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09/2011

Klartext
Aerospace

HEIDENHAIN Controls in the Aerospace Industry

PRACTICAL CONTROL TECHNOLOGY
FOR ACCURACY AND PRECISION

THREE-POINT LANDING with TNC Controls

Ready for take off

With HEIDENHAIN Controls: Ready to Take on New Challenges in the Aerospace Industry

In this first special issue of Klartext, devoted to aerospace topics, we will grant you insights into problems and their solutions in the manufacturing process for the aerospace industry.

This industry already places high demands, and they continue to rise. Accuracy and precision in production are required here. Thanks to modern technology "Made in Germany," this balance act can now be accomplished better than ever. What do all the solutions provided by HEIDENHAIN have in common? They increase efficiency, are user-friendly in operation, and grant assurance that the technology is reliable.

So let us take you on a literary journey and show you the possibilities for solving the conflicting goals of speed and detail accuracy, dimensional accuracy and machine precision.

This issue also focuses on the functions that support process reliability during operation. Particularly with time-consuming machining operations, such as are typical for the aerospace industry, reliable strategies are important in avoiding complications.

In our report from the field you will see how wind-tunnel models are produced with the iTNC 530. The machine tool specialist Deharde GmbH equips his machine tools with HEIDENHAIN controls, and achieves very precise results with them.

So please enjoy the interesting topics in "Aerospace," our first special issue of Klartext.

Your Klartext staff

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All other images

Contents

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TNC Controls for High Contour Accuracy During HSC Milling

Near-Net-Shape Manufacturing at High Speeds

Near-net-shape production intends to automate as many process steps as possible and to eliminate the need for reworking. At the same time, HSC operations are supposed to shorten the machining cycles. This results in a conflict between machining time, surface quality and geometrical accuracy. Examples from the aerospace industry show which requirements a control must fulfill in order to harmonize efficiency and accuracy.

Compressor blades: complex 5-axis machining

The blades of a jet engine are finished using 5-axis machining. In order to minimize or even completely avoid reworking, the surface definition and geometrical accuracy must attain an especially high level. Typically, free-form surfaces like these blades are created in a CAD/CAM system. The resulting machining program consists of numerous straight-line blocks. These straight-line blocks are an approximation of the actual contour, and inevitably lead to deviations. This particularly applies to program sequences where changes in direction are defined. Even when the combination of machine and control is operating very precisely, there would be contour deviations on the surface if no further measures were taken. Insufficient accuracy or resolution of the CAM tool's program output can lead to unwanted jumps, which then appear as facets on the finished surface.

The rapid reversal motions of the tool are another problem. Rapid changes in direction occur at the narrow ends of each blade, which necessitates large compensating movements of the linear axes. This results in two challenges: on the one hand, the cutting conditions in the highly heat-resistant material are to remain constant despite the dynamic machine motions—even at the reversal point. On the other hand, the abrupt motions cause the machine to oscillate, which results in inaccuracies. It just so happens that HSC machining, which is based on high feed rates, is most affected by these problems, which are obstacles to high surface definition and geometrical accuracy.

Bringing speed and accuracy into harmony is a true balancing act.

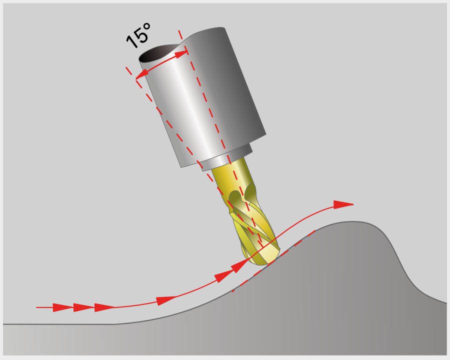
Compressor blades of a jet engine—the iTNC's precise guidance of the tool ensures high surface definition.

Powerful motion control: ensuring high surface definition

Let's go back to the beginning of the manufacturing process: In the machining program created by the CAD/CAM system, the transitions between the many straight-line blocks present a particular challenge. A powerful control like the iTNC 530 automatically smoothes the block transitions, leading the tool over the workpiece surface at a constant speed. The control ensures that the relatively high feed rates are in concert with the very precise tool guidance.

