BESSY II*: EXCEEDING DESIGN PARAMETERS THE FIRST YEAR OF USER SERVICE

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Abstract

The 3rd generation low emittance high brilliance synchrotron light source BESSY II stored first beam in April 1998[1]. In the same year the first experiments were performed and the regular scientific program started in January 1999. At the beginning of 2000 seven insertion devices (IDs) had been put into operation as well as 16 beamlines. In parallel the machine was continuously improved. Already prior to start of the user service basic machine parameters as beam current, beam emittance, coupling etc. were reached or surpassed the design goal. This paper describes the status of the synchrotron light source 2 years after start of commissioning.

1 INTRODUCTION

The BESSY II synchrotron radiation facility is a 3rd generation light source optimised for the vacuum ultraviolet to the X-ray regime, making use of various insertion devices (IDs) such as hybrid and pure REC undulators, superconducting wave-length shifters, wigglers and radiation from bending magnets. The sixteen double bend achromat structures offer 14 free straight sections of ca. 4.5 m each for IDs.

2 STORAGE RING PERFORMANCE

2.1 Operation Energy Range

The BESSY II storage ring was planned to operate at a standard beam energy of 1.7 GeV. Nevertheless, requirements to cover the energy range 0.9 to 1.9 GeV were considered as an option. Thus flexibility was put to the 1.9 GeV full energy booster to extract at variable energy. Optimised settings were developed for 0.9 GeV and for the standard 1.7 GeV operation. Raising the beam energy to 1.9 GeV was successfully tested.

2.2 Intensities in Single and Multibunch Mode

In the design stage, a moderate 100 mA circulating current was adopted, to take into consideration thermal limitations, deteriorating optical components at the beam lines. As it turned out that the photon-beam power gives no severe draw back, beam intensity was raised to 150 and later to 200 mA. Higher currents can be realised on demand, as stable beams of 400 mA are stored routinely during machine r&d shifts. Beam is synchronously injected from the booster to the storage ring such that two bunch trains are circulating, separated by gaps of 75 empty buckets. In asynchronous injection mode, a bunch train of 350 equally filled buckets is generated using a knock-out kicker. For clearance of ions a gap of 50 empty buckets was chosen. Injection rates of up to 15 mA/s have been recorded.

Using the fast 2 ps short pulse from the recently installed electron gun, single bunch currents of up to 10 mA were stored in the ring at an injection rate of 2 mA/min.

2.3 Beam Lifetime

Beam lifetime in the BESSY II storage is ultimately limited by Touschek effect rather than by the vacuum pressure. The design of BESSY was, to achieve a product

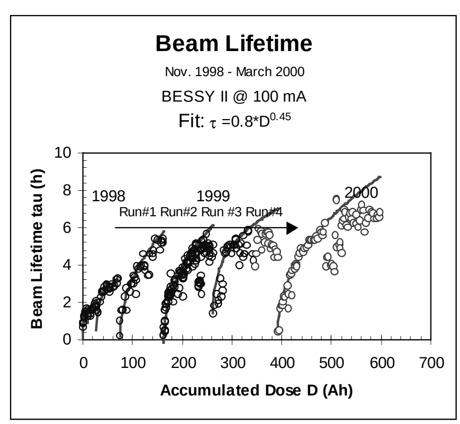

Fig. 1: Beam lifetime at 100 mA as function of the accumulated dose since November 1998.

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1) M. Abo-Bakr, W. Anders, R. Bakker, T. Birke, R. Brühl, K. Bürkmann, V. Dürr, H. Dreßler, F. Falkenstein, D. Faulbaum, J. Feikes, W. Gericke, T. Görgen, M.v. Hartrott, H.G. Hoberg, S. Horn, S. Khan, J. Kolbe, D. Krämer, B. Kuner, B. Kuske, P. Kuske, S. Kuszynski, T. Knuth, R. Lange, K. Ludwig, M. Loßmann, M. Martin, D. Müller, I. Müller, R. Müller, J. Rahn, D. Richter, H. Rüdiger, T. Schneegans, G. Schindhelm, D. Schüler, D. Simmering, E. Weihreter, G. Wüstefeld and E. Jaeschke

of beam current times lifetime of ≥600 mAh. Fig. 1 shows the development of beam lifetime of a 100 mA beam as a function of accumulated dose D (integrated stored current). A dose of 80 Ah is needed to reduce stimulated desorption to a level resulting in a gas lifetimes ≈8h at 100 mA. At these intensities the measured Touschek lifetime is approx. 25h as expected. The poor lifetime data in the graph resemble phases when major parts of the machine had been vented for installations.

