

Influence of Position Measurement on Accuracy in 5-Axis Machining

Productivity and accuracy are important attributes in the competition for machine tools. Five-axis machining provides considerable potential for increasing productivity. In many cases it permits higher metal removal rates than 3-axis machining. Production times can be significantly shortened thanks to a reduction of time required for resetting, for example, or through multi-operation machining in one setup. In any case, with increasingly complex workpiece geometry, 5-axis



machining is becoming an indispensable part of the machining process.

Since significantly larger traverse ranges of linear axes are usually required for 5-axis machining, machines need to provide high accuracy over the entire working space. Moreover, the two rotary axes in a 5-axis machine tool can greatly influence attainable workpiece accuracy. Besides the rotary axes, in most cases the linear axes must also be moved in order to change the orientation of the cutter to the workpiece surface. This can cause visible flaws in the traverse range of up to five axes within a small area of the workpiece surface. In 5-axis machining, precision-limiting effects in the drives, such as screw-pitch and transmission error, reversal error or thermally induced displacement can therefore much more quickly lead to the production of scrap. The positioning accuracy of linear and rotary axes play a decisive role here in the performance of a 5-axis machine tool.

Did You Know...

...that HEIDENHAIN encoders are used in a new government-sponsored titanium-cutting machine now showing great promise? This is of particular note to the aerospace industry where strong but lightweight parts make a critical difference in the success of aircraft missions.

Project leader and developer REALLCO (Rockford Engineering Associates LLC) calls this development the Super-Stiff Vibration-Free (SSVF) Machine, and it is the result of a three-year \$2 million NIST (National Institute of Standards and Technology) research project with the intent to re-shape the future of cutting titanium and other hard-to-machine alloys. With the combination of new advanced technologies, this new machine is showcasing a 50% to 150% increase in tool life and material removal rates for high temperature alloys over current state-of-the-art systems. It is also cutting titanium at an estimated 50% faster cutting speed with excellent surface finish and maintaining very high accuracy.

To develop such a machine, REALLCO had to address two critical trouble spots as they relate to cutting tool failure in machining titanium: sensitivity of thermal stresses and impact of vibration on the cutting edge. These issues, which translate to machine stiffness and damping, are addressed with this new machine solution that combines the use of HEIDENHAIN absolute linear encoders right near the critical points, linear motors, the unique use of MDR (Membrane Dual Restrictor) hydrostatics for way guidance throughout the machine, and an ultra high-pressure (3000 psi) coolant system. The patent-pending combination alleviates the high amount of vibration and heat issues seen when cutting titanium that often lead

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REALLCO partners Kanwar Singh and John Hurd

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to catastrophic cutter failure and/or excessive machine tool wear.

“With the use of linear motors (rather than a more common ball screw drive system) and the donated HEIDENHAIN LC 183 absolute linear scales on the X, Y and Z axes of the SSVF, we have been able to design for exceptionally high position loop gains on our axes,” explained Mark Tingley, REALLCO Chief Design Engineer. The HEIDENHAIN encoders are positioned such that no compliance exists between the load and the reader head of the encoder. Proximity of the encoders to the load was chosen to minimize compliance outside of the position control loop. Since all loads and compliance are within the positioning loop, it is necessary to eliminate structural compliance to have a very high servo gain. And because the linear scales have a high-resolution serial output, no additional interface was required which enabled REALLCO to install them right at these critical points in tight

spaces and interface directly to the control. “This gives us the ability to run an exceptionally stiff and accurate machine, perfect for titanium cutting,” added Tingley.

Tingley also added that the use of absolute linear scales for motor commutation was important, and that the SSVF Machine is now achieving position loop gains of 10 mm/min/micron (10 inch/minute/mil). He explains that the SSVF Machine is able to circular interpolate a 25 mm diameter circle at 200 mm/min within a total error of 1.1 microns, including reversal errors at transition points. This compares to position loop gains of 0.5 to 1.5 in most machine tools and geometric error of 10 to 25 microns. “We have never seen performance this good,” added partner Hurd. “If we didn’t have the high resolution in the HEIDENHAIN scales, we couldn’t achieve these high gains with the linear motor system. This really is an enabling technology.”

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By now, 5-axis machining has become indispensable in many areas of metal-cutting machining. Clear economic advantages result from the capability to machine workpieces completely in one setup: the door-to-door time of a part can be dramatically reduced. At the same time, part accuracy can be significantly increased.

Beyond this, the additional rotary axes allow better access to complex workpiece contours, for example cavities in dies or molds. Often, they permit shorter tools with less inclination to chattering so that even higher metal removal rates are achieved.

With 5-axis simultaneous machining, the cutting speed at the tool tooth can be held within narrow limits even on complex contours. This brings significant benefits with regard to the

attainable surface quality. What is more, the use of highly productive tools (e.g. toroid cutters) when milling freeform contours would not be possible at all without 5-axis simultaneous machining.



Fields of Application for 5-Axis Machining

Parts for Aeronautics and Space Industry High strength and low weight are essential for the aeronautics and space industry. Integral construction has established itself as the way to minimize the weight of “airborne” parts: components with

complex structure are manufactured completely from a single blank. Metal removal levels can be as high as 95 %. This high “buy-to-fly” rate leads to high costs for the raw material of the blanks.

