ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPGW015

PETRA III OPERATION AND STUDIES 2018

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Abstract

At DESY the Synchrotron Light Source PETRA III offers scientists outstanding opportunities for experiments with hard X-rays of exceptionally high brilliance since 2009. This paper describes the operational schedule, the operational statistics and the most important beam studies done at PETRA III in 2018.

USER OPERATION

During the two-month-long winter shutdown 2017–2018, which ended in February 2018, an in-vacuum undulator, and a short undulator for the side beamline including front end components were installed for the beamline P21 in the Ada Yonath experimental hall, see Fig. 1. Preparative work was done for the installation of components for the beamline P61 which will make use of the radiation from the damping wigglers in the North. Thanks to essential efforts of all technical groups all activities could be finished within the schedule. Regular user operation was resumed on March 26, 2018 after a short commissioning period of only 5 weeks. A four week long summer shutdown was used to install a new absorber for the synchrotron radiation from the wigglers in north straight section and front end components for the beamline P61 in the Paul P. Ewald hall. A photon extraction vacuum chamber is integrated in the new absorber which will open the possibility to use the wiggler radiation for the beamline P61. Furthermore the in-vacuum undulator for the beamline P21b was replaced with an improved version. After a start-up period regular user operation was resumed on September 3 and continued until December 21. The necessary maintenance was done in four dedicated service periods distributed over the year and additionally during the summer shut-down period. On Wednesdays, user operation was interrupted by weekly regular maintenance, machine development activities, and test runs for about 24 hours.

The distribution of the different machine states in 2018 is shown in Fig. 2. In total, about 4200 h had been scheduled for the user run, and in addition 855 h of test run time were made available to users.

During user runs, the storage ring was operated in four distinct modes characterized by their bunch spacing. In the “continuous mode”, 100 mA were filled in 480 or 240 evenly distributed bunches, corresponding to 16 ns or 32 ns bunch spacing. The “timing mode” allows users to perform time-resolved experiments and is thus characterized by considerably larger bunch spacing of 192 ns, corresponding to 40 evenly distributed bunches. The detailed distribution of the operation modes in 2018 is shown in Fig. 3. For the beam operation in the timing mode, very good bunch purity is required. Unwanted satellite bunches were routinely cleared by making use of the multi bunch feedback system. Furthermore, PETRA III was operated this year for a short period in a “timing mode” with 80 evenly distributed bunches to provide “timing mode” like conditions for users during a period when originally “continuous mode” beam operation was scheduled.

Figure 1: The first in-vacuum undulator in PETRA III.

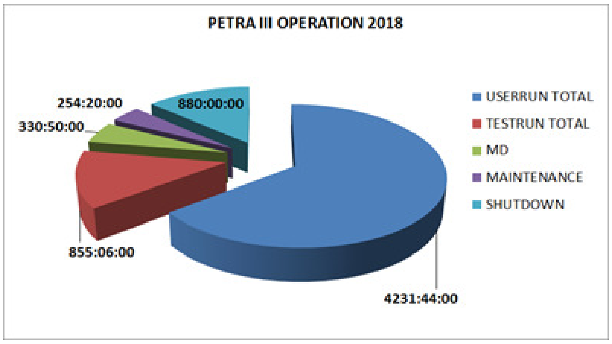

Figure 2: Distribution of the different machine states.

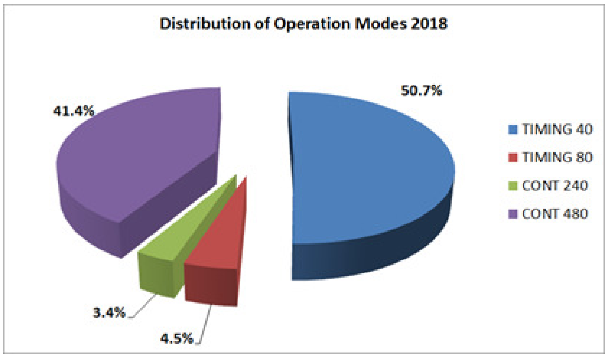

Figure 3: Distribution of the different operation modes.

Availability

High reliability is one of the key requirements for a synchrotron radiation facility. The key performance indicators are availability and mean time between failures (MTBF). In 2018, the weekly availability reached 100% for several weeks of the year. At the end of the user run the average availability turned out to be 96.37 % which is 1.73 percentage points lower than the availability of the previous year. This is due to three major faults during operation in 2018: a vacuum leak at a diagnostics device (current monitor) in week 13, a failure of a 10 kV switch in a power station on the DESY site in week 19, and a faulty synthesizer in the timing system in week 27.

