MEASUREMENTS OF SOLEIL INSERTION DEVICES USING PULSED WIRE METHOD

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Abstract

SOLEIL permanent magnets insertion devices are usually measured with a Hall probe in order to evaluate the electron angular deflection, their deviation and the optical phase error [1]. A pulsed wire bench is developed at SOLEIL for reducing the measurement time of an undulator and for providing a measurement method without lateral access. A current pulse injected in a stretched wire inside the magnetic field area generates an acoustic wave. The wire motion is detected by optical sensors whose signals are proportional to the local integral value. The signal-to-noise ratio of this method is often reduced due to several effects such as acoustic noises, external and wire vibrations. However, following some hardware optimization it was possible to increase it up to almost 26 dB, making the method accurate and reproducible in order to realize efficient corrections. Measurements of first and second field integral performed with pulsed wire and Hall probe are compared on two different types of insertions: an $HU60$ APPLE-II undulator and a $WSV50$ in vacuum wiggler [2].

INTRODUCTION

SOLEIL storage ring is equipped of 20 permanent magnets undulators of various kinds [3] (12 APPLE II, 7 planar in-vacuum and 1 in-vacuum wiggler) with a period ranging from 18 mm to 80 mm. Some can also provide elliptical or quasi-periodic field with a magnetic length varying from 1.6 m to 2 m. Measuring the magnetic field point by point with Hall probe is necessary to evaluate the trajectory of the electron and the optical performances as phase errors, but is time-consumming even if it may be one of the most accurate and reliable methods. The pulsed wire method has been developed in 1988 [4] as an alternative technique to characterize narrow gaps or lateral accessless insertion devices. The advantage of this method is to measure in few ms the first or second field integral of an undulator reducing the time to correct magnetic field errors. However, it suffers from various effects which tends to add noise and distortions to the main signal. Figure 1 shows the set-up of the bench consisting in a thin wire stretched along the magnetic axis of the insertion device. A current pulse excites acoustic waves, generated by Laplace forces, which travel at both extremities. Optical sensors measure the wire transverse and vertical deflection which permits to calculate the first or second field integral point by point. Sending a pulse shorter than the time spent by the wave to propagate along a single period of the insertion enables to measure the angular deflection according to Equation (1) (resp. Equation (2)) in the vertical (resp. horizontal) plane [4].

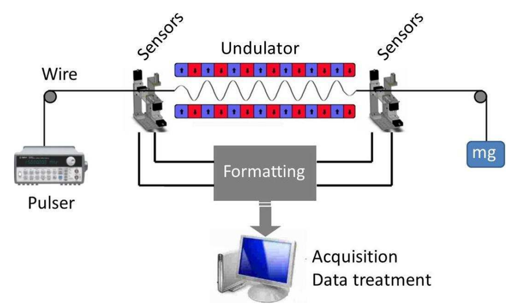

Figure 1: Set-up of the pulsed wire bench.

$$z(t) = -\frac{I_0\,\Delta_t}{2\mu c}\int_0^{ct} B_x(s)\,ds \quad (1)$$

$$x(t) = -\frac{I_0\,\Delta_t}{2\mu c}\int_0^{ct} B_z(s)\,ds \quad (2)$$

with I_0 and Δ_t the intensity and duration of the pulse, μ the wire linear mass density, c the wave speed, B_x (resp B_z) the horizontal (resp. vertical) magnetic field. The second integral, obtained by injecting a pulse longer than the time spent by the wave to propagate along all the insertion device is given by equation (3) (resp. equation (4)) in the vertical (resp. horizontal) plane [4]. This quantity represents the electron beam path along the insertion device.

$$z(t) = -\frac{I_0}{2\mu c^2}\int\int B_x(s)\,ds\,ds' \quad (3)$$

$$x(t) = -\frac{I_0}{2\mu c^2}\int\int B_z(s)\,ds\,ds' \quad (4)$$

THE PULSED WIRE MEASUREMENT BENCH AT SOLEIL

Signal to Noise Ratio Improvements

Even if the major drawback of the pulsed wire method is the low signal to noise ratio, the set-up developed at SOLEIL aims at avoiding the averaging of the measurements. For this purpose each source of noise has first been

