DESIGN AND MAGNETIC MEASUREMENTS ON BI-HARMONIC UNDULATOR*

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Abstract

In this paper, we report the design and fabrication of seventh and ninth harmonic undulator for free electron laser applications. The permanent magnet undulator is a four block per period design and has been modified with CRGO shims along the length of the undulator. The undulator is a variable gap type and consists of NdFeB magnets with six periods; each period is of 5cm length. The modified bi-undulator has been measured in hall probe and pulsed wire bench

INTRODUCTION

The measurement of undulator is an important issue in design of uniform, precise and quality undulators for synchrotron radiation and free electron laser applications. Such measurements are usually made point to point by a Hall probe. The pulsed wire method was suggested as an alternate method for field integral measurements [1]. In this method, a thin wire is stretched along the undulator axis. When a current flows through the wire, a force proportional to the local transverse field component is exerted on the wire. This force evolves into a wave on the wire that propagates from the vicinity of the wire to a sensor located at the undulator ends. The sensor output versus time is the field integral versus position along the wire. The pulsed wire method has been used successfully used for magnetic measurement studies of planar undulators [2, 3] and gives good agreement with the Hall probe results. Recently a scheme was devised to design higher bi-harmonic undulators for free electron laser applications [4].In an earlier paper we reported magnetic measurement studies of the third, fifth bi-harmonic undulators in the pulsed wire bench [5]. In this paper we report the measurements studies of the seventh and ninth bi-harmonic undulators in the same pulsed wire bench. The transverse motion equation in the wire is given by

$$\frac{\partial^2 x}{\partial z^2} - \frac{1}{v^2}\frac{\partial^2 x}{\partial t^2} = -\frac{B_u(z)I(t)}{T} \qquad (1)$$

where $v = \sqrt{T/\mu}$ is the wave velocity. T is the tension on the wire. $I(t)$ is the current in the wire and $B_u(z)$ is the magnetic field at a location of z. For a short pulse the first field integral is given as

$$x_1(t) = -\frac{I_0 \Delta t}{2\mu v}\int_0^{vt'} B_u(z)dz \qquad (2)$$

For a longer pulse the second field integral is given by,

$$x_2(t) = -\frac{I_0}{2\mu v^2}\int_0^{vt'} dz \int_0^{z} B_u(u)du \qquad (3)$$

I_0 is the current injected to the wire. The first and second field integral i.e. Eq. (2) and Eq. (3) in the pulsed wire method is measured by an appropriate pulse width. The field integral data obtained from the pulsed wire method is compared with Hall probe data.

MEASUREMENT RESULTS

The bi-harmonic undulators are modified planar sinusoidal fields for third, fifth, seventh and ninth harmonic undulators and are fabricated by locating shims along the length of the undulator. The pulsed wire bench is set with two wire diameters of 250 µm CuBe wire having $\mu = 4.1\times10^{-4}$ *kg/m* and 125µm CuBe wire having $\mu = 1.01\times10^{-4}$ *kg/m*. The wire length is 1.39 meter, which is more than four times the length of the undulator. Two sensors are employed for wire deflection measurements. One is an optocoupler and the other is a laser –photodiode pair [6] . Both the sensors are kept at the location of 148mm away from the ends of the undulator. In our present measurement, with a given SNR, a current of 1.9A and 0.6A is used for wire diameters of 250µm and 125µm respectively. The sensitivity of the both the sensor is kept at 8mV/µm (250 µm wire) and 6mV/µm (125 µm wire) respectively [6]. The PWM data is plotted for the seventh and ninth harmonic undulator collected from the two sensors for the two wire diameters. The measurements are taken at shim gap of 4mm, 7mm and 10mm respectively. The data for the second field integral is double differentiated to get the magnetic field profile. The results for the seventh harmonic undulator with 250µm wire diameter is plotted in Fig 1a and Fig 1b. The results for the seventh harmonic undulator with 125µm wire diameter is plotted in Fig 2a and Fig 2b respectively. The magnetic measurement results for the ninth harmonic undulator with 250µm wire diameter is presented in Fig 3a and Fig 3b. The magnetic measurement results for the ninth harmonic undulator with 125µm wire diameter is presented in Fig 4a and Fig 4b respectively.

