Prototype Developement of the BESSY II Storage Ring Magnetic Elements*

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Abstract

The lattice magnets for the 3rd generation synchrotron light source BESSY II under construction were designed and storage ring dipole, quadrupole and sextupole preseries magnets are presently manufactured in industry. This paper reviews the design as well as the main magnet parameters and describes the features of the magnetic elements according to the specific constrains by the compact lattice structure.

I. Introduction

BESSY II presently under construction at Berlin, Germany, is a 240 m circumference 1.9 GeV low emittance high brillance 3rd generation synchrotron light source [1]. The 16 double bend achromat structures are composed out of two dipole, four quadrupole and 3 sextupole magnets. A quadrupole triplet and doublet each of them on one side of the achromat with two sextupoles in the zero dispersion regions complete the structure, Fig.1. As experiments require full operation at energies ranging from 0.9 to 1.9 GeV all magnet yokes are made from 0.5 and 1.0 mm thick low carbon 2% Si transformer steel to ensure low hysteresis and high reproducibility for the magnet settings. The lamination thickness selected was based on a compromize of meeting the tight tolerances for the stamped lamination of typically 0.015 mm and economic considerations.

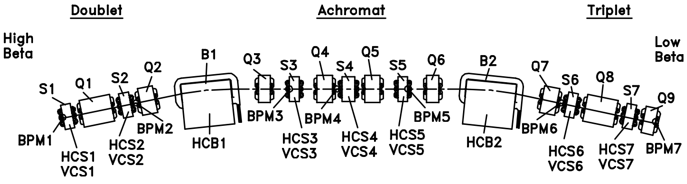

Figure. 1. BESSY II DBA-cell.

All laminations will be shuffled in order to provide high reproducibility and identity within each magnet family. This implies flipping the lamination to compensate the barrel effect present in all laminations.

II. Storage Ring Magnet Designs

A. Dipole Magnet

As the storage ring is an isomagnetic lattice 32 C-shaped dipoles with parallel poles are used. Fig. 2 gives a view of the bending magnet. Though the bending radius is $\rho = 4.355$ m the core is a straight box type with parallel ends rather than a curved yoke in order to facilitate meeting the mechanical tolerances of the magnet. The additional costs of iron due to the sagitta of 10.5 mm were considered advantageous for a straight core compared to smaller pole size implying a much stronger influence on mechanical tolerances of shims. To achieve a magnetic length of 855 mm the core of the 50 mm gap dipoles was set to a mechanical length of 810 mm deduced from the magnetic data of similar magnets [2]. The content of higher harmonics in the integrated field will be mainly of sextupole type when a chamfer of $45^\circ \times 8$ to 10 mm in length is applied. An integrated sextupole component of $\mathrm{m} \cdot \mathrm{L} <$ -0.5 m^{-2} is expected.

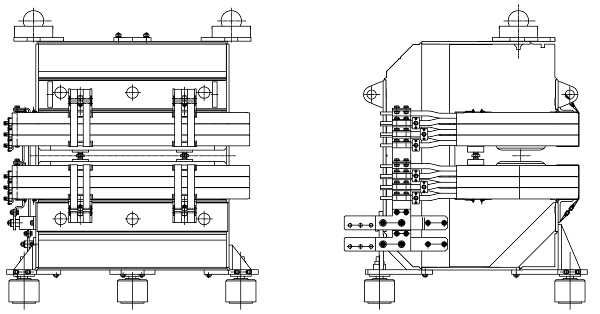

Figure. 2. View of the storage ring dipole magnet.

The yoke will be made from 0.5 mm thick laminations which are insulated by back-lack. The stack is compressed by stiff baked endplates and plates are welded to the other sides of the core. A SURAHAMMA DK-70 steel grade is used for the inorganic insulated laminations. Coils are made from rectangular hollow OFHC conductors of 21×12 mm^2 in size giving six pancakes of 84 windings altogether. To minimize coil overhang, to give more space for the crotch absorbers, the height of the coil cross-section is significantly larger than its width. Fig. 3 gives the expected excitation curve as was calculated by the 2D code POISSON [3]. To correct for finit length of the bending magnet the increase of flux density in the iron core due to the endfield was taken into account, resulting in a much steeper saturation at high field levels. At full beam energy corresponding to a field of 1.45 T, saturation is expected to be below 3%. Table 1 gives a list of magnetic and electric parameters.

