HEIDENHAIN

Technical Information

Fast, Accurate Contour Milling with High Surface Definition

Manufacturing processes in mold and die making, as well as in aerospace technology, can be optimized through modern milling technologies like High Speed Cutting (HSC). Economic benefits, however, can only be achieved if both the machine tools and the control can handle higher traverse speeds than those used in conventional machining.

Machine motions that are very fast and yet true to the contour require very precise control of the acceleration and braking processes along a programmed contour. In the conflict of interests between machining time, surface quality and geometric accuracy, modern controls must be capable of making an approach optimized for the milling machine and the manufacturing process. But end users also need to be able to influence the result of milling with simple changes to the parameters. The path control of the CNC has a decisive influence on the optimization of machining times under given requirements for accuracy and surface quality.

HSC in mold and die making—requirements on machine tool controls
HSC technology offers many new machining possibilities for hardened and alloyed tool steel. Next to the classic die-sinking operations, direct HSC milling of molds in hardened materials is therefore gaining in economic significance. In comparison with conventional milling, the essential advantage of HSC machining lies in its distribution and removal of heat generated during the cutting process. High cutting speeds and feed rates, together with small depths of cut enable the chips to carry most of the heat away from the workpiece.

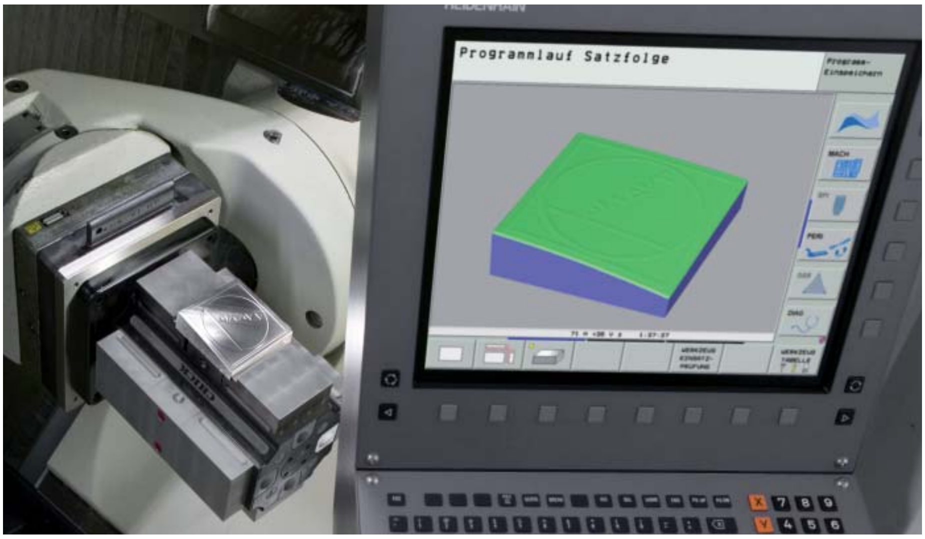


Figure 1: Free-form machining (doubly curved surface)

September 2007

HSC Machining
– Prerequisites and Influences

The high feed rates characteristic of HSC machining increase requirements for higher contouring acceleration rates on curved workpiece contours. This places the mechatronic characteristics of a machine tool squarely in the limelight. If the acceleration rates of the feed drives increase, greater acceleration forces are introduced into the structure of the machine tool. This consequently increases the risk of exciting troublesome machine oscillations that can result in loss of surface quality. The control therefore requires a strategy of motion control that minimizes machining time and yet achieves optimum surface quality under compliance with accuracy specifications. The control must therefore offer both the manufacturers of machine tools and their users ways to optimize the path control.

Machine tool builders require optimal interfacing of the control to the characteristics of the machine. The control must provide a clearly structured arrangement of parameters for motion control and the control loops of the feed motors. Machine tools are frequently evaluated by their range of possible finished parts. Each machining task must be performed so that highly dynamic movements do not produce disturbance from machine vibration. The control must therefore be integrated in the machine to ensure high resilience in any machining task.

