國家同步輻射研究中心
National Synchrotron Radiation Research Center

Vibrating Wire Method and Related Positioning Study for TPS

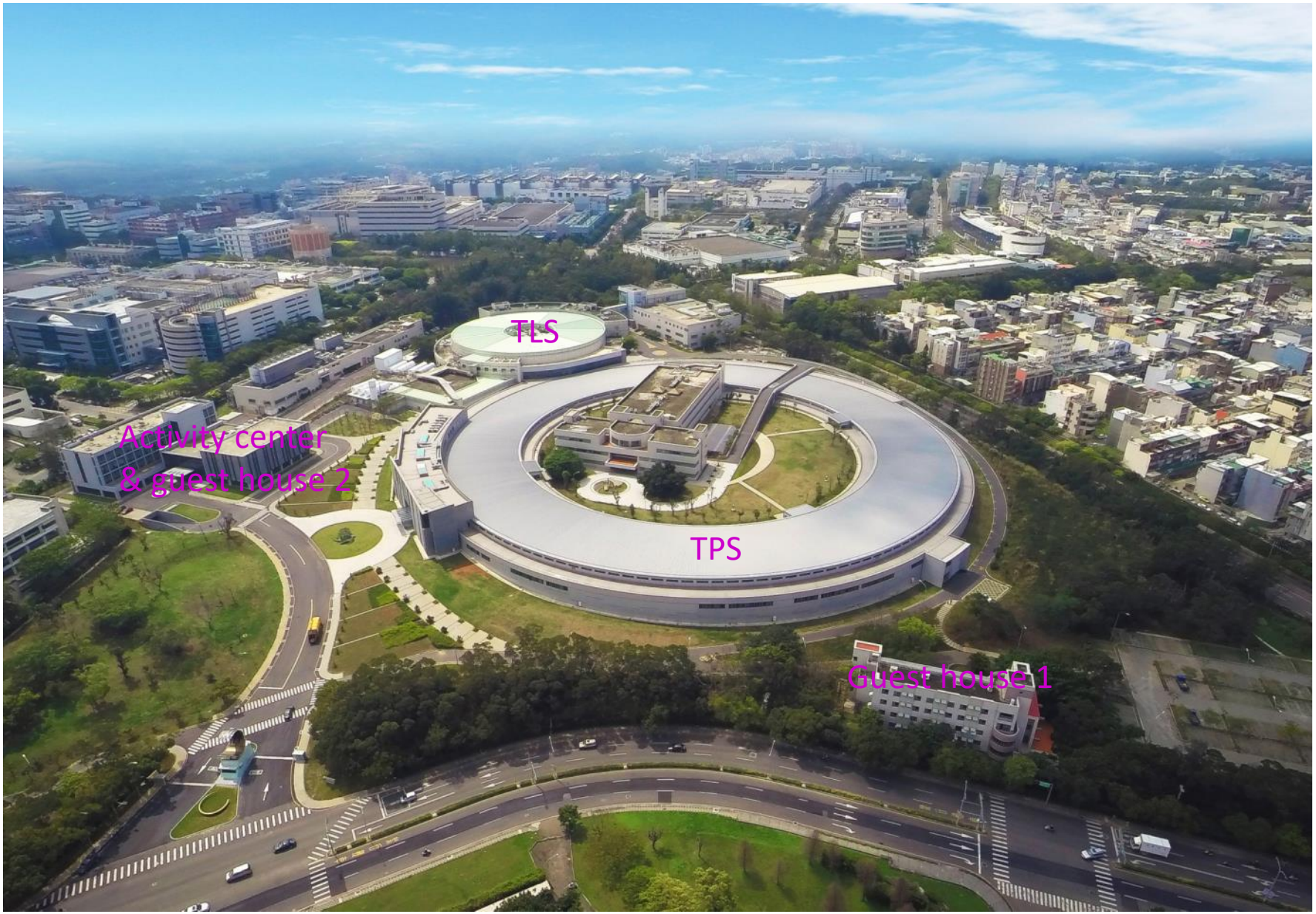
Tse-Chuan Tseng
NSRRC, Taiwan

IMMW21 , June. 28, 2019

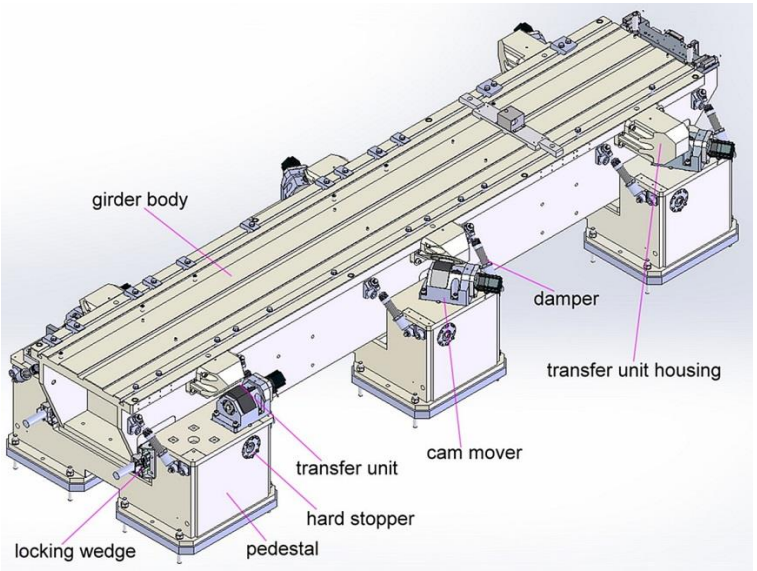
Outline

- Introduction
- VWM System & Testing Bench Setup
- Hardware Testing
- Magnet Testing Results
- Girder Moving Testing Results
- Conclusions

NSRRC Site Aerial View



TPS Storage Ring Girder Design

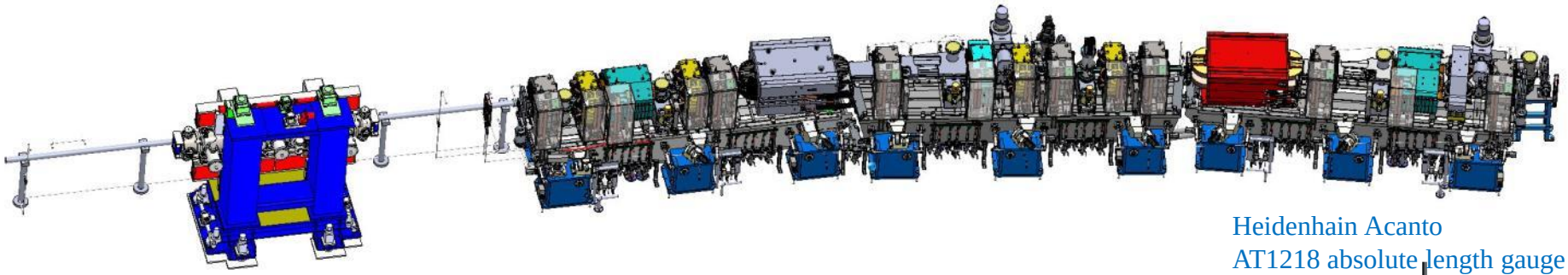


- 3 girders to form a bending section and 72 girders to fit 24 lattice sections.
- Each girder can be 6 axially adjusted with a resolution of 1um and the whole ring positioning accuracy is within 500um.
- Each girder surface was precisely machined with reference channels of flatness < 15um/4m to accommodate and align magnets.

