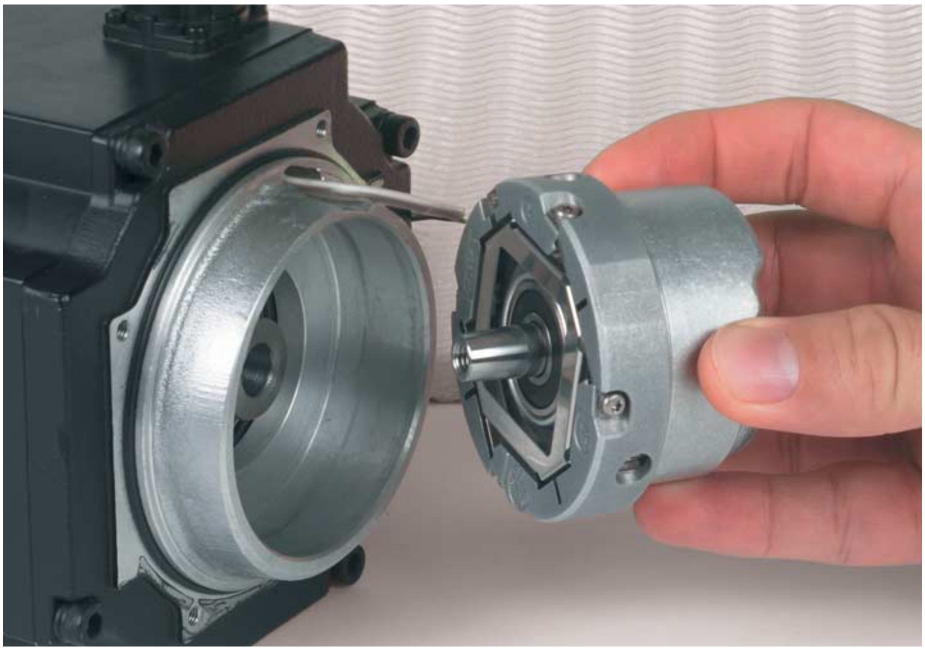
Rotary Encoders for Highly Dynamic Servo Drives

Controlled servo drives are used in many areas of automation technology, robotics and handling systems as well as in the drive technology of production machines and machine tools. The requirements regarding dynamics, speed stability and rigidity necessitate ever increasing gain factors in the control loops. The position encoders used are an important factor in the control quality of the drive. The position resolution and the position error within one signal period are distinctly in the foreground.
The selection of a certain encoder technology is strongly dependent on the accuracy requirements of the respective application.
A flexible mounting situation on the motor as well as a uniform data interface to the control enable the integration of various encoder technologies, thereby supporting modular drive assemblies.

Position encoders for servo drives
The features of encoders typically used for reporting speeds to servo drives differ significantly.

Resolvers mostly have only one signal period per motor revolution. Therefore, the position resolution is strongly limited, and the position value determined is absolute within one revolution. **Inductive rotary encoders** feature a graduation with 32 or 16 signal periods per revolution, and therefore achieve a significantly higher position resolution. The angular position is determined as an absolute value. **Optical rotary encoders** are based on very fine graduations of 512 or 2048 signal periods, and therefore have much higher resolutions. The multiturn versions of both inductive and optical rotary encoders can uniquely determine the absolute position within 4096 revolutions.

Inductive and optical rotary encoders from HEIDENHAIN with the EnDat 2.2 digital interface feature an integral **signal evaluation.** The control receives the digitized absolute position value directly, without any additional calculations being necessary. With resolvers, on the other hand, the analog signals must be generated and evaluated. This elaborate evaluation must also be considered as an additional cost factor. Resolvers, however, are also well-known for their robustness; but rotary encoders from HEIDENHAIN also permit real-world **acceleration values.**



	Resolvers	Inductive rotary encoders	Optical rotary encoders
Line count per revolution (typ.)	1	32	2048
Interpolation	External	Internal	Internal
Resolution	Typically 14 bits 16384 pos/rev	17 bits 131 072 pos/rev	25 bits approx. 33 million pos/rev
Accuracy	Typically ± 480“	± 280“	± 20“
Minimum possible measuring step	Approx. 80“	Approx. 10“	Approx. 0.04“

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Influence of periodic errors on the control behavior

In order to achieve the high resolution required, the sinusoidal scanning signals must be interpolated. Inadequate scanning, contamination of the measuring standard, and insufficient signal conditioning can lead to the signals deviating from the ideal sinusoidal shape. During interpolation, errors then occur whose periodic cycle is within one signal period. Therefore, these position errors within one signal period are also referred to as "interpolation error." On high-quality encoders they are typically 1% to 2% of the signal period.

