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STATUS OF THE PETRA IV MACHINE PROJECT

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Abstract

DESY is planning the upgrade of PETRA III to a fourth-generation light source, providing high brightness, quasi diffraction limited hard X-ray photons. The project is underpinned by the construction of a new storage ring PETRA IV, based on a 20 pm accelerator lattice using a hybrid 6-bend achromat concept. We review here the status of the machine project, the latest development in the different technical subsystems, the status of the engineering integration and the plans for the implementation of the new ring in the existing PETRA III tunnel.

PROJECT OVERVIEW

The PETRA IV machine project aims at the construction of an ultra-low emittance storage ring delivering operating at 6GeV with a 20 pm emittance, to be installed in the existing 2.3 km PETRAIII tunnel. Significant changes to the machine concept were made since the CDR [1]. The PETRA IV complex will reuse the existing LINAC-II (450 MeV) and the PIA accumulator ring. A new low emittance booster DESY-IV, will replace the existing DESY-II booster. The storage ring will follow the geometry of the old PETRA collider with 8 octants made of arcs, each hosting nine H6BA cells, connected by long straight section as shown in Fig. 1.

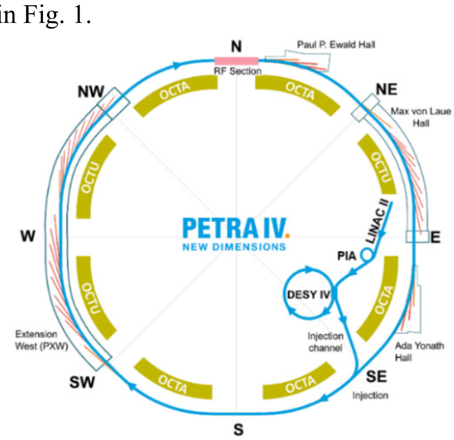

Figure 1: Layout of the PETRA IV accelerators and the experimental Halls.

Given the constraints on the DESY campus, only three octants can host beamlines (OCTU). The facility will reuse the PIII experimental halls and will build a new experimental hall covering two octants of the ring in the West. The remaining octants (OCTA) will host Damping Wiggler for the control of the emittance. The design operational parameters of the storage ring are reported in Table 1. The present timeline assume that, in funding will be available by mid-20204, the PETRA III shutdown will starting in January 2027, and with two years dark period, the machine operation can restart in January 2029.

Table 1: PETRA IV Main Parameters

Energy	6 GeV
Emittance (with DW)	20 pm
Rel. energy spread (with DW)	$9.0 \cdot 10^{-4}$
Loss per turn	4.19 MeV/turn
Momentum compaction	$3.3 \cdot 10^{-5}$
β_x, β_y, (at IDs)	2.2m; 2.2m
RF voltage (main, 3HC)	8 MV, 2.4 MV

LATTICE

The H6BA lattice is a modification of the H7BA developed for the ESRF-EBS. The main improvement consists in the replacement of the quadrupole doublet in the undulator straight section, with a triplet allowing a better control of the optics function for matching the electrons and the photons phase space. Dispersion bumps are generated to locate the chromatic sextupole families. The central part of the H7BA section is simplified to two quadrupole gradients with a phase advance of π in both planes, unlike (3π, π) in (H, V) as in H7BA. This sextupole pairing allow a very effective chromatic correction. Figure 2 shows the optics function in the H6BA cell.

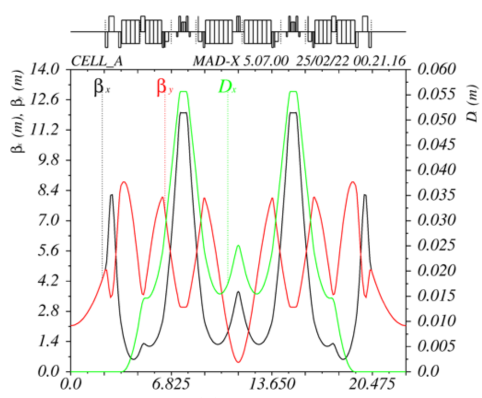

Figure 2: H6BA optics functions and layout from MAD-X.

The cell design is relaxed to provide an emittance of 43 pm. The target emittance of 20 pm is achieved by using damping wiggler in the straight section of the five octants that will not host beamlines. Details of the beam dynamics optimisation are reported in a companion paper [2].

MAGNETS

The H6BA cell consists of 6 dipoles, two of which are combined longitudinal and transverse gradient dipoles

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(DLQs) and four combined dipole quadrupoles (DQs). The cell has 17 quadrupoles arranged in eight families, six sextupoles arranged in two chromatic families, four octupoles and a total of seven correctors. The dipoles are all designed from permanent magnets. The DLQs consist of four modules with a dipole field of 0.6 T to 0.3 T while the DQ have. The quadrupoles triplet in the straight section requires a relative high gradient of 115 T/m, achieved with an aperture of 11 mm and high permeability pole. Figure 3 shows the 2D cross section with the relative magnetic field map.

