PETRA III OPERATION

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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 challenges of daily operation, including different bunch patterns and their side effects, a procedure to clear spurious bunches, the operational statistics and the main contributions to down time.

PETRA III OVERVIEW

PETRA III is a third generation light source with a circumference of 2.3 km, a beam current of 100 mA and a beam energy of 6 GeV. The horizontal beam emittance is 1.2 nmrad with an emittance ratio of 1 %. Currently 17 experimental beamlines are operational.

BUNCH PATTERNS

For user operation at PETRA III five different bunch patterns are foreseen, of which four are in regular use. For each bunch pattern a set of machine parameters is stored in a file system. In general the total beam current should be constant, independent of the bunch pattern in use. However, sometimes the RF cavities need a conditioning phase after switching to certain bunch patterns. In this case the total beam current is reduced to 90 mA for some days.

Timing Mode

Some user experiments require timing mode for time dependent measurements, e.g. pump probe experiments. Due to the big circumference of PETRA III a bunch separation of 192 ns can be offered in 40 bunch mode with an equally filled machine and nominal beam current. With the high bunch current in the 40 bunch mode there is an increased risk of reflected power interlocks due to higher order modes in the 500 MHz RF cavities. As a result of the high bunch current and the low transverse emittance the Touschek effect reduces the beam life time to roughly 1.2 h in the 40 bunch mode. This short beam lifetime causes constant beam losses at distinct positions in the machine, resulting in local activation of the beam pipe. In the 40 bunch mode the top up procedure, which keeps the total beam current constant on a 1 % level, triggers the injection of 1 mA every minute. For some user experiments the small orbit deviations during this frequent injections cause a distortion in data taking.

A second, relaxed timing mode can be offered with 60 equally distributed bunches and a bunch separation of 128 ns.

Some user experiments require very high bunch purity during timing mode. Spurious bunches have to be reduced to a level of 10^{-8} with respect to the main bunches.

Those users that are not interested in the time structure of the bunch pattern can use both timing modes at full beam current without restrictions, apart from the slightly increased risk of RF trips in 40 bunch mode.

Continuous Mode

Three different modes with multi bunch fillings are available: A rarely used 240 bunch mode with 32 ns bunch spacing, a 480 bunch mode with 16 ns bunch spacing, and a 960 bunch mode with 8 ns bunch spacing. After longer shutdowns or interventions in the vacuum system the 960 bunch mode has a tendency to show beam blow up due to ion problems. In this case some weeks with 480 bunch mode help to condition the vacuum system.

Table 1 shows the parameters of the different bunch modes. Given are the number of bunches, the bunch current in mA, the bunch separation in ns, the typical beam lifetime in hours and the fraction of usertime this bunch mode was used in 2016.

Table 1: Parameters of different bunch modes

# bunches	**40**	**60**	**240**	**480**	**960**
Bunch current	2.5 mA	1.7 mA	0.4 mA	0.2 mA	0.1 mA
Bunch separation	192 ns	128 ns	32 ns	16 ns	8 ns
Beam lifetime	1.2 h	2h	7 h	11 h	18 h
Usertime 2016	42 %	12 %	0 %	26 %	20 %

DIFFERENT BEAM OPTICS

Beamline P07 at PETRA III needs two different optics of the electron beam to perform different kinds of user experiments at the beamline. A high beta optics provides a wide photon beam, while a low beta optics delivers a narrow photon beam. Therefore each set of machine parameters for the different bunch patterns has to be provided for two different beam optics at P07. For the other beamlines the beam parameters are unchanged.

SPURIOUS BUNCH CLEARING

In the 40 or 60 bunch mode some experiments require a bunch purity of the order of 10^{-8}[1]. The chain of preaccelerators serving PETRA III, i.e. LINAC II, PIA and DESY II, produces spurious bunches 8 ns away from the main bunches. In PETRA III some electrons escape from the stored bunches, but are captured in the next 500 MHz buckets, 2 ns (and multiples of 2 ns) away from the main bunches. Figure 1 shows the typical bunch population in PETRA III without any clearing. Shown is a time resolved photon count at beamline P01. The vertical axis shows the number of photons counted on a logarithmic scale.

