# MODIFICATION OF THE BESSY II OPTICS FOR THE IMPLEMENTATION OF A SMALL GAP UNDULATOR

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## *Abstract*

BESSY II faces an increasing demand for photons in the range from 60 eV to 8 keVto be available at the same experimental station. A double undulator scheme is planned where a small period cryogenic undulator with a small gap is combined with a standard circularly polarized undulator. Several optics schemes for the 1.7 GeV BESSY II storage ring are discussed. BESSY II has two different types of straight sections, a high beta straight with $\beta_{x,\ min}$=15 m and $\beta_{y,\ min}$ =4.5 m and a low beta straight with $\beta_{x,\ min}$=$\beta_{y,\ min}$=1.2 m. We discuss the present plan using a small detuning of an existing low beta straight to shift the small vertical beta waist to the centre of the small gap cryogenic undulator with only minor impact to the machine.Machine optics tests with a shifted vertical focus started in 2011.

## INTRODUCTION

The development of thin film solar cells is an important field of research at the Helmholtz-Zentrum Berlin (HZB). Quantum efficiencies above 20% are the long term goal. Future solar cells will consist of up to 40 layers with thicknesses down to a few nm. The chemical and structural compositions of these layers and their interfaces have a dominant influence on the chemical and electric properties of the cells. A "**S**olar Cell **In**-**S**itu Lab at a **Sy**nchrotron Beamline" (SISSY) will be built at BESSY II. This facility will permit in-situ monitoring of growth processes, in-situ diagnostics of individual layers, and characterization of interfaces. A sample transfer under UHV conditions between the so-called clustertool for sample preparation and the analytics chamber will be possible. Various techniques for characterization will be available such as photoelectron spectroscopy and photoelectron emission microscopy close to the sample surface or X-ray absorption, X-ray emission, X-ray fluorescence spectroscopy or X-ray diffraction at deeper interfaces. A depth profiling from the *nm*- to the *µm*-range can be accomplished with an appropriate choice of the spectroscopy method and the incoming photon energy, which will range from 60 eV up to 8 keV. High photon energy is needed also for another class of experiments, called **Ha**rd **X**ray**P**hoto **E**lectron **S**pectroscopy(HAXPES). A small spot size at the sample of 100*µm* guarantees a high resolution of the secondary spectrometers.

Two undulators and three dipole magnets in a canting e-beam geometry in one straight section with a canting angle of 4 mrad are planned. Due to geometric constraints permanent magnet dipoles similar to the ones described in [1] will be employed to deflect the electron beam. Elliptically polarized photons in the soft X-ray regime will be provided by an APPLE II type undulator, and X-rays from 2 keV up to 8 keV will be generated by a cryogenic planar undulator. Two monochromators using ruled gratings and crystals, respectively, will transport the light downstream to three end stations.

The cryogenic small period undulator requires a small gap to provide a sufficiently high tuning range. The beam optics has to be modified in order to avoid a beam scraping with closed gap. Three options for a canted undulator design have been evaluated: The 1st option needs a quadrupole triplet in a long straight section to generate two vertical foci. The vertical tune is shifted by π whereas the horizontal tune remains unchanged. The horizontal betatron function is 18 m [2]. The 2nd option is a reconstruction of an existing high beta section into a low beta section with a shifted vertical focus. In the 3rd option the two undulators are installed in an existing low beta straight. The tunes of the machine remain at the old values and the only modification is the shift of the vertical focus with an asymmetric powering of adjacent quadrupoles and sextupoles.

The first scheme is not the optimum because the small vertical beta is needed only for the cryogenic device and the large horizontal beta function reduces the brightness of the radiation. The 2nd scheme has been excluded due to major modifications to the storage ring and unpredictable implications to the ring optics (change of horizontal and vertical tunes). In the following we will discuss the 3rd scheme.

## CRYOGENIC UNDULATOR

Cryogenic undulators provide significantly higher fields as compared to room temperature in-vacuum undulators. ANdFeB-based cryogenic undulator has been built for the Swiss Light Source. It has to be operated at 150K which is accomplished with a combination of a liquid nitrogen cooling system and a heater [3]. PrFeB-based devices can be operated at liquid nitrogen temperature which makes the heater obsolete. A device of this type has been built for SOLEIL [4]. We will use a new grade of PrFeB-material as developed by VAC [5].

