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FIELD INTEGRAL MEASUREMENTS OF DAVV UNDULATORS AND FUTURE MEASUREMENT PLAN

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Abstract

The Insertion device development and Application (IddA) laboratory of Devi Ahilya University, Indore, India has ongoing activities on undulator design and development[1-3]. In this paper, we analyze the field integral properties of the two DAVV undulator. The first is the IddA U20 prototype NdFeB-cobalt steel hybrid in house designed device of 20 mm period length with twenty five periods. The uniform gap variable hybrid undulator provides magnetic flux density (in rms) from 2400 G to 500 G in the 10 mm-20 mm gap range. The second is the NdFeB based U50II undulator of 50 mm period length with 20 number of periods. Hall probe results are described. A short description of the measurement plan of the undulator on the pulsed wire bench and stretched wire bench is described.

INTRODUCTION

In the case of an undulator, the magnetic flux density.on axis is given by,

$$B_y = \hat{y} B_{peak} \sin(k_u z)$$

Where B_{peak} is the peak magnetic flux density. In case of hybrid undulator, it is given by

$$B_{peak}(T) = a \exp\left[b(g/\lambda_u) + c(g/\lambda_u)^2 \right] \quad (1)$$

where the a, b, c are the empirical coefficients of Eq. (1) and depend on the magnet–pole dimensions, material properties of the NdFeB or $SmCo_5$ magnets and the poles of the undulator. g, λ_u are the undulator gap and period length respectively. In the case of PPM undulator $c = 0, b = \pi$ Eq. (1) describes the field integral as,

$$I_1 = \int B_y dz \quad I_2 = \int \left(\int B_y dz \right) dz \quad (2)$$

Eq. (2) when multiplied by $(e/\gamma mc)$ gives the calculated angular deviation and trajectory offset of the electron respectively. A typical requirement for a good quality undulator is that the value of the measured field integral values should be less than the tolerance limit. A standard procedure to determine the field integrals is the Hall probe measurement. In this method, the field is mapped by the Hall probe point by point along the length of the undulator and the field is integrated by a numerical code over the length of the undulator.

HALL PROBE MEASUREMENT

The undulators specifications are described in Table.1 Fitting the Hall probe data for U20 hybrid undulator to Eq.(1) reads the field coefficients reads a =3.06, b = -5.59, c =1.123 (Fig. 1). The uniform gap variable hybrid undulator provides a magnetic flux density (in rms) from 2400 G to 500 G in the 10 mm-20 mm gap range. Fig. 2 describes the Hall probe data for the PPM undulator. A linear fit of the Hall probe data for reads a=1.62 and b=-3.24. The magnetic flux density for U50II undulator with variation in the gap range from 10 mm to 35 mm is 1 T to 0.1612 T. Fig. 3 and Fig. 4 are the Hall probe data field mapping for U20 and U50II undulator for the gap of 10 mm. Fig. 5 represents the magnetic field deviation(rms) for the both the undulators. In the operating gap of 10 to 20 mm, the deviation is in 60-140 G range for U50II undulator and 20-50 G for the U20 udulator.

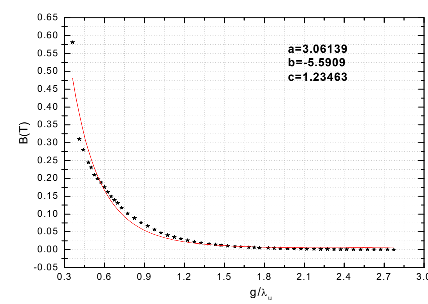

Figure 1: Linear fit to Hall probe data of U20 undulator.

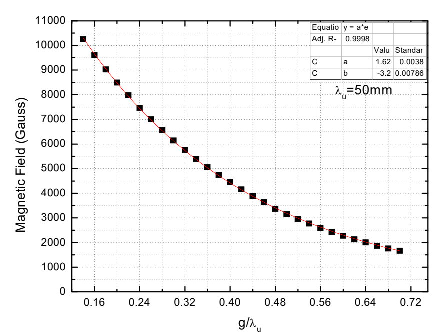

Figure 2: Linear fit to Hall probe data of U50II undulator.

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PULSED WIRE MEASUREMENT BENCH

The laboratory has developed[4] and upgraded[5] the pulsed wire bench for the field integral measurements. In this paper we describe the available parameters of the pulsed wire method. In a pulsed wire technique, a thin wire is used along the undulator axis.

