PULSED WIRE MEASUREMENT OF 20 mm PERIOD HYBRID UNDULATOR*

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Abstract

We investigate pulsed wire measurements of field integrals and phase error of a 20 mm-period, 500 mm-long undulator and discuss variation in performance with Hall probe data without any dispersion correction algorithm.

INTRODUCTION

The Pulsed wire method is alternate to Hall probe method and is preferred in in-vacuum, out-vacuum undulators with limited access. The pulsed wire technique finds potential applications in in-vacuum undulators and cryogenic undulators. The pulsed wire method is faster and suitable in detecting magnet position errors and replacing it. The pulsed wire technique with orthogonal pair of sensors can be utilized as similar to Hall probes with multi axis Hall sensors. Nevertheless, although the pulsed wire method proposed three decades back in 1988 and successfully improved over the years, the method needs to be carefully calibrated for wave dispersion & accurate pulse widths, sensor sensitivity and more importantly the tension in the wire in order that the method emerges as individual precision measurement system independent of the Hall probe method. The wire sag arises due to catenary weight of the wire and poses a serious threat for measurement of long undulators. The second important issue of concern is the dispersion associated with finite rigidity of the wire.

PULSED WIRE MEASUREMENT SYSTEM

The Hall probe and Pulsed wire magnetic bench have been described in Ref. [1]. A motorized linear translation stage with a Hall probe measures the magnetic field profile. The undulator length is 500 mm with 20 mm period length. The accuracy of the Hall probe position during the motion along the undulator length is measured by a position sensitive measuring detector system. The pulsar in the pulsed wire bench is a 50V-12A High Current Voltage Source (HCVS). Two CuBe wires of different diameters are used for the experiment. The 250 µm wire is used with a current of 5A in the wire. The 125 µm wire is used with 1.32 A for the experiment. A current probe measures the current in the wire. We use Tektronix make, Model No A622 AC/DC current probe for the measurement. The total wire length is 1660 mm and passes through the 500 mm length undulator on axis. The pulley end is 660 mm away from the undulator end. The fixed end is 500 mm away from the other undulator end. The wire length in the arrangement is kept at 3.32 times the length of the undulator. The transverse wire displacement propagates along the wire as a wave longitudinally along both the directions and is detected by a laser-photodiode sensor located at the ends of the undulator. The wire displacement at the sensor for the first field integral is given by:

$$x(0,t) = -\frac{i_0 \Delta t_{short}}{2\upsilon\mu} I_1 \text{, where } \Delta t_{short} < \lambda_u / 2\upsilon \qquad (1)$$

and i_0 is the amplitude (A) of the current pulse, υ is the velocity of the wave (m/s) in the wire, Δt is the pulse width (s), μ (kg/m) is the mass per unit length of the wire. Equation (1) is evaluated by looking at the wire displacement with a current of short duration applied to the wire. The wire displacement at the sensor for the second field integral is given by for a longer pulse:

$$X(0,t) = -\frac{i_0}{2\upsilon^2\mu} I_2 \text{, where } \Delta t > N\lambda_u / \upsilon \qquad (2)$$

FIELD INTEGRAL MEASUREMENT

The first and second field integrals of U20 are measured by Hall probe [2]. The second field integral centroid is displaced from the axis by 500 Gcm^2. From the peak field data, first field integral (rms) is 732 Gcm and the second field integral (rms) reads 553 Gcm^2.

We choose tension at a preselect sag for the measurement. The second field integral from the pulsed wire data is captured at a tension of 22.9N as shown in Fig. 1. The sag with the 250 µm wire is 52 µm. The pulsed wire integral data is stretched beyond the Hall probe data implying that the pulsed wire is tension under-compensated. The tension is gradually increased. We define the tension compensated length as the difference in length of the und-

