Focusing the beam with Focus Finder and XRT at P04 Beamline, PETRA III

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Abstract

The exact position of the focus is crucial in an experiment. Because of the inaccuracy in manufacturing, measuring and assembling, it is hard to predict the exact position of the actual focus. In the P04 XUV Beamline at PETRA III we use Focus Finder to find and characterize the focal spot. But to simplify the procedure of focus finding one can make simulations and use modeling data in future tuning of the optical system. The main purpose of this work is to make simulation of the P04 Beamline optical system with XRT (XRayTracer) package, study the relation between its parameters and position of the focus and compare modeling data with experiment.

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1 Introduction

Let us start with a brief description of the P04 Beamline optical system.
One of the 14 beamlines of PETRA III is the Variable Polarisation XUV Beamline P04, equipped with a 5 m long APPLE-II-type undulator. The undulator consists of 4 magnetic arrays. The period is 65.6 mm. Changing the gap between upper and lower arrays, one can vary the magnetic field and consequently tune the energy of the photon beam from approximately 250 eV and up to 3000 eV.
Therefore we had to adopt the optical design given in Figure 1 [1] especially to be able to cover the required large range of photon energies. As there is no standard coating material available which has no absorption edge in this photon energy range, we had to use at least two coatings on the optical elements. This in turn favored the use of plane optical elements in order to use a simple translation for a change of the coating without the need for re-alignment. As the photon beam divergence and also the vertical source size is already diffraction limited in the full energy range, one may use the uncollimated beam up to the focusing optics in front of the experiment. Therefore the first two optical elements (M_1 and M_2, respectively) can be plane mirrors.

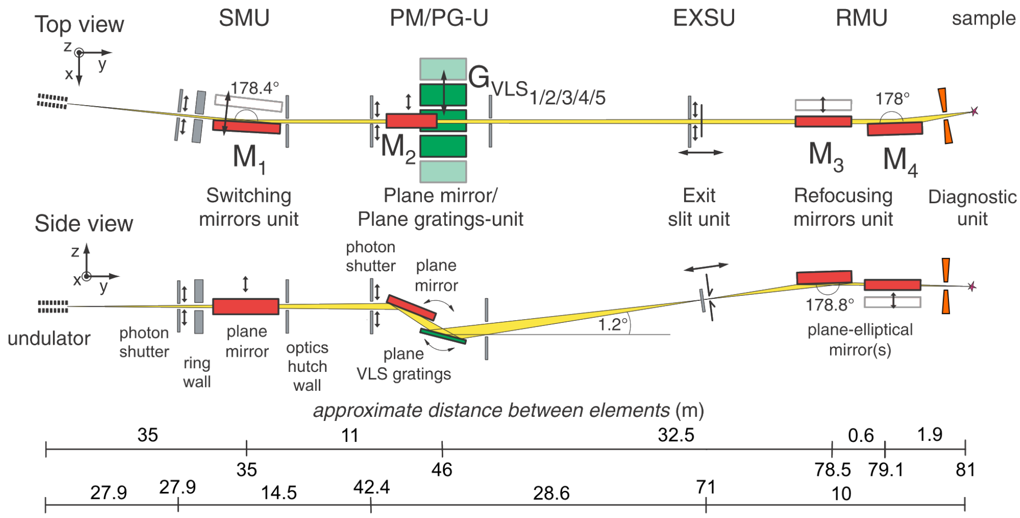

Figure 1: Schematic layout of the Variable Polarization XUV Beamline P04 at PETRA III. The main opto-mechanical components are labeled. This includes the switching mirrors unit (SMU) which distributes the radiation in one of the two branch lines. As a consequence of this, all following components need to be realized twice: the plane-mirror/planegrating-units (PM/PG-U), the exit slit units (EXSU) as well as the refocusing mirrors units (RMU). Both RMU can operate two sets of fixed Kirkpatrick-Baez(KB)-focusing mirror pairs each having two different foci. All optical elements have to be translatable in order to access the two different coatings (Au/Pt or Rh, respectively) required to cover the full range of photon energies.

This project is connected with RMU part of the whole optical system. The focusing onto the different sample areas is performed via two different pairs of mirrors (M_3 and M_4) having a fixed shape in Kirkpatrick-Baez (KB)-geometry [2] in order to achieve simultaneously a vertical and horizontal focus at the given sample plane. The individual adjustment of the horizontal focusing mirror allows to reduce an unwanted effect due to the thermal deformation of mirror M_1 namely the change of the effective source distance and hence of the effective demagnification ratio of the optics.

