Design and fabrication of wire displacement sensors for undulator field measurement applications

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Abstract : In this paper, we describe the design and working principle of two wire displacement measuring sensors. The two sensors are used in a pulsed wire setup for undulator magnetic field measurements. First one is optocoupler sensor consists of a LED - phototransistor pair and the other one is a laser sensor of laser photodiode pair. Both the sensors work on the principle of light interruption and gives comparative results in our experimental setup.

1. Introduction
The magnetic measurement of the 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 [1-5] was suggested as an alternate method for field integral measurements. In this method, a thin wire is stretched along the undulator axis. When a dc current flows in the wire, a Lorentz force proportional to the local transverse field component is exerted on the wire. The Lorentz force makes the wire to vibrate. These vibrations are picked up by a sensor located at the end of the undulator. The sensor output versus time is the field integral versus position along the wire. In this paper we describe technical design details of two types of sensor used in the pulsed wire setup. One is the optocoupler and the other one is the laser-Photodiode detector pair. We describe the design details, calibration of the sensor. We used these sensors to pulsed wire measurements on our 30 cm long PPM undulator.

Fig 1. Optocoupler detection system
2. Design and working principle

The optocoupler sensor is a Motorola make Model No is MOC7811. The optocoupler sensor consists of an infrared LED and a phototransistor which are molded in a plastic housing. The mount assembly consists of two circular rings. The outer diameter of the outer ring is 85 mm and the outer diameter of the inner ring is of 60 mm. The outer ring is marked. The inner ring can be rotated inside the outer ring. The optical switch is fixed on the inner ring. The rotation of the inner ring allows the optical switch to measure both the horizontal and vertical field integral data. There is a slot of 12 mm width for removing and inserting the wire. The schematic and the photograph of complete installation of the system are shown in figure 1. The mount assembly is attached to a post of 12 mm diameter and 58 mm in length and is mounted on a rail through xyz translation stages. The rail allows the switch to be fixed at minimum distance of 148 mm and maximum of 560 mm distance from the undulator end. The xyz stages give vertical, horizontal and height alignments to the switch. The optocoupler works on the principle of current flowing in the circuit by photo illuminated transistor and the principle of operation is represented by [2],

\[ V_{CE} = V_{CC} - I_{Q} R \]  

When the wire blocks the LED light path, no light falls on the photo transistor and the current flowing is zero i.e \( I_{CE} = 0 \) and \( V_{CC} = V_{CE} \). \( V_{CC} \) is the supply voltage so voltage recorded is maximum when the light path is interrupted. As the wire moves away from the center, the light path is opened up and allows the light to fall on the photo transistor. A current flows and reduces the recorded voltage. The voltage versus distance curve for the optocoupler is shown in figure 3a. The slope of the curve is the sensitivity of the sensor. The sensitivity of the two output curves are calculated in the linear portion of the curve and is 8 mV/µm (250 µm wire) and 6 mV/µm (125 µm wire) respectively.

![Fig 2. Laser-photodiode detection system](image)

A laser-photodiode sensor is used as a detector at the other end of the undulator. The 5 mW, 635 nm laser is Coherent’s Ultra Low Noise series diode laser Model No. 31-0144-000 module. The rms noise typically \( \approx 0.06 \% \). The laser spot size is 1mm. The laser is fixed on a laser mount vertical facing downwards through xyz stages. The xyz stages gives a movement of 5 mm each in upward, downward and forward direction. The photodiode for the system is Newport, USA make silicon detector Model No.818-BB-21. The 818-BB-21 High Speed silicon photo detector operates from 300 nm to 1100 nm with a 0.40 mm active diameter and has rise time less than 300 ps. It is connected to Tektronix TDS2024B, 4 channel, 200 MHz digital storage oscilloscope through a 50 ohm BNC connector output. The schematic of principle of laser - photodiode sensor and laser mount assembly is seen in figure 2. The laser – photodiode detector
works on the principle of interception of a Gaussian distribution of intensity. The un-interrupted light through a wire is given by [3],

\[
P(x) = \frac{2P}{\pi w^2} \left[ \int_{-w}^{w} \int_{-\infty}^{\infty} 2e^{-\frac{x^2 + y^2}{w^2}} \, dx \, dy \right]
\]

where \( r_w \) is the wire diameter and \( w \) is the laser beam spot size. When the wire is located at the center of the laser beam, the power not blocked by the wire is minimum. It is seen that from figure 3b, that the minimum voltage occurs when the wire completely blocks the laser light. At the center, the intensity of the laser is maximum, the interrupted light is maximum hence this corresponds to minimum voltage. As the wire moves away from the center, more and more light falls on the photodiode and the output voltage rises. The laser used has a spot size of 1000\( \mu \)m. A number of pinhole diameter was used to reduce the beam spot size and the pinhole diameter of 300 \( \mu \)m is placed to reduce the laser spot and gives a sensitivity same as that of the optocoupler. Thus sensitivity of the laser-photodiode with the 300\( \mu \)m pinhole is 8 mV/\( \mu \)m (250 \( \mu \)m wire) and 6 mV/\( \mu \)m (125 \( \mu \)m wire) respectively.

![Fig 3a. Calibration curve for a) optocoupler sensor b) laser photodiode sensor](image_url)

**3. Measurement results and discussion**

The experimental results of pulsed wire method on 30cm planar undulator. The measurements are taken by both the sensors located at 148 mm away from the end of the undulator and results are compared with the hall probe results. The CuBe wire is fixed at one end and the other end of the wire hangs over a pulley with a weight. The pulsed wire bench is set on the same vibration isolation support [2]. Two CuBe wire having diameter of 250 \( \mu \)m with \( \mu = 4.1 \times 10^{-4} \) kg/m and 125 \( \mu \)m with \( \mu = 1.01 \times 10^{-4} \) kg/m is installed for magnetic measurements. The wire length is 1.39 meter, which is more than four times the length 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 250 \( \mu \)m and 125 \( \mu \)m respectively. The first and second field integral in the pulsed wire method is measured by an appropriate pulse width [4]. Figure 4a and figure 4b shows the comparison of the second field integral and magnetic field obtained by pulsed wire method and hall probe method for wire diameter 250\( \mu \)m. Similarly, figure 4c and 4d shows the same for wire diameter 125\( \mu \)m. Figure 5 shows the \( \Delta B_{rms} \) versus tension for gap 24mm, 27mm and 30 mm respectively from both the laser sensor and optocoupler sensor, where \( \Delta B_{rms} \) is the deviation in magnetic field from the hall probe data. It is clear that for wire diameter 250\( \mu \)m as we increase the undulator gap the result discrepancies from both the sensors also increased, while this is not seen for wire diameter 125\( \mu \)m. Possible reason may be the stiffness and thickness of the wire affect the results at higher gap because at higher gap undulator magnetic field decreases.

In conclusion wire displacement sensors are successfully designed and fabricated for undulator field measurement application by pulsed wire method. To ensure the reliability and repeatability of the results,
two wires of different diameters are used. The results prove that the laser sensor and the optocoupler works on different principles of light interception, however gives equal results at equal sensitivities.

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