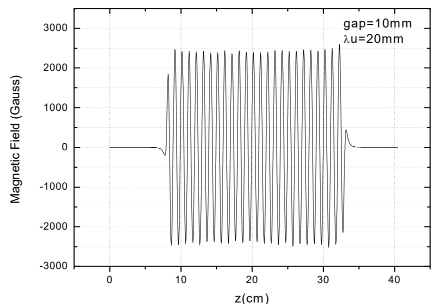

Figure 3: Measured magnetic field of U20.

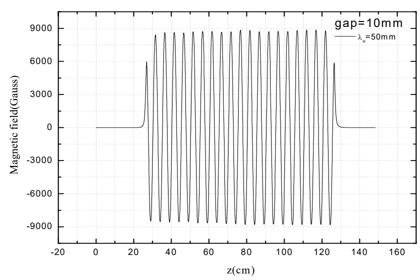

Figure 4: Measured magnetic field of U50.

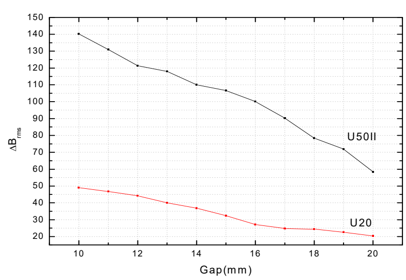

Figure 5: Variations in magnetic field of U50II undulator.

Table 1: Undulators Specification

U20	Undulator type	Hybrid
	Magnet material	NdFeB
	Pole material	Cobalt steel, M35
	Gap	Grade
	Magnetic flux	10-20 mm
	density	0.24-0.05 T
	No. of periods	25
	Period length	20 mm
U50II	Undulator type	PPM
	Magnet	NdFeB
	Period length	50 mm
	Number of periods	20
	Gap	10-35 mm
	Magnetic flux density	1T- 0.17 T

One end of the wire is fixed and the other end carries a load over a pulley. Both the ends of the wire is connected to a source of pulse current. A current pulse to the wire produces a force on the wire proportional to the undulator magnetic field. The transverse wire displacement propagates along the wire as a wave longitudinally along both the directions and is detected by a sensor located at the ends of the undulator. The wire displacement at the sensor is given by,

$$x(0,t) = -\frac{I_0 \Delta t}{2\upsilon\mu} I_1 \quad (3)$$

I_0 is the amplitude (amp) of the current pulse, υ is the velocity of the wave (m/sec) in the wire, Δt is the pulse width (sec), μ (kg/m) is the mass per unit length of the wire. Eq. (3) is evaluated by looking at the wire displacement when a current of short duration is applied to the wire. The short pulse width must satisfy

$$\upsilon \Delta t < \lambda_u \quad (4)$$

For U20, $\lambda_u = 0.02$ m , $\upsilon = 130.05$ m/sec, Eq. (4) requires a pulse width of $\Delta t <$ 153 µsec for the first field integral measurement. For U50, $\lambda_u = 0.05$ m, $\upsilon = 130.05$ m/sec, Eq. (4) requires a pulse width of $\Delta t < 384\mu$sec For $I_1 = 40\mu Tm$, $\mu = 4.04\times10^{-4} kgm^{-1}$, $I_0 = 12A$, Eq.(3) predicts a maximum wire displacement of $0.698\mu m$ and $1.754\mu m$ for the two undulators. The wire displacement at the sensor for the second field integral is given by for a longer pulse,

$$X(0,t) = -\frac{I_0}{2\upsilon^2 \mu} I_2 \quad (5)$$

The current pulse must satisfy

$$\upsilon \Delta t > N\lambda_u \quad (6)$$

For the U20 and U50-II, the pulse requirements calculated from Eq.(6) are 3.84 msec and 7.689 msec respectively. If $I_0 = 12A$ and $I_2 = 40\mu Tm^2$, wire of diameter $250\mu m$, $\mu = 4.04\times10^{-4} kgm^{-1}$ from Eq.(5) we get the minimum wire displacement as $3.54\mu m$. Table 2 describes the pulsed wire bench parameters for the DAVV undulator measurements.

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Table 2: Pulsed Wire Parameters

Pulse generator	0.2 µs-200 ms
Maximum current	~ up to 12 amp
Wire material	CuBe
Resistivity(ρ)	5.4x10^{-8} Ω m
mass per unit length(µ) 250µm- diameter	4.10×10^{-4} kg/m
µρ 250µm- diameter	2.2×10^{-11} kg Ω
Pulse width requirement	U20 1st integral- $\Delta t <$ 153 µs 2nd integral - $\Delta t <$ 3.84 ms
	U50II 1st integral- $\Delta t <$ 384 µs 2nd integral– $\Delta t <$ 7.689 ms
Sensor type	Laser -Photodiode
Sensitivity	8 mV/µm