Automatic smoothing of the contour results in a certain amount of deviation from the contour. On free-form surfaces, the deviation from the geometry of the CAD model can, in the worst case, consist of the sum of the defined contour tolerance and the chordal deviation defined in the CAM system. In the end, the result on the workpiece also depends on the total characteristics of the machine and the values adjusted for the jerk and acceleration of the feed axes. That is why the operator must be able to easily and directly influence the relation between the machining speed and the tolerance. In a cycle on the iTNC 530 the operator can enter specific values for the permissible contour deviation, depending on the application's requirements.

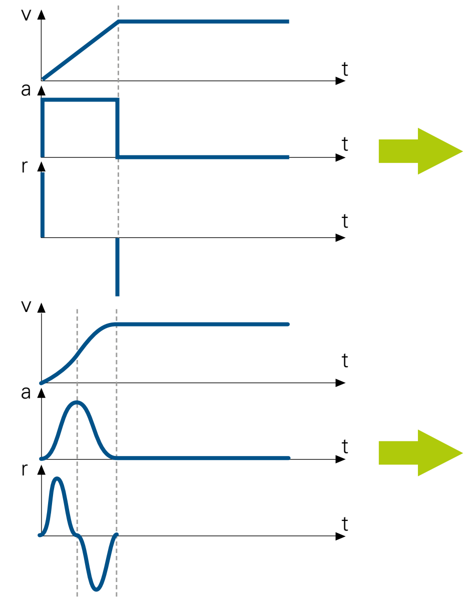
Conclusion: If machining programs were created with a CAD/CAM system, TNC controls can ensure high surface definition through their block-smoothing capability.



With TCPM the iTNC ensures that the tool is guided exactly along the contour.

Outstanding contour accuracy: complex motion control in five axes

That leaves us with the rapid changes in direction during tool movements and the resulting compensating movements, which in turn can lead to other deviations. One of the solutions for this is TCPM, the Tool Center Point Management function. In five-axis machining the tool is always led perpendicular to the workpiece surface or at a different specified angle. The TNC includes compensations for the machine geometry and tool length, as well as 3-D tool radius compensation, when doing so.



v = velocity, a = acceleration, r = jerk, t = time

You can see the difference: the iTNC 530's jerk limiting avoids surface blemishes.

This function for guiding the tool point can force large compensating movements, depending on the change of curvature, leading to very high axis feed rates. The resulting jerk causes significant oscillations of the machine, and path deviations are the consequence. The iTNC 530's motion control acts preventively by smoothing the jerk. This ensures that the contour tolerances set are not exceeded, even if the path changes abruptly. In this case as well the operator can influence the machining time with the values he chooses for the tolerance.

Conclusion: The path control of the TNC ensures high contour accuracy, avoids damage to the contour, and supports constant cutting conditions.

Contour pockets: high surface definition, no reworking

Supporting structures, such as frames, feature a complex pattern of contour pockets. The surfaces in the pockets must be of excellent definition, otherwise reworking becomes necessary, since a layer of paint applied later must not be too high as the result of uneven surfaces.

The TNC smoothes the jerk and avoids marks that would remain on the surface upon abrupt changes in motion. This eliminates the highly time-consuming reworking of the many pockets.

Obvious benefits: user-friendliness combined with perfected HSC technology

The TNC control makes it easy for the operator to optimize sophisticated HSC operations. Easily understood dialogs and practical cycles are used to influence the machining process precisely, for example by the simple entry of tolerances.

State-of-the-art feedforward control as well as powerful motion control optimize the machining time with the best possible surface definition, while at the same time consistently maintaining the defined accuracy. This is even the case if the point distribution varies strongly in the program generated by the CAM system.

The technical advantages of the HEIDENHAIN control help to avoid costly optimization phases, and to quickly produce the first good part.

KinematicsComp and KinematicsOpt for More Accurate Machine Tools

Dimensional Accuracy Permits Automation

Production of very large parts is an inherent challenge of the aerospace industry. The accuracy of fit places a decisive role, since the production of mating parts other components that must all fit together when the airplane is assembled is distributed over numerous locations. Only under this precondition is automation of production even possible, and can manual reworking be avoided.

Accuracy of fit demands dimensional accuracy of the parts involved. It must be possible to put together assemblies consisting of very different components, such as the landing gear, very precisely. The holes drilled into the frame (the ribs in an airplane chassis or wing) must line up perfectly when assembled.

