MODIFICATIONS TO THE MACHINE OPTICS OF BESSY II NECESSITATED BY THE EMIL PROJECT

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Abstract

The Helmholtz Zentrum Berlin and the Max Planck Society are going to build a new dedicated X-ray beam line at the synchrotron light source BESSY II which will be used for analyzing materials for renewable energy generation. The new large scale project has been dubbed EMIL.

In this document we present the modifications to the machine optics and to what extent these changes affect the performance of BESSY II.

PROJECT DESCRIPTION

The Helmholtz Zentrum Berlin (HZB) and the Max-Planck Society (MPG) are going to implement EMIL, the Energy Material in situ Lab at the BESSY II synchrotron light source.

The EMIL-facility is dedicated to in-situ and in-system X-ray analysis of materials and devices for photovoltaic applications and for (photo-) catalytic processes. EMIL is subdivided into SISSY@EMIL for the investigation of photovoltaic materials and processes and CAT@EMIL for ambient-pressure spectroscopies at catalytic materials. The large variety of available methods (PES, PEEM, HAXPES, XES, XAS, XRF, XRD) will enable the investigation of sample structures with information depths ranging from a few nanometer up to the micron scale.

The X-ray light source for these stations will consist of two canted insertion devices, a variably polarizing APPLE II undulator for soft X-rays (80 eV- 2.2 keV), and a planar cryogenic undulator for hard X-rays up to 10 keV. The end stations can either be operated with both beams simultaneously in a common focus or use alternatively either the soft- or the hard X-ray radiation. Two beamlines are attached to the undulators and disperse and distribute the radiation to the various end stations. A double crystal monochromator is used for the hard X-ray branch, while a collimated plane grating monochromator with variable deflection angle is planned for the soft X-ray branch.

EMIL includes two undulators. The undulator U16 is foreseen as a cryogenic in vacuum undulator with a period length of $16.25\,\mathrm{mm}$ and a peak field on axis of $1.16\,\mathrm{T}$ at a nominal gap of about $5\,\mathrm{mm}$. The second undulator, generating predominantly soft X-rays, is of APPLE II type and has a period length of $48\,\mathrm{mm}$. To mitigate deleterious effects of the undulator on the performance of the storage ring and to avoid beam scraping the β-functions along the undulators have to be kept sufficiently small.

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REQUIREMENTS FOR THE MACHINE OPTICS

To separate the beam cones generated by the two undulators, the undulators have to be *canted*; i.e. there has to be some deflection between those undulators. The undulators will be installed in a triplet section of the BESSY II storage ring [1].

In the following, we show that the vertical beam waist can be shifted by about a meter from the center of the straight at the planned location of the cryogenic undulator keeping the original value of the vertical β-function at $\beta_{yo} = 1.2\,\mathrm{m}$ at the beam waist.

Finally, a refined machine optics is presented which enhances the performance of the undulators by optimizing the vertical β-function locally and minimizing the perturbations in the rest of ring.

THE MACHINE TEST

The modifications to wirings of the magnets in the section T6 are shown in [1].

At BESSY II all elements of the quadrupole families $Q3$, $Q4$ and $Q5$ are wired in pairs connected along the straight. Each pair in a straight is powered by a single power supply. Only for this test a facility was provided to power the quadrupoles in a single section asymmetrically.

Since power supplies providing the full current for the new circuits were not available, equipping the ring with power supplies and the required large cross section cables and the cuts through the shielding would have required a long shutdown (postponing the test by at least a year), the additional power feeds required for the EMIL optics are provided by floating power supplies, capable of providing offsets of $\pm 40\,\mathrm{A}$ (four quadrant power supplies).

The requirements for the test are: Keeping the properties of the users' optics intact while shifting the vertical β-function in one of the short straight sections (T6) by $0.8\,\mathrm{m}$ downstream utilizing no new optical elements. The minimum of the β-function at the beam waist should remain at $1.2\,\mathrm{m}$ and the tune has to remain the same [1]. The result of optics simulation with the help of MAD8 [2] for the straight T6 in comparison to the original optics is shown in Fig. 1.

The β-functions for the entire BESSY II storage ring after the modification is presented in Fig. 2. The area shaded in yellow indicates the modified section T6.

With the help of LOCO [3, 4] and the Matlab Middle Layer (MML) [5], we were able to dial in the machine optics within two iterations. The resulting optics obtained fol-

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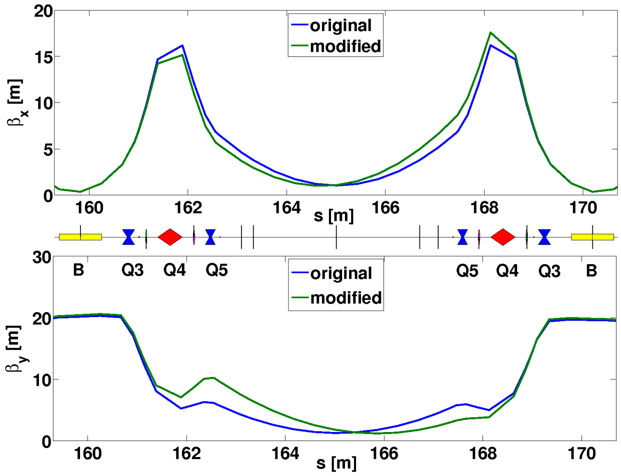

Figure 1: β-functions in the straight T6. Blue lines indicate the original optics, green lines the optics modified for the project EMIL.