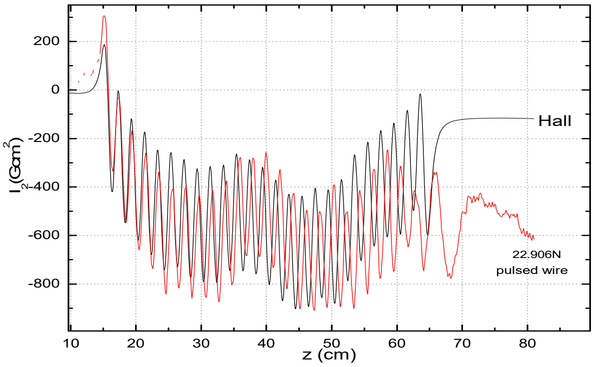

Figure 1: Second field integral at a wire tension.

ulator calculated by the Hall probe data and pulsed wire data. The minimum tension when it happens is called the optimum tension. The tension compensated length versus tension is shown in Fig. 2. The optimum tension for the 250 µm wire is 26.2N and for the 125 µm wire, it is 0.911 N. Beyond this point the wire is overcompensated with tension and then the pulsed wire result moves away from the Hall probe result. In Fig. 3, the field integral data is shown for the optimum tension and the pulsed wire data with overcompensated with tension. From the peak data, the second field integral (rms) reads from Fig.3 as 555 Gcm^2 and reaches an accuracy of 02 Gcm^2 between the two methods. The theoretical value of the velocity is 253.1 m/s. The experimental value of the velocity is 253.7 m/s. There is a difference between the theory and the measured is 0.2%. The long pulse is given by Eq. (2). With the measured value of the velocity the lowest pulse requirement is 1.97 ms. We vary the integral measurement with pulse width. The measurement gives good results at 4 ms. The second field integral is measured at 4 ms which is:

$$\Delta t_{long} = \alpha N \lambda_u / \upsilon$$

where $\alpha = 2.03$. The measurement is repeated with 125 µm diameter wire. From the peak data, the field integral measures 554 Gcm^2 at the optimum tension of 0.911 N in Fig. 4. The pulse width for this measurement is 10.5 ms, $\alpha = 1.99$. The theoretical value of the velocity is 95 m/s. The experimental measured value of the velocity is 94.86 m/s. There is a difference between the theory and the measured value is 0.15%.

The second field integral measured at the end of the undulator is seen at Fig. 5 for both the wire. The 125 µm wire pulsed wire data shows better result close to Hall probe data. At the optimum tension, the 125 µm wire gives the second field integral as 225 Gcm^2, the 250 µm wire reads as 650 Gcm^2 where the Hall probe reads the field integral as 125 Gcm^2.

The first field integral from Hall probe data and pulsed wire data with 250 µm wire is shown in Fig. 6. From the peak data, The Hall probe gives first field integral-rms data of 732 Gcm where the pulse wire data gives an rms value of 735 Gcm. Thus the accuracy is 3 Gcm between the two methods. The pulsed wire data is measured at 19.7 µs. The pulse requirement is given by Eq. (1). According to this at the measured value of the velocity of 253.7 m/s, the maximum value of the pulse requirement is 39.4 µs. The first field integral is measured at 19.7 µs which is:

$$\Delta t = \lambda_u / \alpha 2\upsilon$$

where $\alpha = 2.00$. The calculation for the first field integral is repeated for the 125 µm wire diameter in Fig.7. The field integral-rms measures 734Gcm at the optimum tension. The pulse width for the first field integral for 125-µm wire diameter is 50 µs and $\alpha = 2.10$.The end first field integral for the 250 µm wire from the Fig. 6 reads 85.5Gcm whereas with the 125 µm wire, this value is 24 Gcm as seen in Fig.7. The Hall probe data reads this value as 0.975 Gcm.

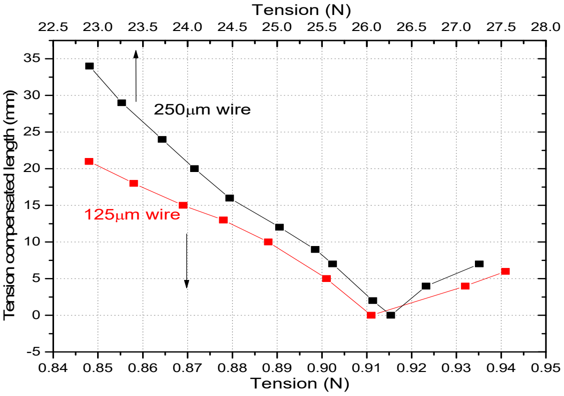

Figure 2: Calculation of optimum tension.

