HEIDENHAIN

HEIDENHAIN Axis Motors for Machine Tools

A key factor in machining quality

Technical Article

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For greater accuracy and surface quality, machining firms invest a lot of time and expense in machine tools, measurement technology, tooling, training, and controls with specialized functionality and options. But machining quality is also strongly affected by the axis motors.

To achieve exceptional machining results, all of a machine tool's components must be designed and well-matched for this demanding requirement. The axis motors are no exception. Along with the motor's maximum torque, other key criteria include the torque ripple and the inertia ratio between the motor and its load. These criteria directly affect the quality of the workpiece being manufactured.

Axis motors specifically designed for machine tools, such as the QSY series of HEIDENHAIN motors, provide a balanced moment of inertia and very low torque ripple for exceptional machining results and dynamic motion control. Their disturbance resistance and acceleration capability are therefore well balanced. For use in machine tools, their high-accuracy optical rotary encoders and high mechanical rigidity are also very beneficial.

Resistant to disturbances

A system's disturbance resistance is important for its ability to handle the disturbances arising from vibrations or milling forces. The higher the disturbance resistance, the better. Disturbance resistance is heavily influenced by the inertia ratio between the motor and the moving mass (load) of the feed axis. Thus, the larger a motor is relative to its load, the more disturbance resistance a system has when subjected to fluctuating milling forces or vibrations. Figure 1 shows how high a sudden change in load must be in order to temporarily cause a given position deviation in a drive system (as a function of the inertia ratio between the motor and the load).

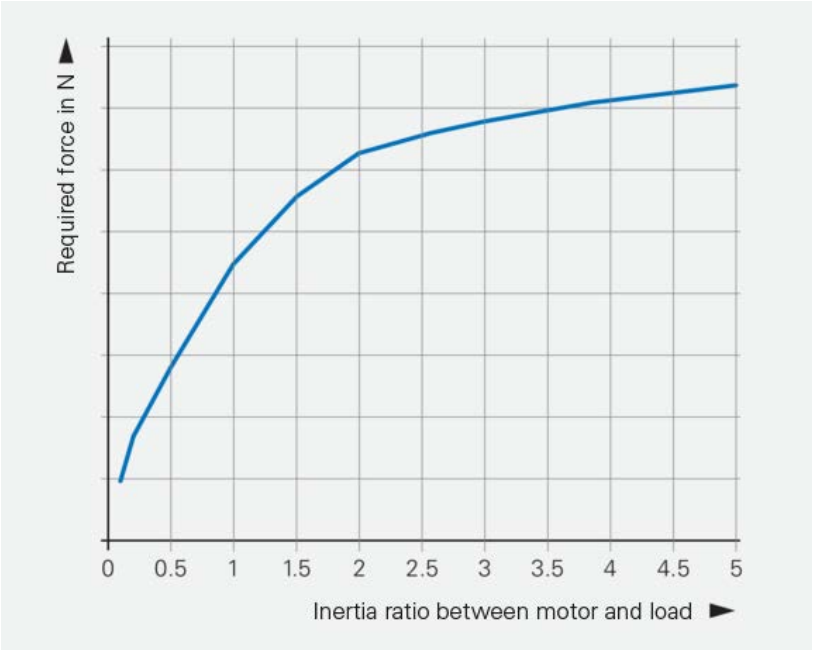

Figure 1
Required sudden change in load for a given position deviation as a function of the inertia ratio between the motor and its load

If the inertia difference between the motor and its load is high, then the loop gain will need to be reduced. Lowering the loop gain lowers the disturbance resistance, causing the overall system to react more sensitively to load disturbances, such as those induced by milling forces or vibrations. Therefore, a balanced inertia ratio between the motor and the load should be selected for machine tools. A balanced inertia ratio ensures sufficiently high disturbance resistance in order to render the overall system insensitive to external load influences, thereby eliminating their effect on the machining results while still allowing for high loop gains.

Dynamic

A motor designed for the highest possible moment of inertia would contradict the goal of having the highest possible acceleration capability. That's because the inertia of the motor has a significant effect on the acceleration capability of the overall system. This direct correlation can be seen in the formula for calculating acceleration capability and in the graph in Figure 2:

$$\acute{\omega} = \frac{M_{max}}{(J_{Load} + J_{Motor})}$$

With a given maximum motor torque M_{max} and a given load inertia J_{Load}, the acceleration capability $\acute{\omega}$ of the overall system decreases as the motor inertia J_{Motor} increases. Conversely, a motor with low inertia delivers high acceleration. That's because the higher a motor's own inertia is, the more torque it must produce in order to accelerate the given load as desired.

