The Single Point Diamond Turning (SPDT) Of Optical Surfaces For Visible Wavelength Applications

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Presentation Summary[†]

Recent advances in machine tools for single point diamond turning have significantly improved the quality of machined surfaces available. The most recent generation of SPDT machines are producing optical surfaces suitable for many visible wavelength applications. This presentation will examine the quality of current SPDT surfaces and compare them with reasonable criteria for visible wavelength surface specifications.

Criteria for optical surface specifications are application related. These specifications are typically related to performance parameters influenced by surface errors of related spatial frequencies. Long spatial wavelength errors, usually referred to as surface irregularity or distortion, influence system wavefront performance. Surface scatter is attributed to short spatial wavelength errors (*i.e.*, surface roughness). Separate criteria are generally established for these two performance parameters.

One classical specification for an optical system's performance is Maréchal's Criteria[1], which sets a permissible value on diffraction focus intensity. Although the translation of system wavefront specifications to permissible surface form tolerances is specific to the individual system, it is reasonable to expect form errors to be on the order of system wavefront criterion. Using Maréchal's suggestion that a well corrected optical system has a normalized intensity at its diffraction focus of at least 0.8, it follows that surfaces should have form error typically no larger than $\lambda/14$ *rms* to be acceptable. This equates to a form error of less than 45 nm *rms* at a wavelength of 0.6328 μm.

The establishment of a criterion for scatter specification is difficult because of its extreme application sensitivity. Unlike polished surfaces whose suitability is usually specified by roughness alone (*e.g.*, *rms* or R_a), directly machined surfaces have the additional considerations of periodicity and lay. One technique for establishing a criteria for scattering intensity is the application of classical scalar scattering theory[2]. With this theory, a roughness height tolerance can be specified by its relationship to total integrated scatter. If we assume a total integrated scatter of one-tenth of one percent (a value consistent with the obscuration ratio typical of an 60/40 cosmetic surface quality[3]), then the *rms* surface roughness specification required would be approximately $\lambda/400$. This equates to a surface roughness of 16 Å *rms* at a wavelength of 0.6328 μm.

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Advances in the design of SPDT machine tools have permitted directly machined surfaces to achieve these criterion for visible wavelength applications. These advances can be classified as improvements in machine tool mechanical designs, environmental (thermal and vibrational) considerations, and servo/feedback control systems.

Perhaps the most important advance in SPDT machine tool design is the use of oil hydrostatic slides. The current generation of modular slide designs incorporate fully constrained symmetrical bearing cross-sections that have greater stiffness and damping characteristics than previous air bearing designs. The elimination of roller bearings permits significant reduction in short term slide motion errors and overall improvements in slide straightness. The most recent slide design uses an air isolated capstan drive system to remove lead screw coupling effects.

Environmental considerations are critical to the obtainment of directly machined surfaces suitable for visible wavelength applications. Current designs address thermal effects through the use of large thermal mass synthetic "granite" machine bases, aerostatic work holding spindle athermalization techniques, servo controlled environmental enclosures, active laser refractometry, and thermally insensitive metrology reference axes. Machine tool vibrations have been reduced in current designs by the use of vibration isolation, oil hydrostatic slide designs, and the use of materials with high damping properties.

Improvements in servo control and feedback systems have also benefitted the quality of SPDT surfaces produced. Distributed processing and the use of enhanced interpolation schemes have significantly improved machine tool positioning accuracy. The use of new generation laser interferometers, with resolutions in the nanometer range, as feedback devices have also improved machine tool positioning.

A number of SPDT surfaces will be evaluated to demonstrate the effects of these machine tool advancements. By showing favorable comparisons with the above criteria, these surfaces demonstrate their use for visible wavelength optical applications.

References

[1] M. Born and E. Wolf, Principles of Optics (Pergamon Press, Oxford U.K., 1975), pg. 468.

[2] J.M. Bennett and L. Mattsson, Introduction to Surface Roughness and Scattering (Optical Society of America, Washington, D.C., 1989), pg. 51.

[3] "General specification governing the manufacture, assembly, and inspection of optical components for fire control instruments" Military Specification MIL-O-13830A Unites States Department of Defense.