The undulator is called U16, and has a period length of 16.25 mm, a minimum gap of 6 mm and a magnetic length of 1.5 m. The period length has been chosen such that the 3rd harmonic goes down to 2 keV and the 3rd and 5th harmonic overlap. The device will be operated up to the 9th harmonic. Figure 1 shows the brilliance and flux of U16. At high energies a comparable flux can be achieved with a dedicated wiggler, a W91, with a period length of 91mm, 16 periods operated at a minimum gap of 11.0 mm. However, brilliance is much lower as compared to the U16 and the high heat load of 2.4 kWpresents a difficult problem for the beamline optics.

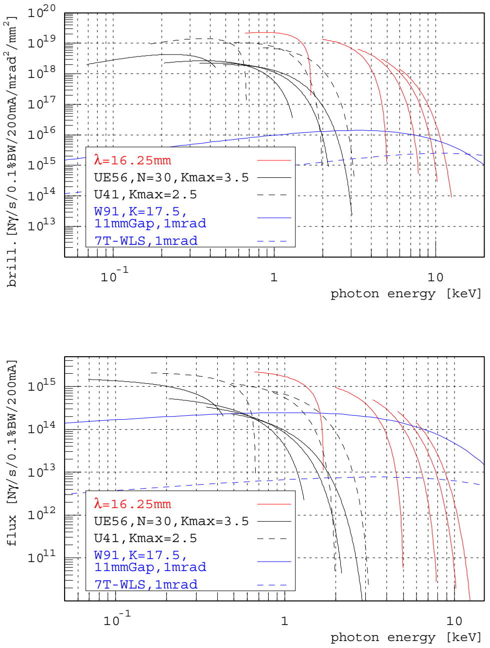

Figure 1: Brilliance (top) and flux (bottom) of a cryogenic undulator with a period length of 16.25mm and a total length of 1.5 m. The data are compared to existing devices and a hypothetical in-vacuum wiggler W-91. The fluxes of the W-91 and the SC-WLS are given for a horizontal angle of 1 mrad (vertically integrated). An electron beam energy spread of 0.08% is included.

## TRACKING SIMULATIONS

The linear beam optics in the modified straight is shown in Fig. 2. The modified optics has a minimum vertical beta of 1.2 m (measured). The better choice for a 1.5 m long undulator is a minimum beta of 0.75 m. However, the 1.2 m value is consistent with the value of the present optics, and leads to an only 10% larger beta function at the undulator edges. A moderate reduction of the beta function seems possible.

For the nominal vertical physical aperture of 11 mm in the other undulator chambers (assuming an ideal alignment of all existing ID-chambers and negligible fabrication errors) a cryogenic undulator with a length of 1.5 m does not reduce the vertical aperture. A collimator will be provided to avoid electron deposition in the magnets.

The modification is small and it is confined to the low beta straight. The working points of the optics stay unchanged. The minimum values of the beta functions are unchanged, only the locations of the minima are adjusted. The minimum of the vertical beta function is shifted longitudinally off center by 0.75m. There was no constraint on the minimum of the horizontal beta function.

The BESSY II optics is sometimes operated with a chromaticity of about +3 in both planes. Because of a nonlinear chromatic tune shift, particles at -3% momentum deviations approach critical resonances. The chromatic tune shift measured with the present machine optics and compared with simulations of the modified optics is shown in Fig. 3.

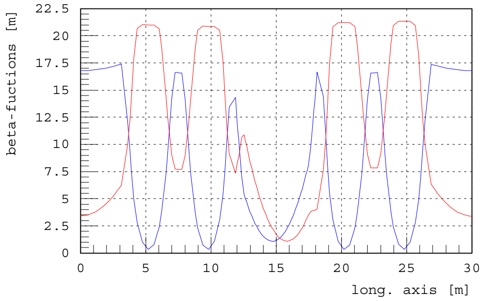

Figure 2: Linear SISSYOptics functions, blue: $\beta_x$, red: $\beta_y$. The foci are moved by an asymmetric detuning of the upstream and downstream the quadrupoles. The small gap cryogenic undulator will be installed in the low vertical beta region and centered at position 15.75 m.

