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FIXED-GAP UNDULATORS FOR ELETTRA AND FERMI

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Abstract

In the context of an R&D program on alternative undulator schemes, a fixed-gap, linearly polarized, adjustable-phase undulator (APU) was built and successfully operated on the Elettra storage ring. As a further elaboration on the fixed-gap concept, an elliptically polarized undulator (EPU) has been developed for the FERMI free electron laser (FEL). We are now constructing a novel double period APU. We present here the main design and construction aspects of the new devices under development.

LINEARLY POLARIZED APU

The adjustable phase undulator was proposed in 1991 as an alternative to the adjustable gap undulator [1]. A prototype was built and tested soon afterwards at SSRL [2]. In an APU the field strength is varied by sliding longitudinally the upper and lower magnetic arrays while maintaining a fixed separation between them. The advantages of a fixed gap device are a simple, cheap and compact mechanical structure, a simplified control system and a reduced variation of field integrals and focusing strength. Two decades after this initial experiment, the APU concept was applied to an undulator upgrade program at CESR [3]. At Elettra, a compact APU was also recently built and installed, to replace an old variable gap device. A novel mechanical design was developed that allows to easily open and close the structure (Fig. 1). This is possible because the magnetic force between the upper and the lower parts change from attractive to repulsive while shifting one of the two arrays relative to the other.

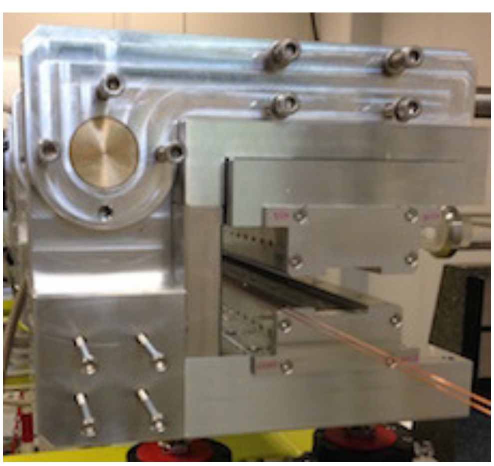

Figure 1: The Elettra APU has 21 periods of 7 cm, and K_{MAX}=3. Clearly visible is the hinge mechanism that allows opening and closing the structure.

This feature proved to be of great help during assembly, measurement, installation and maintenance. The magnetic field varies with the longitudinal shift precisely as expected (see Fig. 2), and its operation has been trouble-free in the three years since its commissioning [4].

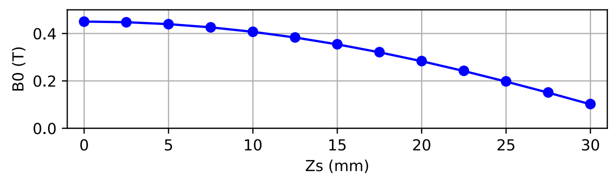

Figure 2: Measured (dots) and predicted (line) peak field.

FIXED-GAP EPU PROTOTYPE

The idea of testing a compact, fixed-gap variably polarized device followed from the positive results of the APU project outlined above. Also this concept is not new, having being proposed in 1993 [5,6]. The first device of this kind was realized and operated at SLS [7]. Its commissioning immediately showed some unwanted effects (wavelength shifting between right and left-handed circular polarization, spectral line broadening) which made operation of the device challenging [8]. These effects were later understood to be caused by the appearance of strong on-axis field gradients in the elliptical polarization modes. However, an analysis of the parameters involved suggested that linac based FELs with small emittances should not be affected too much by these field gradients. For this reason, and to gain some first-hand experience, a prototype fixed-gap variable polarization undulator was designed and built for FERMI. Its magnetic structure (see Fig. 3) is optimized for a circular vacuum chamber, similar to the APPLE-III [9].

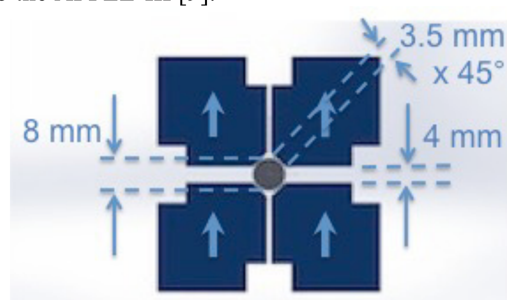

Figure 3: Cross section of the magnetic structure. Chamfered corners allow space for an 8 mm diameter vacuum chamber.

With a small vertical gap of 4 mm, a period length of 3 cm and a maximum horizontal/vertical field of 0.95/0.83 T the device provides an extended tuning range and nominally better performance compared to the existing FERMI variably polarized undulators.

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A mechanical design similar to the APU was adopted (see Fig. 4). Also in this case opening and closing is possible thanks to the existence of repulsive force conditions.

