Pulsed wire magnetic field measurement system for short-period long undulators

Johann E. Baader and Sara Casalbuoni
European XFEL, Schenefeld, Germany

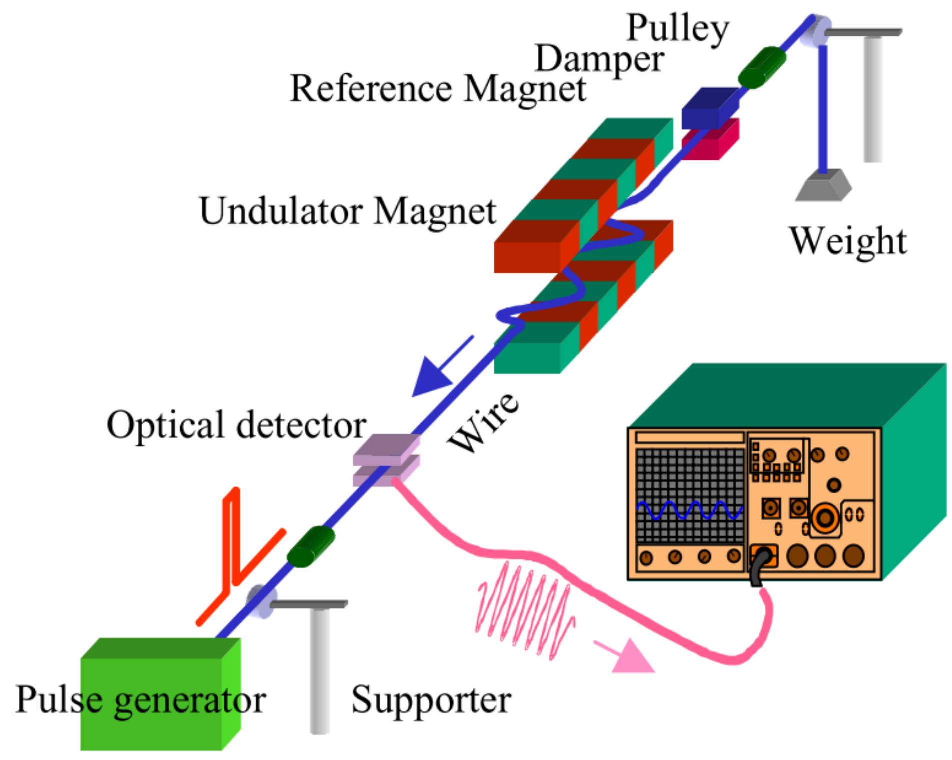
12th International Particle Accelerator Conference - IPAC'21
(May 24-28, 2021)

Poster ID: WEPAB126

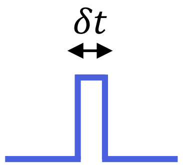
Abstract

The pulsed wire method is an attractive option to measure the magnetic field in insertion devices, mainly for those with restricted access (e.g., small gaps, in-vacuum/cryogenic environments, etc.). Besides first and second field integrals, experiments have proved the feasibility of reconstructing the magnetic field profile. Undulators with a small gap and short period are — and are planned to be — used at diffraction-limited storage rings and free-electron lasers. This contribution outlines the pulsed wire system's requirements to perform magnetic field reconstruction in such undulators. We examine the main expected limitations, particularly the dispersive, finite pulse-width, discretization error, and sag effects. Furthermore, we present the current status of developing the pulsed wire system at the European XFEL.

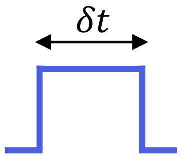
Pulsed wire method overview



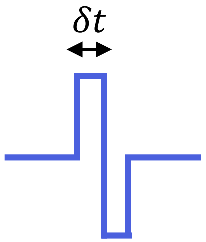
Simplified diagram of the pulsed wire system [1]



- *Short pulses* ($\delta t \ll \lambda_u / c_0$): displacement of the wire is proportional to the **first field integral**



- *Long pulses* ($\delta t > L / c_0$): displacement of the wire is proportional to the **second field integral**



- *Positive-negative short pulses*: displacement of the wire is proportional to the **magnetic field**

