LOCAL IMPROVEMENT OF THE FIELD HOMOGENEITY FOR A LIGHT SOURCE DIPOLE MAGNET

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Abstract: The BESSY electron storage ring is used as a primary radiation standard by the Physikalisch-Technische Bundesanstalt (PTB) for metrology purposes. In order to optimize the calibration accuracy of the spectral irradiance , the field homogeneity along the electron orbit has been improved in the region of the source point of the synchrotron light. With two identical air coils arranged symmetrically in the magnet gap for local compensation of the field variations caused by the finite length of the magnet, a homogeneity of $\frac{\Delta B}{B}=\pm 2 \cdot 10^{-5}$ can be achieved over the source volume at a field level of 1.5 Tesla. Field calculations and measurements are reported.

Introduction

PTB utilizes the electron storage ring BESSY as a primary standard of the spectral irradiance E_λ in a broad wavelength range from the infrared to the soft X-ray region. The radiometric work is carried out using three separate beamlines extending from the same BESSY dipole magnet (Fig. 1).

The relative uncertainty of the spectral irradiance is composed of the individual contributions of the storage ring parameters the electron energy, the magnetic induction at the tangent point of observation, the electron current, and the distance between the source and the observation point. It has been shown that a relative uncertainty of E_λ of 0.23 % can be reached at 1 eV photon energy[1]. The particular contribution $\frac{\Delta B}{B}$ to the total uncertainty is significant even at such a low photon energy and is dominating at photon energies above the characteristic photon energy, especially for beamline 1 and 3 where the field homogeneity is very poor.

The driving motivation of this work is to improve the field homogeneity $\frac{\Delta B}{B}$ to less than $1.0 \cdot 10^{-4}$ in the region of the three source points of the synchrotron radiation in order to optimize the electron storage ring BESSY for radiometry.

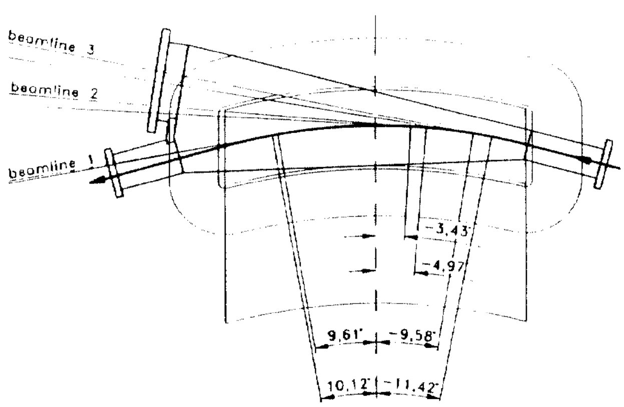

Fig.1: Position of the three beamlines in the horizontal symmetry plane of the BESSY dipole magnet (bending radius $\rho = 1.778$ m, bending angle $\theta_D = 30°$)

Field variation on the nominal orbit

The bending field in a dipole magnet along the nominal orbit cannot be perfectly constant, because of its finite length and due to saturation effects. To get a quantitative picture of this variation, the longitudinal field distribution of the BESSY dipole has been measured with an accuracy of $1 \cdot 10^{-5}$, using a high precision temperature stabilized Hall probe system (B-H 15, Fa. Bruker). Variations of the magnet excitation current were below $1 \cdot 10^{-5}$ over the measuring periods of typically 30 minutes, and the relative positioning error of the probe was of the order of 0.01 mm. The mechanical set-up for the field measurement is shown in Fig. 2.

As the BESSY ring is operated for metrology purposes at different energies, the field distribution has been measured for various excitation levels. The measurements show significant change of the bending field within the horizontal opening angel of the beamlines (Fig. 3). These variations are particularly large at high excitation levels due to saturation effects.

Improvement of local field homogeneity

There are at least two methods available to improve the field distribution: 1) passive correction with thin shims attached to the iron poles in the gap, 2) active correction with local correction coil[2]. With iron shims, the field can be corrected perfectly only for one excitation level. At other field levels, the improvement is only partial. Because of the non-planar contour of the pole face, it is also difficult to machine thin shims of adequate shape and attach them correctly. Glueing is not possible, because the vacuum chamber is baked out at 250°C from time to time, and other mechanical fixtures need more space. For all these reasons, a set of local correction coils has been designed for each beamline to minimize the field variation over the source volume.

