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COMPACT APPLE X FOR FUTURE SXL FEL AND 3 GeV RING AT MAX IV LABORATORY

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Abstract

An overview of the design of compact elliptically polarizing undulator with small round magnetic gap to provide full polarization control of synchrotron radiation in a more cost effective manner and consuming less built in space than the state of the art devices. This type of undulator is meant as source for the potential future Soft X-ray (SXL) FEL beamline using the linear accelerator at MAX IV. In addition, it offers new capabilities for future beamlines at the 3 GeV ring to use full polarization control to photon energies using the fundamental harmonic which are not attainable with today's technology of the out-of-vacuum insertion devices at 3 GeV beam energy.

INTRODUCTION

A Soft X-ray Laser (SXL) beamline utilizing MAX IV Linear accelerator and the FEL technology is being designed at the MAX IV Laboratory and in collaboration between several Swedish Universities. The baseline goal of the SXL beamline is to generate intense and short pulses in the range 250-1000 eV [1].

The choice of undulator technology for the SXL beamline is presented in this paper. The final undulator design must be compliant with the specifications such as the required photon energy range, the full polarization of the photon beam and the compactness of the structure. The suitable undulator magnetic circuit structure is the APPLE X type used at the ATHOS beamline at SwissFEL [2]. This structure is composed of four permanent magnet blocks with triangular shape, and magnetized at 45°. They are disposed radially at equal distance around the electron beam axis. This leads to a symmetric structure, which allows to obtain the same energy range in all polarization modes. The polarization tuning is realized by shifting longitudinally two magnets girder array. In addition, the energy tuning is performed by moving the permanent magnet blocks radially in order to adjust the magnetic gap. New feature of using a closed support frame to structurally take care of the magnetic forces, and hence, reduces the size of the undulator considerably.

UNDULATOR DESIGN

The out-of-vacuum undulator installed at the MAX IV rings have an elliptical cross section of vacuum chamber of (H x V) 38 mm x 8 mm [3]. The large horizontal dimension is dictated by the fact that the ring is injected by horizontally off-axis electron beam, which requires large horizontal acceptance. One of the consequences is the fact that it is not efficient from magnetic point of view to produce both vertical and horizontal magnetic fields of equal intensities for polarization control. This leads to the use of strong magnets, with high remanence and big volume, which results in strong magnetic forces and torques and requires a strong support system of the undulator, in other words, the undulator becomes bulky and expensive.

The potential upgrade of the injection scheme for the MAX IV 3 GeV storage ring to use on-axis injection scheme opens the possibility to use round vacuum chamber, i.e. small and equal acceptances needed by the ring in the horizontal and the vertical planes.

In addition to the potential use at the 3 GeV ring, the proposed Free Electron Laser beamline in the soft X-rays at MAX IV using the 3 GeV Linac is a single pass accelerator and hence also here a round vacuum chamber fulfills the beam stay clear requirements.

The proposed design of an undulator with round magnetic gap will take advantage of this feature of small acceptances needed in both types of accelerators, the Linac and storage ring.

Some preliminary design work based on the magnet circuit used at ATHOS but with compact mechanical frame was carried out for the photon energy range between 250 eV and 1000 eV with full polarization control. A period length of 40 mm and 8 mm diameter magnetic gap can fulfill the photon energy range and full polarization control for the proposed soft X-rays FEL at MAX IV. The respective magnetic forces result in a maximum of ~15 µm deformation in all phases at minimum magnetic gap. Using a magnet girder of aluminum gives an overall transverse dimension of 50 cm diameter. The impact of such structure on the cost is estimated to be a 30 % reduction on the overall cost of a 3 m long undulator. Other advantages of such a structure is that the high first eigen-frequency minimizes the transmittance of ground vibrations and thus provides a high stability of the source point of the radiation as an advantageous bi-product.

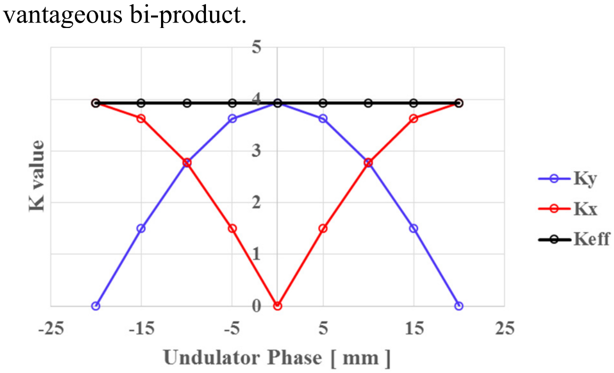

Figure 1: Achieved Effective K at minimum gap.

