Slow Slide Servo (S^3) Machining of Freeform Optical Surfaces - Abstract

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In recent years a significant amount of work has been accomplished in the area of generation of freeform optical surface. Most of this work is driven by market demand for these types of surfaces, which includes eyewear, electro-optics, defense, automotive and other industries. Presently, there are several methods of manufacturing such surfaces of which the most common are grinding and raster flycutting. Both grinding and flycutting rotate the tool and traverse either the tool and/or the workpiece in three linear axes to cut the surface. Grinding and fly cutting can produce very accurate surfaces but require long machining cycles and are difficult to set-up. Another method of fabrication is the Fast Tool Servo (FTS), which is widely applied in the contact lens industry. However, most FTS systems have a maximum travel range of less than 1mm and therefore are limited to certain part geometry with small departures.

Moore Nanotechnology Systems (Keene, NH, USA) has been applying an alternative method to generate freeform optical surfaces via "Slow Slide Servo". The Slow Slide Servo method is similar to the FTS in that, the part is mounted on the spindle and as the spindle rotates, the tool oscillates (Figure 1). Unlike the FTS method, this system does not use any additional axes for oscillating the tool; the Z-axis slide generates the oscillations. Another difference is the spindle position control (or C-axis). In an FTS set-up, the spindle has an encoder that feeds the position to the FTS unit without putting the spindle in position control. In a Slow Slide Servo all axes are under fully coordinated position control. The Slow Slide Servo can oscillate at ranges up to 25mm, is easy to set-up, inexpensive, and allows the manufacturing of highly accurate parts.

To implement the Slow Slide Servo method, several key features must be available on a diamond turning lathe. Most of these features are the same for both the linear and the rotary axes. They include friction-free bearings that generate little heat, direct drive motors with no mechanical compliance between the motor and the feedback system, high-resolution encoders, and minimal structural dynamics in the control loop. Another key feature is the control system or the CNC. The CNC must have high-speed data processing, look-ahead capability, a high-resolution data acquisition system, and high-order trajectory generation.

Several different freeform surfaces have been machined using the Slow Slide Servo method to show the viability of this type of machining. One example of these surfaces is the cubic phase plate shown in Figure 2. This part was machined in Zinc Sulfide with a negative rake-angle diamond tool. The sag of the surface was 100 μm Peak to Valley (PV). The form results shown in Figure 2 indicate that the PV error is 0.26 μm and the surface finish is 4.6 nm (Ra).

Another example of the use of this method is the machining of an off-axis sphere. A 75 mm diameter 6061 aluminum concave sphere with a 75 mm radius is offset from the spindle center by 7.686 mm. The sphere is then cut with a 1.5 mm radius diamond tool. The maximum oscillation of the Z-axis was approximately 11 mm. The form accuracy results of the sphere were 0.33 μm PV and the finish results showed a roughness average of 5.6 nm. Several other surfaces have been machined using this method including tilted flats, progressive lenses, cylinders, torics and biconics on a variety of materials. They all showed comparable form and finish results to the above samples.