2 Simulation with XRT

Package XRT (XRayTracer) is a python software library [3] for ray tracing and wave propagation in X-ray regime. It is primarily meant for modeling synchrotron sources, beamlines and beamline elements. Includes a GUI tool for creating scripts - XrtQook. With this package one can create any optical system he/she wants. There are a list of radiation sources such as undulators, wigglers, bending magnets; optical elements like lenses, gratings, plane and elliptical mirrors. You can also add apertures to your optics and screens for being able to control position, shape, and sometimes presence of the beam. Every element has list of properties that you can easily change. After construction of the optical system XrtQook generates for user python script which allows study the behavior of the beam.

One of the basic ideas of the work was to make a simulation of the P04 Beamline optical system in XrtQook and study the influence of changing RMU parameters on the position of the horizontal and vertical focus.

Previously, it was found that changing pitch of the elliptical mirror always leads to movement of the focus position away from the optical axis. Therefore the simplest way to return focus back to the optical axis is to shift elliptical mirror in opposite direction. So, it is useful to know the relation between pitch and shift of the elliptical mirror for both horizontal and vertical foci. We should keep in mind that described above actions return focus to the optical axis but not onto the previous position, and to new position along the beamline. It means that we also should know the relation between pitch of the mirror and longitudinal shift of the focus position.

In this work original XrtQook script was modified for our aims and now allows us to get horizontal and vertical profiles of the beam for every set of parameters (new pitches and shifts of the elliptical mirrors). Typical pictures of profiles from XRT calculation are shown in Figure 2.

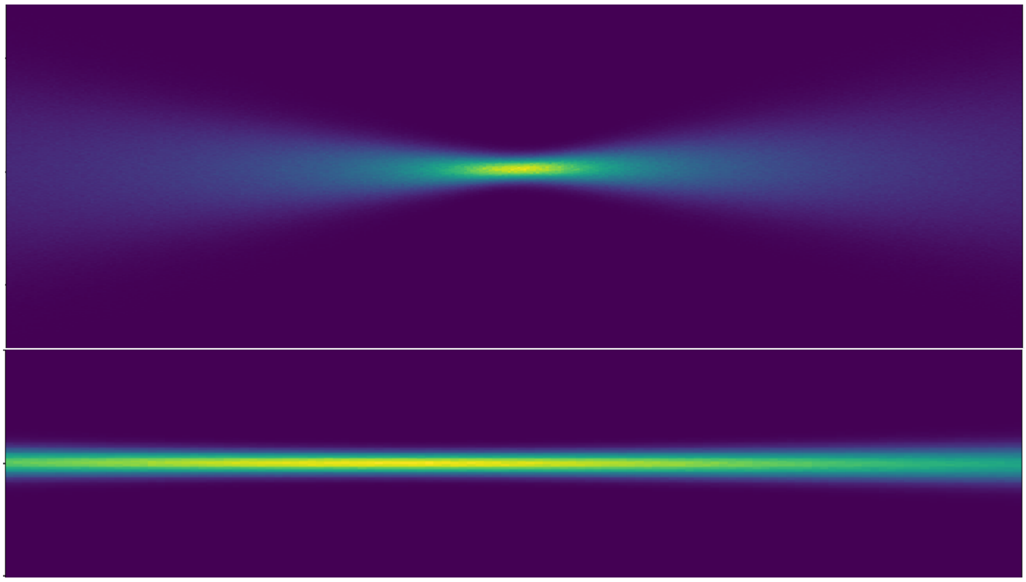

Figure 2: Horizontal (top) and vertical (bottom) profiles of the beam obtained with XRT.

Spending a lot of time simulating profiles for different sets of mirrors' parameters we have found the relations mentioned above. But another idea of this project is to compare results from XRT-modeling with experimental data from the Beamline. So that model results will be shown below in compare with experiment.

3 Experimental measurements with Focus Finder

3.1 A few words about Focus Finder

The purpose of the Focus Finder is to find and characterize the focal spot of the P04 XUV Beamline at PETRA III [4], but likewise of any focused X-ray beam. The device is ment to simplify and speed up the calibration and allignment of a beamline and its optical components. Scheme and actual view of the Focus finder are shown in Figure 3.

