PREPARATIONS OF BESSY FOR TOP-UP OPERATION*

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Abstract

BESSY was upgraded for top-up operation during the last 3 years. The work culminated in a one week long test run at the beginning of this year. The efforts and achievements are described: Improvements of the injector, the pulsed injection elements, the timing system, insertion devices, the additional safety interlocks, and the shielding of the ring.

INTRODUCTION

BESSY is a 3rd generation light source in operation since 1998. The facility consists of a full energy injector synchrotron (1.9 GeV) and the storage ring operating at 1.7 GeV. During top-up operation lost electrons are replaced after minutes and not after hours. Due to the constant heat load on mechanical and optical components in combination with an increased average intensity the quality of the photon beams is superior to the operation in the decaying mode. Top-up injections have to take place while beam shutters are open and users take data. This requires certain precautions: At BESSY radiation safety [1] demands interlocks for an injection efficiency larger than 90 % under all operating conditions, interlocks for the existence of stored beam, and additional shielding measures at some locations close to the first optical components. Time between injections was required to be larger than 10 s. Orbit jitter induced by the injection process is quite large at BESSY and needs to be improved. During the top-up test blank pulses indicating injections were supplied to the beam lines. Operation in top-up mode was only permitted under the condition that the experimental area is inaccessible during the one week long test. The hardware of the radiation safety interlock was modified in order to permit injections with open beam shutters.

IMPROVEMENTS

Since BESSY was not designed for operation in top-up mode many components of the facility had to and still have to be improved in order to fulfil the above mentioned requirements. In the following an overview of the achievements and ongoing activities is given.

Microtron

For the top-up tests the operating conditions of the triode gun of the 50 MeV microtron were chosen to deliver a 120 ns long and flat current pulse preserved during the acceleration in the synchrotron. With RF-knockout in the synchrotron the bunch train is cut down to 50 bunches with rather small intensity variations from bunch to bunch and injected at 7 consecutive positions on the circumference of the storage ring. The eighth position is left empty in order to create a 100 ns-long gap for ion-clearing. Traditionally at BESSY this fill pattern is created with RF-knockout in the storage ring. The corresponding losses of 12.5% already violate the requirement for an injection efficiency of > 90 %.

In the future the microtron will be replaced by a 50 MeV linac. This will enable fast accumulation of a few intense bunches in the storage ring satisfying the requests of users for time resolved experiments [2]. Top-up injections with single bunches into targeted buckets on the circumference of the ring is the preferred way to keep the fill pattern over longer periods of time [3]. At BESSY this will require also a new timing system. For the top-up tests the existing timing system was modified: The repetition rate of the injector was reduced to 1 Hz and injections were only possible every 10 seconds. A hybrid or camshaft bunch was not produced.

Synchrotron

A good match of the 6 dimensional phase space between the synchrotron and the storage ring is needed in order to achieve high injection efficiency. The horizontal emittance in the synchrotron was reduced by ~40% by moving the horizontal tune up from Q_x=4.55 to 5.9. The non-linear horizontal to vertical coupling in the extraction path was significantly reduced by moving the beam upwards at the time of extraction (Fig. 1). The mismatch between the bunch length in the synchrotron and in the storage ring was significantly reduced by increasing the accelerating voltage in the synchrotron in combination with the smaller momentum compaction factor given by the higher horizontal tune. Usually the energy spread matches nicely between the two rings, however, the bunch length mismatch leads to a corresponding increase of the energy spread of the injected beam after a quarter of the synchrotron period in the longitudinal phase space of the

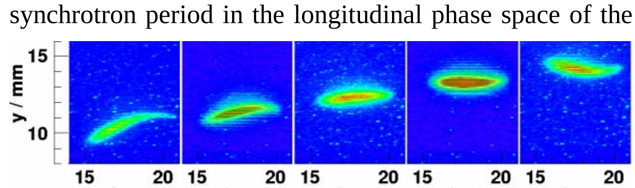

Figure 1: Impact of the vertical beam position of the extracted beam on the measured particle distribution in the transfer line. The initial situation is shown in the left.

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storage ring. Very often losses of the injected beam show up at this time when both the horizontal amplitude and the energy spread of the injected beam are still large.

