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FEM SIMULATIONS FOR A HIGH HEAT LOAD MIRROR

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Abstract

At the variable polarization XUV beamline P04 of PETRA III the first mirror is used to switch the beam between the two branches of the beamline. The heat load on this white beam mirror is dependent on the degree of polarization and the energy of the first harmonic of the synchrotron radiation. For this project the water cooled "notched" mirror approach by Khounsary, and Zhang et al., has been evaluated with FEM simulations. These show promising results for linear horizontal (LH) polarization in which the heat load profile is aligned with the mirror length. For linear vertical (LV) polarization the heat load is concentrated in the mirror centre, which violates the basic concept of the "notched" mirror design and therefore the simulation results indicate only poor performance. To compensate for this a secondary cooling loop has been implemented and will be shown to improve the performance for the LV case significantly. Additionally, a new design approach is evaluated to reduce the peak temperatures of the mirror, which otherwise ranged at 140-180 °C.

P04 VARIABLE POLARIZATION XUV BEAMLINE

Beamline P04 at the 6GeV storage ring PETRA-III is a XUV to soft x-ray facility in the range of 250-3000 eV. The 5 m long APPLE-II undulator allows to change polarization rapidly while achieving high brightness and coherence. The frontend consists of several apertures of which the smallest has a diameter of 4mm. A set of a vertical and a horizontal slit can be used to further reduce the footprint of the beam. The first set of optics at 35 m from the undulator is used to switch between the two branches of the beamline.

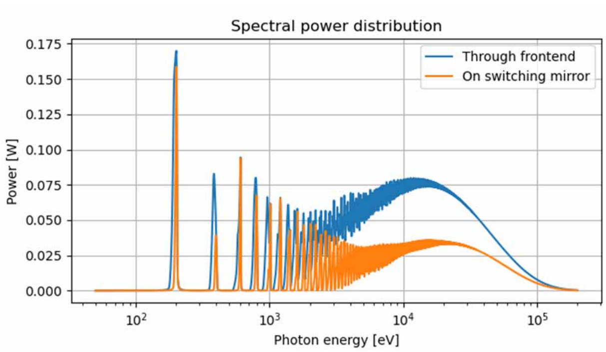

Figure 1: Spectral power distribution with open frontend apertures (blue) and on the mirror (yellow).

This switching mirror unit (SMU) consists of two mirrors facing each other, were one mirror at a time is used to reflect horizontally into its beamline branch at a grazing incidence of 0.8° [1].

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HEAT LOAD CONSIDERATIONS

High K (up to K=7.1) operation of the undulator combined with the high electron energy of the storage ring results in high on-axis heat load due to higher harmonics contributions. Figure 1 shows the simulated spectral power distribution done with SPECTRA [2].

The high flexibility in terms of polarization of the APPLE-II undulator leads to different power distributions for each polarization setting, as the plots in Fig. 2 from OASYS-SRCalc show [3-4].

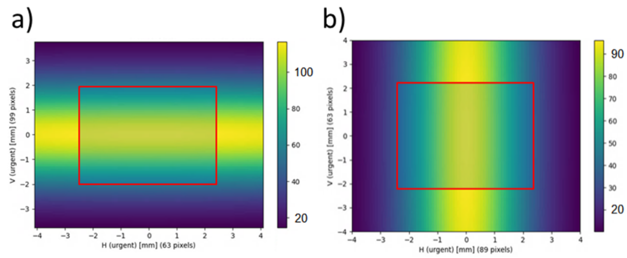

Figure 2: Power density [W/mm²] distribution with open frontend apertures for a) LH and b) LV polarized light. The footprint on the mirror is marked in red.

For LH polarization we expect the highest power on the mirror which will be distributed along the whole length of the mirror (400 mm). LV polarized light has lower absolute values but the power density is focussed in the centre of the mirror (Table 1).

Table 1: Polarization Cases

Polarization	**LH**	**LV**	**Circular**
Total power [kW]	3.90	3.21	0.6
Mirror power [kW]	2.1	1.5	0.3
Max. power den. [W/mm²]	1.66	1.30	0.13

Besides LH and LV polarization all other linear orientations are also possible but aren't broached by this study. The case of circular polarization is easier in terms of heat load considerations, since the higher harmonics are distributed radially and therefore easily cut by the frontend apertures.

NOTCHED MIRROR DESIGN

The water cooled "notched" mirror approach by Khounsary [5] and Zhang et al. [6] has been chosen instead of an internal cooling design as shown by Reininger et al. [7]. This design uses the bulk material of the mirror for stabilization, by cooling only on a small segment on the mirror sides, separated by a notch. By changing the depth of the notch, the profile of the mirror centreline can be shaped for a known heat load. This design favours a uniform heat load distribution along the mirror length, which is incompatible with varying heat loads at first.