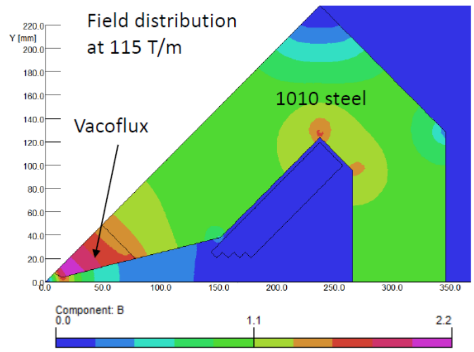

Figure 3: 2D cross section foe the high gradient quadrupole PQA of PETRA IV.

The total power consumption of the magnet systems amounts to 3 MW. Further details of the magnets optimisation are reported in a companion paper [3].

GIRDERS

Numerical simulation of the misalignment errors of the orbit and optics correction of the H6BA lattice showed that a set of four girders per cell is adequate in controlling their impact on the beam dynamics misalignments. The distribution of the magnet in the cell require girders of 4.8 m and 4.2 m length, of three different types, the last one being the symmetric of the first one.

The girder design is based on the topological optimisation of the structure, based on the FEA optimisation of the structure using as constraints the stiffness, the eigenfrequencies, and the minimisation of the weight. The girders should not have eigenfrequencies below 30 Hz although higher eigenfrequencies designs will be favoured (above 50 Hz). The overall weight of the fully loaded girder must not exceed 12 tons due to the quality of the concrete slab in the old tunnel part of the PETRA IV tunnel. The naked girder weight less than 5 tons. The outcome of the topological optimisation is shown in Fig. 4.

A comparison with more familiar welded box structure has revealed that the constraints on the eigenfrequency content can be met with significantly lighter structures. The topological optimised girder can be built with a cast iron manufacturing process. For large series production like the 288 girders to be installed in PETRA IV, it turns out that cast iron process are not more expensive than standard welded boxes. Fixation and final alignment of the magnet in the girder will be ensured by the use gluing pots for all resistive magnet. Experience at PETRA III [ref] shows that 30 µm rms magnet-to-manet alignment can be reached. The dipole magnets (DLQs and DLs) will have a moveable support that allow the accurate alignment and the possibility of shifting the dipoles during the NEG activation of the dipole chambers.

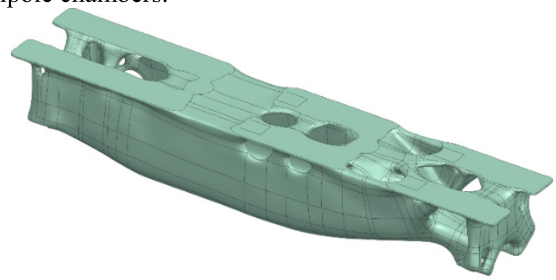
Figure 4: 3D layout of the first girder of the H6BA cell.

The girders will be supported on both ends with movers for all degree of freedom. The baseline design foresees the remote control of the adjustment of the position of the girders, limited to ±0.5 mm**.** This is considered sufficient to control the alignment girder-to-girder to within 100 mm using beam-based alignment strategies currently tested in PETRA III [4]. Larger offsets will require manual intervention in the tunnel and are limited to ±3 mm for every axis. Wedge movers will be used at support points at the vertical direction and a special designed rail for movements in the transverse and beam direction.

VACUUM

The vacuum system of PETRA IV will make extensive use of small aperture NEG coated chambers. The arc sections are based on a cylindrical pipe with inner radius 10 mm and outer radius 11.5 mm except for triplet where the shape will be elliptical with inner dimension inner radius will be 20 mm x 13 mm.

The sectioning of the vacuum pipes will follow the four girders structure of the cell with one valve to separate the cell vacuum. The absorbers in the arcs are located at the end of DL2. Extraction of the photon pipe is achieved with 6 mm internal vertical aperture through the magnetic poles of the PQD quadrupole whose vertical pole-to-pole distance is limited to 11 mm. Preservation of the canted angle (±2.5 mrad) of some of the PETRA III beamline requires a complex photon extraction shown in Fig. 5 that is currently under investigation and will require modification of some of the magnets yokes.

Vacuum pressure simulations show that NEG coated chamber can provide an adequate pressure level better than 10^{-8} bar after 100 Ah. In situ NEG activation is foreseen by means of thin heat tapers of 400 µm thickness.

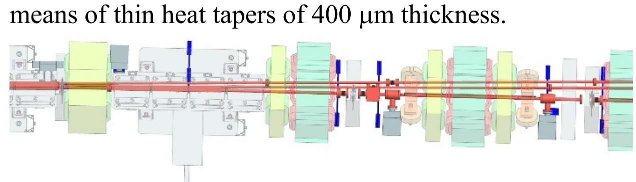
Figure 5: Photon extraction from canted beamlines.