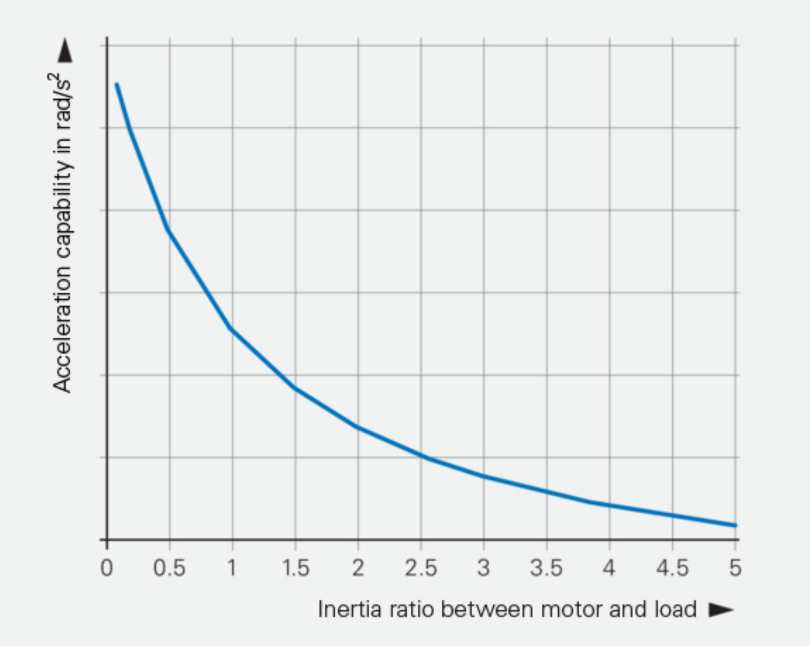

Figure 2
The acceleration capability of a motor as a function of the inertia ratio between the motor and the load

When it comes to torque performance, cost-effectiveness becomes a factor as well: the higher the maximum torque required, the more expensive the motor will be. This is because higher performance requires more or better magnetic materials for larger or optimized motors. As a result, acceleration behavior and cost considerations call for a ratio between the motor and the load that is both balanced and well-adapted to the intended application.

Smooth

In addition to the above-mentioned external influences, the motor itself can introduce disturbances into the system that influence machining and workpiece surface quality. A critical factor in this is the amount of torque ripple, which is induced by the motor even despite a sinusoidal current. As a result, the output torque fluctuates slightly over the course of a complete revolution of the motor shaft.

In order to investigate the torque ripple of various motor designs, a comparative measurement was performed. The Z axis of a machine tool was first driven by a HEIDENHAIN axis motor designed for machine tools and then by an automation-industry axis motor not designed for machine tools but rather merely adapted for this application. Otherwise, the setup and test conditions were identical. A machining operation was performed for an oblique surface on a sample workpiece. During the face milling operation, the Z axis was moved at a feed rate of F = 6250 mm/min for 60 mm in the Y direction and for 17.5 mm in the Z direction.

These tests confirm the anticipated effect of the torque ripple—not only based on the measured contour deviation (the difference between the contour actually milled and the desired contour, Figure 3) but also through the visible effects on the sample workpiece's surface.

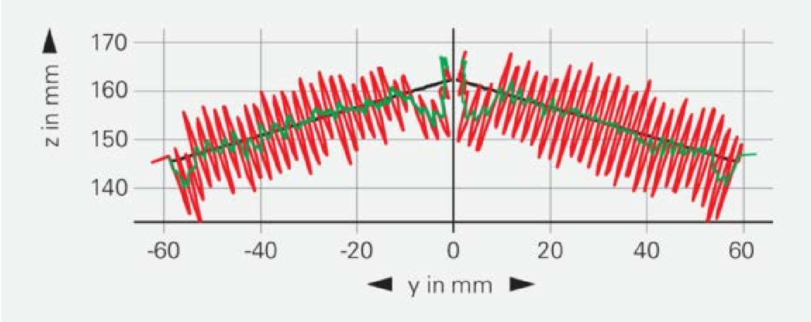

Figure 3
Contour deviations measured during the test: a HEIDENHAIN axis motor with low torque ripple (green line) and an adapted motor with significantly higher deviations (red line); contour deviation magnified by a factor of 1000

Test setup: machining an oblique surface using differing motor designs for the Z axis