In the area of structural components, 5-axis machining opens new opportunities for reducing weight without loss of component strength. First, a computer-aided topology optimization is conducted that adapts the geometry of the component to the respective loads. The result: the material is brought specifically to where the mechanical load can be highest. In the other areas, material is specifically reduced. For example, the thickness of walls for stiffening can be easily adapted to the load distribution in the component. The wall thickness can decrease with increasing height, for example. This workpiece geometry can be realized in a simple way through 5-axis pocket milling.

Five-axis machining has long become the standard for the machining of jet engines. High efficiency requirements are driving continuous improvements in the flow characteristics of all jet engine components. The resulting component geometries are very complex and are therefore manufactured exclusively in 5-axis simultaneous milling movements.



5-axis machining in automobile manufacturing

Uncounted molds and dies are needed in automobile

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manufacturing for sheet metal and plastic processing. Dies for sheet metal forming can be up to 6 m long and need to be milled at the very high accuracy of ± 0.02 mm so that the upper and bottom dies can work together with the correct gap. Moreover, a very high surface quality of all functional surfaces is necessary in order to ensure that the forming tools have a long service life.

When manufacturing the tool contour, the machine has to maintain a very small distance between cutting paths in order to fulfill the requirements for high surface quality. This automatically lengthens the run times of the NC programs. The required accuracy of the forming tools is a formidable challenge for machine tools: high accuracy during long program run times on large components necessitates high thermal stability of the machine structure and the feed drives.

Five-axis machining opens new perspectives for shortening machining times because even deeply curved contours of forming tools become more easily accessible. In addition, special tools such as toroid or radius cutters can be used that permit significantly larger path spacing and therefore reduce program run times.

Five-axis machining in the field of medical technology

In the field of medical technology, demand is high for devices that are adapted to special examinations or therapies. This can make treatments considerably more precise and reduce



aftereffects on the patients. The devices are often characterized by very complex geometries that make 5-axis machining of single parts on milling machines attractive.

Increasing life expectancy brings with it an increase in demand for tooth and joint implants. Today, hip and knee replacements offer many people the opportunity for a significantly better quality of life. In their external form, tooth and joint implants have to be perfectly fitted to the

specific mating surfaces of a human body. Implants are mostly manufactured on milling machines, because milling makes even small batch sizes possible. Due to complex shaping of implants, medical technology is one of the largest fields of application for 5-axis machining. A prerequisite for the economical manufacturing of such sophisticated components is machines with high-accuracy position measurement for accurate and precise feed movements.

Requirements of Position Measurement

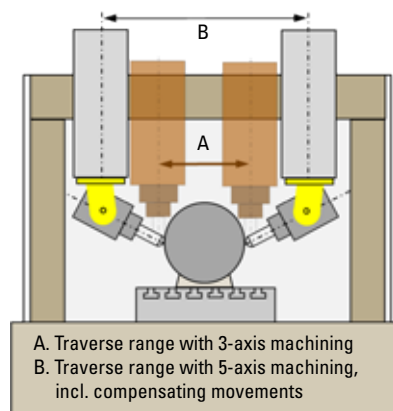
In 3-axis milling, the feed axes move within the dimensions of the workpiece plus the tool diameter. Unlike with 3-axis machining, in 5-axis machining the inclination of the tool can be adjusted with respect to the workpiece surface. If the position of the tool center point (TCP) remains unchanged, a change in



the cutter orientation usually requires additional movement in the linear axes. These compensating movements necessarily increase the traverse range required by the linear axes. Because increasing traverse range also means increased positioning error, feed axes of 5-axis machines need significantly higher accuracy and reproducibility.



The compensating movements of the linear axes are superimposed on the movements of the tool center commanded by the NC program in X, Y and Z. Due to this superimposition, the axis feed rates for the tool center can significantly exceed the programmed feed rate. The increase in feed velocity results in increased heat generation in the motors, transmission and recirculating ball screw. Depending



on the principle of position measurement, the generation of heat can cause significant position error. To prevent faulty workpieces, precise position measurement in the feed axes directly at the moving machine elements is imperative.

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Position acquisition on linear axes

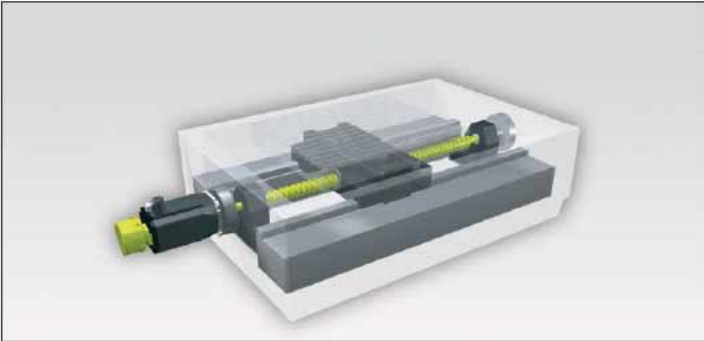


Figure 1: Semi-closed loop – Position measurement of a linear axis by a rotary encoder in the feed motor

The position of a feed axis can be measured either through the recirculating ball screw in combination with a rotary encoder, or through a linear encoder. If the axis position is determined from the pitch of the feed screw and a rotary encoder (Figure 1), 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 a highly accurate 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 in this way, this is called operating in a semi-closed loop. Positioning errors of the drives become unavoidable and can have a considerable influence on the quality of workpieces.

