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Pulsed wire magnetic field measurement system for in-vacuum undulator

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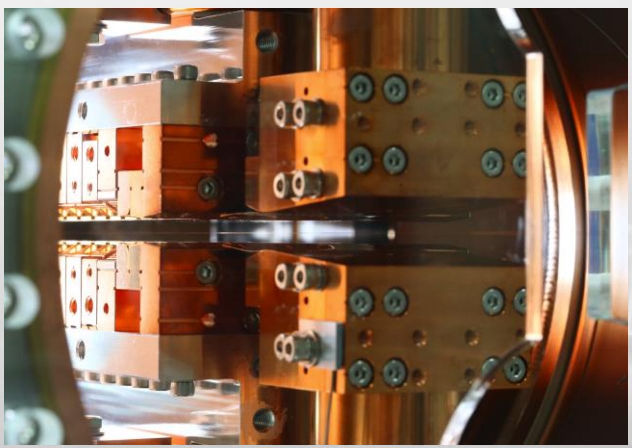
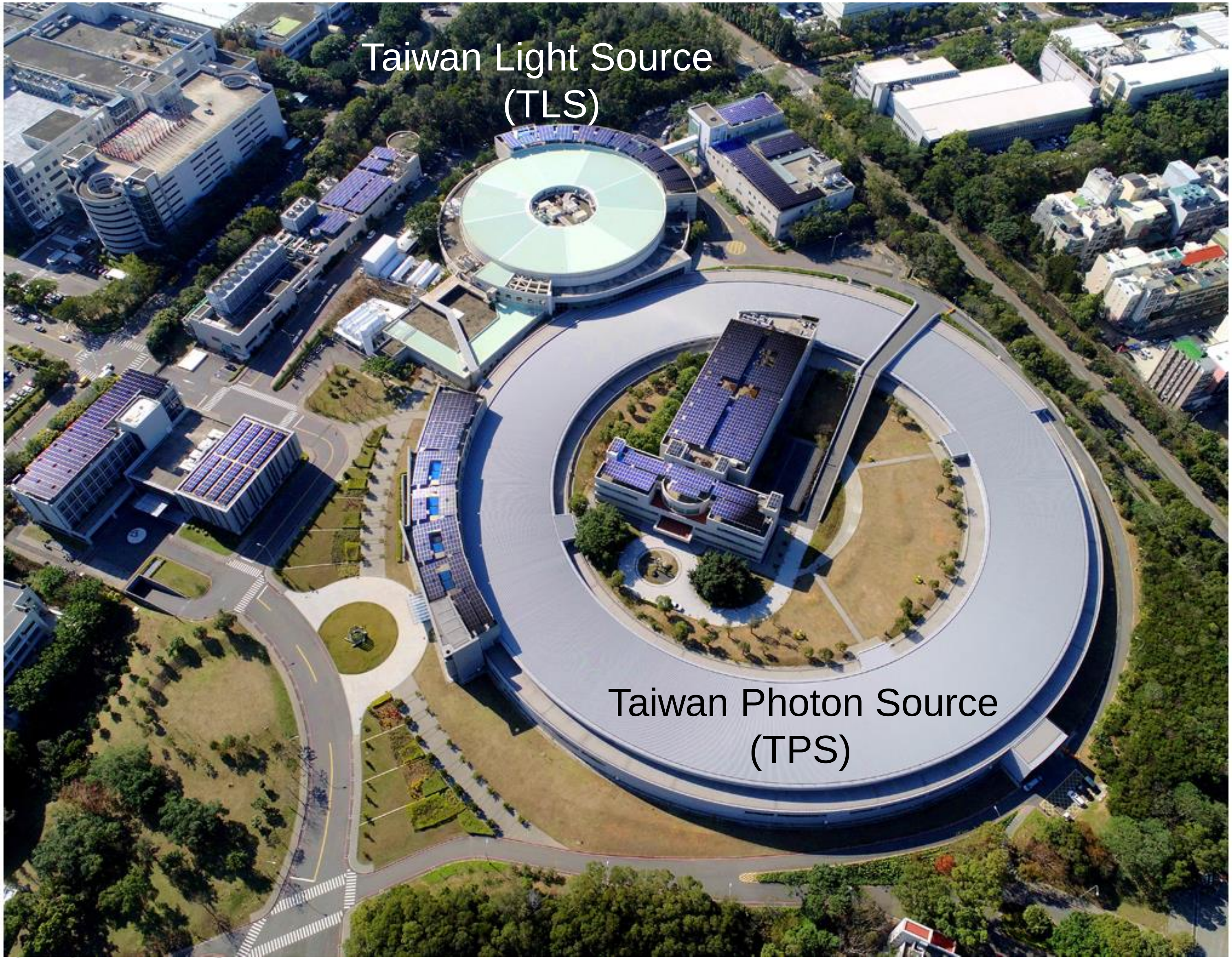
22nd International Magnetic Measurement Workshop (IMMW22)



Outline

- **Introduction**
- **Pulsed wire system composition**
  (1) Wire tension , (2) Wire sag measurement,
  (3) Wire-displacement Detection system,
  (4) Current pulse circuit , (5) Oil damper
- **Pulsed wire system for magnetic-field measurements**
- **Summary**

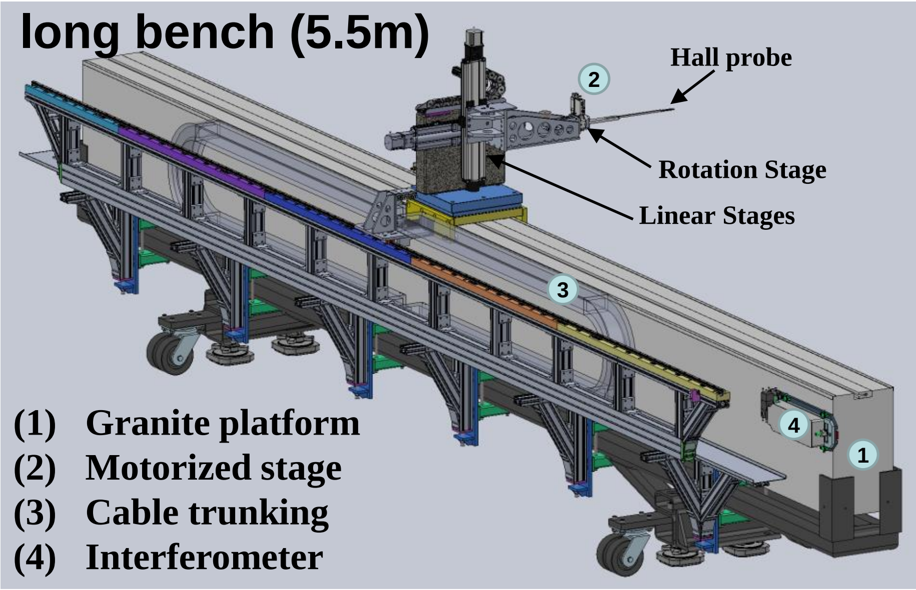
Aerial view of NSRRC



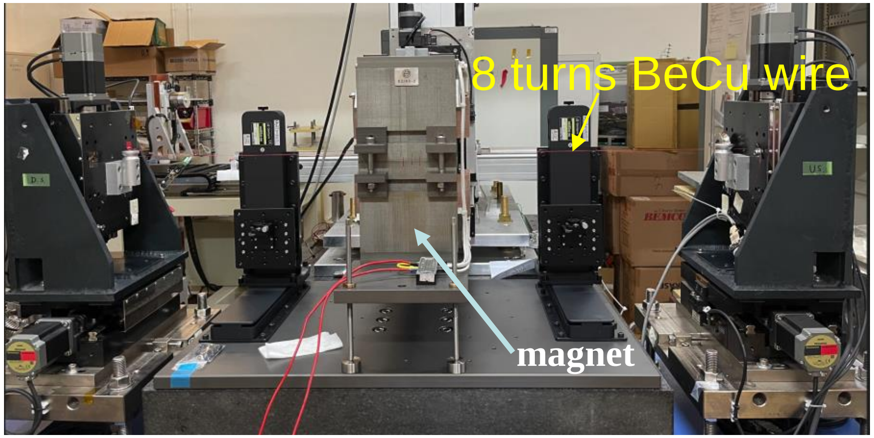
Ref. https://www.nsrrc.org.tw/NsrrcWebSystem/UPLOADS/CHINESE/IMAGES/9/05f0058a5c.jpg

