THE STUDY OF ERRORS OF ALBA FIXED STRETCHED WIRE BENCH

Jordi Marcos*, Josep Campmany, Dieter Einfeld
CELLS, P.O. Box 68, 08193, Bellaterra, Catalonia, Spain

Abstract

The new synchrotron radiation source ALBA to be built nearby Barcelona is planned to start operation in 2009. The facility includes a laboratory for magnetic measurements devoted to Insertion Devices (IDs). The foreseen measurement benches include a fixed stretched wire bench aimed to characterise the inhomogeneities of magnet blocks and hence to assist the in-house building of IDs. The design of the system is based both on the ESRF/SOLEIL and BESSY previously existing designs. In this paper we present an exhaustive analysis of error sources and tolerance requirements for that particular design.

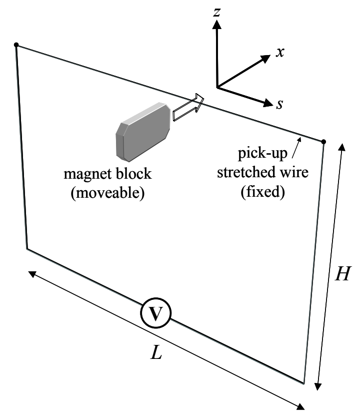

Figure 1: Sketch of a fixed stretched wire system.

INTRODUCTION

The stretched wire measurement technique is widely used to obtain magnetic field integrals [1, 2]. This technique is based upon the displacement of a stretched wire relative to the magnetic structure to be measured. In the most usual configuration, the magnets are kept fixed while the wire is moved. This arrangement is especially well suited for measuring big structures such as full undulators or their jaws. In contrast, in the fixed stretched wire configuration, the magnetic structure is moved relative to a stationary pick-up coil with a straight segment. This layout is convenient for the measurement of small units, such as individual magnet blocks or magnetic modules. These measurements allow characterising the inhomogeneities of the building blocks of an undulator. This information is stored in a database and used thereafter to cancel out the residual field integrals of the device to be built.

THEORETICAL BACKGROUND

A schematic drawing of a fixed stretched wire experimental set-up is shown in Fig. 1. Consider that the pick-up coil has N turns and that the measuring straight segment has a length L. Consider also that the return loop of the coil is far away enough from the magnet block to be measured so that it can be assumed that the magnetic field at the location of the return loop is zero. If the magnet block is displaced by a small horizontal distance δx or, alternatively, if the pick-up coil is displaced by a distance $-\delta x$, then the change in the magnetic flux through the stretched wire is given by

$$\delta\Phi = \int_{-L/2}^{L/2}\int_{x+\delta x/2}^{x-\delta x/2} B_z(x', z, s)\,\mathrm{d}x'\mathrm{d}s \approx -\delta x\, I_z(x,z)\,, \tag{1}$$

where $I_z(x,z)$ is the vertical field integral along the longitudinal (s) direction calculated at the transverse position (x,z). In the case that the displacement of the wire has both a horizontal (δx) and a vertical (δz) component, the magnetic flux change is given by,

$$\delta\Phi = -\delta x\, I_z(x,z) - \delta z\, I_x(x,z)\,, \tag{2}$$

where I_x is the horizontal field integral. The instantaneous voltage induced in the coil is given by Faraday's law

$$V(t) = -N\tfrac{\delta\Phi}{\delta t} = N\left[v_x(t)\, I_z(x,z) + v_z(t)\, I_x(x,z)\right]\,, \tag{3}$$

being v_x and v_z the horizontal and vertical components of the velocity of the magnet block relative to the stretched wire, respectively. Therefore, the vertical component of the field integral can be measured by moving the magnet block horizontally,

$$I_z = \frac{V(t)}{N\, v_x(t)} = \frac{V(t)}{S}\,, \tag{4}$$

where $S = N\, v_x$ is the sensitivity of the experiment.

Usually one is interested in scanning the field integrals along the horizontal direction at a fixed vertical distance —equal to half the minimum gap setting of the undulator being built— in order to determine the magnetic multipoles generated by each block. However, the direct measurement of the vertical (normal) and horizontal (skew) components of the field integral requires the ability of moving the magnet blocks along both the x and z directions. In order to simplify the experimental setup, one can restrict to movements of the block along the horizontal direction and compute numerically the horizontal component making use of the dispersion relation [1]

$$I_x = -\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{I_z(x',z)}{x'-x}\mathrm{d}x'\,. \tag{5}$$

* jmarcos@cells.es

OPTIMISATION OF PARAMETERS

Modelling of the experiment

In order to reproduce the results of a hypothetical experiment, we have taken as a reference a magnet block with dimensions $50\,\text{mm} \times 15.75\,\text{mm} \times 5.25\,\text{mm}$ and 5 mm–depth $45°$ chamfered corners (corresponding to the 21 mm–period in-vacuum undulator being designed at ALBA). The used magnetic material has been Sm_2Co_{17} with remanent field $B_r = 1.05\,\text{T}$. It has been considered that the block is magnetised along the longitudinal (s) direction with a small misalignment characterised by polar and azimuthal angles θ and ϕ, respectively. The calculation of the field integrals generated by such a block at different transversal positions (x, z) have been performed using RADIA code [3].