Machine tool users require the control to enable them to take into account job requirements for machining time and workpiece accuracy. The specified accuracy requirements must be met with the very first part without time-consuming tests. The requirements must be defined in the NC program to ensure a permanent assignment to the work order. Moreover, to keep the production times for molds and dies in an acceptable range, free form surfaces are frequently milled with path directions reversed between passes. Meanwhile, the control must generate reproducible tool paths when approaching contour elements from opposed directions. Otherwise one must expect a loss in surface quality.

Influence of data processing on workpiece accuracy
The manufacture of components with metal-cutting operations requires numerous intermediate steps in which the data of a CAD model geometry is transformed into tool paths:

- **CAD** (Computer Aided Design): The workpiece contour is normally modeled with NURBS (non-uniform rational B-splines). NURBS makes it possible to mathematically describe free-form surfaces.
- **CAM** (Computer Aided Manufacturing): The tool path elements are calculated point by point under consideration of the milling strategy and tool compensation values from the CAD geometry, whereby the predefined chordal deviation (model accuracy) determines the distance between points.
- **CNC** (Computerized Numerical Control): The NC program is converted point for point into axis movements and velocity profiles.Here preset path tolerances are taken into account. To attain high surface definition, the deviations between adjacent milling paths must remain significantly smaller than the defined path tolerances.
- **Mechatronics:** The axis movements are available in a fixed time grid as nominal and actual movements and are converted over the machine geometry into tool and workpiece movements. The following error of the feed axes, deviations from the nominal geometry of the machine, thermal influences and vibrations in the machine frame and motors can reduce the workpiece accuracy.

CAD	Design
CAM	Path generation
	Tool compensation
CNC	NC program interpreter
	Path control
	Tolerance monitoring
	Velocity profiles
Mecha-tronics	Feed rate control
	Machine and drives

The need to optimize machining times, surface definition and workpiece accuracy results in the following basic requirements on the CNC:

- Effective monitoring of contour tolerances
- Exact reproduction of adjacent paths after direction reversal
- Avoidance of vibration from highly dynamic movements

For two-dimensional tool movements, the influences of the data processing chain on the workpiece accuracy can be inspected with a KGM 182 grid encoder from HEIDENHAIN. The characteristics of motion control by a HEIDENHAIN iTNC 530 can be illustrated with a demonstration unit on a gantry machine. The KGM serves as the basis for evaluation of attainable contour accuracy.

Fast, Accurate, True to Contour
– High Speed Milling with the iTNC 530

Effective control of contour tolerances
NC programs for free-form surfaces are usually created with a CAM system and consist of simple line segments. HEIDENHAIN controls automatically smooth the block transitions while the tool moves continuously on the workpiece surface. This automatic smoothing is controlled by an internal function that monitors the contour deviations. This function (Cycle 32) enables the user to define the permissible contour deviation as desired. The default value is defined by the machine tool builder in a machine parameter of the control (typically 0.01 to 0.02 mm). In addition, the tolerance also affects the traverse paths on programmed circular arcs.

On free-form surfaces, the deviation from the CAD model geometry can, in the worst case, consist of the sum of the defined contour tolerance and the chordal deviation defined in the CAM system. The result on the workpiece depends in the end on the total characteristics of the machine and the values adjusted for the jerk and acceleration of the feed axes.

The workpiece corner shown in the illustration requires a circular arc path by the center of a ball-nose cutter (TCP = Tool Center Point, see Figure 2). Without smoothing of the nominal path data, the Y axis of the machine would have to accelerate abruptly at the transition point. The resulting jerk causes significant oscillations of the machine. Moreover, the physical limits of normal drives prevent them from generating such virtually infinite jerk. Without expanded measures in path control, the unavoidable result is contour deviations that can assume significant proportions, depending on the change of curvature and contouring speed.

The path control of the iTNC 530 smoothes the jerk and complies with the given contour tolerance even during strong changes in contouring speed (Figure 3). If a larger tolerance can be defined, the production times can be shortened significantly. In the example shown here, the machining time is reduced by about 12 % by increasing the contour tolerance from 0.01 mm to 0.02 mm.

