DESIGN OF AN ELECTROMAGNETIC ELLIPTICAL WIGGLER FOR ELETTRA

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Abstract

The main aspects of the design of the electromagnetic elliptical wiggler under construction for ELETTRA are summarized.

1 INTRODUCTION

An electromagnetic elliptical wiggler (EEW) was first proposed for ELETTRA in 1991 as a source of circularly polarized VUV/Soft X-ray radiation with variable helicity [1,2], but due to funding limitations was not able to be constructed at that time. The present project commenced in February 1996 with partial European Commission funding as a collaboration between Sincrotrone Trieste, BESSY and MAX-lab. The project also includes the construction of a soft X-ray polarimeter which will be used to make a complete analysis of the polarization properties of the source in the 80-1000 eV range.

The detailed mechanical design and construction of the EEW is presently being carried out by Danfysik A/S, Denmark. The power supplies are under construction by OCEM SpA, Italy, while the control system and dynamic correction system are being developed at Sincrotrone Trieste. Following a period of magnetic testing at Trieste in September/October the device will be installed in ELETTRA and commissioning will start in November.

2 MAIN DESIGN PARAMETERS

Period	212 mm
No. vertical poles	32
No. horizontal poles	31
Length	3.332 m
Gap	18 mm
Max. vertical field	0.5 T
Max. horizontal field	0.1 T

The original parameters of the device were 12 periods of 230 mm with maximum vertical and horizontal field of 0.6 T (K_y=13) and 0.046 T (K_x=1) respectively. A review of these parameters was firstly carried out in order to optimize performance in the 5-1500 eV range, using both undulator and wiggler modes of operation, but within the constraints imposed by the existing beamline design [3] of not increasing significantly either the radiation power or the vertical source size. A better optimum proved to be with a reduced period length and an increased number of poles, with a reduced vertical field strength of 0.5 T. The maximum vertical deflection angle was also increased to $\pm 1.5/\gamma$ in order to provide more circularly polarized flux at low photon energies in the wiggler mode. The final parameters are listed in the table above.

The vertical field component will be powered with d.c., but three different operating modes are required for the horizontal field : d.c., trapezoidal from 0.1-1 Hz and sinusoidal from 10-100 Hz, to enable different types of data acquisition methods to be used in order to maximize the dichroism signal detection.

3 MAGNETIC DESIGN

The initial concept of the EEW was a combination of a vertical permanent magnet to generate a wiggler field and a horizontal electromagnet in order to provide the possibility of switching the helicity of the radiation. A new requirement however was the need to operate also in the undulator mode, requiring low vertical field strengths and therefore a large vertical gap. In order to avoid potential problems with field quality under these conditions, it was decided to investigate solutions involving two electromagnets. A scheme proposed by E. Gluskin of the APS was first studied which uses 3-poles to generate the horizontal field and therefore has the advantage that it is open on one side of the device [4]. It was found however that the asymmetric structure leads to small field gradients on the beam axis which might have unwanted beam dynamics effects in lower energy machines. From this we then developed the idea of a symmetric planar structure which is open on both sides of the median plane, as shown in fig. 1.

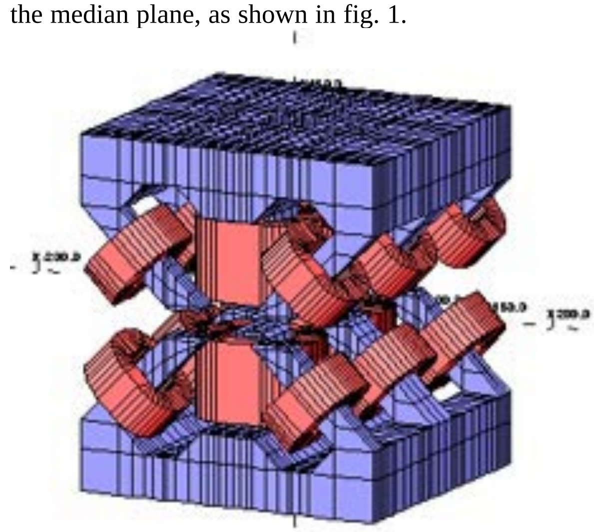

Figure 1. One-period model of the EEW for 3D field calculations.

A longitudinally anti-symmetric arrangement was chosen for the vertical field in order to have an equal number of positive and negative poles and hence a symmetric distribution of circularly polarized flux with respect to the median plane (when $K_x \neq 0$) to avoid any intensity differences between positive and negative excitation in the event of a vertical misalignment. A symmetric horizontal field is therefore demanded in order to give equal vertical deflections to corresponding vertical poles. "No displacement" terminations will be used for both field components to avoid variation or oscillation in the beam position with excitation, by means of a 1/4, -3/4, 4/4 end-pole sequence.