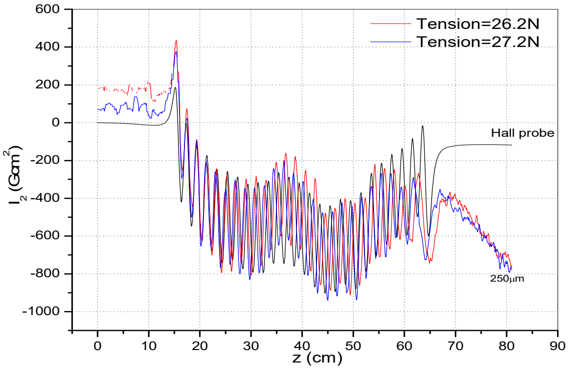

Figure 3: Field integral at the optimized wire tension 26.2N and higher than the optimized tension 27.2N for the 250µm wire.

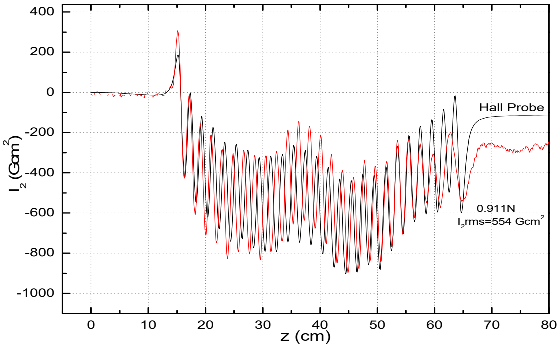

Figure 4: Second field integral at the optimized wire tension for the 125 µm wire.

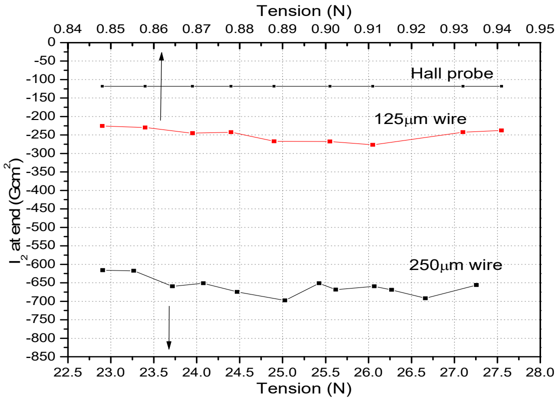

Figure 5: Second field integral measured at the end of the undulator.

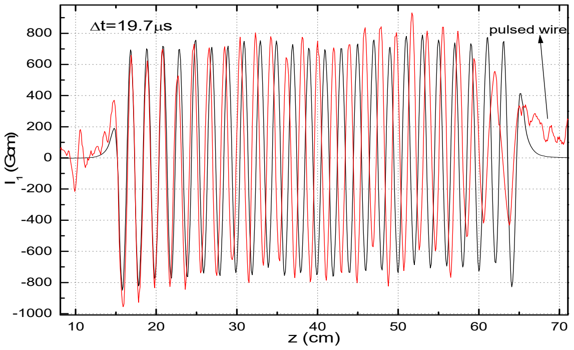

Figure 6: First field integral for the 250 μm wire.

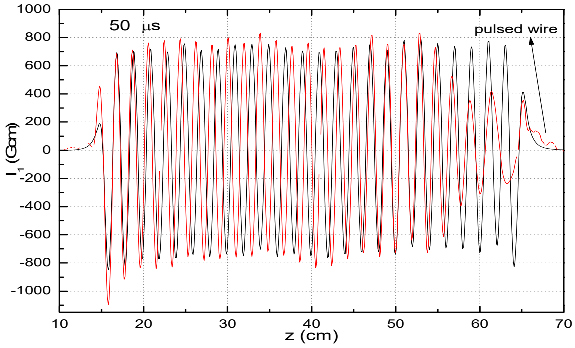

Figure 7: First field integral, 125 μm wire.

