Status of the Development of Insertion Devices for ELETTRA

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Abstract

The status of development of the insertion devices for the ELETTRA synchrotron radiation source is described, including details of recent progress with a prototype pure permanent magnet undulator and hybrid wiggler, and plans for construction of the devices for the first phase of operation.†

1. INTRODUCTION

The 1.5-2 GeV ELETTRA storage ring [1] has been optimized for the operation of up to 11 insertion devices (IDs), up to 4.8 m long. The devices presently forseen include pure permanent magnet undulators, hybrid multipole wigglers and a special source of circularly polarized radiation. Table 1 lists the main parameters of the devices that are associated with beamlines that are approved and under construction. The IDs will be constructed in the order in which they appear in the Table.

Table 1. Main parameters of the initial ELETTRA undulators (U) and wigglers (W); gap in mm.

Beamline	ID	N	Gap	B_0 (T)	K
Photomemission	U12.5	36	25.0	0.486	5.67
Superesca	U5.6	81	25.0	0.445	2.33
			20.0	0.590	3.09
Diffraction†	W14.0	30	25.0	1.15	15.0
			20.0	1.55	20.3
Surface diffraction†	U8.0	57	25.0	0.692	5.17
			20.0	0.840	6.28

† parameters not yet definitive

The first two undulators will be installed before the start of beam commissioning (September 1993). At this time the standard cross-section vacuum chamber will be installed in the straight sections, restricting the magnet gap to a minimum value of 60 mm. After a period of beam commissioning, insertion device vacuum vessels with an external magnet gap of 25 mm will be installed for the first phase of operation at 1.5 GeV. Later, when 2 GeV operation is established, a reduction of the magnet gap to 20 mm will be possible. However, undulator U12.5 (and possibly U5.6) will not benefit from this reduction, and so will remain with the larger gap.

In addition to the IDs in Table 1, other beamlines requiring insertion device sources have been approved but are presently not under construction. One of these is a beamline dedicated to experiments using circulalrly polarized radiation, for which a novel electromagnetic elliptical wiggler has been proposed [2,3]. With such a device it should be possible to switch the helicity of the radiation on axis at up to 100 Hz. A prototype of the device is presently under construction to test the design principles. Recent studies of the possible effects of the device on the electron beam show that operation in ELETTRA is feasible [4]. Other proposed beamlines are for gas-phase photoemission and X-ray microscopy, for which undulators with periods of 12.5 cm and 6.3 cm are required.

2. UNDULATOR PROTOTYPE

Previous measurements of the 1.5 m long, 5.6 cm period, prototype undulator were described in refs. [2,5]. Since then, a complete re-measurement of all of the permanent magnet blocks has been carried out, followed by re-assembly using a new block arrangement and re-measurement and optimization of the complete undulator. A number of significant improvements have been made in the procedure for block measurement :

i/ The new insertion device laboratory is air conditioned and maintains a more stable temperature (± 2 °C) than previously, thus reducing the significant errors introduced by the variation of block magnetization with temperature.

ii/ A new Hall probe has been constructed [6] with which it is possible to measure both transverse field components thus eliminating the previous need to measure the blocks with two different systems; also, the measurements are now taken "on the fly", so reducing the measurement time from 45 mins. to 10 mins. per block.

iii/ More measurement data has been taken for each block, at transverse coordinates x=0, ±10, ±20 and ± 30 mm, in order to allow a better correction of the field integral variation.

Following block measurement a configuration was sought using 'simulated annealing' using a similar 'cost function' to that used previously with factors related to the trajectory straightness, peak field variation and multipole errors [2]. The result was significantly better than previously :

- straighter trajectory, in particular at larger gaps (e.g. 50 mm)
- better spectral performance - e.g. an intensity of the 5th harmonic relative to that of an ideal undulator of 0.9 (0.6) at a gap of 20 (50) mm, compared with 0.8 (0.2) previously.
- less variation of the field integrals along the beam axis with gap, 870 G mm (Ix) and 140 G mm (Iy) between gap=20 mm and 50 mm, compared to values of 2200 G mm and 860 G mm previously.
- less variation of the field integrals with horizontal position; previously errors up to 8 G m were obtained, now errors are less than 2 G m.