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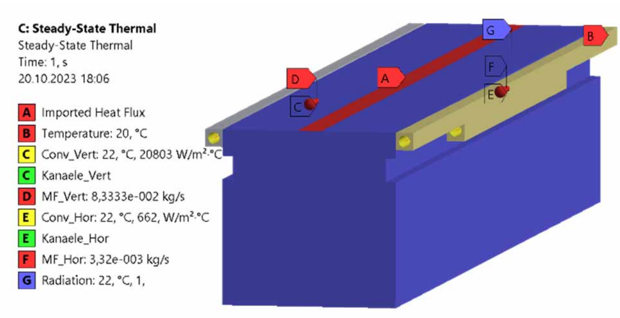

Figure 3: Boundary conditions for SST calculation in Ansys® on notched design.

To overcome this limitation, a second, shorter cooling loop was added, to be able to switch the cooling according to the expected heat load. An Ansys® simulation [8] using a "Steady-State Thermal" (SST) model, which simulates the temperature profile resulting from the beam footprint and the cooling scheme, was set up (Fig. 3). In this model the water is treated as beam like, to allow for the increasing temperature along the mirror length.

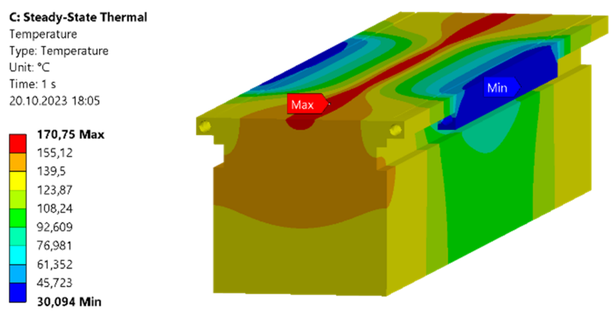

Figure 4: LV polarization on notched design result for SST calculation in Ansys®.

Figure 4 shows a result for LV polarization, where the second, shorter cooling lines take the bulk of the power from the mirror.

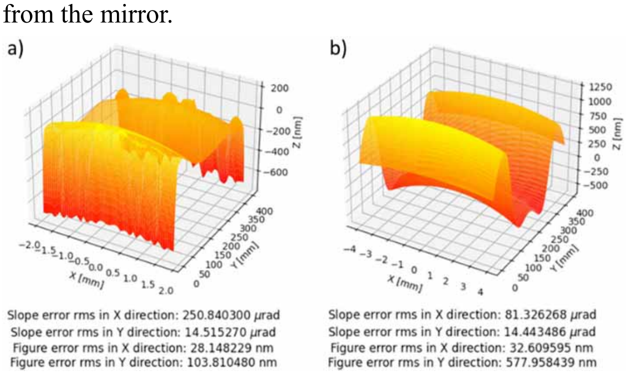

Figure 5: Resulting mirror surfaces for a) LH and b) LV polarization on the notched design.

The result of the SST model is forwarded to a "Static Structural" model in Ansys® to simulate the thermal deformation of the mirror (Fig. 5).

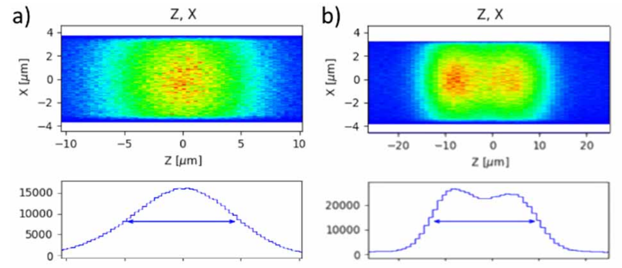

Figure 6: Resulting focus profiles for a) LH and b) LV polarization for notched design.

These are exported to OASYS-Shadow [9], to ray-trace the whole beamline without any deformations and with deformations on the switching mirror. Ray-tracing is done with a monochromatic beam close to undulator resonance of one million rays, which uses mostly the central region of the mirror. The resulting profiles of the beam focus make it easy to evaluate the changes inflicted by surface deformation, even for arbitrary surface profiles. In Fig. 6 the vertical (X) focus size is defined by the exit slit of the monochromator, while the horizontal (Z) size for a beamline with perfect optics should be about 9 µm (FWHM) and gaussian shaped. The LH case comes close, but the LV case has a second focus and double the width (Table 2). The peak to valley (P-V) height of the centreline is measured normal to the mirror surface in the 200 mm long region around the mirror centre.

Table 2: Results for Notched Design

Polarization	LH	LV
Max. temperature [°C]	163.8	170.8
P-V height of centreline [µm]	0.17	0.92
Focus width (FWHM) [µm]	9.81	23.4

DOUBLE BRACKET DESIGN

To reduce the overall temperature the cooling power had to increase, but with the position of the notch, there was very little room for improvement left. On a first try the upper "lips" of the mirror were extended to make space for one cooling bracket on top and a second below the lip on each side. This already reduced the temperature significantly, but the centreline profile now couldn't be influenced by the depth of the notch as before. The notches were removed and it was possible to use the height of the lips for the same purpose instead.