Precise 5-axis machining of large parts while at the same time ensuring their dimensional accuracy is a real challenge, particularly on large machine tools. Long distances traversed and the large moving masses cause relatively large deviations.

There are also other sources of error: for example, ISO 230-1 assigns six possible component errors to a linear axis. Sources of error include positioning errors, roll, pitch and yaw, as well as angular errors.

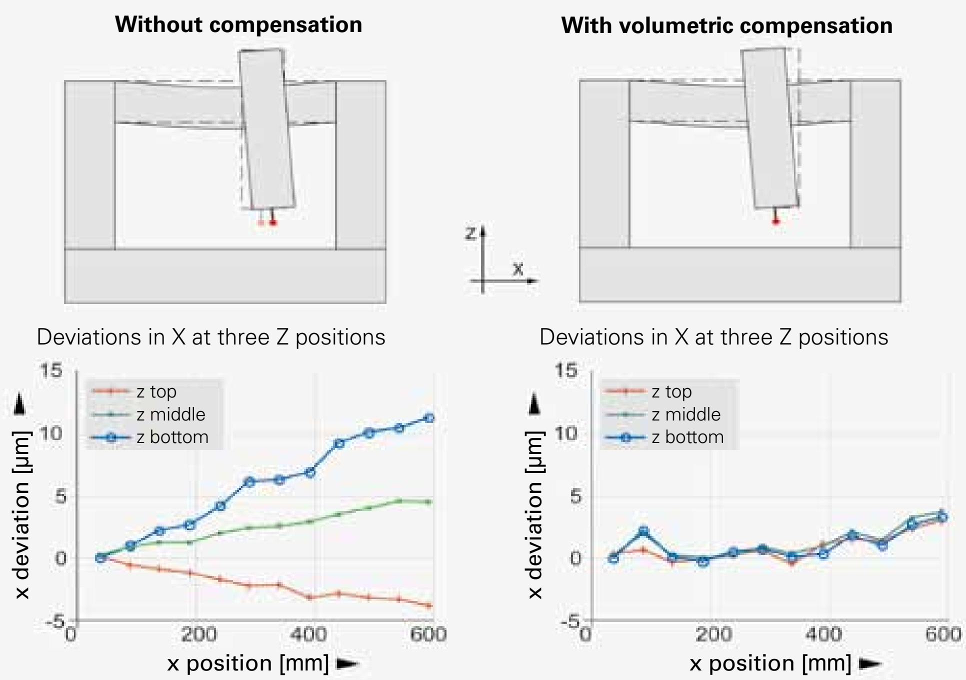
But as if that weren't enough: the axes are also subject to drift, resulting from inhomogeneous temperature distribution in the machine components. This becomes apparent in the form of linear movements (translations) and rotational movements (rotations).

So the question arises, how can these errors be managed?

Managing the deviations: volumetric compensation

HEIDENHAIN offers effective assistance here: the KinematicsComp function of the iTNC 530 enables the machine manufacturer to save a comprehensive error description of the machine in the control. In the kinematics model, the manufacturer describes the machine's degrees of freedom and the positions of the rotary axes. Without KinematicsComp it had only been possible to define the nominal geometry of the machine. Now the actual behavior of all axes can be integrated in this original kinematics model.

KinematicsComp can also be used to describe the position-dependent temperature compensation. Data is received from multiple temperature sensors attached at representative locations on the machine. Some of the measurement methods that are necessary to isolate these errors are already used for the calibration of measuring machines. For example, laser tracer systems, which are capable of high-precision measurement of spatial errors of the tool tip, can be used for such a task. But the iTNC 530 also has features, such as KinematicsOpt, to enable the machine manufacturer to compensate specific existing machine errors.



The comparison shows that volumetric compensation makes a machine tool even more precise.

Managing thermal influences: recalibration suited for a machine shop

The kinematics of a machine tool can change as the result of temperature changes and mechanical loads. But the actual kinematics then no longer match the kinematics model stored in the control. Inaccuracies on the finished workpiece are the consequence. This is precisely where KinematicsOpt comes into play: if the machine changes as the result of temperature influences during machining, then the kinematics model of the machine must also be adapted, rather than modifying the NC program. This recalibration can be performed daily, because HEIDENHAIN makes it that simple: the KinematicsOpt software is a touch-probe cycle of the TNC that makes it easy and practical to inspect or recalibrate the rotary axes. A machine operator can run the cycle in just a few minutes.