The weekly availably of PETRA III during the period with user runs is shown in Fig. 4. A black outline around the bars is marking the weeks where the major faults occurred. This availability statics is based on a metrics which is in agreement with internationally used metrics, and does not include "warm-up" time after each fault.

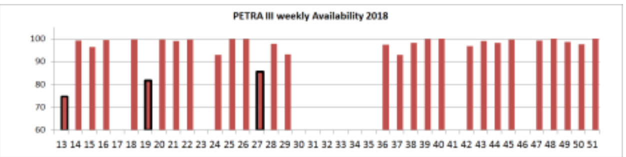

Figure 4: Weekly availability in 2018. The three major faults occur in the weeks 13, 19 and 27 which are marked with a black outline around the bars.

Although the availability of PETRA III in 2018 was lower than in 2017, the total number of faults could be further reduced. The average mean time between failures (MTBF) at the end of the year was 50 hours which is also better than in the previous year. The number of faults normalized to 1000 h of user operation has decreased during the last four years (see Fig. 5), indicating that the process to improve the technical reliability of PETRA III has made some progress after the availability review, which was held in 2016.

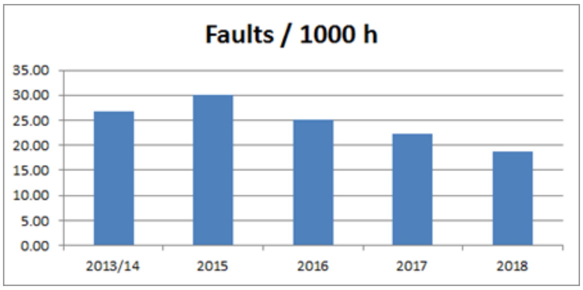

Figure 5: Long time development of the number of faults per 1000 h of user operation.

Although an internal review process was implemented in 2018 to monitor the availability of PETRA III and to guarantee a good root cause analysis of all faults during the user run, it was not possible to maintain the availability level of the year 2017 (see Fig. 6).

Figure 6: Long time development of the availability of PETRA III.

Plans for 2019

During the winter shut-down 2018/19 a two meter long insertion device was replaced with a four meter long in-vacuum undulator for the beamline P07 in the Max von Laue hall. Additional front end components were installed in the Paul P. Ewald hall to prepare the possibilities for the installation of additional insertion devices. In the arc region West to Northwest ten vacuum chambers in the dipole magnets were replaced with NEG coated vacuum chambers to investigate the activation process of the NEG material related to synchrotron radiation. A better understanding of this process will be beneficial for the technical design of the upgrade of PETRA III towards an ultra-low emittance synchrotron light source PETRA IV. This will only be possible with an essential effort from all involved technical groups.

EFFECT OF IN-VACCUM UNDULATOR ON THE TUNES

Here we report the first batch of tune shift measurements during 2018 in conjunction with in-vacuum undulators. The first IVU has been installed during the 2017/18 winter shut down. For the purpose of before and after comparison we recorded tune dependence on the bunch current. Without any IVUs in the ring the measured tune shift was -1.69 kHz/mA for the vertical collimators open and -2.20 kHz/mA for the vertical collimators closed (there are four vertical collimators in simultaneous operation). The impact of collimator gaps are 500 Hz reduction in vertical tune for a range of 1.0 mA. This is larger than the nominal chromatic tune spread of 150 Hz.

In March, 2018, the first measurement was performed varying the IVU gap from 22 mm (neutral position) down to 7 mm. For each gap the tune was measured. For this measurement we had increased the chromaticity slightly up to two in the vertical plane and the rf gap voltage was set to 20 MV so that the bunch length is close to 12 mm for bunch currents up to 2.5 mA [1]. This bunch length will be used in the analytic estimate later on. Overall results are shown in Fig. 7. Fitting the raw data we reduced the measurement to the tune slope as a function of IVU gap, from which we found that the fully closed gap stiffen the tune slope by about 15 to 20 Hz/mA. On average of all gaps the slope is -1.718 kHz/mA, which is 28 Hz/mA down compared to no IVUs in the ring. If we use this as the impedance estimate, the IVU's impedance is 4.0% of vertical collimators impedance (closed).

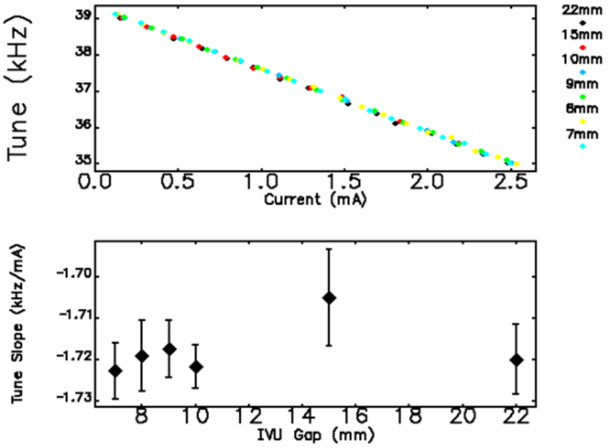

Figure 7: The tune shift data as function of current for a range of gaps (top) and the corresponding tune slope as a function of gap (bottom) based on the March 15, 2018, data.