Transfer Line

Matching of the beam by the transfer line optics turned out to be more difficult than expected. It appears as if the extraction septum acts transversely focusing which is not yet included in the linear optics model. Up to now unrealistic conversion factors relating magnet currents to K-values have to be used in order to theoretically explain the value of the dispersion function at the end of the transfer line.

Two sets of collimators were installed in the transfer line for shaping the distribution of the injected beam and thus improving the injection efficiency [4]. Current transformers at the end of the transfer line and close to the storage ring septum turned out to be useless because of the large noise contributions from the fast nearby injection kicker magnets. Finally the current of the injected beam was determined with the help of RF signals delivered by a set of striplines. These signals are acquired, analysed, and transferred as EPICS variables to the control system by a single fast digital scope. The RF sum signals were calibrated against the DCCT-reading in the synchrotron assuming 100 % extraction and transfer efficiency. For each shot the system delivers the intensity and the position of the beam at the end of the transfer line. It turned out, that the collimators were not yet relevant for achieving an efficiency of more than 90 %.

Injection Process and Ideas for Improvement

At BESSY the injection straight section is very short and the required strength of the 4 fast injection kicker magnets is one of the critical factors [5]. Even with carefully adjusted pulse shapes of the independently powered magnets the non-closure of the injection bump leads to a significant orbit distortion of the stored beam. The leakage and stray fields of the septum magnet add to the observed distortion as shown in Fig. 2. The non-linear dependence of these effects on the distance of the stored beam to the septum is another reason for the non-closure of the bump. After the installation of small gap vacuum chambers for the insertion devices (IDs) and with the fs-slicing set-up in place [6] the horizontal acceptance of the ring is no longer given by the septum magnet. Improvements of the reliability and in the adjustment of

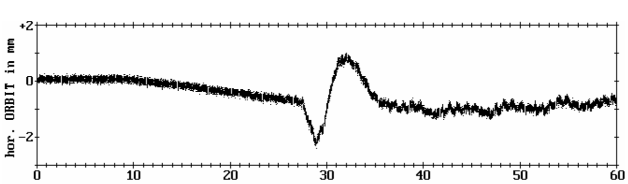

Figure 2: Transient horizontal orbit distortions of the stored beam measured bunch-by-bunch induced by the stray field of the septum and the mismatch of the 4 injection kicker magnets. The amplitude of the vertical orbit distortion reaches also 1 mm.

the fast kicker magnets can be expected if the septum is moved 7-8 mm closer to the stored beam axis. The kick amplitudes can be reduced correspondingly. This relaxed injection geometry will be implemented during the next shut down.

The closure of the injection kicker bump can be significantly improved by powering neighboring kicker magnets with only one power supply (PS) and thus reducing the sensitivity to amplitude and timing jitter of the PSs by more than one order of magnitude. The vertical orbit distortion will be minimized by mechanical adjustments of one of the kicker magnets. In addition the impact of the septum has to be significantly reduced by using a full instead of the half sinusoidal current pulse and adding a better magnetic shield. This would suppress the long lasting eddy current tail and the direct leakage field [7]. The still remaining horizontal and vertical orbit distortions can be reduced further with a digital bunch-by-bunch feedback or feedforward system[8]. Such a system is under consideration as replacement for the existing purely analog feedback in operation at BESSY.

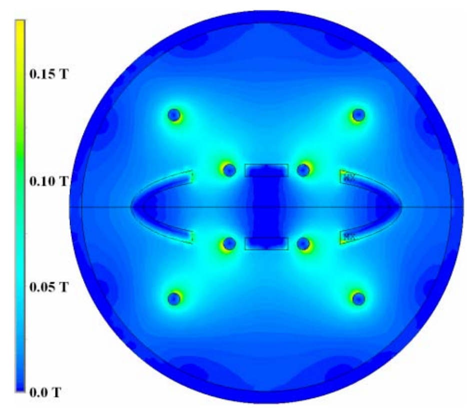

Figure 3: Arrangement of pulsed injection kicker magnet. The current in the 4 inner wires is opposite to the current flowing in the 4 outer wires. Shown is the result of a time-dependent ANSYS calculation assuming a 1 µs long pulse.