Magnetic Field Measurement Technology in NSRRC

(1) Hall probe measurement bench for insertion devices

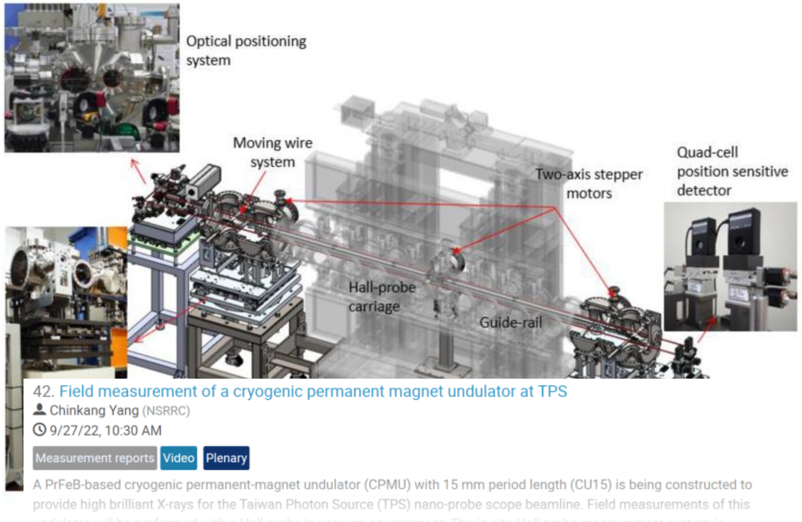


(3) Stretch wire system

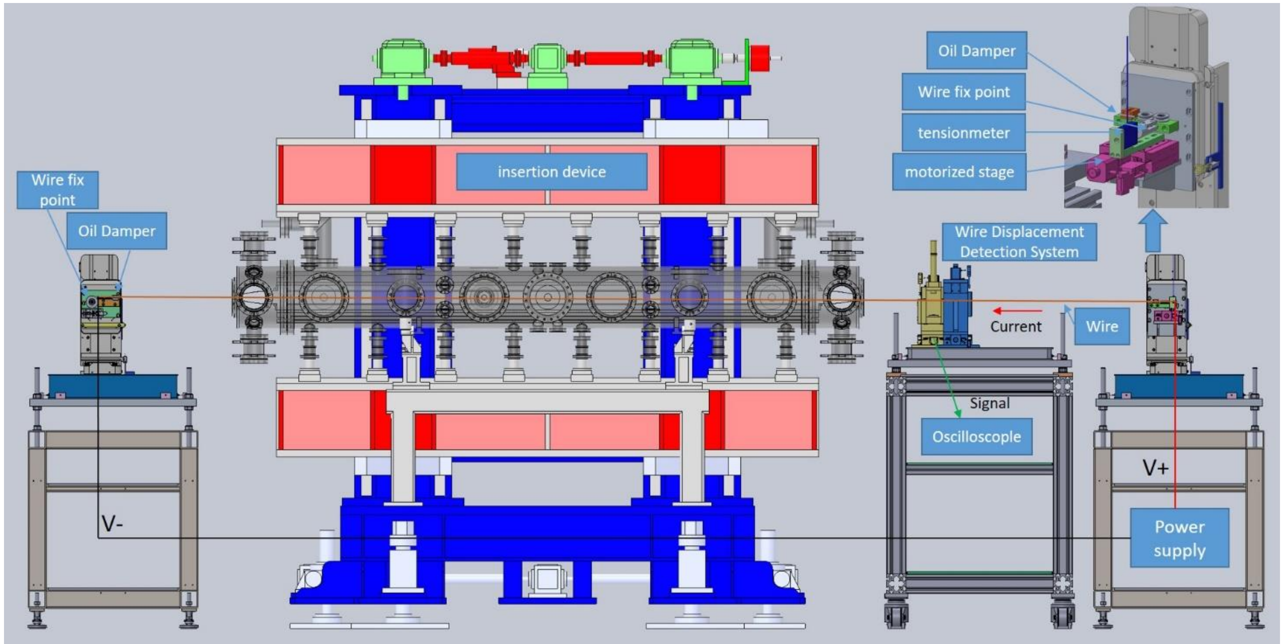


(2) Hall probe measurement bench for accelerator magnets

(4) In-situ field measurement system



Pulsed wire system composition



Pulsed wire measurement(PWM) system

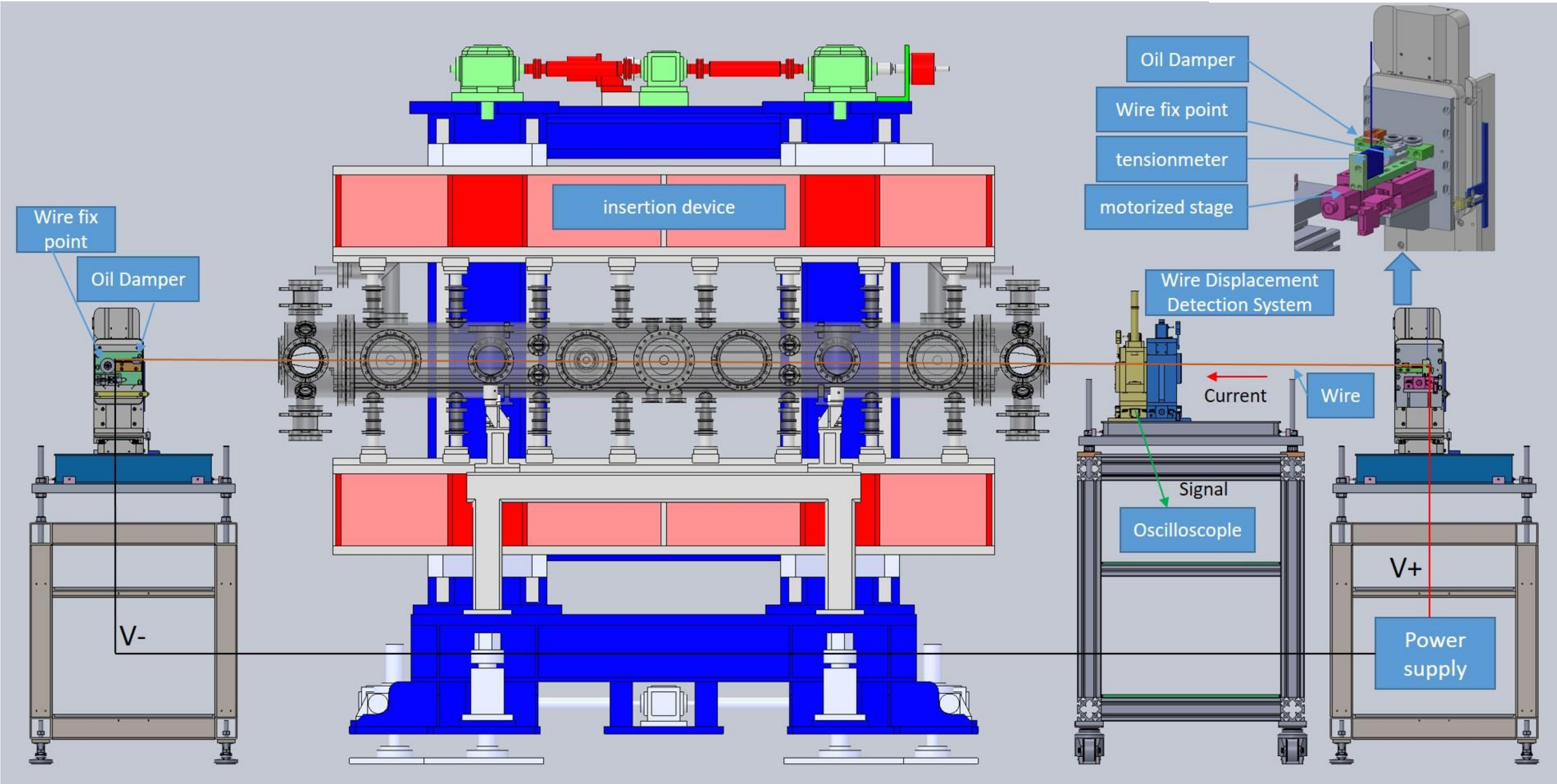
Fast measurement
Magnet alignment
First and second Field integral measurements
Local field measurement (Similar to Hall probe)

Theory
Lorentz Force
General traveling wave

From Warren (1988)

$$u_{s0}(t) = \frac{Ic_0\delta t}{2T}\int_0^{c_0 t} B(\tilde{x})d\tilde{x}\,,$$

$$u_{s0}(t) = \frac{I}{2T}\int_0^{c_0 t}\int_0^{\tilde{x}} B(\hat{x})d\hat{x}d\tilde{x}.$$



