Studies of the Effects of an Elliptical Wiggler in ELETTRA

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Abstract

An electromagnetic elliptical wiggler with variable helicity is potentially a useful device for generating circularly polarized light. Beam dynamics, linear and non-linear and ion trapping studies, of the impact of this device on the circulating beam show no noticeable effects compared to a conventional device.

1. INTRODUCTION

There is currently a great deal of interest in using circularly polarized radiation from synchrotron sources for a wide range of experiments in condensed matter physics, chemistry and molecular biology. A source of intense circularly polarized radiation will be required for the ELETTRA facility [1] with the possibility of a rapid switching between right- and left-handed polarization to carry out experiments on chiral systems and surface magnetism in the VUV and soft-Xray region. To meet this need a novel insertion device, an electromagnetic elliptical wiggler (EEW), has been proposed [2,3]. The device consists of a pure permanent magnet structure generating a strong periodic ("wiggler") field component in the vertical plane, together with an electromagnet generating a weaker horizontal field of the same periodicity but out of phase by 90°. The electromagnet is excited with alternating current in order to vary the helicity of the emitted radiation. A maximum frequency of 50 to 100 Hz may be possible depending on eddy current effects. Table 1 summarizes the main parameters of the proposed device.

Table 1. Main parameters of the proposed electromagnetic elliptical wiggler.

Period	0.23 m
Number of full poles	24
Field amplitudes (B_x, B_y)	0.0466, 0.61 T
Deflection parameters (K_x, K_y)	1.0, 13.2

In order to assess the feasibility of installing such a device in ELETTRA several effects have been considered that could in principle disturb the electron beam.

2. LINEAR BEAM DYNAMIC EFFECTS

In a third-generation light source such as ELETTRA the electron beam sizes and divergences are very small, and consequently the closed orbit must be very stable in order to maintain the high brightness of the radiation beams. In general this implies that strict limits must be set on the variation in field integrals during operation of the insertion devices [4]. In particular for the EEW this means that no variation must occur during the a.c. cycle of the electromagnet. Some empirical adjustment of the end-pole compensation will therefore be required. In principle effects could also arise due to differences in steel behaviour from pole to pole, however, with the proposed design the field in the electromagnet pole is small, about 0.2 T, compared to the 1.0 T steel saturation field and so non-linear effects are expected to be small. However, if necessary even these effects could be overcome with a correction coil driven by an appropriate non-sinusoidal waveform. Measurement of small field integral variations during the a.c. cycle will be able to be made easily by measuring the induced voltage in a static long coil, and so in principle this could be used as the input to a feedback system for maintaining zero field integral variation.

It is well known that a periodic insertion device introduces a focussing in the same plane as the field component. In the EEW therefore the a.c. excited horizontal field will cause an oscillation in the horizontal focusing. However, in the present design the small horizontal magnetic field component results in a very small focussing parameter, $k_x \sim 5\ 10^{-5}\ m^{-1}$ (1.5 GeV), and hence the induced tune change ($\Delta Q_x \sim 10^{-4}$) and beta modulation ($\Delta\beta/\beta \sim 6\ 10^{-4}$) are completely negligible.

3. NON-LINEAR BEAM DYNAMICS

The additional linear and non-linear terms introduced by a helical insertion device have been found to reduce strongly the dynamical acceptance of ELETTRA [5] especially in the horizontal plane. Investigations of the dynamic aperture for various proposed helical structures [6] have shown that the EEW is the most appropriate from the beam dynamics point of view. While the value for the vertical field amplitude in table 1 will assure an acceptable linear distortion around the ring (the maximum $\Delta\beta_y/\beta_y$ was found to be 2% after re-installing the tunes), the small value for the horizontal field amplitude will limit the intrinsic non-linear and coupling effects of the device.

