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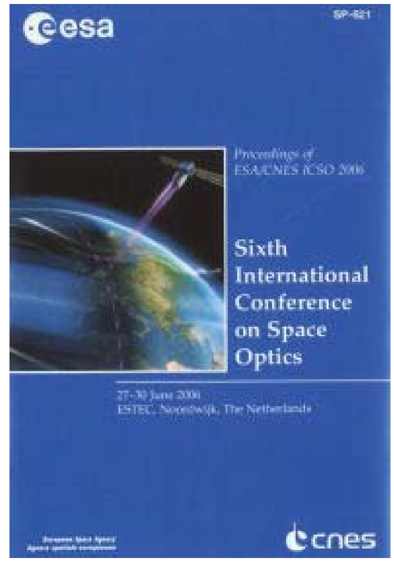

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DESIGN OF AN X-RAY TELESCOPE OPTICS FOR XEUS

Roland Graue[(1)], Dirk Kampf[(1)], Kotska Wallace[(2)], David Lumb[(2)], Marcos Bavdaz[(2)], Michael Freyberg[(3)]

[(1)] *Science and Earth Observation, Kayser Threde GmbH; 81545 Munich, Wolfratshauserstr. 48; Germany,*
Email: roland.graue@kayser-threde.com; dirk.kampf@kayser-threde.com
[(2)] *Science Payload and Advanced Concepts Office of ESA, ESTEC, Postbus 299, NL-2200AG Noordwijk, The Netherlands,*
Email: kotska.wallace@esa.int
[(3)] *Max Planck Institut für Extraterrestrische Physik, Giessenbachstr.1, D-85748 Garching, Germany,*
Email: mjf@xray.mpe.mpg.de

ABSTRACT

The X-ray telescope concept for XEUS is based on an innovative high performance and light weight Silicon Pore Optics technology. The XEUS telescope is segmented into 16 radial, thermostable petals providing the rigid optical bench structure of the stand alone X-Ray High Precision Tandem Optics. A fully representative Form Fit Function (FFF) Model of one petal is currently under development to demonstrate the outstanding lightweight telescope capabilities with high optically effective area. Starting from the envisaged system performance the related tolerance budgets were derived. These petals are made from ceramics, i.e. CeSiC. The structural and thermal performance of the petal shall be reported. The stepwise alignment and integration procedure on petal level shall be described. The functional performance and environmental test verification plan of the Form Fit Function Model and the test set ups are described in this paper. In parallel to the running development activities the programmatic and technical issues wrt. the FM telescope MAIT with currently 1488 Tandem Optics are under investigation. Remote controlled robot supported assembly, simultaneous active alignment and verification testing and decentralised time effective integration procedures shall be illustrated.

Keywords: XEUS; Silicon Optics; Modular Structure; Telescope; Petal

1. INTRODUCTION

The Petals provide the very precise and stable optical mounting base for the Pore Optics, mounted at the Mirror Support Structure (MSS). The Petal with its Pore Optics Tandems (Wolter I configuration) and thermooptical baffles, directly attached at the petal, is designed as thermomechanical stand alone unit. The FFF model envelope is defined by the inner and outer radius respectively and the radian. The FFF Model of the petal is a radially scaled model wrt. the current baseline concept of the Flight Model (FM) petal as given in the Fig. 1.

	FFF Model	FM
Outer radius	2100 mm	2120 mm
Inner radius	1000 mm	630 mm
Radian	20.6 deg	20.6 deg

Fig. 1. Petal Dimensions

There are no programmatic and technical limitations (performance, manufacturing capabilities, etc) to extend the petal to the full FM size. The axial length of the petals is dependant on the radial position of the tandems, the focal length (FM: 35m) and the HEW: goal 2 arcsec, threshold 5 arcsec. The current cross section is given in Fig. 2.

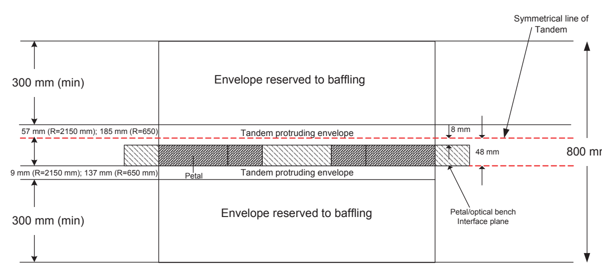

Fig. 2. Axial envelope cross section

Further System aspects are described in reference 1.