TPS Storage Ring Girder System Design

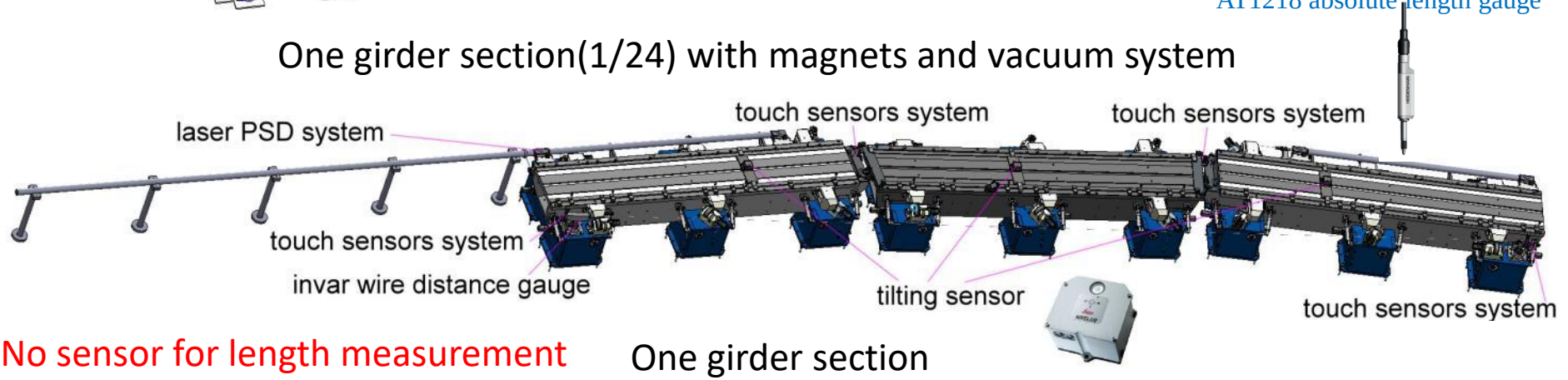
3 kinds and 5 types of girder

1/6 ring symmetry super-period configuration



Heidenhain Acanto
AT1218 absolute length gauge

One girder section(1/24) with magnets and vacuum system



No sensor for length measurement of straight section

One girder section

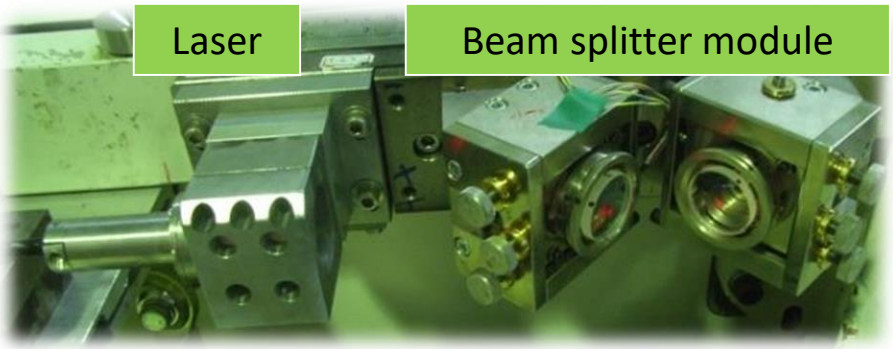
Leica Nevil220 tilting sensors

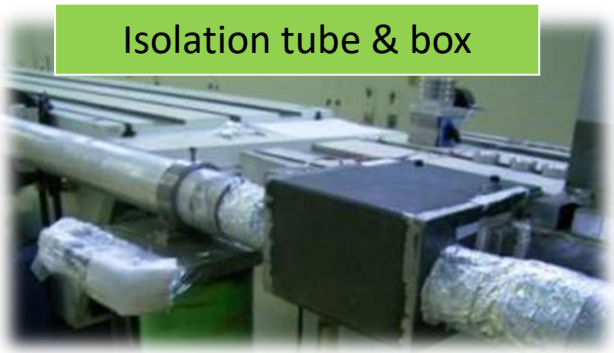
Laser PSD System Architecture

- Fiber Laser
  - Gaussian distribution at 4 operation locations
  - small pointing drift (<±0.5 um within 1000 sec)
- PSD
  - 4 sets of PSD indicate to positions of two girders
  - 0.5 um resolution
- Beam Splitter Module
  - installed on girder and combined with PSD
- Isolation tubes and box
  - constructed by aluminum tube and foam tube
  - cover whole laser path to prevent temperature variation and air disturbance

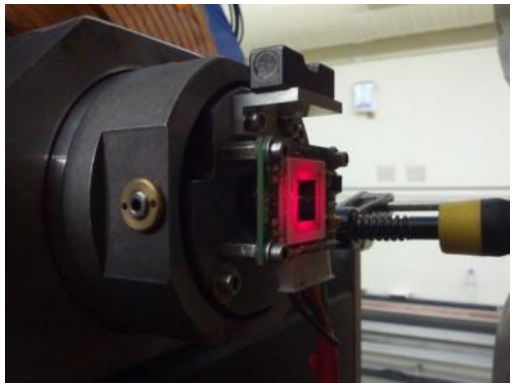
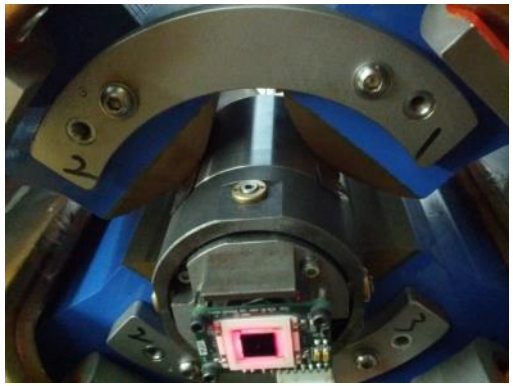
13m , for short straight section

- **Problem**
  - Decay of the expensive laser
  - Incapable to detect the variation in longitudinal direction

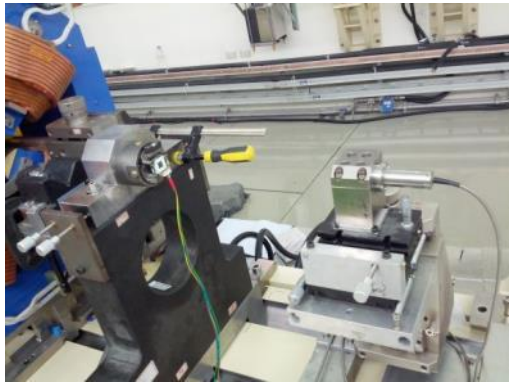
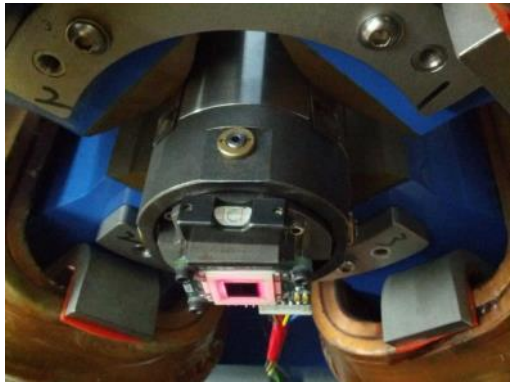




Magnet Centralizing

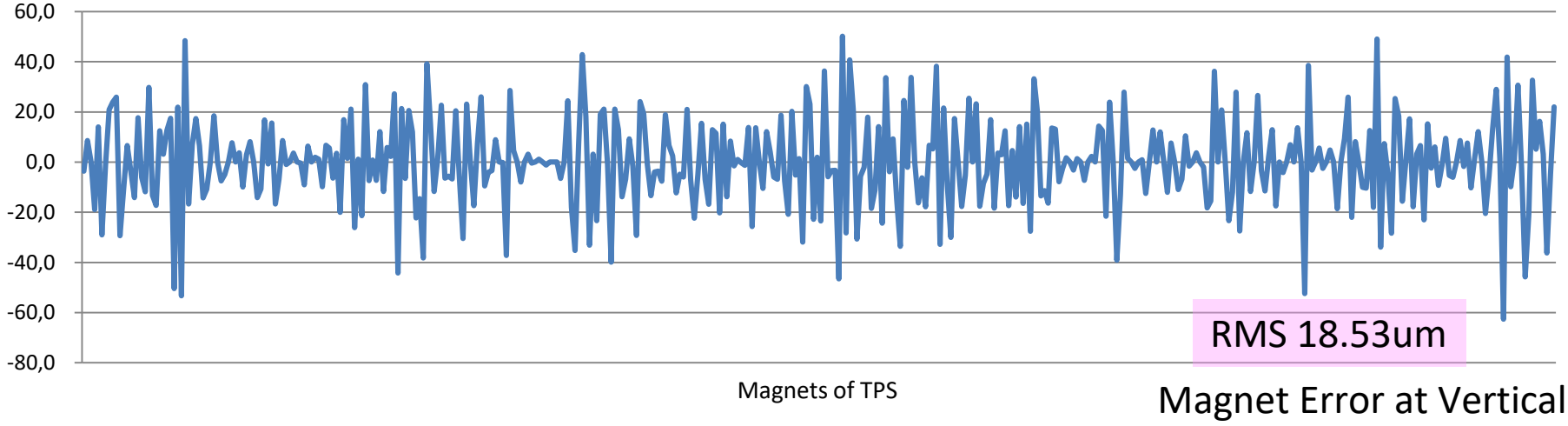



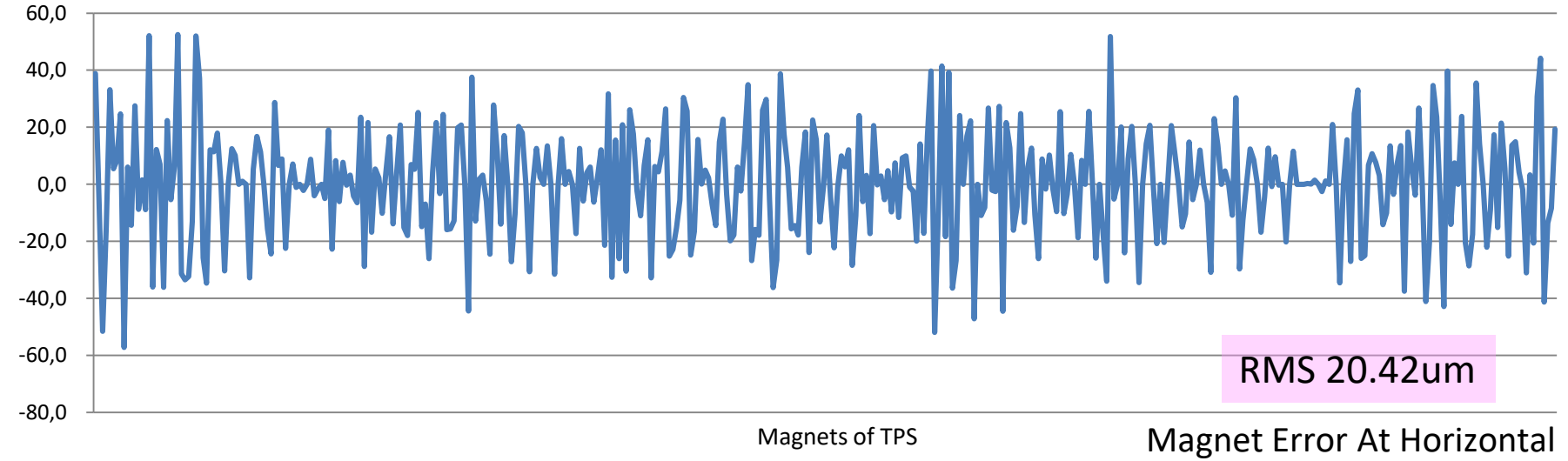



- Adjust Position Jig and Circular PSD jig
- Install two position jigs with PSD on girder
- Adjust laser to parallel and have equidistance to girder datum plane
- Replace the Position jig with the quadrupole and sextupole magnets
- Insert Circular PSD jig on the center of quadrupole and sextupole magnets
- The offset of beam position can be detected by PSD
- Insert the steel shims between magnet and girder for error compensation