In order to compare the experiment with the theory we use the tune shift formula

$$\frac{\Delta f}{I_b} = -\frac{\langle \beta \rangle k_\perp}{4\pi (E/e)}, \quad (1)$$

where I_b is the bunch current, β is the beta function, $k_\perp$ is the transverse kick factor, and E is the beam energy. For low frequency impedance the kick factor can be simplified as

$$k_\perp = \frac{\operatorname{Im} Z_\perp c}{2\sqrt{\pi}\sigma_z}, \quad (2)$$

where c is the speed of light and σ_z is the rms bunch length.

For the impedance we use a well-known formula developed for flat chambers which is reproduced here [2]

$$Z_y = j\frac{\pi Z_0}{4}\left(w\int_{-\infty}^{\infty} \frac{(g')^2}{g^3} G_1\left(\frac{g}{w}\right) dz + \int_{-\infty}^{\infty} \frac{(g')^2}{g^2} G_2\left(\frac{g}{w}\right) dz \right),$$

where g(z) is the vertical gap profile along the z axis, w is the full width, and the rectangular functions are defined as

$$G_1(x) = x^3 \sum_{m=0}^{\infty} (2m+1)\operatorname{csch}^2\left(\tfrac{(2m+1)\pi x}{2}\right)\coth\left(\tfrac{(2m+1)\pi x}{2}\right)$$

$$G_2(x) = x^2 \sum_{m=0}^{\infty} (2m+1)\operatorname{sech}^2\left(\tfrac{(2m+1)\pi x}{2}\right)\tanh\left(\tfrac{(2m+1)\pi x}{2}\right).$$

In the limit of small g/w, G_1 and G_2 becomes $1/\pi$ and $1/\pi^2$, respectively.

Then, for a linear taper connecting two beam pipes from the gap g_0 to g_1 varying as $g(z)=g_0+\alpha z$, where $\alpha=(g_1-g_0)/L$ over the length L of beam direction, the vertical impedance becomes

$$Z_y = j\frac{Z_0}{4}\left(\frac{w\alpha}{2}\left[\frac{1}{g_0^2} - \frac{1}{g_1^2}\right] + \frac{\alpha}{\pi}\left[\frac{1}{g_0} - \frac{1}{g_1}\right]\right).$$

In PETRA III, the taper connecting the vacuum chamber to the magnet array of the IVU has dimensions such that g_1 = 22 mm and L=144 mm. In spite of the copper foil covering the undulator magnets, resistive-wall impedance of the long (4 m) undulator with a narrow gap makes considerable contribution into the kick factor. For this we use the formula [3]

$$k_y = A\frac{c}{2\pi^2 b^3}\sqrt{\frac{Z_0\rho}{2\sigma_z}}\Gamma(\tfrac{1}{4}) \quad (3)$$

where A is 1 for the round chamber and $\pi^2/8$ for the flat chamber, respectively, 2b is the gap, Z_0 is 376.7 Ω, ρ is the resistivity, and Γ(1/4)=3.6256. This formula compared very well with the numerical simulation of kick factors for a wide range of bunch lengths [4, 5].

The tune slope is computed by using Eq. (1-3) whose result is shown in Fig. 8. From which we expect the tune slope will be down by 25 Hz/mA at 7 mm gap compared to the neutral position of 22 mm. This is a tantalizing result if we can correct the measurement at 22 mm in Fig. 7. Presently we have been compiling data with the improved accuracy in tune measurement whose full results will be reported in future.

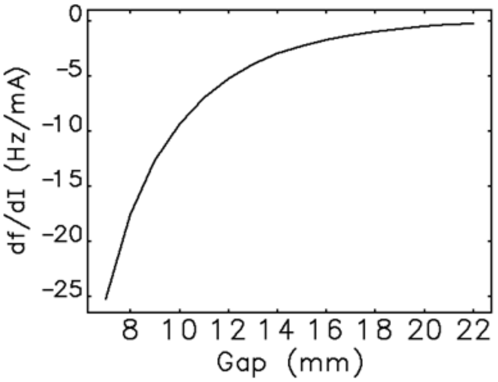

Figure 8: An analytical estimate on the tune shift due to IVU's impedance (geometric and resistive wall impedance) as a function gaps.

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