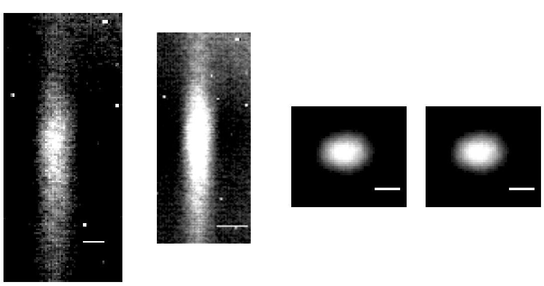
An empirical scaling of the total lifetime proportional to D to the 0.45th power was observed.

2.4 Beam Stability and Feedback Systems

In multibunch operation, higher order modes (HOMs) of cavities and resistive wall effect are the origin of coupled multi-bunch instabilities (CMBI). At currents in excess of 15 mA transverse and at 40 mA longitudinal CMBI have been observed in the start-up phase. Installation of damping antennas to the four 500 MHz DORIS-type single cell cavities cured most of the HOM driven longitudinal instabilities. To damp transverse instabilities, chromaticity had to be set to large positive values ($\xi_{x,z}$≈+5) on the cost of loss in beam lifetime.

In 1999 commissioning of a analogue transversal bunch-by-bunch feedback system (TFB) acting in both horizontal and vertical plane [2] and a digital longitudinal bunch-by-bunch feedback (LFB) [3] improved the situation considerably.

Since operation of the TFB chromaticity was reduced to +1 in both planes restoring dynamic aperture and thus the beam lifetime. Fig. 2 shows beam images taken with a pinhole camera [4] for TFB switched on/off. Especially the vertical beam oscillations at low chromaticity settings are effectively damped.



A B C D

Fig. 2: Beam image with both TFBs switched off (A), horizontal TFB on (B), only vertical TFB on (C) and both planes damped simultaneously (D).

The LFB reduces the energy spread from 8.5 to $7.8 \cdot 10^{-4}$ close to natural energy spread. For the users, the resulting increase in brilliance is of more importance. Fig. 3 shows doubling of the brilliance in a dedicated experiment with the feedback active.

The demand for further increase of average beam intensities lead to fight Touschek lifetime by applying bunchlengthening using 3[rd] harmonic cavities. Thus four 1.5 GHz pill box cavities were installed and tested [5].

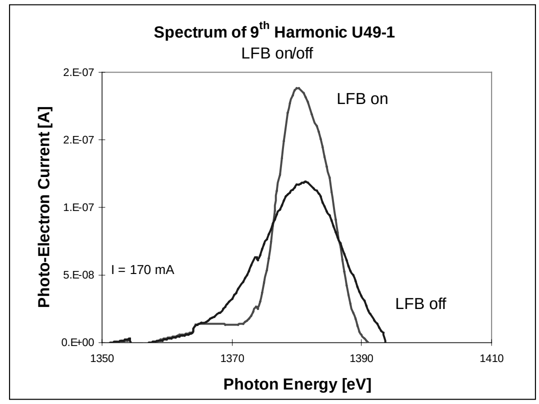


Fig.3: Brilliance measured at the 9[th] harmonic of undulator U49-1with and without LFB in operation.

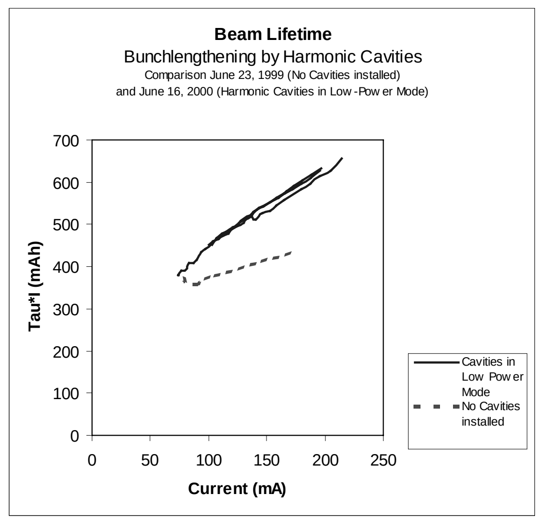


Fig. 4: Comparison of beam lifetime times current for harmonic cavities in low power mode and in parking position. Already at vacuum dominated conditions the cavities give a significant increase in total beam lifetime.