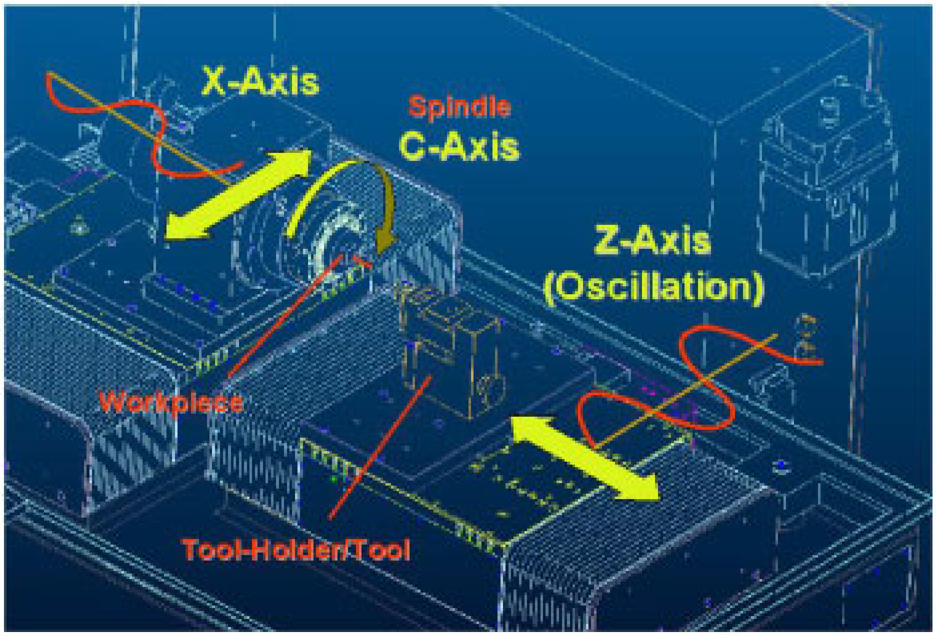

Figure 1: Setup for machining with Slow Slide Servo

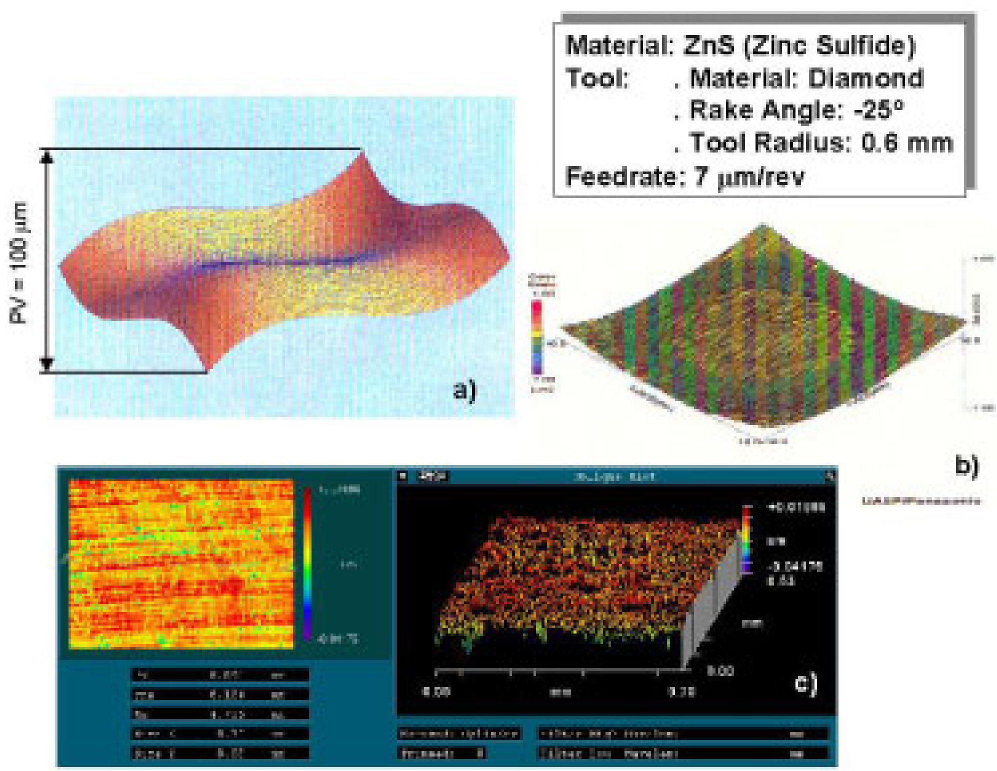

Figure 2: Cubic Phase Plate Surface. a) Mathematical representation of the cubic phase plate surface. b) Form accuracy measurement results (measured with Panasonic Profilometer UA3P). c) Surface finishing results (measured with Zygo NuView).