ENCODER TECHNOLOGY

Technical Articles

Rotary Encoders or Resolvers?
The Characteristics of Two Measuring Systems

Besides the actual position value, servo motors also need a sensor for the rotor position and the actual speed value for velocity control. Which type of sensor is better suited for this task: the resolver or the rotary encoder?

In the 1980s, the most commonly used technology for controlled drives in machine tools, printing or textile machines was the dc motor. In recent years, however, the desire for low-maintenance, highly dynamic drives has resulted in an increasing trend in the direction of three-phase ac motors. Of these, the introduction of new magnetic materials such as rare earth elements has made the synchronous motor the system of choice for servo drives. For spindle drives, particularly for machine tools, the dc motor has been replaced by the asynchronous motor. **Table 1** compares the advantages and disadvantages of these three types of drives.

The Servo Motor

DC motors switch between rotor coils by using a mechanical commutator and brushes. Brushes are associated with high wear, dirt, sparks, and limited shaft speeds. Brushless dc motors, a special type of synchronous motors, were developed in an attempt to eliminate these disadvantages by replacing the brushes with electronics. Here the rotor position is measured with optical sensors or Hall generators and fed to the control unit. As with conventional dc motors, a tachometer generator is used for velocity control. For axis position control, an additional rotary encoder or resolver is used (Figure 1). Since the individual coils are switched with rectangular-shaped voltage sections, this is called block commutation. The induction of the coils results in a trapezoidal current waveform.

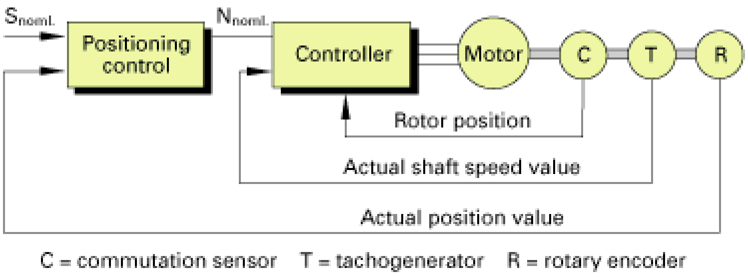
Table 1

Characteristics	DC Drive	Synchronous AC Drive	Asynchronous AC Drive
Overall size/power density	+	++	-
Acceleration	+	++	-
Shaft speed limits	-	+	++
Thermal overload	--	+	+

Service life	--	+	++
Wear	-	+	+
Robustness	-	+	++
Moment of inertia	+	+	-
Control complexity	++	+	-

The synchronous motor with electronic commutation has significant advantages over the dc motor since it permits a high degree of protection (IP 65). It can be used in explosive atmospheres, and provides good heat conductance through the stator coils.

The disadvantages of block commutation are the cost for the rotor position sensor, tachogenerator, and rotary encoder, plus the torque jump during switching between the individual phases, which appears as torque ripple. Recent efforts to remedy these problems include powering with sine-valued pulse width modulation (PWM). This method has the following advantages (Figure 1):



- Sinusoidal current with low harmonic content
- Low torque ripple and low oscillating torque
- Higher speed ranges and fewer motor losses at high shaft speeds
- Jitter-free running at low speeds
- Low acoustic noise

The introduction of microprocessors and digital signal processors (DSP) in the early nineties enabled the digital control of speed and current. The application of ASICs made it possible to incorporate peripheral functions such as pulse width modulation, measuring channels for current, rotor position and speed. The feedback for rotor position, speed and position is generally provided by resolvers and specialized rotary encoders. With digital control, there is no temperature drift or offset, and control adjustment is simpler.

In some cases, the asynchronous motor is also used as a servo drive. Controlling the asynchronous motor is somewhat more costly than with the synchronous motor, but since the rotor is designed as a squirrel cage in which current is induced, there is no need for a rotor position encoder.

Digital Speed Control

The sampling intervals for digital speed control lie in the range of 50 to 600 microseconds. The shorter the sampling times, the better the dynamic performance of the drive. The speeds required today lie in the range of 0.01 to 12,000 rpm (e.g., for high speed cutting). To be able to control a speed n of 0.1 rpm at a sampling interval Ts of 500 µs, one needs at least one pulse (measuring step) of the feedback sensor. The following formula results in 1.2 10^6 measuring steps per revolution:

$$n_{max} = \frac{f_{osz} \cdot 60}{2^x}$$

x = resolution in bits

No feedback sensor can directly provide such a high number of measuring steps per revolution - the output signals must therefore be multiplied by means of interpolation. A rotary encoder with 2048 lines whose output is interpolated by a factor of 1024, for example, provides a resolution of 21 bits (approx. two million measuring steps). In order to keep frequencies low on the transmission line from the encoder to the controller, the analog sine and cosine signals are transmitted uninterpolated at levels of 1 Vpp and are interpolated and digitized in the controller.