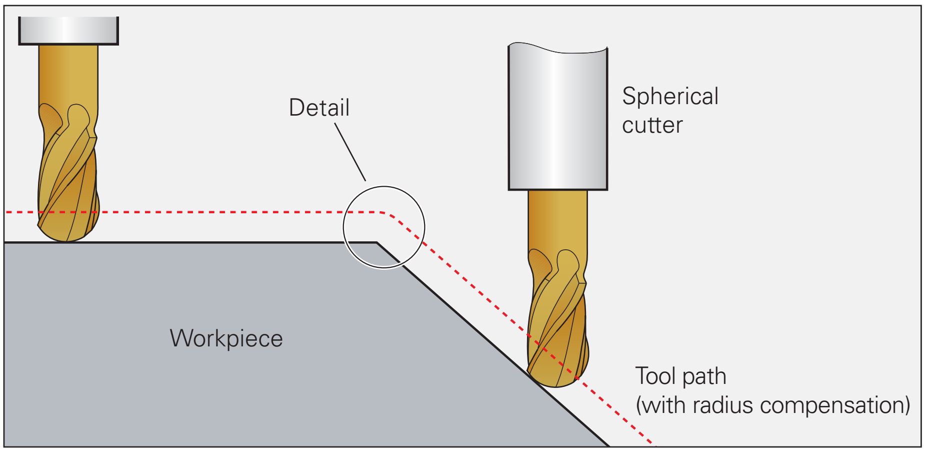


Figure 2: TCP tool path for a ball-nose cutter

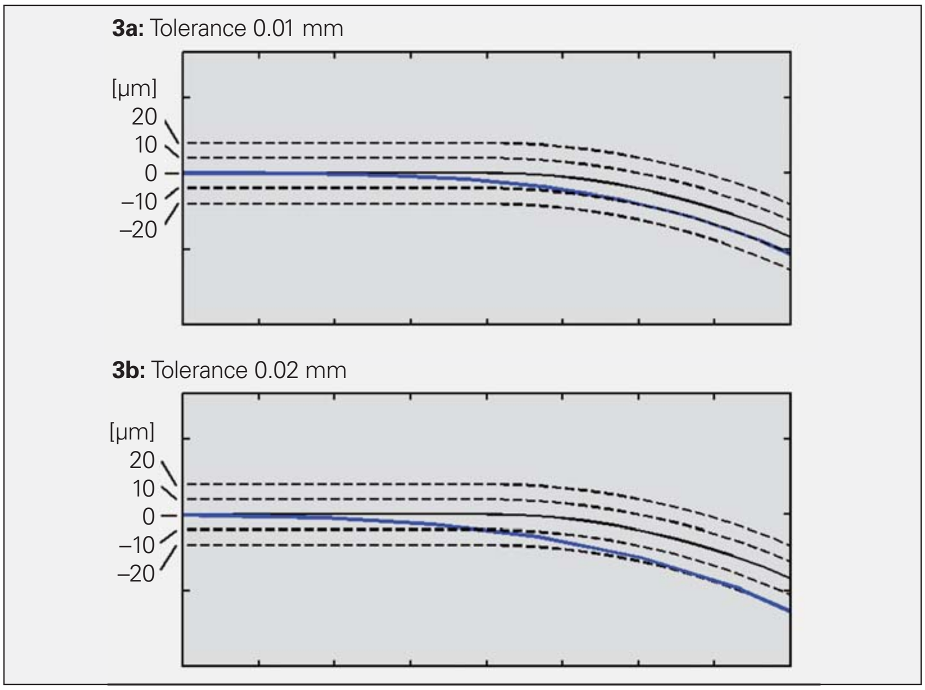


Figure 3: Enlarged detail showing the contour-monitored nominal path of the TCP

High reproducibility of adjacent paths in alternating directions

Figure 4 shows a detail of a workpiece and the corresponding line blocks of the TCP path. Neighboring paths were milled efficiently with reciprocating movements (multipass milling with direction reversal). The individual passes consist of only few straight-line blocks with very different lengths. The chordal deviation set in the CAM system is 3 µm.