[1] T.C. Fan et al., PAC2001, pp. 2775-2777

Pulsed wire method overview

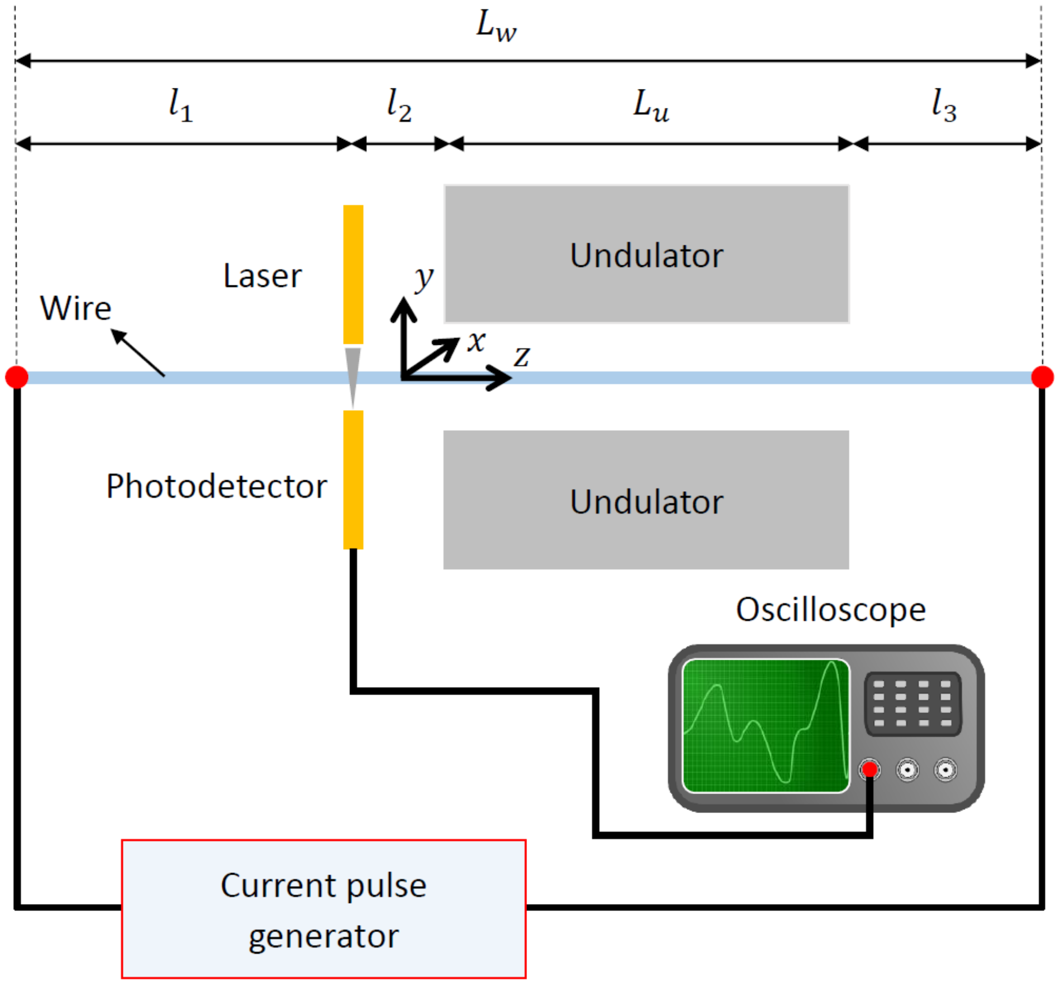
Advantages

- Suitable for devices with small aperture
- Fast
- Easily measures both transversal field components

Disadvantages

- Poor signal-to-noise ratio
- Signal reflection
- Sag
- Finite pulse width effect
- Dispersion

Limitation caused by dispersion [2]:	**Limitation caused by sag [2]:**	**Limitation caused by reflection:**
$L_u \ll \frac{\lambda_u^3 T}{2\pi^2 E I_w}$	$L_w < \sqrt{\frac{8TS}{g m_L}}$	$L_w > 2 l_1$



