Technical Information

Sustained Accuracy in Small and Medium Batch Production

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 tight tolerances depends on accuracy from the first to the last part. In such an environment the thermal accuracy of machine tools plays a decisive role.

The feed drives are of particular importance in this context. High traversing speeds and accelerations put a heavy load on the feed drives, causing much heat to be generated. Without suitable position measuring technology, this rise in temperature can quickly lead to positioning errors of unexpected magnitudes. The rise is temperature of a one-meter long steel recirculating ball screw from 20 °C to an entirely typical 45 °C can result in an expansion of 250 µm (coefficient of thermal expansion for steel: 10 µm per meter length and degree of temperature change).

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 ball screws can be changed very rapidly by feed rates and moving forces. On machine tools without linear encoders, the resulting changes in length can cause significant flaws in the workpiece.

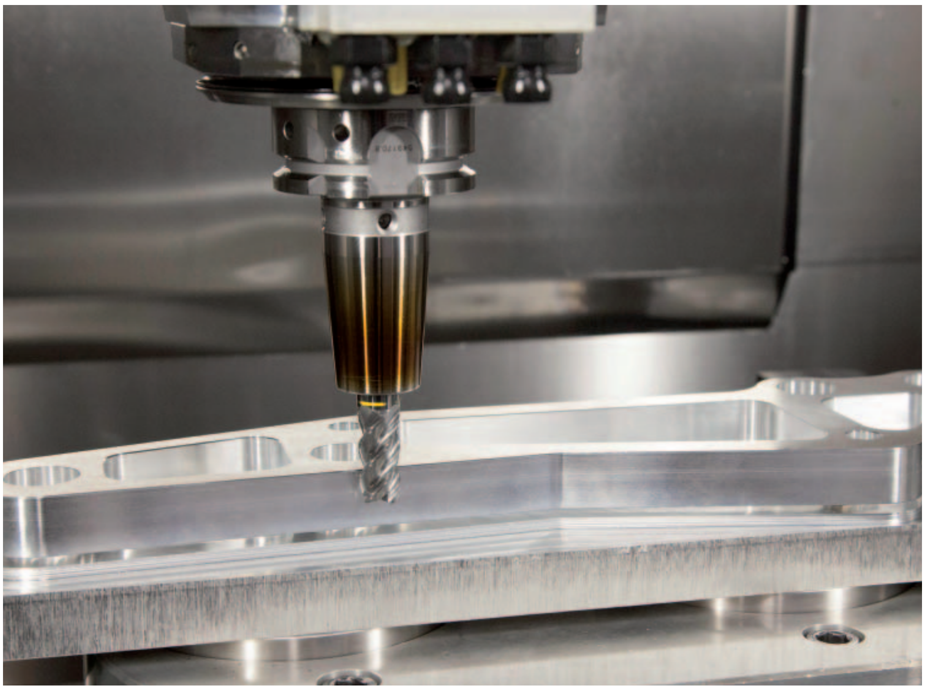

Figure 1 Typical machining situation

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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 dual 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 Semi-Closed 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. This means that the accuracy of the measurement depends almost solely on the precision and location of the linear encoder.

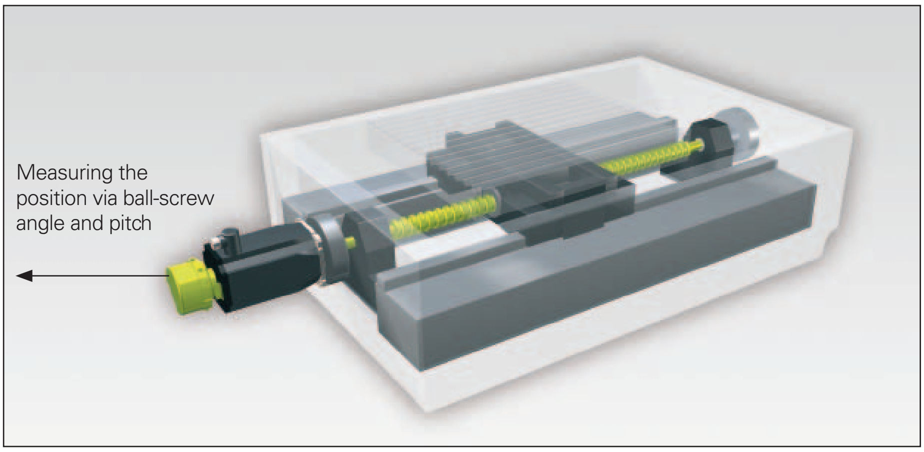

Figure 2 Position feedback control with a recirculating ball screw and a rotary encoder in Semi-Closed Loop mode