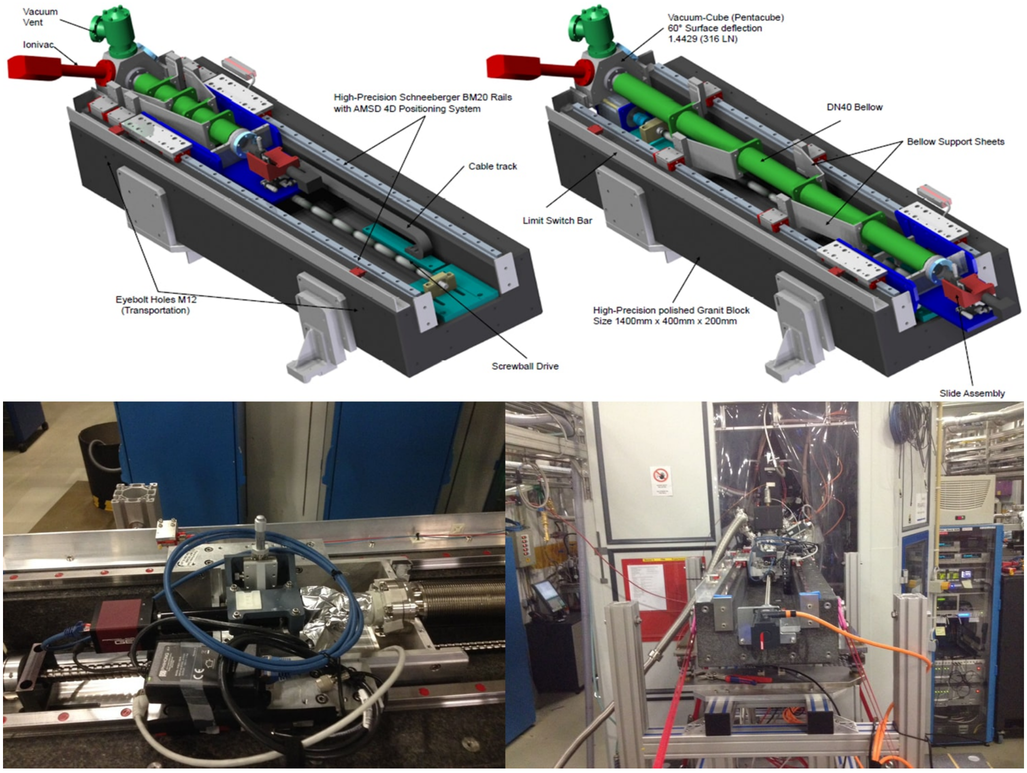

Figure 3: General scheme of the Focus Finder platform (top) and actual view of the platform itself (bottom)

The working principle is optical analysis of the longitudinal beam shape. A YAG-Screen is used to make the X-ray radiation visible for the high resolution camera. Mounted on a precision slide, images of the current beam-shape are taken and processed in MATLAB. The image with the minimum number of illuminated pixel corresponds to the focus. Examples of horizontal and vertical profiles of the beam (with zoom) obtained with Focus Finder are shown in Figure 4.

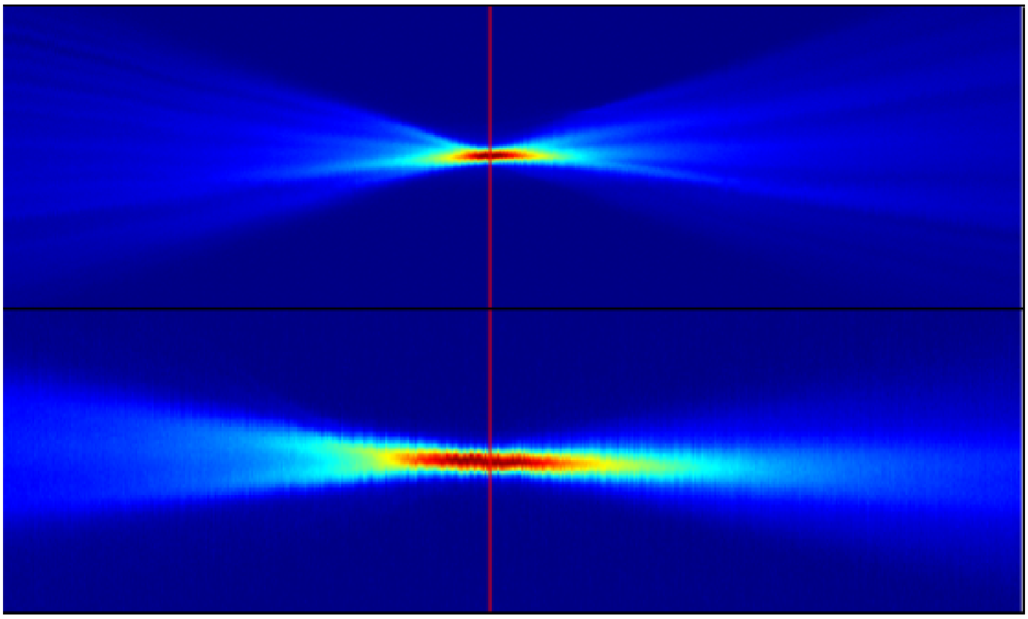

Figure 4: Horizontal (top) and vertical (bottom) profiles of the beam obtained with Focus Finder. Red line indicates position of the focus

3.2 Results

In this section one can find the comparison between results of XRT-simulation and experimental data of Focus Finder algorithm. But before presenting results it is necessary to introduce some notations adopted for various parameters of optics.