Based on a much improved block configuration the possibility to make further improvements using shimming has been found to be much easier. By suitable arrangement of only 15 shims the field integral variation has been able to be reduced to within ± 1500 G mm, within an aperture (x) of ± 25 mm, for gaps between 20 and 50 mm, as shown in Fig. 1. At the same time the trajectory and the spectral performance has also improved.

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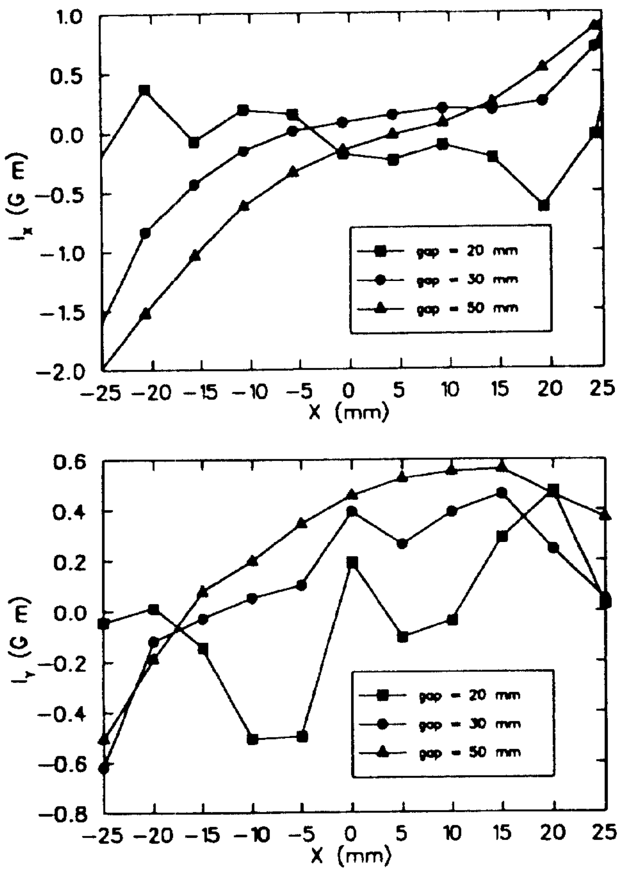

Figure 1. Variation of horizontal (I_x) and vertical (I_y) field integrals in the prototype undulator.

Figure 2 shows the trajectories in both planes at two different gaps. Table 2 summarizes the performance at various gaps, including rms field variation (ΔB/B) and intensity (on-axis angular flux density) of the first, third and fifth harmonics ($I_{1,3,5}$) of the emitted radiation relative to that for an ideal undulator, calculated assuming zero electron beam emittance. Significant improvements have been made in the performance of the prototype undulator, both in terms of the effect on the electron beam (field integrals) and the spectral performance.

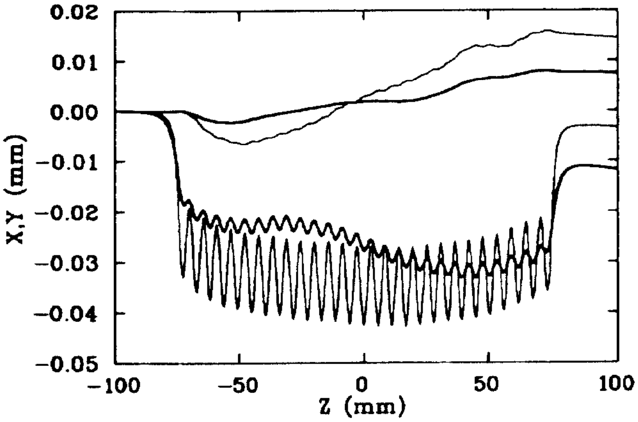

Figure 2. Horizontal (lower) and vertical (upper) trajectories in the prototype undulator at gaps of 20 mm (thin line) and 50 mm (thick line).