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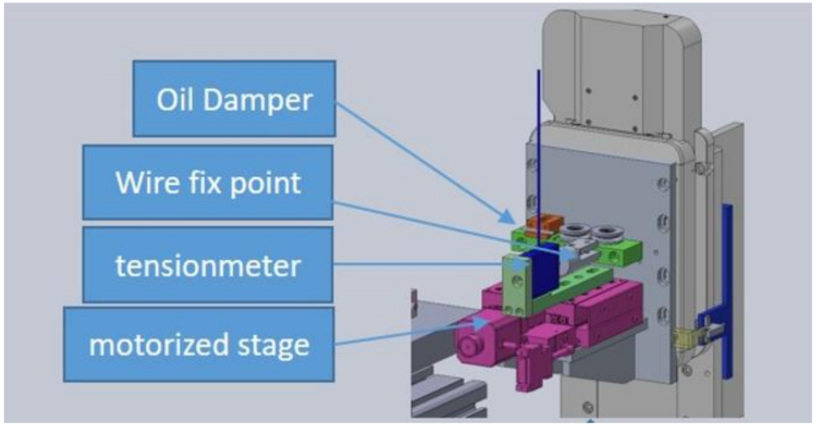
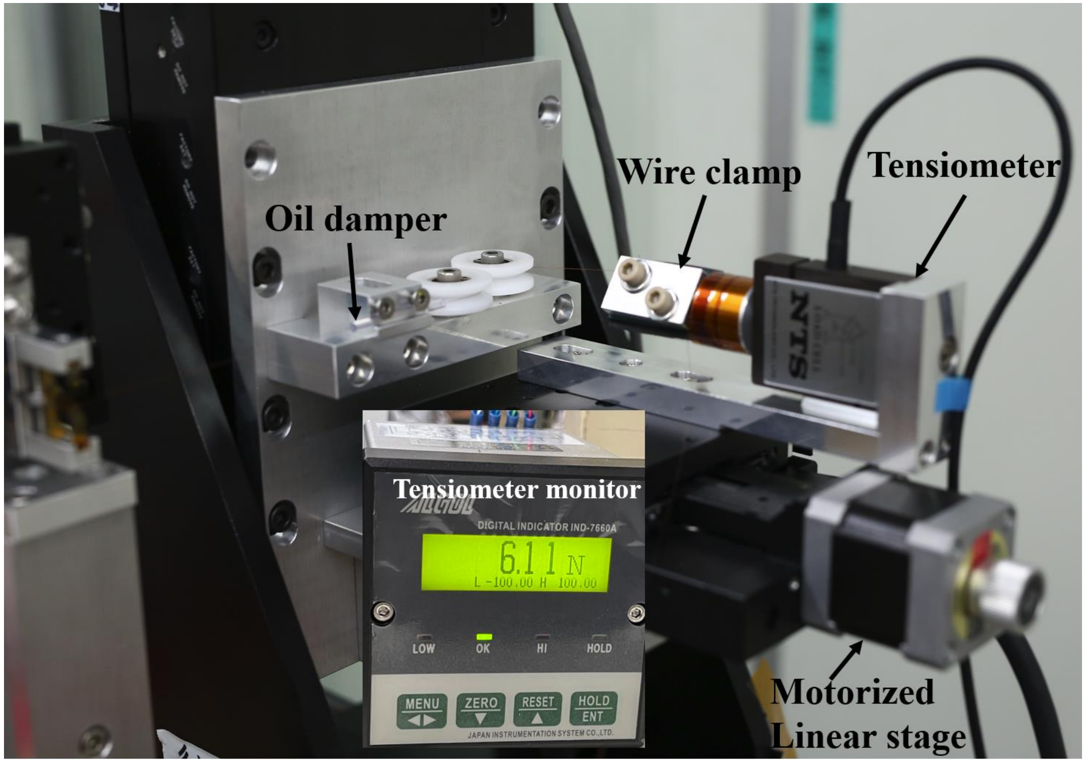
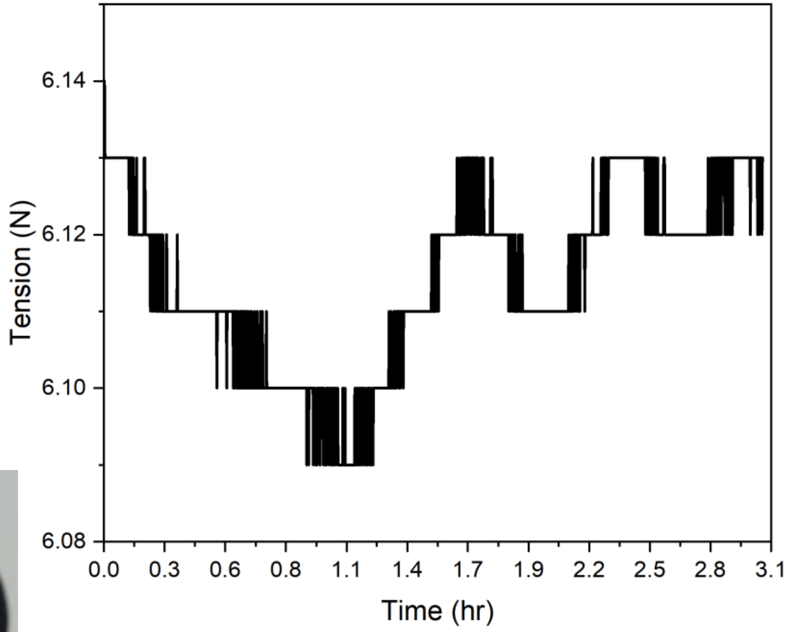
Ref. 1. T.C. Fan, F.Y. Lin, C.S. Hwang and Ian C. Hsu, "Pulsed wire magnetic field measurements on undulator U10P", Proceedings of the 2001 Particle Accelerator Conference, Chicago
2. R.W. Warren. "Limitations on the use of the pulsed-wire field measuring technique", Nuclear Instruments and Methods in Physics Research Section A, Vol.272, 257-263 (1988)

Tension





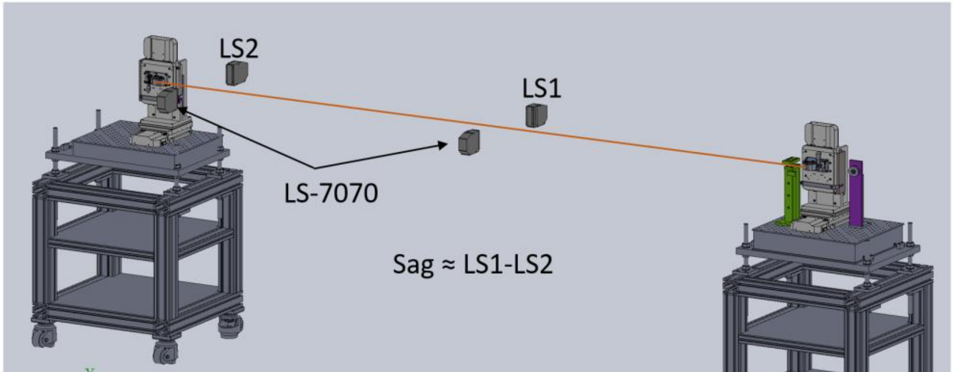


1. wire on one side is fixed at a clamp to connect the tensiometer

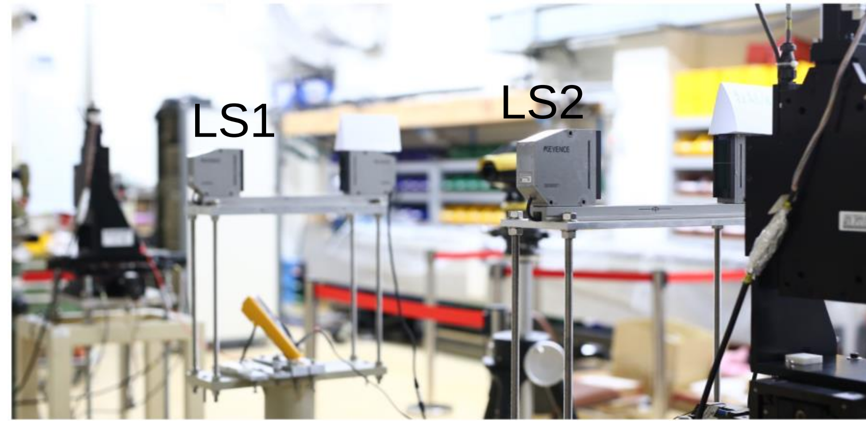
2. tensiometer is mounted on a motorized stage to control the wire tension.

3. test wire clamp
wire tension varies by ±0.02N

Wire sag measurement

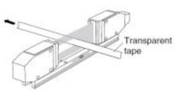


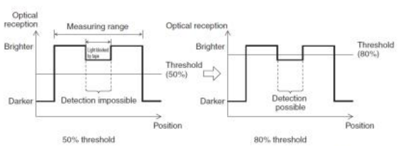
LS7070 : High-speed, High-accuracy Digital Micrometer



Change of Edge Detection Threshold

The following section provides information on how to make threshold changes for the measurement of highly transparent objects.



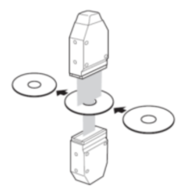


When measuring a highly transparent target, such as a plastic tape, the amount of light blocked by the tape is minimal. Therefore, the tape may not be detected if the threshold is low.

