STATUS OF ELETTRA INSERTION DEVICES

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The design, construction and testing of the fourth ELETTRA insertion device, undulator U8.0, is described and some details are given of recent developments of a "phase shimming" technique and of a new "moving wire" system for insertion device integrated field measurements.

I. INTRODUCTION

The ELETTRA storage ring will shortly contain four insertion devices, three pure permanent magnet undulators (U) and one hybrid multipole wiggler (W). The main parameters of the devices are summarized in Table 1. The first three devices are each composed of 3 separate sections, with a total length of approximately 4.5 m, and the values in the table refer to the present minimum operational gap in the storage ring. The latest device (U8.0) consists of a single section which will be installed at the beginning of May this year.

Table 1. Main parameters of the ELETTRA Insertion Devices; the number following U/W indicates the period length in cm. N = number of periods.

ID	N	Gap (mm)	B_o (T)	K
U12.5	36	28.0	0.506	5.91
U5.6	81	27.0	0.444	2.34
W14.0	10	26.0	1.30	17.0
U8.0	19	25.0	0.713	5.33

The construction of the first three devices have been reported previously [1,2,3] and the initial operation in ELETTRA has been described in ref. [4].

II. UNDULATOR U8.0

Undulator U8.0 was designed to cover a very wide photon energy range from 250 eV to 8 keV, with operation at 2 GeV. Below about 2 keV the device operates in an undulator mode, (variable gap) and above 2 keV in a wiggler mode (fixed minimum gap). The parameters were optimized for the final vacuum vessel which will permit a minimum gap of 20 mm; in an initial phase the minimum gap will be 25 mm. A period length of 8 cm was selected as a compromise between the conflicting requirements to optimize the undulator (short period length) and wiggler (long period length in order to maximize the field amplitude) modes. A standard pure permanent magnet arrangement of 4 blocks per period with 40 mm block height was used. A block width of 100 mm was chosen to obtain a field roll-off at minimum gap given by $k_x/k < 0.1$, where $B_y = (1-k_x^2x^2/2)\cos(kz)$. The mechanical design of the magnetic arrays is the same as used for the U5.6 device [2] : blocks are clamped into individual holders, which are assembled onto 0.5 m long baseplates, which are then mounted on the 1.5 m I-beams of the standard support structures.

NdFeB permanent magnet blocks were obtained from Outokumpu magnets (NEOREM 450i), with an average measured magnetization of 1.17 T and minimum intrinsic coercive force of 1400 kA/m. The estimated remanent field, taking into account the average working points of the different block types, is 1.19 T. The blocks were passivated and oiled to prevent corrosion. Each block has been measured in detail in the two possible orientations that were allowed for assembly using a small Hall plate bench dedicated to block measurements. Both transverse field components were measured at a grid of points, 81 points in z over ± 2 period lengths and 13 points in x over ± 60 mm; the vertical height (y) corresponded to the future minimum gap of 20 mm. About 15 minutes were required for each block and about 3 weeks to measure all 190 blocks. A reference block was measured each day in order to guarantee that there were no changes in conditions during the measurement period.

Data from the measurements were used in a "simulated annealing" program to optimize the block configuration, based on linear superposition of the fields of different blocks. The cost function to be minimized included the following terms : first and second field integrals of both field components at all x positions within ± 60 mm, r.m.s. phase error and trajectory straightness separately for the top and bottom arrays [5].