Two-dimensional scheme of the pulsed wire system and main lengths

[2] R. W. Warren, NIMA, Vol. 272, Issues 1-2, pp.257-263, 1988

Magnetic field reconstruction program

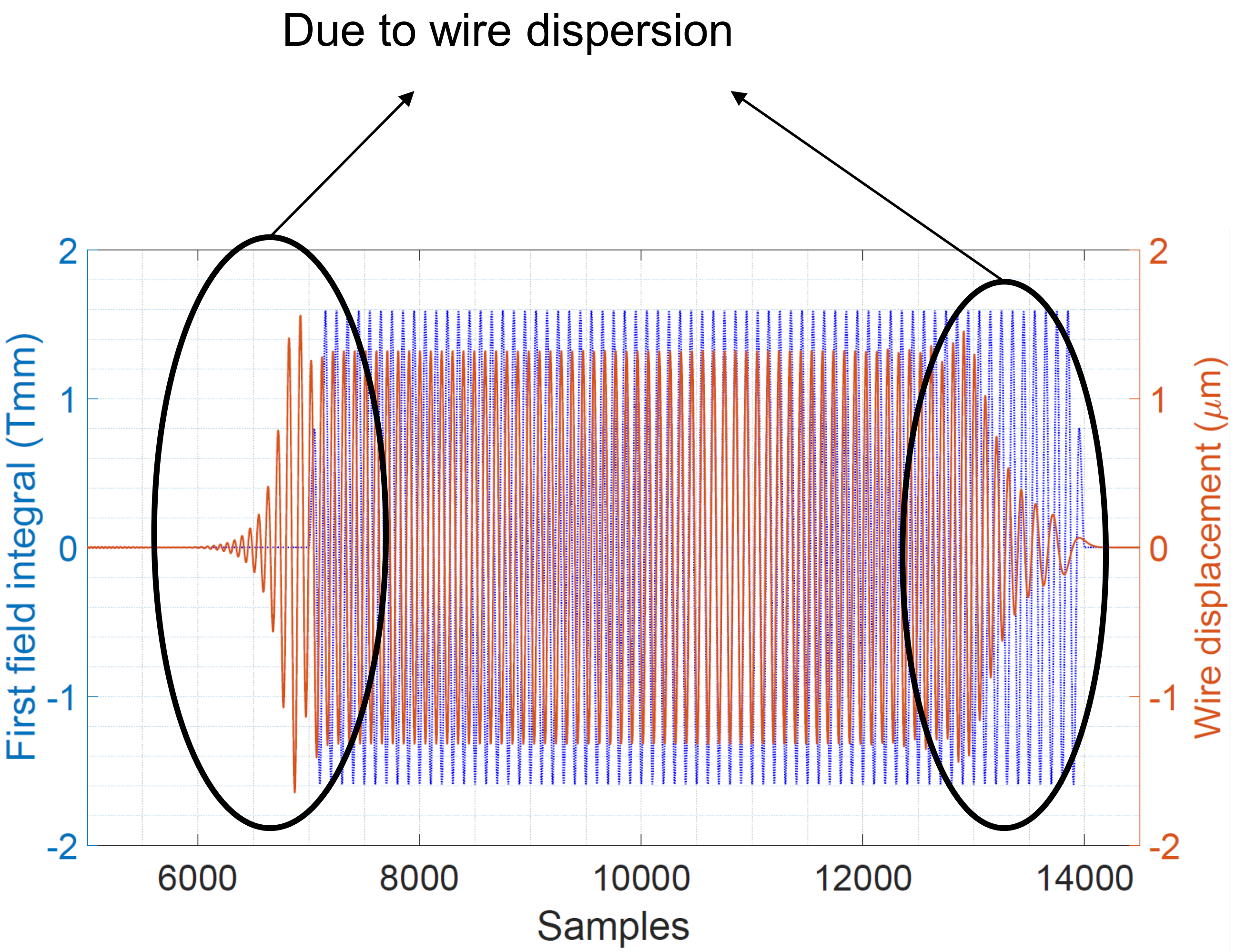
- A program has been developed in Matlab to correct dispersion, finite pulse width, sag and discretization errors [3]
- Due to the finite flexural rigidity of the wire, longer wavelengths travel faster than the shorter wavelengths — a phenomena named **dispersion**. Ref. [4] proposed numerical techniques to compensate the dispersion in the frequency domain, and a similar approach is used in our software as well
- Theoretically, the first field integral is proportional to the wire displacement for a pulse width going to zero. In experiments, nevertheless, this is impracticable. The pulse width must be finite, which will also introduce errors. Ref. [4] shows how to correct the **finite pulse width** effect, which is also considered in our program
- **Sag** is corrected numerically in the space domain, since the vertical component y of the magnetic field is $B_y = B_0 \cosh(2\pi y/\lambda_u)$, with B_0 being the field amplitude and λ_u the undulator period
- The wire displacement is sampled, which introduces errors in the magnetic field. The program corrects the **discretization effects** in the frequency domain