RF

PETRA IV will operate the main RF system at 500 MHz, based on 24 normal conducting single cell HOM damped

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RF cavities. This will be newly procured and guarantee an improvement over the seven-cell cavities used in PETRA III. The main RF system will provide 800 kW synchrotron losses and the nominal voltage is 8 MV. An active third harmonic cavities system consisting of 24 cavities operating at 1.5 GHz is foreseen to guarantee the bunch lengthening required for stable operation. Extensive use of SSA will provide the required power both at 500 MHz and 1.5 GHz.

Main RF

The 24 500 MHz HOM damped cavities are a development of the original BESSY design (shown in Fig. 6). They guaranteed a well controlled HOM spectrum that allows operation in brightness mode and timing modes. They will be grouped in 6 RF stations, each driving a block of 4 cavities with their own SSA transmitter. Each cavity must deliver a voltage of 333 kV (transit time corrected from the 475 kV in the cavity gap) that is well within the maximum voltage that can be safely operated. With a shunt impedance of 3.4 MΩ per cavity, the power input to each cavity is 37.4 kW for replacing the beam energy and 16.3 kW foreseen for the copper loss in the cavity. Including 5% transmission losses we foresee a total input power 56.4 kW per cavity.

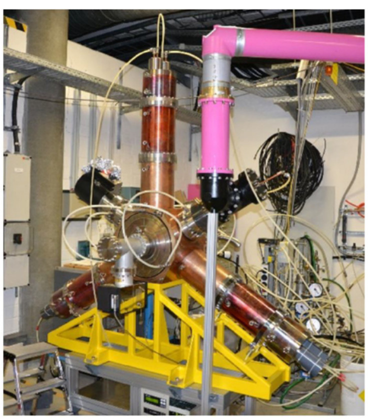

Figure 6: 500 MHZ HOM BESSY-type damped cavity.

The RF system is dimensioned to provide high availability and reliability to guarantee continues beam operation in case of failure of one cavity and even in case of failure of one full RF station. In this case operation with 20 cavities the voltage required raises to 400 kV. In this case the power dissipated in the cavity raises to 23.5 kW per cavity, the power to o the beam is 44.8 kW and the total power requested is 72 kW including 5% transmission losses. Each cavity is fed by a SSA that can deliver 110 kW to buffer a range of failure scenarios. The efficiency of the SSA is 50%. The total power budget for the main RF system is therefore about 2.6 MW in normal operation.

Harmonic RF Cavities

PETRA IV will operate an active NC at 1.5 GHZ, supposed to be operated at ideal bunch lengthening with 2.4 MV. fed from SSA. The HC design is based on a single cell HOM damped cavity developed in a collaboration between ALBA-HZB-DESY. A prototype was built at ALBA and is currently under power test at BESSY with the plan to install it in the BESSY-II ring in summer 2022. The HC active system allows large flexibility to set amplitude and phase at different operating currents for optimal bunch lengthening at different currents. A total voltage of 94 kV per cavity and with a shunt impedance of 1.5 MΩ per cavity, it requires 3.33 kW per cavity. This power will be provided by 10 KW SSA transmitters. The total power budget for the HC is 240 kW.

Total RF Power

The total RF power of the main and HC system is about 2.9 MW. The cooling system of the RF stations will need to provide cooling of the power generated at the SSA and of the power damped in the cavity walls for a total of about 3.3 MW.

ENGINEERING INTEGRATION

The engineering integration of the accelerator elements is made with the CAD software NX [ref]. The PETRA IV elements are inserted in a DESY wise CAD system containing also the buildings and associated infrastructure. An automatic scripting allows to place the elements in the 3D reference system of the accelerator directly from a MAD-X output. The CAD system is linked to a central database based in Teamcenter that allows to link each element with the corresponding documentation (e.g. specifications and later procurement reports). Figure 7 shows the current CAD model of one girder with the magnetic elements, vacuum chambers, water manifold and cabling. This model allows a precise check of the clashes of the elements and is an essential tool in the engineering integration of the subsystems.

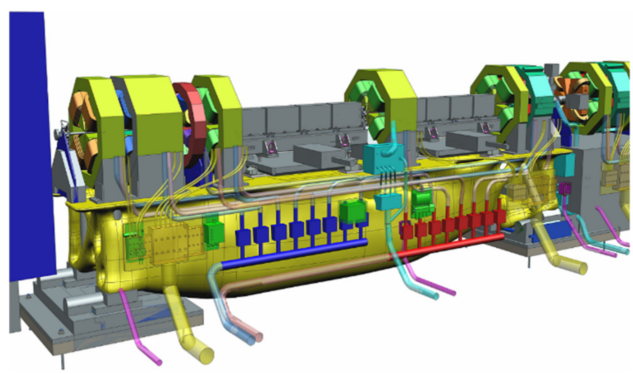

Figure 7: CAD model of fully loaded girders in the H6BA cell.

CONCLUSION

We presented the status of the PETRA IV machine project. The design and prototype of the main subsystems is well advanced and will be ready for the completion of the Technical Design Report to be delivered by end of 2023.

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