Vibrating Wire Method and Related Positioning Study for TPS

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Outline

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• Hardware Testing
• Magnet Testing Results
• Girder Moving Testing Results
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NSRRC Site Aerial View

Activity center & guest house 2

TLS

TPS

Guest house 1
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

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

3 kinds and 5 types of girder

1/6 ring symmetry super-period configuration

Heidenhain Acanto AT1218 absolute length gauge

No sensor for length measurement of straight section

Leica Nevil220 tilting sensors
Laser PSD System Architecture

- **Fiber Laser**
  - Gaussian distribution at 4 operation locations
  - Small pointing drift (\( \pm 0.5 \text{ um within 1000 sec} \))

- **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

- **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
Most magnets were acceptable but a few were still shimmed after double checked.
TPS COD before Correction

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

Measured COD with all correctors off
After LOCO and BBA

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 term
\[
U_g(x) = -\frac{\mu g}{2T} x(x - l)
\]

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

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

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

Wire vibrating mode amplitude

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

1-st PACMAN Workshop, CERN Feb 2-4, 2015
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!
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.


After the colleague left NSRRC and no manpower to resume this study, all the components were put into storage for ten years.
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 1\textsuperscript{st} 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)

- The noise level of NI221 is nearly 10 times of USB NI9234
The linearity and effective range is not so good.
The linearity and effective range is Better 1μm->0.25~0.3mV
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, there 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

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