[3] J. E. Baader et al., to be published

[4] D. Arbelaez et al., NIMA, Vol. 716, pp. 62-70, 2013

Program validation and results

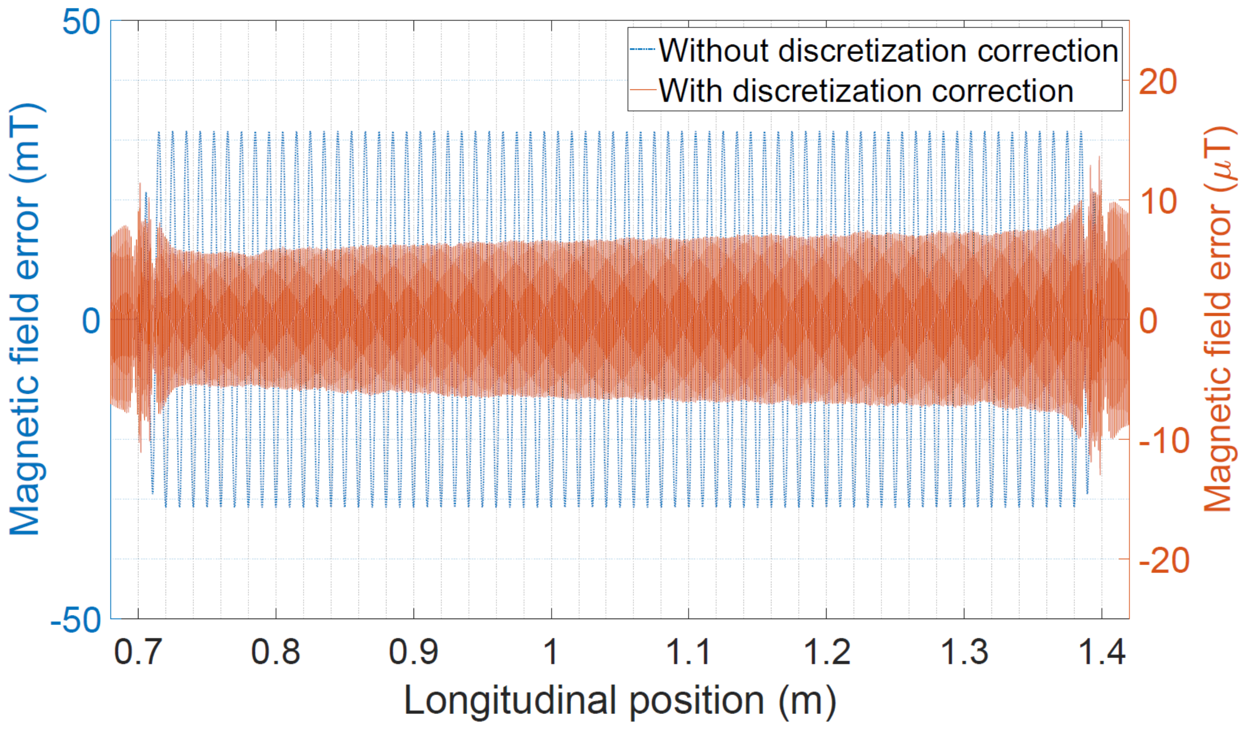
Parameters for simulation	Values
Magnetic field amplitude	1 T
Undulator period	10 mm
Undulator length	70 cm
Wire diameter	75 µm
Wire Young's module	124 GPa
Wire tension	2 N
Wire linear density	3.88×10^{-5} Kg/m
Current pulse amplitude	5 A
Current pulse width	3 µs