However, as may be seen from the comparison in figure 1 of the dynamic aperture when the horizontal field is on and off, there is still a significant reduction in the maximum horizontal stable amplitude. The presence of the horizontal field introduces a non-linear coupling by which a particle starting in the horizontal plane will be lifted off, yielding a final vertical amplitude $y = L[\cosh(k\ x_o) - 1]/(\rho_x k)$ where x_o is the horizontal coordinate at the entrance of the device, $k = 2\pi/\lambda_o$ with λ_o the period length,and L, ρ_x, are respectively the length and the horizontal bending radius. This effect combined with the strong sextupoles and the vertical non-linearities of the field generated by the permanent magnet structure will in turn limit the maximum horizontal stable amplitude. Thus the effect on particle dynamics is similar to that of a planar structure on a particle starting with a non-zero vertical amplitude. As a confirmation, in figure 2 the horizontal phase space for several initial conditions are reported for a) the electromagnetic elliptical wiggler with zero initial vertical amplitude, b) a planar structure (B_y = 0.63 T and λ_0= 7.3 cm) with zero initial vertical amplitude, and c) the planar structure with initial vertical amplitude of 1 µm. Cases a) and c) show very similar dynamic behaviour and the corresponding vertical phase spaces presented analogous characteristics.

The dynamic aperture with a realistic scenario of six insertion devices with and without the helical structure is shown in figure 3. In this case the major effect is due to the six insertion devices that are present, and the additional effect of the EEW is negligible. The removal of the stable points with zero initial vertical amplitude at $x > 24$ mm when the EEW is included is a further confirmation of the effect of the lifting of the particle off the horizontal plane described above.