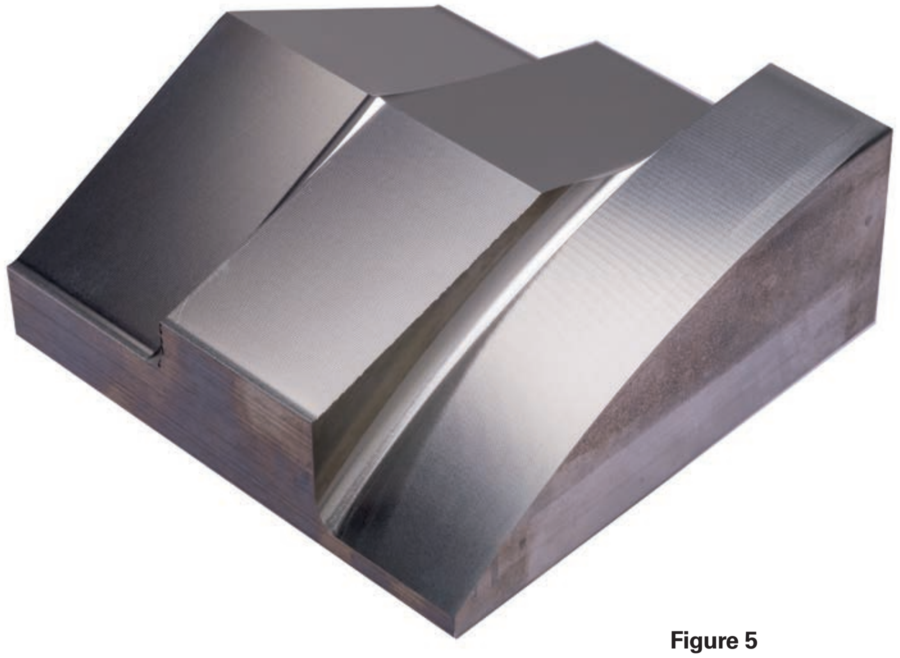

Figure 5
The HEIDENHAIN motor designed specifically for machine tools produces an evenly angled surface without visible shading.

The HEIDENHAIN axis motor optimized for machine tools exhibits low torque ripple and produces an evenly angled surface without visible shading (Figure 5).

The automation-industry axis motor merely adapted to machine tools shows the effects of torque ripple in the form of clearly visible shading on the oblique surface (Figure 6).

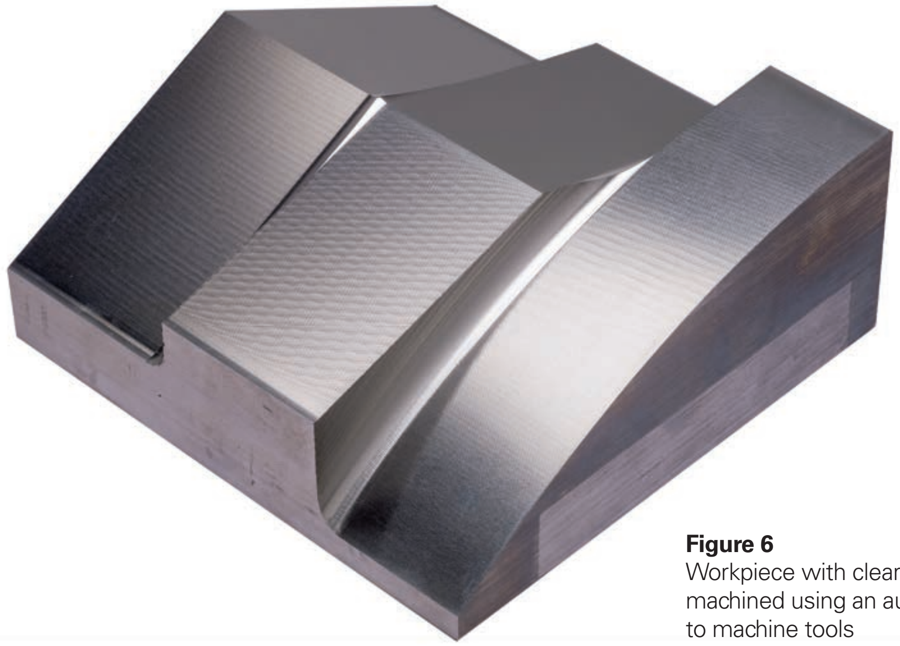

Figure 6
Workpiece with clearly visible shading on the oblique surface, machined using an automation-industry motor merely adapted to machine tools

Expressed in measured values, the HEIDENHAIN axis motor achieves an effective contour deviation of just 0.2 µm at the level of visually discernible deviations. By contrast, the effective deviation of the axis motor adapted to the machine tool is 1.2 µm, which is greater by a factor of six.

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