HARDWARE UPGRADES IMPROVE THE RELIABILITY AT BESSY II*

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Abstract

The synchrotron light source BESSY II is now in its second decade of operation. Already in 2012, both TopUp and fast orbit feedback have been introduced into user operation. Currently, the facility is undergoing significant hardware upgrades in order to fulfill the increasing demands of its user community in terms of reliability, stability and flexibility. These include replacement of the DORIS cavities with EU HOM damped cavities, the upgrade of the RF transmitters to solid state amplifiers, implementation of the shifted waist optics for the new in-vacuum undulator, and refurbishment of the superconducting multi-pole wiggler. In this contribution, the status of BESSY II operation and its upgrade projects is reported.

INTRODUCTION

The BESSY II storage ring is a 3rd generation light source, with a beam energy of 1.7 GeV, and a maximal beam current of 300 mA. Since 2012, the machine is operated in TopUp-Mode with an average injection efficiency of 95%, providing very stable experimental conditions to its users. Being in the second decade of operation, the focus of accelerator physics activities lies both in improvement and preservation. Therefore, a number of hardware activities have been performed in recent years, addressing the increasing demands of its user community in terms of reliability, stability and flexibility.

HOM DAMPED CAVITIES

Already in 2000 a joint effort between BESSY (Germany), Daresbury (UK), DELTA (Germany) and Tsing Hua University (Taiwan) was started to develop a new cavity for the use in storage ring operation [1]. The aim of this project was to develop a modern normal conducting HOM damped cavity, that meets the requirements of synchrotron radiation sources. Special focus laid on strong HOM damping in order to inhibit cavity induced coupled bunch instabilities for high current operation while taking into account the tight space constrains put by the existing infrastructure. Table 1 gives an overview of both DORIS and EU-cavity parameters.

First installations of this new cavity type took place at DELTA (Darmstadt, Germany) in 2004/2005 [2]. In the following years these cavities have been put into operation at the Metrology Light Source (Berlin, Germany) and the ALBA synchrotron (Barcelona, Spain) [3]. In 2013 a modified version of the EU cavity, scaled to a frequency of 352.2 MHz, was put into operation at European Synchrotron (ESRF, Grenoble, France) [4].

Table 1: Key parameters of BESSY II RF cavities before upgrade (DORIS-type) and after upgrade (EU-cavity)

Parameter	**DORIS-type**	**EU-cavity**
RF frequency	500 MHz	500 MHz
Number of cavities	4	4
Max cavity voltage	780 kV	735 kV
Quality factor Q	26700	29600
Shunt impedance $R_{s,0}$	3.1 MΩ	3.4 MΩ

The replacement of the four DORIS type cavities of the BESSY II storage ring was performed in two shutdowns. The first two cavities have been installed in September 2013, while the second pair was put into operation in November 2015. Figure 1 shows the final configuration in the storage ring tunnel.

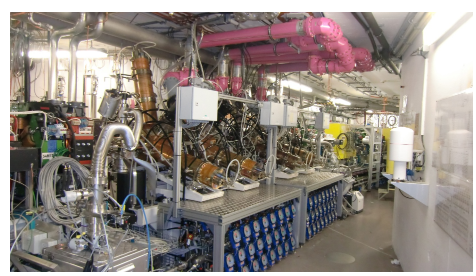

Figure 1: Final configuration of new HOM-damped cavities after installation in BESSY II storage-ring in Nov. 2015.

SOLID STATE TRANSMITTERS

Until the beginning of 2015 the four cavities of the BESSY II storage ring have been powered by four klystron based RF amplifiers, some of which have been in operation for more than 100 thousand hours. In order to maintain reliability and performance, replacement was needed. As it became increasingly difficult to find manufacturers for spare klystrons, it has been decided to replace both storage ring and booster klystrons with high power solid state amplifiers (SSA) which have become available recently. Compared to klystrons these SSAs provide higher efficiency and at the same time exhibit lower RF-noise, see Fig. 2. An additional advantage is very good maintainability and reliability due to the redundant design, modular structure and low operating voltage.