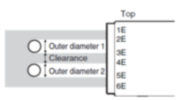
In that case, increase the threshold level so that the tape will be detected

E (Edge) Mode

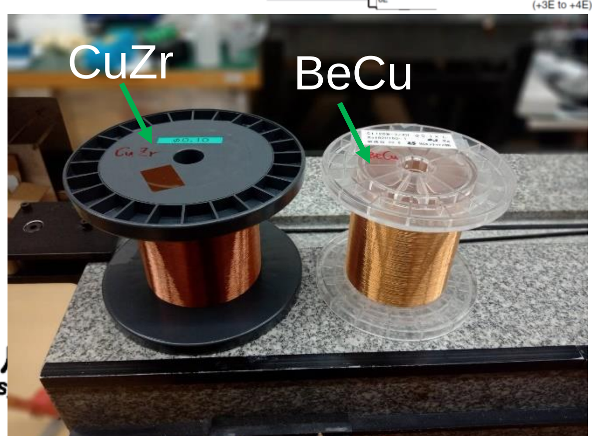
The LS-7000 Series measures objects based on the edges in this mode.

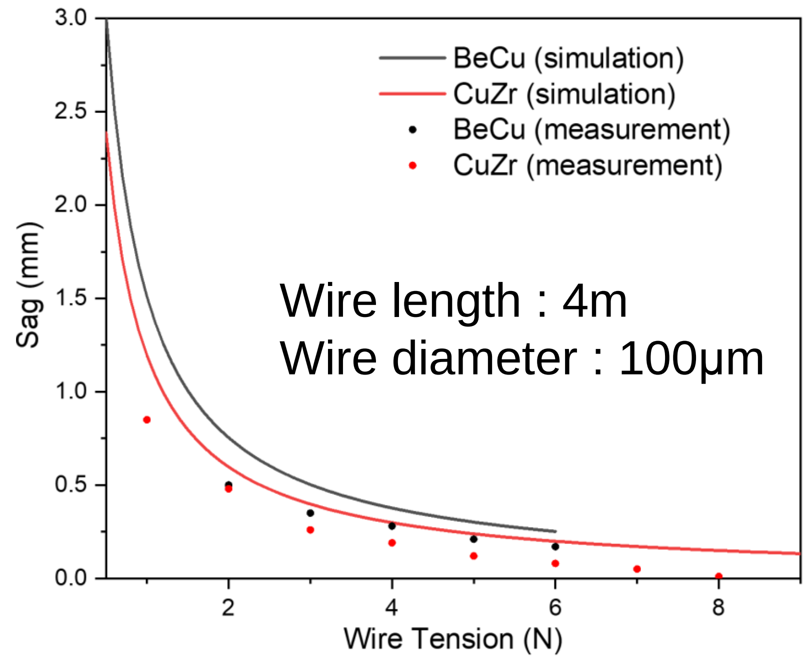


Set the edge numbers to positive values beginning with the top of the measuring head. The following example shows positive edge numbers and measuring portions.



Outer diameter 1: Space between 2E and 3E (+2E to +3E)
Outer diameter 2: Space between 4E and 5E (+4E to +5E)
Clearance: Space between 3E and 4E (+3E to +4E)





The relative amount of wire sag is determined by LS2-LS1.
The sag of a CuZr wire is smaller than that of a BeCu wire under the same conditions.

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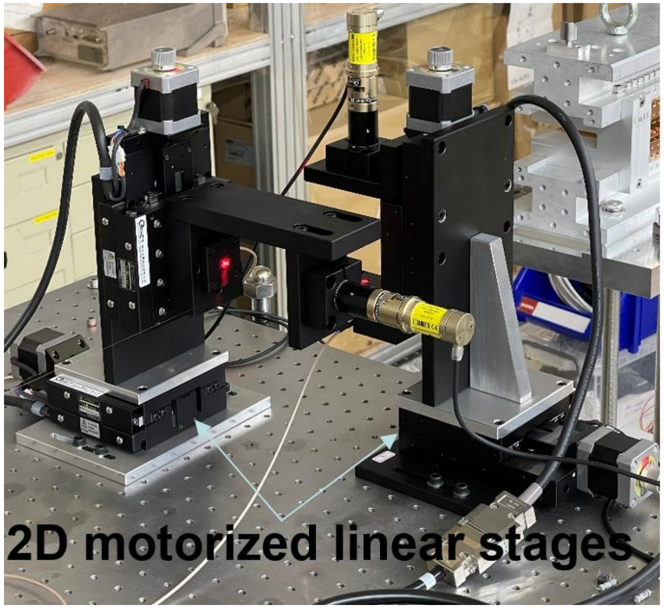
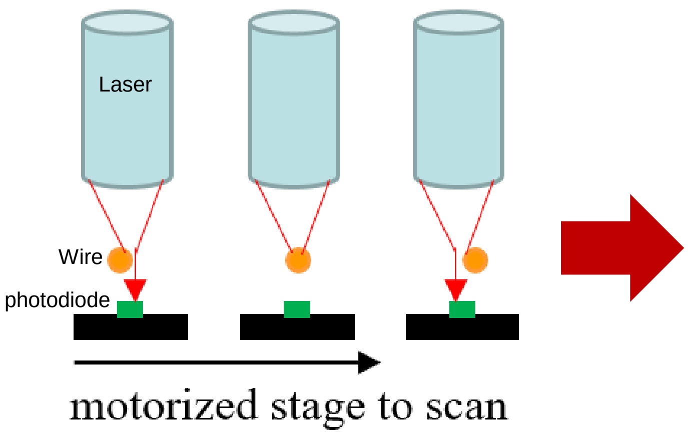
Wire-displacement Detection System

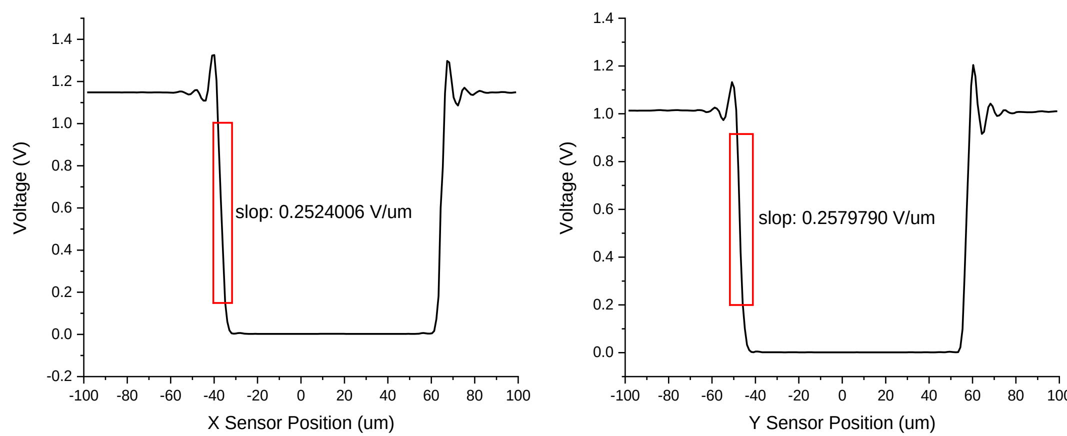


LNC-13MMC, 633 mm,
Schäfter+Kirchhoff GmbH

Photodiode



1. laser beam focused on the wire
2. photodiode is installed on the opposite side of the laser to detect the light intensity that is not blocked by the wire



These slopes with values around 0.25V/µm are the transfer coefficient of voltage and wire displacement

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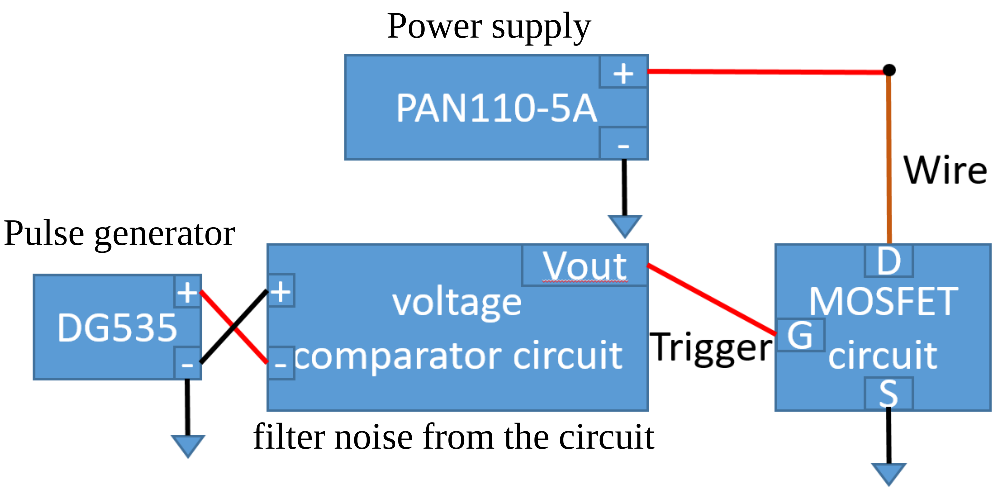
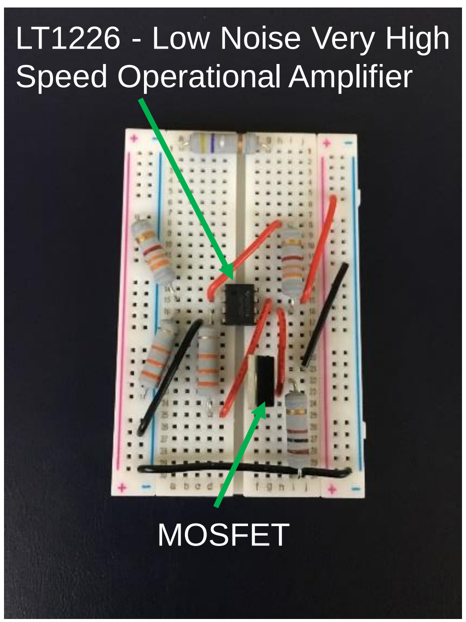
Current pulse