Frequent recalibration with KinematicsOpt guarantees high production quality. The machine can move the tool more accurately along a programmed contour. KinematicsOpt ensures reproducible accuracy, even over long periods of time. The compensation directly affects the accuracy of the machine itself, and therefore of every workpiece as well. One nice side effect is that an enormous amount of time is saved, since you almost never have to completely calibrate your machine from scratch again.

Precise and automated production of parts can reduce assembly costs.

Simple and quick recalibration: how KinematicsOpt works

A 3-D touch-probe cycle uses an inserted HEIDENHAIN touch probe to fully automatically measure the rotary axes present on your machine. It does not matter whether the axis is a rotary table, a tilting table or a swivel head.

To measure the rotary axes, a calibration sphere is fixed on the machine table and probed with the HEIDENHAIN touch probe. But first you define the resolution of the measurement and define for each rotary axis the range that you want to measure. From the measured values, the TNC calculates the static tilting accuracy. The software minimizes the spatial error arising from the tilting movements and, at the end of the measurement process, automatically saves the compensation value in the respective machine constants of the kinematics table. Of course, a comprehensive log file is also saved with the actual measured values and the measured and optimized dispersion (measure for the static tilting accuracy), as well as the actual compensation values.

Compensation of deviations and drift: for very high accuracy and precision

Conclusion

The KinematicsComp and KinematicsOpt functions can be used to meet the growing demands on accuracy and precision placed by the aerospace industry. This even pays off twice: error compensation and recalibration suited for the workshop ensure high dimensional accuracy, and workpieces can be produced in an automated process, rather than mating parts still having to be modified during assembly of the airplane. Manual reworking of parts is no longer necessary, which saves time and money.

Wind-Tunnel Models with the iTNC 530

Exact Down to the Last Detail – CNC Manufacturing for Aerospace Engineering

Highest levels of precision and the consistent avoidance of scrap are of the utmost priority for Deharde Maschinenbau Helmut Hoffmann GmbH, especially since aerospace engineering companies are among the clients of this machine tool specialist. For the production of wind-tunnel models, plant equipment and numerous other difficult parts, Deharde relies on machine tools equipped with HEIDENHAIN controls.

The iTNC 530 is chosen not only for investments in new machines, but also when machines already in the shop are overhauled in order to extend their lifetime. One advantage of this is that all production employees at Deharde can operate all of the machine tools. Furthermore, this excludes the possibility of errors arising in the programs during transfer to other types of controls.

"The value added by us in each working step is enormously high, whereas the tolerances during production are extremely tight. That is why any deviations or scrap are extremely expensive," explains Klaus Gerken, Operations Manager at Deharde. If required, the company can guarantee tolerances of ±0.015 mm for contours, ±0.01° for angles, and ±0.02 mm for positions over a distance of 2500 mm. "The price for a day in the wind tunnel – where the air-flow properties and the forces acting on individual airplane parts are measured based on true-to-scale airplane models – is in the high five digits. That is why each of the delicate holes where the air flow is measured must be 100% correct. Also, the exchange of model parts, such as the various contour variants of jet engines or body fairings, or differently shaped parts for adjusting the flaps used during landing, must be possible without losing any time," is how Tobias Schwarz, Engineering Manager at Deharde, describes the extremely high demands placed on the finished parts.

Programming is based on CATIA V5 and Edgecam

Working from the customer's specific requirements, the ten-man design team creates 3-D models using CATIA V5 and presents them to the customer for approval. In the next step, one of the five programmers uses CATIA V5 or Edgecam to write the CNC programs that will later be transmitted to the HEIDENHAIN controls on the machine tools. Deharde even has a special precautionary measure: for reasons of safety, the programs for "flying parts," i.e. those that will later be used in air or space travel, cannot be edited while at the machine. Any necessary changes can only be made by the production planning & programming employees.

For all other parts the production employees can correct the programs directly at the machine, and in some cases they even enter new program sections. "I find it especially helpful that entire machining cycles, such as for face milling, tilting or bore milling, are stored on the iTNC 530. These cycles are needed frequently, and I can enter them in just a couple seconds," reports Stephan Coquille, a production employee at Deharde. The iTNC 530 features a quick and convenient editor for programming while at the machine.

Airplane wing of a wind-tunnel model, which can consist of up to 800 parts.