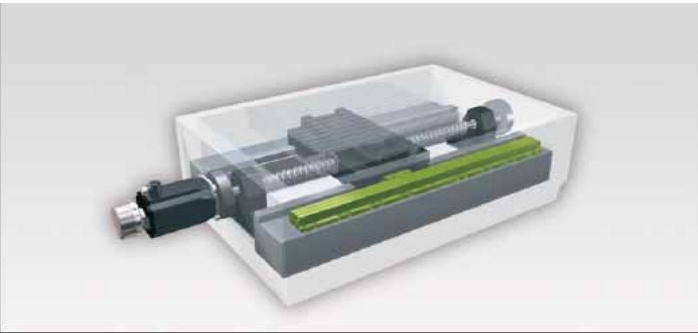


Figure 2: Closed loop: Position measurement of a linear axis by a linear encoder

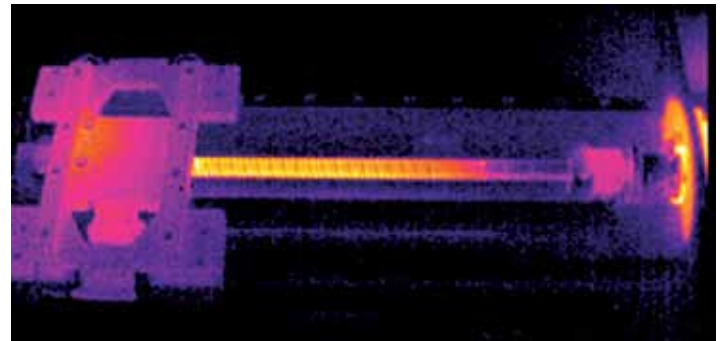
If a linear encoder is used for measurement of the slide position (Figure 2), the position control loop includes the complete feed mechanics. This is referred to as closed-loop operation. Play and inaccuracies in the transfer elements of the machine have no influence on position measurement. This means that the accuracy of the measurement depends almost solely on the precision and location of the linear encoder.

Various conditions of application together with growing feed

rates and forces lead to constant changes in the ball screw's thermal condition. Local temperature zones develop on a recirculating ball screw, which change with every change in position and decisively reduce accuracy in the semi-closed loop.

High reproducibility and accuracy over the entire traverse range of linear axes can therefore be achieved only through operation in a closed loop. The results are precise workpieces and a drastically reduced rejection rate.

As an alternative to using a recirculating ball screw, linear feed axes can also be driven by linear motors. In this case, the position of the machine axis is also measured directly by a linear encoder mounted on the axis slide. For highly dynamic and at the same time quiet operation, linear motors already depend on high-resolution, accurate linear encoders. For this type of drive, the advantages of closed-loop operation apply unrestrictedly.



Thermographic image of a recirculating ball screw with increased temperature

Position acquisition on rotary axes

The basic principle for linear axes also applies to rotary axes. Here, too, the position can be measured with a rotary encoder on the motor, or with a high-accuracy angle encoder on the machine axis.

If the axis position is measured using a rotary encoder on the feed motor it, too, is referred to as a semi-closed loop, because the transmission error of the gear mechanisms cannot be compensated through a closed position loop.

Error of the mechanical transmission in rotary axes are caused by

- eccentricity of the gear wheels,
- play, or
- friction and elastic deformations in the tooth contacts and the bearings of the transmission shafts.

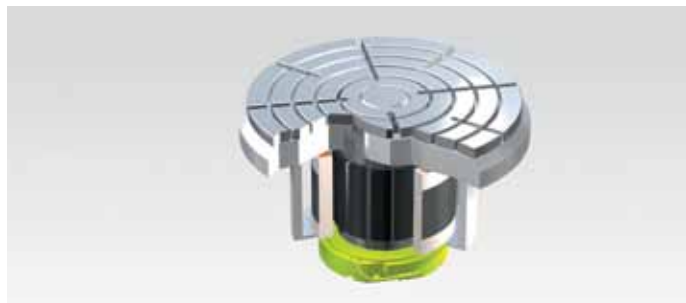
Beyond this, most pre-stressed transmissions are subject to significant friction that heats the rotary axes and can therefore—depending on the mechanical design—result in positioning error.

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In a semi-closed loop, the error in the transmission of rotary axes leads to substantial positioning error and to significantly reduced repeatability. The errors of the rotary axes are transferred to the geometry of the workpiece, which can greatly increase the number of rejected parts.

The positioning accuracy and repeatability of rotary axes can be decidedly improved with the use of precise angle encoders. Since the axis positions are no longer measured on the motor, but rather directly on the rotary axes of the machine, this is referred to as closed-loop operation. Errors of rotary axis transmissions have no influence here on positioning accuracy. The accuracy with which a rotary axis can move to a certain axis position over a long period is also decidedly increased. Economic manufacturing with minimal scrap is the result.

