A 7T WIGGLER FOR BESSY II: IMPLEMENTATION AND COMMISSIONING RESULTS*

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Abstract

To generate hard X-ray beams for residual stress analysis and for magnetic scattering with the BESSY II SR source, a 7T wiggler with 17 poles has been implemented. Several problems had to be solved. Wake fields due to small geometrical steps in the radiation shield inside the beam chamber led to intolerable LHe consumption, which have been analysed numerically and then cured by improving the shield geometry. Much of the routine operation procedures are influenced by the unusually high radiation power level of max. 55 kW. For system protection an interlock system dumps the electron beam automatically in case of relevant error events. This wiggler is by far the strongest perturbation of the linear beam optics, breaking seriously the symmetry of the ring. Beam optical parameters including tune shift and beta beat have been measured to quantify these perturbations and develop efficient cures to limit the negative effects on beam lifetime and dynamic aperture. The wiggler is operated up to 7.0 T and max. currents of 250 mA in normal user shifts.

INTRODUCTION

To provide high flux hard X-ray beams for material science, a 17 pole wiggler (13 poles at full field) with a maximum field of 7T has been built and implemented in the BESSY II storage ring. Table 1 shows the essential parameters. The most unusual feature is the high radiation power generated by this device. Although the BESSY II ring is running at 1.7 GeV / 250 mA in normal user operation mode, all relevant vacuum chambers and absorbers were designed for 1.9 GeV / 500 mA (56 kW radiation power) to provide room for future upgrades.

Table 1: Wiggler magnet parameters

critical energy (@ 1,9 GeV)	16.8 keV
max. field on axis	7.0 T
max. field on coils	8.1 T
periode length	148 mm
number of poles main poles	13
end poles	4
horiz. beam chamber aperture	110 mm
vert. beam chamber aperture	13 mm
magnetic (iron) gap	19 mm
stored magnetic energy	450 kJ
total radiation power (1.9 GeV, 500 mA)	56 kW

Details of the conceptual layout, the technical design and the field measurements of the superconducting magnet including the down stream vacuum chambers of the wiggler were presented in previous reports [1,2,3]. Here we concentrate on observations which have been made after installation of the wiggler in the ring.

BEAM INDUCED LHE CONSUMPTION

The wiggler magnet is installed in a LHe bath cryostat operated at 1.13 bar, which features two radiation shields (at 20K and 60K) and super-isolation to minimize radiative heat transfer. Inside the cold electron beam chamber (4.2K) a radiation shield (liner) has been installed (see Fig.1) and connected thermally to the 20K shield to avoid back scattered radiation from the first radiation absorber downstream of the wiggler and radiation from other sources to reach the beam chamber. Four cryo-generators are used with a total cooling power of 2W at 4.2K, 25W at 20K and 280W at 60K with the intension to allow for closed cycle operation after initial cool-down of the system. It turned out, however, that additional 0.6 l/h of LHe (0.43W) have to be provided at 7T in the steady state without beam.

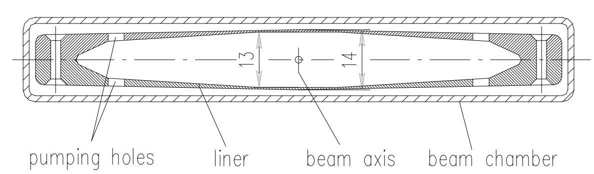

Fig. 1: Cross-section of the beam chamber

When operating the wiggler with beam for the first time, an unexpectedly high beam induced LHe consumption rate was observed of about 1.1 l/h (0.8W) at 100mA. The consumption rate was observed to scale with the square of the beam current indicating that wake fields were the source of the problem rather than synchrotron radiation from the up-stream magnets or from the wiggler itself. Also the liner temperature was observed to increase from 20K to about 38K. With a beam induced power transfer of about 4.9W to the LHe vessel at 250 mA it became clear that the problem had to be cured before starting normal user operation with the wiggler.

In an attempt to find out the reason for the problem three mechanisms were studied in detail:

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i) Following [4] resistive wall losses due to mirror currents in the liner (copper, 1mm thickness) give an estimated power of 1.2 W.

ii) Several smaller cross-section changes of the order of 1mm in vertical direction have been identified in the liner, in particular in the transition region between the spring holder and the copper flange (20K) and, unavoidably, at the junction of the spring holder and the rf-spring (see Fig.2). Numerical loss factor calculations indicate that a wake field induced power of the order of several 10W may be generated by these cross-section steps.

iii) As indicated in Fig. 1 the liner was fitted with pumping slits (15mm length, 2mm width) in 40mm horizontal distance from the beam axis. Numerical estimates of the wake fields induced by the slits along the beam axis show that only a power level in the μW range can be expected.