Electronic Commutation

To direct the current, synchronous motors need the information on the angular position of the rotor relative to the stator. The accuracy of this commutation signal should be approx. ±0.5 degrees to ±1 degree. At the moment that the motor is turned on and is not yet moving, it can operate with reduced accuracy, provided that within one revolution the rotor of the encoder traverses the reference mark to find and process the more exact angular position. The following methods have become common:

- Incremental rotary encoder with 2048 lines, one reference mark and an additional track with one sine and one cosine signal per revolution (z = 1). The accuracy of this track is ±3.6 degrees.
- Absolute encoders with a Gray code graduation and a resolution of, for example, 13 bits, where the code signal is transmitted as a synchronous-serial data telegram. The accuracy of the rotor position is ±1 bit (2.6'). An additional output from the finest track is provided for speed control. Such absolute rotary encoders are also available in multiturn versions with 4096 resolvable revolutions.
- Quasi-absolute rotary encoders that work according to a

multitrack method by which, for example, three incremental tracks with z1 = 1 period per revolution, z2 = 16 periods per revolution, and z3 = 256 periods per revolution, with tracks z2 and z3 each using its coarser neighbor as a reference (Figure 2). The absolute value acquired in this manner is transmitted serially to the controller.

- Bipolar resolvers output one sine and one cosine per revolution. The accuracy grades of such encoders lie in the range of ±8' and ±30', depending on the mechanical design.

Figure 2: **Glass Disc For Rotary Encoder**

Resolver or Rotary Encoder?

In literature on control technology the resolver is often mentioned as a suitable feedback sensor since it supplies one absolute signal per revolution and, due to its design, is highly tolerant to vibration and high temperatures. However, supplying only one period per revolution negatively affects performance at low speeds. Standard Resolver-to-Digital (R/D) converters with 12-bit resolution and a sampling time of 500 µs attain a minimum speed of approx. 30 rpm. The maximum speed, on the other hand, is limited by the oscillator frequency to approx. 1 MHz. With a 12-bit converter this results in a maximum speed of 15,600 rpm.

A 14-bit R/D converter reduces both the minimum and maximum speeds by a factor of four compared with the above mentioned 12-bit R/D converter.

Table 2 compares pancake resolvers with incremental rotary encoders that were specially designed for drives. It shows a 150 C specified in the isolation class F. For high control quality one needs a high number of measuring steps with uniform spacing between periods. Both requirements are greatly influenced by the quality of the encoder's analog output signal, which affects the subsequent interpolation error.

Characteristic	Resolvers	Rotary Encoders
Signal periods per revolution	1	2048

Interpolation	4096 = 12 bits	512 = 9 bits
Accuracy per 360 degrees	± 1200 angular seconds	± 20 angular seconds
Interpolation error	± 600 seconds + 1LSB	± 6.5 angular seconds
Rotor position information	Yes	With additional track
Number of lines	6	8 plus 4 for rotor position
Temperature range	-50 C to 150 C	-20 C to 120 C
Max. controllable speed (1)	15,600 rpm	10,300 rpm
Min. controllable speed (1)	30 rpm	0.1 rpm
(1) with controller scanning time TA=500 µs		

Table 2: Comparison of pancake resolvers with rotary encoders

The possible causes of interpolation error include datum deviations of the signals (offset), deviations of the phase angle, unequal signal amplitudes, and harmonics. It is of decisive importance for the control quality that the interpolation error remain constant over the entire temperature range. It is possible to attain a quality of analog signal that limits interpolation error to 1% of the grating period or less. This corresponds with the ± 6.5 angular seconds listed in **Table 2.** The position value error of a rotary encoder at different points within one temperature cycle is shown in **Figure 3.**

