Integrating Figure and Finish Measurements with Surface Profiling Instruments*

BNL--47220

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Recently developed instrumentation and measurement techniques now make it possible to extend profilometry into the realm of surface figure measurement. This view of surface figure errors differs significantly from the traditional optician's approach.

*This research was supported by the U. S. Department of Energy:
Contract No. DE-AC02-76CH00016.

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Conventional figure measurement techniques are inadequate for testing aspheres for grazing incidence applications. Conventional techniques are best suited for optical components in the shape of flats, spheres, or conical surfaces of revolution, used mainly in normal incidence applications. These optics usually have their symmetry axis coincident with the local surface normal direction. Grazing incidence optics, on the other hand, are usually cylindrical, toroidal, or ellipsoidal in shape, with the symmetry axis intersection far outside the clear aperture. Such surfaces are not axisymmetric when viewed along their surface normals. They are highly anamorphic, having vastly different curvatures in the two directions parallel and perpendicular to the symmetry axis. It is extremely challenging to test these optical components during fabrication to insure that they indeed meet the specifications for figure and finish quality. It is because of the extreme difficulties involved in developing reliable tests with conventional interferometric techniques that we decided to use profiling techniques to characterize the figure and finish of synchrotron radiation (SR) optics.

SR optics are generally used in grazing incidence applications where good control over image quality is required only in the plane of incidence. For example, light that is scattered or deflected along the length of an entrance or exit slit inside a monochromator is acceptable, but light that is scattered or deflected perpendicular to the slit must be minimized. At grazing incidence angles Church [1] has shown that surface errors in the plane of incidence are responsible for producing much more scattered light than are surface errors in the transverse direction. Tolerances on optical fabrication thus need not be the same in all directions on SR optics. What is of primary concern to SR users are the axial finish and figure errors on cylindrical optics.

Until about ten years ago it was very difficult to routinely measure the roughness of optical surfaces, especially on large, full-sized grazing incidence mirrors. The only quantitative technique available was by stylus profiler [2, 3]. Development of a commercial micro phase-measuring interferometer (PMI) early in the last decade has made it possible to measure the axial roughness of large cylindrical aspheres rapidly and accurately [4]. Accuracy, however, in surface roughness measurement requires one to have a thorough understanding of the performance limitations of the measuring instrument. A significant effort has been made to characterize the error sources in PMI profiling instruments, and models have been developed to correct for inherent limitations in each optical system [5-9]. We have developed analysis techniques that compute the power spectral density of the surface profile and use it to predict the distribution of scattered light from the surface. A significant effort has gone into the development of the analysis code to insure that artifacts introduced into the data by the optical system or the analysis process are minimized.

In order to deal with the figure measurement problem on large (up to 1 meter long) SR optics, we developed a scanning profiling instrument, the Long Trace Profiler (LTP) [10, 11]. This instrument has enabled us to measure the axial shape of large aspheric surfaces with accuracies in the range of 1/100 of a wavelength of visible light, i.e. with RMS error bars of less than 10 nanometers. The range of spatial periods sampled by this instrument complements that of the PMI: the LTP covers the 1 meter to 1mm spatial period range, while the PMI instrument covers the 5mm to 10mm range. The region of overlap in the frequency domain between the two instruments is very important in assessing the quality of data from each instrument.

The use of a profiling instrument to measure what is traditionally regarded as "figure" on an optical surface has required an unconventional approach to quantifying large-scale surface shape errors. We use the same analysis techniques for macroroughness as we do for microroughness, that is, we analyze the surface profile in terms of its power spectrum. One major result to come out of this work is the removal of the artificial distinction between

figure and finish on an optical surface. We have developed a theoretical model that predicts the core image intensity and scattered light distribution from knowledge of the source coherence properties, detector size, and spectrum of the surface irregularities over the 5 decade range covered by the two profiling instruments [12-14]. Another significant result of this work with profiling instruments is the observation that most polished optical surfaces tend to have spectral distributions that follow inverse power law functions with exponents in the range of 1.2 to 1.5 [15]. Such behavior over such a large range of spatial frequencies is indicative of a self-affine fractal process. Microscopic models of surface properties explaining this behavior are currently under investigation.

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6/02/92**