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The PETRA III Extension

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Abstract. The 3rd generation low-emittance 6 GeV PETRA III facility has been substantially modified to add new beams. This extension project involved the complete removal and reconstruction of part of the storage ring with a double-bend achromat lattice as well as the construction of two new experimental halls. Making use of two long straight sections and a canted undulator scheme in the rebuilt arcs, up to ten new insertion device beamlines can be accommodated. In the current phase of the project, seven insertion device and one bending magnet beamline are being implemented.

OVERVIEW

PETRA III is a low-emittance 6 GeV storage ring having evolved from the conversion of the 2.3 km PETRA accelerator into a 3rd generation light source since 2007 [1]. Today, a total of 14 undulator beamlines with 15 experimental stations operating in parallel for high-brilliance techniques are in user operation in the Max-von-Laue experimental hall which covers 1/8 of the storage ring. In order to extend the experimental capabilities with more beamlines, a major reconstruction started in February 2014 adding two smaller halls in the north and the east of the present Max-von-Laue hall by making use of two long straight sections and part of the adjacent arcs (Fig. 1) [2].

The northern straight section already accommodates a series of damping wigglers producing an extremely hard X-ray beam while the eastern straight is available for additional insertion devices (IDs). For the implementation of ID beamlines also in the original arcs, the machine lattice had to be modified to allow for suitable straight sections. Due to the large machine radius, the use of the arc sections for X-ray bending magnet beamlines is not feasible. During the reconstruction, the existing ring tunnel at the site of the new buildings had been completely removed and rebuilt as part of the experimental halls. In the east, the tunnel lies below ground level resulting in a complex reconstruction scenario. After eleven months of shutdown, the rebuilt machine had been re-commissioned for operation of the existing beamlines while in parallel the completion of the new halls and installation of new beamlines continued [3]. The initial project phase comprising the implementation of seven new X-ray ID beamlines and one VUV bending magnet beamline will be completed in 2018.

FIGURE 1 Two new experimental halls in the north and the east have been added to the PETRA III storage ring. The initial 14 beamlines are located in the Max-von-Laue hall.
STORAGE RING RECONSTRUCTION

In order to allow for the use of insertion devices in the northern and eastern arc sections, the existing cell structure (with 5.3 m long dipoles) has been partly replaced by double-bend achromat (DBA) cells using 1 m and 0.5 m dipoles. Similar to beamlines in the Max-von-Laue hall, the straight sections between the DBA cells are shared by two independent 2m long IDs by using a canting dipole in the middle of each cell. For the PETRA III Extension, a canting angle of 20 mrad was chosen to allow for sufficient space downstream for photon science instrumentation. The new lattice configuration with two DBA cells is shown in Fig. 2 for the northern arc. A high-β optics was chosen for all ID sources. The lattice modification implies a change in the synchrotron integrals \( I_2 \) and \( I_5 \) resulting in a 20% emittance increase. The measured horizontal emittance after storage ring re-commissioning was 1.2 nmrad, the coupling being 1%. The main machine parameters are summarized in Tab. 1.

Two 60m long arc sections of the storage ring, adjacent to the long straights, were completely reconstructed. In order to accommodate the beamline front ends, 80m long segments of the concrete tunnel were demolished and later rebuilt as part of the new experimental halls on a common thick concrete slab together with the canted beamlines. Both straight section IDs, however, remain on the original, separate concrete foundation.

The damping wiggler section was left unchanged, only the end piece of the high-power photon absorber will be replaced to extract a 3x2 mm\(^2\) cross section of the on-axis photon beam. The downstream part of the eastern long straight section (total length 108m) will be modified to realize two straights of 5m length with \( \beta_{\text{hor}} = 20 \) m and \( \beta_{\text{vert}} = 3.5 \) m for use of a 4m long \textit{in-vacuum} undulator and a canted (1mrad) 2m long side station ID. The new ID vacuum chambers (extruded NEG-coated aluminum profiles with 7 mm aperture) allow for a minimum magnetic gap of 9.5 mm. The impedance increase is about 40%, which is expected to be compatible with 40 bunch mode operation at 100 mA total current.

- **Energy**: 6 GeV
- **Circumference**: 2304 m
- **Emittance (hor. / vert.)**: 1.2 / 0.012 nm rad
- **Total current**: 100 mA
- **Number of bunches**: 960 / 40
- **Bunch population**: 0.5 / 12 \( \times 10^{10} \) e
- **Bunch separation**: 8 / 192 ns

Two 60m long arc sections of the storage ring, adjacent to the long straights, were completely reconstructed. In order to accommodate the beamline front ends, 80m long segments of the concrete tunnel were demolished and later rebuilt as part of the new experimental halls on a common thick concrete slab together with the canted beamlines. Both straight section IDs, however, remain on the original, separate concrete foundation.