The rotary axes that are driven directly by a torque motor play a special role. The torque motors' special design permits very high torque without additional mechanical transmission. Rotary axes with torque motors require a high-resolution angle encoder immediately on the machine axis. They are always operated in a closed loop.



Torque motor: Rotary axes with torque motors are operated in a closed loop.

Machining Examples

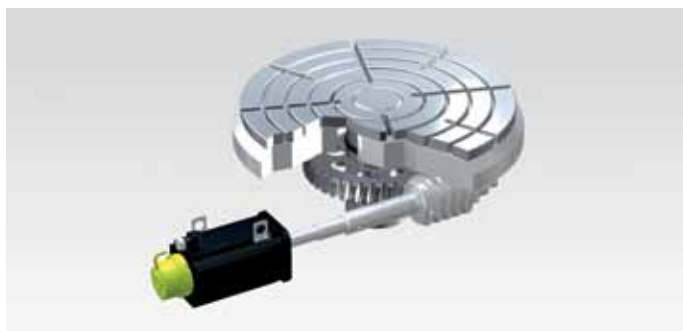
Five-Axis Simultaneous Machining with Very High Precision

Telstar soccer ball

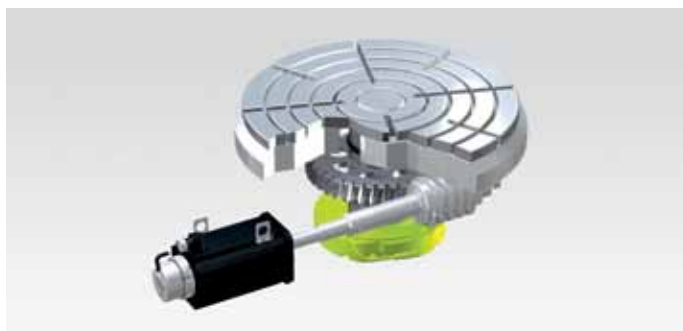
Five-axis manufacturing of the Telstar World Championship ball of 1970 and 1974



The soccer ball for the FIFA World Championships of 1970 and 1974 were named after the Telstar, the first non-military communication satellite, which was launched into space by the NASA and AT&T in 1963. The Telstar ball bears over 20 white hexagonally and 12 black pentagonal pieces that were sewn together.



Semi-closed loop: Position measurement by rotary encoder on the feed motor. Errors of the drive mechanism are not recognized.



Closed loop: Position measurement by an angle encoder on the machine axis. Errors of the drive mechanism are compensated.

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This ball serves as the model for a workpiece that can be milled on a 5-axis machine tool. The resulting workpiece is being used as a test piece to prove machining accuracy with 5-axis milling.

The Telstar workpiece was manufactured in three machining steps on the basis of pre-turned blanks:

- Three-axis milling of the pentagons with vertical paths and inclined cutter
- Three-axis milling of the hexagons with horizontal paths and inclined cutter
- Five-axis milling of the seams

A perfect optical appearance of the Telstar workpiece is possible only if the "seams" between the pentagons and hexagons are milled with consistently superb precision despite a machining time of over two hours.

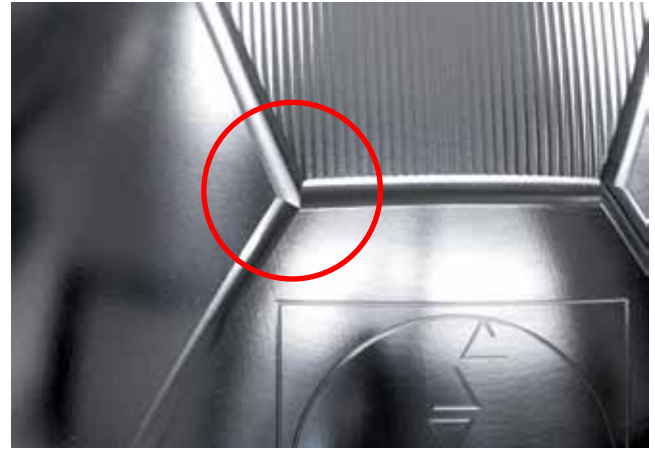
Machining sequence for 5-axis machining of the Telstar workpiece



Milling the pentagons: 3-axes, inclined cutter	Milling the hexagons: 3-axes, inclined cutter	Milling the seams: five axes simultaneously
Climb milling	Climb milling	
Machining time: 22 minutes	Machining time: 2 h 17 min	Machining time: 11 minutes
Feed rate: 6 m/min	Feed rate: 6 m/min	Feed rate: 0.4 m/min
Cutter: $\varnothing = 16$ mm	Cutter: $\varnothing = 16$ mm	Cutter: $\varnothing = 25$ mm
Line spacing: 1.5 mm	Line spacing: 0.2 mm	
Inclination angle: 40°	Inclination angle: 40°	Inclination angle: 55°

At the intersections, exactly three seams meet that are milled with various cutter inclinations. An intersection can therefore be machined precisely only if the cutter's tool center point (TCP) is positioned with three differing inclinations at exactly the same point.

However, the three inclination angles of the cutter require large compensation movements in the linear axes. For each seam, a much different position of the linear and rotary axes results at the TCP position of an intersection.