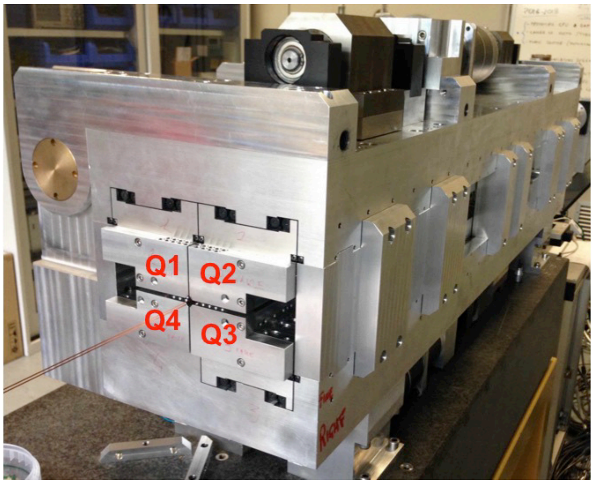

Figure 4: The fixed-gap EPU with the 4 magnet arrays labelled. The central section of the sidewall is removable for lateral access, which is essential for Hall probe field measurements. The wall can be completely removed in “neutral” force conditions, allowing scanning the probe over the whole length of the magnet.

Three of the four magnet arrays are movable. As in any APPLE-type undulator, the polarization is changed by shifting two diagonally opposite arrays (Q1 and Q3), while the field strength is adjusted by moving the two upper arrays (Q1 and Q2). Following the terminology originally proposed in [6], we call the first movement a “row-phase” shift and the second one a “jaw-phase” shift. Another way to vary the field is through a “pair-phase” shift (Q2 and Q3).

Measurement of the central field is possible through a lateral opening in the frame, offering access to one third of the magnet length (see Fig. 5). This is enough to accurately measure the average field.

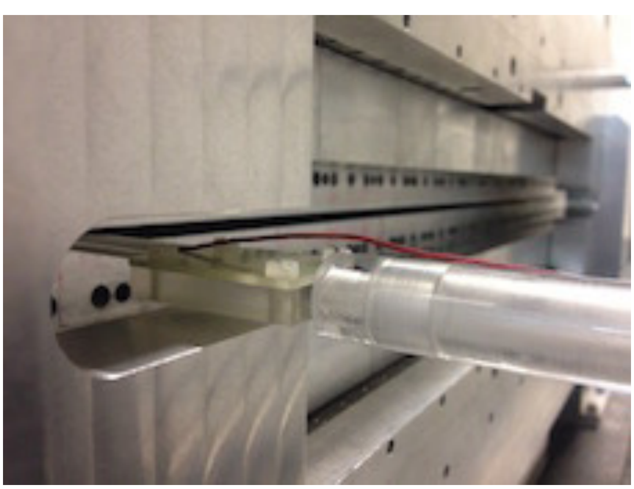

Figure 5: Hall probe measurement in the central part of the undulator.

As an example, Fig. 6 and Fig. 7 show how the peak field varies with the jaw-phase.

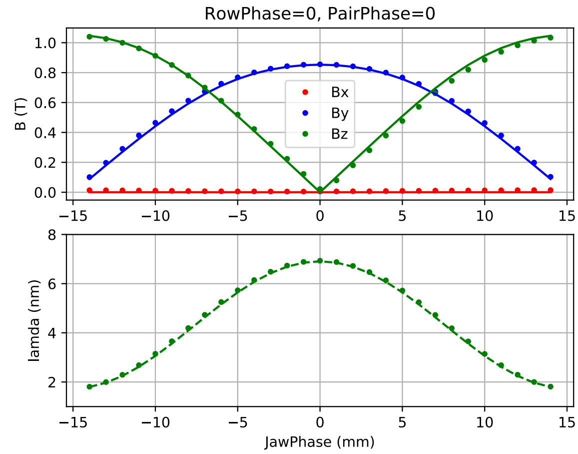

Figure 6: Measured (dots) and predicted (line) peak magnetic field as a function of the jaw-phase. Upper graph: transverse (Bx, By) and longitudinal (Bz) field components. Lower graph: radiation wavelength for 1.5 GeV electrons. Horizontal polarization mode.

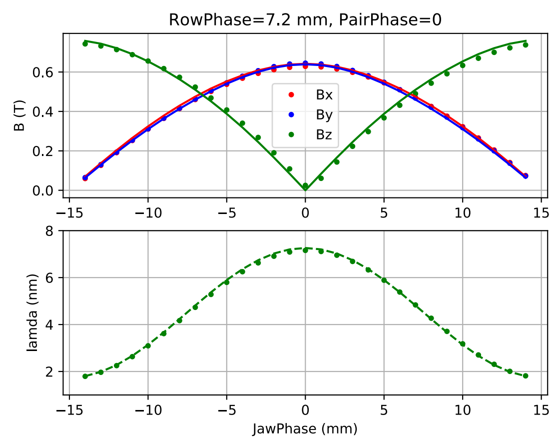

Figure 7: As Figure 6 in circular polarization mode.

Shimming was performed using small cylindrical magnets placed on the side of the main blocks and at the two extremities (“magic fingers”). Straight trajectory (see Fig. 8 and Fig. 9) and small multipole errors were obtained with standard techniques without specific problems.