"A control from HEIDENHAIN ensures the greatest degree of flexibility for us, and therefore naturally for our customers as well."

Klaus Gerken, Operations Manager at Deharde

Impressive additional functions

In order to take the most advantage of the machine tool in terms of quality and machining time, Deharde uses the KinematicsOpt and the AFC (adaptive feed control) functions.

KinematicsOpt is a software option that is integrated directly in the iTNC 530. It eliminates deviations of rotary axes due to thermal influences, and compensates their drift. This way the operator can use KinematicsOpt to recalibrate his milling machine's rotary axes himself. The associated measuring process takes only a few minutes. "On average we calibrate some of our machines in this manner once a week. For parts with very tight tolerances we also use this function before each work step," comments Dietmar Warns, Machining Manager at Deharde.

The adaptive feed control (AFC) regulates the feed rate automatically, depending on the respective spindle power and the limit values defined by the operator. This can notably shorten the machining time, especially for castings, which have intrinsic and significant fluctuations in their dimensions and material strengths. The adaptive feed control ensures that the spindle power remains constant at the programmed level throughout the entire work step. For example, Deharde uses AFC for the machining of titanium and aluminum workpieces, reducing the roughing time by 5% across the board. "A very important advantage in our opinion is that the machine automatically interrupts the program if the feed rate drops below the minimum defined value. This is usually a sign that the tool has become blunt. We can therefore avoid expensive damage to the workpiece and the machine arising from tool breakage," says Operations Manager Klaus Gerken.

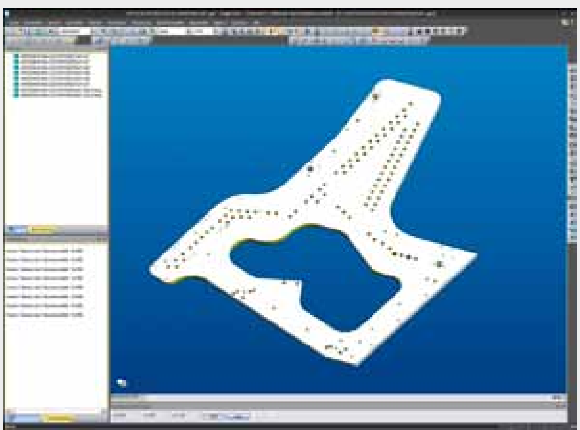
Looking toward the future

Older machines, already in the company's machine park, are overhauled in order to extend their lifetime and are retrofitted with an iTNC 530. Deharde even ordered a new five-axis milling center with four exchangeable pallets with a HEIDENHAIN control. "This ensures the greatest degree of flexibility for us, and therefore naturally for our customers as well," emphasizes Klaus Gerken. The controls use a third party's measuring software. The touch probes and software are used to fully automatically measure the workpieces and generate measuring logs. "There were no problems in connecting the software to the iTNC 530 via standard interfaces," notes Thomas Oltmanns, Planning & Production Manager. As a next step, Deharde plans to configure the measuring program so that it can intervene in the CNC program and make corrections automatically. Deharde is aiming for highly-automated production with this milling center.

The results at a glance

By using the iTNC 530 control from HEIDENHAIN, Deharde Maschinenbau Helmut Hoffmann GmbH profits from the following advantages:

- Very high precision during production
- Elimination of scrap
- Fast and error-free transmission of the CNC programs to the machine tools via Ethernet
- The optional KinematicsOpt function eliminates deviations of rotary axes and compensates their drift
- The optional adaptive feed control (AFC) function automatically regulates the contouring feed rate



One of numerous work steps: Working from specific customer demands to create 3-D models.

Functions for Process Reliability

Producing the First Good Part Quickly and Reliably

Various obstacles need to be surmounted on the way from the CAD/CAM system to the first good part: tests, modifications to machining programs and optimization of parameters all take up time and result in additional costs. Interruptions during actual machining of the workpiece must be prevented, or at least minimized. Particularly with time-consuming machining operations, such as are typical for the aerospace industry, effective strategies are needed in order to avoid complications.