At the present user run the harmonic cavities are set to a low power mode, e.g. detuned some hundreds of kHz away from the revolution harmonic $3 \cdot f_{rf}$. Thus the beam induced voltages depending on current, are reaching 30 kV max. in each cavity at 200 mA. In this mode bunchlengthening starts around 100 mA and lengthens the bunches by a factor of up to 1.7, as was confirmed using a Hamamatsu C5860 streak camera. This leads to a significant increase in the total beam lifetime, see fig. 4. Though at the time of the measurement the beam lifetime was vacuum dominated, the gain in the product of beam current times lifetime was a factor of 1.5.

2.5 Summary of Achievements

The BESSY II storage ring design goals have been met and some essential parameters were surpassed during the commissioning phase. Table 1 gives a comprehensive list of the most relevant parameters, comparing design values and achievements. This situation offered good working conditions to the many user groups in the first year of operation.

On the other hand, the reliability of the synchrotron light source turned out to be acceptable. Already during the first year an availability of the ring of 95% was achieved with a cracked rf window causing the major loss in scheduled beam time. Starting with 1800h of beam to the users in 1999 operation will steadily be increased over the years aiming for 6000h/y

Table 1: Summary of machine parameters: Comparison of design values and achievements

Machine Parameter	Design	Achievements
Beam energy E	0.9 -1.9	0.85 -1.9 GeV
Standard energy E_o	1.7	1.720 GeV
Beam current I_{max}	100	Standard 200 mA 400 mA max.
Beam emittance ε_x	6	(6±1) nm rad
Coupling	< 3	0.6 ... 1.6%
Lifetime * Current	600	850 mAh
Bunchlength σ_l @ 100mA	18	17 ps
Energy Spread @ 200 mA	$7*10^{-4}$	$8.2*10^{-4}$ LFB off $7.8*10^{-4}$ LFB on
Momentum compaction	$7.3*10^{-4}$	$7.8*10^{-4}$
Chromaticity setting	+1	+5 without <+1 with TFB
Bunch-lengthening by harmonic cavities	-	2.7
ID-chamber vertical aperture	± 8	± 5.5 mm
Vertical Orbit stability		< 3 µm/h
Spurious dispersion in straight sections		< 2 cm

3 FUTURE PLANS

At the time of writing (June 2000) 8 IDs have been installed in the ring, at the end of the year 2000 there will be 9 undulators and 2 superconducting wigglers operational. Others are funded and are under construction occupying all available straights. Table 2 gives a list of IDs already in use or under construction. The abbreviations are U for planar undulators, UE for APPLE type structures emitting circular polarised radiation, whereas the number gives the period length of the magnet structure in mm; WLS denotes 3 pole wigglers with a central field according to the value; MPW stands for multipole wiggler.

Full integration into machine operation thus is and will be a major task to enable independent control of the undulators to the experimenters as well as controlled scanning of undulator and monochromator simultaneously.

Much effort was spent to reduce orbit distortions of the undulators to a level ≤ 5µm in the vertical and ≤15µm in the horizontal plane at any gap settings using feed-forward techniques to the correction coils. Nevertheless, at very small gaps non-linear effects excite third and/or forth order resonances that need further compensation.

Table 2: Insertion devices at BESSY II already installed or under construction.

Insertion Device	**Photon-Energy Range** (eV)	**Operational** since/in
U49-1	130 - 1600	1998
U180	25 - 1900	1998
U125-1	20 - 1900	1998
UE56-1	90 - 1300	1999
U41-1	170 - 1800	1999
UE56-2	90 - 1300	1999
4(6) T WLS	≥7000	1999(2000)
0.4 T WLS	650	1999
7 T WLS	4000 - 50000	2000
U49-2	130 - 1600	2000
U125-2	4 - 1200	2000
UE45-1		2001
7 T WLS		2002
7 T MPW		2002
U49-3		2002

ACKNOWLEDGEMENTS

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