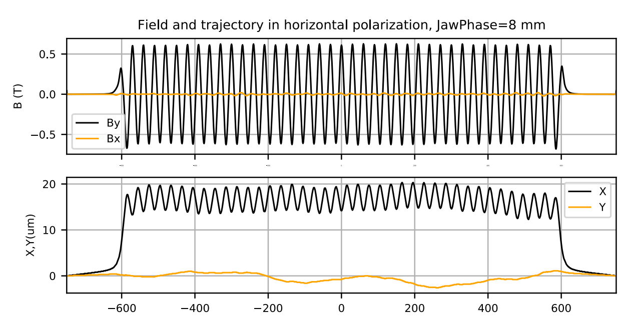

Figure 8: Measured fields and corresponding trajectories in linear polarization mode, “neutral force” set point.

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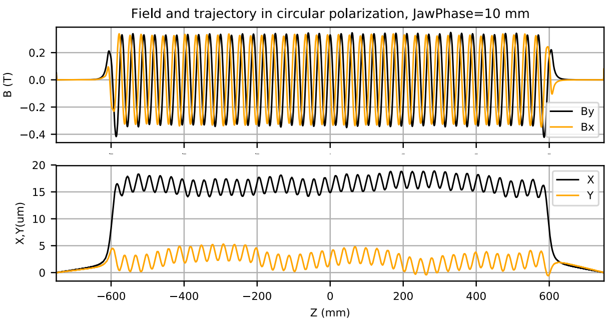

Figure 9: As Figure 8 in circular polarization mode.

As mentioned above, transverse field gradients (dB_X/dx, dB_Y/dx) are present in elliptical polarization away from the maximum field (i.e. for non zero row-phase and non zero jaw-phase). As a consequence, dynamic integrals show up in the horizontal plane, causing a net trajectory deflection proportional to the undulator length and inversely proportional to the square of the electron beam energy. In the present case the gradients reaches up to 100 T/m, causing a maximum central trajectory kick of 12 mrad for 1.5 GeV electrons. In operation this kick will be corrected by the trajectory feedback, and the residual effect seems tolerable. However, the non-uniformity of the field across the electron beam is likely to produce spectral broadening and gain reduction. These effects are difficult to model and experiments are required to assess their impact on the FEL performance. Depending on the availability of accelerator physics beam time on FERMI, the EPU will be installed in one of the next machine shutdowns.

DOUBLE PERIOD APU

The small size and low weight of the fixed-gap undulators suggested the idea of a double period APU, where two linearly polarized undulators are mounted on a common frame, similar to that developed for the EPU. The structure is mounted on a motorized sliding table so that either one or the other undulator source can be positioned on the beam axis with a switching time of a few seconds (see Fig. 10). With this setup only three motors are required for source selection and photon energy adjustment.

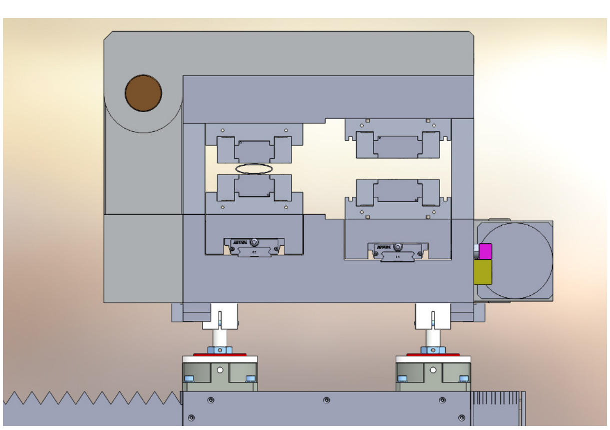
Figure 10: Cross section of the twin APU.

The new device will be installed on a short straight section of the Elettra storage ring, replacing an old 5.6 cm period variable gap undulator. The addition of a shorter period source will significantly extend the photon energy range available at the beamline (see Fig. 11).

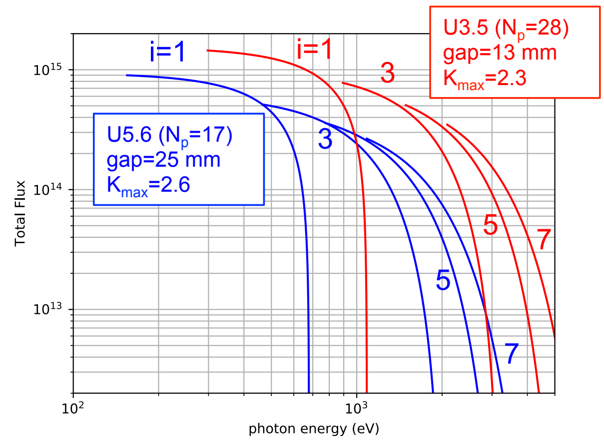

Figure 11: Flux curves (photons/s/0.1%bw) for the odd harmonics of the twin APU.

The undulator mechanics is presently being assembled, and we expect the magnetic field optimization and measurement to be completed during the summer.

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