B. Storage Ring Quadrupoles

There are 144 quadrupole lenses grouped into nine families. All magnets are made from laminations of same cross section but differ in core length L (L=200, 250 and 500 mm). The poles and shims were optimized in 2D approximation using the codes [3], [4]. For achieving gradients of up to 16.5 T/m the poles have

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SR Dipole Magnet	
Rectangular C shaped type	
Gap	50 mm
Field range	0.7 - 1.45 T
Good field area	60×35 mm^2
Homogeneity dB/B	$5\cdot10^{-4}$
Current	710 A
Resistance	16 mOhm
Inductance	38 mH

Table I

Design parameters for storage ring dipole magnets.

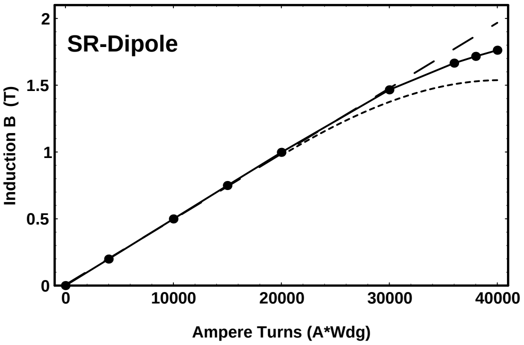

Figure. 3. Calculation of the storage ring excitation curve. The solid dots were calculated by the 2D POISSON code. Correction of the data for the finit length results in saturation starting much earlier (dashed line). At design field of 1.45 T saturation of less than 3% is expected.

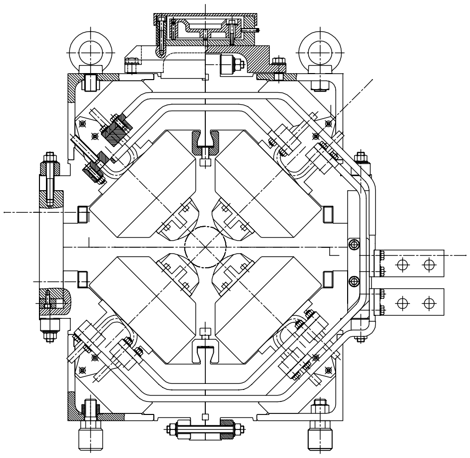

Figure. 4. Storage ring quadrupole magnet.

SR Quadrupole Magnet	
Magnet type	**Figure of eight**
Apertur radius	35 mm
Core length	500/250/200 mm
Gradient	16.5 T/m
Good field radius	r=30 mm
Homogeneity	$dGL/GL \leq 2\cdot10^{-3}$
Current	365 A
Resistance	34/19/16 mOhm
Inductance	38/19/10 mH

Table II

Design parameters for storage ring quadrupole magnets.

conical shape at the same time allowing for inserting simple and costefficient race-track coils.

The geometry of the lamination is mainly determined by the boundary that synchrotron radiation beamlines are penetrating the return yoke. Thus the magnets are figure of eight type using variable formed spacers at the mid plane in order to allow 22 mm vertical clearance. To retain the magnet symmetry the spacers are mirrow symmetrical as they are made from soft magnetic steel. This was decided to be advantageous to shield the magnet center from external fields and shunt the iron regions to compensate the anisotropy in permeability.

A chamfer of $45^\circ \times 8.5$ mm is considered to be sufficient to cancel the dominant systematic harmonics in the focussing strength (e.g. N=6 and N=10) to achieve homogeneous integrated gradient distribution $dGL/GL<0.002$ within a radius of 30 mm. Fig.4 gives a view on the storage ring quadrupole, the main performance data are listed in table II. 2D calculations, corrected for the finit length of the lenses were performed, showing that the design gradient is achieved at a saturation level of 0.7% / 6.8% / 11.8% for the 500/250/200/ mm long elements, Fig. 5.

C. Storage ring sextupole magnets

Seven families of 16 magnets each are used as chromatic and harmonic sextupoles. As for the other multipoles the yokes are stacked from identical laminations to two different types differing in length (L = 160 and 210 mm).

A sextupole strength of 600 T/m^2 is required to be able to combat resistive wall instability though in the standard optics the strength is considerable less. Furthermore the magnets will be used as horizontal and alternatively as vertical dipole correctors. These fields are generated by additional coil systems. The reason for the integrated function is the lack of space in the compact lattice which does not allow installation of lumped correctors. Fig. 6 gives a view of the sextupole which is build up from 3 segments to retain the odd symmetry rather than beeing of C shape type. Massive low carbon soft magnetic spacers from ARMCO iron modelled according to the crossing SR beamlines are used. Thus it is expected to minimize irregular harmonics during dipolar correction associated with significant flux density changes in the core, resulting in running at different hysteresis loops for neighbouring poles. In table III the magnetic and electric data are listed.