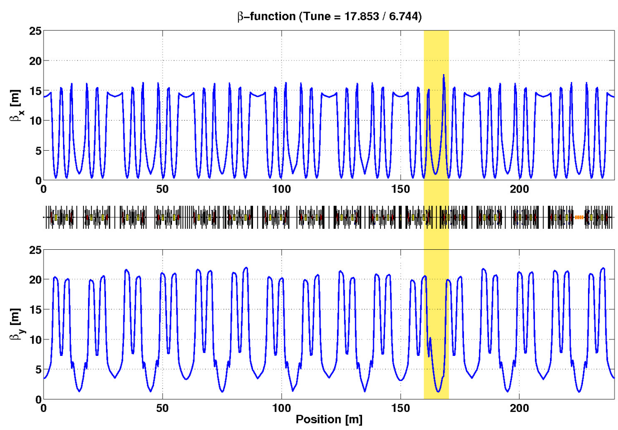

Figure 2: Design optics for EMIL after modifying section T6.

lowing a LOCO analysis is presented in Fig. 3.

A comparison between the design optics and the measured one predicted by LOCO is shown in Fig. 4 convincingly demonstrating that the vertical beam waist can be shifted to the appropriate location.

The required and the achieved figures for the shift of the vertical beam waist Δs_0 and the vertical β-function β_{y0} at this location are compiled in Table 1.

Table 1: Comparison of design and measured figures for the shift of the vertical beam waist Δs_0 and the vertical β-function β_{y0} at the vertical beam waist.

	design	measured
Δs_0	0.856 m	0.923 m
β_{y0}	1.194 m	1.212 m

After optimizing the settings of the sextupoles in section T6 while keeping the settings of the remaining sextupoles

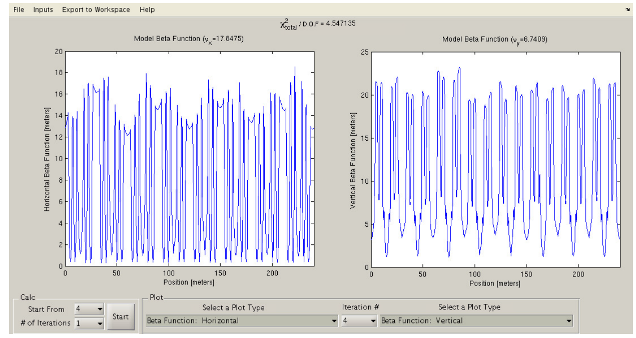

Figure 3: Measurement: LOCO-Analysis of the optics modified for the EMIL project.

at their usual values, the lifetime at a current of 300 mA can be restored to 10 h, somewhat less than the typical 12 h for the original optics. The injection efficiency did not change appreciably from the values obtained for the standard optics.

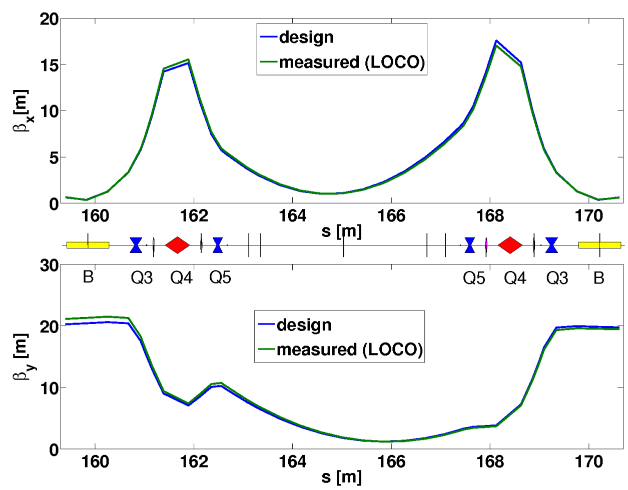

Figure 4: Comparison of the β-functions of the design optics and the actual optics measured by LOCO.

RECENT DEVELOPMENTS

Combining the center dipole of the straight with a quadrupole is beneficial in two aspects: i) in the current optics design the minimum vertical betatron function is 1.2 m. Decreasing this value permits a smaller magnetic gap of the cryogenic undulator without sacrificing beam aperture (lifetime reduction). This permits a reduction of the period length which enhances the flux in the hard X-ray regime; ii) The large betatron function at the UE48 downstream end is reduced avoiding a beam scraping with the undulator chamber. Reducing the gap of the cryogenic undulator to less than about 5 mm, increases the photon flux by a factor of two for hard X-rays.