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reduced. The use of granite table to support the wire and detectors reduces ground vibrations. The wire vibrates at its resonant frequency, proportional to the length and mechanical strength applied on it, using some oil [5] at both extremities reduces the amplitude of this natural vibration from few %. Electrical and optical noise are lowered by increasing the calibration coefficient of the sensors. The second step was to improve the wire deflection. Care was taken in the wire choice in order to ensure a low resistivity (more current) and linear mass density (maximal deflection), according to Equations (1) to (4). Efforts were made in order to increase the pulse current value, keeping in mind no to heat too much the wire during long pulse. These efforts have led to an increase of the signal-to-noise ratio from 12 dB to 26 dB.

The Wire

A 7 m long 125 μm diameter tungsten wire has been selected. The wire is stretched at 11 N so that the sag (given by equation (5)) in the middle of the undulator is smaller than the radius of the wire. A numerical correction is applied to reconstruct the field on axis, even if the sag is very small in comparison with the insertion devices minimal gap value (5.5 mm for SOLEIL in-vacuum undulators).

$$\Delta_z(s) = \frac{g\,\mu}{2\,T}\,s(s-L) \qquad (5)$$

with $\Delta_z(s)$ the sag value along the longitudinal position s, g the acceleration of gravity, L the magnetic length of the insertion device and T the mechanical strength applied on the wire. It is supported by a set of $X-Y$ stages for a precise alignment on the magnetic axis. The mechanical strength is controlled by a motorized actuator.

The Detection System

The bench (see Figure 2) is composed of one detector at both sides of the undulator. Each detector consists in an horizontal and a vertical optical sensor ($BPX65RT$ from Centronix). They are based on a laser diode focused on the wire in front of a photodiode which measures the variation of light due to the shadow of the wire.

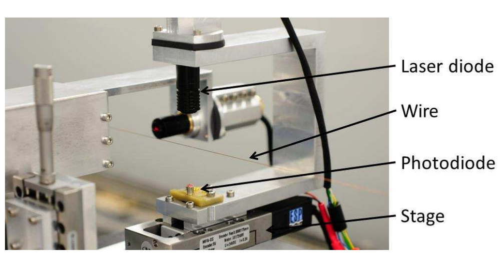

Figure 2: A detector composed of a vertical and horizontal sensor, based on a laser diode coupled with a photodiode.

The photodiode generates a current injected in an homemade electronic card whose functions are to convert it into voltage, amplify and offset it in order to adjust it to the proper range of the data acquisition card. A motorized stage enables to measure a calibration curve to convert the variation of light measured by the photodiode in a variation of position as shown in Figure 3. Setting the sensor in the linear range of this one enables to obtain a voltage proportional with the wire deflection.

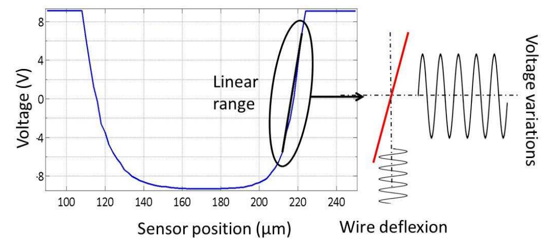

Figure 3: Voltage from a sensor according to its position while crossing the wire.

The slope of the calibration curve, here 1.25 V per μm deflection enables to lower the electrical or optical noise against the main signal. Sensors also have to be fast enough to obtain a good spatial resolution.

The Pulser

An homemade pulse power supply adapted to the pulsed wire method has been developed. It can inject in the wire a pulse from 5 μs with a maximal amplitude of 5 A. A capacitor is charged under 300 V. A waveform generator sends a signal on four power transistors which conduce by pairs in order to generate a positive, negative pulse or a combination of both.The signal to noise ratio of the measurement has been increased due to the use of this power supply. No lack of current is visible during long pulses due to its high speed regulation, whereas rise and fall times ($<\ 2\ \mu s$) are mainly governed by the wire inductance. This power supply has been developed to measure first and second integral and try to observe the magnetic field by injecting a short positive and negative pulse.

PULSED WIRE MEASUREMENTS

The pulsed wire method has been used to characterize the undulators with parameters listed in Table 1.

