A Pulsed Wire Magnetic Measurement System for Superconducting Undulators

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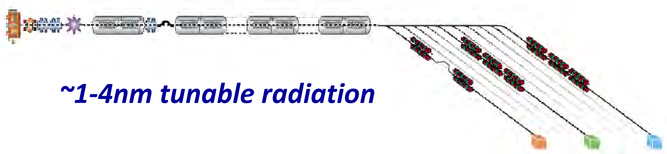
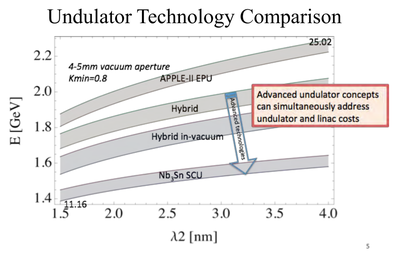
Superconducting Undulator R&D

Superconducting undulators for an FEL facility

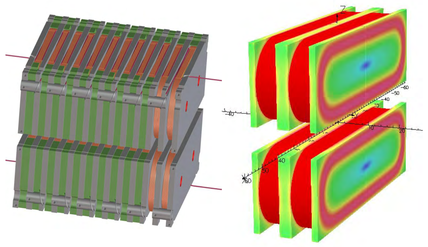
- Increase spectral range and/or lower electron beam energy
- Shorter FEL lines





Superconducting undulator R&D challenges

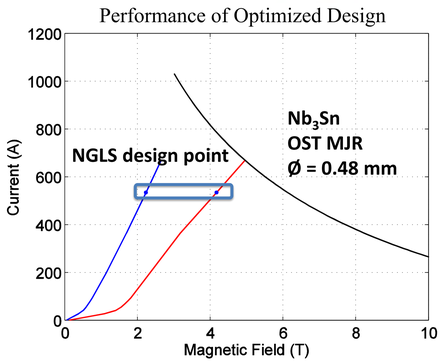
- Fabrication methods (precise winding and machining)
- Cryogenic design and understanding of heat loads
- Magnetic field measurements
- Correction of trajectory and phase errors



Superconducting Undulator Magnetic Measurements

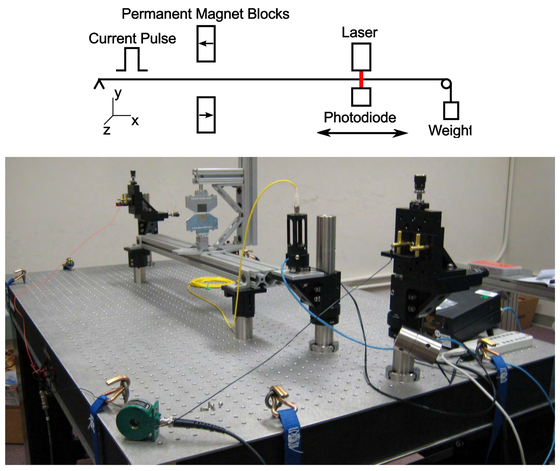
A pulsed wire system is being developed for the measurement of superconducting undulators

- Can be used at cold temperatures
- Can be used in confined spaces
- Direct measurements of 1st and 2nd integrals of magnetic field



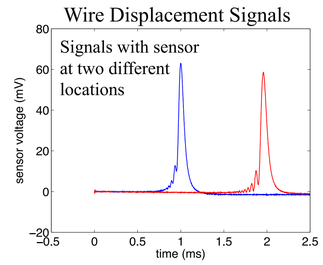
Pulsed Wire Correction Algorithm

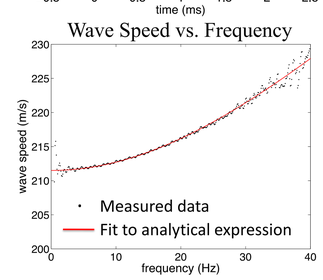
Pulsed Wire Test Bench:



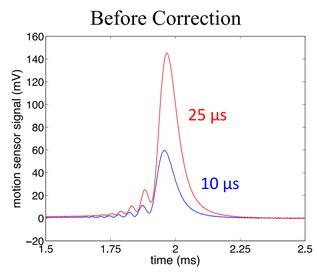
Wave Speed Measurement

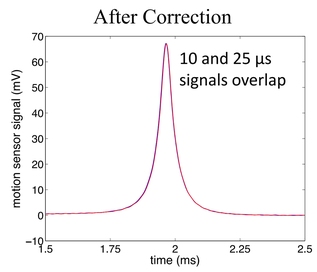
Wave speed is obtained by placing the motion sensor at two different locations and measuring the phase difference as a function of frequency





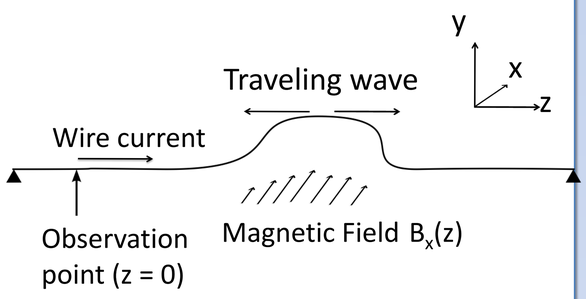
- A correction algorithm has been developed to correct for dispersion and finite pulse width effects
- Signal is transformed to frequency domain
- Appropriate scaling and frequency shifts are applied
- Signal is transformed back to time domain