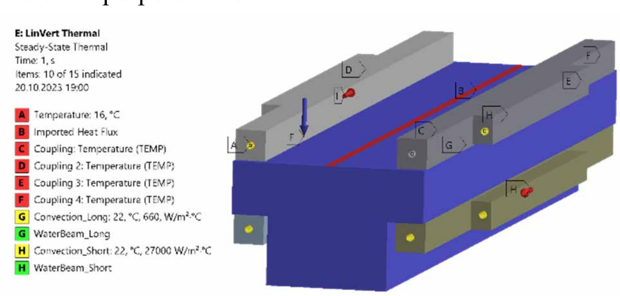

Figure 7: Boundary conditions for SST calculation in Ansys® on double bracket design.

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The boundary conditions for the SST model are similar to Fig. 4, except that the upper water lines are coupled to their lower counterparts to even out the effects of increased water temperature and to minimize the number of individual water lines (Fig. 7). In Fig. 8 the temperature performance of this approach is obvious when compared to Fig. 4. In both cases the shorter cooling lines take the bulk of the power, but Fig. 8 shows a much better contained thermal profile.

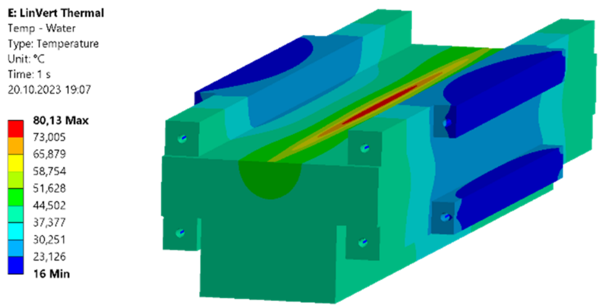

Figure 8: Result for SST calculation in Ansys® for LV polarization on double bracket design.

The resulting mirror profile for the LH polarization looks similar to the already good result of Fig. 5a), while the LV case has improved due to a relative broad and relative flat area in the mirror centre (Fig. 9).

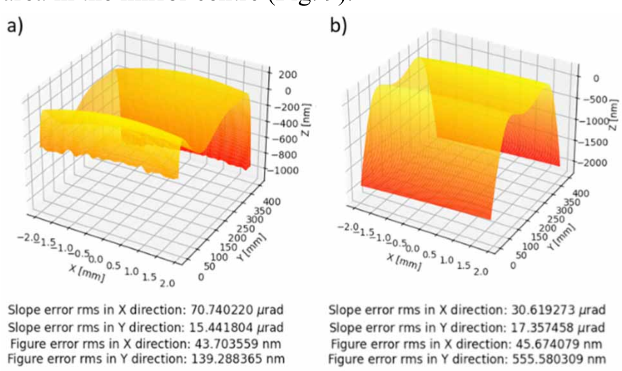

Figure 9: Resulting mirror surfaces for a) LH and b) LV polarization on the double bracket design.

The focus profile for the LH case repeats the performance from the notched design as expected (Fig. 10a)). For the LV case the horizontal FWHM could be improved to 15.5 µm (Table 3) and the profile is focussed to a single point (Fig. 10b)).

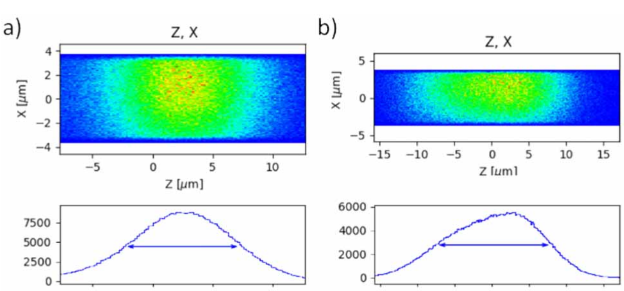

Figure 10: Resulting focus profiles for a) LH and b) LV polarization for double bracket design.

Table 3: Results for Double Bracket Design

Polarization	LH	LV
Max. temperature [°C]	88.76	80.13
P-V height of centreline [µm]	0.16	0.19
Focus width (FWHM) [µm]	9.66	15.52

CONCLUSION

The notched design shows good results in terms of thermal deformation and focus footprint for the LH case. With the second cooling line the LV polarization can be handled too. However, the temperature on the mirror surface is getting far too high, due to the smaller effective cooling area of the second cooling loop.

The double bracket design more than doubles the contact surface of the cooling lines which leads to strongly reduced maximum surface temperatures. This makes improvements for two thermal load cases much easier and improves the thermal deformations especially for the LV case.

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