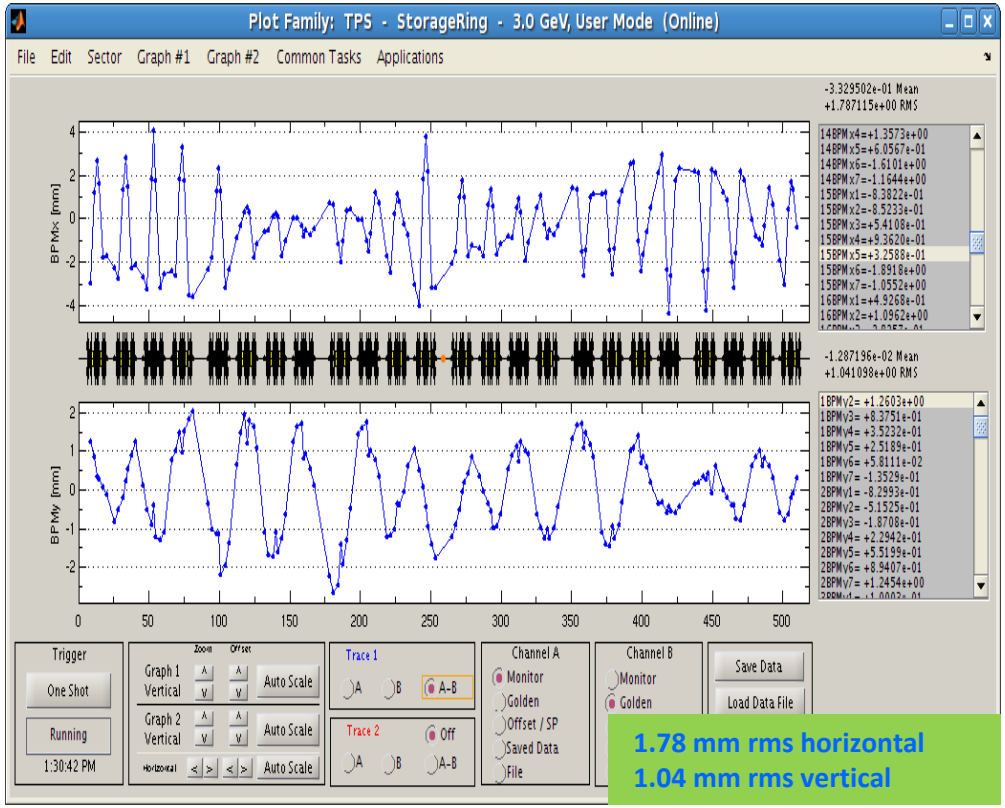
Magnet Centralizing Results





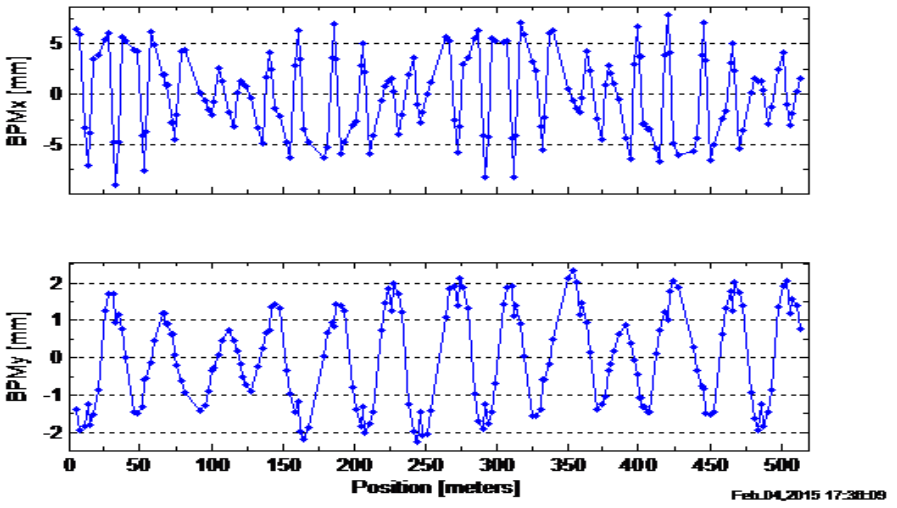
Most magnets were acceptable but a few were still shimmed after double checked

TPS COD before Correction



1.78 mm rms horizontal
1.04 mm rms vertical

Measured COD with all correctors off
After LOCO and BBA



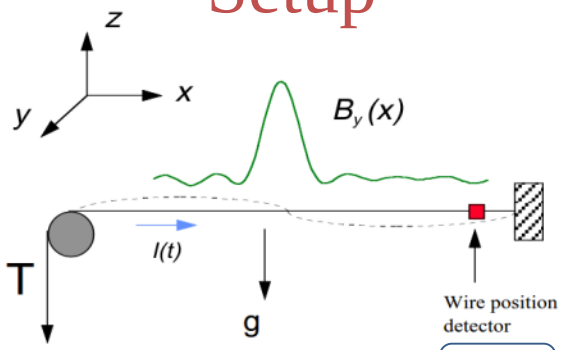
Simulated COD with all correctors off
from alignment errors, dipole field errors

The measured data were even better shows good alignment conditions

* *C. C. Kuo, et al., "Commissioning of the Taiwan Photon Source", IPAC'15* .

Theory of Vibrating Wire (VW) Magnetic Field Measurement Technique

Setup



Motion equation

$$\mu\frac{\partial^2 U}{\partial t^2} = T\frac{\partial^2 U}{\partial x^2} - \gamma\frac{\partial U}{\partial t} - \mu g + B_y(x)\cdot I_0 exp(i\omega t) \quad (1)$$

Taut wire free motion — Damping — Gravity — Lorenz forces between magnetic field and driving current

General solution $U(x,t) = U_g(x) + U_b(x)\cdot exp(i\omega t)$ with boundary condition: $U(t,0) = U(t,l) = 0$

Gravity — Wire motion induced by Lorentz forces

Gravity term $U_g(x) = -\frac{\mu g}{2T}x(x-l)$ with minimum $S = -\frac{\mu g}{8T}l^2$ (sag) at $x = l/2$

$U_b(x)$ and $B_y(x)$ can be represented in the similar way: $U_b(x) = \sum_{n=1}^{\infty} U_n \sin\left(\frac{\pi n}{l}x\right)$; $B_y(x) = \sum_{n=1}^{\infty} B_n \sin\left(\frac{\pi n}{l}x\right)$

$$\sum_{n=1}^{\infty} U_n\cdot\left(\omega^2 - \omega_n^2 + i\gamma\omega\right)\sin\left(\frac{\pi n}{l}x\right) = \sum_{n=1}^{\infty}\frac{I_0 B_n}{\mu}\sin\left(\frac{\pi n}{l}x\right) \quad ; \omega_n = 2\pi\frac{n}{2l}\sqrt{\frac{T}{\mu}}$$

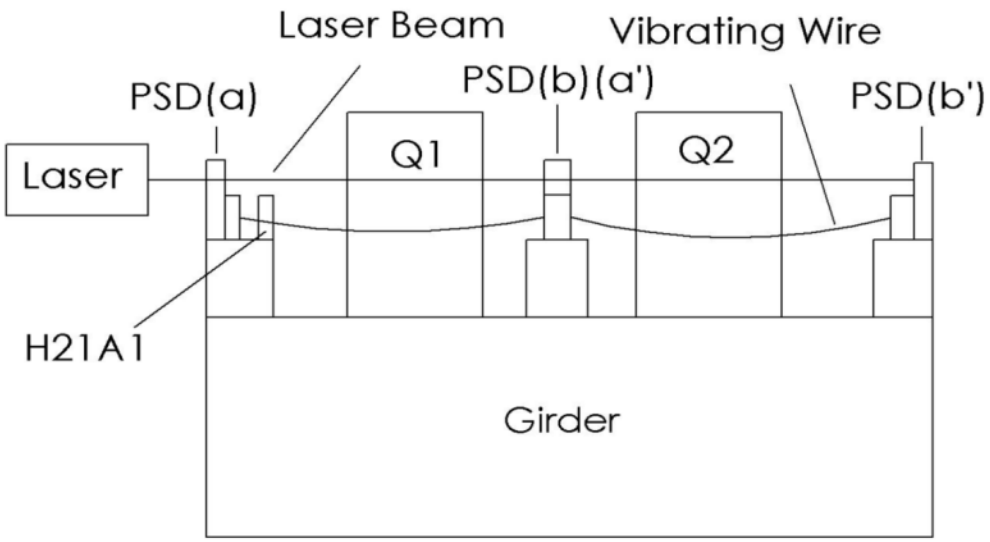
Wire vibrating mode amplitude → $U_n = \frac{I_0}{\mu\left(\omega^2 - \omega_n^2 + i\gamma\omega\right)} B_n$ ← Term in the magnetic field Fourier sine series expansion

A. Temnykh, Vibrating wire field-measuring technique, NIMA 399 (1997) 185-194

The Reason for VWM

- the magnetic centers & mechanical center alignment are still a discussion topic.
- The PSD method relies on skilled technician. After the installation of TPS, while the short time technician left, our colleague seems hard to reproduce the precise measurement.
- The successful and admiring result of NSLS II in addition with the experiences in other facilities
- The VW method is interested the magnet people not only for magnetic field measurement but also for alignment magnet on the girder in case the installed magnets in TPS storage ring is out or order and a replacement is demanded. – not urgent work!

