DELTA UNDULATOR MAGNET FOR CORNELL ENERGY RECOVERY LINAC

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Abstract

We designed, built and tested a short undulator magnet prototype optimised for operation with Energy Recovery Linac. The magnet provides full x-ray polarization control. It is very compact and has 40% stronger magnetic field in linear and approximately 2 times stronger in circular polarization modes than existing undulator magnets with similar gap. The built prototype is 30cm long, has pure permanent magnet (PPM) structure with 24mm period and 5mm diameter round bore and can be enclosed in 20cm diameter vacuum vessel.

In the design and construction we used a number of nonconventional approaches. The magnetic field strength is controlled via longitudinal motion of the magnet arrays. This motion is also applied to x-ray polarization control. Compactness is achieved by using the recently developed NdFeB permanent magnet block soldering technique and box-like structural frame.

The paper describes the design concept, some aspects of the construction and test results.

INTRODUCTION

The Delta design has a few distinguishing features.

First it is round gap (bore). In compare with storage rings, Linac (or ERL) based synchrotron radiation facilities have a smaller beam emittance and consequently smaller beam size. In addition, they do not requirement extra aperture for residual oscillation of the injected particles. This allows to reduce the horizontal beam aperture to the size of the vertical one and to make insertion devices with round gap (bore).

Second, we used adjustable phase (AP) scheme for the field strength control. In this scheme the peak field is controlled by the magnetic arrays moving relative to each other in the longitudinal direction. The same motion can be used for x-ray polarization control. A theoretical model of the AP scheme has been developed by Roger Carr in [2] and [3]. A beam test result was described in [4]. Presently, an AP undulator successfully operates as x-ray source for the "ADRESS" beam line at the Swiss Light Source.

In addition, the Delta type undulator very compact due to the use of box-like frame and permanent magnet (PM) fastening by soldering.

The conceptual idea for Delta undulator was presented in 2006 [1]. Encouraged by the interest from Cornell x-ray user community, this idea evolved into a short prototype.

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CONCEPT

Fig. 1 illustrates conceptual design. Four identical magnet arrays assembled on base plates are symmetrically placed around beam axis. To provide longitudinal displacement for the field strength and polarization control, bases are mounted on miniature rails to the rigid plates forming a frame. In the planar mode, the pairs generating vertical and horizontal magnetic field are in phase. In this case combined field is planar and $\sqrt{2}$ stronger than field from a single pair. In helical mode, pairs are shifted relative to each other by 1/4 of period or by 90^0. The resulted field is helical. To change the field amplitude, two arrays forming the pair should be shifted longitudinal in opposite directions.

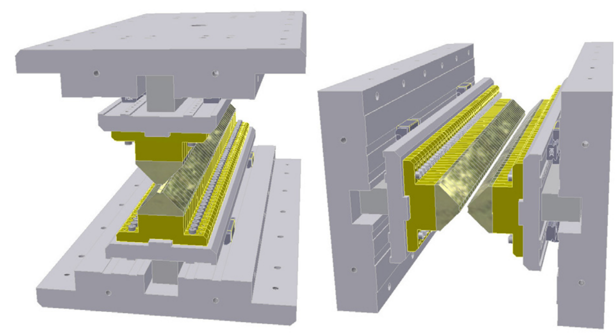

Figure 1: Two pairs of magnet arrays forming Delta undulator structure. On the left side are arrays generating vertical field, on the right - horizontal.

This arrangement can be considered as a combination of two independent AP undulators. It can also be viewed as a kind of Apple-III structure mentioned in [7]. The Delta structure has similarities with undulators described in [5] and [6] as well.

The peak field, calculated as a function of ratio of gap to period for the Delta undulator ($B_r = 1.26T$) in comparison with other undulators, is given on Fig. 2. Data for "PPM planar vertical/horizontal field" and "PPM helical field" were found in reference [9] and characteristics for Apple-III structure are from [7]. The plot shows the advantage of the Delta structure. In planar mode it provides $\sqrt{2}$ times stronger magnetic field than conventional PPM undulators; in helical mode field is approximately two times stronger.