The magnetic material used in the simulations is SmCo with magnetic remanence of Br=1.1 T for the radially magnetized and the longitudinally magnetized blocks.

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The magnetization of the magnet blocks assumed in the simulations is uniform.

The achieved effective K value in the horizontal and vertical planes at minimum magnetic gap of 8 mm for the helical mode of operation is shown in Fig. 1. The operational gap range to fulfil the requirements on the photon energy range is from 8 to 17.3 mm gap range. The conceptual structure design provide a maximum gap of 28 mm, i.e. an effective K value of 0.55 where the undulator will not be fully transparent on day one for commissioning, see Fig. 2.

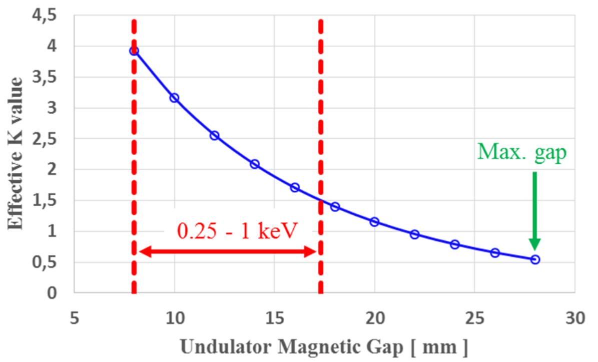

Figure 2: Operational gap range of the APPLE X undulator.

Table 1 summarizes the basic parameters of the APPLE X conceptual design for the SXL beamline.

Table 1: Undulator Basic Parameters

Parameter	Value
Magnet Material	SmCo
Period Length	40 mm
Photon Energy Range	0.25 – 1 keV
Magnetic Gap Range	8 – 17.3 mm
Effective K range	3.9 – 1.51
Max. Gap / Min. Eff. K	28 mm / 0.55
Magnetic Length	3

UNDULATOR STRUCTURE

The frame of the APPLE X undulator is called the strong back. It comprises of two half cylinders made of aluminium EN-AW 6082 with a diameter of 500 mm and a length of 3000 mm, see Fig. 3. The material combines sufficient strength and lightweight with good machining properties. The resulting deformation of the strong back at present magnetic forces of the 3 m long undulator is below 15 µm at minimum gap. The lateral opening is meant to gain access for magnetic measurement, see Fig. 4. The design allows for gap and phase adjustment, which are realised by wedges as shown in Fig. 5. There are four magnet rows mounted on their respective sub-girders, which can be moved individually and independent from each other by four motor axis. The gap motion also relies on the wedge principal and has additional four motors [2].

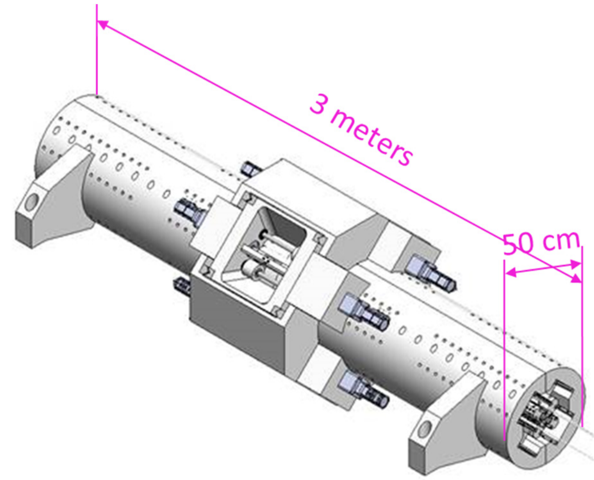

Figure 3: Schematic view of compact APPLE X undulator.

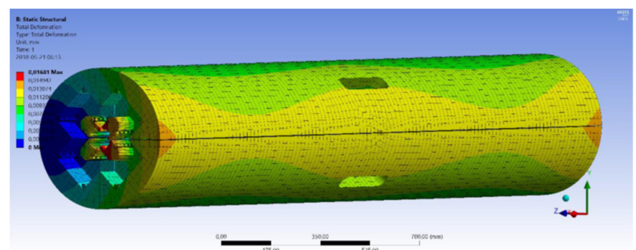

Figure 4: Undulator FEA model gives maximum 7 µm deformation along the bulk and <15 µm at the extremities.