Thus, to reduce the dominating contribution to the wake field induced power, a new liner with improved geometry had to be installed. As the pumping slits were not strictly necessary at 20K no slits were cut in the new liner, and the spring holder was fitted to the beam tube flange (at 300K) in order to allow the power generated by the unavoidable step between the spring holder and the rf-spring to be (mainly) absorbed at room temperature level in contrast to the 20K level before. As a result of these modifications the beam induced LHe consumption rate has been reduced successfully by more than a factor of 20 down to a negligible value of < 0.1l/h.

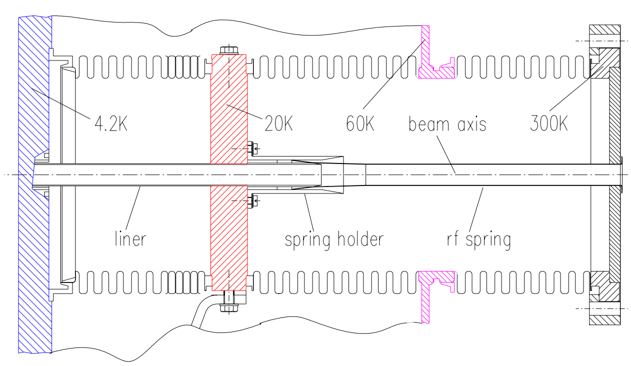

Fig. 2: Liner and rf-spring assembly before modification

BEAM INTERLOCK SYSTEM

The wiggler emits radiation of 56 kW power in a horizontal fan of +/-27 mrad. Therefore the photon absorbers and parts of the vacuum chamber are heated by high power densities of up to 10^9 W/m^2. Expected heat loads on all components were calculated and 18 independent water cooling circuits are designed for optimum heat removal. To allow safe operation of the complete system, cooling water temperatures, flow rates and surface temperatures are checked permanently for the most critical parts of the vacuum chamber.

A special interlock system is used to protect all relevant components and vacuum chambers in normal user operation (see Fig. 3). This system dumps the electron beam within about 100 msec in case of critical vacuum incidences, magnet quenches, excessive vacuum chamber surface temperatures, low cooling water flow, and after intolerably large orbit excursions in the wiggler straight section.

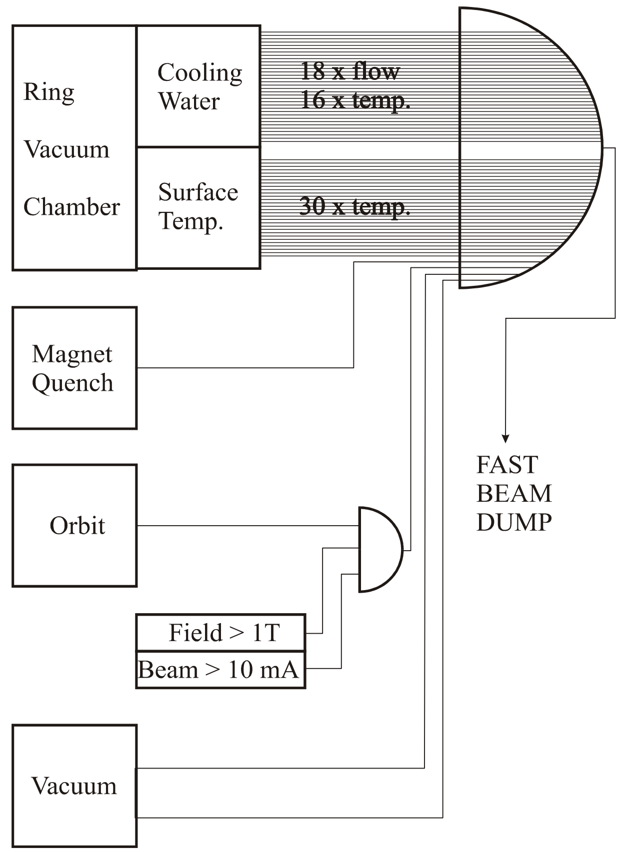

Fig. 3: Schematic of the beam interlock system

BEAM OPTICAL IMPLEMENTATION

The wiggler is by far the strongest linear perturbation of the BESSY II ring optics, leading to large values for the tune shift, the tune spread, and the β beat for the vertical particle motion. This perturbation must be compensated at least in part to avoid an unacceptable lifetime reduction. To minimize these effects the device has been installed in a "low beta section" of the ring (β_y = 1.2 m). Figure 4 shows the strong vertical tune shift scaling in good approximation with B^2 as expected. The measured horizontal tune shift at 7T is only 0.004, over a factor of 20 smaller than vertically, and scales linearly with the field, presumably due to a small misalignment of the wiggler.