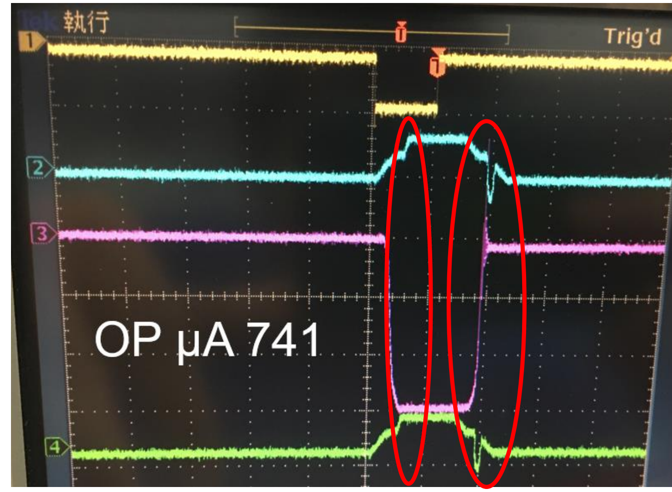


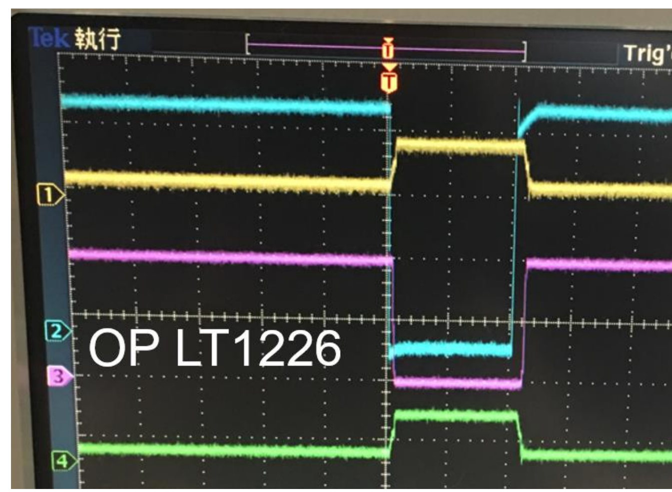


MOSFET (IRF840)
Switching on (rise time 21ns)
Switching off (fall time 9ns)