Special attention was paid to the PM magnet block fastening technique. Mechanical fastening was not considered as practical, because it would take additional space and, probably, would require specially shaped magnetic blocks. The latter could considerably increase the cost of

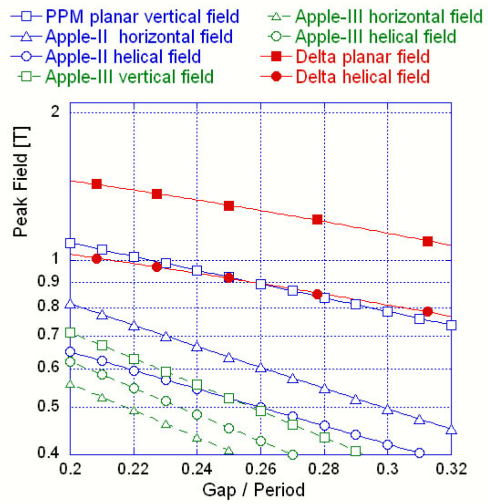

Figure 2: Peak field as a function of gap to period ratio for various types of undulators.

the project. Gluing was also undesirable because it is not compatible with in-vacuum operation. After appropriate investigation we developed a technique for soldiering of Ni coated NdFeB (40SH) magnets to copper holders without demagnetization [8].

Undulator type was named as a "Delta" after the shape of the PM blocks.

CONSTRUCTION ASPECTS

To illustrate the structure of Delta undulator Fig. 3 shows the partly assembled model. Here can be seen a $148mm \times$

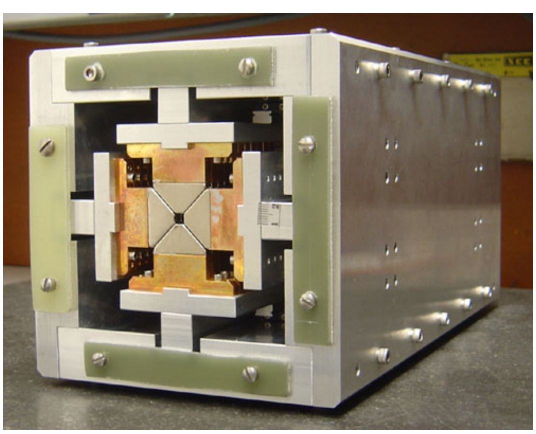

Figure 3: Partially assembled model with visible magnet arrays.

$148mm \times 300mm$ box-like frame with four magnet arrays inside. The round bore in the center has 5mm diameter. Four 0.5mm wide slits between magnet arrays provide enough conductance for the gas flow from the beam region to the pumped volume to satisfy vacuum condition at the beam location.

The Delta shape NbFeB(40SH) PM blocks with $B_r = 1.26T$ coated with Ni were ordered from "Stanford Materials Corp" (Aliso Viejo, CA, USA). Blocks were soldered to copper holders by the method developed in [8]. For soldering we used Sn/Pb alloy with melting point 183^0C. To prevent PM demagnetization during the soldering, blocks together with copper holders were enclosed in "steel jackets". The jackets reduced PM self demagnetizing field, that resulted in the increase of the PM demagnetization temperature from 132^0C to 228^0C. The latter was well above the solder melting point.

Because of inability of the magnetic field tuning in the assembled magnet, each magnet array was tuned individually prior to the magnet assembly. Fig. 4 shows one of

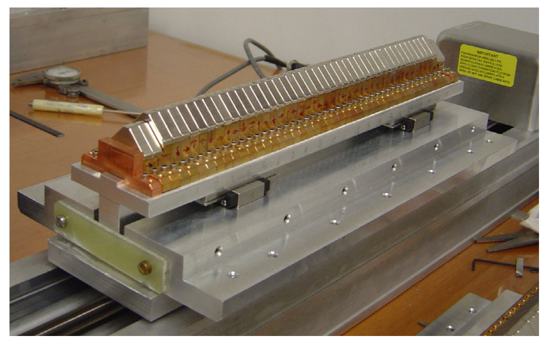

Figure 4: Magnet array on the field measurement bench.

the arrays on the magnetic field measurement bench during the tuning process. One can notice that two end PM blocks are displaced relative to the others. It was done for proper magnetic field "end termination".

The assembled magnet field properties were verified with a special magnet field measurement setup as described in [11].

