Position encoders for feed axes

Direct drives have secured a lasting market share in many areas of the semiconductor and electronics manufacturing industries. This share is growing in the machine tool industry. The benefits of direct drive technology are low wear, low maintenance, and higher productivity. However, this is possible only if the control, the motor, the mechanical elements of the feed axes, and the position encoder are optimally adjusted to one another.

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The performance of direct drives is decisively influenced by the selection of the position encoder, and direct drives place rigorous demands on the quality of the position signals. Optimum measuring signals:

- increase the quality of the machined work piece surface,
- reduce vibration in the machine frame,
- stop excessive noise exposure from velocity-dependent motor sounds,
- prevent additional heat generation in the motor.

The efficiency of a direct drive is therefore greatly influenced by the selection of the position encoder. Encoders with optical scanning methods provide benefits in the accuracy, speed stability, and thermal behaviour of a direct drive. HEIDENHAIN offers a wide range of linear and angular encoders with technical characteristics specifically designed for direct drives.

The control loop

The decisive advantage of direct drive technology is the very stiff coupling of the drive to the feed component without any other mechanical transfer elements. This allows significantly higher kV factors in the control loop than a conventional drive.

On direct drives there is no additional encoder for measuring the speed. Both position and speed are measured by the position encoder: linear encoders for linear motors, angular encoders for rotating axes; see Figure 1. Since there is no mechanical transmission between the speed encoder and the feed unit, the position encoder must have a correspondingly high resolution in order to enable exact velocity control at slow traversing speeds.
The higher kV factors permitted by direct drives also increase the influence of the position encoders' signal quality on positioning behaviour. Direct drives therefore require position encoders with small signal periods and high signal quality.

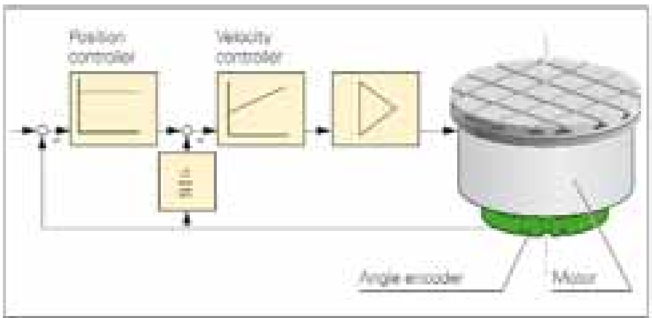


Figure 1. Control loop with rotational direct drive (torque motor).

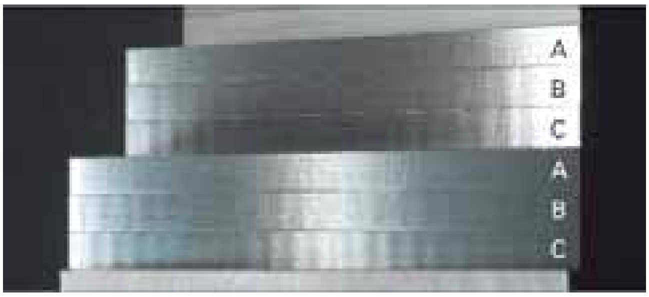


Figure 3. Quality of the milled workpiece surface for:
A: Position encoder with ± 0.4 μm interpolation error.
B, C: Position encoder with ± 1 μm interpolation error.

Signal quality

Modern encoders feature either an incremental, which means counting, or an absolute method of position measurement. The path information is transformed in the encoder into two sinusoidal signals with 90° phase shift. Both methods require that the sinusoidal scanning signals be interpolated in order to attain a sufficiently high resolution. Inadequate scanning, contamination of the measuring standard, and insufficient signal conditioning can lead to the signals deviating from the ideal sinusoidal shape. During interpolation, short-wave errors occur whose periodic cycle is within one signal period of the encoder's output signals. These errors are termed 'position errors within one signal period', or also 'interpolation errors'; see Figure 2. On high-quality encoders they are typically 1 to 2% of the signal period.