The PWM data for the magnetic field is compared with the Hall probe data in Fig 5 for a shim gap of 4mm (i.e. undulator gap 24mm) for all the harmonic undulator including the planar undulator results. The results are shown for the B_{RMS} versus tension over the pulley with wire diameter of 250µm. the optocoupler sensor shows the best matches results with the Hall probe data. The disagreement is 0.27% at a tension of 4.14N. For a 5% disagreement with the Hall probe data the tension range is found to be 2.49N to 7.24N. The laser photo-diode sensor gives 3% disagreement with the Hall probe data at 4.55N and the tension range is 2.49N to 6.82N for a 5% disagreement with the Hall probe data. The third, fifth and seventh harmonic undulator measurements show best matching results in a tension range of 2.48N to 5.19N whereas for the ninth harmonic undulator the range is around 3.3N to 5.62N. The measurements are repeated with the 250µm diameter wire for a shim to shim gap of 7mm and similar observations were seen for a gap of 7mm. The optocoupler and laser – photodiode sensors give best matching results at 3.3N with 1.5% and 6% disagreement with the Hall probe data. The overall tension range is from 2.88N to 7.24N for both the sensors. The tension range is limited for all other higher harmonic undulator measurements. For undulator gap at 30mm (shim to shim gap of 10mm) the planar undulator measurements shows best results in the range of 3.71N to 5.62 N. For bi-harmonic undulator measurements good agreement with the Hall probe data is obtained in the range of 3.71N to 4.82N. The measured data gives a disagreement of 62Gauss and 97 Gauss at 24mm measurements at the 5th harmonic with the Hall probe data. At 27mm gap, the measurement gives a disagreement of 134Gauss and 245 Gauss at the third harmonic with laser photo diode and optocoupler sensor respectively. At

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this gap the 7th harmonic measurement disagree with the Hall probe data up to 200 Gauss with both the sensors. At a gap of 30mm, the PWM data disagrees with the Hall probe data by 66 Gauss and 252 Gauss with the optocoupler and laser sensor respectively for the planar undulator. For the ninth harmonic measurements the maximum disagreement is 152 Gauss by the optocoupler sensor. All these measurements give an important conclusion that the PWM data is close to the Hall probe data up to 250 Gauss maximum in our measurement setup. The bi-harmonic measurements are repeated for the wire diameter of 125 µm. The PWM data are taken at 24mm, 27mm and 30mm (Fig 6a, Fig 6b) for all the harmonic undulators. For a good agreement with the Hall probe data the tension range do not change appreciably for both the planar and bi-harmonic undulator measurements. Figure 6b gives a summary of all measurements. The optocoupler sensor shows perfect matching results with the Hall probe results. The laser photo diode sensor data disagree with the Hall probe data. The disagreement is 210 Gauss and 250 Gauss for the 5th harmonic at a gap of 24mm and 27mm respectively. For the undulator gap of 30mm, the laser sensor data disagrees from the Hall probe data by 80 Gauss and 34 gauss at the 3rd and 5th bi-harmonic undulator. At these harmonic undulator measurements, the optocoupler sensors data provide a discrepancy of 205 Gauss and 119 Gauss from the Hall probe results.

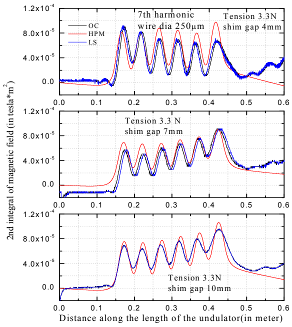

Figure 1a: 2nd field integral for 7th bi-harmonic undulator.

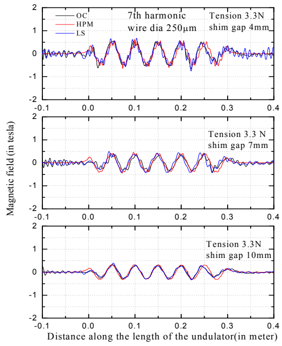

Figure 1b: Magnetic field for 7th bi-harmonic undulator.

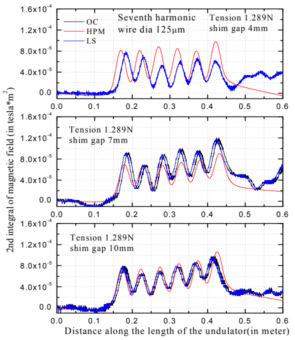

Fig 2a 2nd field integral for 7th bi-harmonic undulator.

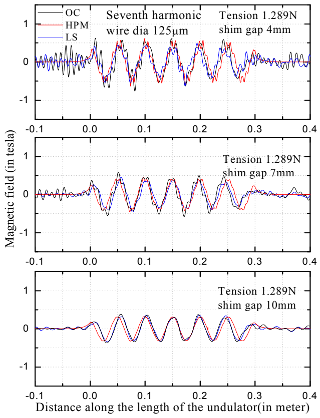

Figure 2b: Magnetic field for 7th bi-harmonic undulator.

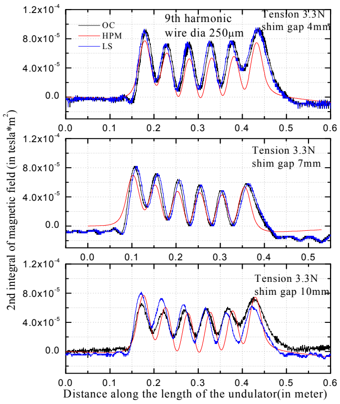

Figure 3a: 2nd field integral for 9th bi-harmonic undulator.