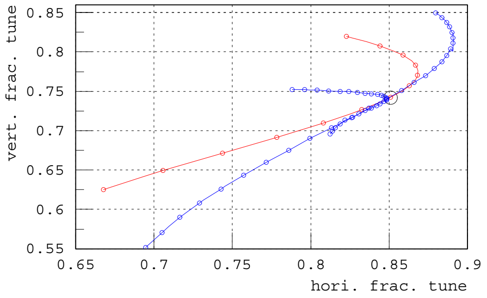

Figure 3: Chromatic tune shift of BESSY II measured at chromaticities of +0.7 and +3 (blue), and simulated at chromaticities of +3 (red). The working point is indicated by the circle.

The measured nonlinear chromatic tune shift is not well modeled by the optics simulation using harmonic sextupoles. But the critical range for negative momenta close to fractional tunes of 1/2 and 2/3 becomes apparent. The simulation is done with the cryogenic undulator, which has only a marginal effect on the chromatic tunes.

Figure 4 shows the survival plot for on-momentum particles over 1000 turns, and Figure 5 is the related plot of the frequency map.

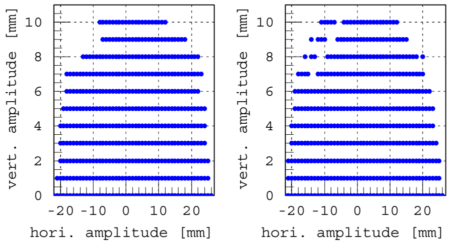

Figure 4: Dynamic aperture for the modified optics (left, bare lattice) including the ID (right), shown are tracking results for 1000 stable turns.

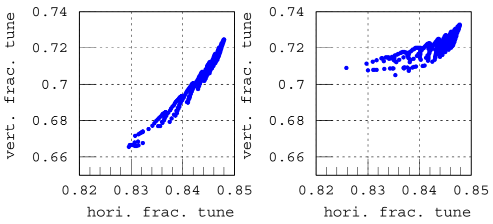

Figure 5: Frequency map of the tracked particles of Fig. 4. Shown are results of the modified optics (bare lattice, left) and results including the ID (right, no tune correction).

The dynamic aperture for positive momenta is comparable to the presented results, for negative momenta less than 2% the dynamic aperture degrades. This could require relaxing the chromaticies from +3 to smaller values. The presented results are achieved with the harmonic sextupole settings of the present optics. For the finally applied modified optics and machine tests it is foreseen to tune the harmonic sextupoles in the modified straight independently by separated power supplies.

The tracking simulations are based on analytic generating functions [6]. The complete 3D-undulator fields are represented by scalable analytic expressions which are directly implemented into the generating functions. A numerical FEM code is required [7] to evaluate the transverse field profile at one pole which is decomposed into Fourier components for the field parameterization.

## MACHINE TESTS WITH MODIFIED OPTICS

The modified optics as described in the previous section will be tested before the canted undulator scheme will be realized. The quadrupole and sextupole families will be broken up upstream and downstream of a low beta section. Seven additional power supplies will provide sufficient flexibility to shift the vertical and horizontal focus. The arrangement of the power supplies is shown in Fig. 6.

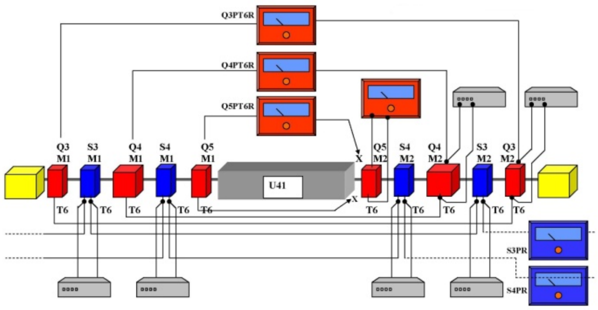

Figure 6: Seven additional power supplies allow for an independent and asymmetric tuning of the quadrupoles and sextupoles in the straight section.

The storage ring performance and, in particular, the injection efficiency for top up operation will be tested in the optics. A final decision on the optics is expected at the end of 2011.Recently, this optics modification was set up and first tests performed. The injection up to 300 mA is possible, the beam has a good life time, topping up experiments are started.

## CONCLUSION AND FUTURE PLANS

The modified optics as described in this paper provide a higher brightness as compared to a quadrupole triplet solution as studied earlier. The storage ring modification is small and first results are promising.

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