Semi-closed loop: influences of the drive mechanics impair machining accuracy. The seam width varies. The seam intersections are visibly inaccurate.



Closed loop: Thanks to the precise linear and angle encoders from HEIDENHAIN, errors in the drive mechanics have no influence on the result of machining. The seams are milled to the correct width, and the intersections all match up exactly.

During milling, positioning errors in one or more feed axes inevitably prevent the TCP positions from coinciding when milling the three seams at their intersection. High accuracy in the positioning of all feed drives is indispensable for precise machining of the seams, including the intersections.

For a simple visual evaluation of the Telstar workpiece's accuracy, a 0.15 mm deep seam is manufactured throughout with a 25 mm diameter cutter. This results in a very flat seam cross-section, so that even the smallest error in the seam's depth (± 10 μ m and less) causes clear fluctuations of the seam width.

If the Telstar workpiece is manufactured on a machine in a semi-closed loop, the positioning accuracy and repeatability

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is limited by the transmission error of the recirculating ball-screw in the linear axes and the transmission in the rotary axes. The result: the seam width fluctuates on the Telstar workpiece. The intersections cannot coincide exactly with each seam, so that a clear displacement of the seams' centers results.

In a closed loop, the feed axes attain very high positioning accuracy and repeatability over the entire traverse range. This makes precise machining of neighboring sections on the workpiece possible, even with large changes to the cutter orientation and substantial periods between the individual machining steps. The attainable precision is visible in the intersections of the seam paths. Each intersection is approached in all three neighboring seams. In addition, the seam width remains constant over the entire circumference of the Telstar workpiece.

Five-Axis Simultaneous Plain Milling

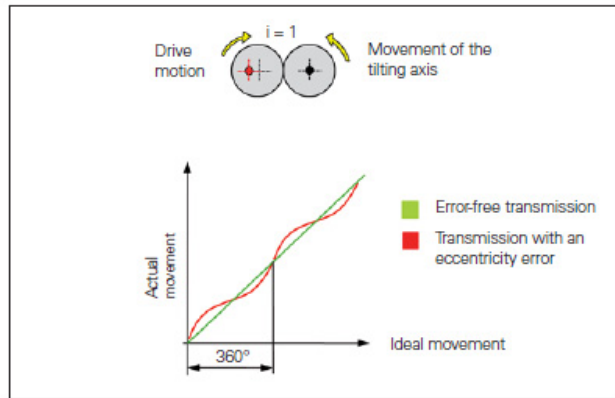
Polygonal workpiece

Five-axis machining provides considerable potential for reducing machining times. The lateral surface of a polygonal workpiece is finished simultaneously with a plain milling cutter in 5-axes in one revolution of the workpiece. Compared with 3-axis machining of the lateral surface with a ball-nose cutter, 5-axis machining reduces machining time to 30 %.

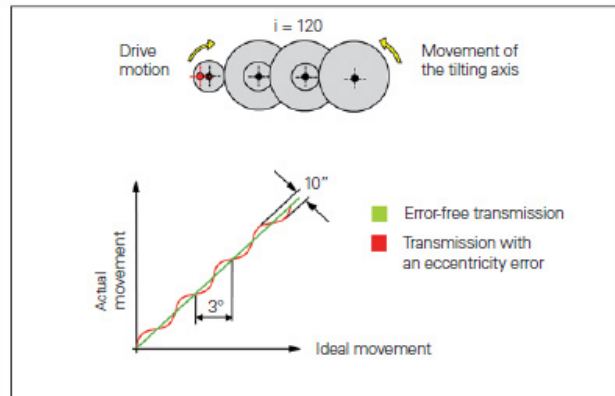
Precise machining with five simultaneously moving feed axes place stringent requirements on the accuracy of the feed drives. Depending on the type of position measurement, the errors of the additionally required rotary and tilting axes can cause significant limitations on workpiece quality. It is therefore

essential to pay special attention to the correct encoder and its integration into the control loop.

The periphery of the polygonal workpiece is machined in one revolution of the C axis with simultaneously interpolated movement of the B axis. During machining of the lateral surface, the B axis is tilted in and out five times in a tilting range between 1° and 19°.



Position errors on rotary axes due to eccentricity in the transmission, gear reduction $i = 1$



Position errors on rotary axes due to eccentricity in the transmission, gear reduction $i = 120$



To examine the effect of position measurement on the result of machining, workpieces were machined with the B axis separately in a closed loop and in a semi-closed loop. All other axes were in a permanent closed loop.

In a **semi-closed loop**, mechanical errors of rotary axes can cause position errors and therefore result in inaccuracy. Tilting axes often have drives with multiple-stage gearing. For uniform motion in a tilting axis, all gear components must have high manufacturing accuracy and be assembled precisely. Even small eccentricity errors of the gear can cause distinct fluctuations in the speed of the tilting axis.