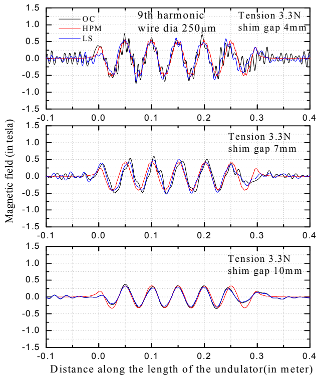

Figure 3b: Magnetic field for 9th bi-harmonic undulator.

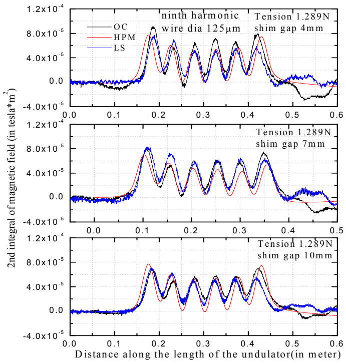

Figure 4a: 2nd field integral for 9th bi-harmonic undulator.

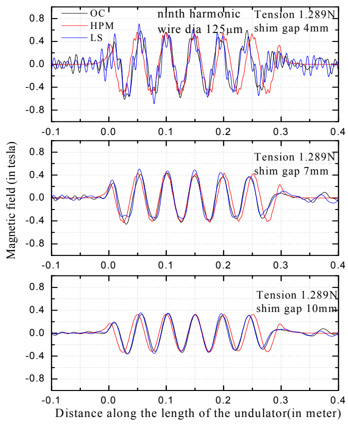

Figure 4b: Magnetic field for 9th bi-harmonic undulator.

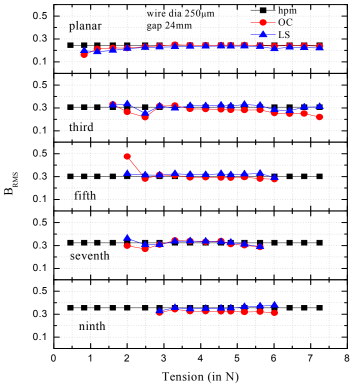

Figure 5a: B_{RMS} versus tension.

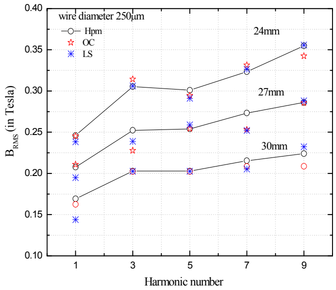

Figure 5b: B_{RMS} versus harmonic number at optimum tension.

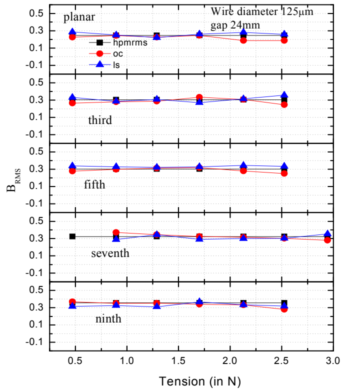

Figure 6a: B_{RMS} versus tension.

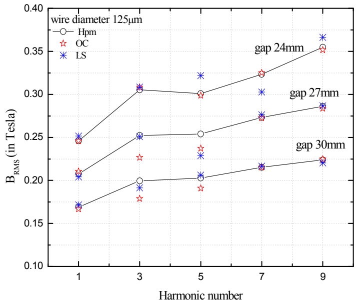

Figure 6b: B_{RMS} versus harmonic number at optimum tension.

DISCUSSION & CONCLUSION

A pulsed wire system for magnetic measurements has been successfully tested with bi-harmonic undulators. The experimental results verify the applications and ability of the PWM to measure multi peak magnetic field profiles. To ensure the reliability and repeatability of the results, two detection systems with different principles are used in the set up. Two wires of different diameters are used. The results prove that the stiffness and thickness of the wire do not affect the PWM accuracy to detect multi peak sinusoidal magnetic field profiles. The 250 μm wire diameter and 125 μm wire diameter reproduce PWM data with an accuracy of 250 Gauss with that of The Hall probe data.

Second, the 250 μm wire diameter and 125μm wire diameter measurements gives another important observations on bi-harmonic measurements. The two wires give good matching results at optimum tension. A variation from this value introduces errors in the measurements. The 250μm wire diameter gives good agreement with the hall probe data in a limited tension range in comparison with the planar undulators. This is not observed in the case of 125μm wire diameter. The bi-harmonic field undulator is represented as $\vec{B} = \sum_{h=1}^{N} B_h \sin\left(k_h z\right)$.

In the bi-harmonic undulators the wire oscillates at two frequencies i.e. at the primary frequency and at the harmonic of the fundamental frequency. The wave velocity dispersion in the thick wire gives a narrow tension window for bi harmonic undulator measurements in comparison to the planar undulator measurements. This effect is not observed in the case of 125 μm wire diameter as the dispersion effect is proportional to the square of the wire diameter.

Third, The laser sensor and the optocoupler works on different principles of light interception, however gives equal results at equal sensitivities.

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