Automatic program creation has its limitations

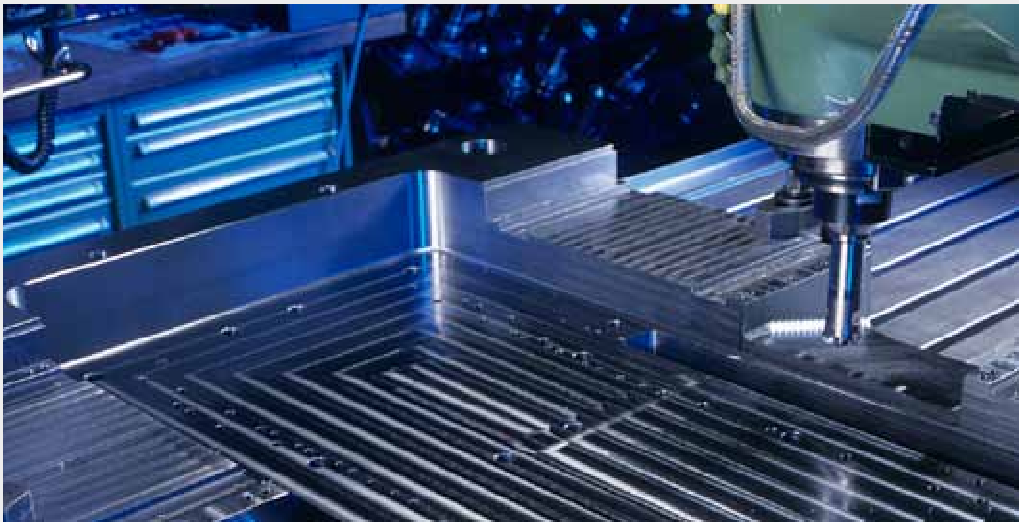
Machining programs for complicated operations are created using CAD/CAM systems. Tests and optimizations are usually necessary in order to achieve the required accuracy and surface definition. However, CAD/CAM systems postprocessors are often not perfectly configured for the actual behavior of the control and machine. The real result does not become apparent until the first test parts are produced, which may also included changes to the machine settings.

A typical challenge that makes subsequent optimization necessary is an inhomogeneous distribution of points in the generated machining program. This is particularly noticeable during forward/backward milling of free-form surfaces, and in the worst case can cause visible blemishes on the surface.

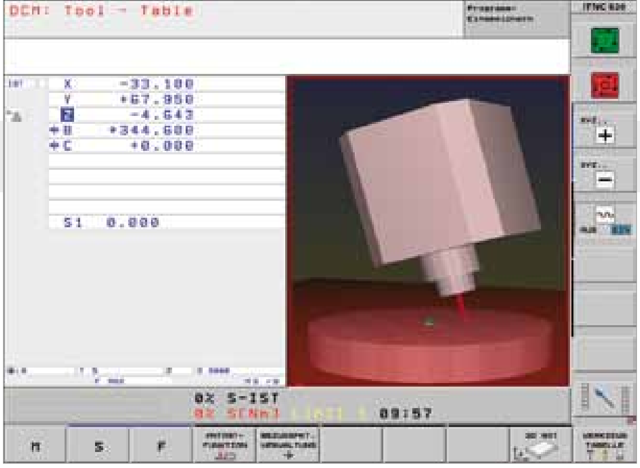
Large and very complex workpiece require much machining time. This especially applies to highly heat-resistant materials, such as titanium, which increasingly being used by the aerospace industry. This increases the desire for unattended manufacturing. Of course interruptions to such unattended operations must be avoided. And if they do happen, a rapid reaction must be possible.

If the automatically generated program uses complicated 5-axis control functions, then the actual behavior of the control cannot always be perfectly simulated in advance, since the control's functions cannot be reproduced in external simulation systems. The machining program and parameters must be adapted in this case as well.

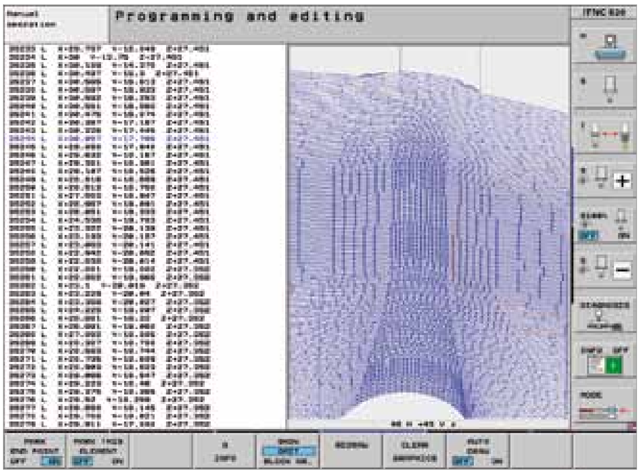
It is not unusual for the last changes and optimizations to the machining program to be made directly at the control. Depending on the editor, changes to long machining programs can become a very time-consuming matter, and can even provoke errors.



