# RECENT DEVELOPMENTS IN DIAMOND TURNING

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ABSTRACT

The science of diamond turning has continued to advance during the two years since the last machine tool show here in Chicago. Pneumo Precision now offers diamond turning machines which feature state of the art oil hydrostatic way systems with enhanced rigidity. A rotary axis is available which was designed to satisfy the particular requirements of diamond turning. We have also added a grinding accessory which fits onto our diamond turning machine and allows the machining of materials which are too hard or too brittle to be turned even with a diamond tool.

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## HYDROSTATIC WAYS

Early this year Pneumo Precision began producing diamond turning machines which use oil hydrostatic way systems. This type of way was chosen because it has a zero coefficient of static friction, and also because the oil film has significant vibration dampening properties. By careful attention to the design variables, the hydrostatic bearings can be made to be insensitive to short term errors in the straightness of the machine way surfaces. This is a significant advantage over ways which use rolling elements such as balls or rollers. The presence of squeeze film and shear damping contribute to greater dynamic rigidity than can be obtained with air bearing ways.

Thermal stability is vital to machines which must hold microinch tolerances, and because of this the hydrostatic bearings must operate on a bare minimum of power. This has led to a somewhat unconventional bearing design. To minimize the power used by the oil pump and to minimize pressure pulsations from the pump, a rather low operating pressure of 80 psi is used. Bearings operating at this pressure can easily support the loads required, but the low operating pressure causes the stiffness of the bearings to be lower than desirable. The stiffness of the bearings cannot be increased by using a trapped or preloaded design because of space limitations. Instead custom designed flow control valves are employed to enhance the performance of the bearings. The use of flow control valves theoretically allow the bearings to be designed with almost any desired value of stiffness. However manufacturing tolerances limit what can actually be achieved in a production environment to an improvement of four or five times the stiffness that can be achieved with orifice compensated bearings. Using this approach to bearing deisng, we have achieved slide stiffness of several million pounds per inch and the entire hydraulic system has a power consumption of only five watts.

Because the bearings are very rigid and the slides are small and act like rigid bodies, care was taken to ensure that the slides were deterministically supported and guided. This means that there can be no more than three points of support and two guide points for each slide. Because of this, the system is sensitive to the magnitude of the supply pressure.

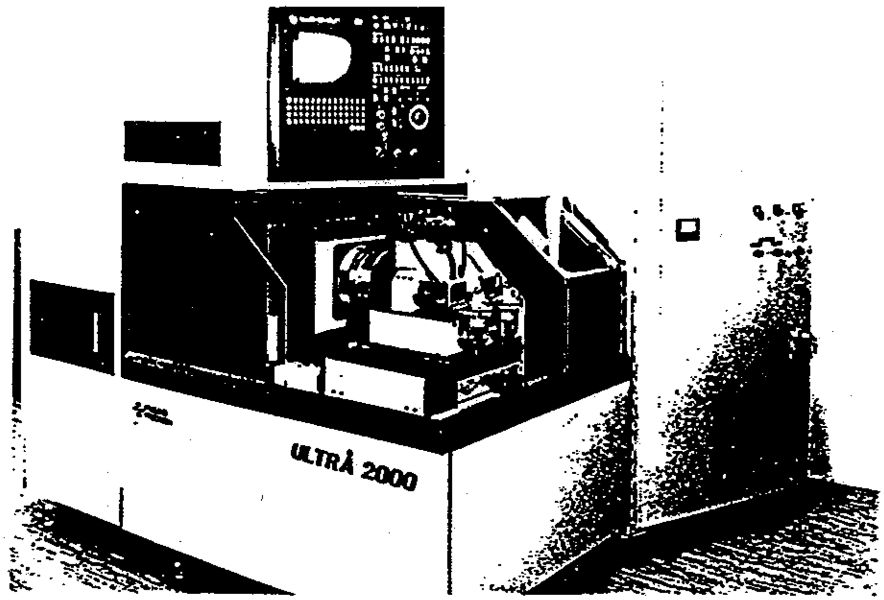


Figure 1

An Ultra Precision 2000 two axis diamond turning machine with hydrostatic ways. A twin spindle grinding accessory is mounted on the X axis in place of the tool holder.