Furthermore, photon beam calculations suggest that the canting angle can be lowered to 2 mrad.

We estimate the vertical β-function at the location

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of the downstream end of the undulator UE48 has to be kept smaller than originally thought requiring an additional quadrupole modeled as a gradient on top of the deflecting dipole in the center of the straight if the beam waist at the center of the cryogenic undulator is further decreased.

Utilizing the well-known formula for the propagation of a β-function in a drift [6], the value of the β-function $\Delta s = 3.37\,\mathrm{m}$ distant from the waist is calculated to $13.5\,\mathrm{m}$ for a β-function $\beta_0 = 0.9\,\mathrm{m}$ at the location of the waist.

Since a β-function of this size equates to a vertical aperture of $6.6\,\mathrm{mm}$ given BESSY II's vertical acceptance of $3.2 \times 10^{-6}\,\mathrm{m\,rad}$ leading to beam scraping and thus a reduction in life time, an additional focusing element is mandatory.

The detailed requirements for the refined optics are: A vertical β-function at the beam waist in the center of the cryogenic undulator of $0.9\,\mathrm{m}$, a shift of the vertical beam waist by $1.125\,\mathrm{m}$ and a β_y-function at the downstream face of the undulator U48 of less than $6.4\,\mathrm{m}$. A machine optics for the cell including T6 which fulfills the requirements and minimizes the optics perturbations caused by the EMIL optics is shown in Fig. 5. The beam cross sections and the emittances remain at almost the same values as those for the user optics.

To maximize space available for undulators, the extra deflection can be provided by reducing the main dipoles deflection by $1\,\mathrm{mrad}$ compensating the bending angle of the additional dipole at the center of the straight T6. Furthermore, a gradient on this dipole provides focusing in the simulation, minimizing the vertical β function at the downstream end of the undulator U48 (drawn in red in Fig. 5). The location of the cryogenic undulator is indicated in blue.

We are confident that a value of $\beta_{y0} = 0.9\,\mathrm{m}$ for the vertical β-function at the center of the cryogenic undulator would allow a full gap of $5\,\mathrm{mm}$ and thus the undulators can provide the requested flux and brightness.

The resulting optics for the entire BESSY II storage ring is presented in Fig. 6.

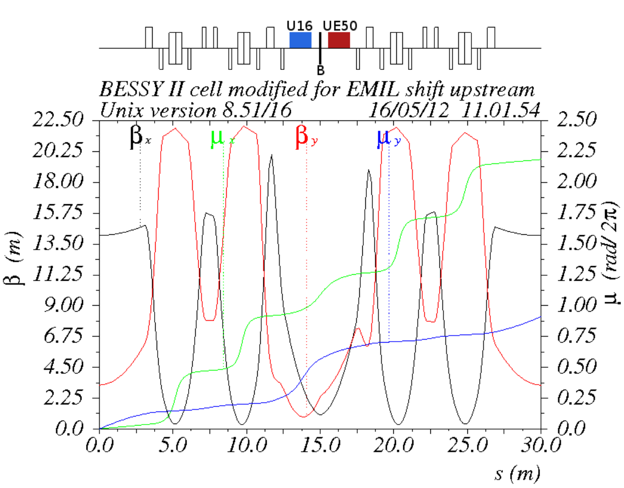

Figure 5: Simulation of the refined unit cell for EMIL.

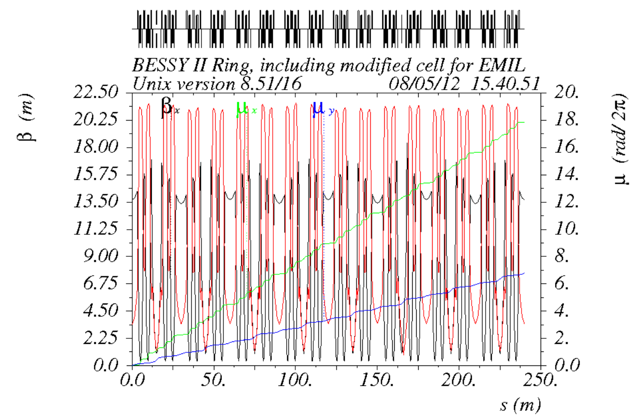

Figure 6: Simulation of the β-functions for BESSY II including the refined unit cell modified for the project EMIL.

CONCLUSIONS

The Project EMIL necessitates modifications to BESSY II's machine optics. The vertical beam waist in straight T6 has to be shifted. We successfully demonstrated that during an experiment a shift by the required amount keeping the original value of the vertical β-function at the beam waist is indeed possible without hampering the performance and the beam parameters of the BESSY II storage ring.

If smaller values of the vertical β-function at the beam waist are required for optimizing the performance of the undulators, this quantity can be lowered to $0.9\,\mathrm{m}$ without substantially altering the beam properties of BESSY II.

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