OP (μA741)
rise time & fall time 300ns

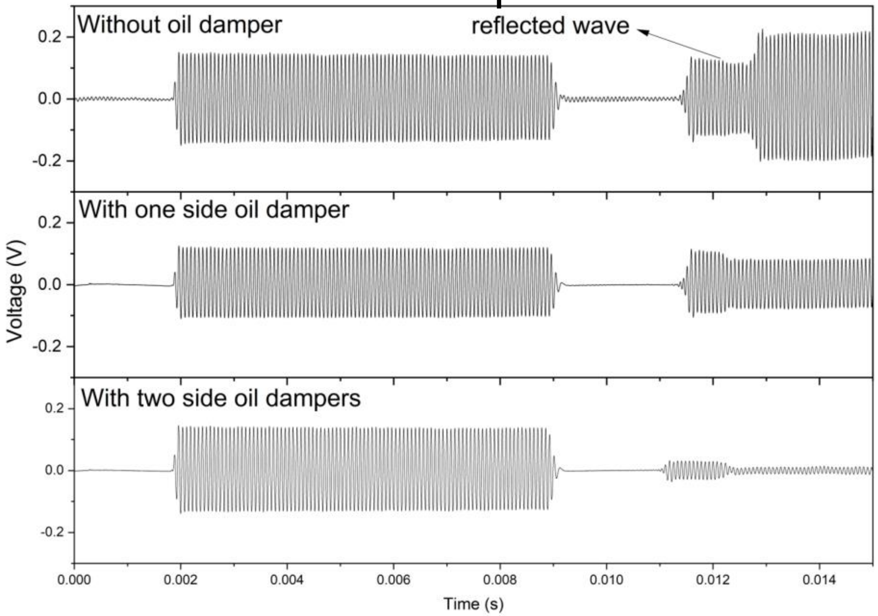
OP (LT1226)
rise time & fall time 8ns



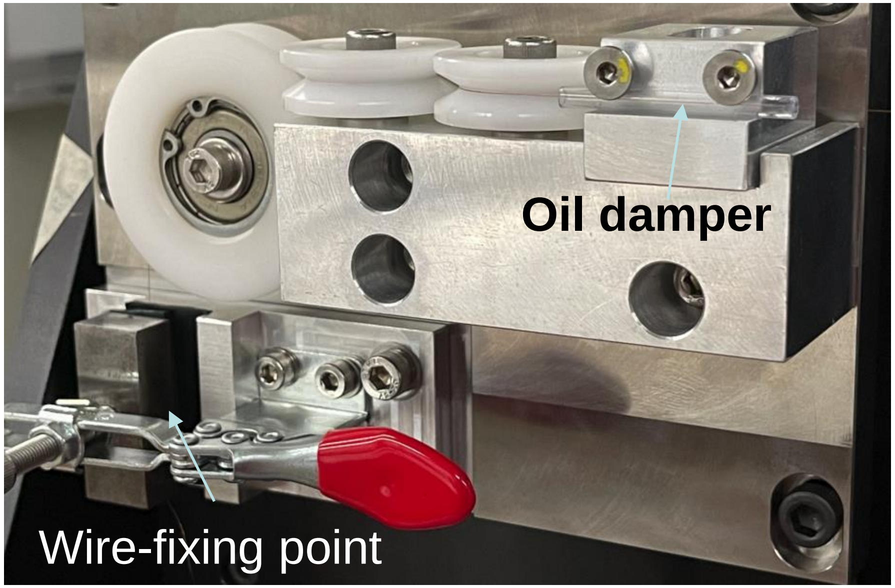


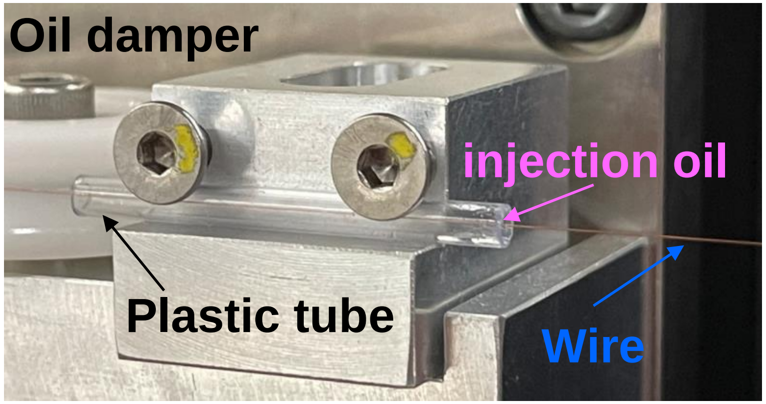
Oil dampers

used the oil dampers in PWM

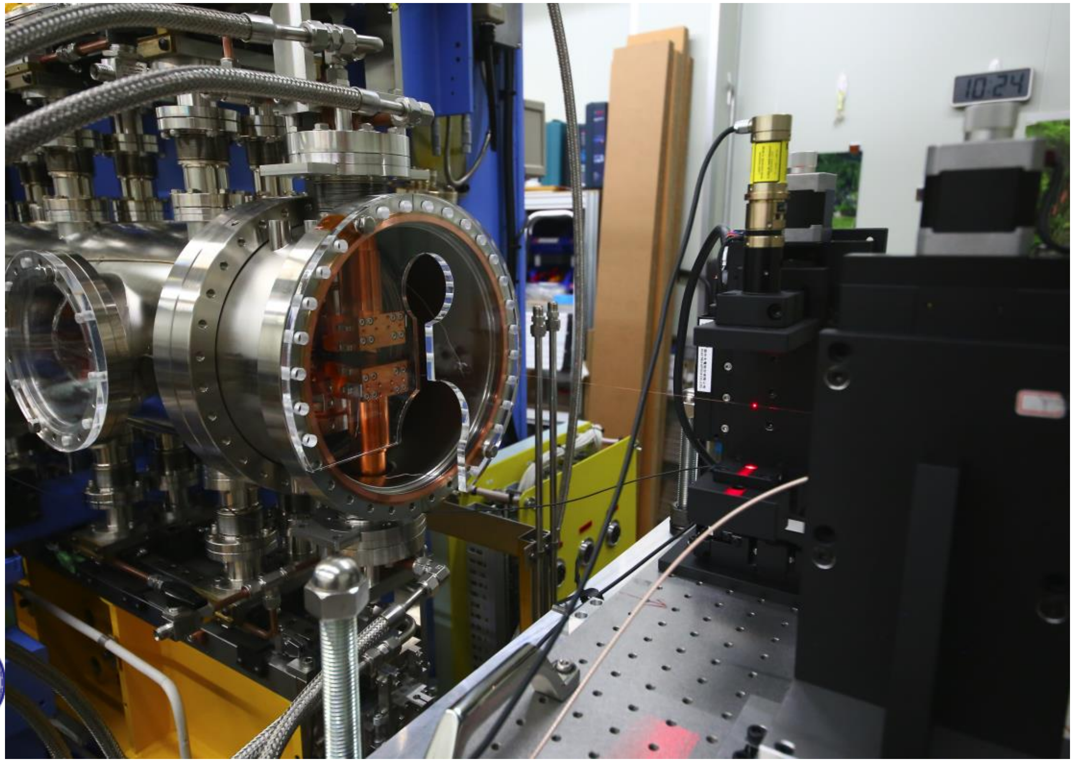


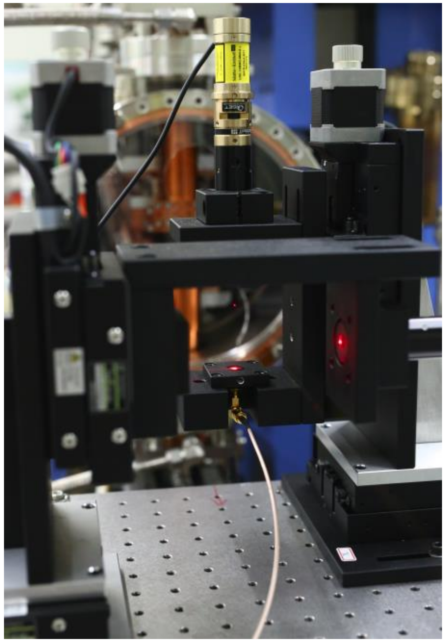
the oil damper near the wire-fixing points to eliminate dispersion and reflected waves





Pulsed wire system
for magnetic-field measurements

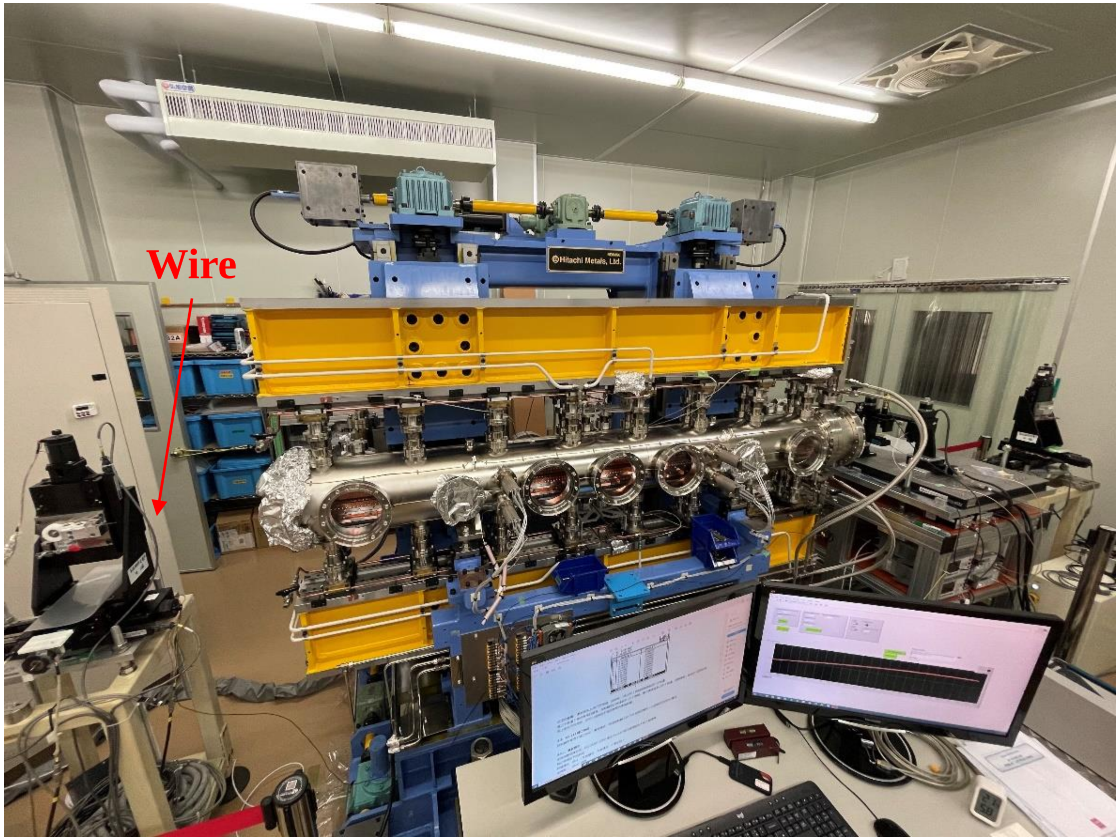


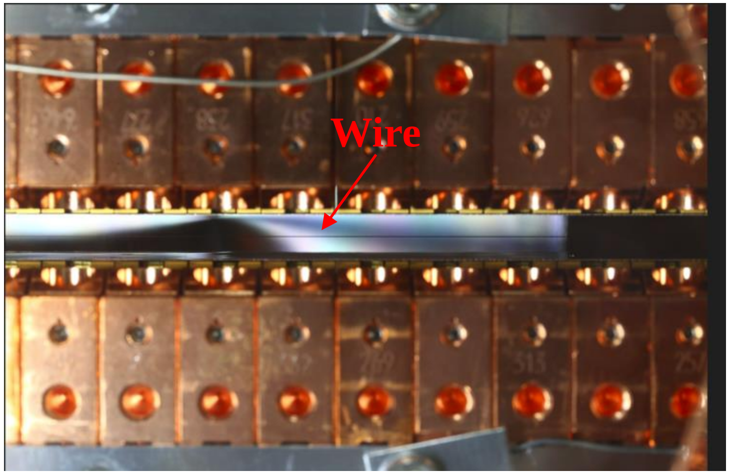


PWM system for 2m-IU22

Short pulse $\Delta ts \ll \frac{\lambda_u}{2*C0}$, $\lambda_u = 22mm, C0 = \frac{300m}{s}$, Δts << 37us

Long pulse $\Delta tl > \frac{L}{C0}, L = 2.2m, \Delta tl >$ 7ms





Short Pulse: 10us
Long Pulse : 20ms
Tension : 6N
Wire R =38.1 ohm
Wire Voltage : 50V
Wire D:100um CuZr
Wire L : ~5m

