Applications and Benefits Related to the Precitech Hydroround CNC B Axis

By Kirk Rogers

Abstract:
There is resurgence in the use of B axis technology on ultra-precision machine tools. Advanced control capabilities have eliminated the additional setup time historically needed to set tools for use on a B axis. Modern CAM tools support innovative uses of coordinated motion of the B and X or B and Z axes. This paper outlines the current uses for B axis technology and discusses the benefits of each.

Prior to the availability of cost-effective controlled waviness diamond tools, the B axis on a diamond turning machine was used to support "single-point diamond turning." Pivoting the tool under Computer Numerical Control (CNC) kept the tool in the same angular relationship to the surface normal vector and the same spot on the tool in contact with the surface (AKA tool normal turning). When used in this fashion the waviness of the edge of the diamond tools does not affect the form accuracy of the turned surface. As controlled waviness diamond tools became more available and cost competitive, the need for the B axis diminished. Recent advances in CNC controller technology have made the setup of tools at the center of B as fast and accurate as the setting of fixed tools. Because of this, many customers are "re-discovering" the B axis as a cost-saving and enabling technology. Precitech's self-compensating, oil-hydrostatic Hydroround B axis has become one of the most valuable and versatile machine options available on an ultra-precision system.

The stiffness, damping characteristics and accuracy of the Precitech Hydroround B axes together allow users to get the greatest benefit from B axis technology. Air-bearing B axis designs are neither stiff enough nor provide the damping characteristics needed to take advantage of many of the benefits below. The Precitech Hydroround B axis is also stiffer and better damped than any mechanical bearing.

The Hydroround B axis is available in two sizes. The Small Hydroround is used on Precitech Nanoform 250Ultra and drum roll lathe systems. The Large Hydroround is used on Nanoform 700 Ultra and Freeform 700 systems.

Summary of product specifications for Hydroround B axes:

Specification	Large Hydroround	Small Hydroround
Table Top Size	380mm (15") ø	330mm (13") ø
Range of Motion	360 degrees, bi-directional	360 degrees, bi-directional
Load Capacity	454 Kg (1000 lbs.)	225 Kg (500 lbs.)
Feedback resolution	0.003 arc sec	0.004 arc sec
Axial Stiffness	875N/µm (5,000,000 lbs/in.)	600N/µm (3,428,000 lbs./in.)
Radial Stiffness	525N/µm (3,000,000 lbs./in.)	225N/µm (1,280,000 lbs./in.)
Moment Stiffness	17 N-m/µrad, (150 in-lbs/µrad)	3.4N-m/µrad. (30 in-lbs/µrad)
Radial Error Motion	0.10µm (4µ") @ 1" above table	0.10µm (4µ") @ 1" above table
Coning Error	1.0nm/mm (1.0µ"/in.)	1.0nm/mm (1.0µ"/in.)

Eight Ways a Hydroround B axis Improves Profits and Increases Capabilities:

B axis applications related to processing crystalline infrared materials:

Rapid manufacture of Germanium (Ge) lenses: The Hydroround B axis allows customers to use very large radius tools to produce Ge lens at 3x to 5x the normal feed per revolution[1]. More information on this method is available from Precitech.

Selective use of diamond tools when cutting Silicon (Si): Silicon is a challenging material to diamond turn. Silicon abrades diamond tools faster than other materials. Tool normal machining allows users to rough in parts with one section of the edge of the tool and index to a fresh section for the finish cut.

The hardness of the edge of diamond tools is not uniform around the sweep angle of the edge of the tool. This is due to the crystal orientation of the diamond. Using tool normal cutting allows users to control what portion of the sweep angle is used to cut parts and eliminate the effects of crystal orientation on cutting results.

Reduced subsurface damage and improved yields when cutting Ge and Silicon (Si): Acceptable surface finish from diamond turning either Ge or Si depends on cutting the material in a ductile state and minimizing the amount of material removed by brittle fracture. The material is put into the ductile state by the compressive force from a negative rake tool. When using fixed tools, the effective negative rake angle gets shallower as the contact point between the surface and the tool moves away from the axis (or tip) of the tool. This reduction of the effective negative rake angle increases the amount of brittle fracture taking place leading to poorer surface finish and more subsurface damage. Using a Hydroround B axis and tool normal machining allows customers to cut the entire surface at an optimal and consistent negative rake angle.

