

## Technical Information

# Linear Encoders Improve the Machining Accuracy

The capability of a machine tool to cope with rapidly changing operating conditions is a decisive factor for its accuracy. A transition from roughing to finishing completely changes the mechanical and thermal load on the machine, which can cause considerable changes in accuracy. Similar load changes occur during machining of smaller production runs. Permanent changes between setup processes and order-specific machining cause varying heat inputs with the corresponding effects on accuracy. Particularly in small production runs, however, the profitable manufacturing of orders with narrow tolerances depends upon the accuracy of the first part. That's why the thermal accuracy of machine tools has become a prominent issue.

The feed drives are of particular importance in this context. High traversing speeds and accelerations put a heavy load on the feed drives, causing heat to be generated. Without suitable position measuring technology, this rise in temperature can quickly lead to positioning errors of up to 100  $\mu\text{m}$ .

### Thermal stability of machine tools

Solutions for avoiding thermally induced dimensional deviations of workpieces have become more crucial than ever for the machine tool building industry. Active cooling, symmetrically designed machine structures and temperature measurement are common practice today.

Thermal drift is primarily caused by feed axes on the basis of recirculating ball screws. The temperature distribution along the ball screw can rapidly change as a result of the feed rates and the moving forces. On machine tools without linear encoders, the resulting changes in length (typically: 100  $\mu\text{m}/\text{m}$  within 20 min.) can cause significant flaws in the workpiece.



Figure 1 Typical machining situation

### Position Measurement of Feed Drives

The position of an NC feed axis can be measured through the ball screw in combination with a rotary encoder, or through a linear encoder.  
 If the slide position is determined from the pitch of the ball screw and a rotary encoder (Fig. 2), then the ball screw must perform two tasks: As the drive system it must transfer large forces, but as the measuring device it is expected to provide highly accurate values and to reproduce the screw pitch. However, the position control loop only includes the rotary encoder. Because changes in the driving mechanics due to wear or temperature cannot be compensated, this is called semiclosed-loop operation. Positioning errors of the drives become unavoidable and can have a considerable influence on the quality of workpieces.

If a linear encoder is used for measurement of the slide position (Fig. 3), the position control loop includes the complete feed mechanics. This is referred to as closed-loop operation. Play and inaccuracies in the transfer elements of the machine have no influence on position measurement. Measurement accuracy depends almost solely on the precision and installation location of the linear encoder.

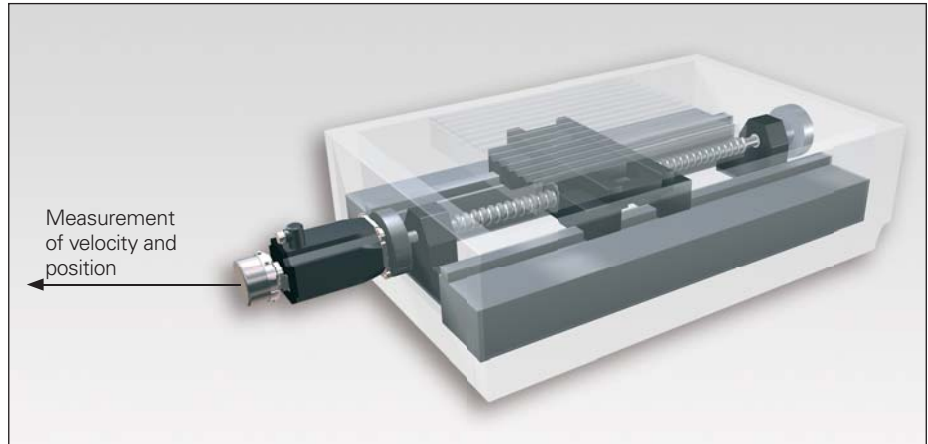


Figure 2 Position feedback control with a recirculating ball screw and a rotary encoder in semiclosed-loop mode