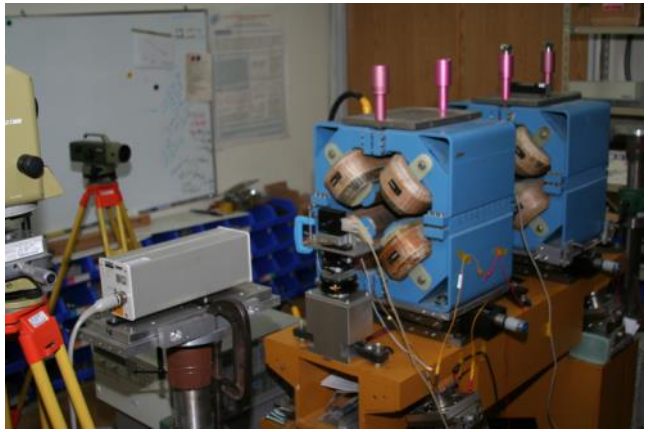
Vibrating Wire Method Studied in the Past



EXPERIMENT SETUP

Liren Tsai,etl., "Precise Positioning of Quadruple Magnetic Field Centers on the Girder," APAC2007

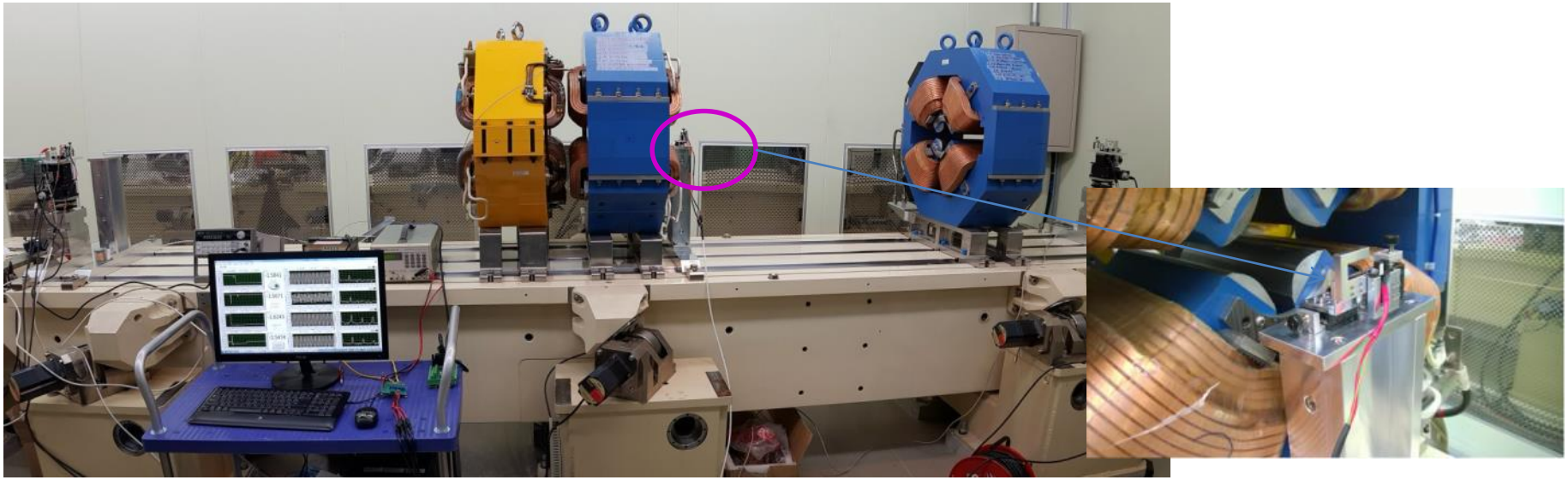
After the colleague left NSRRC and no manpower to resume this study, all the components were put into storage for ten years.



The accuracy of the measurement system was checked with level and theodolite

The PSD is on a slide which allowed the laser beam to pass through the quadrupole to reach the PSD at the other end.

Testing Bench on a TPS Backup Girder

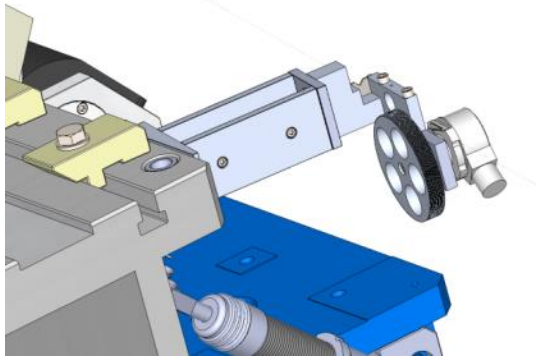


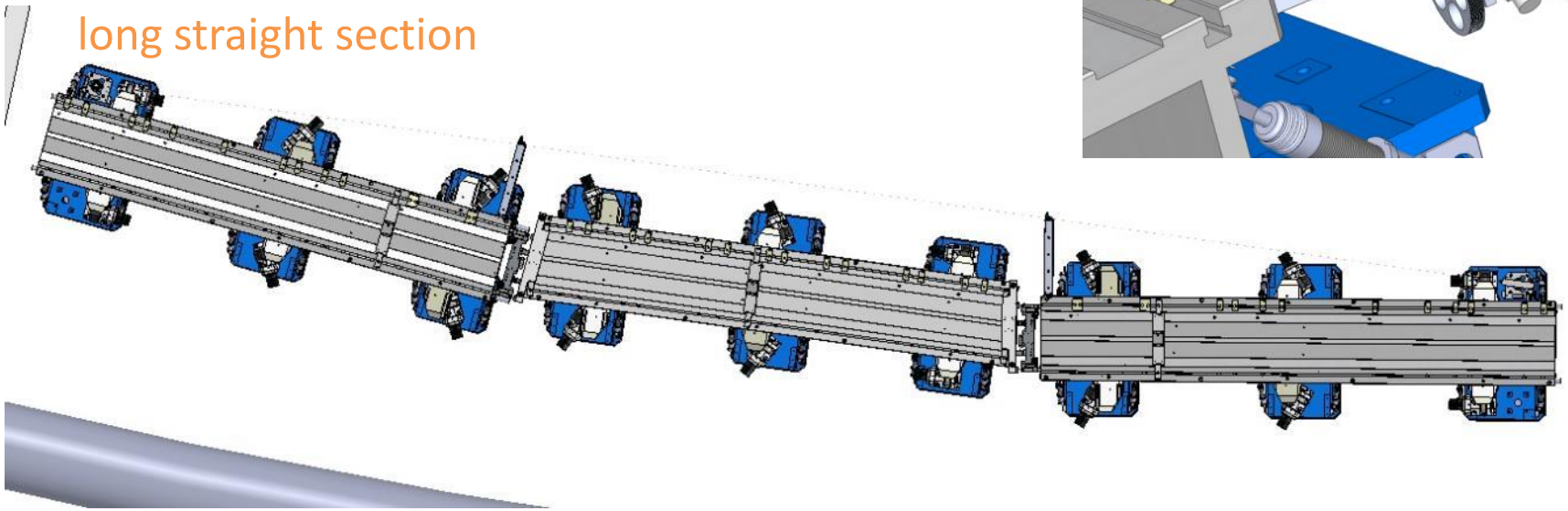
- Modified the past study system for the TPS girder and magnets
- 4.5m long 0.1mm diameter beryllium copper wire
- 0.86kg tension weight on the pulley side which results a 29.003Hz 1st NF and 0.001Hz deviation is detectable
- Movable wire stages, two sets of vertical and horizontal wire vibration sensors
- Fixed magnets as a center reference
- Various types of magnets (sextupoles and quads)
- Prepared for out of order magnet replacing

A Wire Positioning Study System use Phototransistor Sensor

An attempt to replace the decaying laser PSD system and complete the entire TPS storage ring girder sensors system

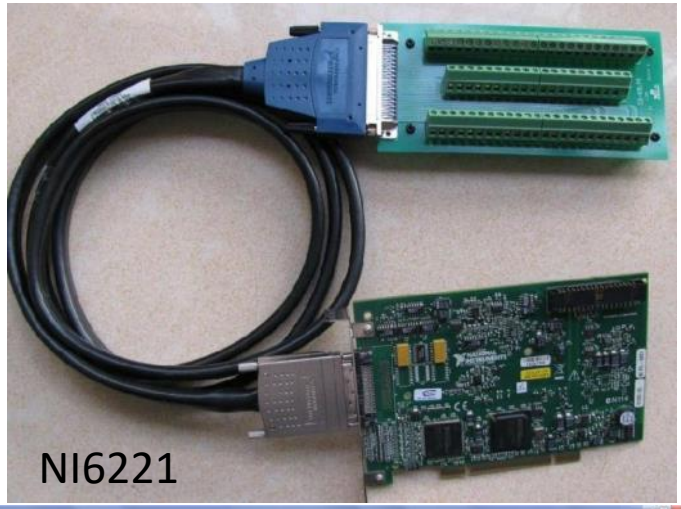
- 13m long 0.25mm diameter invar wire
- 1.6kg tension weight on the pulley side
- A Heidenhain ECN425 rotary encoder for longitudinal direction sensing
- 20m long wire will be required in the TPS long straight section



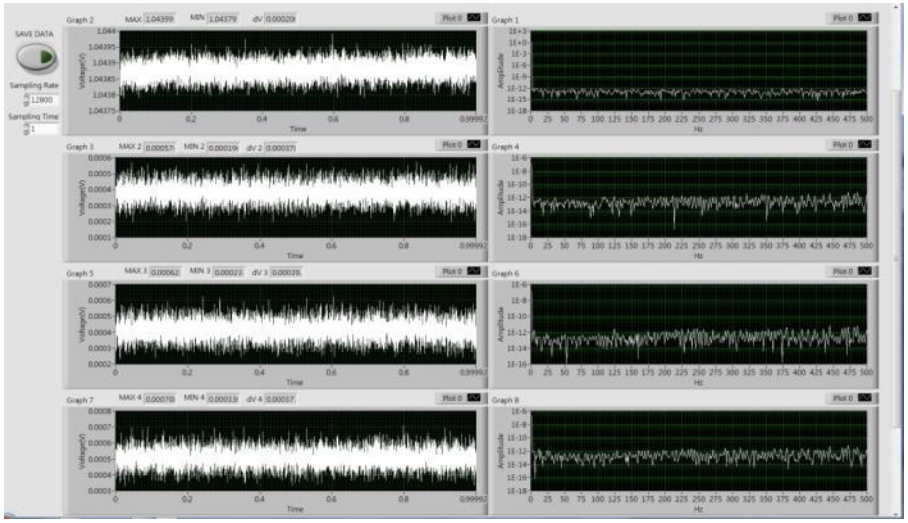


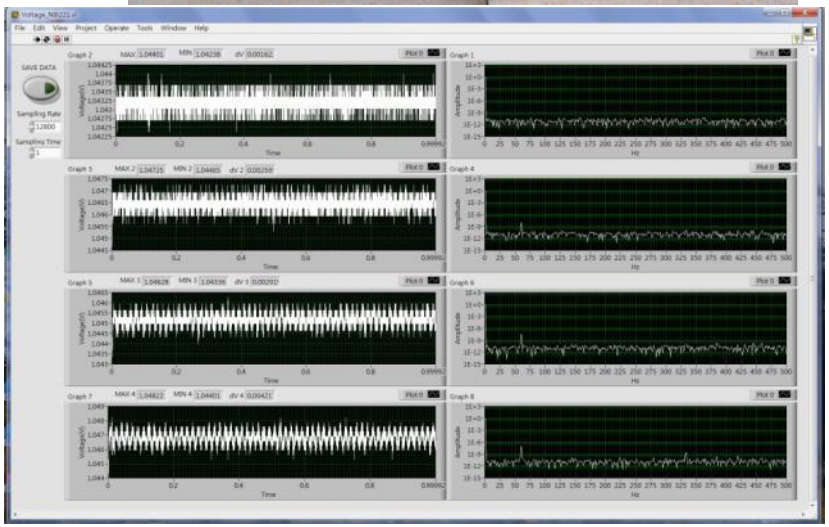
Test of DA Card (NI9234 & 6221)