B axis applications related to the processing of all optical and mold materials:

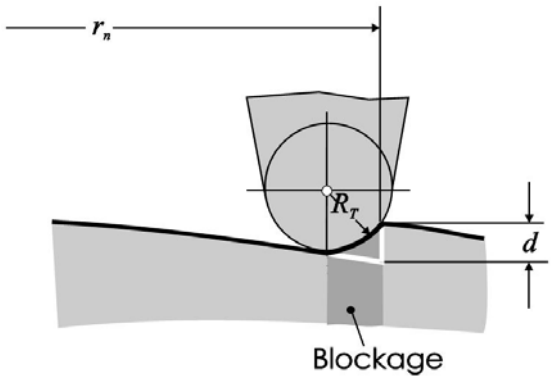
Enabling the manufacture of "steep surfaces": Steep surfaces or surfaces with a wide variation in local slope can be difficult or impossible to make with fixed tools. The sweep of the controlled waviness edge of a fixed tool must include the full range of slopes on the surface being cut. A Precitech Hydroround B axis allows the user to pivot the tool to "follow" the surface slope keeping one spot on the tool in contact with the surface. This is commonly referred to as tool normal machining.

Improving yields related to form while reducing the cost of diamond tools: Tool normal machining eliminates one source of error in form, the waviness in the edge of the tool. When turning with a fixed tool users minimize the affect tool waviness has on form accuracy by purchasing expensive "controlled waviness" tools. The Hydroround B axis allows users to improve form accuracy and use less expensive "non-controlled-waviness" tools.

Increasing diamond tool utilization and lowering tool maintenance costs: The Hydroround B axis increases productivity by reducing tool changes and extending the life of tools. One zone of the edge of the tool can be used for roughing. A different zone can be reserved for finishing. Alternately all passes can be performed by one location on a tool. When that location shows signs of becoming dull, the tool is rotated to use a fresh spot.

Improving the efficiency of diffractive optics, while reducing manufacturing time: Using the Hydroround B axis with a split radius tool allows high-efficiency diffractive optics to be manufactured

with lower cycle times. The diagram below[2] shows the transmission blockage or loss of a diffractive surface due to the tool radius. The accompanying equation[2] estimates the total loss. With a static tool, losses are kept to an acceptable level by using a small radius tool. The small radius limits the speed at which the refractive surface can be machined with an acceptable surface finish. A split radius tool features a large radius edge that is truncated at the tool's center line by one flank of the diamond tool. The intersection of the flank and the radius forms a corner with a much smaller radius. The refractive zones of a diffractive lens can be turned at high speeds using the large radius portion of the split radius tool. The tool is rotated as it approaches the transition or diffractive step so that the sharp corner radius produces a small radius at the base of the step. This results in a high-quality diffractive optic that can be manufactured efficiently.