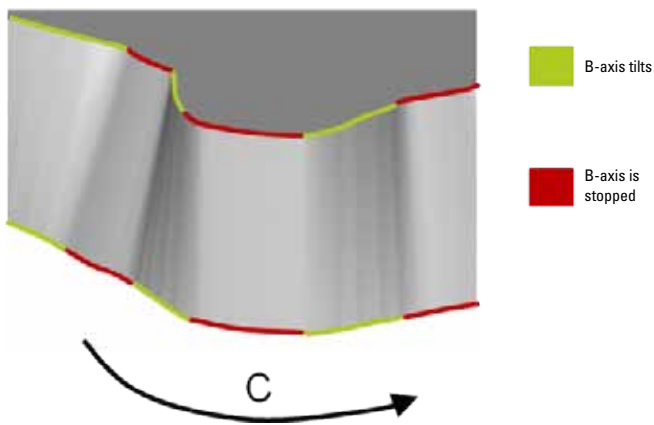
Influence of Position Measurement on Accuracy in 5-Axis Machining *continued from Page 7*



Semi-closed loop: Polygonal workpiece with surface error.



Closed loop: Polygonal workpiece with very high surface definition.



Machining a polygonal workpiece with plain milling and rotary and tilting axes

Illustrations 3 and 4 show the effect of eccentricity in a gear stage. The transmission with precisely assembled gears transfers the motion of the drive motor without error to the tilting axis. If a transmission gear wheel is eccentric, the movement of the tilting axis has a sinusoidal error.

The illustrated polygonal workpiece was manufactured on a milling machine whose tilting axis has a transmission reduction of $i = 120$. The motor pinion has a diameter of 40 mm. The radial runout of the pinion is ± 0.058 mm.

If the tilting axis is controlled in a semi-closed loop, the sinusoidal position error generated by the transmission cannot be detected by the drive controller. One revolution of the drive motor with eccentric pinion causes motion errors of the tilting axis in the range of ± 10 angular seconds. The error repeats itself every 3° with respect to the tilting angle.

In a first experiment, the polygonal workpiece is machined in the semi-closed loop. The position errors generated by the transmission are clearly visible as surface ripple on the lateral surface of the polygonal workpiece. The resulting form deviation is ± 0.015 mm. The transmission error is visible only on the sections of the workpiece at which the tilting axis moves.

In a second experiment, the tilting axis was controlled in a **closed loop**. Here a HEIDENHAIN angle encoder with optical scanning was employed. The angle encoder measures the axis position directly at the tilting axis. In this way the effect of the transmission error from the gears is immediately detected. The drive controller reacts immediately to very small deviations and generates the equivalent countermovement of the feed motor. The transmission errors therefore have no effect on the result of machining.

Thanks to the HEIDENHAIN angle encoders on the rotary axes, the lateral surface can be milled in 5-axes simultaneously with short machining time and, at the same time, high surface quality and accuracy.

Machining in Opposite Orientations

Requirements for the accuracy of rotary axes

The sides of prismatic components are often machined in opposite orientations. In this case, one side is machined first—perhaps by using a tilting axis to incline the workpiece with respect to the tool. The workpiece is then turned 180° by a rotary table to machine the opposite side.

Machining in opposite orientations places stringent demands on the positioning accuracy of the rotary table. Even small angular errors in the turnabout movement result in errors in the

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parallelism of opposite sides of the workpiece. On a workpiece with a 500 mm edge length clamped at the center of a rotary table, a positioning error of only two millidegrees results in an error of 0.01 mm perpendicular to the surface. Positioning errors can occur on rotary axes when the machining position is measured at the shaft of the drive motor (semi-closed loop), because the errors in the rotary axis transmission (play, elasticity, radial runout of the gear shaft) cannot be included in the position control and are not compensated. Depending on the design of the drive mechanics, semi-closed loop control can result in positioning error in the turnabout movement of ± 10 millidegrees and more.

The accuracy of a rotary table can be dramatically improved by using precise angle encoders that measure worktable movements directly. The transmission error in the gears of rotary tables are ascertained by the angle encoder and therefore compensated in the position control (closed loop). In closed loop operation, the precision of the angle encoder largely decides the accuracy of the turnabout movement. Angle encoders with optical scanning can make values of less than 0.3 millidegree possible.

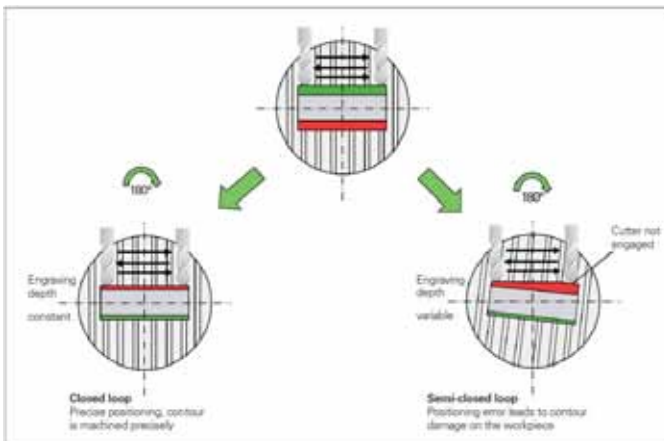
To illustrate the influence of positioning accuracy in rotary tables on machining in opposite orientations, a text was carved out of the sides of a cuboid component. First the component is probed on a 5-axis milling machine on one of the workpiece sides in the tilted plane. Then a text is cut out with a ball-nose cutter and 3-axis interpolated climb milling and up-cut milling. The characters have a height of 0.025 mm. Then the component is turned around on the rotary table by 180° in order to carve out a second text with the same character height on the opposite side.