STRETCHED WIRE MAGNETIC MEASUREMENT BENCH

A stretched wire bench has been developed at DAVV for magnetic measurement of the two undulators. The components of the system are assembled on a pneumatic vibration isolation table (Holmarc, India make, model No. TTNM 240-120) with honeycomb table top of width 200 mm. The table is 2400 mm in length and 1200 mm wide. Two units of X-Y translation stages are placed at two ends of the table. The distance between these two units is kept at 1860 mm. The translation stages (Holmarc, India make, model No. LMS-100-100) have a travel range of 50 mm, load capacity 15kg. 1 mm pitch and resolution 0.0025 mm each. The physical size of the translation stages measure 100 mm×100 mm. The translation stages are driven by stepper motor of Holmarc, India make, model no. 57SH51-4ASM. Motion controller of Holmarc, India make, model No. Ho-HPC-2H and used to interface the stages with the desktop computer system. Both the units of translation stages given a height 355 mm from the table top through which the wire hangs at a height of 275 mm from the table top. Both the units of translation stages sit on a labjeck to provide another height adjustment of 60 mm to 115 mm. Litz wire of 100 strands with overall size 1400 µm including enamel coating of the single wires is used for the measurements. The total length of the wire is 5 m. The wire tension plays an important role in controlling sag and thereby the accuracy of the measurement. A digital display unit at the load end reads the tension upto 50 Kg in three digits. Series connections of the 100 strands are made in a PCB located in a terminating box from where the output goes to the integrator through a low pass filter circuit. The input to output length of the wire measures a resistance of 1.13 ohm. The low pass filter circuit has a cutoff frequency of 10 Hz, $f_c = (0.5 * \pi * R_t * C_t)$. Two $15K\Omega$ resistors in series make $R_t = 30K\Omega$. Two capacitors of $1\mu f$ each joined in series makes $C_t = 0.5\mu f$. Keithley 2182 A nano voltmeter is used for the voltage integration. A Labview code is written to control the synchronous motion of the positioning stages and the integrator to record the voltage signal induced by the wire movement. The two field integrals are evaluated through,

$$\frac{1}{N\Delta x}\int_0^{\Delta t} V dt = I_1 \tag{7}$$

$$I_2 = \frac{L}{2}\left(\frac{-\int_0^{\Delta t} V dt}{N\Delta x} + I_1\right) \tag{8}$$

Eq. (7) and Eq. (8) gives the first field integral and second field integral from stretched wire method. Where N the no. of strands in the wire is, Δx is the movement of the wire, L is the length of the wire stretched along the undulator and V is the voltage produced in the wire. The first field integral measurement is completed for the U50II undulator and the stretched wire result is compared with Hall probe data in Fig. 6. for the different undulator gap from 10 mm to 20 mm. The result shows a good agreement between the two methods at wider gaps and differs by ~60 Gcm at 10 mm. To make a single measurement, the wire is moved in the forward direction by a certain quantity and then moved in the backward direction by the same quantity. The two integrated voltages are averaged and recorded. This procedure eliminates the integrator drift. The sampling distance of the measurement is 2.5 mm and the wire translation velocity is 3.125 mm/sec. The accuracy of the measurement is obtained for a five set of measurements and gives a value better than 2 G cm. The stretched wire measurement is compared with Hall probe results. Table3. describes the starched wire bench parameters.

Table 3: Stretch Wire Parameters

Wire	copper Litz
Number of strands	100
Diameter of single wire including coating	14 µm
Sampling step	2.5 mm
Displacement velocity	1.6 mm/sec
Total length of wire	5.187 m
Stretched Wire length (inside the undulator)	1.8 m
Tension	10.14 kg

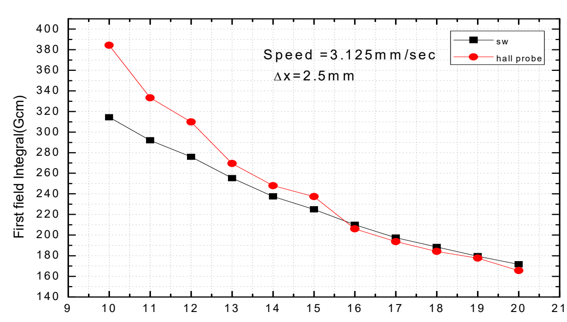

Figure 6: Comparison of first field integral for starched wire and Hall probe measurement.

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CONCLUSION

A stretched wire bench and pulsed wire bench has been developed for precision measurement of DAVV undulator system along with Hall probe measurement. A preliminary measurement of U50II in stretched wire bench gives good agreement with Hall probe data. The agreement with Hall probe data is 60 G cm-6 Gcm in the 10 to 20 mm gap

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