The interpolation error adversely affects the positioning accuracy, and also significantly degrades the speed stability and noise behavior of the drive. The speed controller calculates the nominal currents used to brake or accelerate the drive depending on the error curve. At low feed rates the feed drive lags the interpolation error. At increasing speeds the frequency of the interpolation error also increases. Since the motor can only follow the error within the control bandwidth, its effect on the speed stability behavior decreases as the speed increases. However, the disturbances in the motor current continue to increase, which leads to disturbing noises in the drive at high control-loop gains.

The attainable accuracy of a servo drive depends on the amplitude as well as the period of the measuring error. Since the **resolver** only generates one signal period per revolution, the interpolation error has a large effect: Using the values from the table on page 1 and a control bandwidth of 100 Hz, the drive follows a sinusoidal interpolation error whose period corresponds to one signal period of the encoder (1-phi error), up to 6000 rpm. This means that fluctuations of the speed can be expected any at speed.

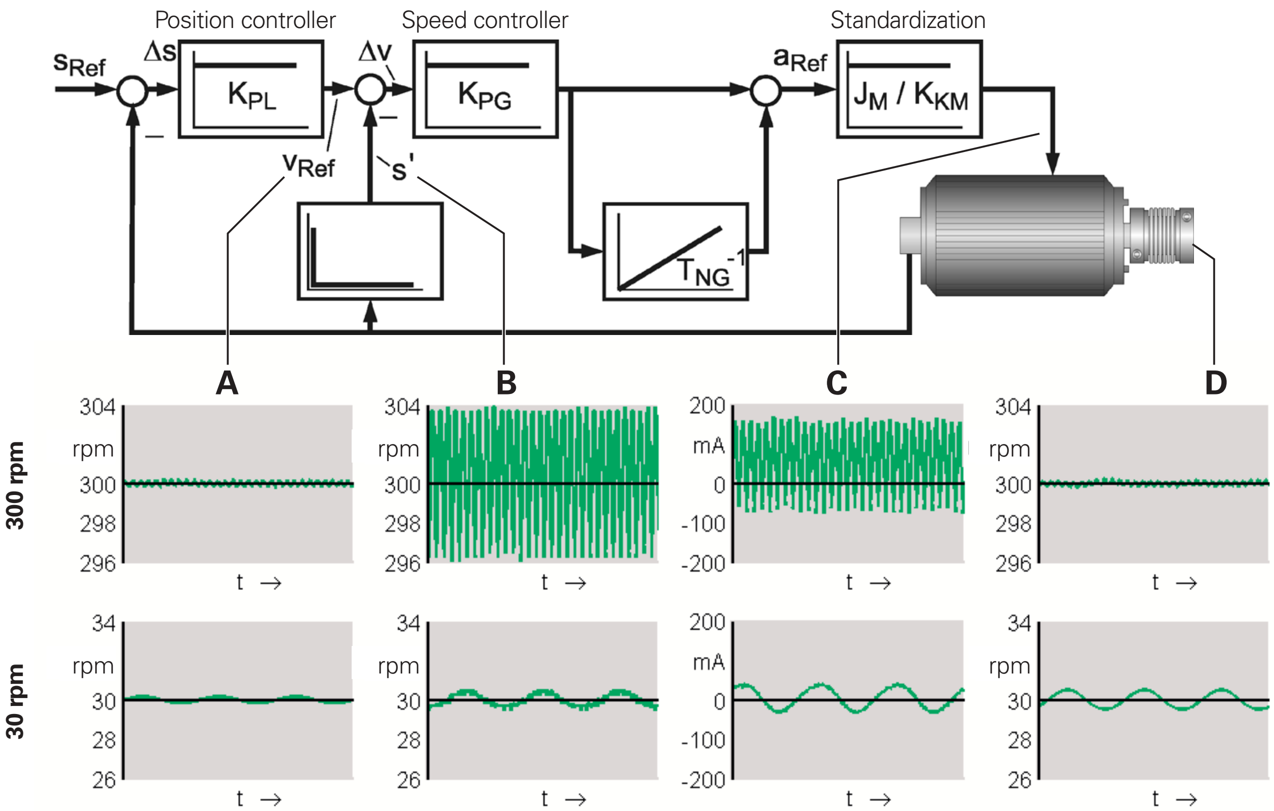
With an **optical rotary encoder** the drive only lags an interpolation error at low speeds. Using the same example, but with a rotary encoder with 2048 lines, a 1-phi error becomes apparent in a speed range between 0 and 2.8 rpm. The position errors resulting from this usually remain within an interval of approx. ± 6".