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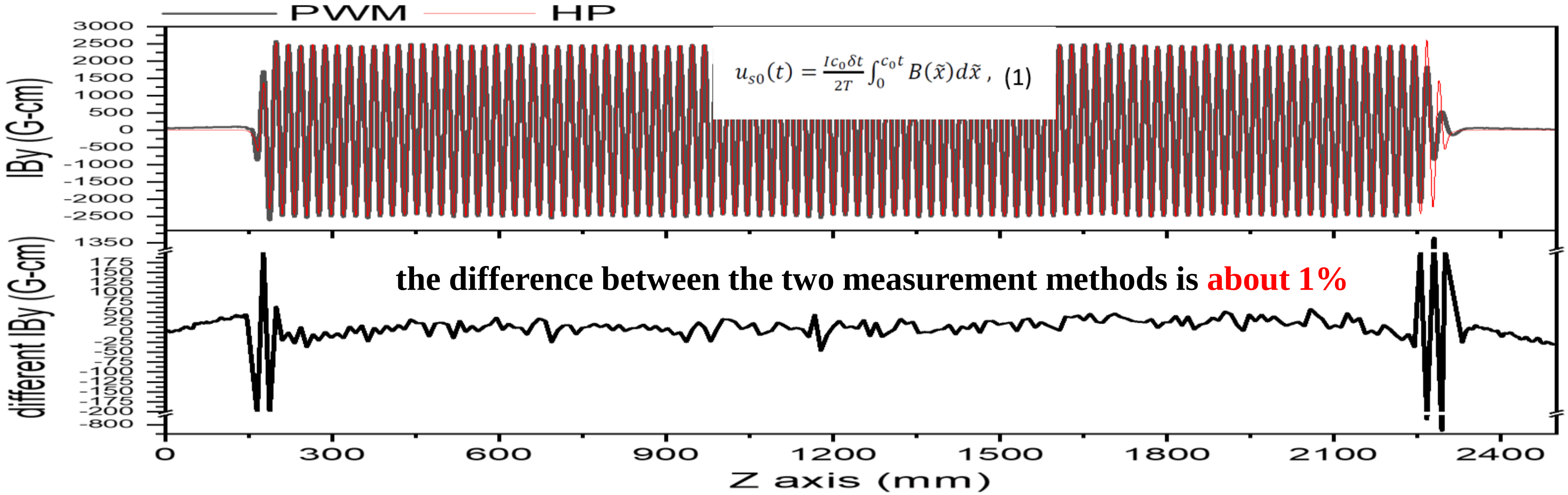
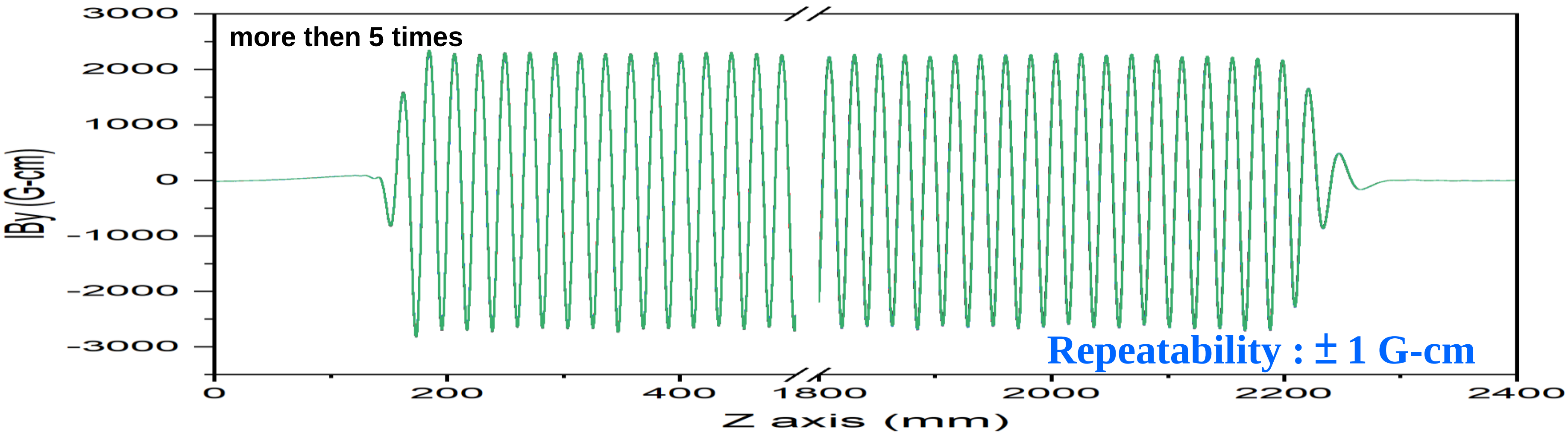
Ref. 1. C.W. Chen, H. Chen, J.C. Huang and C.S. Hwang, "Pulsed-wire system for magnetic-field measurements on an in-vacuum undulator at NSRRC", Physics Open , (2022)
2. P. N'gotta , M. Ebbeni, A. Thiel, H. Tarawneh, First Results of a Pulse Wire Measurement System for ID Characterization at MAX IV, IMMW21 Grenoble, France.

First integral field measurement

Short Pulse: 10us

- The first integral field of the Hall-probe measurement is obtained on numerical integration of the results of the magnetic-field measurement.
- the pulsed-wire measurement data are inserted into equation (1) to obtain the first integral field

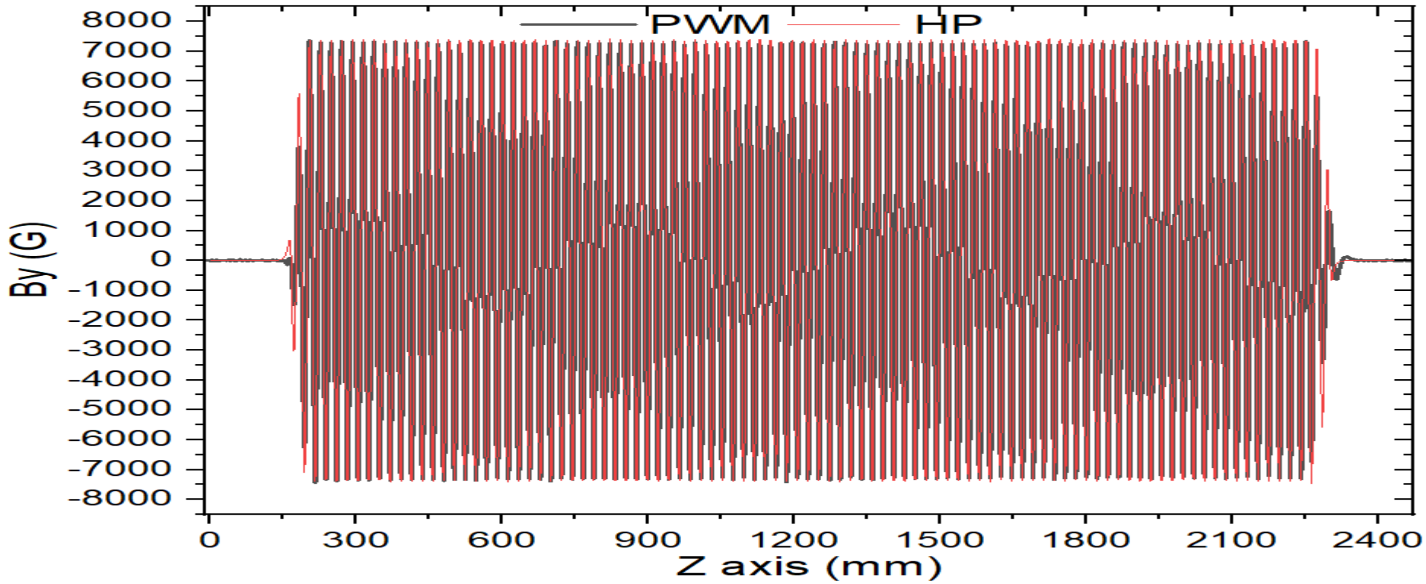


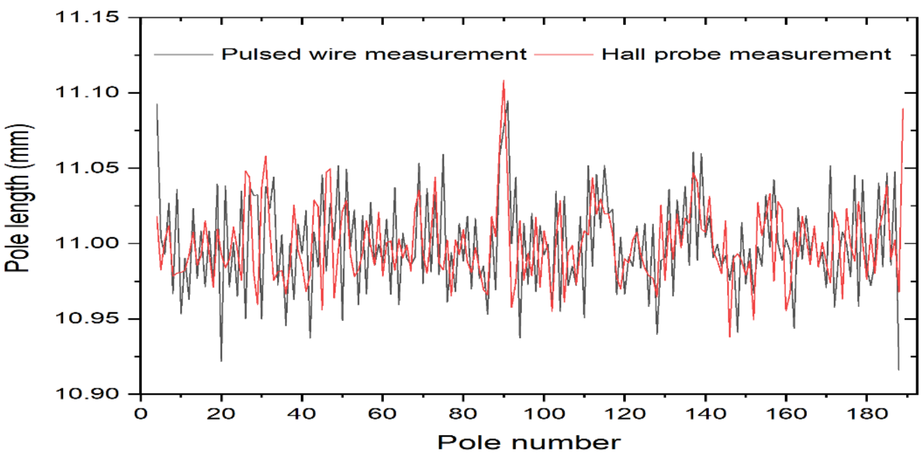


Magnet field results

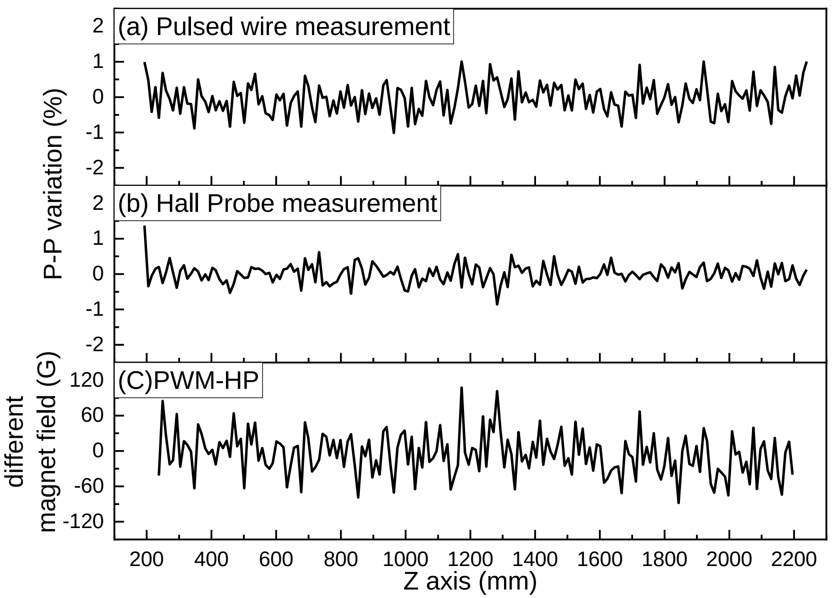
IBy

differential





the average pole lengths of the pulsed-wire and Hall-probe measurements are 10.9995 mm and 10.9990 mm; the variation is less than 1 %



