An overview of the undulator field measurement studies at insertion device lab, DAVV

1Mona Gehlot*, 1G Mishra, 1G Sharma, 2J Hussain.
1School of physics, DAVV, Indore, India.
2Department of Applied Physics, RGPV, Bhopal, India.
E-mail: mona_gehlot@yahoo.co.in

Abstract. This paper describes undulator field measurement procedures by hall probe and the pulsed wire method. The Hall probe method gives the direct field mapping and calculates the field integrals through double numerical integration. A pulsed wire magnetic measurement method is an optical method which has been independently developed by DAVV. It gives directly the field integrals and calculates the field mapping via a double numerical differentiation. The measurement methods are illustrated with field measurement of a six period PPM undulator and a third harmonic undulator.

1. Introduction
Wigglers/undulators are the most used insertion devices in applied physics research in synchrotron radiation and free electron laser science. The fundamental issue in the design of a planar undulator/wiggler is to produce a periodic magnetic field with a high peak field in a given period and given gap. The performance of a synchrotron radiation source or a free electron laser depends on undulator properties which depend on several parameters such as the gap mismatch along the undulator length, uniform periods, precise length and precise undulator parameter, mechanical arrangement, transverse misalignments, construction errors, radiation damage and its end field configuration. The fabrication of a permanent undulator/wiggler is therefore a complicated process that involves selecting individual magnets, assembling the magnets and testing & correcting the assembled undulator. It is therefore required to obtain precise values of the undulator field parameters by precise and accurate measurements of the undulator to assess their performances.

There are several magnet measurement systems to characterize the undulator magnet. The simplest procedure with a hall probe is to sample the magnetic field at many points along the undulator and numerically calculating the quantities of interest. There is a pulsed wire system which gives directly the the first and second field integrals of the undulator field. In this paper we review the working principles of the Hall probe [1] and pulsed wire method [2] and discuss the novel features of both the measurement procedures and relevant physical consequences of the measurements.

2. Measurement procedure of Hall probe Method
The measurement of field integrals is straightforward in Hall probe method. The method makes use of the Lorentz force equation to express the field integrals as,

\[ \int B_z(z')dz' = \frac{\gamma_0}{mc} \int B_z(z')dz' \]  \hspace{1cm} (1)

\[ \int \int B_z(z')dz' = \frac{\gamma_0}{mc} \int \int B_z(z')dz' \]  \hspace{1cm} (2)

Using a 1 D Hall Probe mounted on a three axis bench one builds up the magnetic field profile. In the standard practice, the Hall probe is moved continuously in steps for taking longitudinal
measurements. The two field integrals are obtained from this data by a simple FORTRAN code using trapezoidal rule.

In terms of the practical parameters, \( e/mc = 0.058 \times 10^4 \, 1/T - m \). The calculation of the field integrals when multiplied by this factor gives the electron trajectory. The second field integral data in Eq. (2) in terms of the practical parameter can be converted to electron trajectory,

\[
x_m(z) = \frac{0.3}{E(Gev)} \int_0^z \int_0^z B_u(z')dz'
\]

(3)

3. Measurement procedure of Pulsed Wire Method

The pulsed-wire technique is an alternate magnetic field measurement method for small gap undulators. In the pulsed wire method, a thin wire is stretched along the undulator axis. Under the combined action of the current and magnetic field, mechanical vibrations are generated which propagate along the wire. The transverse motion equation of the traveling acoustic wave in the wire is given by

\[
\frac{\partial^2 x}{\partial z^2} - \frac{1}{u^2} \frac{\partial^2 x}{\partial t^2} = -\frac{B_u(z)i(t)}{T}
\]

(4)

Where \( x \) is the displacement, \( i(t) \) is the current in the wire at time \( t \), \( B_u(z) \) is the undulator magnetic field at \( z \), \( T \) is the wire tension, the wave velocity \( u \) is given by

\[
u = \sqrt{\frac{T}{\mu}}
\]

(5)

\( \mu \) is the mass per unit length of the wire. For a short current pulse, the wire displacement at sensor location is given by

\[
x'(t) = -\frac{i_o \Delta t}{2\mu u} \int_0^z B_u(z')dz'
\]

(6)

\( i_o \) is the peak pulse current, \( \Delta t \) is the current pulse width. For a longer pulse, the wire displacement is given by

\[
x''(t) = -\frac{i_o}{2\mu u^2} \int_0^z dz'' \int_0^z B_u(z')dz'
\]

(7)

Eqs. (7) and (8) gives the first integral and second integral of the undulator field strength respectively and can be determined at appropriate pulse widths.