Hrotz - pitch of the horizontal elliptical mirror;
Hx - corresponding shift of the horizontal mirror for returning focus position back onto optical axis;
Vrotx - pitch of the vertical elliptical mirror;
Vz - corresponding shift of the vertical mirror for returning focus position back onto optical axis.

First objects for discussion are relations between pitches and corresponding shifts for both horizontal and vertical mirrors. Results for these cases are shown in Figure 5 and Figure 6.

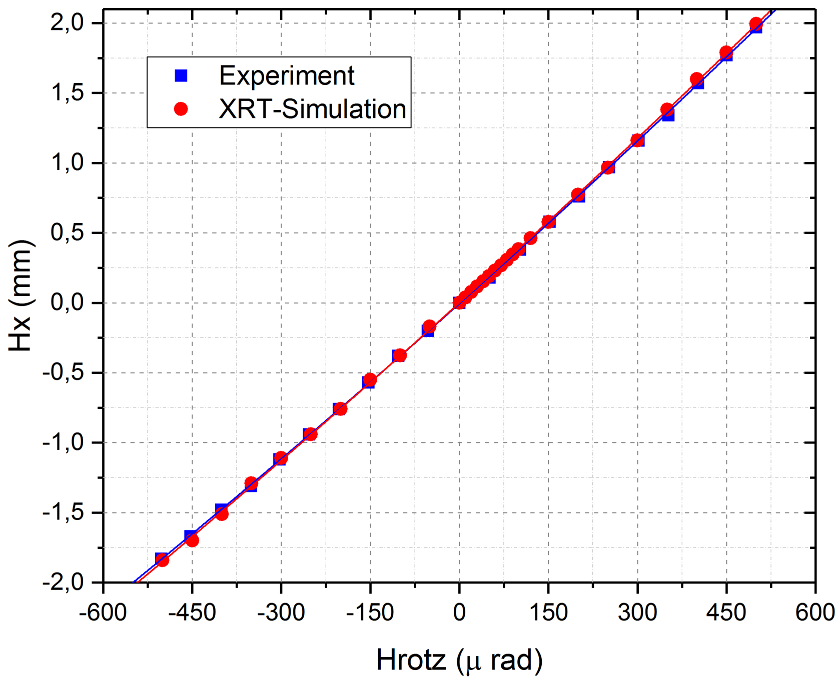

Figure 5: Relation between parameters *Hx* and *Hrotz*. Simulation and experimental data.

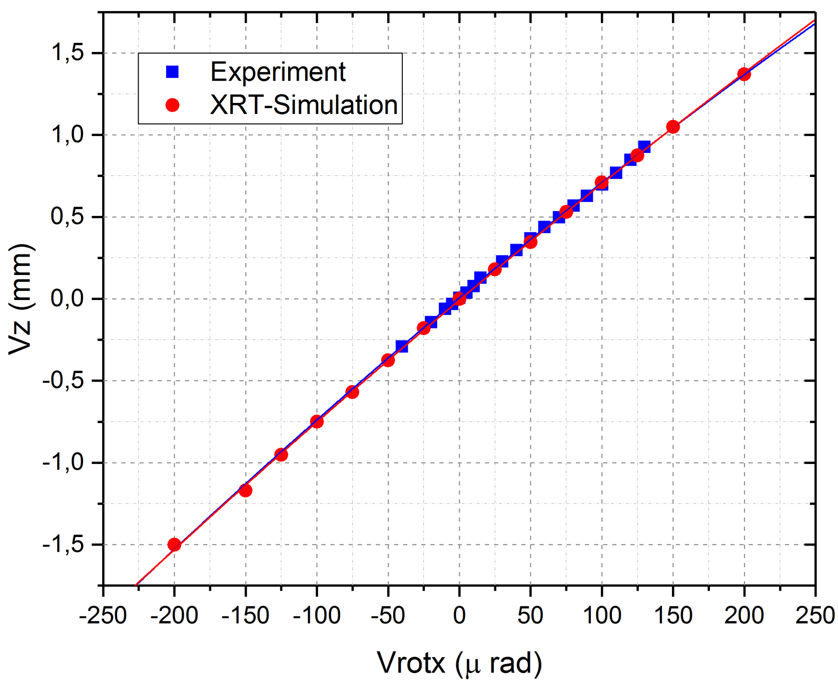

Figure 6: Relation between parameters *Vz* and *Vrotx*. Simulation and experimental data.