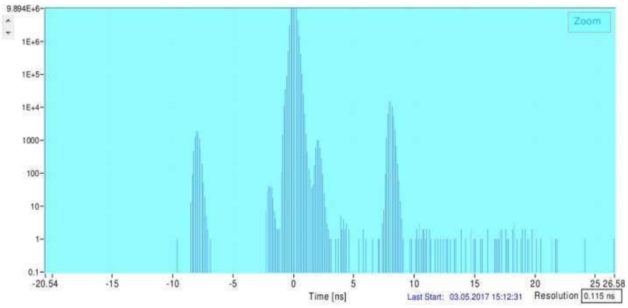

Figure 1: Bunch population in PETRA III with the main bunch at 0 and spurious bunches at multiples of 2 ns.

Spurious bunches have substantially less bunch current than the main bunches and therefore different betatron tunes. The transverse multibunch feedback system, designed to damp transverse bunch oscillations, can also be used to resonantly excite the spurious bunches at their betatron frequency. The timing of this excitation is set to clear spurious bunches more than 2 ns after the main bunch. If the parameters are carefully chosen, the spurious bunches are kicked out, while the main bunches are not affected by this procedure. This cleaning procedure is routinely applied for 2 seconds after each injection. Figure 2 shows the bunch population after clearing. This measurement integrates of a long time and shows some single photons from spurious bunches, emitted between injection of the bunch and the cleaning process, following directly after the injection.

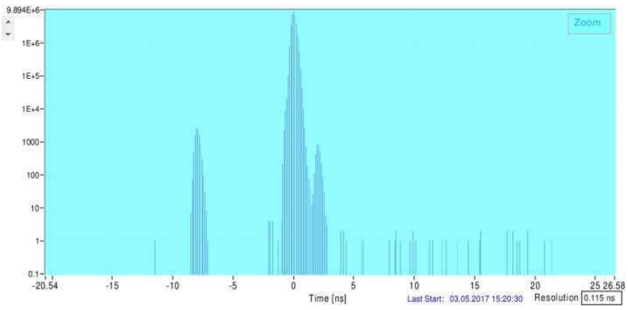

Figure 2: Bunch population after clearing of spurious bunches.

AUTOMATION OF OPERATION

During a user run PETRA III is running without much operator intervention. Multibunch feedback systems damp all oscillations of the beam, both longitudinal and transversal. A fast orbit feedback keeps the beam position and angle constant at the positions of the undulators. An automated top up procedure keeps the beam current constant within 1 % of the nominal beam current and equals out the bunch currents between the different bunches. Betatron tunes are kept constant by a tune controller.

The main task of the operators is to constantly optimize the performance of the less automated preaccelerators. LINAC II shows occasional trips of RF modulators, but has enough modulators running as hot spares to keep the performance up. Tuning of orbits and RF phases are standard procedures at the LINAC II.

The high degree of automation at PETRA III helps to make the machine run smoothly, but reduces the operational experience of the operators. On average, an operator experiences a beam loss only every 4th shift. Systems like an alarm viewer and an automated fault analysis tool in the machine protection system help the operator to identify the cause of the beam loss. A well-documented filling procedure can reduce the filling time after a beam loss to less than 15 minutes.

BEAM TIME SCHEDULING

A normal week of PETRA III user operation offers 6 days of beam time for external users. Every Wednesday user operation ends at 7:00 am. Wednesdays are used either for a day of machine studies, or, at every other Wednesday, for a 7 hour maintenance period, followed by machine studies in the afternoon. Late in the afternoon, depending on the amount and success of the machine studies, operation switches to a test run. This test run, lasting until 7:00 am on Thursday, is used as test time for new machine settings, as conditioning time for new RF or vacuum parameters and as user time for inhouse users. This test user time is not subject to the review process, through which user time for external users is scheduled. Thursday at 7:00 am starts another 6 day period of user time for external users.

Every 5-6 weeks this pattern is interrupted by a service week. From Monday 7:00 am on the tunnel is open for maintenance and repair. Depending on the demand for service, the maintenance period ends on Thursday or Friday, followed by machine studies during daytime. The nights between machine studies and the weekend after the service week are devoted to test runs again. Normal user operation resumes on Monday, 7:00 am.