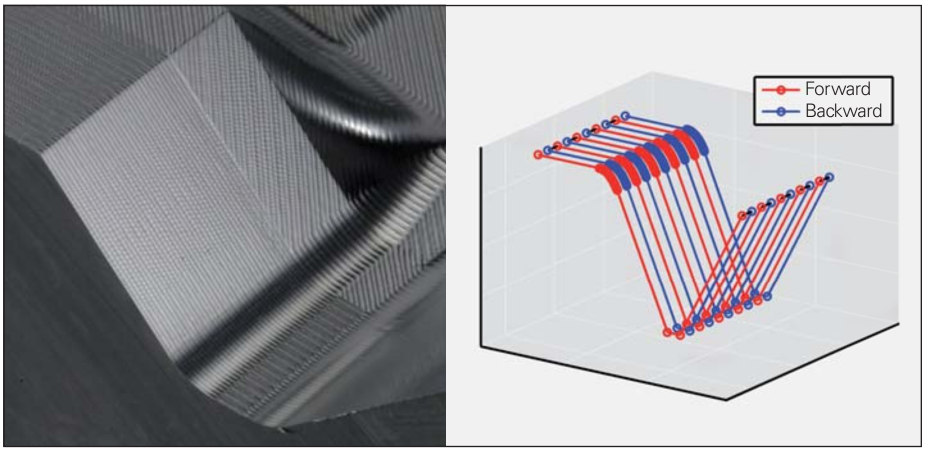


Figure 4: Workpiece contour and associated line blocks with reciprocating traverse. The points represent the data points in the program.

Figure 5 gives an enlarged representation of the tool path deviation from the programmed contour. The deviation is shown with respect to the ideal line-to-circle transition, whereas the part program (Fig. 4) exists of line blocks with a chordal deviation of 3 µm from the model. The chordal deviation affects only the curved areas and is superimposed on the contour tolerance set in the CNC. HEIDENHAIN controls attain very high reproducibility in multipass movements with direction reversal (Fig. 5). Contour deviation between forward and backward paths stays negligible, resulting in very high workpiece surface definition.

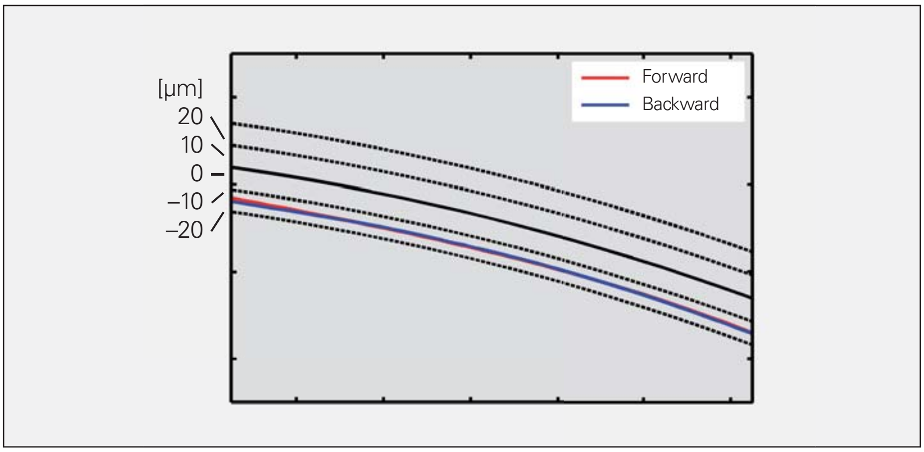


Figure 5: Deviation of the tool path in the curved area of the workpiece contour (feed rate = 10 m/min, tolerance = 0.01 mm)

The workpiece photographs in Figure 6 show the difference that can be made by optimized motion control. The free-form surfaces were machined in reciprocating passes (programmed feed rate 10 m/min, finishing allowance 0.1 mm). The surface quality of the workpiece shown in Fig. 6a is unacceptable. The machining result using an iTNC 530, shown in Fig. 6b, illustrates the high reproducibility of adjacent paths.