USB NI9234



NI6221

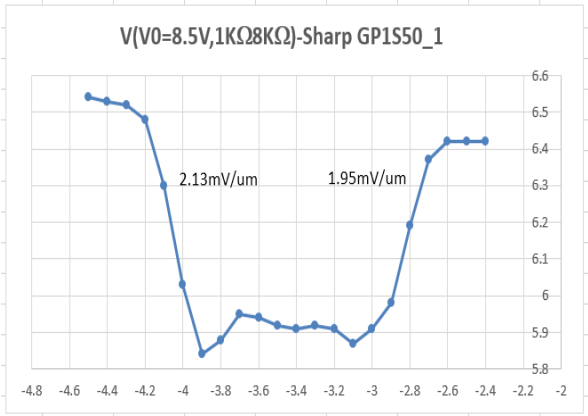


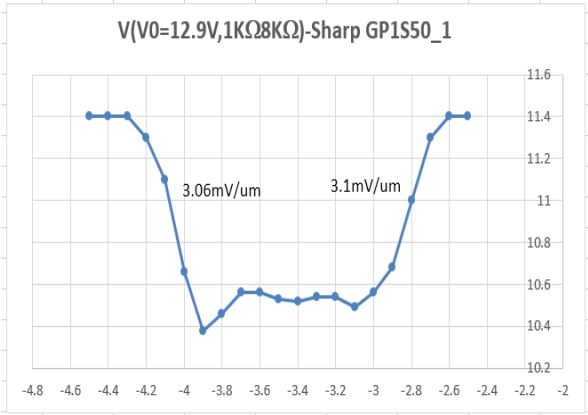


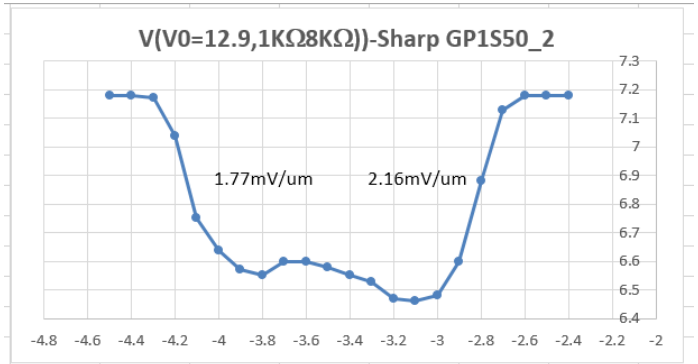
- The noise level of NI221 is nearly 10 times of USB NI9234

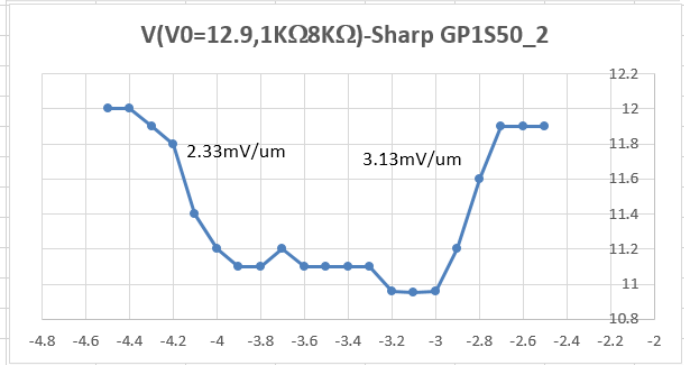
Phototransistor Sensor Test _ Sharp GP1S50

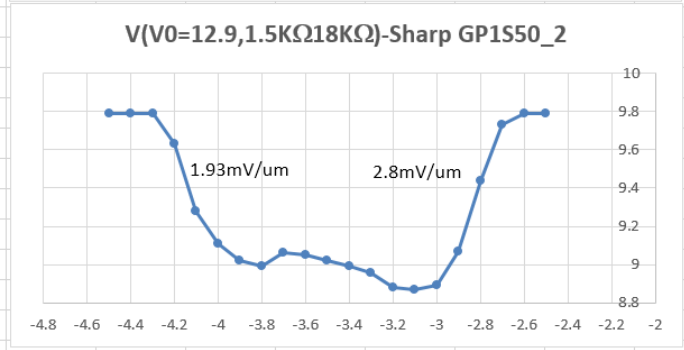
The linearity and effective range is not so good



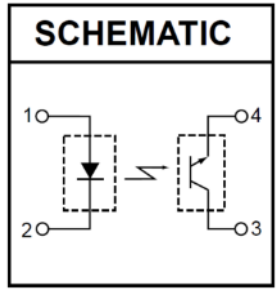




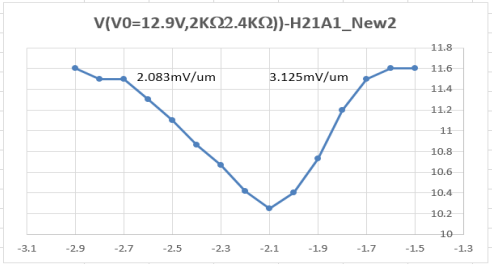


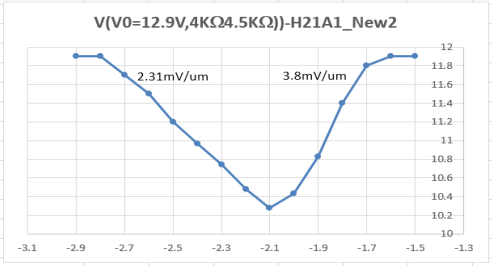


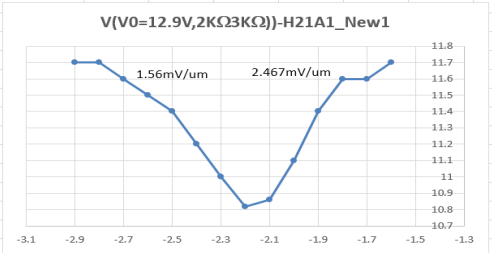
Phototransistor Sensor Test _ H21A1

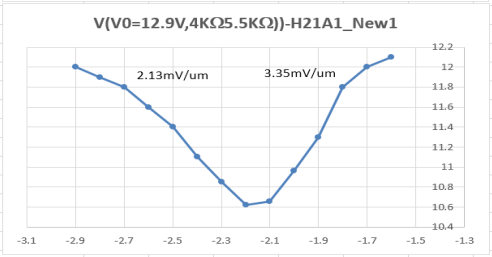


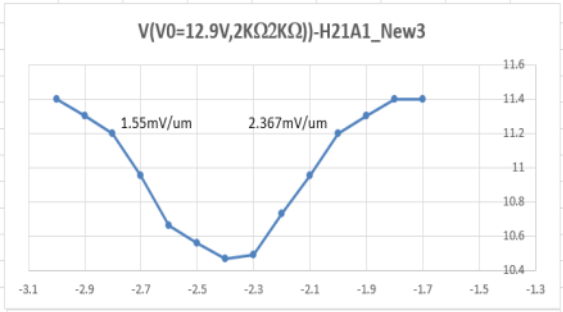
The linearity and effective range is Better
1um->0.25~0.3mV