The replacement of the klystron based amplifiers has been performed within a very tight time-scale. The delivery

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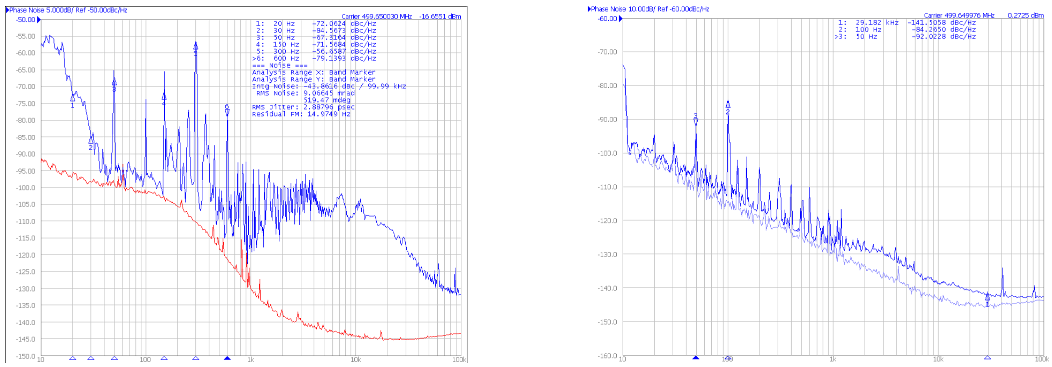

Figure 2: Comparison of phase noise of solid-state amplifier vs. klystron amplifier: Left: Klystron amplifier noise without feedback (blue), master oscillator (red). Right: SSA noise without feedback (blue), master oscillator (light blue).

started with the 40 kW booster SSA in mid-2014, and was completed with the delivery of the last 75 kW storage ring SSA at end of 2015. The replacement of all klystron amplifiers was conducted in 2015. Four amplifiers have been replaced during two 8-week shutdowns. One amplifier was replaced in normal user operation, relying on the redundance provided by the remaining three storage ring amplifiers.

Since the beginning of 2016 all SSAs are in operation, which coincided with the completion of the cavity upgrade program.

SUPERCONDUCTING WIGGLERS

At BESSY II three superconducting insertion devices are currently in operation: two wave length shifters and one 7 T wiggler with 17 poles. The radiation power of the multi-pole wiggler (MPW) of 27 kW constitutes a 50% addition to the total radiation loss of the storage ring. Thus, both damping power and energy spread are significantly enlarged, leading to an increase in bunch length and lifetime, and providing a positive effect on general beam stability [5].

In 2012, the MPW was taken out for a refurbishment. The goal was to keep the existing magnet structure but equip it with a state-of-the-art cryostat. This should allow for a closed helium circle and remove the need for the weekly refilling procedure. In August 2013, the renovated cryostat arrived at HZB. Without beam the device demonstrated the expected excellent cryogenic properties. But first beam tests lead to a substantial heating of the connecting vacuum flanges, necessitating the incorporation of RF-springs and delaying the start of operation until January 2014. Then careful investigation with beam were conducted, leading to the identification of the magnetic centre of the device and an optimized set of the beam parameters.

Unfortunately, in May 2014 an accidental missteering of the beam lead to a damage of the exit section of the MPW by its own synchrotron radiation. While the vacuum system of the storage ring was intact, lifetime was diminished. Thus, the MPW needed to be removed from the ring. After the repair, including a redesign of the liner sections (entrance and exit), the installation of a front adsorber and a more stringent machine protection mechanism, the MPW was reinstalled in March 2015. The control of the beam induced heat-load remained challenging. The stable operation in 300 mA TopUp mode is possible, but a dedicated adjustment of the bunch length by adequate settings of main RF and Landau cavities became necessary [6]. Also the bunch lengthening effect of the MPW itself contributes with a stabilising effect.