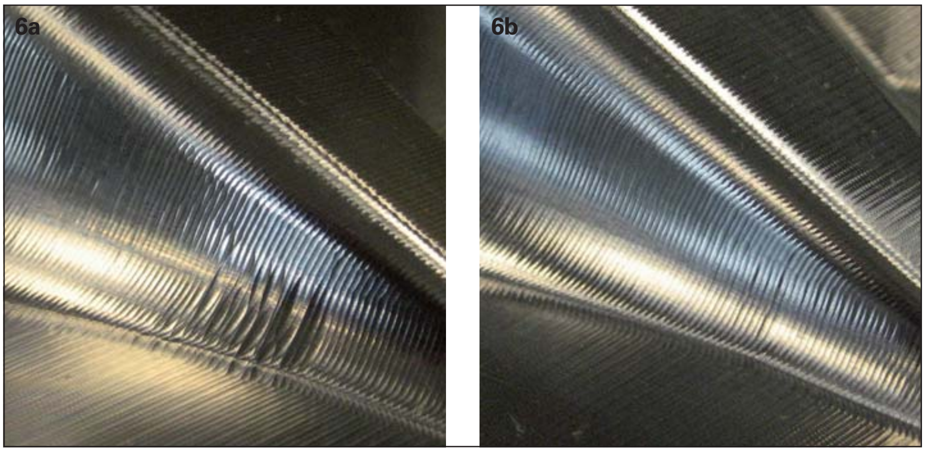


Figure 6: Multipass process with direction reversal, reproducibility of adjacent cutter paths
6a: Deviations between adjacent paths result in a poor surface
6b: Milling result with an iTNC 530: Consistent surface with forward and backward traverse

Effective avoidance of vibrations during highly dynamic motion

The feed velocities required for HSC milling technology place machine controls before a great challenge. Short machining times can be achieved only at higher mean contouring feed rates. However, wherever the milling path includes small radii, the velocity has to be drastically reduced in order to keep path deviations within the permissible tolerance band. In addition, the accelerating and braking motions can cause frame vibrations that impair workpiece surface definition.

Jerk and acceleration are smoothed in the extraordinary motion control offered by HEIDENHAIN. This can suppress machine vibrations very effectively. If necessary, the control automatically reduces the programmed feed rate to reduce the excitation of vibration to a minimum. Effective prevention of excessive machine vibration enables a part program to run at very high velocity and thereby decisively reduces machining times.

Figure 7 shows the actual tool path of a machine tool on a programmed two-dimensional contour. If the jerk is not smoothed, the machine's acceleration phases excite vibrations (Figure 7a). Motion control by the iTNC 530 from HEIDENHAIN effectively prevents excessive vibration (Figure 7b) Once again, the workpiece surface shown in Figure 8 clearly illustrates the benefits of motion control by HEIDENHAIN controls. Movement along the illustrated circle segments requires a change of axis acceleration at every point, which usually causes machine vibration (Figure 8a). By smoothing the jerk, the iTNC 530 makes it possible to realize high surface definition without disturbing effects from vibration (Figure 8b).

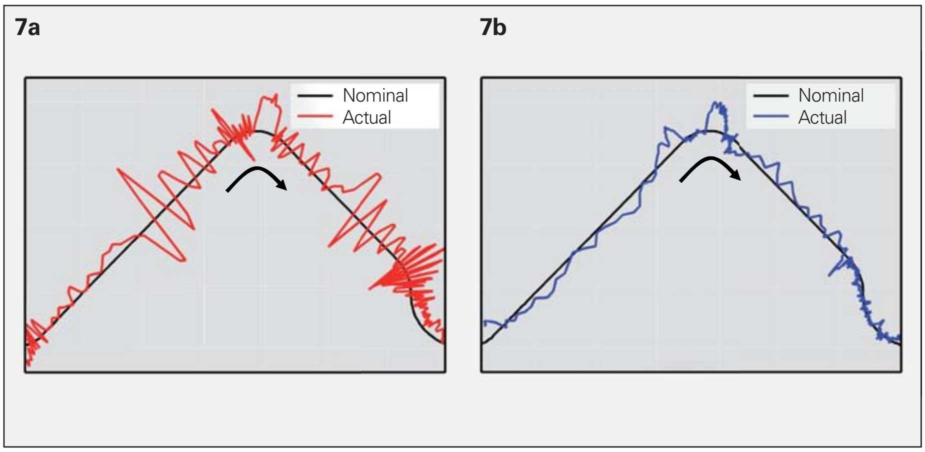


Figure 7: Measured actual positions, recorded with a grid encoder at a rounded corner without and with position nominal value filtering (7a and 7b, respectively) of the NC data.