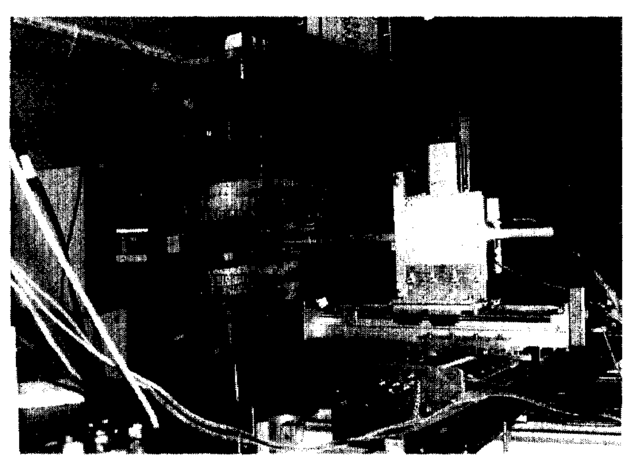

Fig. 2: Magnetic measuring system set-up

The calculation and optimization of the end field is a three-dimensional problem. However, the field produced by a small correction coil, located at the pole face, can be estimated in two-dimensional approximation and the permeability μ_r is sufficiently homogeneous in the iron region near the correction coil ($\mu_r \simeq 1000$) when the magnet is excited by the main coils. Fig. 4 shows, that such a two-dimensional treatment (POISSON) is in good agreement with a fully three-dimensional calculation (TOSCA).

Several coil configurations have been studied in two-dimensional approximation. Fig. 5 shows the layout of an optimized correction coil for beamline 3, and a plot of the longitudinal cross-section and the flux lines calculated for the coil is given in Fig. 6. The coils are made of copper conductor material with a quadratical cross-section. Because of a maximum current density of 3 A/mm^2, air cooling is sufficient. The conductors are oriented in radial direction and pressed into slits of plastic plates which are then mounted in pairs to the pole face of the magnet. The significant improvement of the field homogeneity is obvious from Fig. 7, showing a measurement of the longitudinal field distribution before and after correction. For every beamline an optimized coil configuration has been designed. The improvements of the field distribution are summarized in Table 1 for different operation energies.

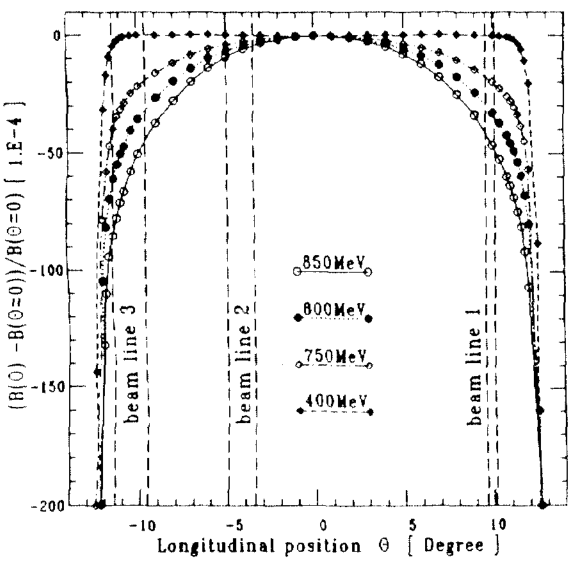

Fig. 3: Variation of the bending field for different energies on the nominal radius (ρ = 1.778 m) in the BESSY bending magnet

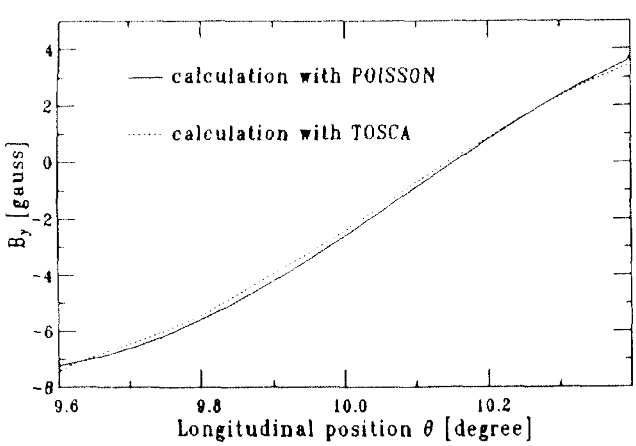

Fig. 4: Field distribution of a correction coil calculated with TOSCA and POISSON

