DAMPING WIGGLERS FOR THE PETRA III LIGHT SOURCE

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Abstract

Within the reconstruction of the PETRA booster ring at DESY towards a third generation light source after 2007, damping wigglers will be installed to reduce the emittance to a value of 1 nmrad. Two damping sections in the long straights of PETRA have been assigned to accommodate 20 wigglers in total. The wigglers will be permanent magnet devices with a fixed gap which are surrounded by an iron enclosure to reduce the leakage flux. Each wiggler will provide a damping integral of 4 T^2m per segment and generate a synchrotron radiation power of 42 kW. A short one period long prototype has recently been built to prove the magnetic design and study the correction scheme for tuning the pole strength. The wiggler segments will be followed by an SR absorber protecting the downstream quadrupole and successive wiggler segment. The accumulated on-axis power of about 200 kW will be taken up by the final absorber at the damping section end.

INTRODUCTION

Beginning in mid 2007, the PETRA storage ring will be converted to a 3rd generation light source operating at 6 GeV and a nominal current of 100 mA [1,2]. One eighth of the ring will be equipped with synchrotron radiation (SR) beamlines. Eight straight sections provide space for 5m long insertion devices, five of these straights will be split into two canted beamlines with 2m long undulators. Additionally, a long straight section for a 20m long undulator is available. In total, 14 independently operating undulator beamlines will be realized in this octant of the ring. Along the rest of the machine major components have to be refurbished, the vacuum system [3] will be completely replaced.

While the new octant consists of nine double-bent achromat cells, the previous FODO lattice remains in seven old octants, the latter being the major source for the expected horizontal emittance of 4 nmrad. For a further emittance reduction down to 1 nmrad, different lattice options have been investigated [4]. The installation of damping wigglers is the only option to achieve this goal while preserving a sufficient dynamical aperture in the machine [5]. The wigglers will be placed in the long dispersion-free straight sections in the West and North.

The very most of the ~5.3 m long drifts between the F and D quadrupoles have to accommodate both, a wiggler segment and a regular SR absorber protecting the downstream components (Fig. 1), furthermore two BPMs, steering magnets, and vacuum pumps. The BPMs do serve not only for orbit correction, but are integral part of a safety system preventing the vacuum chamber from being hit by synchrotron radiation.

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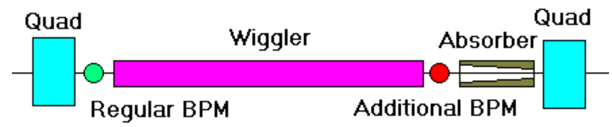

Figure 1: Layout of a cell in the damping wiggler section.

RADIATIVE DAMPING

Within a wiggler or a bending magnet, particles in the bunch emit synchrotron radiation and thus change their momentum opposite to their direction of flight. The momentum is restored by the RF accelerating force, which is in average parallel to the design orbit. The net effect of both processes is a reduction of the transverse beam emittance. The radiation damping is described by the synchrotron integral

$$I_2 \propto \int B^2 dl \tag{1}$$

Quantum fluctuations of the synchrotron radiation lead to a growth of the beam emittance. This quantum excitation and the radiation damping result in an equilibrium value of the beam emittance.

The horizontal emittance is mainly generated in the storage ring arcs and in the damping wigglers and can be written as

$$\varepsilon_x = \frac{1}{1+F_W}\left(\varepsilon_{arc} + F_W\, \varepsilon_{wig}\right) \tag{2}$$

where F_W represents the ratio of the wiggler to arc synchrotron losses. Without damping wigglers PETRA could reach an emittance $\varepsilon_{arc} \sim 4$ nmrad (including contributions from the undulators). A damping integral $I_2 \sim 100$ T^2m, i.e. $F_w \sim 4$ is required to reach the emittance goal of 1 nmrad. This in turn restricts the maximum tolerable wiggler emittance ε_{wig} which scales with

$$\varepsilon_{wig} \propto B_0^3 \lambda_U^2 \beta_x \gamma^{-1} \tag{3}$$

where B_0, λ_U, and β_x are the wiggler peak field, period length, and averaged beta function, respectively. For a given $\beta_x \sim 18$ m, Fig. 2 illustrates the available design space $B_0 \cdot \lambda_U < 0.2$. For a given maximum length of ~100 m for the damping wigglers, a peak field of at least 1.5 T and a period length of 20 cm have been chosen.