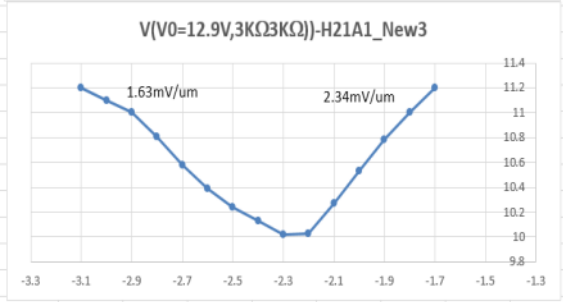


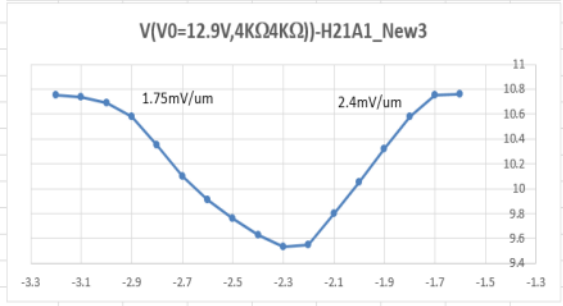


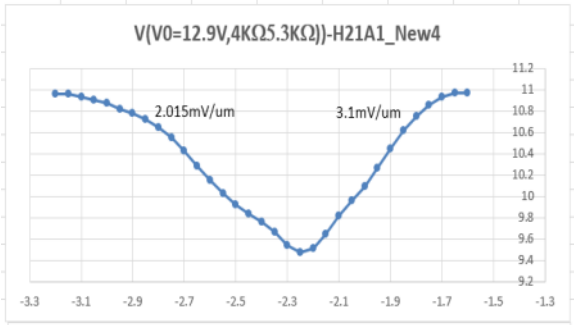


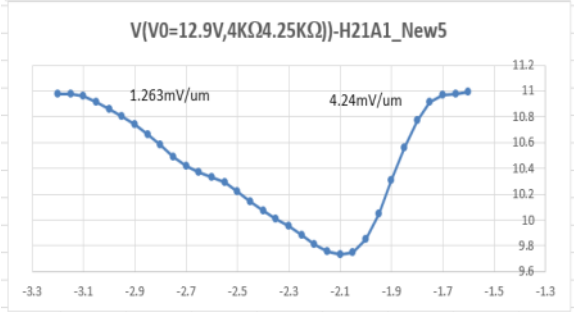


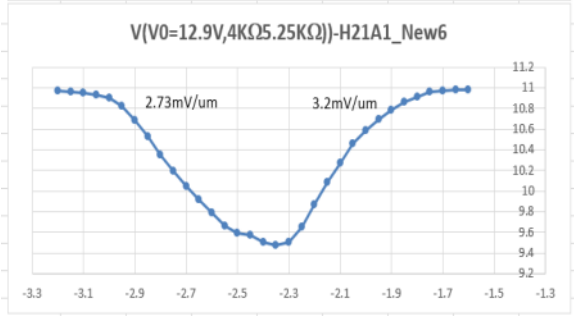












Phototransistor Electronic Circuit Design

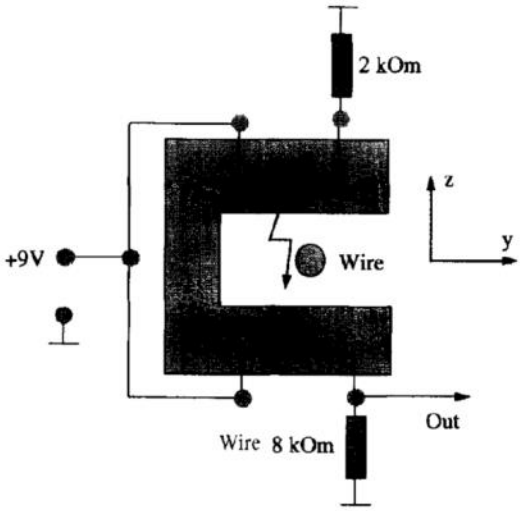
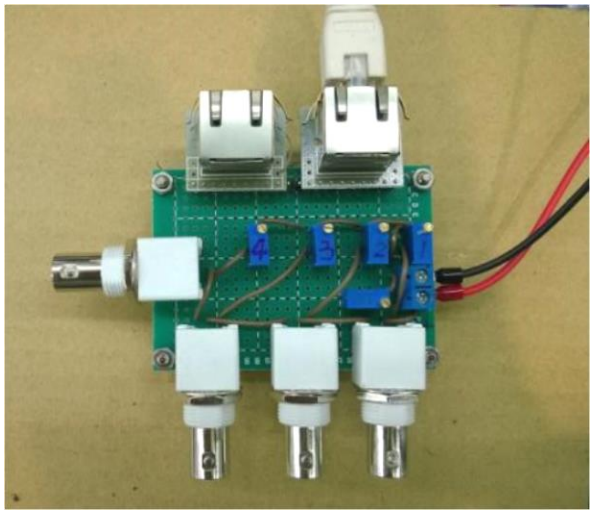
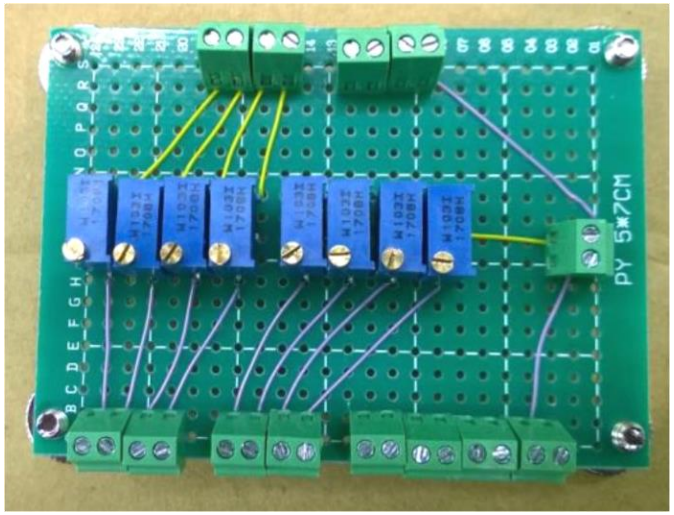


Fig. 2. Schematic view of LED-phototransistor assembly used as a wire position detector.

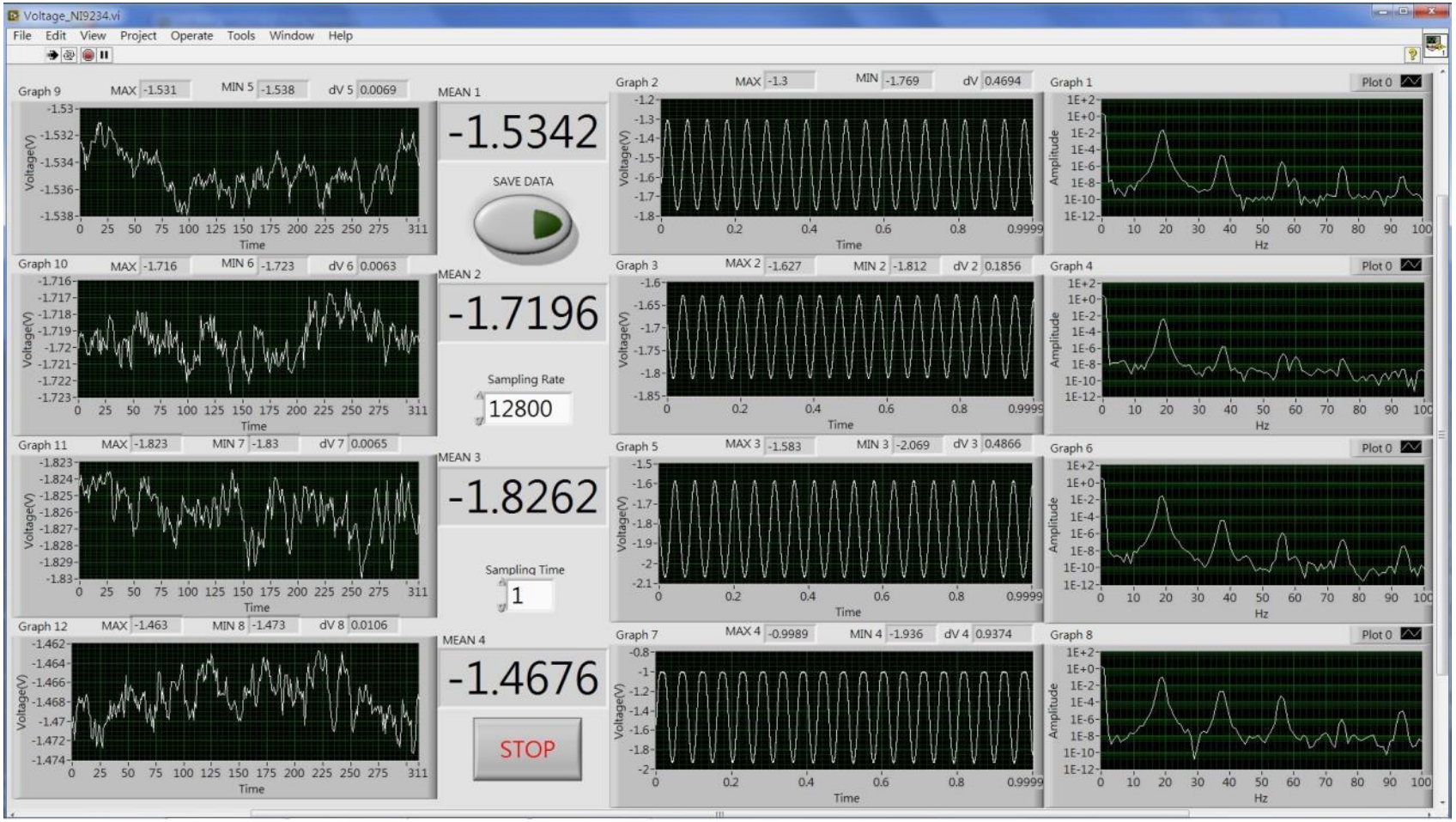
A. Temnykh, Vibrating wire field-measuring technique, NIMA 399 (1997) 185-194

there is interactive between with only one input resistor!





