Proceedings of the MEDSI 2014 Conference

Melbourne, Australia - October 2014

FEA simulation for adaptive mirrors at European XFEL

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Abstract The European XFEL will be a high-power x-ray free electron light source, which is now in construction and installation period, located in Hamburg, Germany. In the beam transport system, X-ray optical mirrors are the important components, which need to fulfil the highly demanding specifications. Because of the 2nm profile error and heat load requirements from the x-ray beam, the mirror design is extremely restricted in cooling, bending and supporting conditions. Therefore, adaptive mirrors with piezoelectric actuators attached on silicon substrate are considered as new generation adaptive mirror for x-ray beams. By implementing on the PZT actuators several control electrodes, the deformation of the mirror can be controlled locally to correct the bending caused by heat load and other constraints. Initially the first mirror prototype was under a first inspection at the Optical Metrology Laboratory at HZB in Berlin and is already delivered to the metrology lab for measurements. In this presentation, the FEA thermal and mechanical simulations of the mirror performance will be compared to some measured results. Implementing pulse functions to the metrology algorithm, the bendable mirror should be able to correct heat load, polishing errors and misalignment effects.

***Keywords*:** adaptive mirror, FEA simulation, piezoelectric actuators, X-ray FEL optics, metrology measurements

1. Introduction

The European X-ray free electron laser facility is a complex and technically demanding project under construction in Hamburg area in Germany. Until now, the project has reached certain milestones such as installation of the first components for the accelerator, the electron source and the photon beam transport. In 2017, the high transversal coherence, repetition rate and power level beam will offer new research opportunities for scientists in various areas, e.g. material science, biology infrastructure and serial femtosecond crystallography. In Figure 1, the layout of the photon beamlines and experimental branches are illustrated.

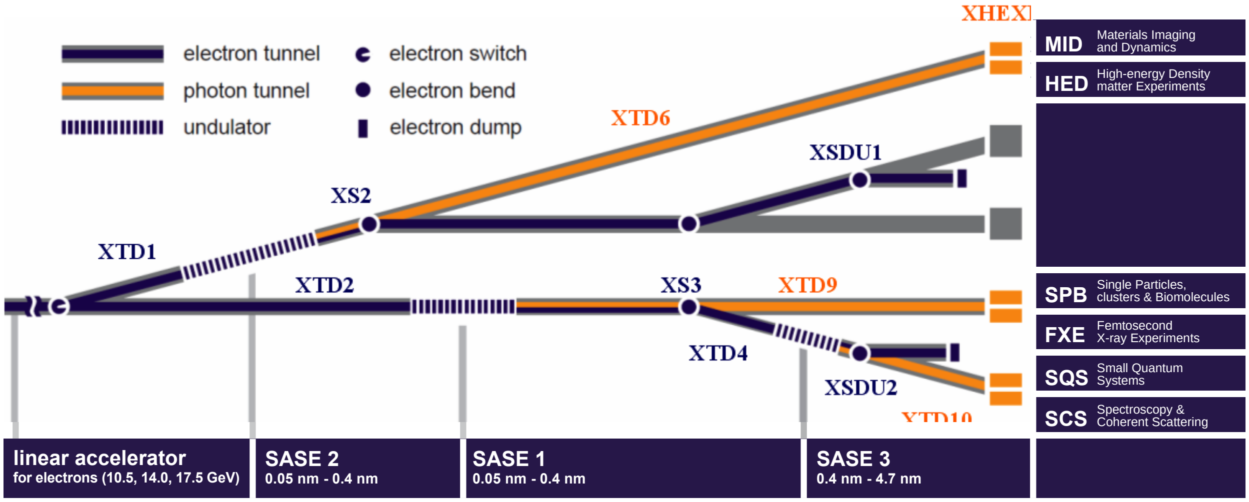

Figure 1. General scheme of European XFEL project beamlines

To transport the high intensity X-rays from the undulator to the experimental hall with a photon range between 0.5 keV and 12.4 keV, the optical components need to fulfill extreme technical requirements and engineering challenges. In this contribution, the first prototype of an adaptive mirror with piezoelectric actuators is described. The system needs to adapt its spherical bending from flat to about 50km of radius of curvature, to compensate thermal deformation and to create an intermediate focus, see Sinn et al. (1989). Moreover, to preserve the high quality of the XFEL beam in all the experiments, it is required that the shape error of the mirror should be at the unprecedented level of better than 2nm peak-to-valley over 850mm optical length.