Obviously we found very good agreement between simulation and situation in real optical system.

It is worth noting that in simulation with XRT we imposed restriction for the physical limits of mirrors' size. Therefore plots have limits for parameters *Hrotz* and *Vrotx*, i.e. if we try to pitch the mirrors by larger values then beam does not reach the final screen and stop on the elliptical mirror. Taking into account that we have elliptical mirrors of cylindrical shape it can be expected the quadratic behavior of discussed relations. That is the reason why we have fit all the data with second-power polynomials. As one can see this assumption is well correlated with the data obtained.

Next step was to study relation between mirrors' pitches and shift along the optical axis (when the focus have already returned back to it). Corresponding plots are shown in Figure 7.

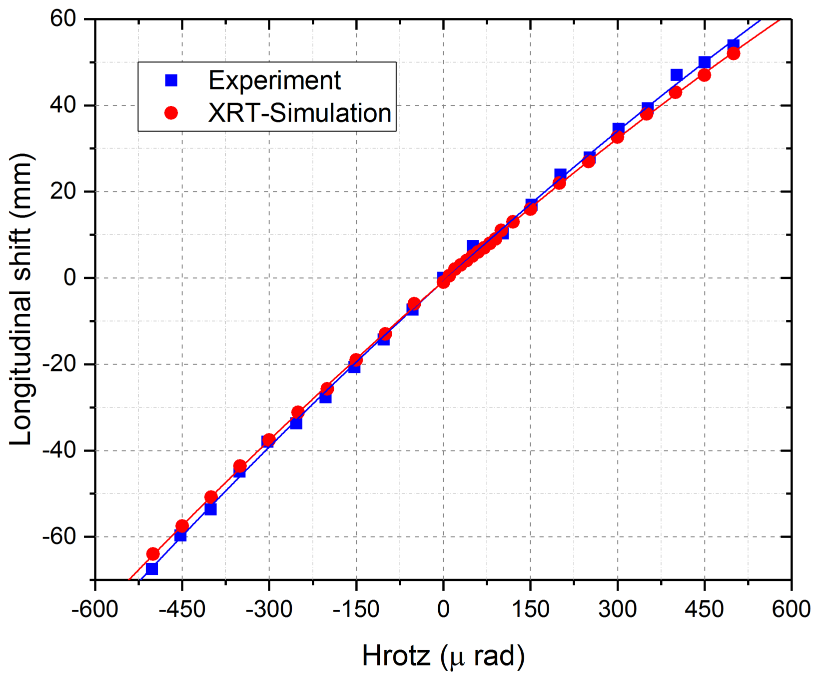

Figure 7: Relation between longitudinal shift of the focus position and *Hrotz*. Simulation and experimental data.

In this case we have not so good agreement as in previous relations. One of the explanations of such discrepancy is that after making profile with XRT we have no algorithm to find the exact coordinates of focus - the problem becomes the user's responsibility. And of course the accuracy in definition of longitudinal coordinate is worse than accuracy in definition of vertical coordinate (because we have asymmetrical region with the highest intensity of the beam in terms of these directions - it could be easily seen from Figure 2). Nevertheless, observed picture is satisfactory and simulation is not in deep contradiction with experiment.

4 Conclusions

Studying the RMU part of the P04 Beamline optical system with XRT shows us that for future preparations and focusing of the Beamline we can use XRT-simulations to find needed positions of optical elements. XRT gives a good opportunity to predict positions of horizontal and vertical foci, so that procedure of system optimizing could be really simplified. One of the slight drawbacks of working with XRT is that if user wants to have profiles (horizontal and vertical) with high resolution then every calculation takes very long period of time. However, it is clear that in case of beamtimes it is better to have necessary relations between different parameters in advance, then users will have more time to study main problem.

5 Acknowledgements

At first I want to thank DESY Summer School organization team for given opportunity to take part in such school and to have an experience in working with international team of scientists. Also I am incredibly grateful to my supervisors: Kai Bagschik - for his great contribution to this project and spending a lot of time explaining different mistakes and technical moments of using XRT; Jens Viefhaus - for leading of our group, support on different steps and for given chance to assemble some parts of experimental setup by myself. Furthermore I want to thank Jens Buck for explaining the technical sides of the beamline.

References

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