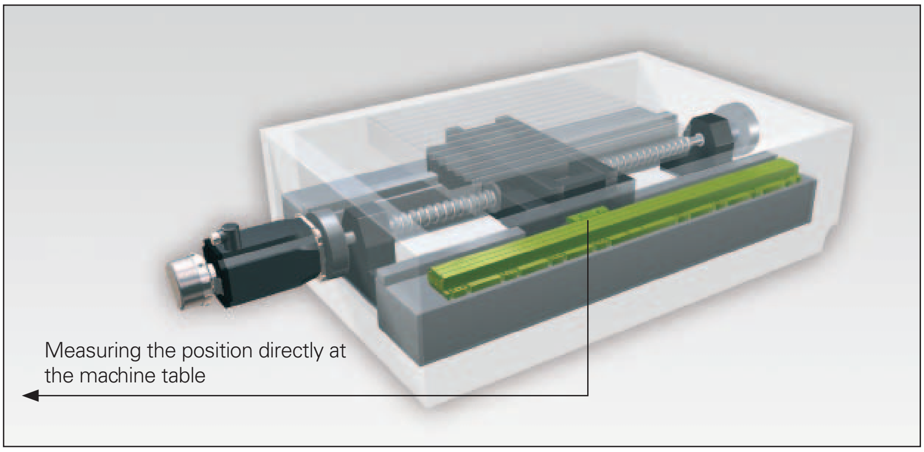

Figure 3 Position feedback control with a linear encoder in a Closed Loop

Proof of drive accuracy

Example: contour milling and drilling

The differences in drive accuracy between the Closed Loop and Semi-Closed Loop modes are well illustrated in this example of a moderately difficult operation without especially high traversing speeds for the machine table. The maximum feed rate for this job is 3.5 m/min. Two holes 350 mm apart are to be drilled in 40 parts and the contour milled. The job takes five and a half minutes; the tolerance for the distance between the holes is ±0.02 mm.

The ball screw drive heats up continuously during machining. After conventional position measurement in a Semi-Closed Loop, the subsequent quality control shows that, of the 40 parts to be produced, only the first 25 are within the specified tolerance. After the 25th part, the heat increase has reached the critical point when the thermal expansion of the ball screw drive causes the tolerance of ±0.02 mm to be exceeded. The deviation on the last part was even 70 µm.

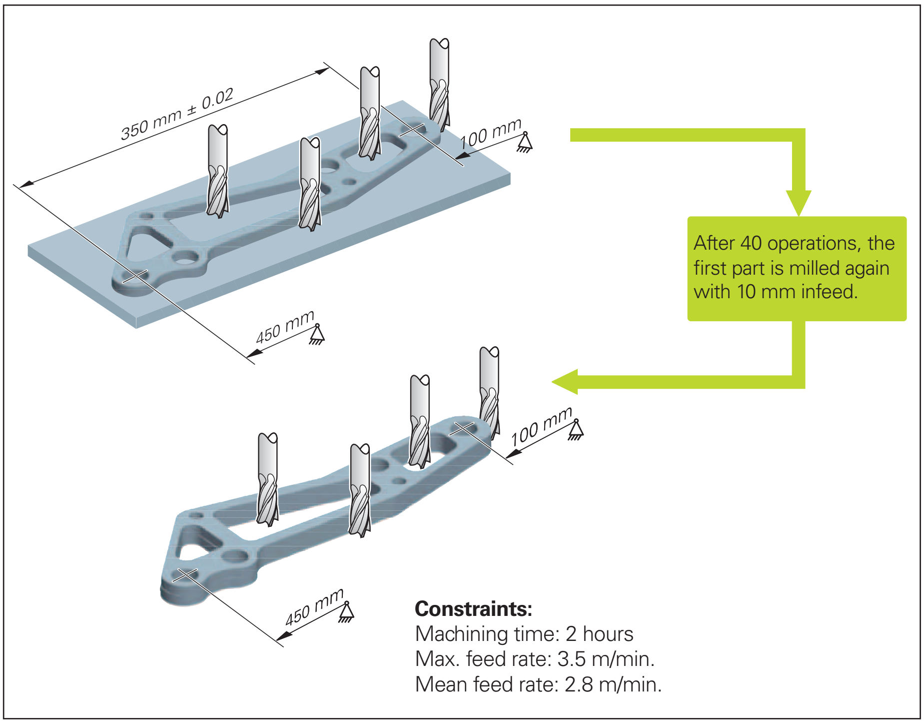

Figure 4 Manufacturing the coupling lever
= Fixed bearing of the recirculating ball screw

After finishing the 40th part, a second run on the first part during which the infeed in Z direction is halved makes this error clearly visible. The second holes made in this way in the finished part leave a clearly visible edge in the existing holes, likewise the second milling operation on the contour. This is the result of the 70 µm deviation due the thermal expansion of the ball screw drive.

