Status of PETRA III photon beamline frontends and optical systems

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The status of the PETRA III photon beamline frontend components and major optical components will be reported. In the frontend, the design of filter systems, high power slit systems, beam position monitors and CVD screens followed a generic approach. This allows the use of the same components in four single undulator and five canted undulator sectors with a total of 14 beamlines. A generic cryogenically cooled high heatload monochromator has been developed and installed at the beamlines. Large mirror systems for higher harmonic suppression, collimation and basic focusing have been tailored towards the need of the specific beamline. The goal of a 1% top-up operation with 100 mA, and the 1 nmrad emittance operation of PETRA III has been achieved and is provided in the user runs. The beamline and optics concepts proved to be robust and versatile during the commissioning and the user operation of all beamlines. The components and systems are now further developed for enhancing the capabilities of the beamlines.

1. PETRA III
In the following, the design and implementation for the frontend and optical components at PETRA III beamlines are described. The technical design report for PETRA III [1] is the reference for the whole project and also provides the physics cases for the beamlines and the experimental stations. Here, the generic systems approach [2] is presented. In particular, technical solutions special to PETRA III are highlighted.

The angle between two beamlines in a canted undulator sector at PETRA III is 5mrad. There are no bending magnet beamlines between the undulator sectors due to the space constraints on the experimental floor. Still, the photon beam separation between two beamlines is small. The parallel, independent operation of two undulator beamlines in a canted sector is accomplished by installing a jacket pipe in the high heat load monochromators, allowing the adjacent beam to pass through the vacuum vessel. Further special optical systems, large offset monochromators (LOM [3]), are installed in sectors where the natural displacement between the experiments at adjacent beamlines is insufficient. All systems are designed for a future machine current of 200 mA; the present machine operation is capped at 100mA. The top-up mode of PETRA III has to be taken into account in respect to the radiation protection and the thermal management considerations of all components.

2. Photon Beam Frontend
All systems dealing with the white undulator photon beam are located inside the photon beam frontend. The vacuum system, apertures and slit systems for the white beam, and the absorbers and shutters for the radiation protection are installed on a girder system with 5 granite girders. Each girder
Figure 1. PETRA III undulator frontend. A granite girder system carries all frontend components. A mounting rail inserted in the top side of each granite is used to align and fasten the components. In the case of the canted sectors the granite benches carry two rails each and the components are mounted in an interleaved fashion. The frontend components start from the left at the PETRA III machine girder with a large ion getter pump to isolate the storage ring vacuum system from the frontend vacuum system. The vacuum chamber with an ion getter pumps behind the storage ring wall inside the optics hutch serves as the interface towards the optics hutch vacuum system.

2.1. Radiation Protection Interlock Systems
The frontend as shown in figure 1 has to guarantee the fulfillment of the radiation protection interlock (RPI) requirements. The relevant systems are the dump magnet and the Bremsstrahlung shutter, which is protected by a photon shutter.

The dump magnet is a requirement due to the top-up mode of the storage ring operation. The magnet prevents that positrons travel along the photon beamline in the case of a failure of the bending magnet downstream of the undulator.

There are two white beam slit systems [4] installed. The first system at 19m from the source collimates the beam in the vertical direction only and takes some of the thermal load. The second system at 28m acts as vertical and horizontal slit system and additionally as a photon shutter. This system is opened and closed by a pneumatic cylinder. The free aperture in the open setting is controlled by stepper motors. In the closed setting the slit systems acts as the photon shutter and protects the uncooled Bremsstrahlung shutter. To ensure that a failure of the photon shutter does not harm the Bremsstrahlung shutter, a special uncooled burn through sacrificial absorber is put into the beam path downstream the photon shutter after closing the photon shutter. The absorber is directly connected to air and melts and vents the vacuum system in the case of a failure of the photon shutter. This absorber carries the limit switches for the RPI and replaces the usual RPI switch systems at the photon shutter. This arrangement takes the complex photon shutter out of the validation process (switches, cooling water flow, and temperature) of the RPI.
2.2. Vacuum- and Technical Interlock Systems

This interlock monitors the vacuum and technical status of the frontend components and allows the control of the vacuum system components. It prevents venting the storage ring due to technical or human failures at the vacuum system side. In this case a fast acting valve is triggered by pressure sensors located in the optics hutch. The interlock takes care of avoiding damage of components and unnecessary dumps of the stored beam by closing of the photon shutter for all events downstream the photon shutter, i.e. vacuum valves closed by failures, or excessive temperatures. For all slow events, i.e. pressure and temperature rises upstream of the photon shutter, the interlock will try to open the undulator gap and will only dump the stored beam in case opening the undulator gap fails.