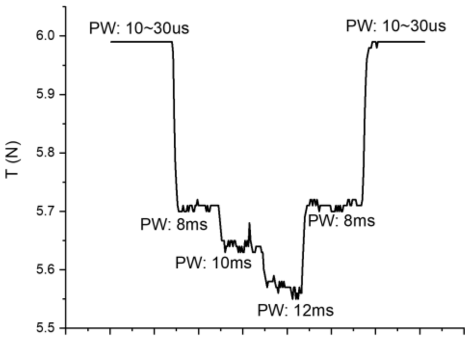
the variation peak to peak is less than 1 %

Second integral field measurement

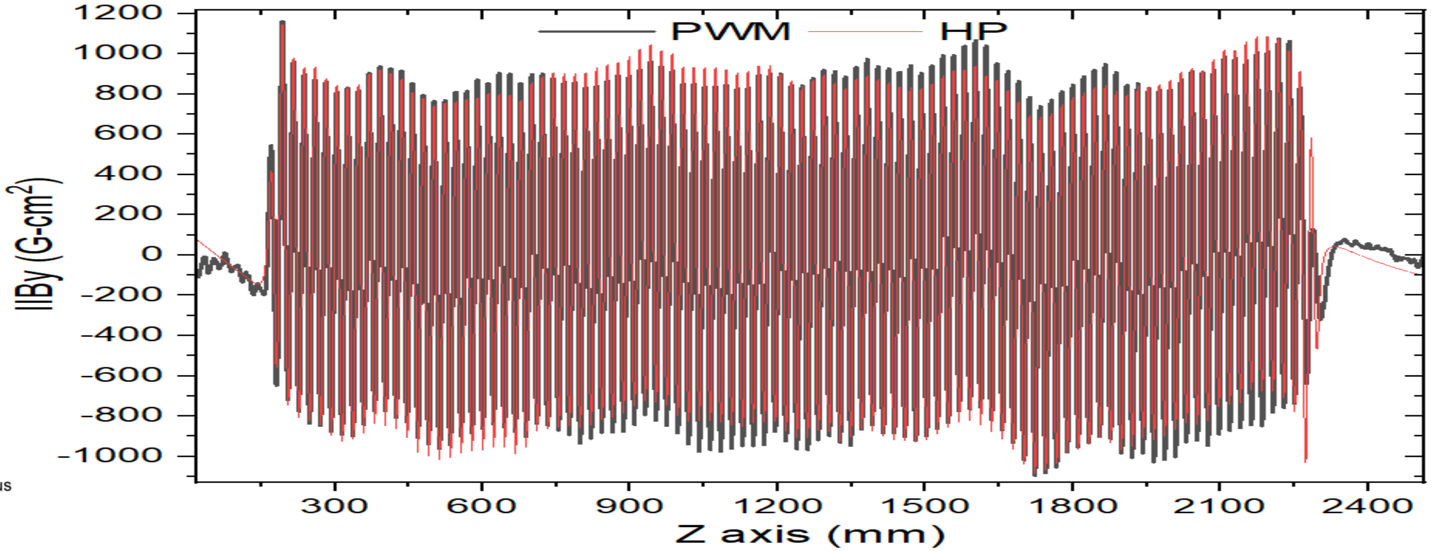
Long Pulse : 20ms

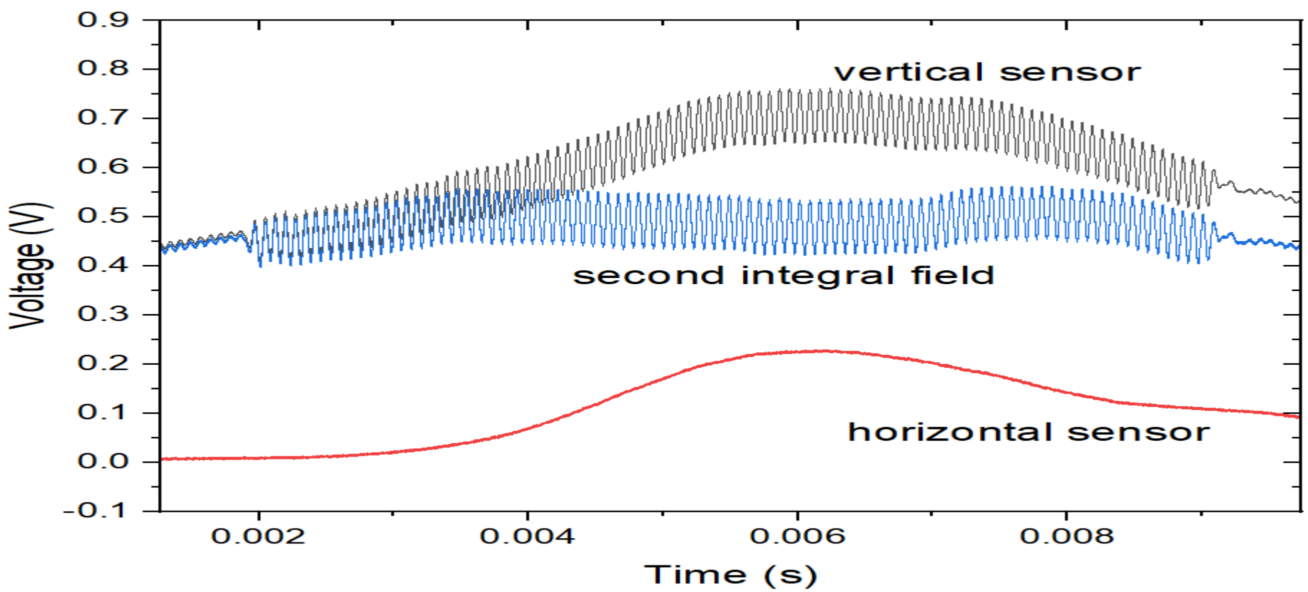
- the performance of the second integral field is similar, but the amplitude is slightly different

- The momentum change is different in the case of the 1st and 2nd integral field measurement. The tension will be also different.



The solution is either to adjust the suitable tension for the 1st and 2nd integral field measurement or subtract the couple effect from the vertical axis to avoid the disturbance.





During the pulsed-wire measurement, we observed that both the vertical and horizontal optical sensor pair detected the displacement signal

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Summary

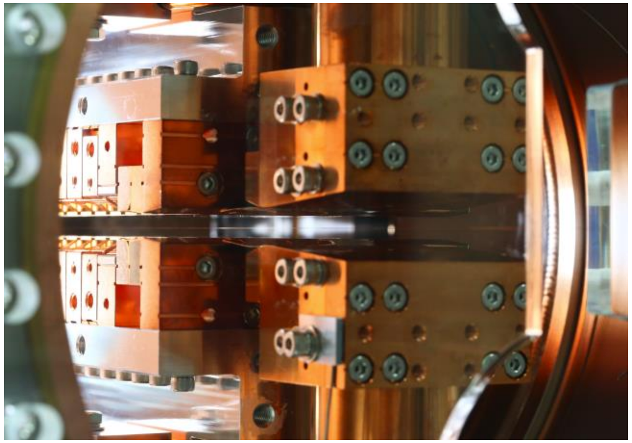
- the CuZr wire is better than BeCu wire in both resistance and sag at the same diameter and length

- the oil dampers can absorb wave dispersion and most reflected waves

- the results of the pulsed-wire measurement with a undulator (length 2 m) are compared with the Hall-probe measurement
  - the performance of magnetic fields is similar
  - the pole-length errors and peak to peak are both less than 1 %
  - the difference in peak magnetic fields between the two measurement systems are less than 1 %.
  - the first and second integral fields are similar

- the pulsed-wire system provides quick measurements of the magnetic field and is easy to install on any undulators

- in the future we can apply to measure the magnetic field of undulators with small gaps



Thank you for your attention

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