At the location of the wiggler the horizontal beta function β_x=1 m and the dispersion D≈0 to avoid emittance increasing effects. Thus for operation at 1.7 GeV the wiggler increases the radiation damping strength by 66% thereby reducing the emittance by about 60% and enhancing the energy spread by 50 %.

The wiggler acts mostly as a linear device on the beam optics as the nonlinear field content is small. However, it disturbs the nonlinear tuning of the ring. To recover an

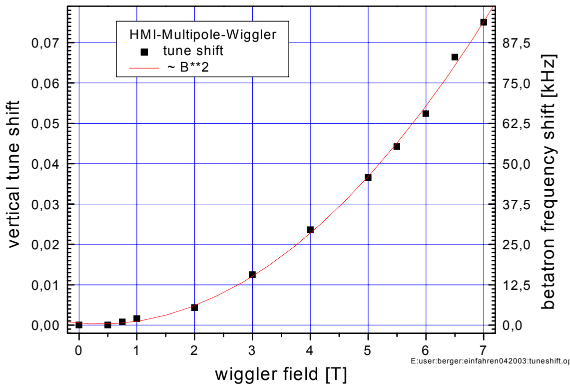

Fig. 4: Vertical tune shift vs. wiggler field

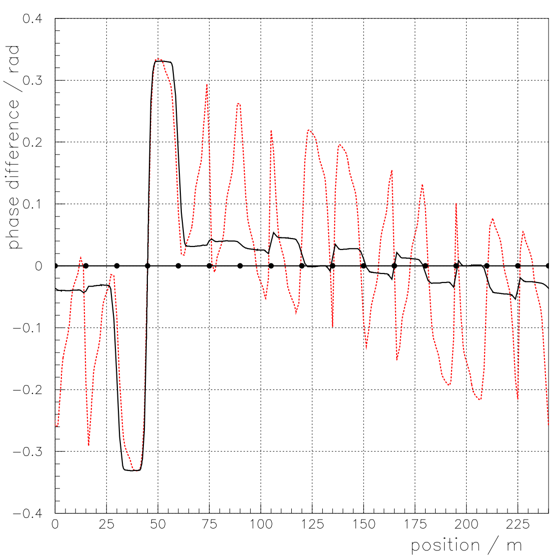

Fig. 5: Beta function phase difference in the vertical plane with local compensation (full line), only with global tune correction (dotted line). The wiggler is located at s=45 m.

acceptable dynamic aperture, the optical corrections are performed similar as described in [5]: The quadrupoles in all straight sections are excited (in pairs) by individual power supplies such that the tune is kept constant, the beta beat is minimized, and the beta function phase error is kept localized in the vicinity of the wiggler straight section as shown in Fig. 5. Here the phase error is the difference of the betatron phase of the unperturbed optics to the corrected optics with the wiggler. With this correction scheme the beta beat can be reduced significantly as shown in Fig. 6 and the reduction in dynamic aperture is relatively small. As a result the beam life time effects of the wiggler are presently dominated by the significant pressure increase in the downstream side of the wiggler straight section chamber due to radiation induced desorption of molecules from the chamber walls giving a lifetime reduction of the order of 20%.

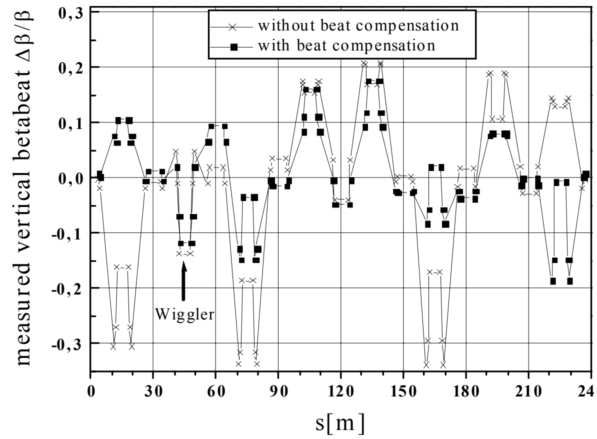

Fig. 6: Measurement of the vertical beta beat in the straight sections before and after compensation of the vertical optics

SUMMARY

A strong superconducting wiggler with a cold beam chamber has been implemented successfully in the BESSY II ring. With a proper design of the beam chamber cryogenic losses due to wake fields can be reduced down to a tolerable level. A beam interlock system is essential to protect the wiggler and the vacuum chambers from excessive power loads. Thanks to the high flexibility of the BESSY II optics the strong linear optical perturbations can be compensated to a great extend. The beam lifetime reduction due to the wiggler is dominated by vacuum degradation in the downstream vacuum chambers and absorbers.

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