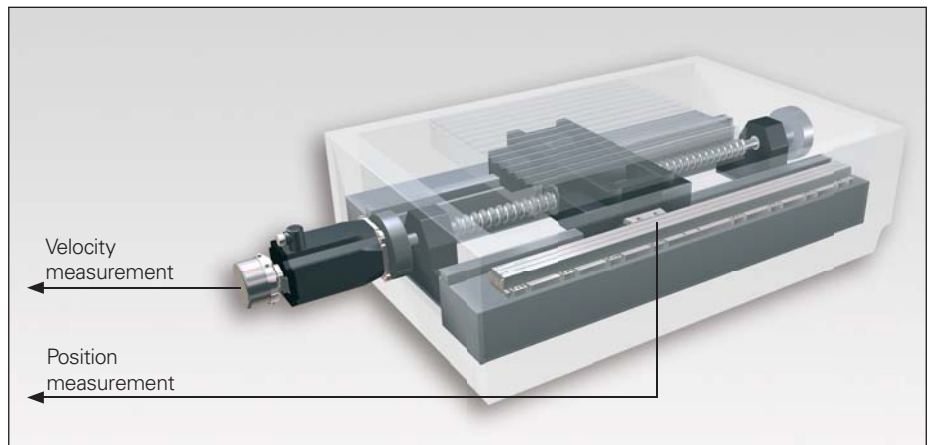


Figure 3 Position feedback control with a linear encoder in closed-loop mode

### Proof of Drive Accuracy

#### Example: Workpiece with hole pattern

The accuracy of a feed axis operated in closed-loop or semiclosed-loop mode can be illustrated by series production of a simple workpiece with a hole pattern that is distributed evenly along its length. In semiclosed-loop operation, the thermally induced error causes a shift of the individual drilling positions, and clearly shows the effects of heating of the recirculating ball screw. Errors occurring in semiclosed-loop mode can be demonstrated by manufacturing several parts of the same batch from one blank form.

Figure 4 shows the production of several workpieces of the same batch from one blank form. In the first step, two front faces and three holes are machined. Then the manufacturing of other workpieces is simulated by 30 repetitions of this machining process without tool contact. After this, the milling operation on the workpiece is continued with an infeed of 2 mm. The

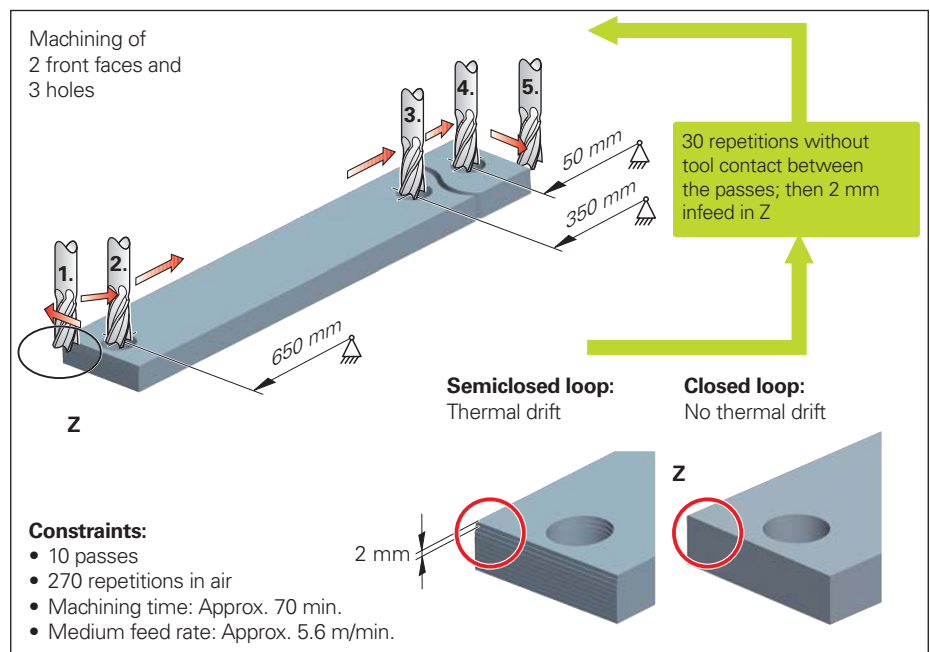


Figure 4 Effect of drive accuracy on series production  
 Δ = Fixed bearing of the recirculating ball screw

machining process finishes after 10 passes and a total of 270 repetitions without tool contact after 70 min. The considerable heat generated in the recirculating ball screw causes thermally induced errors that manifest as steps on the front face and inside the holes (Fig. 5).

The thermal shift of the hole furthest from the fixed bearing of the recirculating ball screw is 213  $\mu\text{m}$ . Similar results are obtained in a thermal position stability test in accordance with DIN ISO 230-3 with a VM 182 comparator system: The farther the ball nut is away from the fixed bearing of the ball screw, the higher the position drift is. In closed-loop operation the thermal drift can be compensated for by using high-precision linear encoders.

The tests according to VDI-DGQ 3431 and DIN/ISO 230-2 that are commonly used for determining the machine accuracy in acceptance testing do not include measurement of thermal errors.

### Summary

The successful fulfillment of manufacturing orders requires machine tools with high thermal stability. Machine accuracy must be maintained even under strongly varying load conditions. As a consequence, feed axes must achieve the required accuracy over the complete traverse range even with strongly varying speeds and machining forces. Thermal expansion in the recirculating ball screws of the linear feed axes adversely affects accuracy and varies depending on the velocity and load. Position errors of 100  $\mu\text{m}$  and more may result within 20 minutes during a machining operation if the slide position is only determined from the spindle pitch and a rotary encoder on the motor side. Because essential drive errors are not compensated in the control loop when this method is used, this is referred to as semiclosed-loop operation of the feed drive. These errors can be completely eliminated by using linear encoders. Feed drives with linear encoders are operated in closed-loop mode because errors in the recirculating ball screw are considered in position measurement and compensated in the position control loop. Angle encoders used on rotary axes provide similar benefits since the mechanical drive components are also subject to thermal expansion. Linear and angle encoders therefore ensure high precision of the components to be manufactured even under strongly varying operating conditions of the machine tools.



