**Final Paper Outline on K-B Mirror Metrology**

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1. Explain why my project on synchrotron radiation is important to APS:

Nanofocusing mirrors are very important to many research applications requiring extremely small beams, including nanofluorescence, nanodiffraction, and other micro- and nano-imaging techniques.

We are trying to improve the fabrication of K-B mirrors using the APS-developed thin film coating technology to achieve 50-nm-focusing K-B mirrors. A K-B mirror has a shape of elliptical cylinder, and is used in pairs to focus the synchrotron radiation coming out of an undulator. The pair contains one vertical and one horizontal mirror. In APS, the hard X-ray comes out of the standard insertion device: Undulator-A, 30 m away from the source, has an elliptical shape with the minor axis of 1mm and major axis of 2mm.

Manufacture of elliptical mirror is very costly (half a million dollars for a pair of mirrors and mounting system). It is less expensive to manufacture them by profile coating flat or preferably cylindrical substrates. The deposition is done by an in-process fashion. The fabrication machine gets the feedback information about the mirror surface from metrology tools. Hence, metrology plays an important role in fabrication process. Accurate in-process metrology is essential to fabricate precise elliptical mirrors.

Fabrication of K-B mirrors using elliptical coating requires metrology tools that are capable of measuring figure error at $10^{-10}$ m level. Currently in APS we are using microscope interferometer with microstitching capability to measure figure error of the mirror substrate and coating.

However, the microscope only works best when the surface under test is flat or mildly curved. Measurement of highly curved or tilted surfaces introduces aberrations and affects the accuracy of measurements. My project is to study the magnitude of measurement errors as a function of tilt angle/curvature of the surfaces under test, and contribute to devising a method to correct those errors within the limits of the microscope capabilities.

Wavefront aberrations for tilted flat surfaces are due to the change in optical path difference, and it is necessary to utilize a mathematical model to describe this phenomenon.

1. Introduce Zernike polynomials as the main tool and describe some useful mathematical properties (orthonormality, completeness, generating function, etc); most of them are fairly easy to be understood for a junior level physics students, because they have encountered several orthogonal polynomials in the context of quantum mechanics. Compare its advantages over other orthogonal polynomials (Legendre, Tchebyshev, Jacobi, Laguerre, Hermite) with respect to this specific optics problem. Compare with Fourier analysis and observe benefits about Zernike polynomials.
2. Multivariate polynomial fitting is a linear least square problem, and there are several practical solutions. Two algorithms of mine are based on Gram-Schmidt orthogonalization and Moore-Penrose pseudoinverse, respectively. Describe the principle and tricks used in my codes.

Compare my own codes: the one using pseudoinverse is more desirable, and explain mathematically why.

Compare the results from the built-in program in the interferometer MicroXAM and those from codes written by myself. The former one is more accurate, and is the major criterion which decides the removal of Zernike polynomials is satisfying or not. One of my future efforts (in the following two weeks) is to improve the accuracy of my codes.