The interlock system is realized by a combination of soft-PLCs connected via EtherCAT [5]. The user interface is generated by separate web-servers and provided either directly via touch panels or by web-browsers via network connections.

3. Frontend Components for setup and alignment

Additional components have been installed into the frontend to allow an easy mechanical setup and alignment, the commissioning, and the operation of the beamline. A laser system with two CVD diamond screens [6] in the frontend allows for an inspection of the alignment of all components along the beampath. The same uncooled CVD screens are used as fluorescent screens in a 1mA machine operation with closed undulator gaps. This mode is used for the beamline setup in order to verify and adjust the direction of the white undulator beam.

4. Generic Optical Systems

A generic approach for the design of the major optical systems is design time and cost efficient, and also speeds up the installation. The parameters of all frontends and basic optics are similar enough to follow this approach. The basic features of the cryogenically cooled high heat load monochromator and the design of the new mirror support will be discussed.

4.1. High Heat load Monochromators

The parameters for the fixed exit high heat load monochromators and the boundary conditions of the canted undulator sectors lead to a generic design for all beamlines [7]. The energy range of the monochromator is determined by the installation of two crystal sets with Si-111 (2.4 keV to 54 keV) and Si-311 (4.6 keV to 103 keV) crystal pairs. The whole monochromator vessel can be shifted perpendicular to the incoming white beam to select the appropriate crystal set. Additionally, a jack system provides the height adjustment relative to the incoming beam, and the yaw rotation of the whole monochromator allows to shift glitches in the monochromatic beam.

The monochromator design is based on a directly driven goniometer which provides the rotation of the crystal cage inside the vacuum chamber. The crystal cage carries the crystal sets, the fixed exit mechanics and the fine adjustment stages for pitch and roll directions of the crystal sets. The Bragg motor is a 3-phase torque motor with an accuracy of 0.1 arc sec over 50 degrees of Bragg angle. The closed loop control system for the Bragg axis has an internal encoder resolution of 960000 increments/degree Bragg angle.

The crystals are indirectly cooled via liquid nitrogen cooled copper plates. The high pressure cooling circuit is driven by a closed loop cryo-cooler system [8]. The cryo-cooler systems at all beamlines are refilled by a central liquid nitrogen distribution system.

4.2. Generic Mirror Systems

In order to provide basic optics for collimation, focusing and harmonics rejection, new mirror systems for up to 1m long mirrors have been developed. The mirrors are mounted inside the vacuum chamber. All degrees of freedom for the alignment, selection of optical surfaces and coatings, and the glancing angle adjustment are realized by a stacked motion system carrying the vacuum chamber. The mirror
Benders are pneumatically actuated [9] with a closed loop pressure control system. In the course of the mirror system development the need for an enhanced mirror support, both for plane and bend mirrors became obvious. The manufacturing quality of these large scale mirrors is in the 0.2 µrad to 0.5 µrad RMS slope error range and the residual tangential radius left by manufacturing errors is in the 200 km to 1000 km range. These values must be preserved while mounting the mirror to the support. The large distances at the PETRA III beamlines also require a controlled tangential bending radius of 2 km to 20 km in order to either focus or collimate the beam. Figure 3 shows the new hanger mounting scheme, figure 4 illustrates the addition of a bending mechanism for a face down mirror.

**Figure 3.** Mirror mounted into the new hanger mount. The new distributed clamping positions along the mirror largely reduce the distortions compared to the conventional Bessel point support positions.

Example: L=1000mm, A=510mm, B=265mm

**Figure 4.** The hanger mount is used as the stable basis for a four point mirror bender scheme. The mirror, hanger mount and the bender arms are mounted into a vacuum chamber. The bending forces are transferred by a system with two bellows in order to compensate differential vacuum forces at the feedthroughs.

5. Summary and Acknowledgement

PETRA III went into operation in 2009. The frontend and optical systems proved to be robust and versatile for the commissioning and for the user operation of all beamlines. The presented systems are now further developed to enhance the capabilities of the beamlines.

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