Figure 5 Deviation between hole patterns in series production

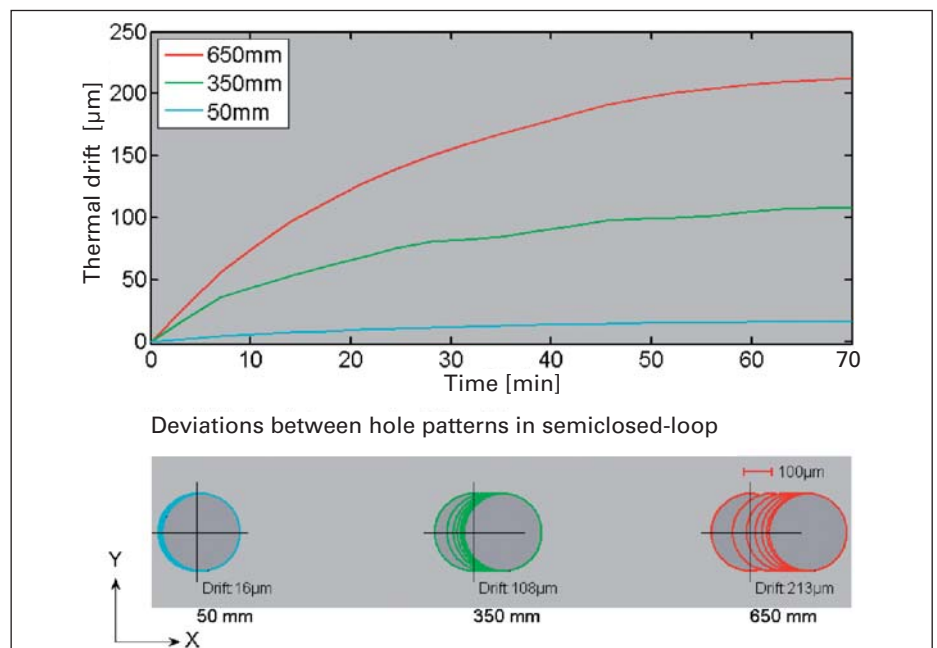


Figure 6 Drift at various positions in the traverse range of the X axis (ISO 230-3)

# Linear Encoders for Machine Tools

Linear encoders for position feedback are indispensable for high positioning accuracy of machine tools. They directly capture the actual position of the feed axis. Mechanical transfer elements therefore have no influence on position measurement—both kinematics errors and thermal errors, or influences of forces are measured by the linear encoder and considered in the position control loop. This can eliminate a number of potential error sources:

- Positioning error due to thermal behavior of the recirculating ball screw
- Reversal error
- Errors due to deformation of the drive mechanics by machining forces
- Kinematics errors through pitch error in the recirculating ball-screw

Linear encoders are therefore indispensable for machines that must fulfill high requirements for **positioning accuracy** and **machining speed**.

Linear encoders from HEIDENHAIN for numerically controlled machine tools can be used nearly everywhere. They are ideal for machines and other equipment whose feed axes are in a closed loop, such as milling machines, machining centers, boring machines, lathes and grinding machines.

The beneficial dynamic behavior of the linear encoders, their highly reliable traversing speed, and their acceleration in the direction of measurement predestine them for use on highly-dynamic conventional axes as well as on direct drives.

	Accuracy grade	Signal period	Measuring length	Interface	Model
<b>Linear encoders with slimline scale housing</b>					
<b>Absolute</b>	± 5 µm; ± 3 µm	–	Up to 2040 mm <sup>1)</sup>	EnDat 2.2	<b>LC 483</b>
<b>Incremental</b>	± 5 µm; ± 3 µm	4 µm	Up to 1220 mm	~ 1 V <sub>PP</sub>	<b>LF 481</b>
	± 5 µm; ± 3 µm	20 µm	Up to 2040 mm <sup>1)</sup>	~ 1 V <sub>PP</sub>	<b>LS 487</b>
<b>Linear encoders with full-size scale housing</b>					
<b>Absolute</b>	± 5 µm; ± 3 µm	–	Up to 4240 mm	EnDat 2.2	<b>LC 183</b>
<b>Incremental</b>	± 3 µm; ± 2 µm	4 µm	Up to 3040 mm	~ 1 V <sub>PP</sub>	<b>LF 183</b>
	± 5 µm; ± 3 µm	20 µm	Up to 3040 mm	~ 1 V <sub>PP</sub>	<b>LS 187</b>
	± 5 µm	40 µm	Up to 30040 mm	~ 1 V <sub>PP</sub>	<b>LB 382</b>

<sup>1)</sup> Over ML 1240 mm only with mounting spar



**LC 483**



**LC 183**



**LB 382**