CONSTRUCTION AND TESTING OF AN ELECTROMAGNETIC ELLIPTICAL WIGGLER FOR ELETTRA

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Abstract

The main aspects of the construction and electrical and magnetic testing of the electromagnetic elliptical wiggler for ELETTRA are summarized.

1 INTRODUCTION

An electromagnetic elliptical wiggler (EEW) was first proposed as a source of circularly polarized radiation with variable helicity for ELETTRA in 1991 [1,2]. The present project commenced in February 1996 with partial European Commission funding† as a collaboration between Sincrotrone Trieste, BESSY and MAX-lab.

The design of the EEW and its power supplies was described in a previous report [3]. Since then the detailed mechanical design and construction of the EEW has been carried out by Danfysik A/S, Denmark; the power supplies have been constructed by OCEM SpA, Italy, while the control system and dynamic correction system have been developed in-house. A brief series of electrical and magnetic tests took place in December 1997, using the new magnetic measurement benches [4]. The EEW was then installed in ELETTRA at the beginning of 1998. The commissioning of the device in ELETTRA in the d.c. mode is described in a separate report [5].

The EC project also includes a soft X-ray polarimeter [6] which was constructed at BESSY and is currently being used to study the polarization properties of the EEW source in the 80-500 eV range. The first measurements of the radiation polarization were made in April at 400 eV and are reported in [7]. Following completion of these tests at the end of July, the a.c. modes of operation will be commissioned.

2 EEW CONSTRUCTION

Table 1. Main EEW Parameters.

	Vertical field	Horizontal field
Period length	212 mm	
Total yoke length	3.322 m	
Pole gap	18 mm	
Maximum field amplitude	0.59 T	0.11 T
Number of poles	32	31
Number of turns/coil	24	8
Maximum current	200 A	300 A
Maximum voltage (100 Hz)	82 V	489 V
Maximum total power	16.4 kW	10.2 kW
Maximum power/coil	~ 270 W	~ 90 W
Inductance, total	-	2.6 mH

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The EEW is a double electromagnet which combines periodic horizontal and vertical fields in the same structure, see Fig. 1. The vertical field is produced by an even number of poles and is therefore antisymmetric, while the horizontal field has an odd number of poles and is symmetric. Both field components have a 1/4, 3/4 1 sequence of coil excitations at the entrance/exit in order to produce a displacement-free trajectory. The vertical field component is powered with d.c., while the horizontal field has 3 different modes: d.c., trapezoidal from 0.1-1 Hz and sinusoidal from 10-100 Hz. The final parameters of the device are listed in Table 1.

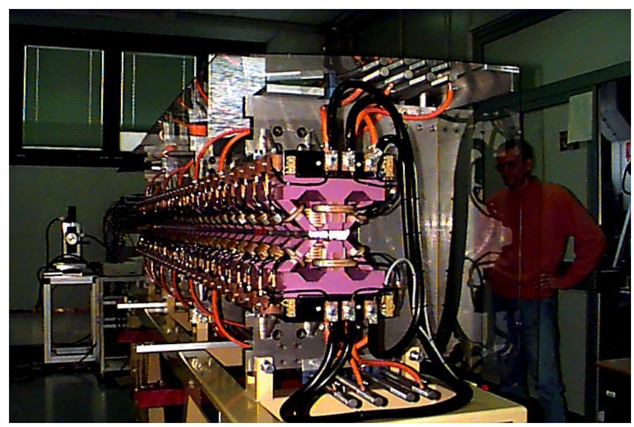

Figure 1. Photograph of the EEW in the magnetic measurement laboratory.

The construction of the device involved the stamping of 3 lamination types: either with a single vertical pole, two horizontal field poles or no poles, however only two stamping tools were required since the latter one was obtained by modifying the first type. Sequences of the different lamination types were stacked to form 10 standard blocks of $1^1/_2$ period length i.e. 318 mm, plus one 142 mm end-block for each array. The blocks were cured using a special tool designed to maintain the correct pole lengths as well as total length. In practise some difficulty was experienced in satisfying the many geometrical constraints and the blocks required a machining of the ends to meet the required tolerance on the total length. The variation in pole length was also more than expected: typically ± 80 μm (horizontal poles) and ± 140 μm (vertical poles). The effect of such errors is however less than might be supposed due to the compensation of the length change with a change of packing factor. The pole heights were constant within one block to 20-50 μm.

The blocks were mounted on two stainless-steel girders by means of tapped holes and pins and shimmed to the same height within ± 25-40 μm. The two completed arrays were then mounted into the holding structure consisting of four C-shaped Aluminium alloy frames arranged in two cross-connected pairs, supported on a base frame. After adjustment the specified final gap tolerance of ± 30 μm was achieved.

The horizontal and vertical pole coils are fed by separate inlet and outlet manifolds on each array to form two separate water cooling circuits. To reduce the number of connections, and because of the small pressure drop in each coil, a number of coils are connected hydraulically in series. The magnet is protected by thermal switches on each coil as well as by separate flow switches for the two circuits.