Similar block measurement, ordering, and shimming techniques will therefore be able to be used for the 'series' production undulators. Studies will continue, however, in an effort to further reduce the field integral variation, and also to extend the method to include correction of the transverse variation of the second field integral errors.

Table 2. Performance of the prototype undulator.
Units - gap (mm), Bo [T], ΔB/B [%], Ix,y [G mm].

gap	Bo	$\Delta B/B_{rms}$	Ix	Iy	I_1	I_3	I_5
20.0	0.66	0.35	-183	194	1.00	0.98	0.89
30.0	0.37	0.36	83	395	1.00	0.91	0.68
50.0	0.12	0.78	-150	457	0.94	0.76	0.54

3. MULTIPOLE WIGGLER PROTOTYPE

A short length prototype of a hybrid wiggler has recently been constructed consisting of 5 full poles and 2 half poles with a period length of 140 mm. The permanent magnet material is Neodymium-Iron-Boron with a remanent field of about 1.2 T. The results of the first measurements were presented earlier [5]. Since then, the iron poles (ARMCO pure Iron) have been replaced by higher permeability Iron-Cobalt poles (VACOFLUX-50), in order to determine the effect on the peak field intensity and transverse field homogeneity. In figure 3 the measured field distribution in the central pole is compared with a prediction based on a combination of two and three-dimensional computer codes.

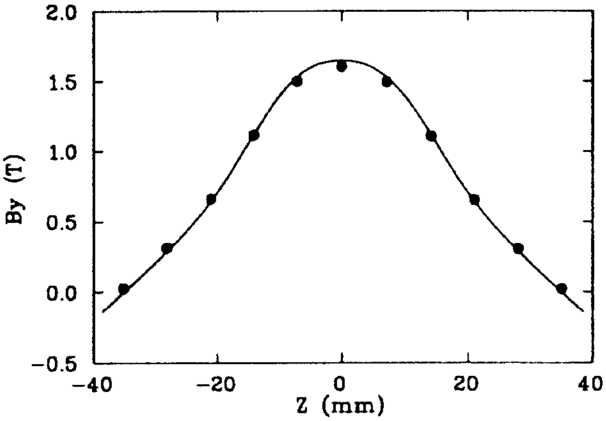

Figure 3 Measured (dots) and computed (solid line) field distribution in the central pole of the prototype wiggler.

Table 3 Predicted and measured peak field and harmonic content for the wiggler prototype at different gap settings.

gap (mm)	B_0 (T) (predicted)	B_0 (T) (measured)	B_3/B_1 (%) (predicted)	B_3/B_1 (%) (measured)
20	1.65	1.60	14.5	13.7
25	1.38	1.35	11.1	10.4
30	1.14	1.13	8.3	7.8
50	0.62	0.62	2.9	2.7
100	0.18	0.19	0.3	0.5

The agreement is very good at the nominal gap of 20 mm, as well as at larger apertures. This can be seen also in Table 3 which summarizes the predicted and measured values of the peak field and of the third to first harmonic ratio. Compared with the previous measurements, the peak field at 20 mm gap has increased from 1.54 T to 1.60 T, with the same third harmonic field content. The high permeability poles have also improved the field homogeneity significantly.

Figure 4 compares the measured transverse field distribution at minimum gap with that obtained with the old prototype, while Table 4 presents the results at various gaps, in terms of the coefficient k_x which describes the quadratic field variation near the axis :

$$B_y = B_o \cos(kz) \cosh(k_y y) \cos(k_x x) \qquad (1)$$

where $k^2 = k_y{}^2 - k_x{}^2$ and $k = 2\pi/\lambda_o$.