Although some initial calculations were successfully carried out using the 2D code POISSON, all subsequent calculations were carried out using OPERA-3D [5] because of the strong three dimensional nature of the problem. The magnetic design had to satisfy many often contradictory requirements :

• a small horizontal pole gap gives a higher horizontal field amplitude;
• to obtain a good transverse field homogeneity requires a wide vertical pole (for By) and not too small a horizontal gap (for Bx);
• to minimize saturation requires wide and long poles - this is important in order to reduce hysteresis losses and also to reduce the variation of field integrals with excitation, due to differences between central and end poles;
• to minimize the interaction between the horizontal and vertical fields requires a narrow vertical pole, a wide horizontal pole gap and short poles;
• it is important to reduce the inductance of the horizontal coils to minimize the power supply requirements, which requires a compact pole and coil design.

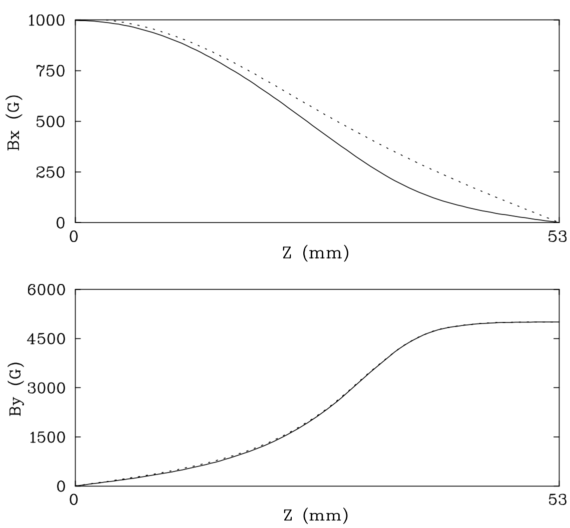

Figure 2. Field distributions in the final EEW design (solid lines) and in the case with only poles of a single type present (dotted lines).

Figure 2 shows the influence of the vertical poles on the horizontal field and vice-versa in the final design. The vertical field is affected very little by the presence of the horizontal poles both in amplitude (< 0.1%) and shape. As might be expected however the horizontal field is affected more, but not so much in peak amplitude (~ 1%) as in the shape in the region of the vertical pole. The resulting reduction in field integral means that a 32 % higher horizontal field is required (0.1 T) compared to a pure sinusoid to obtain the required vertical deflection angle. Further calculations have demonstrated that the effect of interaction is limited to the iron geometry : the additional effect on one component due to switching on the other is negligible, since the flux paths generated by the two sets of coils are to a large extent independent.

Due to the large period/gap ratio and relatively small pole length the vertical field also deviates significantly from a pure sinusoid (see also fig. 3).

The number of turns in the coils was chosen so as to have reasonable values of voltage and current for the power supply construction, as well as being a multiple of 4 to facilitate the implementation of the termination sequence. A small cross-section conductor was chosen (5.8 mm x 3.7 mm, ϕ = 2.5 mm) in order to produce a compact design and to reduce eddy-current effects but without too high a current density. The table below gives the final parameters required to meet the field specification, including an extra margin of about 10% on current.

Electrical parameters	Vertical field	Horizontal field
Number of turns/coil	24	8
Maximum current (A)	175	300
Maximum power/coil (W)	190	140
Inductance, total (mH)	-	2.44
Maximum voltage (V)	66	516†

† at 100 Hz.

In order to reduce eddy current effects in the steel, a laminated construction is necessary. The steel finally selected is 0.35 mm thick STABOCOR M 270-35A from EBG, Germany. By integrating B^2 over the poles and scaling the manufacturer's data for core loss of 2.3 W/kg at 1.5 T, 50 Hz the estimated maximum hysteresis + eddy current losses are estimated as 12 W/pole at 100 Hz with maximum current, which is acceptable. Eddy current losses in the copper have been estimated as 1 W/coil for the horizontal coils, negligible in comparison to resistive losses. For the 1.5 mm thick elliptical stainless steel vacuum chamber a calculation was carried out using the ELEKTRA program [5] which gave a maximum eddy current loss of 10 W/m.

An interesting feature of the present design is the fact that magnetic flux circulates both in the plane of the laminations (generated principally by the horizontal field coils) and also perpendicular to it (due mainly to the vertical field coils). Since the effective permeability in the transverse direction reduces very rapidly as the packing factor decreases, the packing factor was optimized by choosing a steel that is supplied with a thin lacquer ("Stabolit 70") providing both electrical insulation and bonding between laminations. The expected packing factor after block curing is 97 %, which causes an acceptably small reduction of 2.6 % (0.5 %) for the vertical (horizontal) field amplitudes respectively.