2. Comparison of the FEA simulation results and metrological measurements

Based on the pioneer work of Signorato, R. et al. (1998), the latest design of adaptive mirror for European XFEL facility has been proposed by Thales-SESO (patent 2011), see Figure 2.

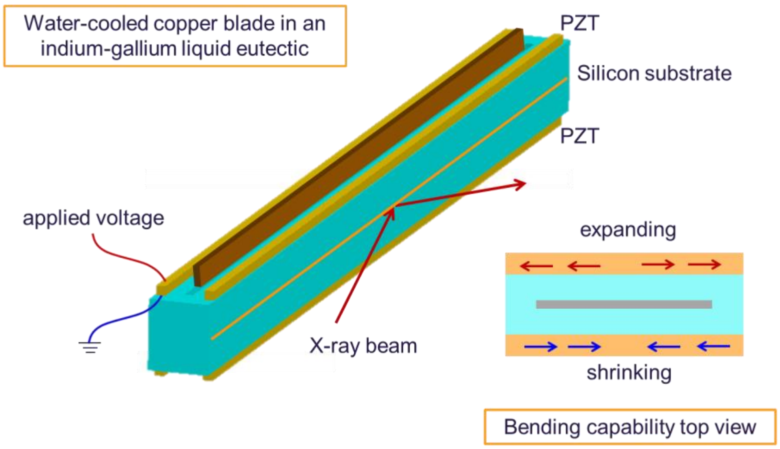

Figure 2. Design scheme of the adaptive mirror for European XFEL beam transport

In this design, the piezoelectric actuators are attached on the side of a silicon substrate instead of building a sandwich structure with inverse polarizations, to prevent possible high heat load related damage to the actuators. The mirror substrate is about 950 cm long with side reflection, and a cooling groove is located on the top of the mirror and filled with indium-gallium eutectic. To reduce the end effect of the glued actuators, the total length of the piezoelectric segments is longer than the 850mm optical length of the mirror. 16 segmented electrodes are attached to the actuators for local shape control. The thermal deformation and stress/strain analysis under spontaneous radiation have been shown in Yang, F. et al. (2012).

Furthermore, applying 1000V on all electrodes, the bending curve of the mid-line on the optic surface is shown in Figure 3 (left) with maximum PV 7.22 micron. Comparing to the measured result of PV 7.09 micron as measured by T-SESO (right), the FEA model delivered relative reasonable results, close to the experimental data.

Affaire : 5174
Fichier source : M0-M10.DAT
Fichier de sauv. : M0-M10C.TXT
Date de sauvegarde : 19 / 4 / 13
Données sur toute la surface
Interféro. Zygo GPI
Dimensions 316 * 177 pix
850 * 41.49 mm
angle de mesure 85° en X
Ecart PV 7.0942 µm
RMS 2.0857 µm
Pentes PV 155.2738 µrad
RMS 21.4863 µrad

zone utile 1 :
Conique de comparaison
Type Meilleure pente
Coefficient 0
Rayon (km) -12.997184
Profil PV .0789 µm
RMS .0237 µm
Pente PV 2.2939 µrad
RMS .3515 µrad

zone utile 2 :
Conique de comparaison
Type Aucune
Coefficient
Rayon (km)
Profil PV
RMS
Pente PV
RMS

Nb de points : 55932
Ecart
PV : 7.0942 µm
RMS : 2.0857 µm
Pente
PV : 155.2738 µrad
RMS : 21.4863 µrad
X : 304
Y : 222
--- (µm)
Moy. de 8 Profils
ZU 1 : 850 mm
ZU 2 : mm
lissage 3
ligne 88

Figure 3. Bending profile of the optic surface: ANSYS result (left) and interferometer measurement performed by SESO (right)

Because of the high flatness requirement on the optic surface, the effect of the glued piezoelectric actuators has also been studied with FEA simulations and verified by metrology measurement. In Figure4, it shows that the effect of the glued PZT on the optic surface completely fades away in less than

10mm from the edge. Therefore, on a width of 30mm the middle section (along longitudinal orientation) of the optic surface, the surface topography is not affected by the glued piezoelectric actuators.