Impedance calculations with CST were performed to identify the cause of the sensitivity to the bunch length. The exit section (see Fig. 3) was found to be susceptible to excitations of a few GHz, matching the typical bunch length of the BESSY II storage ring of 15 ps. Detailed investigation are ongoing.

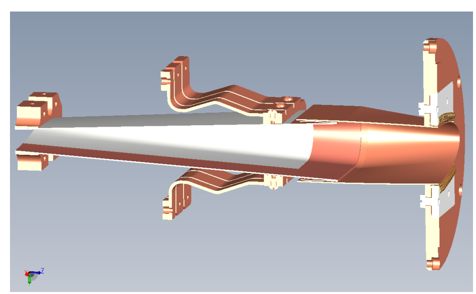

Figure 3: Modified exit section of the 17-pole 7 T wiggler.

NOVEL LABORATORY FOR MATERIAL RESEARCH

The Energy Material in-situ Laboratory (EMIL) is an experimental extension to the BESSY II storage ring currently under construction [7]. This new laboratory includes five experimental end-stations, three of which are designed to simultaneously access soft and hard X-rays in the energy range 80 eV to 10 keV. This is achieved by the installation of two undulators in a canted setup: the UE-48 is of APPLE II type and provides soft X-rays, while the the cryogenic in-vacuum device CPMU-17, currently under fabrication, is to provide hard X-ray radiation. A particular challenge is given by the small minimal vertical gap of 5.5 mm of the CPMU-17.

A local lattice modification had been prepared to support the canted undulator setup in the shutdown 2015 [8, 9].

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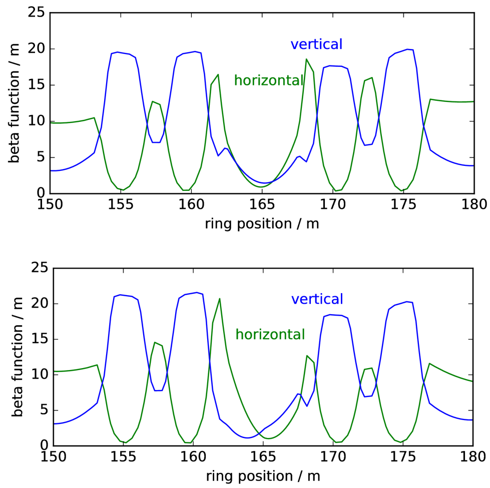

Figure 4: LOCO results of BESSY II storage ring: standard optics (top), shifted waist optics (buttom).

These include the installation of an additional quadrupole at the center of the straight and individual power converters for the adjacent tripletts powering six quadrupole magnets and four sextupole magnets. A modified optics has been developed to support the reduced aperture constraint given by the cryogenic undulator. Compared to the standard optics the vertical beam waist is shifted to the center of the cryogenic undulator, see Fig. 4. The analysis of beam optics measurement using LOCO-fitting have confirmed the anticipated reduction of the maximal vertical beta function from 4.87 m to 1.89 m. Thus, the BESSY II storage ring is well prepared for the commissioning of the UE48 starting in summer 2016, and the installation of the CPMU-17 planned for the beginning of 2017.

CONCLUSION & OUTLOOK

Recent years have shown a number of improvements of the BESSY II synchrotron light source addressing both reliability and performance. Most noticeably are the installation of a 50 MeV injector linac and the start of TopUp operation [10], the implementation of a fast orbit feedback system [11], and the upgrade of the bunch-by-bunch feedback to a fully digital system [12].

Further hardware activities, as discussed in this proceeding, include the installation of HOM-damped cavities and solid-state RF amplifiers, the renovation of the multi-pole wiggler, and an optics modification for the new Energy Material in-situ Laboratory.

Future upgrades are in the focus of the BESSY VSR project [13]. Examples are the development of bunch-resolved beam diagnostics, improvements to the FOFB, a possible injector upgrade and optics modifications for booster and storage ring [14, 15].

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