Interruptions of user operation for several weeks are scheduled during summer holidays or around Christmas time and used for major installation work in the tunnel, followed by annual safety tests, recommissioning of magnet power supplies, and machine studies.

The overall yearly user time for external users adds up to about 4000 hours, depending on the length of shutdowns for installation of new components.

OPERATIONAL STATISTICS

The availability for PETRA III is calculated as the delivered beam time divided by the scheduled beam time. Beam time is considered as delivered if the beam current is above 75 % of the nominal beam current. If the beam current falls below 75% of the nominal beam current, this is considered as a fault and a rather unique way is used to calculate the onset of delivered beam time after the fault. As most of the experimental beamlines are using cryogenically cooled monochromators, the photon beamlines need a certain time to reach thermal equilibrium with every new beam. Therefore, for every beam loss a warm up time is subtracted from the delivered beam time. The down time is calculated from a beam loss to reaching full beam current again. For down times shorter than an hour the warm up time is considered to be as long as the down time. For longer down times the warm up time is considered to be one hour.

This rather unusual way to calculate the availability of PETRA III makes it difficult to compare it with the numbers of similar facilities. Without the warm up time taken into account, the availability of PETRA III would be about 1.4 % higher than shown in this paper.

Availability

PETRA III is in operation since 2010, and since 2010 the availability is rising slowly, but not significantly exceeding 95 %. Figure 3 shows the availability over the years.

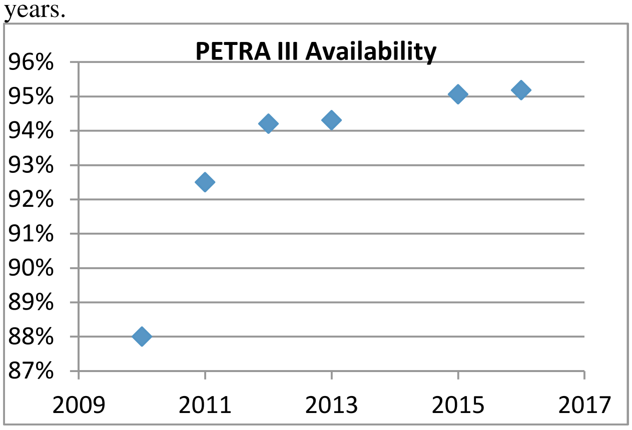

Figure 3: Availability of PETRA III.

Mean Time between Failures

Figure 4 shows the mean time between failures (MTBF) for PETRA III in hours. Since 2010 the MTBF has been rising, but never exceeded 37 hours. This is about half the MTBF of similar facilities.

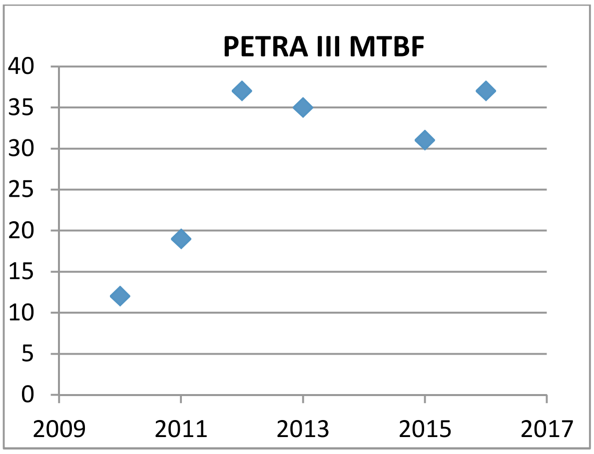

Figure 4: Mean time between failures in hours.

Main Sources of Failures

Looking at the number of failures, the RF systems are the prominent source with 37 of the 111 failures in 2016, followed by magnet power supply trips with 18 failures and all systems of the booster synchrotron DESY II with 13 trips. Users caused 9 beam dumps, 7 beam losses were caused by power glitches. All other systems contributed 6 or less beam dumps each.

Looking at the failure time, the RF systems are again prominent with 50 hours out of 213 hours lost user time in 2016, followed by magnet power supplies with 48 hours. All other systems contributed 19 hours or less each in 2016.

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REFERENCES

[1] J. Keil and H. Ehrlichmann, "Bunch Purity Measurements at PETRA III", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper THPMR020, pp. 3434-3436