Labview Program Developed for Sensor Data Acquisition and Stage Control

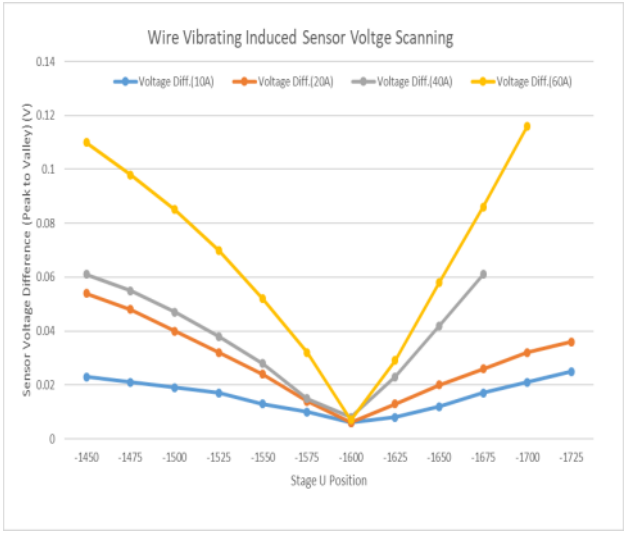


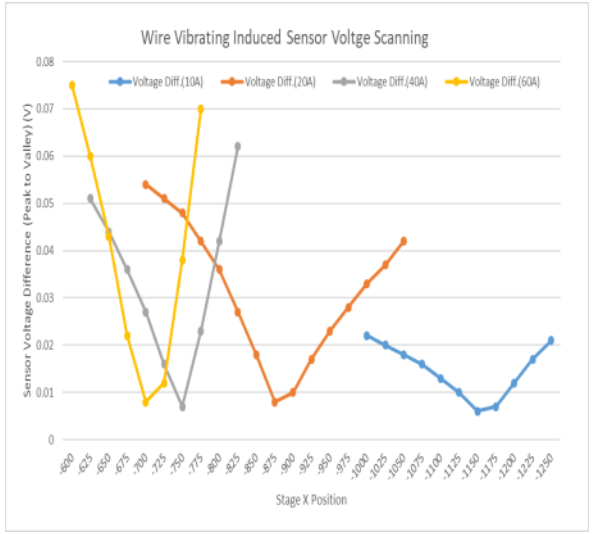
L:4.55m, T:0.33kg, f1=18.787,ml=9.15g/100m (BeCu wire Goodfellow)

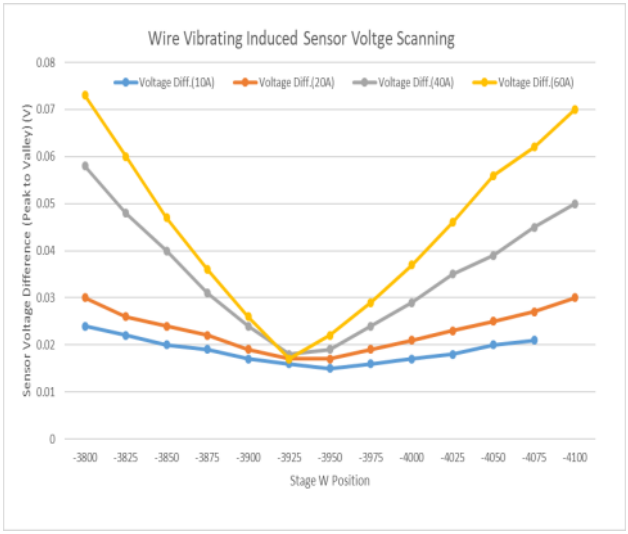
Phototransistor sensing range -1V ~2.4V

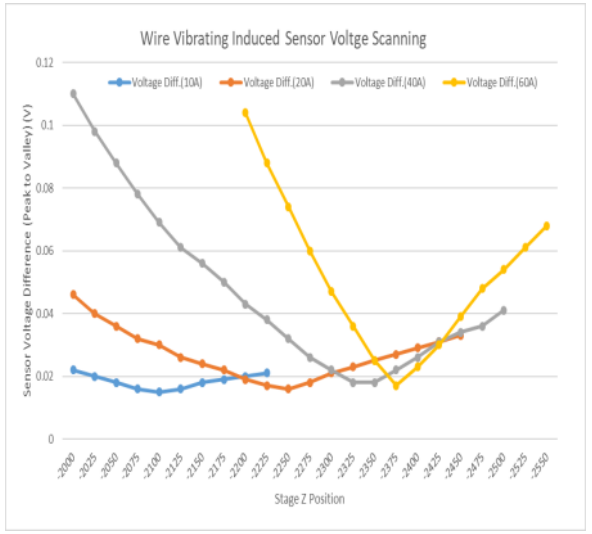
The Quadrupole Test Result

- The wire vibration excited by the magnetic field can be depressed with the adjustment of end stages
- The wire vibration amplitude can be depressed to a few um (P-V) range and the vertical direction is larger
- The stage position is different according to the current applied especially in the pulley side but the stability and repeatability (within 10um) is still good
- Further study and improvement Still required