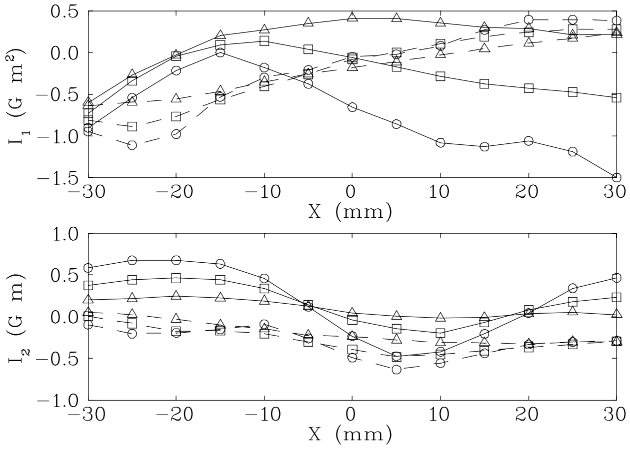

Figure 1. First (I_1) and second (I_2) field integrals for U8.0, at 20 mm (circles), 30 mm (squares) and 50 mm (triangles) gap, horizontal (dashed) and vertical (solid) planes.

Measurements after assembly confirmed the accuracy of the block measurements and sorting procedure : the variation of horizontal (x) and vertical (y) first and second field integrals with transverse position (x) were within the specified ± 1 Gm and ± 2.5 Gm^2 within ± 25 mm, as shown in fig. 1

The r.m.s. phase error was also acceptable : 2.7^o at minimum (20 mm) gap, 3.0^o at 30 mm and 3.3^o at 50 mm.

III. PHASE SHIMMING

Further significant improvement of the quality of the undulator, and hence of the radiation output, have been made using a new technique of "phase shimming" [6]. Previously shimming has been applied in such a way to optimize simultaneously both field integral and phase error performance [5]. The new method consists of a separate correction of the phase errors, leaving the field integrals unchanged. With this method we have succeeded in reducing the phase error to the level of 1 degree. Such a value leads to essentially ideal performance up to very high harmonic numbers : on average, a rms error of 1^o gives an intensity (on-axis angular flux density, for zero emittance and energy spread) of 80% (50%) of the ideal intensity for the 27th (47th) harmonic respectively [7].

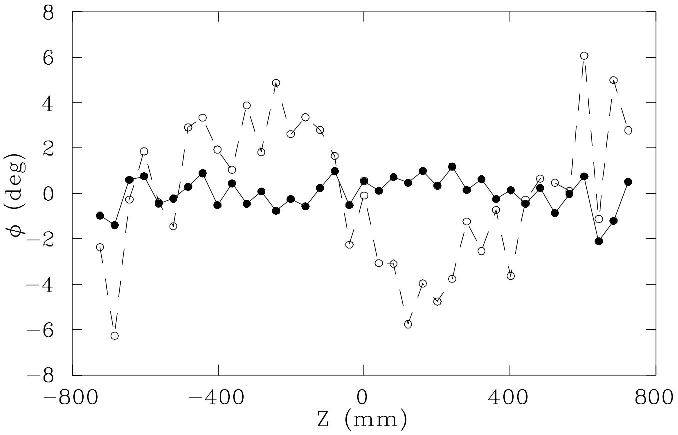

Figure 2. Radiation phase errors at minimum gap, before (dashed) and after (solid) phase shimming for U8.0.

Figure 2 shows the phase errors at each pole of U8.0 before and after shimming and figure 3 shows the corresponding calculated on-axis spectra. The intensities for an ideal undulator (analytic formula) are as indicated. The improvement in phase error and the significant increase in the intensity of the higher harmonics in the radiation spectrum are quite evident.

Table 2. Final magnetic measurement results for U8.0

Gap (mm)	20.0	30.0	50.0
B_o (T)	0.895	0.608	0.276
K	6.7	4.5	2.1
σ_B (%)	0.24	0.17	0.19
σ_ϕ (deg.)	0.6	0.9	1.7

Table 2 summarizes the main results of the magnetic measurements obtained after shimming. Some increase in phase error is observed at larger gap, however in this situation high harmonic numbers are unlikely to be used.

Figure 4 shows the calculated electron trajectories, that remain essentially unchanged by the phase shimming.