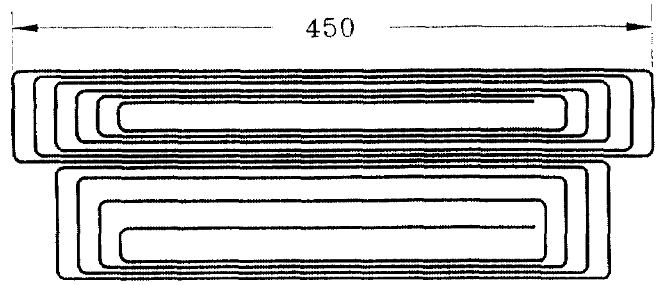

Fig. 5: Layout of the correction coil for beamline 3

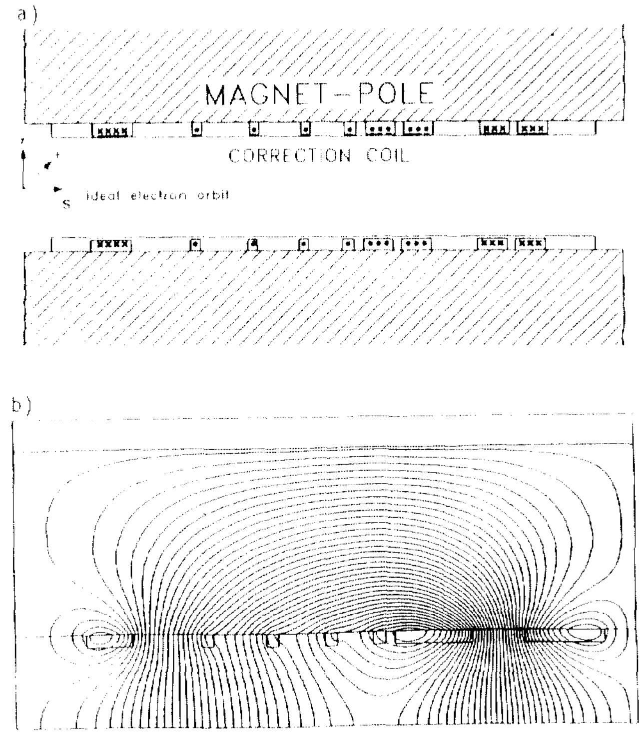

Fig. 6: (a) Longitudinal cross section with two symmetrical correction coils (b) Magnetic flux lines of correction coils for beamline 3 calculated with POISSON

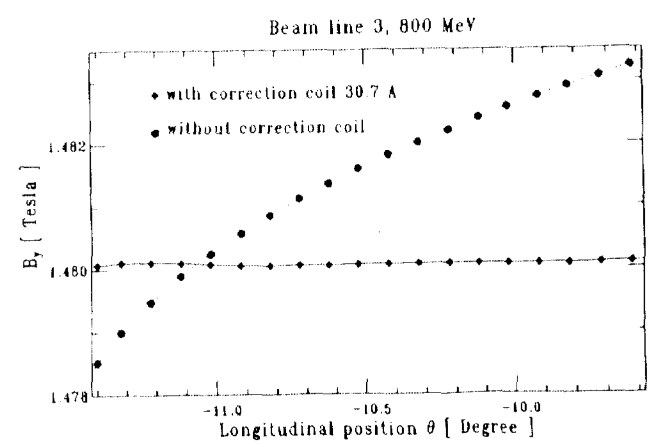

Fig. 7: Magnetic induction measured along the longitudinal position for beamline 3

Table 1: Results of the field variations for the three beamlines at different operating energies

Energy [MeV]	Excitation [A]	Magnetic induction $B(\Theta = 0)$ [T]	$\frac{\Delta B}{B}$ $[10^{-4}]$ before compensation			$\frac{\Delta B}{B}$ $[10^{-4}]$ after compensation			current of correction coil [A]		
			beam line			beam line			beam line		
			# 1	# 2	# 3	# 1	# 2	# 3	# 1	# 2	# 3
350	324.01	0.6518	0.3	0.3	6.6	—	—	1.5	—	—	13.5
750	711.66	1.3958	3.4	2.2	22	0.28	0.14	1.0	14.3	3.0	19.5
800	775.77	1.4890	5.5	3.6	32	0.27	0.20	0.4	24.8	6.0	30.7
850	853.19	1.5816	7.9	5.4	44	0.50	0.25	1.4	37.1	8.0	43.2