Semi-closed loop: Influences on the drive mechanism (e.g. transmission errors) can impair the machine's accuracy and therefore the machining accuracy and surface quality.



Semi-closed loop: Accuracy-limiting influences from the drive mechanics have no influence on the results of machining. Thanks to the precise angle encoders from HEIDENHAIN, a high contour accuracy and excellent surface definition of the workpiece are achieved.



First a workpiece is milled in a closed loop (see on the workpiece). Then, a second workpiece is machined on the same machine in a semi-closed loop (see on the workpiece). The difference becomes apparent very soon. While the texts

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milled in closed-loop control with precise linear and angle encoders were machined without error on both sides, in the semi-closed loop, machining errors are recognizable: on the back of the component milled in a semi-closed loop the engraving is deeper at left while at right the tool is simply cutting air. Position-dependent and direction-dependent positioning errors in the semi-closed loop cause a slant in the machine table and workpiece. This results in a plainly flawed engraving and the rejection of the workpiece.

Encoders

Five-axis machining places particularly demanding requirements on the accuracy of feed drives because the traverse ranges and axis feed rate grow in comparison with 3-axis machining. The generation of heat and mechanical transmission error in the feed drives turn position measurement of the feed drives into a decisive factor for machining precision. Scrap and costs are minimized with the correct position acquisition.

Therefore, linear encoders for linear axes as well as angle encoders for rotary and tilting axes are indispensable for machine tools on which high positioning accuracy and a high machining speed are essential.

Because linear and angle encoders from HEIDENHAIN ascertain the movement of the axis directly and immediately. Mechanical transfer elements therefore have no influence on position measurement—kinematics errors, thermal errors and influences of forces are measured by the encoder and taken into account in the position control loop. This makes it possible to eliminate a number of potential error sources:

For linear axes:

- 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

For swivel, tilting and rotary axes:

- Mechanical transmission errors
- Reversal error
- Errors due to deformation of the drive mechanics by machining forces



HEIDENHAIN's NEW Touch Probes With Hybrid Technology Featuring Both Radio And Infrared Signals

New to the market from HEIDENHAIN are two Touch Probes featuring hybrid technology where each offers both radio and infrared signal transmissions. Known as the TS 460 for workpiece measurement and the TT 460 for tool measurement, these touch probes are highly functional, reliable and easy to use.

The dual signal transmission of these new touch probes enables the user to select either mode, combining the advantages of radio when extended range and large amounts of data are required, or the benefits offered by infrared signals when the highest accuracies and fast signal transmission are called for. This way, one version of a touch probe can be operated on any machine size (from small and enclosed to large and open). Difficult applications, such as plunging into a cylinder and 5-axis articulating spindle heads, are also simple to maneuver giving users greater application flexibility and machine versatility.

The radio transmission uses the 2.4 GHz frequency band, which does not require a license, and has 16 channels. The range is usually 15 m, but much larger ranges are possible under ideal circumstances. The infrared transmission has a range of 7 m. The carrier frequency method makes this transmission very reliable, and the high frequency ensures a short delay time.

No matter which signal transmission chosen, users need only one SE 660 transmitter-receiver unit. And these, as well as all HEIDENHAIN touch probes, have 360-degree range of transmission.

On both the TT 460 and TS 460, the optical sensor is free of wear, and so provides the specified probing reproducibility even after a large number of probing processes (5 million switching cycles during type testing). And the compact design makes it possible to use these touch probes even where installation space is limited. The smaller contours of the TS permit much freedom when tilting into position. The TS workpiece touch probes also have blower jets for cleaning the workpiece, either with coolant or compressed air.

Both touch probes have an optional adapter to protect against collision and thermal decoupling. In these instances, the adapter is placed between the touch probe and taper shank.

Power is supplied by size AA batteries (e.g., lithium or alkaline) or rechargeable batteries. The batteries can be exchanged easily without any tools.



Technical Tidbit:

What Influences Accuracy of Rotary Tables?

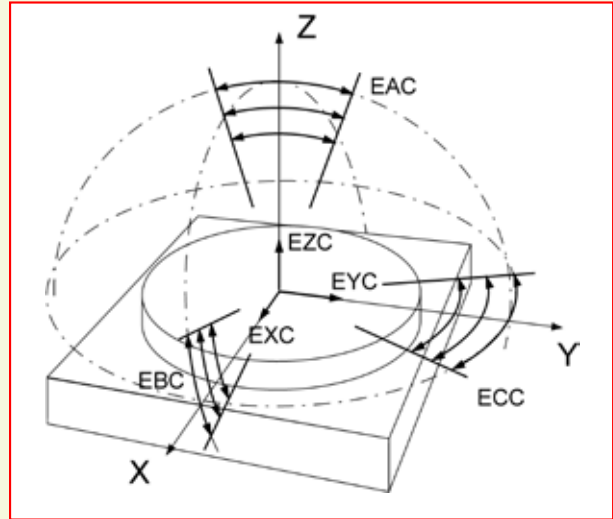
by Nathan Mathiot, HEIDENHAIN Product Specialist

When determining the influencing factors of accuracy on a rotary table, the first thing would be to look at the mechanics of the table itself.