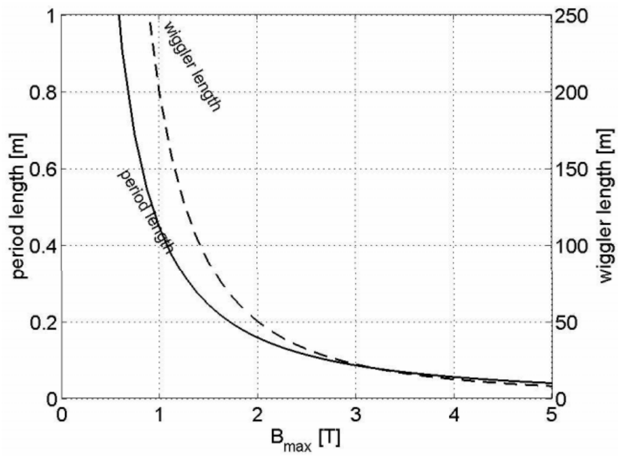

Figure 2: Maximum period length (solid) and required wiggler length (dashed) for a given peak field of a sinusoidal wiggler.

WIGGLER DESIGN

Due to the large number of required wiggler segments, the design has to be reliable and simple in manufacture and adjustment. Also, the amount of permanent magnet material has to be minimized as it is a cost driving part of the device.

Generally, the wigglers have to make only a minimal contribution to the total beam emittance, and the magnet design must be tolerant to temperature gradients to prevent closed orbit distortions.

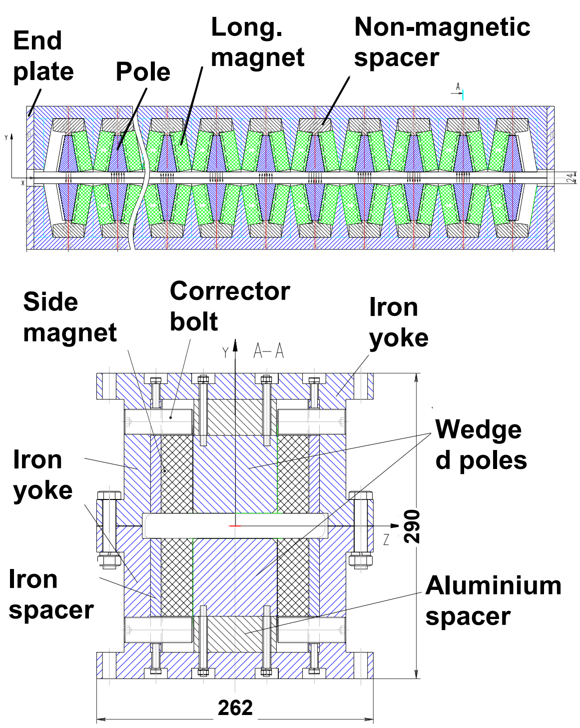

Figure 3: Longitudinal and transverse wiggler cross sections.

The minimum magnetic gap is determined by the demand for a geometric acceptance of 3 mm mrad which requires 17 mm beam-stay-clear to inject the beam safely ($\varepsilon_{inj} \sim 350$ nmrad, $\kappa \sim 10\%$, $\beta_{max} \sim 25$ m). This results in a fixed magnetic gap of 24 mm.

The permanent magnet wiggler is built as an antisymmetric hybrid structure with wedge-shaped iron poles (Fig. 3). Such a design allows splitting each magnet into two of half thickness and placing a V-notch *ARMCO* plate as part of the enclosing yoke between them. Magnetic symmetry provides that the magnetic potential of this wedge-like plate is zero, therefore the electromagnetic coupling between the poles practically vanishes. This makes it possible to adjust the field amplitude for each pole separately without changing it in the adjacent poles. By that means, the wiggler field tuning procedure becomes simple and is reduced to tuning each individual pole.

Special magnets are placed at the wiggler sides (Fig. 3) to reduce the leakage flux from the central iron poles. The reduction of the leakage flux minimizes the size of the central iron pole and main magnets. The iron enclosure around the wiggler provides zero magnetic potential of the iron wedge inserted between the magnets. In order to tune the field amplitude within a few percent for each pole, special adjustment iron screw correctors are placed at all poles. By moving them in and out, the leakage flux changes and the magnetic potential of the pole reduces or increases.

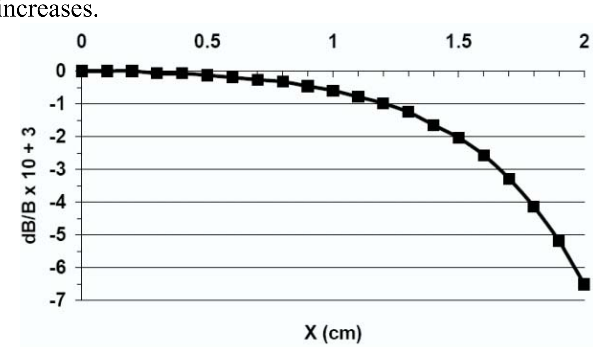

Figure 4: Transverse magnetic field distribution.