Influence of the position resolution on the speed control

Since the resolution and accuracy of encoders typically used on servo drives are often very different, the influence of the smallest possible measuring step on the control loop will be examined more closely. The example shown in the simplified illustration of a control loop (Figure 1) will be used for this. The main influence of a limited position resolution can be estimated by considering the proportional speed gain only. The position controller and the integral speed loop can be neglected. A drive with the following specifications is considered:

Sampling interval T	100 µs
P-gain K_{PG}	600 s^{-1}
Motor inertia J_M	0.001 kgm^2
Torque constant K_{KM}	0.68 Nm/A

With these parameters, the minimum possible measuring step on a resolver with 14-bit lagging interpolation results in a jump of 3.4 A in the nominal current. This is, after all, 50% of the peak current of the motor being considered. On the other hand, the significantly smaller measuring step on an inductive rotary encoder with 17-bit resolution causes a jump of only 400 mA, and on an optical rotary encoder, with e.g. 25-bit resolution, even less than 2 mA.



A = Output position controller vRef = **Δ**s * K_{PL}
B = Measured values speed s'
C = Motor current
D = Actual speed

Figure 1: Effect of the interpolation errors in the control loop of a servo drive at two different speeds

Modular design

Servo drives must be able to be operate under differing accuracy requirements. Since the required accuracy significantly influences the selection of the encoder technology, a universal mounting possibility is an important prerequisite for a versatile and modular drive system. Ideally all different types of encoder variants—optical and inductive rotary encoders as well as resolvers—can be mounted on a motor without any additional intermediate flanges. A design as shown in Figure 2 makes this possible. It should be noted that optical and inductive rotary encoders from HEIDENHAIN already have identical mounting requirements.

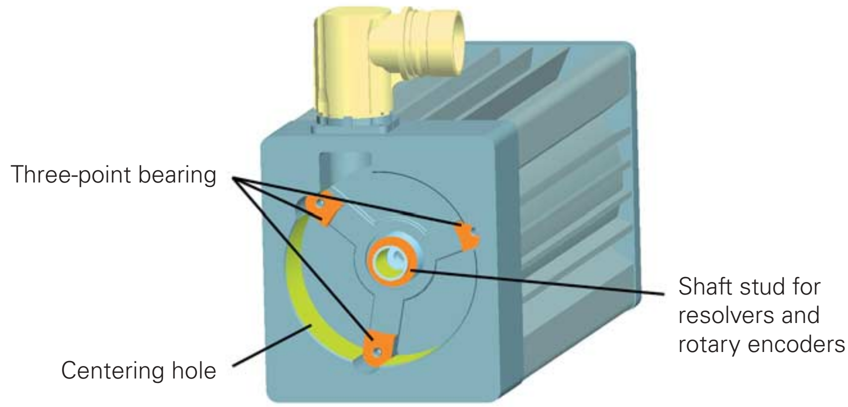


Figure 2: Suggestion for universal mounting possibilities of optical and inductive rotary encoders as well as resolvers on a servo motor

Conclusion

Along with the design and the properties of the control, the measuring technology used is a determining factor for the performance of electrical drives. The positioning accuracy and speed stability behavior of these machine axes significantly determine the quality of the workpieces and products. This necessitates a position encoder with a large number of measuring steps and high signal quality.

Irregularities in the speed stability can be caused by mechanical influences from the drive train as well as by position errors resulting from the encoder technology used. If the resolution of the measured signals is too low, or if the interpolation error is too high, wave-like errors can appear on the workpiece surface. The speed stability of certain motions in production systems can also be considered as a production parameter relevant to the quality.

Higher resolutions and accuracies can decisively improve the speed stability behavior of the motor. In addition, disturbances in the motor current are reduced significantly. The motor operates quietly and develops only a small amount of heat.

Ideal output signals with high resolution support a high bandwidth, which means that load variations only have a minimal effect on the rotational speed.