TEST RESULTS

Mechanical and magnetic properties of the model were extensively tested. Detailed test description can be found in [11]. Below is a short summary.

Helical mode. Fig. 5 shows vertical and horizontal magnetic field components along undulator measured in helical mode (90^0 phase shift between magnet arrays). A sine

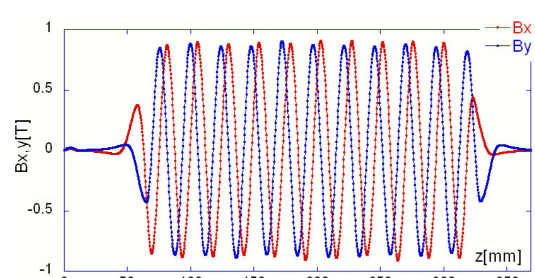

Figure 5: Horizontal and vertical field components measured along beam axis in helical mode.

wave fit applied to the horizontal and vertical field components gave 0.873T and 0.856T for the field amplitudes and 88^0 phase between them. The measured field amplitude is $\sim 13\%$ less than was predicted by calculation. The cause of the field amplitude reduction was found to be the imperfection in the mechanical structure. In the next version of the model it will be fixed .

The field quality was confirmed by calculation of the x-ray flux spectrum using program SPECTRA [12]. Two

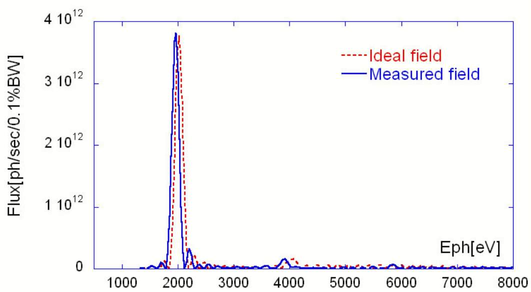

Figure 6: X-ray flux spectrum calculated for the measured and ideal fields in helical mode.

plots on Fig. 6 present spectra of x-ray flux through 0.5mm radius slit 30 meters away from the source calculated for 5GeV, 25mA beam with 8 pm emmitance (ERL type) using the measured (solid line) and ideal (dashed line) helical fields. The negligible difference indicates a good quality of the measured field.

Planar mode. Fig. 7 presents two orthogonal field components, $B1$ and $B2$, measured in planar mode ("zero" phase shift between arrays). . The data indicate $1.26T$ field

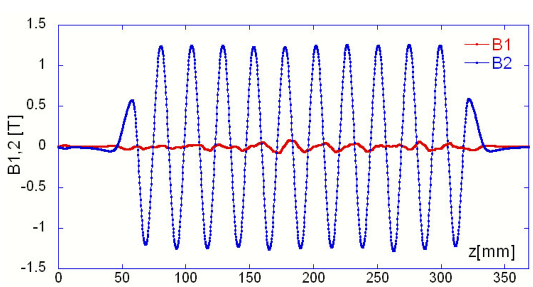

Figure 7: Two orthogonal field components measured along the magnet in planar mode.

amplitude of $B2$, which is $\sim 89\%$ of the predicted.

Flux spectra calculated for the ideal and measured field are shown in Fig. 8. Here the small difference between spectra for the ideal and the measured field indicates satisfying field quality.

DISCUSSION AND CONCLUSION

Magnetic field measurement as well as mechanical properties test confirmed validity of the basic principals used for the Delta undulator design.

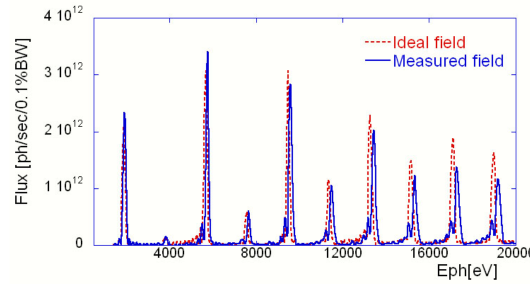

Figure 8: X-ray flux spectrum for the measured and ideal fields in planar mode.

At present we are working on the next short model with improved mechanical structure. This model will be tested with beam in the ATF at BNL. After the test results, we are planning to build a longer device.

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