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2. THERMOMECHANICAL CONCEPT

Under consideration of the operational thermal environment and the applicable temperature gradients of 20 K/m in lateral and 2 K/m in axial direction the computed operational temperature range of the petal is between 161 K and 138 K.

The FFF Model Petal accommodates (see Fig. 3) 90 simplified Tandem mass dummies and 3 optically effective Tandems. The optical and environmental aspects require a thermally stable Petal and Pore Optics Tandem.

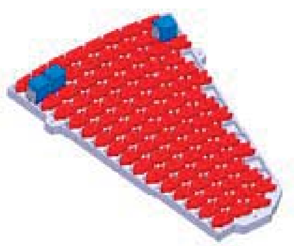

Fig. 3. FFF Model Petal with 3 optical Tandems

The selected Petal structure material is a ceramic matrix composite due to its superior thermo-mechanical figures of merit (low CTE, high strength, high thermal conductivity). The trade off of candidate solutions (geometry, MSS interface and material concepts, thermal concepts, materials) have been performed as given in reference 1. The quasi isostatic mounting interface of the petal to the MSS is given in Fig. 3. Flexible adapters provide the three mechanical interfaces to each Tandem to realize a thermo-mechanical decoupling. During tandem integration a special jig serves as reference for the integration with its own high precision interface. This allows measurement of the reference points at the Tandem, for all theoretical tandem positions, without the petal being present. Therefore, the alignment of the large amount of Tandems using the adapters can be performed independent of the petals. With multiple integration jigs parallel alignment of tandems is possible. The standard "Tandem into Petal" integration step can be accelerated by robot support, providing an at least semi-automatic insertion and alignment of the Tandems in the integration jig. The reference points for the 6 DoF adjustments of the Tandems were designed accordingly for later more effective FM AIT.

3. ERROR BUDGET

The thermomechanical error budgets of the optical system (Pore Optics to the Detector S/C Focal Plane) were assessed wrt.

- Translational lateral and axial displacements
- Distortions (X;Y;Z)
- mirror plates and stacks (High-resolution Pore Optics - HPO)
- Tandem (integration and adjustment/bonding of hyperbolic and parabolic stacks)
- Petal (integration, adjustment and coalignment of Tandems)

in order to define the dedicated alignment requirements for the FFF Pore Optics model.

3.1 System Description

The Pore Optics Tandems (FFF model) are built from two cylindrical HPOs with length L, width W and cylinder radius R. These HPOs are positioned behind each other in Z direction in order to approximate the x-ray optics of WOLTER 1 shape, where a parabola and a hyperbola are used to build a perfect optical system. The HPO-P replaces the parabola, HPO-H the hyperbola part of the Wolter 1 x-ray optics. In order to achieve a good resolution, the length of the mirrors (no curvature in that direction) needs to be limited in order to reduce the image size in the focal plane. The system for one "mirror" only is shown in Fig. 4.

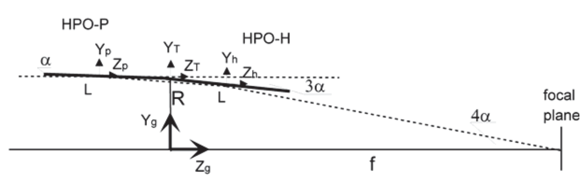

Fig. 4. One mirror layout of the TANDEM with coordinate systems of the telescope, TANDEM, HPO-P and HPO-H

The local coordinate systems are displaced in Z-direction by the length L. With these data a ray-tracing model has been setup using the following parameters:

Focal length f: 50000 mm
Radius R: 2000 mm

Length L: 66 mm
Width W: 54 mm

No ribs as in the real HPO are simulated on the reflecting surfaces creating the pores, as only the optical performance prior and after integration is analyzed. In order to verify the integration tolerances, local coordinate systems are used, as those will be needed during integration and alignment. As these dimensions (length versus focal length) are very small, a graphical layout is not shown. The image expected in the focal plane from this configuration, without scattering (surface roughness, figuring error, pore wall scattering etc.), is shown in Fig. 5. Two different images are presented, a detector with a size of 2” x 2” (left) in linear scale and a detector with 4” x 4” in logarithmic scale in order to see the global image in the focal plane. In order to demonstrate the optical performance with respect to the requirements, 4 additional detectors have been installed in the ZEMAX model, a large 160” x 160” detector to measure all radiation in the focal plane and 3 centered spherical detectors of 2”, 3” and 5” diameter in order to directly evaluate the relative energy as function of errors. Intensity drop due to reflectivity is neglected.