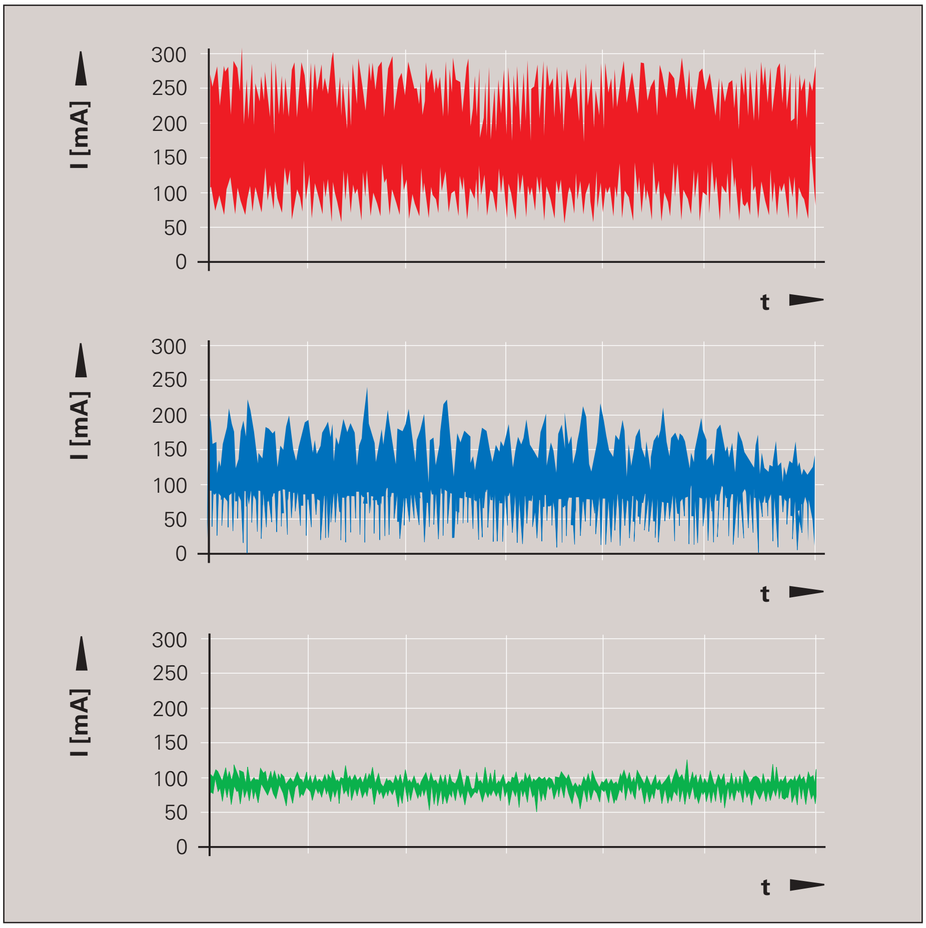


Figure 3: Current variations for different types of scanning systems in the encoders

- Resolver: 1 signal period per revolution
- EQI inductive rotary encoder: 32 signal periods per revolution
- EQN optical rotary encoder: 2048 signal periods per revolution

Rotary encoders for servo drives

Rotary encoders from HEIDENHAIN are optimized for use on motors in automation technology as well as in drive technology for production and machine tools. Their significant advantages are short overall lengths, torsionally rigid couplings and high resolutions. Their intelligent EnDat interface permits a high degree of modularity. It doesn't just transmit the absolute position values, but also additional information such as temperature, diagnostic and test values, as well as parameters, such as those used for automated commissioning. The user then enjoys the following advantages:

- Increased reliability through digital transmission of the position values.
- EnDat supports the automated commissioning of drives, and can therefore contribute to a reduction of standstill times in case service is necessary.
- The simple and low-cost cabling of the EnDat interface simplifies plant project planning of the mechanical equipment.

Design	Resolution Position values/ rev	Size	Version	Model
For typical accuracy requirements: Automation technology, robotics, handling				
Taper shaft	131 072 (17 bits)	Ø = 65 mm l = 29 mm	Singleturn	**ECI 1317**
			Multiturn	**EQI 1329**
Blind hollow shaft Ø 6 mm	65 536 (16 bits)	Ø = 37 mm l = 27 mm	Singleturn	**ECI 1116**
			Multiturn	**EQI 1128**
For high accuracy requirements: Printing presses, machine tools				
Taper shaft	Approx. 33 million (25 bits)	Ø = 65 mm l = 42 mm	Singleturn	**ECN 1325**
			Multiturn	**EQN 1337**
Blind hollow shaft Ø 6 mm	Approx. 2.1 million[1] (21 bits)	Ø = 37 mm l = 39 mm	Singleturn	**ECN 1113**
			Multiturn	**EQN 1125**

1) after 4096-fold interpolation of the incremental signals in the subsequent electronics

ECN 1325
EQN 1337

ECI 1317
EQI 1329

ECN 1113
EQN 1125

ECI 1116
EQI 1128

HEIDENHAIN

DR. JOHANNES HEIDENHAIN GmbH
Dr.-Johannes-Heidenhain-Straße 5
83301 Traunreut, Germany
☏ +49 (8669) 31-0
FAX +49 (8669) 5061
E-Mail: info@heidenhain.de

www.heidenhain.de

For more information
- *Position Encoders for Servo Drives* brochure

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