To simulate the signal generated by the reference block on the pick-up coil, we have assumed that it is moved along the x-direction with a uniform velocity v_x ("on-the-fly" measurement mode). At this stage, if one is interested in analysing the effect of mechanical vibrations, some noise can be added along both x and z directions [$v_x^{\text{vib}}(t)$ and $v_z^{\text{vib}}(t)$]. However, due to space reasons, the effect of vibrations will not be considered in this study.

From the time dependence of the velocity, $v_x(t)$ and $v_z(t)$, and the field integral values calculated using RADIA, $I_z\,[x(t), z(t)]$ and $I_x\,[x(t), z(t)]$, the instantaneous generated voltage $V(t)$ is calculated using Eq. (3).

The instantaneous voltage is then integrated over the selected integration window of the voltmeter, τ, to simulate the data acquisition process. An integration is performed every $\delta t = \delta x / v_x$ seconds, where δx is the selected sampling step. Obviously, the relationship $\delta t \geq \tau$ must hold.

In order to simulate the effect of electrical noise on the measurement, a random number with a *rms* value V_{rms} is generated and added to the integrated voltage. The magnitude of this noise is usually provided by the manufacturer of the voltmenter, and depends on the width of the integration window.

The vertical field integral (I_z) at each step is derived from the simulated voltage using Eq. (4). Finally, the horizontal component of the field integral (I_x) is computed numerically using Eq. (5). The error in the determined field integrals, σ_{I_z} and σ_{I_x}, has been characterised by the *rms* difference between the simulated values and the original values provided by RADIA at the same positions over a certain horizontal range d. Finally, the global error associated to this simulated measurement has been defined as $\sigma_I = \sqrt{{\sigma_{I_z}}^2 + {\sigma_{I_x}}^2}$. This *intrinsic error* of the system takes into account the effect of the finite sampling, the electric noise inherent to the operation of the voltmeter and, if included, the mechanical vibrations.

Acquisition system

For the acquisition system we have adopted a $N = 10$ multiturn coil and a Keithley-2010 digital multimeter with $7\frac{1}{2}$-digits. According to the specifications of the instrument [4], an optimum performance is obtained for an integration time $20\,\text{ms} < \tau < 100\,\text{ms}$, with an associated measuring noise $V_{\text{rms}} \sim 1\,\mu\text{V}$. For this instrument the minimum dead-time between consecutive readings is $t_{\text{dead}} < 8\,\text{ms}$. Therefore, given an integration window τ, we have taken for the time step between measurements $\delta t = \tau + 8\,\text{ms}$.

Optimisation of v_x and τ

The errors in the obtained field integrals have been calculated as a function of τ and v_x. The reference block has a magnetisation misalignment characterised by $\theta = 1°$ and $\phi = 45°$. For each measurement the block was displaced over a distance Δx equal to 4 times its width ($\Delta x = 200\,\text{mm}$), and the *rms* error in the field integrals have been evaluated over a range d equal to 2 times its width ($d = 100\,\text{mm}$).

For each value of τ, it exists an optimum value of v_x where a compromise between the sensitivity (i.e. the level of the generated signal) and the sampling errors is achieved: the smaller the integration window, the higher the optimum velocity. Figure 2 shows the dependence of σ_I to the optimum value of v_x for each integration window. The optimum operation parameters, leading to an intrinsic error of $\sigma_I \sim 0.5\,\text{G·cm}$, are summarised in Table 1.

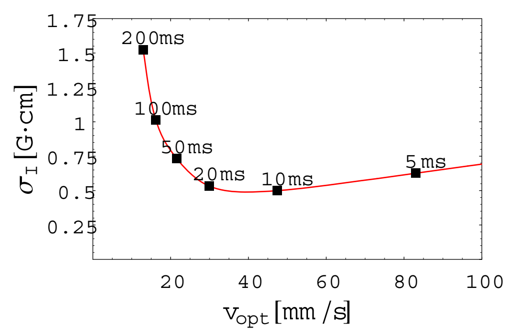

Figure 2: Dependence of the *rms* error in the determination of the field integrals (σ_I) to the optimum velocity (v_x) for different values of the integration window (τ), corresponding to a fixed stretched wire with $N = 10$.

Table 1: Optimum working parameters of a $N = 10$ fixed stretched wire.