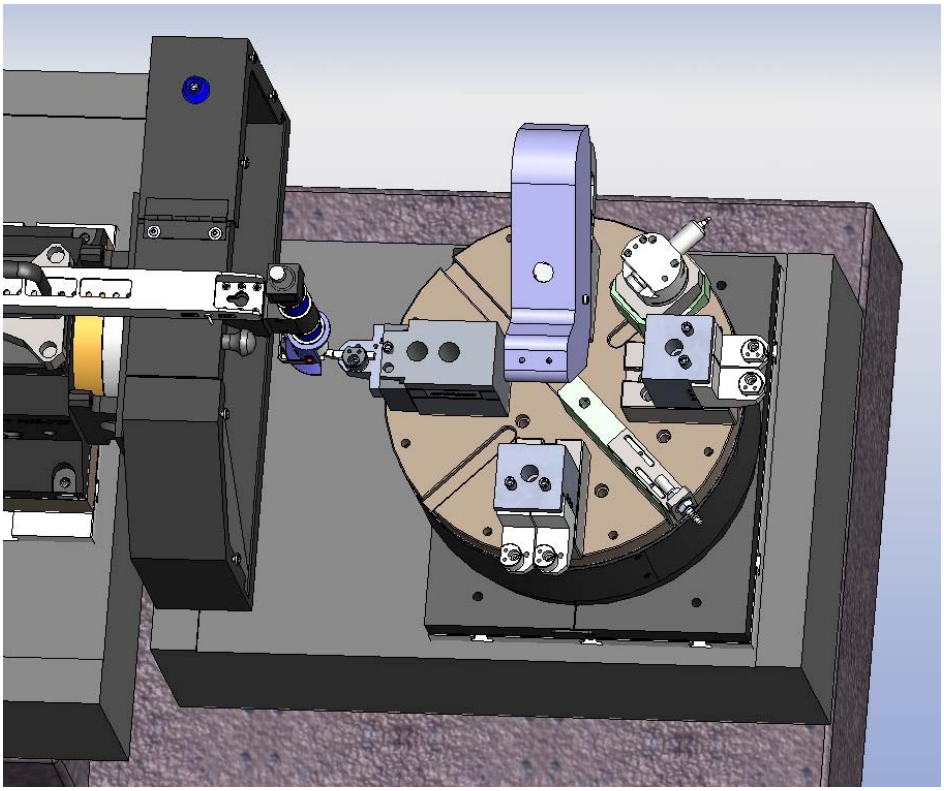


$$L \cong \frac{4}{D}\sqrt{\frac{2dR_T}{n_{r\,total}}}\sum_{1}^{n_{r\,total}}\sqrt{n_r}$$

***D* = Lens Diameter**
***d* = Maximum Step Size**
***R_T* = Tool Radius**
***$n_{r\,total}$* = Total Transition Steps**

Using the B axis as a tool turret to increase production efficiency: Customers who use their Hydroround B axis as a turret typically have an off-shift set up person to mount and set several tools for the coming production shift(s). As tools wear or as different tools are needed the production operators have the tools they need available and ready for use.

The CAD layout on the next page shows a Small Hydroround B axis on a Nanoform 250 Ultra platform. The 330mm diameter B axis table top provides ample space to mount a wide variety of tool configurations. The tools in the dual tool holders are typically angled slightly away from each other so they don't interfere with each other when cutting large convex optics. This layout includes five diamond tools, front surface probe, Part Centering Accessory, UltraComp probe and a dual tool shroud.



Precitech's exclusive Hydro-lock technology: When users want to deactivate and lock their B axis in place Precitech offers a superior solution: ***Hydro-lock.*** Using Hydro-lock the Precitech Hydroround B axis is locked in place by applying hydraulic pressure to only one side of the Hydroround bearing. Once the B axis is Hydro-locked it can resist upwards of 80 ft-lbs of torque. This is many, many times the holding torque that can be provided by older mechanical brakes.

Other products directly related to Precitech's Hydroround B axis:

Virtual Center Technology (VCT): ***Another first-in-the-market innovation from the engineers at Precitech.*** Virtual Center Technology significantly reduces set-up time for tool normal machining (reductions >10X are typical). Before VCT, tools had to be mechanically located exactly at the center of B in order to use tool normal machining methods. Depending on the nature of the work performed tool setting could take over 4 hours.