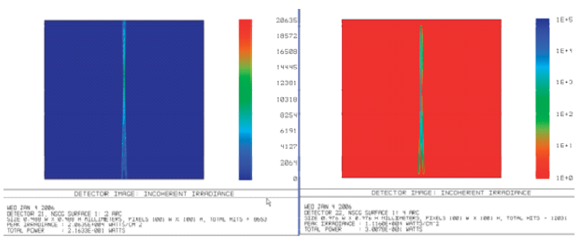

Fig. 5. Spot image in focal plane with 2” x 2” (left, linear scale) and 4” x 4” (right, log scale) detectors

The log scale 4” detector shows a elongation of the spot image of about 660 µm, which corresponds to the length of L = 66 mm of the HPO-P. The length in focal plane DT = 0.66 mm ⇔ 2.7 arcsec. The shape of the spot is due to the cylinder shape of both HPO’s.

3.2 Alignment tolerances

The tolerances to be taken into account for integration of the Tandem into the petal have been evaluated in two independent ways:

- Manual tolerancing
- Optical ray-trace model (50% energy within 2”)

Manual Tolerancing

For the tolerancing of the Tandem integration the local Tandem coordinate system will be used (Fig. 4). All errors to be implemented are named TX, TY and TZ for position and RX, RY and RZ for rotation changes. The sensitivity to misalignments has been analysed.

Fig. 6 shows the actual situation in the focal plane in an optical simulation.

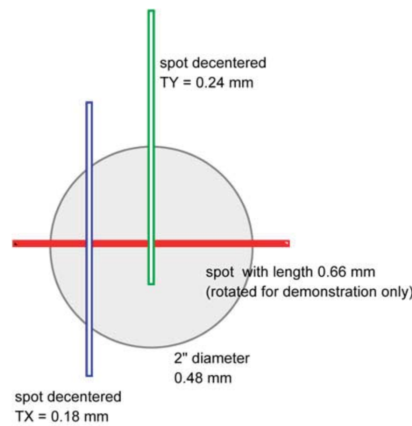

Fig. 6. Focal plane simulation of the current Tandem

- TX decenter

The image of 660 µm length shall be shifted laterally in X-direction to the extent that 50% still remains in the circle of D = 2” = 480 µm diameter. This is achieved with a shift of TX = 175 µm.

This corresponds to the value shown in Fig. 6 achieved with the ray-tracing model (see below).

- TY decenter

A decenter of the Tandem in Y direction would shift the image along the length of the image. In order to let 50% of the image, which is shorter than 4”, remain in the circle of diameter with 480 µm, a shift of TY = 240 µm is allowed only.

- TZ decenter

A decenter of the Tandem in Z direction will provide the same impact as a shift in Y direction, except that the sensitivity drops due to the relation focal length to radius. The effect of a decenter has been estimated for TZ = 6 mm (shifts this large are not expected). As in this assumption the intensity distribution in the spot image is not taken into account, this is a mean of the positive and negative shift in Z-direction

- RX rotation

A rotation of the Tandem around the X axis would result in a reduced effective area only, as the image quality is not (nearly) effected. Assuming a reduction by 10% (no blocking of the next mirrors to the inside has been taken into account) in intensity, a rotation of RX ~ 3.5'can be estimated. As this will change the shape of the image, the encircled energy is strongly dependant on the direction of the rotation. This is shown with the dedicated ray-tracing model

- RY rotation

Due to the cylindrical approximation of the optics, a rotation of the Tandem around the Y axis will result in a lateral X and Y shift in the focal plane. Additionally the image size will be reduced. As this rotation is huge compared to the other errors, the value is achieved with the ray-tracing model only to RY = 1850" = 30'. As the ribs would block the beam with this rotation, only 10% of blocking has been taken into account. With the current free space between two ribs of 800µm, the reduction by 10% results in RY ~ 2'

- RZ rotation

A rotation around the Z axis would mostly result in the same error as a shift in X direction. Therefore the radial position shall be used and the TX value (see above) shall be applied, resulting in a RZ rotation of 18". This is demonstrated with the ray-tracing model, which shows exactly the same errors and lets them be compensated completely.

Optical Ray-trace Tolerancing

The ray-tracing model gives the same results (see Fig. 7) as the manual calculation of integration errors.

Position/Rotation Axis	Error Results
TX	180 µm
TY	240 µm
TZ	+7 /-5 mm (i.e.+/-6 mm)
RX	3.5 arcmin
RY	30 arcmin
RZ	18 arcmin

Fig. 7. Ray Tracing Results

Spot images for different errors present the actual results of ray-tracing calculation.