A rotary table contains six degrees of freedom and this is shown in Figure 1. EXC, EYC and EZC represent the radial and axial error motion of the rotary table. EAC and EBC represent the tilt error motion whereas ECC represents the angular positioning error. Each one of these motions can add to the total amount of positioning error in the rotary table.

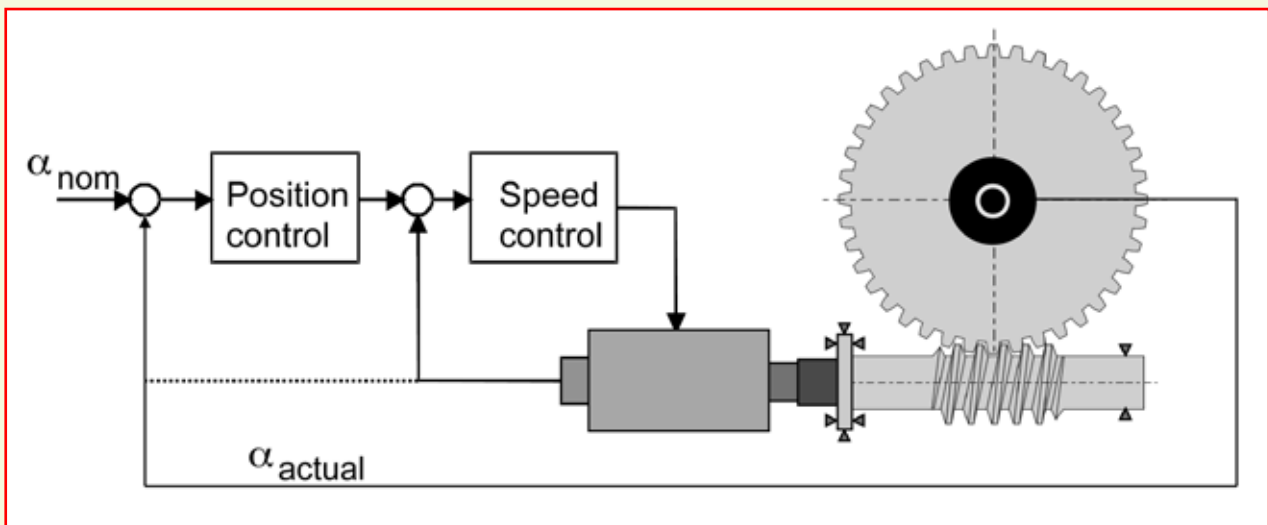
Typically, a rotary table is driven by a worm gear which is connected to a motor with a rotary encoder on the back of it. The table's position can be determined by the number of pulses transmitted from the encoder to the control.

The four major error sources due to semi-closed position loop are geometrical errors, thermal deformations, elasticity and wear. The sum of these errors is known as the angular positioning error (ECC). To greatly reduce the amount of angular positioning error, the ideal position to mount an angle encoder is on the axis of rotation being measured. With an angle encoder mounted underneath the rotary table and the rotary encoder on the back motor, the position loop is now considered to be a closed loop system (Figure 2).



If you have any questions, please let us know.

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Why HEIDENHAIN?

By Chris Weber, National Sales Manager, Machine Tool Division



Chris Weber
National Sales Manager
Machine Tool Division

In 2011, I reached a major milestone in my tenure with HEIDENHAIN: 20 years. This anniversary caused me to reflect on the reasons I have stayed this long, and I came to the conclusion that they are the same reasons why HEIDENHAIN is the right partner for you, our customers.

The Company

You may not be aware but HEIDENHAIN is basically a Foundation. There are no owners or shareholders, and a portion of all profits is donated to charitable institutions. This structure also allows us unparalleled investment in research and development. That is why you see a plethora of new products and technologies being introduced every year by HEIDENHAIN. Our investment keeps us on the leading edge and allows our customers to take their products to the next level of performance.

The Products

HEIDENHAIN builds the best, most reliable motion control products in the world. Our quality is renowned in the industry and the goal of our competitors is to be as good as HEIDENHAIN. There is no other company with the breadth of

product. From CNC controls to gauging systems, from simple rotary encoders to linear scales that are accurate into the nanometer range, no one comes even close. In the U.S, we also represent multiple brands from within the HEIDENHAIN family including Acu-Rite, RSF, Numeric Jena, Renco and Leine & Linde.

The People

We have over 6500 employees worldwide, and like me, the average employee at HEIDENHAIN has been here a lot longer than the industry norm. With this comes experience in applications, products, customers, markets etc. There is a sense of dedication to the company and the customer not found in other companies.

The Support

One of the keys to the success at HEIDENHAIN is the philosophy of lifelong learning. This applies to our service personnel, customer service group, technical support department, sales department etc. The result is a staff that is more knowledgeable and better able to support you, the customer. We are represented in over 50 countries, which means wherever you market your product, we are there to support you.

I want to personally thank you for your business in 2011 and reaffirm our commitment to you in 2012.

CONTACT INFORMATION

For more information about HEIDENHAIN and any of the products or services mentioned here, please feel free to contact us.



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