Pressure regulating valves proved to be unable to control the pressure to the one tenth psi desired at the low flow rates present in the system, so a more technically complex solution was needed. This solution takes the form of a servo-controlled pump, which uses a pressure transducer as the feedback element to vary the rotational speed of the pump so as to maintain a constant pressure to the bearing system. The pump itself has a displacement of .008 cubic inches per revolution and runs at less than 200 rpm. It is driven by a small dc servomotor. The four gallon reservoir is more than adequate to keep the temperature rise of the system to less than one degree Fahrenheit.

ROTARY AXIS

When a two axis lathe machines a contour, the point of contact between the cutting tool and the workpiece moves around the tool nose radius. This means that the accuracy of the completed part is a function of the accuracy of the tool nose radius. Although the diamond tools used for contouring are very carefully lapped to achieve a highly accurate nose radius, the error remaining can be a major contributor to the errors in the finished part.

A solution to this problem is to add a third axis to the lathe. A rotary table can be positioned to carry the cutting tool. This axis is programmed to rotate the tool in such a manner as to maintain the point of contact between the tool and the work at a fixed position on the tool nose radius. By using this technique, the burden of accuracy is shifted from the tool to the rotary axis which must be designed to have a very small radial runout.

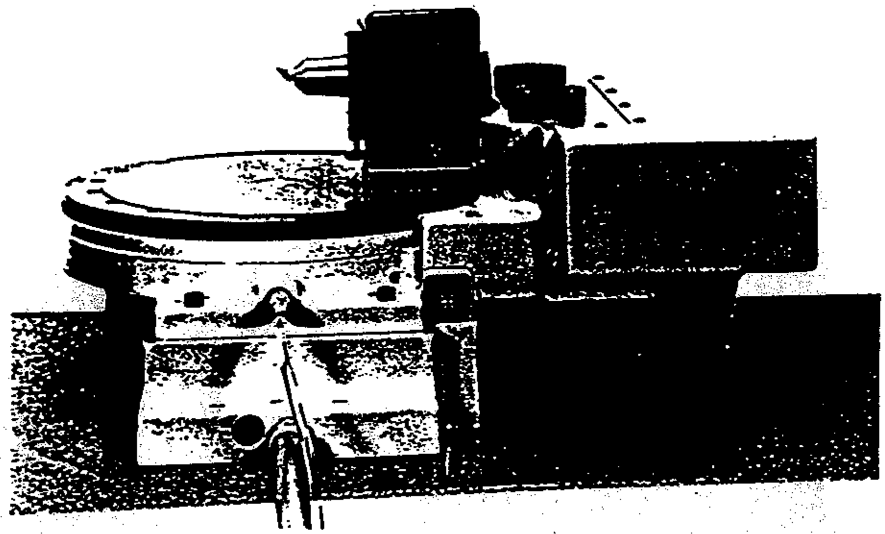

Figure 2

A rotary axis for maintaining tool normalcy while turning aspheric forms. The resolution is .01 degrees.

Pneumo Precision offers a rotary third axis for our standard MSG-325 and Ultra Precision 2000 lathes which has a radial runout of less than 10 microinches. The bearings, although they use oil, are of a design which is similar to that used in our Pneumo Centric 5500 and 5600 air bearing roundness gages. The use of oil in this application provides the high damping which improves machine performance.

While this use of a rotary axis requires a high degree of rotational accuracy, the demands on positioning are substantially less. Normally the cutting tool is positioned so that it's edge is at or very near the center of rotation. Because the tool is so close to the center of rotation, positioning errors have a very small effect on the workpiece. For example, a .020 radius tool positioned with its cutting edge .005 away from the center of rotation will generate an error in the workpiece of only 0.6 microinches when the rotary axis is one degree out of position.

A rotary axis is a particularly valuable tool when the parts to be machined have contours which are deep or have steep sides. These parts would otherwise require using a large part of the tool nose radius.

GRINDING

There is an increasing demand for ultra precise parts made from very hard materials. Examples are the molds used to produce small lenses for reading optical disks. These molds are made of tungsten carbide, silicon carbide, or other refractory materials. The molds must be machined to microinch tolerances and must have optical quality surfaces on their working faces.