The phase error information is an important figure of merit of the undulator and is calculated from Eq. (3):

$$\phi(z)=\frac{2\pi}{\lambda}\left[\frac{z}{2\gamma^2}+\frac{\int(\frac{e}{\gamma mc}I_1)^2dz}{2}\right] \qquad (3)$$

The numerical value of the phase integral (second term in Eq. (3)) and the phase error is an indication of the quality of the undulator. The optical phase advance is shown in Fig. 8 for the Hall probe data and for the two wire measurements. The slope of the optical phase measured by the Hall probe is 24.8 radian per meter.

The pulsed wire probe measures the optical phase advance with a higher slope of 25.5 radian per meter and 27.6 radian per meter for the 250 μm and 125 μm wires respectively. The phase error is calculated from the Fig.8 by a linear fit and is shown in Fig. 9. The Hall probe measurement gives information for the full length of the undulator, whereas the dispersion limited phase growth length inside the undulator is 433 mm and 406 mm for the 250 μm and 125 μm wire diameter respectively. The phase error calculation from the Hall probe data is 2.73 degree where the value reads as 5.25 degree from the pulsed wire data with the 250 μm wire diameter wire and 4.24 degree for the 125 μm wire diameter. The phase error is minimum at optimum tension and gives higher phase error value both at before and after this value as seen in Fig. 10.

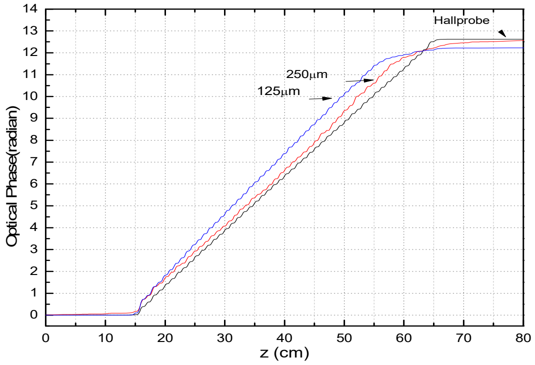

Figure 8: Optical phase advance in the undulator.

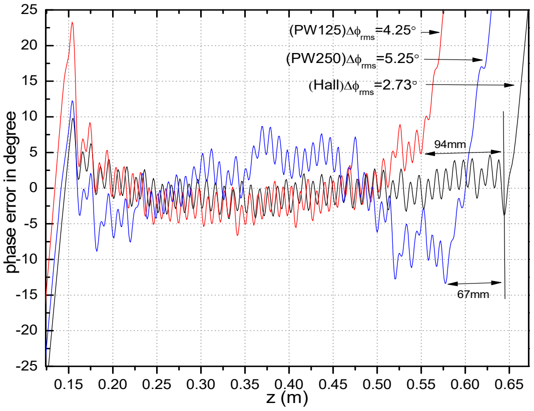

Figure 9: Phase error in degree.

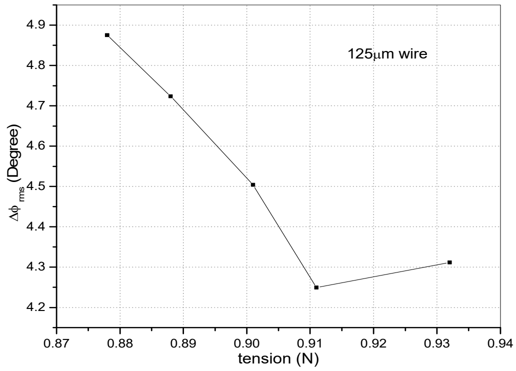

Figure 10: Phase error at the optimum tension.

ACKNOWLEDGEMENT

The work is supported through SERB Grant No. CRG/2022/001007.

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