In addition, an alternative approach for injecting the beam is considered [9]. In this scheme a single and highly non-linear kick is used to diminish the transverse momentum of the injected beam. The required horizontal kick ~10 mm off-axis, at the location of the injected beam, should be on the order of 1 mrad. The on-axis kick experienced by the stored beam should ideally be zero. A preliminary design of an in-vacuum, stripline-like kicker is shown in Fig. 3. Fine tuning of the mechanical arrangement will give the desired field variation as a function of position, the required field strength, and low impedance to the stored beam.

Impact of IDs

All these improvements also have to minimize the oscillation amplitude of the injected beam. This would immediately reduce the observed negative impact of the IDs on the injection efficiency. Usually lower energy rings like BESSY II suffer from the non-linear field components introduced by IDs. Static field errors, measured as straight line field integrals are compensated finally by magic fingers in the undulator U125 down to levels of ±0.01 T·mm for ±25 mm [10]. Nevertheless, this planar ID still reduces the injection efficiency well below the 90%-level. In APPLE II-type undulators like the UE112 the negative impact of dynamic field components in the parallel mode is reduced by appropriate L-shims [11]. This approach requires further improvements. Very promising results [12] were obtained in the anti-parallel mode with compensating coils attached to the vacuum chamber of the ID. These IDs were disabled and set to large gaps during the top-up test.

TOP-UP TEST

One week was used to prepare the accelerators for the top-up mode and for testing the interlock systems. In the following week a few selected user groups were participating in the tests. They used dipole-, undulator-, and superconducting wiggler-beam lines. All experiments had to be remotely controlled and did not suffer from the orbit transients due to the top-up injections taking place every 20-30s. These intervals are long enough even for the Physikalisch-Technische Bundesanstalt (PTB) and their work on radiometry and metrology. On the superconducting wiggler beam line the stability of the spot size and the position of the beam was greatly improved due to the thermal stability of components [13].

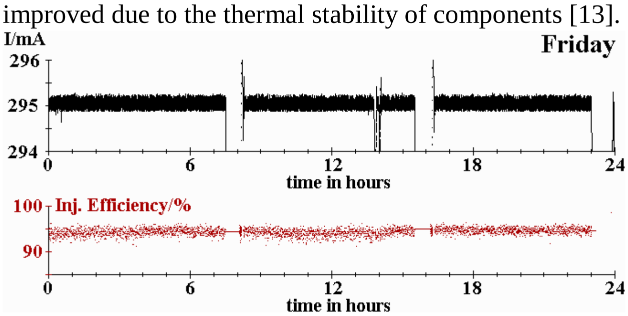

Figure 4: Top-up operation on the last day of the test week: the current was stable to better than ±0.1 mA at 295 mA and the injection efficiency was close to 95 %.

All components of the accelerator worked surprisingly reliable and stable. The constant heat load on the components of the storage ring led to an improved closed orbit stability with reduced action of the correction elements. Operating the injector at 1 Hz and extracting and injecting the beam at even lower rates resulted in a very reproducible performance in terms of the injection efficiency. With 10 Hz injection rate the pulsed equipment usually starts drifting away from the optimized setting and efficiency deteriorates after a few minutes. Fig. 4 shows the situation on the last day of the top-up test. The test ended at 11 pm and there were two planned interruptions of the top-up injections for maintenance work in the experimental hall at 7:30 am and 3:30 pm.

SUMMARY

Top-up operation with a limited number of IDs was successfully tried out at BESSY. The daily operation in this mode requires: 1) Replacement of the microtron by a linac and a renewal of the aging timing system in order to be able to top-up also single bunches. 2.) A further reduction of the orbit perturbations during the top-up injections. 3.) Improvements of the extraction kicker magnets currently not designed for continues operation. 4.) Re-shimming and better compensation for a couple of IDs. 5.) Additional radiation safety measures in the experimental hall.

If the top-up operation is intended to compensate for intentional lifetime reductions by small gap in-vacuum IDs or by increasing the brilliance through a much smaller vertical beam size as is planned at the ALS [14] then the thickness of the shielding wall has to be increased substantially [15].

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