Integration window	τ	10 ms
Displacement velocity	v_x	40 mm/s
Sampling step	δx	0.7 mm
Sensitivity	S	$0.4\,\mu$V/(G·cm)
Intrinsic error	σ_I	0.5 G·cm

Dimensions of the pick-up coil: L and H

In the previous calculations it has been assumed that the stretched wire is infinitely long along the s-direction and that the return loop is not affected by the movement of the magnet block (infinite-coil approximation). The minimum dimensions of the coil (length L and height H) needed in order to this approximation to be good enough have been determined. In order to determine the effect of the finite size of the coil, the output for several pairs of (L, H) values have been compared with the ideal infinite-coil approximation. It has been determined that for dimensions of the coil $L > 800$ mm and $H > 800$ mm the finite-size error is $\sigma_I^{\text{finite}} \lesssim 0.02$ G·cm, well below the intrinsic error associated to electric noise and sampling.

Scanned range: Δx

The accuracy in the calculation of the field integrals does not depend only on the size of the sampling step, δx, but it is also affected by the extent of the scanned range, Δx: i.e. in addition to the sampling error it exists a truncation error which depends on the ratio $\Delta x/d$. We have determined that for $\Delta x \gtrsim 2\,d$ the truncation error becomes negligible compared with the intrinsic error.

Space between blocks: D

If several blocks have to be measured in a single passage of the support table through the pick-up coil (the so-called "petit-train" mode), the distance between them, D, has to be large enough so as to no mutual influences exist. If w is the width of the blocks, a separation of $D \gtrsim 6\,w$ between their centres is enough to get rid of mutual influences.

DETERMINATION OF TOLERANCES

Alignment of the stretched wire

Any misalignment of the measuring stretched wire relative to the direction of motion of the block will change the component of the magnetic field that is integrated and/or will change the direction along which the magnetic field is integrated. Figure 3 illustrates the decomposition of the misalignment of the wire into two components α and β: the angles between the s-axis and the projections of the wire on the horizontal s–x plane and the vertical z–s plane, respectively. It turns out that in order to keep the systematic error due to the misalignment of the wire below the level of the intrinsic error of the system, both α and β must be smaller than $0.01° \sim 0.2$ mrad.

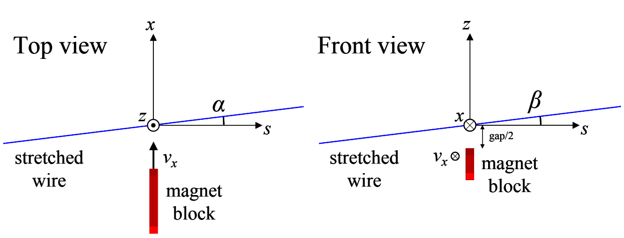

Figure 3: Misalignment angles of the stretched wire relative to the direction of displacement of the magnet block.

Distance between the block and the wire

In a similar manner, we have also determined the maximum tolerable deviation σ_z from its setting value of the distance between the stretched wire and the surface of the block to be measured, which turns out to be $\sigma_z < 0.1$ mm.

Alignment of the magnet block

Another source of error comes from the misalignment of the magnet block relative to the direction of displacement (x) and the direction of the stretched wire (s). Given that the x direction is the direction of motion of the block, we have identified the rotation angles around the x, z and s axes as roll, yaw and pitch, respectively. The most critical misalignments are yaw and roll, which must be kept below $0.01°$, while the tolerance for the pitch is more loose, $0.2°$.

SUMMARY

A scheme to simulate the signal generated in the fixed stretched wire system to be built at ALBA has been developed, and has been used to optimize the design and operation parameters, and to establish the alignment and positioning tolerances, which are summarized in Table 2 below.

Table 2: Optimum magnitudes and tolerances for a $N = 10$ fixed stretched wire (w is the width of the block).

Coil length	L	> 800 mm
Coil width	H	> 800 mm
Scanned range	Δx	$\gtrsim 4w$
Distance between blocks	D	$\gtrsim 6w$
Err. in coil perpendicularity	α	$< 0.01°$
Err. in coil horizontality	β	$< 0.01°$
Distance block–wire	σ_z	< 0.1 mm
Error yaw alignment	ψ	$< 0.01°$
Error roll alignment	ρ	$< 0.01°$
Error pith alignment	π	$< 0.2°$

ACKNOWLEDGEMENTS

The authors wish to thank Johannes Bahrdt (BESSY) and Chamseddine Benabderrahmane (SOLEIL) for fruitful discussions as well as for sharing of information.

REFERENCES

[1] J. Chavanne and P. Elleaume, "Technology of insertion devices" in *Undulators, wigglers and their applications*, ed. by H. Onuki and P. Elleaume (Taylor & Francis, London, 2003), pp. 148–213.

[2] J.A. Clarke, "Measurement and correction of insertion devices" in *The science and technology of undulators and wigglers* (Oxford Science Publications, New York, 2004), pp. 158–179.

[3] P. Elleaume, O. Chubar, J. Chavanne, "Computing 3D magnetic fields from Insertion Devices", PAC'97, p. 3509; O. Chubar, P. Elleaume, J. Chavanne, J. Synch. Rad., **5** (1998), p. 481. Available at http://www.esrf.fr/Accelerators/Groups/InsertionDevices/Software/Radia/

[4] http://www.keithley.com/products/dmm/?mn=2010