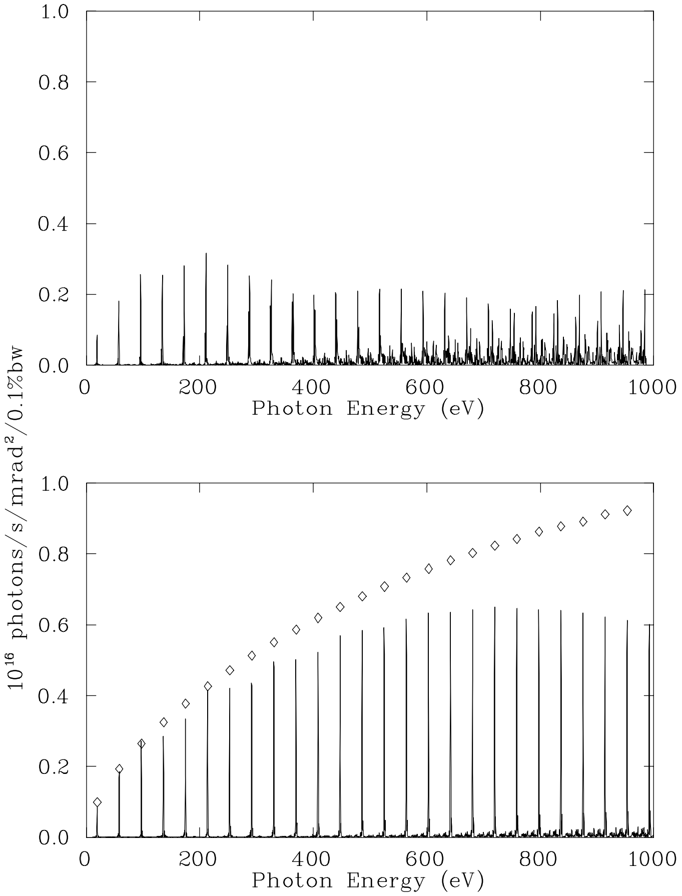

Figure 3. Calculated on-axis spectrum at minimum gap, before (upper) and after (lower) phase shimming for U8.0. The intensities of an ideal undulator are as indicated.

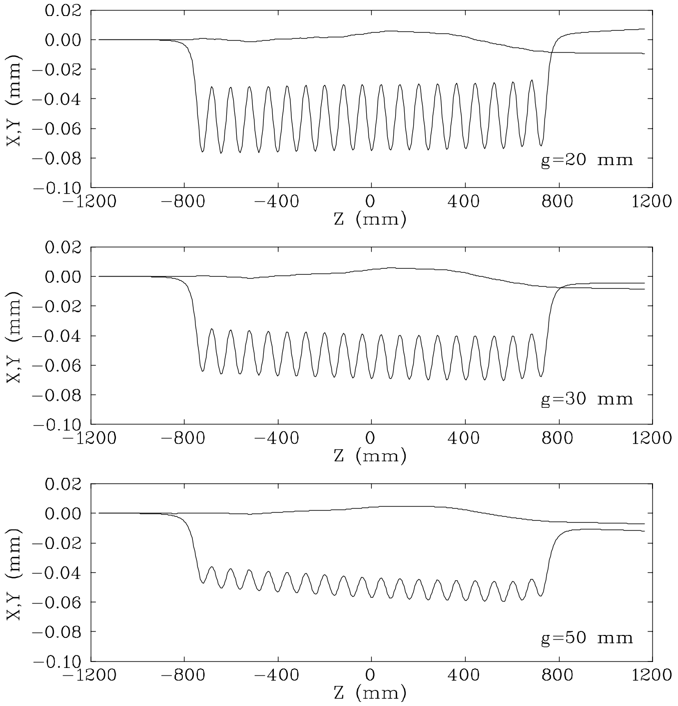

Figure 4. Calculated electron trajectories for U8.0 at various gaps.