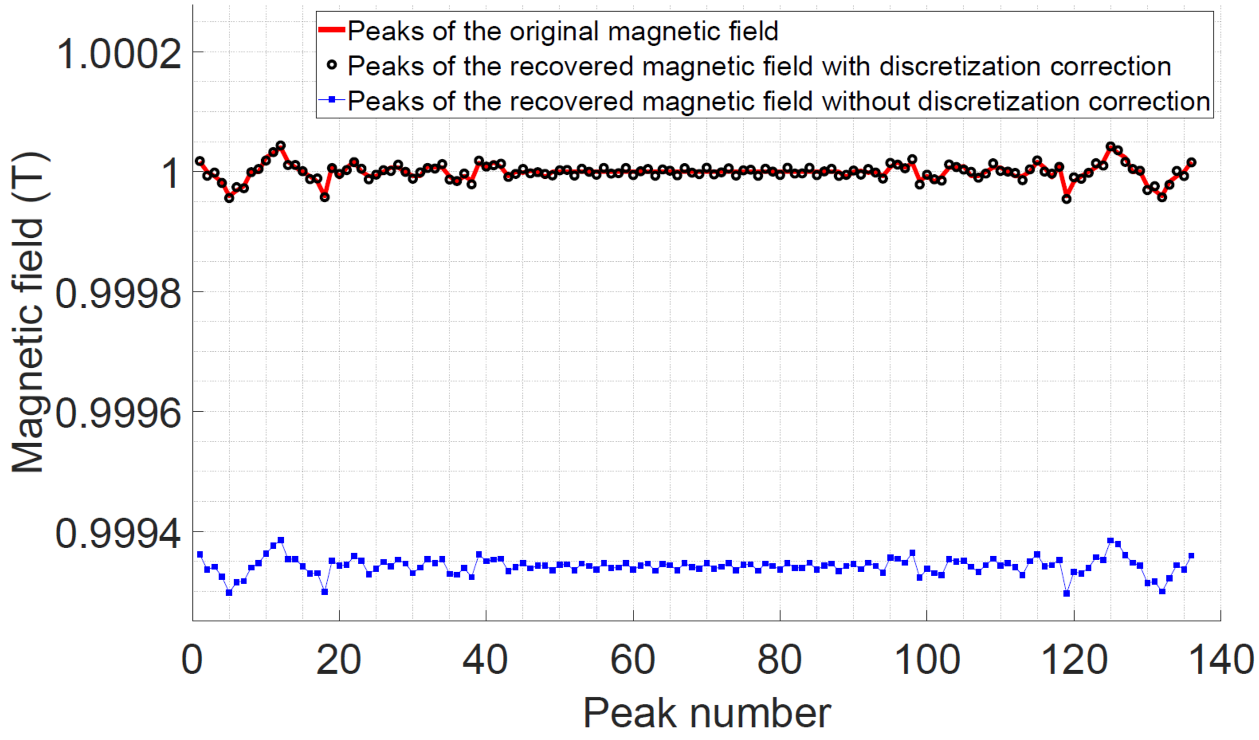
First field integral (blue) and the wire displacement (orange). The effect of the dispersion at the beginning and the end of the signal is evident

Program validation and results

- We found a better agreement between original and recovered magnetic field when correcting the discretization effect
- The results showed below are obtained from a short pulse (first field integral measurement). Similar behavior is observed for long pulses



Magnetic field error comparison for the case where the discretization effect is corrected (orange) and is not corrected (blue)



Comparison among the peaks of the original magnetic field (red line), recovered with (black circles) and without discretization correction (blue squares)

Development status and plans at the European XFEL

- Most of the hardware for the pulsed wire system has been purchased
  - *Motion detection system*: combination of a laser **THORLABS CPS532** and a photodetector **THORLABS PDA100A2**
  - *Oscilloscope*: **LECROY HDO6104A-MS** (12-bit ADC, 10 GS/s)
  - *Wire*: 75 µm Beryllium Copper
  - In-house pulse generator (under development)

- Measuring plans & future developments:
  - Test the system with a prototype undulator* ($B_0 = 0.6\ \mathrm{T}$, $\lambda_u = 1.6\ \mathrm{mm}$, $L_u \approx 30\ \mathrm{cm}$)
  - Measure the U40 planar hybrid undulators at European XFEL ($B_0 = 1.11\ \mathrm{T}$, $\lambda_u = 40\ \mathrm{mm}$, $L_u \approx 5\ \mathrm{m}$)
  - In the SASE 2 SCU afterburner context (see contribution [5] and [6] in the proceedings of this conference), upgrade the system to test and commission it for in-vacuum / cryogenic environments

[5] S. Casalbuoni et al., WEPAB132, in these proceedings

[6] B. Marchetti et al., THPAB035, in these proceedings

Summary and outlook

- The pulsed wire method is a promising solution to map the local magnetic field in small gap long devices
- The technique has to be demonstrated to reconstruct the magnetic field for long undulators with a short period, particularly when the dispersion effect dominates
- Potential improvements fall into the hardware side:
  - calibration procedures
  - noise filtering / mitigation techniques to increase SNR
  - pulse generators and pulse-shape quality (reduce over and undershoots)
- Hardware and software developments are in progress at European XFEL
- We plan to apply the pulsed wire system to test tolerances needed for the FEL process of SCU lines in particular for the SCU afterburner modules (see the contributions below in the proceedings of this conference)
  - Sara Casalbuoni, **Towards a superconducting undulator afterburner for the European XFEL** [WEPAB132]
  - Barbara Marchetti, **Study of the tolerances for superconducting undulators at the European XFEL** [THPAB035]