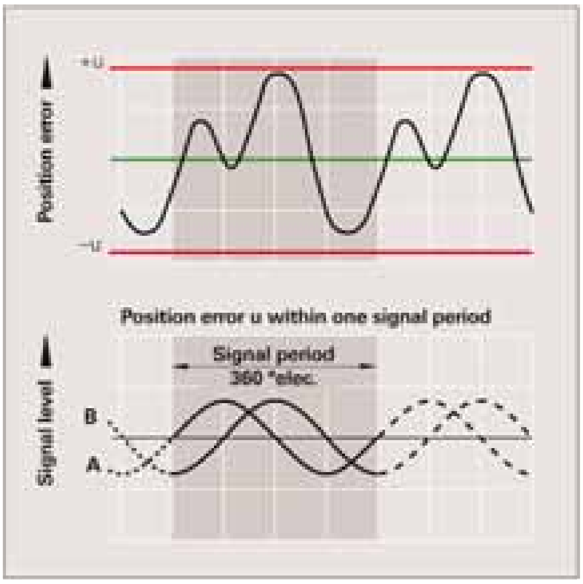


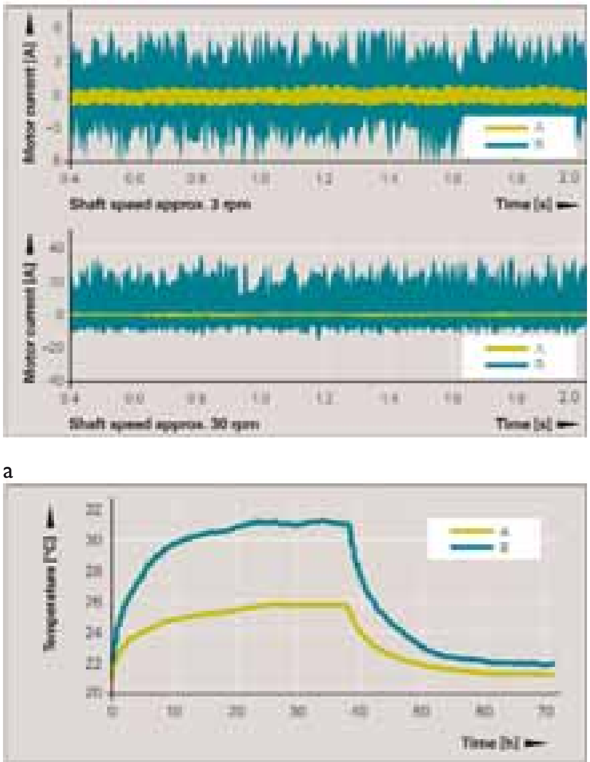
Figure 2. Position error within one signal period.

Interpolation error

The interpolation error not only affects the position accuracy, but also influences the speed stability 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. Since direct drives have a greater control bandwidth due to the kV factor, they can lag the interpolation error over a larger speed range. This can lead to wavelike errors on the work piece surface during cutting processes. The wavelength and amplitude depend on the speeds of the machine axes involved in the feed rate; see Figure 3.

Generation of heat and noise

If the frequency of the interpolation error increases, the feed drive can no longer follow the error curve. However, the current components generated by the interpolation error cause increased motor noises and additional heating of the motor. A comparison of the effects of an optical and a magnetic encoder on a rotary table with direct drive emphasizes the meaning of high-quality position signals; see Figures 4 and



a

b

Figure 4. Direct drive with position encoder: comparison of optical encoder (low interpolation error, A) vs. magnetic encoder (high interpolation error, B).
(a) Motor current.
(b) Temperature variations.

5. A typical optical encoder generates only barely noticeable disturbances in the motor current, and the motor operates normally and develops little heat. Because of its scanning principle, the magnetic encoder has notably fewer signal periods. Significant disturbances therefore occur in the motor current at the same controller settings. This causes an increased amount of noise and heat generated in the motor.

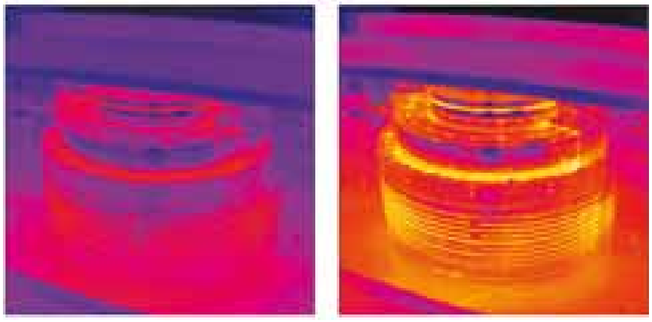


Figure 5. Thermograms of a rotary table with an optical (at left) and a magnetic (at right) position encoder.

Dynamic behaviour

Digital filters are often used with direct drives to smooth the position signals. However, the additional phase delay caused by filtering in the speed-control loop must be kept to a minimum, otherwise the dynamic accuracy decreases. Position encoders with optimum signal quality help to reduce the use of filters, meaning that the control bandwidth is maintained.

Position encoders that generate a high quality position signal with a small signal period are essential for optimal operation of direct drives. Encoders that use photoelectric scanning are ideally suited for this task, since very fine graduations can be scanned by this method. These fine graduations – graduation periods from 40 µm to under 1 µm are typical – can be manufactured in a photolithographic process. They are characterized by their high edge definition and homogeneity.

Application-oriented versions

HEIDENHAIN offers a wide range of photoelectric linear and angular encoders for various applications; see Figure 6. For example, sealed linear encoders on machine tools provide the measuring standard with optimum protection against chips, dust and splash fluids. Exposed linear encoders are ideal for applications with a low risk of contamination, such as in the semiconductor industry. Depending on the model, either very rapid traverse speeds or the highest possible positioning accuracy are possible.

Figure 6. A selection of linear and angular position encoders for direct drives. Signal periods are as low as 4 µm or 36.000 per revolution. Maximum interpolation errors are as low as ± 0.04 µm or ± 0.4".

Absolute position capture

Incremental encoders are increasingly being complemented by encoders that measure the position absolutely, since the position is available immediately after switch-on of these encoders. Absolute measuring procedures provide a high technological reliability, making the usual reference runs unnecessary.

Absolute encoders are especially advantageous on direct drives. Both the current position and the commutation offset are immediately known as soon as the encoder is switched on. The motor can be powered-up at once, and is supported in the control loop. Critical operating states, such as switching on a vertical axis with direct drive or retraction after an emergency stop, are controlled safely.

Information

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