Good and reliable results! HEIDENHAIN ensure maximum process safety, particularly for time-consuming operations.



Dynamic collision monitoring (DCM) includes the actual clamping position and compensation values from the tool table, even during manual traverse.



Many functions of the iTNC 530 optimize the programs, many of them very long, generated by CAD/CAM systems.

Keeping the deadline: preventing interruptions to the machining process

HEIDENHAIN control like the iTNC 530 have strategies that functionally ensure the process reliability. The high degree of availability of the HEIDENHAIN control, which has proven itself with stable hardware and software, is a decisive factor. Preventive measures are possible for problems that frequently occur during extended workpiece machining:

Not only can replacement tools be inserted automatically after the respectively defined tool life, or of course at uncritical positions, but the tool exchange can also depend on the automatically measured wear of the tool.

During complicated and simultaneous 5-axis machining, the iTNC 530 very effectively reduces collisions between the tool, fixtures and permanent machine components within the machine's work envelope. With the dynamic collision monitoring (DCM) function the HEIDENHAIN control monitors all movements and issues a warning in time about an impending collision. This real-time protection is also in effect during setup or while the program is interrupted, for example if the machine operator traverses the axes manually.

Should the machine ever come to a standstill, a quick and reliable reaction is necessary. To this extent the iTNC 530 can immediately inform the machine operator or service technician via a text message, in order to minimize any delays.

The lift-off function permits the TNC to retract the tool from the workpiece upon an NC stop fully automatically, even with tilted axes, without damaging the tool or workpiece. This safety function is even available when the power supply fails.

Functions for reliable program generation

A significant advantage of the HEIDENHAIN controls is their insensitivity to an inhomogeneous point distribution. This point distribution varies greatly from workpiece to workpiece, and cannot be determined precisely in advance. The iTNC 530 features a powerful motion control that ensures precise contours, no matter from which CAD/CAM system they come and with which postprocessor the programs are generated. This makes it easy to switch workpieces, even on short notice, specific changes to the machine settings are not necessary, and optimizations are therefore also not needed.

The programs generated by the CAM system are stored on the control's hard disk. This makes access to the program faster and less complicated, e.g for the final simulation directly on the control with its 3-D line graphics. The logical and well-structured editor makes it easy to modify programs, even large ones, directly at the machine—should any changes even be necessary.

Increasing machine availability: virtual machines shorten running-in periods

The simulation of complex machining processes can be used to significantly reduce the running-in periods on machines with high hourly rates. All powerful CAM systems now have possibilities for simulation. But 100% reliability can still not be achieved. Why not? For one, powerful postprocessors insert additional positioning blocks into the generated NC program. Also, simulation systems cannot reproduce complicated 5-axis control functions.

This is where virtualTNC provides assistance. virtualTNC is the original controlling core of the iTNC 530, and can be integrated in any simulation system via an interface. Using virtualTNC to virtually run an NC program shows exactly those motions that would be performed by the real machine, naturally including the complicated 5-axis functions. That way no surprising compensating movements or reversal motions occur when the simulated program is run on the real machine. The machining programs generated in this manner are created more quickly and are more reliable.

HEIDENHAIN

Getting ahead of the crowd by exploiting tolerances?

People who make use of permissible tolerances when taking a path move decidedly faster than those who stay in the middle of the road. This is just as true in metal cutting as it is in Formula 1 racing. And that's why the micrometer accuracy of a HEIDENHAIN control wins you enormous time advantages. Depending on the machine and the requirements for surface quality and dimensional accuracy, it deliberately cuts curves to make you faster. The result: your TNC achieves optimal results and puts you far ahead in the race for productivity and profitability. HEIDENHAIN (G.B.) Limited, 200 London Road, Burgess Hill, West Sussex RH15 9RD, phone: 01444 247711, fax: 01444 870024, www.heidenhain.co.uk, e-mail: sales@heidenhain.co.uk

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895 760-21 · 15 · 9/2011 · H · Printed in Germany