Modelling the end-termination required extensive cpu-time. Both terminations with an outer vertical pole and outer horizontal pole were calculated. The latter has the advantage that the 3/4 vertical poles receive an equal deflection angle to that of the central poles, however it was found that the horizontal field integral was much larger in this case. The alternative arrangement was therefore selected, which results in only about 5 % less flux in the wiggler mode. Figure 3 shows the final computed field distribution and trajectory in the entrance region. It can be seen that the trajectory is well compensated with the oscillation axis coincident with the magnetic axis.

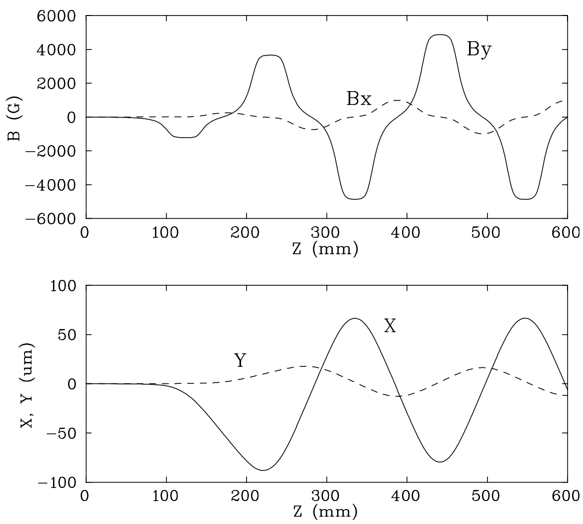

Figure 3. Field distributions (upper) and electron trajectory (lower) in the entrance region of the EEW.

Various pole profiles giving different transverse field distributions were studied and their effect on the beam dynamics properties investigated [6]. Despite earlier indications to the contrary, the pole profile was not found to have a significant influence on the dynamic aperture and so of the solutions investigated the ones giving the best magnetic performance, i.e. minimum field levels in the steel, were chosen.

4 MAIN POWER SUPPLIES AND CONTROL SYSTEM

The vertical field requires a conventional mono-polar d.c. supply, while the horizontal field requires a special bi-polar design capable of operating both in d.c. or a.c. modes with various waveforms. The solution that has been adopted is the use of two switch-mode power supplies in the same cabinet.

Special attention has been given to the stability of the power supplies since it affects directly the detectability of small changes in absorption/scattering etc. due to the change in helicity of the radiation. Calculations show that in the worst case, at the highest photon energies in the wiggler mode (1.5 keV), a given fractional change in either field level causes a similar change in the Stokes parameters that describe the polarization of the emitted radiation. Small ripple and short term stability have therefore been specified (± 5 10^{-5} I_{max}), a performance that has already been met for the existing ELETTRA d.c. supplies. In addition, in the a.c. modes the symmetry of the positive and negative current values is also critically important. Special attention will therefore be given to achieving this level of d.c. offset in the a.c. modes.

In order to achieve the specified stability levels requires an even more stable reference signal to drive the power supplies. For the d.c. modes this can be provided by the standard DAC boards used for the ELETTRA power supplies. For the a.c. modes however a suitable waveform generator could not be identified giving the required performance, particularly in terms of d.c. offset. To resolve this problem a novel solution has been developed. The output signal of a standard DAC board has been synchronized with the pulse from a programmable timer located on the main cpu of the control system interface, thus allowing pre-defined waveforms to be generated step-by-step. Initial tests with a 10-100 Hz sinusoidal waveform show that a practical resolution of 150 μs can be obtained, and that the signal has very good amplitude stability (± 10 ppm of full-scale/^{o}C).

5 DYNAMIC CORRECTION SYSTEM

In order to guarantee that the operation of the EEW in the a.c. mode will not disturb the closed orbit and so not affect other users, a correction system is being developed that is capable of dynamically correcting the field integral errors. The system will have 4 channels for powering horizontal and vertical correction coils at the entrance and exit of the magnet. Suitable air-cored coils have been designed that provide a correction of 7.2 Gm in both planes at 4A excitation, with an inductance of 2.3 mH per coil pair. The coils will be supplied by 4 power modules (Copley mod. 412) integrated in the main supply cabinet which will allow the above current to be produced up to at least 1 kHz. The four channels will be driven using a single VME module (Analogic DVX 2901) containing 4 independently programmable 16-bit, 200 kHz, waveform generators, synchronized to the main power supply.

ACKNOWLEDGEMENTS

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