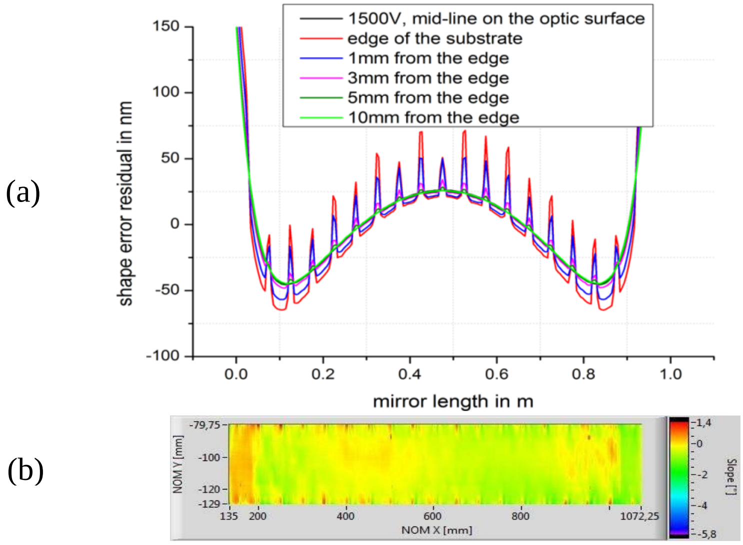

Figure 4. Edge effect on the optic surface: (a) ANSYS result (b) NOM measurement-slope mapping see Siewert F. et al. (2014)

3. FEA simulation of pulse function

The most important feature of this adaptive mirror is the option of a local control of mirror profile, see also former study by Sawhney et al. (2010) on a superpolished mirror of state of the art optical quality. Applying 1000V on each electrode of the prototype sequentially, the FEA results of bending curves and shape error residual are shown in Figure 5. Correspondingly, further metrological measurement methods may be developed referring to these FEA data.

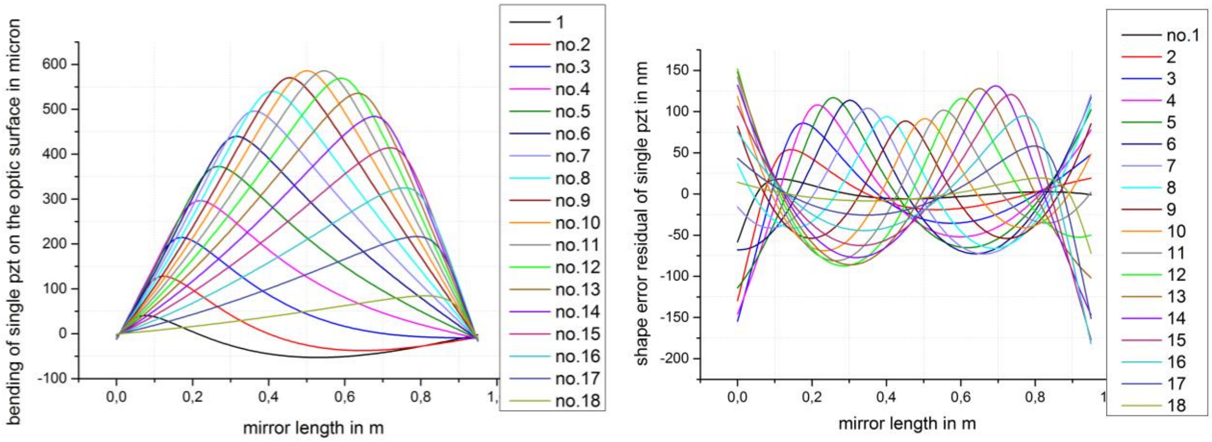

Figure 5. Bending curve on the optic surfacewith 1000V (left)

and the corresponding shape error residual (right)

4. Conclusion

So far the FEM analysis agreed well with the first measurement results (see Fig. 4). The first prototype of this innovative designed adaptive mirror is currently under the metrological testing, as well as the supporting system including the pin supports and the holder frame. Having the metrological data, a better shape of the mirror could be retrieved, as reported in Vannoni, M. et al.(2014). To improve the performance of this adaptive mirror for beam transport, further analysis for its design characterization and optimization are required.

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