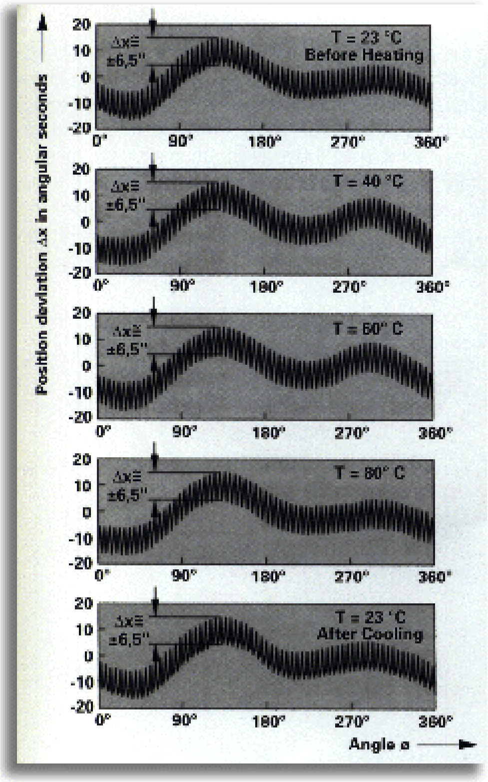


Figure 3: **The position deviations of a modular rotary encoder with 2048 signal periods per revolution in a temperature cycle of 23 C to 80 C.**

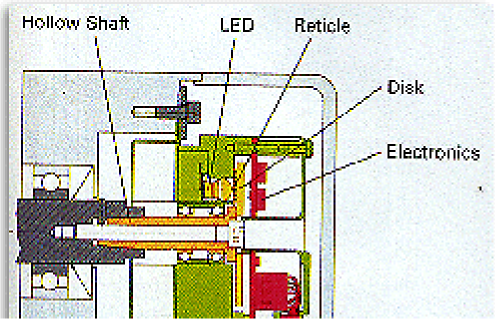
If the feedback sensor is also used for position control, the accuracy per 360 is of critical importance for positioning accuracy. In the case of resolvers, the interpolation error of the R/D converter must also be considered. With rotary encoders, however, the incremental signal can be used directly with the usual four-fold evaluation.

The speed control range possible with resolvers is 1:200, with rotary encoders it is 1:6 x10^5. This applies for a maximum speed of 6000 rpm and a sampling time of 500 ms, which are representative values for modern machine tools.

The selection of the proper resolver or rotary encoder, therefore, depends on the application at hand. If it requires a high control quality and a large speed control range, rotary encoders are the only meaningful solution.

Design Types

In the past, rotary encoder models were usually individually adapted to the mechanical and electrical characteristics of the customer's. This led to a very large number of dimensional variants and design types.



Combining these features in a single series of rotary encoder models has proven effective in reducing costs both for development and production. The encoders are designed so that each component used in as many models as possible.

Figure 4: **Simplified view of a modular rotary encoder with stator coupling: the graduated disk is rigidly connected by its taper shaft to the motor shaft.**

A prerequisite for good control performance is a stiff coupling of the encoder to the motor shaft. For this reason, modular encoders are designed with a stator coupling. The graduated disk is rigidly connected by its taper shaft to the motor shaft (Figure 4). The stator coupling is a spring parallelogram that absorbs the radial and axial offset between the encoder and the motor shaft. The coupling tolerates an axial offset of ± 0.5 mm and radial offset of ± 0.2 mm. The encoder is mounted by inserting its taper shaft into the internal taper of the motor shaft and securing them with a screw. An index pin is used to align the graduated disk to the rotor, and the fine adjustment is performed by rotating the encoder. After alignment the mounting ring is clamped.

All rotary encoders of this series provide sinusoidal incremental signals with 2048 periods per revolution and signal levels of 1 Vpp for digital speed control and, if desired, position control. These levels make it possible to transmit signals over cable lengths up to 150 m (492 ft.). The power supply for all encoder models is 5V ± 5%.

Absolute modular rotary encoders supply the code values through a bi-directional synchronous-serial interface in TTL levels. It is also possible to download, save, and upload motor parameters through this interface. The correct code value is provided up to a speed of 2000 rpm. It is needed only during switch-on, however. After power-on one normally continues working with the incremental values. The encoders are mechanically designed for up to 15,000 rpm, the electronically permissible maximum speed is 10,000 to 15,000 rpm, depending on the electronics.

In the future, the multiturn absolute modular encoder of this series will also be available with a bi-directional interface. This interface transmits with a cyclic redundancy check and makes it possible to save and upload motor-specific parameters and compensation value tables. This enhances serviceability and speeds commissioning. High systems reliability is attained through warning and alarm signals that provide diagnostic information on the encoder's operating condition.

Requirements on servo motors:

- High dynamics/large speed control range
- High speed accuracy and constancy
- Low torque fluctuations
- Small static and dynamic position deviations