On the other hand, position measurement with a linear encoder in the Closed Loop is independent of the thermal expansion of the ball screw drive—and any other influences. The comparative machining run demonstrates the example described above. There is no scrap from a machine with closed loop control; all the parts are within the specified tolerance. After machining the 40th part, a second machining run on the first part at half the feed setting in Z direction leaves no visible edge.

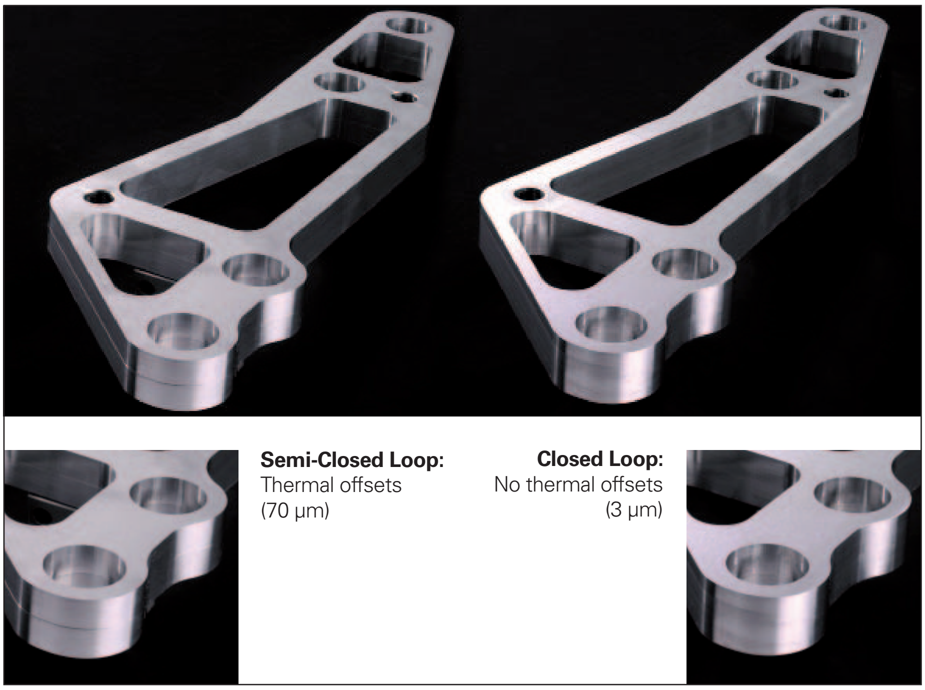

Figure 5 Coupling lever, machined twice from one blank form

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. Consequently, 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 200 µm and more may result during a machining operation if the slide position is determined only from the spindle pitch and a rotary encoder on the motor. Because essential drive errors are not compensated in the control loop when this method is used, this is referred to as Semi-Closed Loop operation of the feed drive. These errors can be eliminated by using linear encoders. Feed drives with linear encoders are operated in a Closed Loop 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.

Linear encoders for machine tools

Linear encoders for position feedback are indispensable for high positioning accuracy of machine tools. They directly and immediately measure 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 taken into account in the position control loop. This makes it possible to 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
- Kinematic errors through pitch error in the recirculating ball screw

Linear encoders are therefore indispensable for machine tools on which high **positioning accuracy** and a high **machining rate** are essential.

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 servo loop, such as milling machines, machining centers, boring machines, lathes and grinding machines.

The beneficial dynamic behavior of linear encoders, their high permissible 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.

LC 485 for up to 2040 mm

LC 185 for up to 4240 mm

LC 201 for up to 28040 mm

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More information:

- Brochure: *Linear Encoders for Numerically Controlled Machine Tools*
- Technical Information *Accuracy of Feed Axes*
- Brochure: *Measuring Systems for Machine Tool Inspection and Acceptance Testing*

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