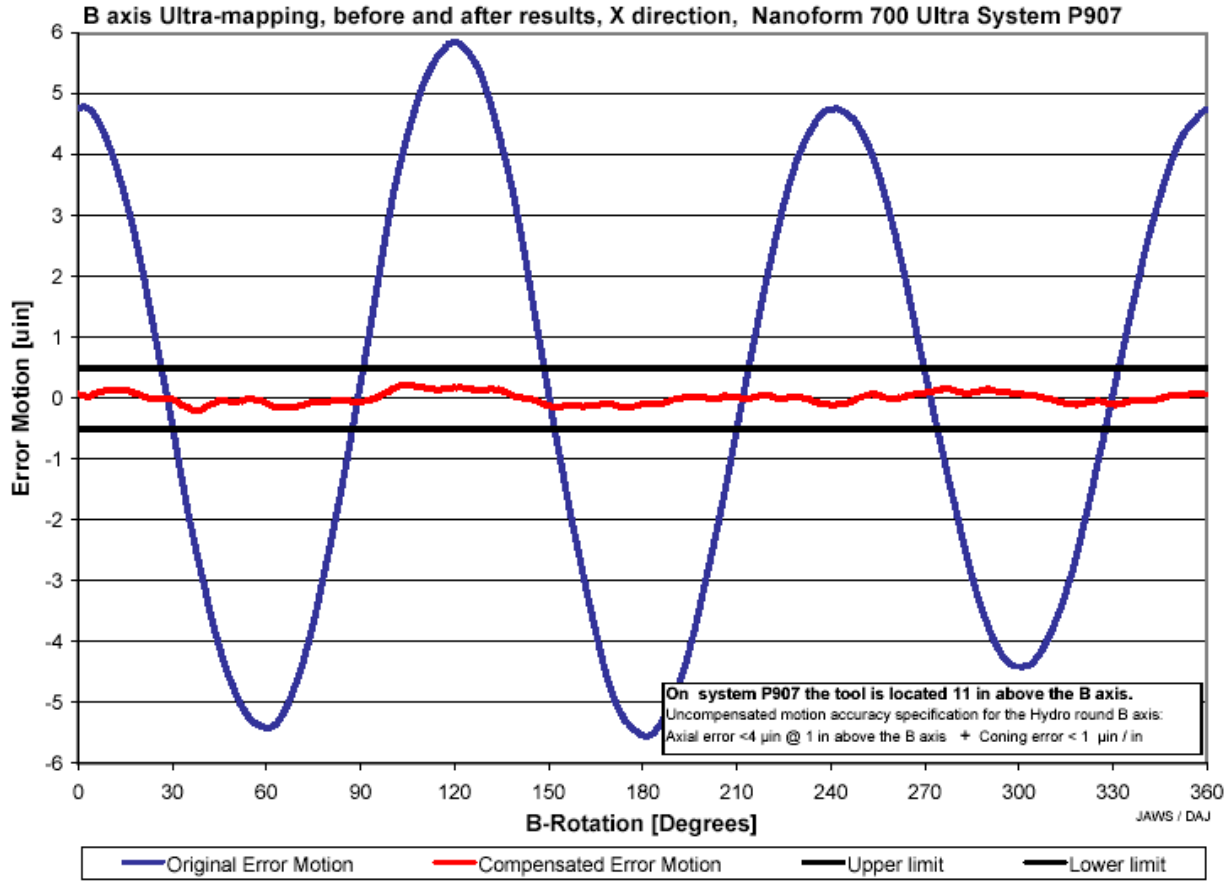
With VCT, users can perform tool normal machining with the tool(s) offset from the true center of the B axis. Once the tools are "set" or located with the optical tool set station, the VCT software and the UPx™ control will use linear motion of the X and Z-axis to compensate for the tool's offset so the tool operates as if it was physically centered on B. VCT operates in the background. No changes need to be made to tool path programs to use VCT. VCT can be applied to the edge of the tool, the center of the tool radius and multiple points on the edge of the tool can be used sequentially in tool normal mode. VCT can be used with grinding wheels and milling tools as well.

The allowable offset from the center of B is virtually unlimited. As the offset increases the physical limits of linear axis motion will increasingly constrain the range of allowable B axis rotation.

Large flat and concave optics that would be difficult to machine with the part over the center of B can now be machined in tool normal mode with the part in front of the B axis. VCT allows users to shorten up fixtures that used to be needed to position parts near the center of B. Holding the part as close as possible to the spindle nose increases the loop stiffness of the machine leading to improved surface finish. This is particularly important for materials that are difficult to machine like silicon.

The tools shown overhanging the side of the B axis in the "tool turret" illustration above can all now be used for tool normal machining (X,Z,B) as well as traditional two axis (X,Z) machining. Tools located further than 25 mm from the center of the B axis should be oriented so that when the tool is at the center of the part (typically zero slope) the projected centerline of the tool lies within 25 mm of the center of the B axis.

Ultra-Mapping, B Axis Radial Error Compensation: The B axis radial error specification is 4 micro inches at one-inch height over the tabletop. The coning error specification is one micro inch per inch of height, which can increase this error motion to be greater than 4 micro inches at the cutting height. This procedure measures the radial error motions of the rotary B axis at the spindle centerline height and implements software corrections to minimize these errors by the use of the X and Z axis motion during B rotation. Total radial error motion (basic error motion plus coning error) is typically reduced to less than 1 micro inch at the spindle centerline height. The plot below shows actual measured results of the use of Ultra-Mapping on a Precitech Nanoform 700 Ultra system where the tool is located **11 inches** above the Hydroround B axis. A tool 11 inches above the B axis could have radial error motion of up to 14 micro inches. Fourteen micro inches equals 4µin 1" above the table + 1µin for each inch in elevation above this.



More information on ultra-precision machine tools and Precitech's Hydroround B CNC rotary axis is available at www.Precitech.com.

References:

1) Ohta T., Yan J., Yajima S., Takahshi Y., Horikawa N., Kuriyagawa T., "High-efficiency machining of single crystal germanium using large-radius diamond tools", International Journal of Surface Science and Engineering, Vol 1, N0. 4, 2007, pp 131-149, Inderscience Enterprises Ltd.

2) Max J Riedl, "Comments to single point diamond turning silicon hybrid lenses for the MWIR region"