Fig. 8 shows the results of 4 different calculations:

- No errors, image in the center
- TX = 175 µm, image at the left side
- RZ = 18", image at the right side
- TX = 175 µm and RZ = 18", image in the center, overlayed

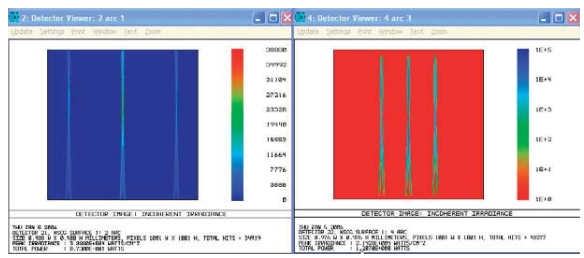

Fig. 8. Spot image in focal plane with 4 calculations (no error, TX, RZ, TX+RZ)

These results demonstrate that these errors can completely be compensated, within the tolerances taken into account, by each other.

Fig. 9 shows the image shift in the focal plane when shifting the Tandem in Y direction for TY = 240 µm, which correspond to 50% remaining energy in the 2" circle.

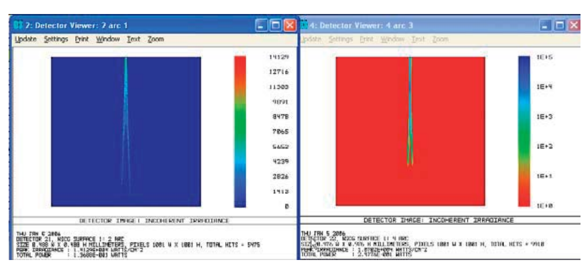

Fig. 9. Spot image in focal plane for TY = 240 µm

Fig. 10 shows the corresponding image as expected for a Z shift of TZ = -5 mm.

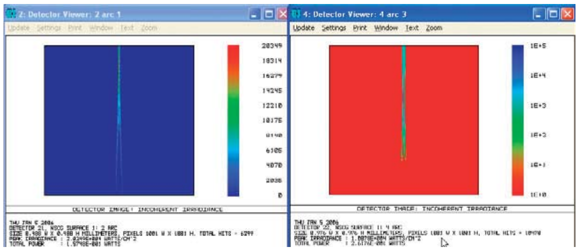

Fig. 10. Spot image in focal plane for TZ = -5 mm

Fig. 11 shows two calculations performed, the rotation RX = 205” with 10” intensity reduction (central image) and RY = 1850” with decentered and miniaturized image (to left top corner).

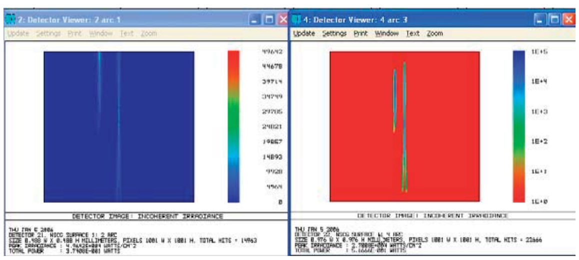

Fig. 11. Spot images in focal plane for two different tolerances, RX = 205” and RY = 1850”

From the spot images presented it might appear, that the rotation around Y axis might be able to be compensated by lateral shifts in X and Y direction. This is demonstrated in Fig. 12, resulting additionally in a performance increase, because 100” energy is within 2” diameter compared to 73% from starting point. Due to the fact that the ribs will be rotated as well, the total throughput would be reduced.

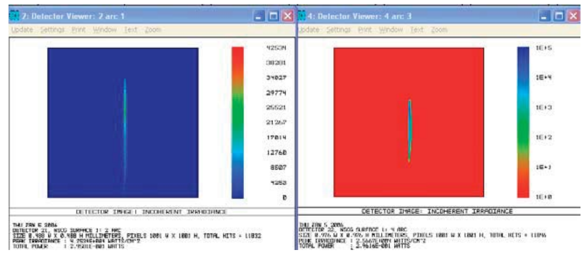

Fig. 12. Spot image in focal plane for RY = 1850” compensated by TX = 70 µm and TY = 240 µm

4. CONCLUSION

The evaluation of the alignment tolerance budget through manual and optical ray tracing modelling has confirmed the principle feasibility of the baseline thermomechanical design and AIT concept of the Pore Optics, based on the autonomous Petal structure with its suspended Tandems.

An optical verification for each Tandem preinstalled in the integration jigs, via the Tandem mounting adapter (and also during alignment), was investigated and is assumed at this time to be possible at Panter Facility, within the context of future projects.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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