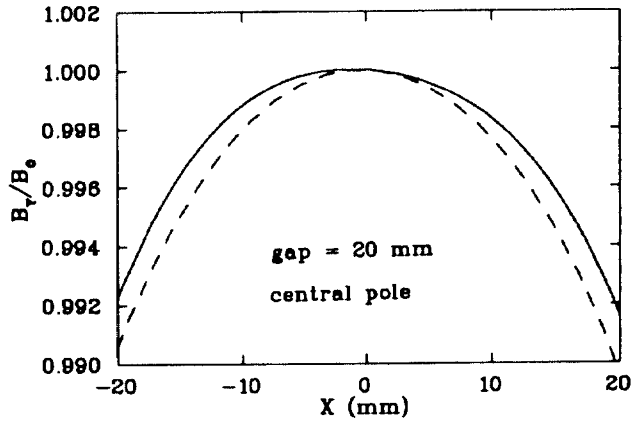

Figure 4 Transverse field distribution with pure Iron (dashed line) and Iron-Cobalt poles (continuous line).

Table 4 Transverse field homogeneity coefficient, k_x, [m^{-1}] with pure Iron (I) and Iron-Cobalt (II) poles at different gaps settings.

gap (mm)	I	II
20	6.6	5.4
25	5.6	4.0
30	4.9	2.6
50	6.2	5.4
100	11.8	11.7

It can be seen that at large gap where saturation effects are not important, the homogeneity is the same. At smaller gaps however there is a significant improvement in homogeneity. Tracking calculations including the quadratic field variation [7] indicate that the homogeneity achieved with the prototype should be acceptable.

Further work on the prototype will include correction of the vertical field integral by means of end-pole height adjustment and use of correction coils, as well as measurement and correction of the transverse variation of the field integrals (i.e the multipole content).

4. UNDULATORS U12.5 AND U5.6

The first undulator to be constructed, U12.5, has been designed to be able to reach a minimum photon energy of 10 eV at 1.5 GeV operating energy (18 eV at 2 GeV) at a minimum gap of 25 mm [5]. A larger period than the minimum possible was chosen in order to reduce the power density of the emitted radiation to within acceptable limits for the beamline components. The resulting field strength is sufficiently low that a space of 5.25 mm can be left between the 26 mm length blocks, and a block height of only 21.5 mm is required, resulting in reduced costs. A simple block holding structure will be used, making use of the space between the blocks. All components are presently on order and due to arrive in the next month.

The period of the second undulator, U5.6, was chosen to be the minimum for which wide tunability is possible using the first and third harmonics, with a minimum gap of 25 mm. Blocks of dimension 85 mm x 28 mm x 14 mm will be used in a standard 4-block per period arrangement, using the same construction technique employed for the prototype. Orders for permanent magnet blocks and support structures will be made in the next few months.

As in the case of the wiggler magnet, tracking studies [8] have indicated that the dynamic aperture is sensitive to the magnitude of the quadratic field variation in the undulators i.e. the value of k_x, see equ. (1), which is determined by the permanent magnet block width. For the smaller period devices a limit of $k_x/k < 0.1$ has been specified which results in a minimum required effective block width (i.e. assuming rectangular faced blocks) of between 75 mm and 100 mm for periods in the range 56-80 mm. For the longer period U12.5 device this would have implied a very wide block, however the field strength is relatively small and a value of $k_x/k = 0.2$ was found to be acceptable, which determined a width of 100 mm.

5. REFERENCES

[1] ELETTRA Conceptual Design, Sincrotrone Trieste, April 1989
[2] C.Poloni et. al., Proc. 1991 US Particle Accelerator Conference, to be published.
[3] R.P.Walker and B.Diviacco, Rev. Sci. Instr., Vol. 63, No. 1, January 1992, p. 332.
[4] C.J.Bocchetta et. al., this Conference
[5] B.Diviacco et. al., Rev. Sci. Instr., Vol. 63, No. 1, January 1992, p. 388.
[6] D.Zangrando and R.P.Walker, this Conference
[7] L.Tosi, Sincrotrone Trieste Internal Report ST/M-TN-89/39
[8] L.Tosi, private communication