3 ELECTRICAL AND MAGNETIC TESTS

Table 1 includes the final measured electrical parameters of the device at the maximum current of the power supplies. In the case of the horizontal circuit, measurements of current, voltage and phase as a function of frequency showed constant inductance and mean power, i.e. no discernible eddy current or hysteresis losses.

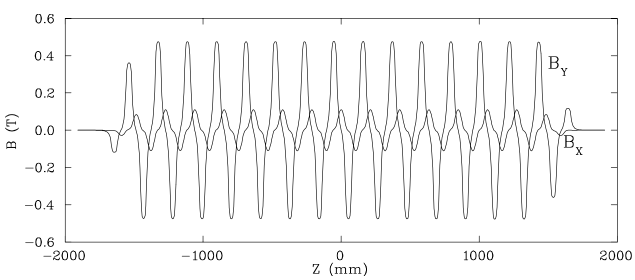

Figure 2. Measured field distributions in the EEW with I_H = 300 A, I_V = 150 A.

Fig. 2 shows the measured on-axis field distributions, which agree well with those expected from 3D field calculations [3], including the significant deviation from a pure sinusoid. The nominal 0.5 T vertical field is obtained with I_V = 160 A (155 A calculated) while the nominal maximum vertical deflection angle of 1.5/γ is obtained with a horizontal excitation of I_H = 275 A , as expected. No saturation is observed in the horizontal field, while the onset of saturation is about 160 A in the vertical case, as expected. The variation of peak field amplitude is very small : 0.2 % rms in the vertical case and 0.3 % in the horizontal case with I_H = 300 A, I_V = 150 A.

The interaction of the two field components is very small: 300 A horizontal excitation reduces the vertical field by about 0.3 %. Vertical excitation has no effect on the horizontal field up to 150 A; at 200 A the effect of saturation reduces the horizontal field by only 0.7 %.

The transverse field profiles under the poles also shows very good agreement with calculations, apart from a systematic asymmetry in the By(x) distribution, probably arising from the arrangement of the conductors feeding the coils.

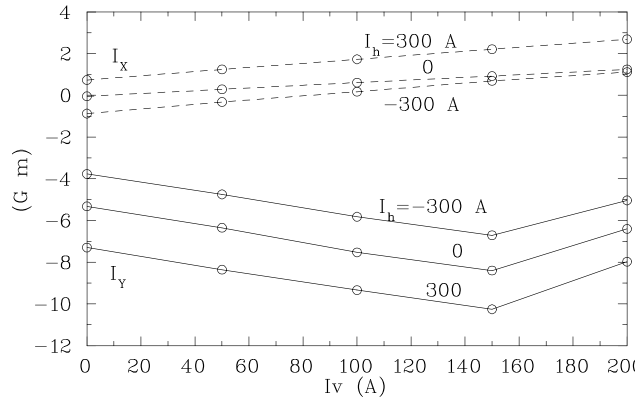

Figure 3. Variation of 1st field integrals with current.

Fig. 3 shows the measured variation of 1st field integrals with current. The offset in vertical field integral at zero current probably arises due to a shunting of the earth's field: calculations show that an external field of 0.5 Gauss is sufficient to create a 5 Gm field integral. The variation of horizontal field integral with current is relatively small. Further analysis shows that the linear variation of vertical field integral with horizontal and vertical excitation is not a localized effect, but is distributed throughout the magnet. On the other hand the increase above 150 A is an end-effect due to a combination of differential saturation of the central and end poles, together with some asymmetry between entrance/exit in the antisymmetric field configuration.

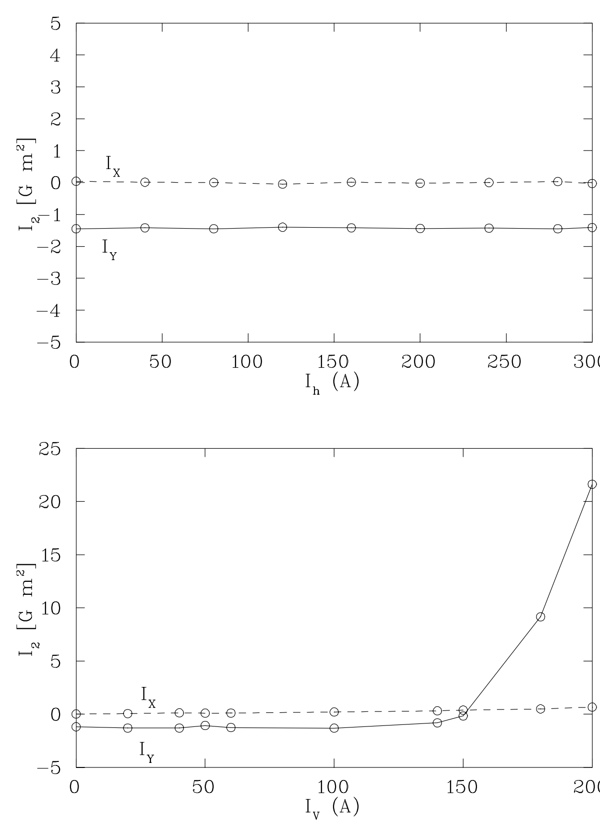

Figure 4. Variation of 2nd field integrals with current.