Pulsed Wire Method Description

- Wire tensioned wire between two points
- Part of the wire is in an external magnetic field
- Current is applied to the wire
- The wire is subjected to the Lorentz force
- A traveling wave moves along the wire
- The displacement at a given point is measured
- First field integral obtained with a short pulse
- Second field integral obtained with a long pulse



Pulsed Wire Method Analysis

$\hat{y}(t)$: wire position at sensor location

T: wire tension

μ: density (mass per length)

δt: pulse time length

I: current amplitude

c_0: wave speed $c_0 = \sqrt{\frac{T}{\mu}}$

Non-dispersive general solution:

$$\hat{y}(t) = \frac{I}{2T}\int_0^{c_0 t}\int_{\eta - c_0 t}^{\eta} B_x(\xi)\, d\xi\, d\eta$$

DC current (long pulse):

$$\hat{y}(t) = \frac{I}{2T}\int_0^{c_0 t}\int_0^{\eta} B_x(\xi)\, d\xi\, d\eta$$

δt → 0 (short pulse):

$$\hat{y}(t) = \frac{I c_0 \delta t}{2T}\int_0^{c_0 t} B_x(\xi)\, d\xi$$

Dispersive effects are present due to the flexural rigidity of the wire (i.e. wave speed is a function of wave number)

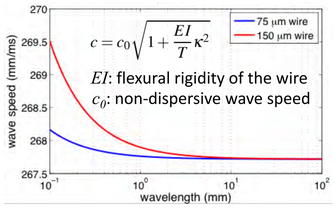
$c(\kappa)$: wave speed

κ: wave number

General solution:

$$\hat{y}(t) = \frac{I_0}{2\mu}\int_{-\infty}^{+\infty} \frac{e^{i\omega\delta t} - 1}{\omega^2\left(c + \kappa\frac{dc}{d\kappa}\right)} \bar{B}(\kappa) e^{-i\omega t} d\omega$$

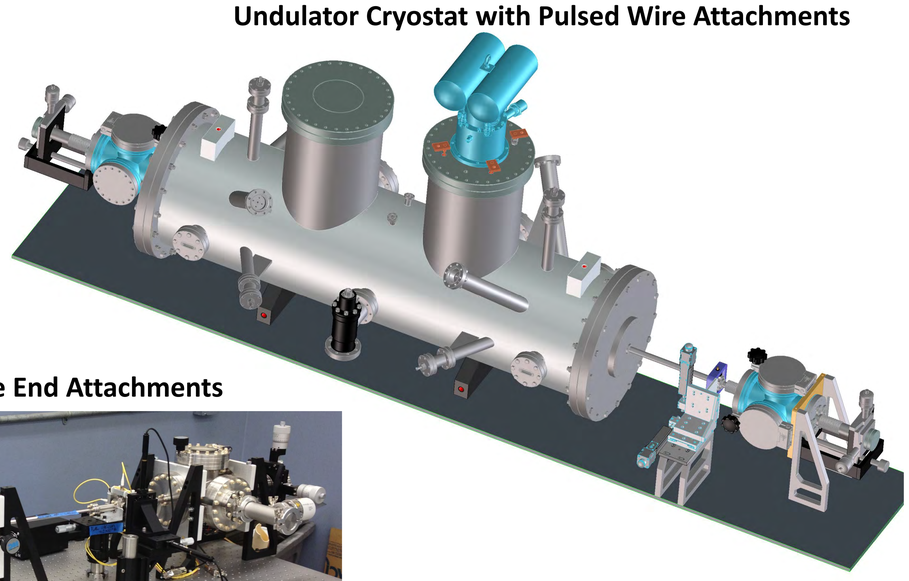
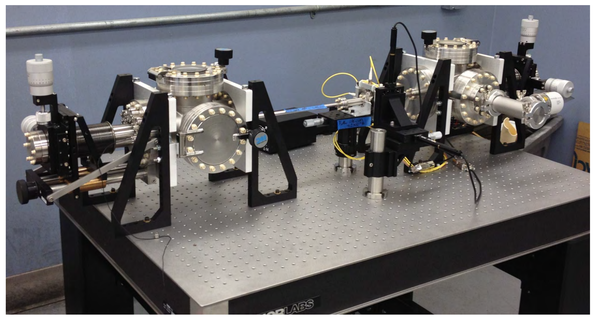
Dispersion Curve



Superconducting Undulator Test Facility

- Cryogen-free cryocooler based cryostat
- Accommodates undulator prototypes with a maximum length of 1m
- Pulsed wire end attachments for first and second field integral measurements (trajectory and phase error measurements)

Undulator Cryostat with Pulsed Wire Attachments



Pulsed Wire End Attachments