Influence on $\int B \cdot ds$

The correction fields of the three beamlines modify the field distribution locally as shown in Fig. 8. To avoid horizontal orbit distortions, the total bending field of the dipole must not be changed. In Fig. 9, the relative change of the field integral is plotted for different radii when all correction coils are excited for operation at 800 MeV. The changes are only of the order of $5 \cdot 10^{-5}$ and can be compensated, if necessary, by the trim coil around the back leg of the dipole magnet.

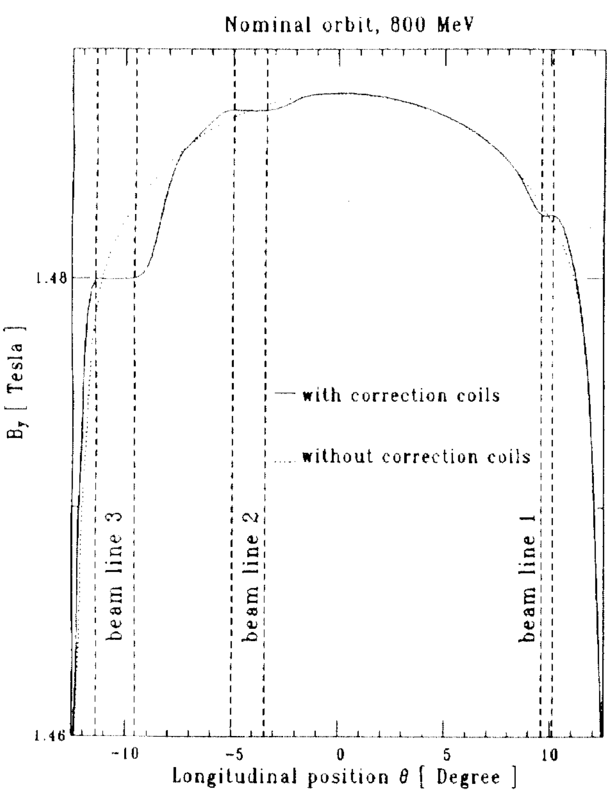

Fig.8: Magnetic induction measured as a function of the position on the nominal orbit

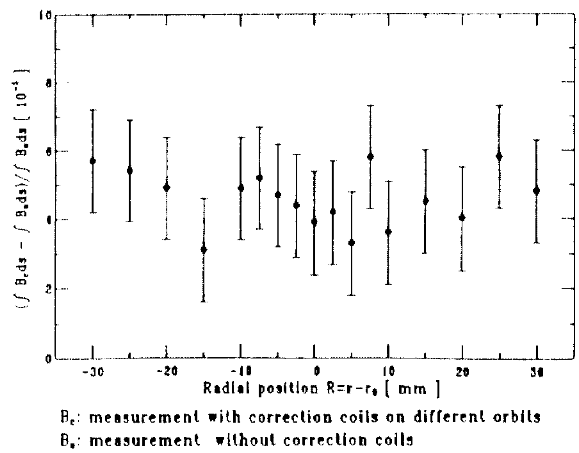

Fig. 9: Change of the field integral due to correction coils for operation at 800 MeV

Conclusions

It has been shown, that the field homogeneity can be improved by at least a factor of 10 with local correction coils. An adjustment of the correcting field for different operation energies is possible with a single power supply per beamline. The influence of these corrections on the bending angle $\theta \sim \int B \cdot ds$ can be neglected. This helps to improve the calibration accuracy of the spectral irradiance significantly for metrology purposes.

Acknowledgements

We want to thanks Dr. B. Krevet (KfK-Karlsruhe) for assistance in the TOSCA calculation and the BESSY machine group for the technical support.

References

[1] F. Riehle and B. Wende ,Establishment of a Spectral Irradiance Scale in the Visible and Near Infrared Using the Storage Ring BESSY (1986), Metrologia 22, 75-85

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