The excitation curve of the sextupoles was calculated in 2D approach and corrected for the finit element length by taking into account that the actual flux density in the core will be about 1.65 times larger than in the pure POISSON calculation. Correcting for this effect results in a saturation curve as shown in fig. 7. Saturation at max. sextupole strength is expected to be in the order of 5%, still tolerable.

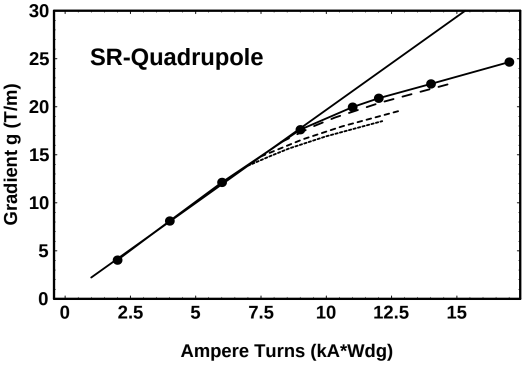

Figure. 5. Dependence of gradient as function of excitation current. The solid line represents the POISSON 2D results. The expected excitation curves for the three lenses of 200/250/500 mm in length is given by the dashed lines.

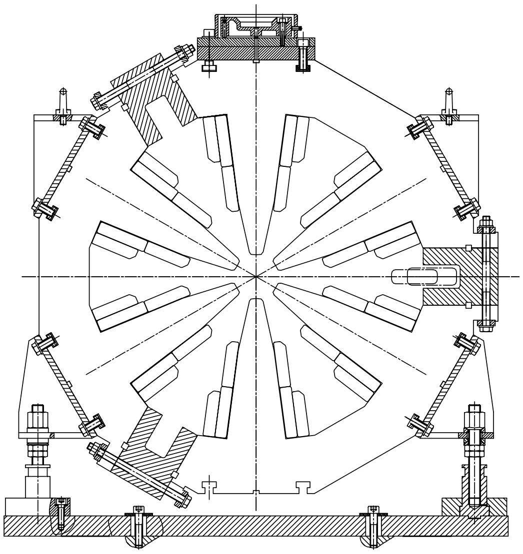

Figure. 6. View of the storage ring combined sextupole and dipole corrector.

References

[1] E. Jaeschke for the BESSY II design team, *Status of the High Brillance Synchrotron Radiation Source BESSY II*, this conference

[2] F. Brinker, *DELTA Int. Rep. 93-5, Dortmund, 1993*

[3] POISSON, Los Alamos Acceletaror Code Group, *LA-UR-87-115, LANL 1987*

[4] MERMAID, BINP Novosibirsk, *unpublished*

SR Sextupole Magnet	
Aperture radius	38 mm
Core length	160/210 mm
Gradient	600 T/m^2
Good field radius	r=30 mm
Homogeneity	dG'L/G'L $\leq 2 \cdot 10^{-2}$
Current	250 A
Resistance	39/33 mOhm
Inductance	7/5 mH
Corrector strength	2 mrad

Table III

Electric and magnetic parameters of storage ring sextupole magnets.

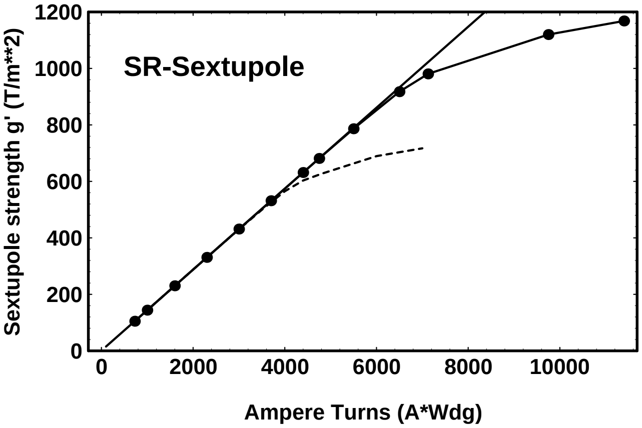

Figure. 7. Calculated excitation curve for the storage ring sextupoles. The solid line is according to the POISSON 2D calculation, the dashed line represents the expected saturation behaviour after correction for the finit element length.