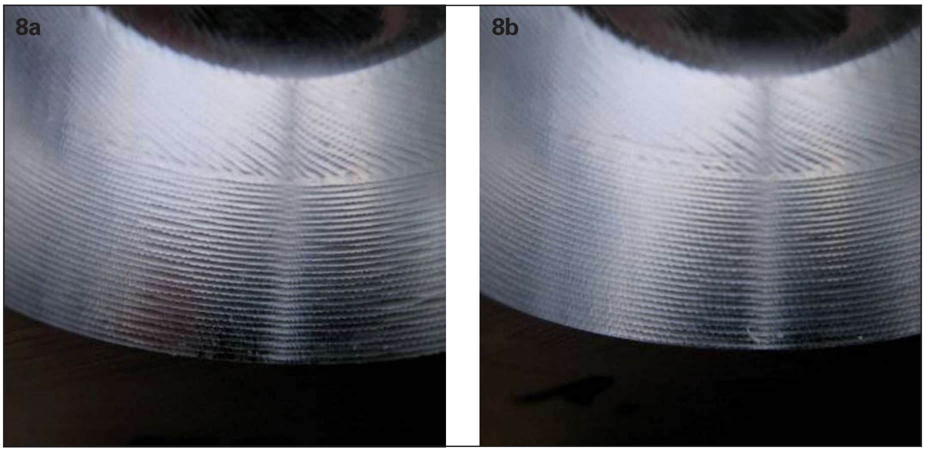


Figure 8: Effects of machine vibration on a workpiece:
8a: Without jerk smoothing, vibration in the Z axis produces notches in the surface
8b: Motion control by the iTNC 530 systematically prevents surface problems caused by vibration

Summary

HSC milling technology has a decisive influence on manufacturing processes in mold and die making as well as in aerospace technology. The required feed velocities place machine controls before a great challenge. In the conflict of interests between machining time, contour accuracy and surface definition, the HEIDENHAIN iTNC 530 control ensures that machining complies with selected preferences. This means that the tool paths are planned so that

- machine vibrations are prevented,
- accuracy requirements are fulfilled, and
- machining time is minimized.

Moreover, the iTNC 530 achieves high reproducibility of neighboring milling paths to enable users to meet very high requirements on surface quality and reduce machining time for reciprocating multipass milling.

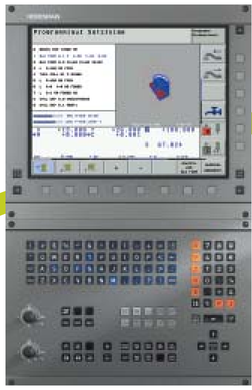
The iTNC 530 has set new standards in the harmonization of the control, the drives and the machine frame. This makes it possible to manufacture a broad range of components of required quality starting with the first part.

Consistently Upward Compatible
– A Promising Future with HEIDENHAIN Contouring Controls

For over 25 years, HEIDENHAIN has been providing customers with contouring controls for milling, drilling and boring. The controls have undergone continuous development during this period: many new features have been added—also for more complex machines with many axes. The basic operational technique, however, has remained the same. The machinist who has been working at a machine with TNC does not have to relearn. On the iTNC 530 he immediately uses all of his previous experience with TNCs, programming and working as before.

2004: iTNC 530 with smarT.NC

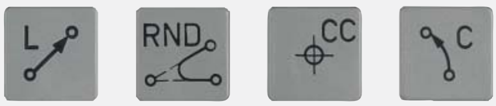
2003: iTNC 530 with Windows 2000



2001: iTNC 530

1997: TNC 426 M
TNC 430

1993: TNC 426 C/P



These contouring keys from the TNC 145 are also on the iTNC 530

1988: TNC 407
TNC 415

1987: TNC 355

1984: TNC 155

1983: TNC 150

1981: TNC 145, the first contouring control from HEIDENHAIN

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