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TABLE 1 PETRA III parameters incl. extension

| Parameter          | Value   |
|--------------------|---------|
| Energy             | 6 GeV   |
| Circumference      | 2304 m  |
| Emittance (hor./vert.) | 1.2 / 0.012 nm rad |
| Total current      | 100 mA  |
| Number of bunches  | 960 / 40 |
| Bunch population   | 0.5 / 12 |
| Bunch separation   | 8 / 192 ns |

The design of the new beamlines is based on the PETRA III generic beamline concept [6,7]. All frontend components have been pre-assembled and aligned on girders for precise and timely installation during the reconstruction (Fig. 3). The canted beamlines are crossing the tunnel concrete shielding at 50 m from the source.
resulting in considerable total lengths up to 110 m, beamline P21 - using the eastern long straight section – extends up to 164 m. The canted beamlines in sectors 2 and 3, i.e. the modified arc sections, share a common optics hutch in each sector for the X-ray optical components such as monochromators, primary mirrors, etc.

| TABLE 2: Insertion device parameters (beam current 100 mA) |
|-------------------------------------------------------------|
| Parameter                      | DW | U21 | U29 | U32 | U33 | U33s |
| minimum magnetic gap (mm)      | 24 | 7.0 | 9.5 | 9.5 | 9.5 | 9.5  |
| period length λ0 (mm)          | 200| 21.2| 29.0| 31.4| 32.8| 32.8 |
| device length L (m)            | 10 x 4| 67 | 61 | 58 | 10 |
| number of periods              | 10 x 19| 184 | 61 | 58 | 10 |
| peak field B0 (T)              | 1.52| 0.71| 0.81| 0.88| 0.88| 0.88 |
| deflection parameter Kmax      | 28.4| 1.41| 2.2 | 2.7 | 2.7 | 2.7  |
| energy of 1st harmonic (keV)   | 35.8 (Ec) | 8.3 | 3.5 | 2.4 | 2.3 | 2.3  |
| total power Ptot (kW)          | 10 x 21| 4.6 | 3.0 | 3.5 | 0.60| 0.60 |
| on axis power density (kW/mrad²) | 10 x 44| 188 | 76 | 80 | 75 | 13  |
| power in 1x1 mm² at 40 m (W)   | 121 | 115 | 47 | 49 | 46 | 8   |

**FIGURE 3** Frontend of a canted undulator sector. a: CVD diamond screen and vacuum valve b: vertical slits c: dump magnet d: vert./hor. photon shutter slit system and filter unit e: Bremsstrahlung collimator and beamstop f: concrete shielding wall

**BEAMLINES**

In the current project phase, seven insertion device and one bending magnet beamline are being implemented, whereof three ID beamlines are realized in collaboration with international partners. Four ID beamlines for hard X-ray techniques are being built in hall east (P21-P24) and three in hall north (P61, P64-65) while three beamports (P62-63, P25) are left open for future options (beyond 2018). A bending magnet beamline (P66) for VUV spectroscopy is located in a separate enclosure outside hall north. Beamlines P22-23, 64 will be equipped with an improved version of the PETRA III LN₂-cooled DCM [8]. Beamline P64 will receive an additional cryo-cooled fast power in 1x1 mm² at 40 m (W)
scanning channel-cut monochromator for time-resolved X-ray absorption spectroscopy. Table 3 summarizes the main characteristics of the new beamlines, which will be implemented in three stages. Stage 1 beamlines P64-65 for XAFS applications are planned to start commissioning in Sept. 2015.

**TABLE 3.** PETRA III Extension beamlines. Beamlines are distributed between hall east (P21-25) and hall north (P61-65). Bending magnet beamline P66 is separate and close to hall north.

| Beamline | Applications/Instruments | Insertion Device | Energy Range (keV) |
|----------|--------------------------|-----------------|-------------------|
| P21      | High-energy X-ray materials science (Swedish beamline)  
broad band diffraction (fixed-energy side station)  
in-situ WAXS/SAXS and imaging | 2m U29  
4m in-vac. U21 | 52, 85, 100  
40 – 150 |
| P22      | X-ray spectroscopy (Indian-German beamline)  
hard X-ray photoemission\(^1\) and energy filtered PEEM\(^2\) | 2m U33 | 2.4 – 15 |
| P23      | X-ray nano-diffraction\(^1\) (German-Russian beamline)  
X-ray diffractometry at meso- and nanoscopic scales | 2m U32 | 5 – 35 |
| P24      | Chemical crystallography : materials & small molecules in complex sample environments\(^1\) | 2m U29 | 8 and 15 – 44 |
| P25      | t.b.d. | t.b.d. |
| P61      | High-energy X-ray materials science  
engineering materials diffraction techniques (HZG)\(^4\)  
extreme conditions in a large volume press\(^4\) (DESY) | 10x4m damping wigglers  
40 – 200 \(\text{monochr. and pink}\) |
| P62/P63  | t.b.d. | t.b.d. |
| P64      | X-ray absorption spectroscopy: high-flux applications  
QEXAFS\(^1\), highly-diluted samples, HERFD-XAFS\(^1\) | 2m U33 | 4 – 44 |
| P65      | X-ray absorption spectroscopy:  
applied XAFS on bulk materials\(^1\) | 0.4m U33 | 4 – 44 |
| P66      | Time-resolved VUV luminescence spectroscopy\(^3\) | BM (12 mrad) | 4eV – 40 eV |

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\(^2\) contributed by Helmholtz Center Jülich;  
\(^3\) Funded by BMBF;  
\(^4\) instrumentation funded and operated by Helmholtz Center Geesthacht

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