Fig. 4 shows the measured variation of 2nd field integrals with current. The only significant variation is that of the vertical integral with vertical excitation, due to differential saturation of the central and end poles combined with the antisymmetric field distribution. Below the nominal operating current however, the effect is very small.

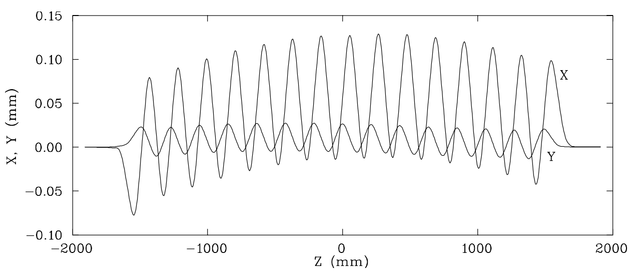

Figure 5. Simulated electron trajectory in the EEW after external correction of the field integral errors, with I_H = 300 A, I_V = 150 A.

Correction of the field integral errors will be carried out using external air-cored coils. Figure 5 shows the calculated trajectory after correction. It can be seen that the remaining curvature of the trajectory is quite small. Calculations of the emitted radiation spectrum in the undulator mode show that the difference with respect to a distributed dipole correction is negligible.

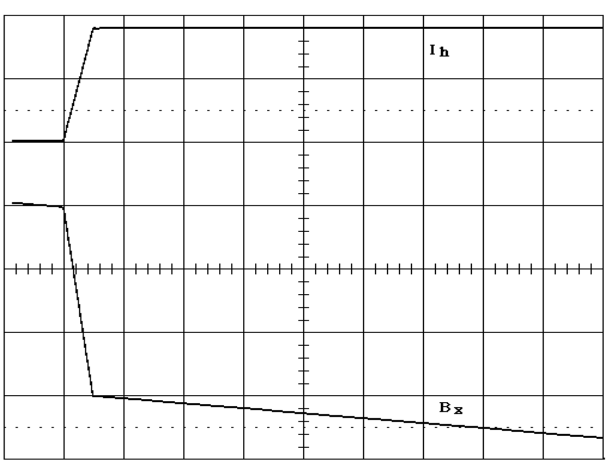

Figure 6. Horizontal current and field in the trapezoidal mode. Horizontal div. = 10 ms.

Measurements of the dynamic behaviour have been made of both the local and integrated fields using a small coil and a stretched wire coil respectively [4]. The local field was found to follow perfectly the current variation in both the sinusoidal and trapeziodal modes with no discernible phase lag or distortion of the flat-top. Fig. 6 shows the result for the trapezoidal mode with a 5 ms switching time. The field integral variation however showed an unexpected result: while the horizontal field integral followed the measured static variation shown in fig. 3, the vertical field integral showed a significant effect, presumably due to eddy currents. The effect is unimportant however as far as the operation of the device is concerned, since the correction system will be capable of correcting any arbitrary error.

4 MAIN POWER SUPPLIES

The main power supplies are of the PWM type with a switching frequency of 14 kHz. The required performance of the current in the DC mode are tight: $\pm 5\ 10^{-5}$ Imax for the ripple and the short term stability (1 hour), $\pm 2\ 10^{-4}$ Imax for the long term stability. In addition, for the AC modes there is a requirement for an offset level better than $5\ 10^{-5}$ Imax. In order to obtain reliable reference voltages 16 bit DAC boards are used. The AC waveforms, trapezoidal and sinusoidal, are generated in a novel way [3], by changing the voltage level of the reference in 250 μs steps. Since the 4 kHz signal generated by the discretization of the waveforms is well within the frequency response of the power supply, an additional filter has been added.

The results obtained from the measurements on the power supplies are within the specification as regards stability, ripple and offset. In the sine mode, the THD measured at different current levels and frequencies, up to 300 A at 100 Hz, is always better than 1% and in some conditions, better than 0.5% and less. Up to now the power supplies are operating regularly in the pure DC mode. More tests are foreseen in future shut-down periods to test some remaining aspects such as the zero-cross trigger pulse generation which is required for triggering the dynamic correction system, as well as the transmission of current signals to the future users of the radiation source.

5 ORBIT CORRECTION SYSTEM

A dynamic orbit correction system has always been foreseen in order to guarantee that the operation of the EEW will not disturb other users [3]. The air-cored correction coils and arbitrarily programmable power supplies have recently been installed and first tests have been carried out [5]. Software is under development firstly for an automatic correction as a function of d.c. horizontal and vertical current, before proceeding to a fast dynamic correction.

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