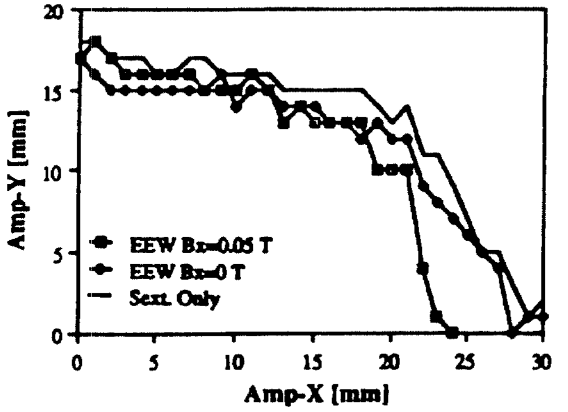

Fig.1 Dynamic apertures for planar and helical structures

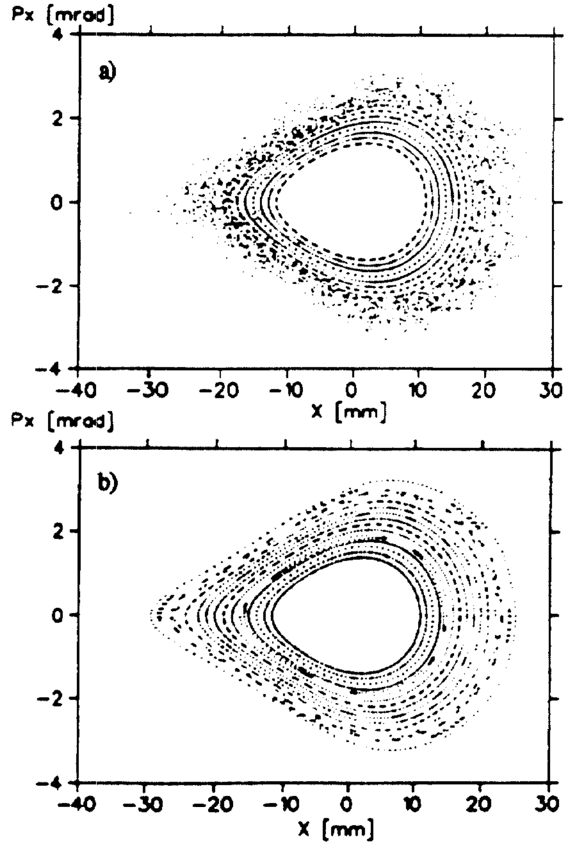

Fig. 2. Horizontal phase spaces for different initial conditions

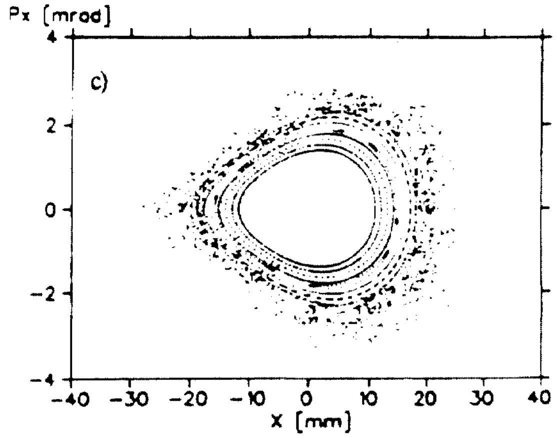

Fig. 2. Continued

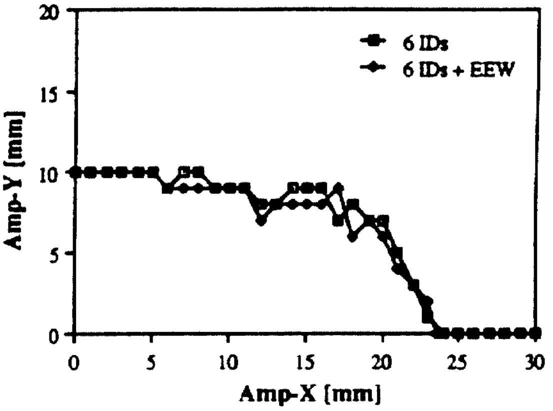

Fig. 3. Dynamic apertures with a realistic scenario of insertion devices

4. ION TRAPPING

It is well known from linear theory that a beam of identical symmetrically spaced electron bunches will trap ions. The smallest ion mass trapped is termed the critical mass, and is a function of the characteristics of the lattice. All ion masses above the critical mass are trapped. By leaving a suitable gap in the bunch structure, the mass continuum of trapped ions is disturbed and only certain masses are capable of executing stable oscillations. When one takes into account that the forces acting on the ions are highly non-linear and that the bunches are not identical, then the situation looks even less favorable for ion trapping. With the inclusion of external magnetic fields, however, ion motion becomes more complicated between bunch passages. In general cycloidal motion will arise, which in a bending magnet may drive the ions longitudinally with possible collection at the edges of the magnet. In a conventional insertion device (ID) characterized by periodically varying magnetic fields, the longitudinal flow of the ion will be inhibited [7]. Furthermore, given that there are regions in the undulator with longitudinal magnetic fields and that the electron bunch kicks are always perpendicular, the ion will be restrained from reaching the surface of the vacuum chamber and being lost. At the joining of the vertical and longitudinal fields, magnetic mirrors acting on vertical and longitudinal ion motion will also be encountered, with the possibility of enhanced trapping. The elliptical wiggler adds an extra possibility for trapping, by providing a horizontal magnetic field.

Significant computational difficulties are encountered in simulating ion trapping effects using realistic operating scenarios. The main difficulty is that of computation time, and for this reason purely qualitative results have been chosen. The two models given in table 2 were examined. The ring parameters used were, emittance (@ 1.5 GeV): $4\cdot10^{-9}$ m rad, ϵ_x/ϵ_y: 10, β_x:8.2 m, β_y: 2.6 m, and ion mass number 28 (CO) was examined in both cases. The ID parameters are given in table 1, and the horizontal field component was varied at 100 Hz, starting from the maximum field value. Non-linear electron bunch kicks were used and the ion was created at the longitudinal centre of a passing bunch.

Table 2. Two models (A & B) for ion studies.

	A	B
Circulating current (mA)	400	10
N° of contiguously filled rf buckets	420	10
N° of contiguously empty rf buckets	12	0
N° machine turns examined	500	12000