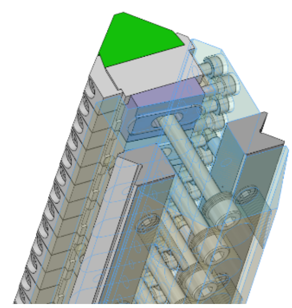

Figure 5: Schematic of undulator sub-girder with wedge and spring loaded magnet module.

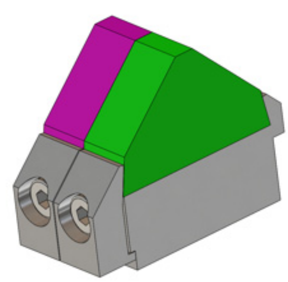

Figure 6: Schematic of magnet module with two magnet blocks.

The magnets are mounted on individual magnet holders, see Fig. 6. Each magnet holder rests on its respective wedge enabling magnetic tuning similar to MAX IV APPLE II devices [3].

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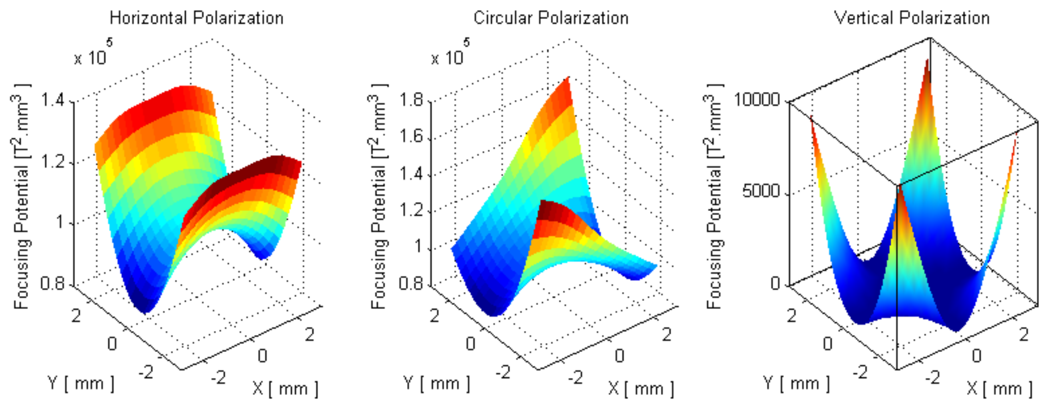

Figure 7: APPLE X undulator focusing potential for horizontal, vertical and circular modes at minimum gap of 8 mm.

The proposed installation scenario for the undulators to be installed in the SXL tunnel together with their respective vacuum chamber section on concrete girders with separate adjustment feet for vertical and horizontal alignment. The calculated total weight of the undulator is about 3.5 t.

UNDULATOR KICK MAPS AND TOLERANCES BUDGET

The first step to investigate the effect of the undulator on the electron beam optics is done by calculating the focusing potential and kick maps to be used in the tracking studies [4]. The undulator has been modeled in three different modes of operation, horizontal, circular and vertical polarization. The kick maps covers an aperture of ±2 mm in the vertical and horizontal planes, which covers the expected beam stay clear aperture for both sources, the Linac and the storage ring with low X & Y beta functions after the on-axis injection scheme is in place for operation. Figure 7 shows the focusing potential for the three cases of polarization in the helical mode of operation at minimum gap of 8 mm.

There are unavoidable erroRs contained in the undulator caused by magnetic and mechanical imperfections. These errors create distortions on the magnetic field, which lead to a reduction of the undulator performances such as photon beam quality and electron beam dynamic disturbance. Magnetic and mechanical tolerances must be specified in order to keep an acceptable tolerance on the magnetic field quality. A statistical approach is used to compute these tolerances by introducing a Gaussian distribution error on the model parameters and computing the impact on the magnetic field. Globally, these tolerances are more stringent due to the small gap especially for the magnetization angle error.

CONCLUSION

The conceptual design for compact APPLE X is presented for Linac and storage ring based sources. The design is mature enough for prototyping, which has not been funded yet, in order to verify its feasibility. Several challenges need to be remedied especially for the shimming process and the magnetic measurement. The solution has taken into account a magnetic characterization using the flat stone Hall probe measurement by having a lateral opening in addition to the current development at MAX IV of new pulsed wire measurement system.

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