Table 1: Insertion Device Parameters

ID	Period [mm]	Nb.	H. field [T]	V. field [T]
HU60	60	28	0.6	0.5
WSV50	50	36	2.1	≈ 0

Elliptical Polarized Undulator $HU60$

This kind of undulator is interesting for pulsed wire measurements due to its adjustable phase [7][8]. Girders which supports permanent magnets can move longitudinally to produce horizontal field by a half of period shift or elliptical one with quarter period shift and vertical field naturally. The minimum magnetic gap is fixed at $15.5\ mm$, for providing field values of Table 1.

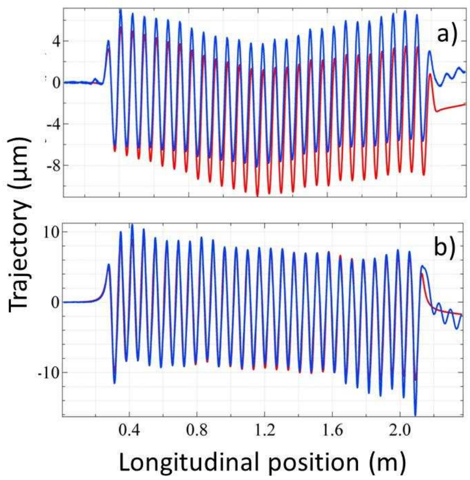

Figure 4: Measurements of the $HU60$ undulator in linear horizontal mode (a) and linear vertical (b). Hall probe in red line, pulsed wire in blue. Pulse time duration fixed at $10\ ms$ with an amplitude of $1\ A$.

Figure 4 shows the trajectory of the electron beam measured with the pulsed wire method in comparison with Hall probe measurements in an elliptical field configuration. The acquisition is made on a vertical and an horizontal sensor at the same time, while the wire vibrates in both planes. Both trajectories have the same shape even if pulsed wire measurements are noisier. The major difference is that entrance angle is different and some spurious distortions are visible after the main signal from pulsed wire measurements. This effect may be due to the wire imperfections and can be slightly reduced by increasing the mechanical strength applied on the wire [6]. These parameters enable to maximize the wire deflection without going out of the linear range of the sensors. The pulsed wire measurement is available in less than half a second whereas it takes 200 times more for an Hall probe one. The reproducity is less than a μm on the trajectory, comparable with the Hall probe characteristics.

In-vacuum Wiggler $WSV50$

The magnetic forces of this planar wiggler are so consequent ($\approx 9\ tons$ at the minimal gap $5.5\ mm$) that this insertion device has been developed with compensation springs to avoid the carriage to be damaged [2]. Pulsed wire method was the more adapted to measure this wiggler because the lateral access was reduced due to the springs. Hall probe measurements can only be done from $10\ mm$ gap where the magnetic field value is close to $1\ T$, magnetic strength are largely reduced in comparison with the minimum gap.

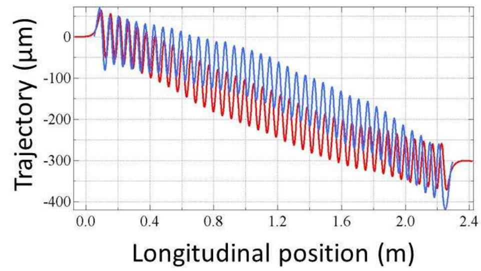

Figure 5: Measurements of the $WSV50$ undulator. Hall probe measurements in red line, pulsed wire in blue. Pulse time duration fixed at $10\ ms$ with an amplitude of $0.2\ A$.

Figure 5 shows the trajectory of the electron beam measured with the pulsed wire method in comparison with Hall probe measurements at gap $10\ mm$. The exit point is the same but the global shape of the trajectory measured with pulsed wire method has parabolic distortion in the middle which may be an effect due to the sag which was at this time larger than the one expressed before.

CONCLUSION

First and second field integral with the pulsed wire measurement bench are obtained without averaging in less than a second. We improved the wire deflection and optimized the signal from the sensors, keeping in mind to minimize the effect of each source of noise. This leads to a reliable and accurate method for first and second integral measurements, tested on different SOLEIL insertion devices.

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