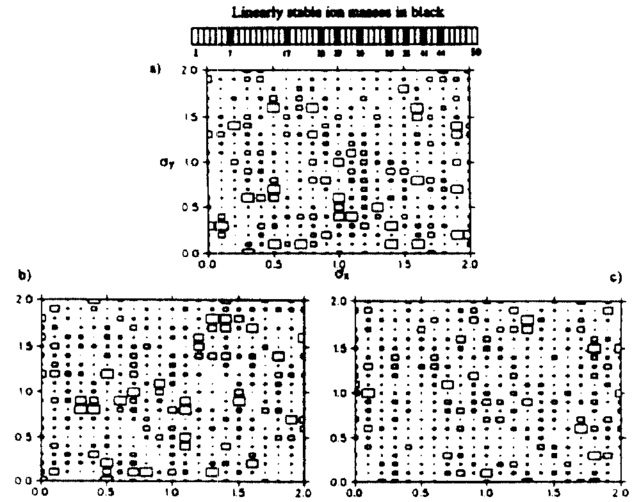

Figure 4: Stability map for model A. Only part ($2\sigma_x$ by $2\sigma_y$) of one quadrant of the transverse vacuum chamber cross-section is shown. The bar shows the stable mass numbers for this configuration.

Stability maps [7], figures 4 and 5, were generated for the case of (a) no ID, (b) EEW with no horizontal field, and (c) EEW with horizontal field. For model A, mass 28 was linearly unstable whilst for model B it was linearly stable. The stability maps show the amount of time an ion remains in the vacuum chamber as a function of its creation point. The largest boxes indicate that the ion was still present at the end of the run. We can say that for model B an ID will in general assist in trapping the ion but there is no difference between an EEW or conventional ID, whilst for A there is no difference between having an ID or not, irrespective of the device. For model A calculations were also done (not shown) where the ion had an initial longitudinal speed of 1000 m/s. In this case there was an increase in trapping when ID's were present, but no difference was seen between an EEW or conventional ID.

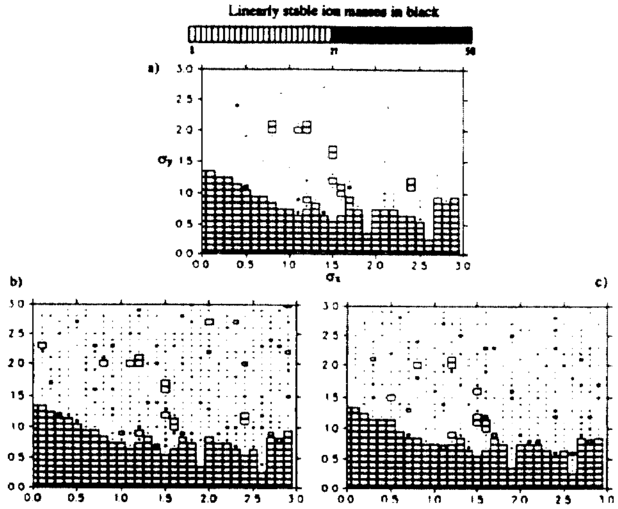

Figure. 5: As for figure 4, but for model B and ($3\sigma_x$ by $3\sigma_y$).

5. CONCLUSION

The results of the studies indicate that the additional effect of the horizontal field component in the EEW compared to conventional plane insertion devices, is negligible as regards focussing effects, non-linear beam dynamics and ion-trapping, and therefore that operation in ELETTRA is feasible. Careful measurement and adjustment of the device will however be necessary in order to eliminate the potentially disturbing influence on the closed orbit. A small model of the device is presently under construction to verify the design principles.

6. REFERENCES

[1] ELETTRA Conceptual Design Report, Sincrotrone Trieste, April 1989
[2] C.Poloni et. al., in Proceedings of. US Particle Accelerator Conference, San Francisco (May 1991).
[3] R.P.Walker and B.Diviacco, Proc. 4th Int. Conf. on Synchrotron Radiation Instrumentation, Chester (UK), July 1992, to be published in Rev. Sci. Instr.
[4] R.P.Walker, Sincrotrone Trieste Internal Report, ST/M-89/1
[5] L.Tosi and R.Nagaoka, Proc. 1990 EPAC, p. 1423
[6] L.Tosi, R.P.Walker and A.Wrulich, Sincrotrone Trieste Internal Report, ST/M-91/7.
[7] C.J.Bocchetta and A.Wrulich, "The Trapping and Clearing of Ions in Elettra", Nucl. Instr. Methods., A278, 807, (1989).