To verify the general applicability of the phase shimming technique, further tests have been carried out using the prototype 5.6 cm device constructed in 1992. In this case it proved possible to reduce the rms phase error from an initial 3.7^{o} to 0.8^{o} at minimum gap without affecting significantly the multipole terms, thus giving us confidence that similarly good results can be obtained for future devices. Full details of the technique will be published in a forthcoming report [8].

IV. MOVING-WIRE METHOD FOR INSERTION DEVICE INTEGRATED FIELD MEASUREMENTS

A new method of measuring both first and second field integral distributions and integrated multipole errors has recently been implemented. The previous technique was a flipping coil method, using a coil made from stretched multistrand Litz wire [9,10]. Such a technique yields values of I_x and I_y as a function of transverse position (usually, the horizontal, x). In the new method only a single side of the coil passes inside the magnet, the return being static and outside the magnet. The wire is translated in x or y to yield individual measurements of I_y and I_x respectively at a given point. The advantages of this method for first integral measurements are that it eliminates the sensitivity of the flipping coil output to variations in coil width, and allows a variable integration step (equivalent to the coil width) to be used. It also allows a simple measurement of the second field integrals, by translating the two ends of the wire in opposite directions. Further, by making the wire follow a circular path, the multipole terms can be obtained directly from a Fourier analysis of the integrated voltage as a function of angle. In this way the uncertainties involved in determining the multipole terms from flipping coil data, that result from making a polynomial fit to the $I_x(x)$ and $I_y(x)$ distributions, as well as the smoothing effect of a finite coil width, are eliminated.

In the present case with a 40-turn coil and using a Schlumberger 7061 Voltmeter as an integrator, the reproducibility (rms) of the first and second field integral measurements is 0.02 G m and 0.01 G m^2 respectively for a wire translation of 10 mm.

For the multipole measurement, a radius of 10 mm is used as standard, reduced to 8 mm at the minimum 20 mm gap, with 16 measurements per 360^{o}. The reproducibility of the single measurement in this case (worst case rms deviation for a series of 10 measurements at various gaps) is 1.8 G cm, 3 G, 4 G/cm, and 6 G/cm^2 for the dipole, quadrupole, sextupole and octupole terms respectively. An improvement in accuracy can of course be achieved by averaging over a series of measurements. The method is therefore sufficiently accurate to be used as a direct means of determining the multipole terms even in the case of the most stringent tolerance limits.

Table 3 summarizes the results of the multipole measurements of undulator U8.0 made with the new system. The results presented are the maximum absolute values of the normal (B_n) and skew (A_n) multipole coefficients from dipole (n=1) to octupole (n=4) between 20 mm and 100 mm gap. As mentioned earlier, the device is within the specified limits as regards the first and second field integral distribution, whereas limits were not set for the individual multipole terms. The normal quadrupole term is the largest error, at minimum gap, however the maximum tune shift introduced (in the horizontal plane) is negligible ($\sim 5\cdot10^{-4}$).

Table 3. Maximum multipole coefficients for undulator U8.0.

n	A_n	B_n	units
1	63.	47.	G cm
2	30.	70.	G
3	20.	45.	G/cm
4	< 10	< 10	G/cm^2

V. FUTURE PLANS

The first four insertion devices have been installed with a vacuum chamber that permits a nominal 25 mm magnetic gap (20 mm internal), which is sufficient to give acceptable performance only in the case of U12.5 and possibly also the U5.6 device. A first chamber permitting a reduced gap of 20 mm (15 mm internal) is presently under construction and will be installed this Summer, replacing the existing wiggler vessel, thereby allowing the design field of 1.6 T to be reached. The spare vessel will be used for the 5th device, a second 4.5 m U12.5 undulator that is presently under construction.

It is hoped that the sixth ID to be approved for construction will be an electromagnetic elliptical wiggler. Development of a prototype mini-gap undulator is also being considered.

VI. REFERENCES

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