An oscilloscope connected to the sensor reads the wire displacements in volts versus time. The output voltage can be translated into wire displacement by a calibration factor. To construct the calibration curve, measure the output voltage without applying current to the wire while the wire is moved over the laser output path typically in steps of 10\( \mu m \). From the output voltage versus position, identify a region where the output voltage is linear with the wire position and the slope of the calibration curve gives the sensitivity in volts versus wire displacement. This provides a suitable factor to express the wire displacement from the oscilloscope output in voltage. By determining the calibration factor helps to determine the second field integral as,

\[
\int_0^z dz'' \int_0^z B_u(z')dz' = x''(z) \frac{2\mu u^2}{i_o}
\]

(9)

And with a similar procedure one calculates the first field integral. The second field integral can be differentiated to find the magnetic field profile.

4. A pulsed wire Measurement system at DAVV: The entire magnetic field measurement system [3] for the pulsed wire method. The optical sensor is the key component of the pulsed wire measurement system. In this set up each laser-photodiode pair is mounted on translation stages. The laser, the wire and the photodiode are aligned to obtain approximately one half of the nominal voltage from the laser. A suitable sensitivity factor for a given wire diameter is chosen for best
optimum results. The sensitivity of the optical sensor is defined by the voltage recorded in the oscilloscope with the wire displacement across the laser output.

![Figure 1 An optical sensor at DAVV](image1)

Figure 1 An optical sensor at DAVV

![Figure 2 Hall probe data for magnetic field profile](image2)

Figure 2 Hall probe data for magnetic field profile

The sensor of the pulsed wire set up at DAVV as shown in Figure 1 is an orthogonal pair of laser and photo diode movable on a rail. It consists of coherent’s ULN series diode laser model No. 31 - 0144 - 000 modules for the laser which gives 5 mW power at 635 nm. The detector for the system is Newport’s silicon biased detector model no. 818-BB-21. It has both rise time and fall time < 300 ps and responsivity at 830 nm is 0.4 mA/W.

5. Example

To illustrate the integral measurement procedures consider a typical magnetic profile of a six period undulator measured with the help of a Hall probe and represented in Figure 2.

One period of the undulator is 5 cm. The undulator is of PPM type with six periods. The first and second field integrals are obtained when integrated the data of the Figure 2 and represented in Figure 3a),b) respectively. The field integrals in the pulsed wire method are determined by the use of appropriate pulse widths.

![Figure 3. first field (a) and second field integral (b) data from magnetic field profile.](image3)

Figure 3. first field (a) and second field integral (b) data from magnetic field profile.

A typical output of a oscilloscope connected with the PWM gives the data for the second field integral with a pulse width of 4.32 ms in Figure 4. When this data is differentiated twice with above algorithm, the magnetic field profile of the undulator is reproduced in Fig 5.

6. Third harmonic undulator: We use CRGO shims for third harmonic undulator [4] of 1.5 mm × 9.0 mm × 28 mm in thickness, height and length respectively. We placed shims at each joints of magnets in every period as shown in figure (6). The distance between the centres of the two shim groups is 12.5 mm.
The substrate thickness is 2.0 mm. Figure (7) gives the hall probe measurement of the magnetic field of the modified undulator. The measurements are done at shims gaps of 7.0 mm. By shim gap we mean the spacing between the shims that are placed opposite to each other. Figure (8) shows the modification ratio of computed by Fourier transforming the measured field profile. The third harmonic component with a shim gap of 7.0 mm is ≈18% of the fundamental where as the fifth harmonic is ≈9% of the fundamental.

5. Conclusions

We have discussed undulator field measurement procedures, numerical algorithms for the pulsed wire set up at DAVV. The results of the measurement of a six period undulator are presented in this set up. Lists of error sources are identified. The results show that the pulsed wire parameters are required to be optimized for matching the results with the hall probe data. The third harmonic undulator is very well characterised.

References
1. R. S. Popovich, 9th International Magnetic measurement workshop, CEA/Saclay, June, 1995.
2. R.W. Warren, Nuclear Instruments and Methods in Physics Research A 272(1988), p-257.
3. Sumit Tripathi, Mona Gehlot, Jeeva Khan Hussain, G.Mishra, Sanjay Chouksey, Vinit Kumar, Umesh Kale, Pravin Nerpagar, IL Nuovo Cimento, B, Vol.124, No.3, 2009.
4. Nakao Naoya et.al, Jpn. J. App. Phy. vol 37(1998).