Based on tracking calculations, a transverse field quality $\Delta B/B \leq 10^{-3}$ in a good-field region $\Delta x = \pm 1$ cm has been specified in order to inject safely into PETRA III without losses. Therefore, the transverse dimension of magnets and iron poles was chosen to 8 cm. The expected field distribution at the pole center along the horizontal axis is shown in Fig. 4. The calculated field amplitude is $B_0 = 1.52$ T, providing a damping integral of 3.9 T^2m for a 4 m long wiggler segment with 38 full poles. The parameters of the PETRA III damping wiggler are listed in Tab. 1.

The top and bottom halves of the wiggler are made from a single piece of iron with a milling accuracy of ±0.1 mm. After the wedge-like poles have been installed, the pole surface facing the gap and the joint plane of top and bottom halves are ground. Previous experience with this technology has shown that sufficient gap accuracy

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(±30 µm) can be reached. This manufacturing technique will allow significant simplification and acceleration of the wiggler assembly as well as a reduction of the number of parts in the wiggler design.

Table 1: Damping wiggler parameters

Peak field B_0	1.52 T
Magnetic gap	24 mm
Period length λ_U	0.2 m
Number of poles	38 + 2 half poles
Magnet volume per period	2200 cm^3
Field quality at x_0 = 10 mm	$< 10^{-3}$
Damping integral per segment	3.9 T^2m
Number of wiggler segments	2 × 10

A short one period long prototype wiggler has been built and completed recently (Fig. 5) in order to verify several aspects, e.g. feasibility of the magnet design, applicability of the pole strength tuning, practicability of the mechanical design, or proof of reproducible re-assembly of the wiggler halves for insertion of the vacuum chamber.

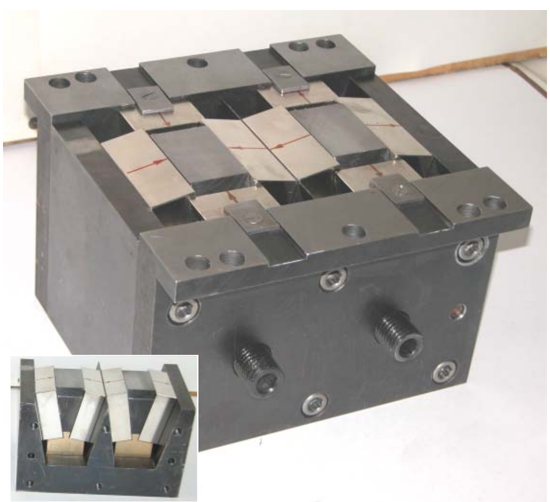

Figure 5: Lower half of the short prototype wiggler.

The applied magnet material shows a remanent field of ~1.3 T and a coercive force of ~17 kOe. Magnets of different qualities will be compared regarding their strength, magnetization errors, and inhomogeneities. A solenoid measurement stand and dedicated Hall probe setup are being built at present to characterize the integral magnetic moments and local inhomogeneities in an assembled state-like geometry, respectively.

An array of 7 transversely spaced Hall probes is used for characterization of the local field dependence within the magnet structure. It is attached to a rod which is moved through the wiggler aperture by means of a linear stage with a precision <0.2 mm. The entire array has been characterized in a calibration magnet with a homogeneity $<10^{-5}$ using an NMR probe, resulting in a measurement accuracy of ~0.5 G. The total field integrals will be measured with a moving wire allowing for adjusting the 1st integral to ~10 Gcm.

First measurement results showed a peak field value of B_0 = 1.52 T as expected. Possibly, parts of the iron poles will be substituted by Vanadium permandur to enhance the peak field and improve field homogeneity. The screw correctors proved to be a sensitive tool to adjust the strength of all poles individually. Sufficient tuning range of about 100 G was found. The exact electron trajectory through the wiggler is not important as the generated SR will not be used by any experiment. Nevertheless, a uniform pole strength has to be assured within a few percent to avoid local bumps which would cause an exceeding of SR power deposition in the regular absorbers along the damping section.

WIGGLER RADIATION

Tab. 2 summarizes the relevant SR properties of a single wiggler segment. The given total power value of 42 kW corresponds to a potential beam current of 200 mA for which all components are designed. A detailed analysis has been performed for the partial contribution of all upstream wiggler segments to the total SR power load of each absorber. Different closed orbit deviations have been taken into account. As a result, a horizontal half aperture > 30 mm has been chosen to limit the maximum power load of the regular absorbers to ~15 kW. The final two of the ten regular absorbers in each section have to dissipate 70 kW. The accumulated on-axis power of about 200 kW will be taken up by a large final absorber in the dipole at the damping section end. All these components are in the design phase.

Table 2: Synchrotron radiation properties

SR critical energy	35.8 keV
K–Parameter	28.4
Wiggler SR power	42.1 kW
Vertical SR spread	170 µrad
Horizontal SR spread	4.84 mrad

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