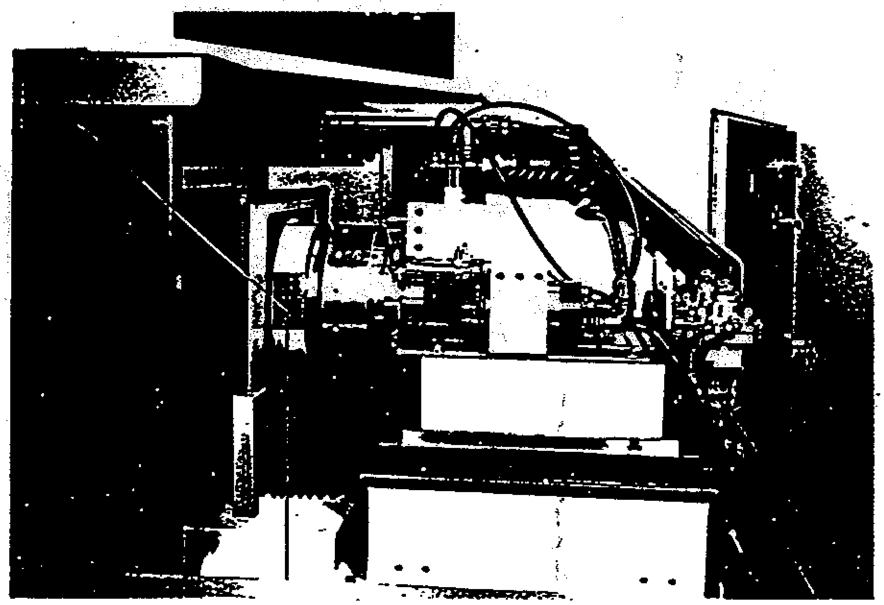

Figure 3

A closer look at the twin spindle grinding accessory. The grinding wheels arevisible inside the plastic guarding.

The grinding system which was designed to grind these and other similar parts uses two high speed, ball bearing grinding spindles, which are mounted on the X axis of a two axis CNC controlled lathe in a special holding fixture. These spindles operate through a speed range from 40,000 to 110,000 rpm. The ball bearings in these spindles are oil-mist lubricated by lubricators mounted on the holding fixture. The workpiece is mounted in a fixture, which in turn is attached to the air bearing spindle of the lathe. This spindle has less than 4 microinches of axial and radial runout.

One of the grinding spindles is mounted vertically with its axis perpendicular to the axis of the workpiece. This spindle is used to grind the optical surface on the end of the workpiece by contouring the part using simultaneous motion of the X and Z axes. The other spindle is mounted horizontally, parallel to the axis of the workpiece. This spindle is used to grind diameters and shoulders when such work is required.

Peripheral equipment required to operate the grinding system is mounted on a cart which can be positioned behind the machine. This equipment includes the electronic variable speed drive for the grinding spindles, the coolant system for the spindles, and a separate coolant system for cooling and lubricating the cutting process.

The grinding wheels typically used with this grinding system are resin bonded diamond wheels of 1200 to 1800 grit and 75 to 100 concentration. The wheel used for contouring is dressed to a spherical form on the machine. The wheels are run at about 6000 SFPM; the depth of cut varies from 20 to 200 microinches and the feedrate across the surface of the part is typically .05 to .10 inches per minute. Coolant is water soluble oil at 20:1.

## FUTURE DEVELOPMENTS

Where will we be in another two years? In some ways diamond turning is a mature process and in others it is still in its infancy. The process has been moving out of the laboratory and into the production environment, and it will continue to do so in the near future. New machine designs will be more rugged and better able to handle their environment. The use of flood coolant rather than spray mist will be more common. Diamond turning machines will become easier to use, as will all machine tools. The sway of the battle in the "map or lap" controversy is surely going to favor the mapping of machine errors into the memory of the control computers where these maps will be used for real time compensation for the errors.

Ceramics and other low density materials will become more common system components as designers try to push the natural frequencies of the machine structure ever higher.

Although the resolution of the machine control system can be increased beyond today's 0.4 microinch, it may be some time before the performance of the rest of the system will be good enough to justify going to increased resolution.

## REFERENCES

1. Chaloux, Leonard, "Diamond Grinding of Optical Surfaces on Aspheric Lens Molds" Proceedings SPIE, Vol. 656, April 1986.