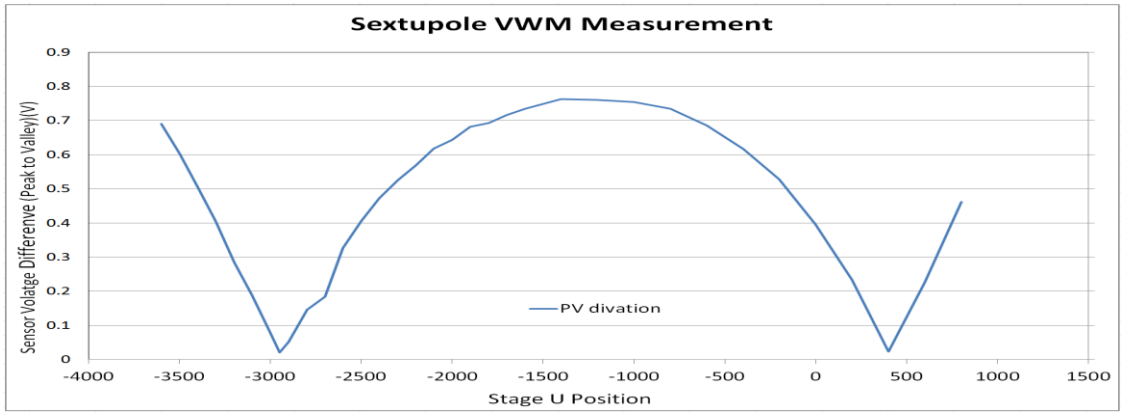


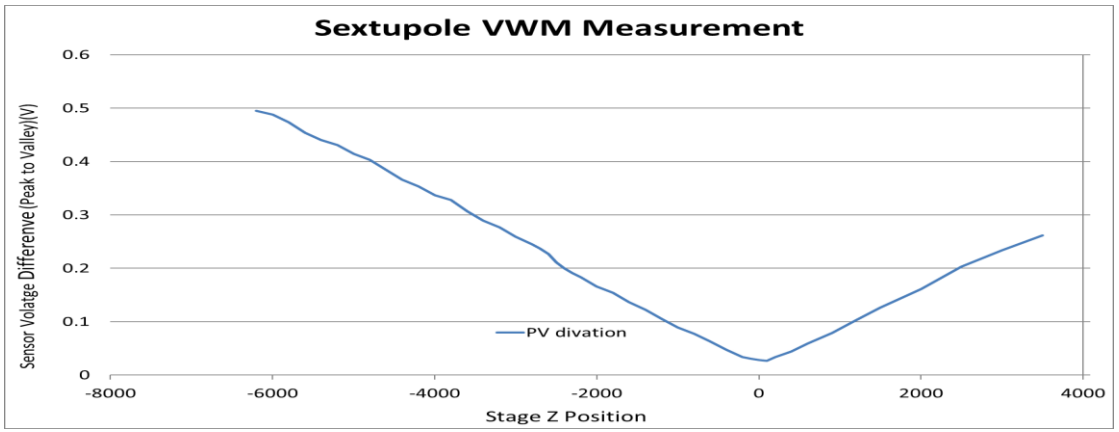


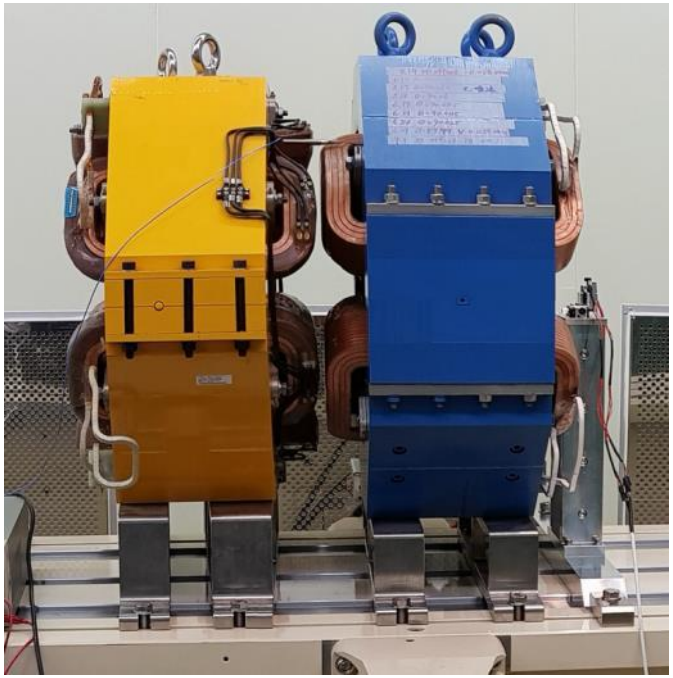




The Sextupole Test Result



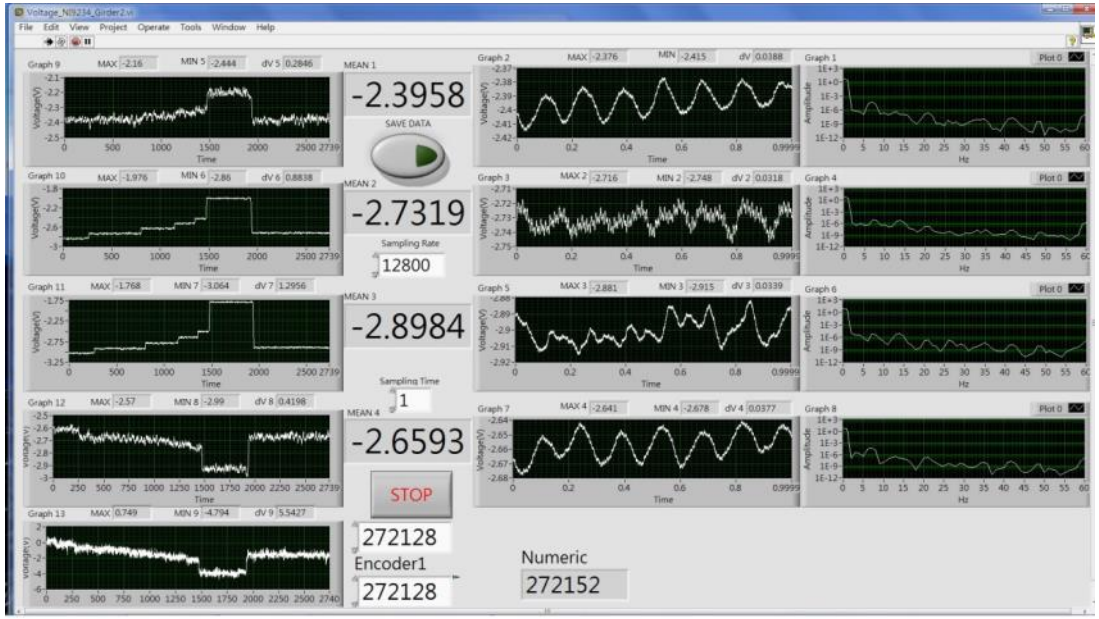




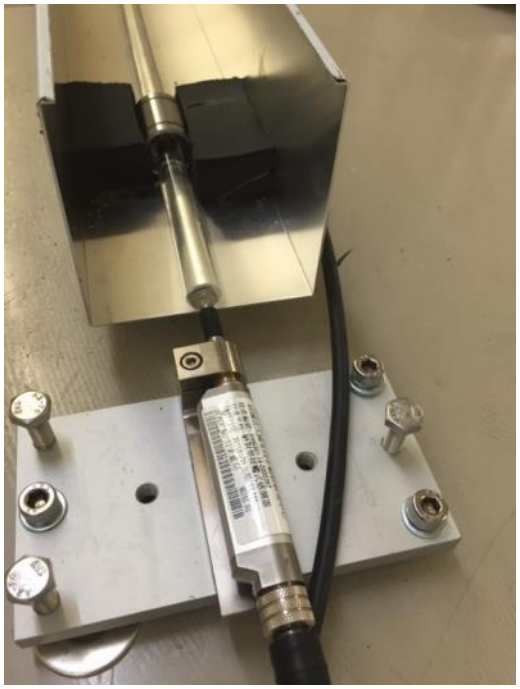
- 80A current
- The position average of the smallest voltage difference is -1275 while the center position detected from the quadrupole is -1600
- The center position of the quadrupole seems not at the position of the smallest voltage difference and also need to be scanned widely for a determination.
- Due to the system improvement for the sextupole scanning, the was no enough time for quadrupole re-scanning before this conference.

‘WPS’ Study Result

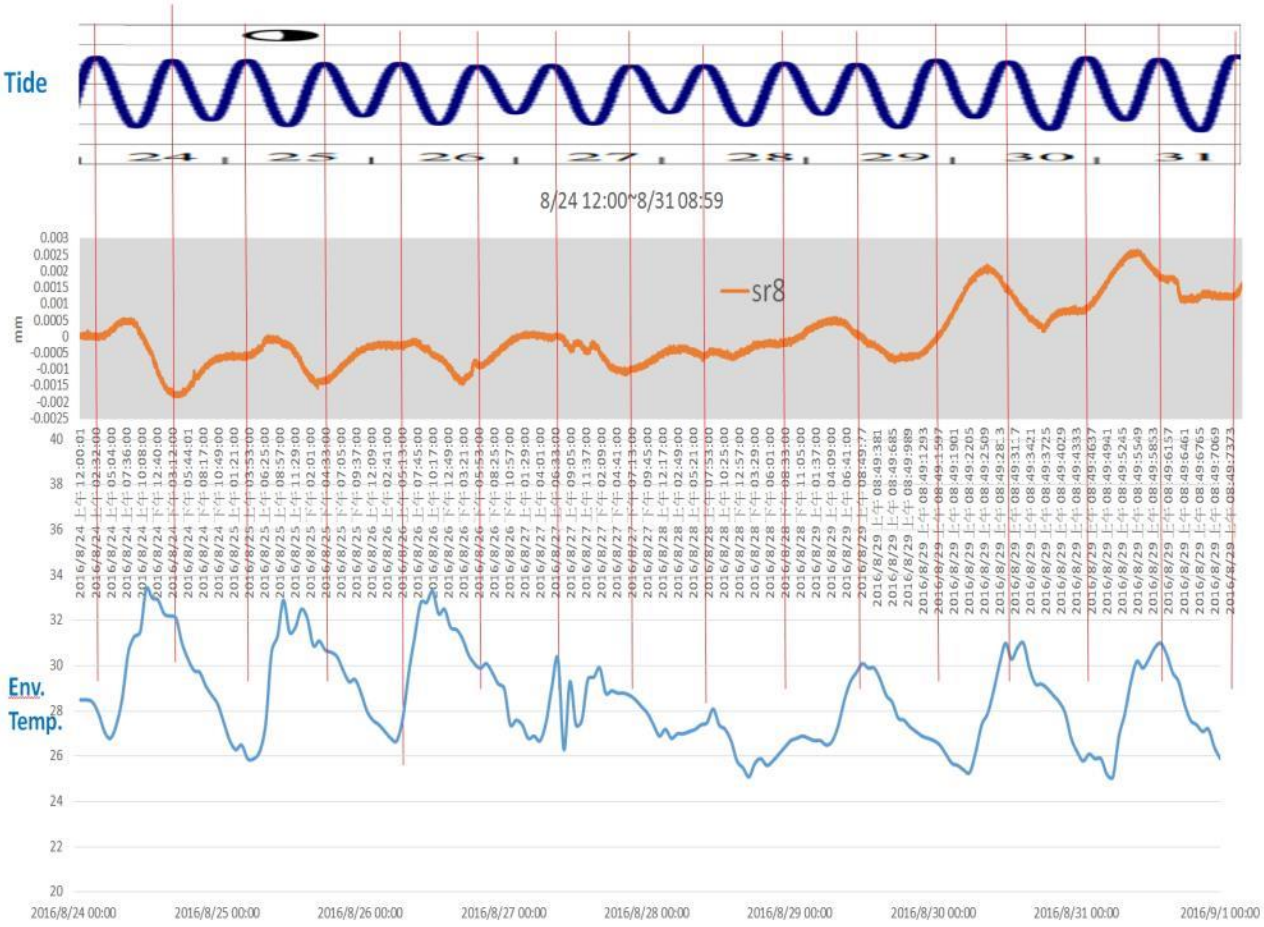
- A 8Hz 1st NF excitation detectable which induces 20 um vibration
- With curve fitting and elimination can get a few um stability
- A 0.1mm girder moving in the longitudinal direction and only a few um detected in the encoder indicate the friction effect hard to eliminate
- The raising in the vertical direction is obvious indicate the tension is increased
- However, the stability is still good and **with the combination of other sensors data** it can be calculated to an accuracy about 10um (this study)
- Further study and improvement still required



Ground Variation Due to Temperature and Tide



10M quartz glass bar on
4 girder section



Commissioning team found there is about 90~100um circumference variation correlated to daily environment temperature change and tide

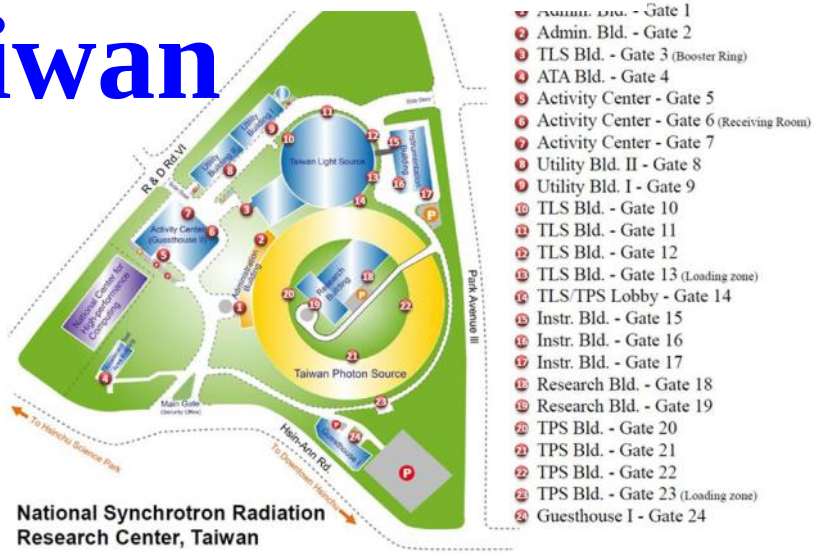
For a circumference of 518m, 3um deviation should be detectable in the longitudinal direction

Conclusions

1. A testing bench for vibrating wire method and related positioning (WPS) study was setup on the backup bending section 3 girders system in the TPS lab.
2. The preliminary quadrupole test results shows good repeatability condition but the accuracy still need to be investigated.
3. The preliminary sextupole test results shows good condition for magnetic field corresponding but The center position deviation form the quadrupole needs to be further check and the environment error compensation should be take into consideration.
4. Magnets fully current load with water cooling will be tested to decrease the scanning range and minimize the environment error .
5. The 'WPS' system attempt shows not so promising result and the system need to be further improved to meet the requirement !

Thank you for your attention!

Welcome to join IWAA2020 Oct. in Taiwan



1 Admin. Bld. - Gate 1
2 Admin. Bld. - Gate 2
3 TLS Bld. - Gate 3 (Booster Ring)
4 ATA Bld. - Gate 4
5 Activity Center - Gate 5
6 Activity Center - Gate 6 (Receiving Room)
7 Activity Center - Gate 7
8 Utility Bld. II - Gate 8
9 Utility Bld. I - Gate 9
10 TLS Bld. - Gate 10
11 TLS Bld. - Gate 11
12 TLS Bld. - Gate 12
13 TLS Bld. - Gate 13 (Loading zone)
14 TLS/TPS Lobby - Gate 14
15 Instr. Bld. - Gate 15
16 Instr. Bld. - Gate 16
17 Instr. Bld. - Gate 17
18 Research Bld. - Gate 18
19 Research Bld. - Gate 19
20 TPS Bld. - Gate 20
21 TPS Bld. - Gate 21
22 TPS Bld. - Gate 22
23 TPS Bld. - Gate 23 (Loading zone)
24 Guesthouse I - Gate 24