Conceptual idea

Vibrating wire scanner - dream of 1994

FARADAY CUP 1994

Vibrating wire scanner test in lab
[Arutunian et. al., PAC (March 29 - April 2, 1999, New York City)]
Simple theory: why VWS sensitivity is extremely high?

\[
F = \frac{1}{l} \cdot \sqrt{\frac{\sigma}{\rho}} \\
\frac{\Delta F}{F} = \frac{E}{2\sigma} \cdot \frac{\Delta l}{l} \\
\frac{\Delta F}{F} = -\frac{E}{2\sigma} \cdot \alpha_s \Delta T \\
E = 200\text{GPa} \\
\sigma \ll \text{tensile strength} = 500 - 800\text{MPa} \\
E / \sigma \approx 500
\]

\(\rho\) material density \\
\(\sigma\) wire strain \\
\(l\) wire length \\
\(E\) modulus of elasticity
Single wire VWS (DESY, PETRA)

1- wire
2- clips
3, 4 – magnet poles
5 – support
6, 7 – fastening details
Frequency measurement algorithm

Time $t_1$ – wire periods counting start
Time $t_2$ – wire periods counting end

$T_{wire}$ – wire oscillation period
$T_q$ – quartz oscillation period
$F_{wire} = F_q \times N_{wire} / N_q$
$t_2-t_1=$ gate in range 100 ms-30 s

Measurement resolution at $F_{wire}$ about 5000 Hz and $F_q=1.0000$ MHz

<table>
<thead>
<tr>
<th>gate, s</th>
<th>Resolution, mHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>50</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td>0.16</td>
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VWS mounted on the vacuum below with 1 \( \mu \text{m} \) step motor feed

Scan of the electron beam at the Injector of Yerevan Synchrotron with an average current of about 10 nA (after collimation) and an electron energy of 50 MeV
Proton beam

PETRA proton beam parameters
E=15 GeV, I=15 mA
sigmax = 0.6 cm, sigmaz = 0.5 cm

1- VWS frequency,
2 – proton current,
3 – VWS position,
4,5 - scintillator-photomultiplier pickup signals (PM).
Full scan – 20 mm PM1 began to increase beyond the position 9.3 mm, VWS – immediately
Discussion

1. Vibrating wire sensors can be used for many types of beam diagnostics because only a small amount of heat transfer from the measured object to wire is needed. VWS can be successfully applied to electron, proton, ion, photon and neutron beam monitoring.

2. Special tasks: weak beam instrumentation, beam halo and tails monitoring.

3. Property to measure very hard spectral component permits to separate the radiation from insertion devices and to cut unwanted contributions from other accelerator sources.

4. Recent application of the VWS in air has allowed a dramatic reduction in response time, together with a reduction in system cost by a large factor.

5. So called “smart aperture” concept (G.Decker)
Hard X-ray synchrotron radiation measurements at the APS with vibrating wire monitors*

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2008 Beam Instrumentation Workshop, Lake Tahoe, CA
VWM Exploded View

1. VWM Base
2. Vibrating wires
3. 4, 5. Fastening Parts
6. Fastening Plate
7. Contact Plate
8. Soldering Surfaces
9. Screw
10. Permanent magnet
11. Magnet poles
12. VWM mounting screw
Plan View of VWM@APS Experimental Arrangement

Undulator
Capacitive button pickup electrodes
Decker-Distortion Dipoles*

Stray Radiation
X-rays
e⁻
Beryllium Filters, 7 mm total
Cooled aperture, mounted together with VWM on translation stages

E = 7 GeV
I₀ = 4.5 mA
APS Undulator type A,
Gap = 45 - 80 mm
(normal range 11 - 30 mm)

5 meters
52 meters

Vertical Undulator Local Bump Angle Scan Data, 5 µrad Steps

Undulator
Gap = 60 mm,
K = 0.023

Elapsed Time (Hr)
Undulator Beam Profiles after Segment Curve Fitting, Thermal Drift Subtraction, and Beam Current Normalization

\[
\frac{\Delta T_C}{\Delta T_D}
\]

\[\Delta T_C, \Delta T_D \text{ (K)}\]

\[\text{Vertical Position (mm)}\]

\[\text{Vertical Position, (Shifted for } \Delta T_D \text{) (mm)}\]
Conclusions

• Vibrating wire monitors provide quantitative measure of hard x-ray power density.
• Detectors are sensitive to sub-milliwatt levels of beam power.
• Temperature changes as low as milliKelvins resolved.
• Five-wire unit with inclination provides possibility of providing real-time beam size monitoring of beam size less than 100 microns with 100-micron diameter wires.
Commissioning of
SOLEIL
Fast Orbit Feedback System

Nicolas HUBERT
Synchrotron SOLEIL
On behalf of the Diagnostics group
SOLEIL Main Characteristics

- Storage Ring circumference: 354 m
- Energy: 2.75 Gev
- Nominal current: 500 mA (fall 2008, presently 300 mA)
- 3rd generation => 29 % of circumference for Insertion devices)
- Extended photon spectral range :
  - From UV (5 eV) up to hard X-rays (30 keV)
  - First beam in 2006
  - 14 beam lines take beam
  - +12 beam lines under construction
  - 800 A.h integrated current (today)
Beam Stability

- Great care has been taken in the design of the machine to improve its stability:
  - Long term (year):
    - Foundations:
      - Slab of the ring and experimental hall on ~600 15 meters long piles
  - Medium term (24 hours):
    - Temperature is regulated:
      - Experimental hall $21^\circ C \pm 1^\circ C$
      - Storage ring (air and water cooling) $21^\circ C \pm 0.1^\circ C$
    - BPMs blocks are bolted to girders and mechanically isolated (bellows)
    - A Slow Orbit Feedback System (since May 07)
      - Correction rate 0.1 Hz
    - Top-up (end 2008)
  - Short term:
    - Girder design (lowest ringing frequency: 46 Hz)
    - Fast Orbit Feedback System
Fast Orbit Feedback Principle

- **Purpose of the system**
  - Stabilizing the beam position in the high frequencies (>0.1 Hz)

- **Perturbation sources in this frequency range:**
  - Ground vibrations (girder modes)
  - Mains frequency (50 Hz)
  - Overhead cranes of the Experimental Hall
  - Insertion devices (transitions of the feedforward correction during gap changes)

=> Fast orbit feedback system should have its cut-off frequency above 150 Hz
Fast Orbit Feedback Principle:
Correctors

• Choice of the correctors:
  - 56 Slow correctors for slow orbit feedback are located inside the sextupoles.
  - Vacuum chambers are in Aluminum for low vacuum chamber impedance with NEG coating
  - Eddy currents in Al prevents high frequency corrections

=> Necessity to have different correctors for the Fast Orbit Feedback

  - Air-coil correctors
  - Over stainless steel bellows
  - Located on each side of the 24 straight sections
    => 48 units
  - 20 µrad maximum strength
  - Cut-off frequency: 2.5 kHz
FOFB Architecture

- An ‘all embedded’ solution
  - All the processing of the FOFB is done in the LIBERA FPGA, on top of the position calculation provided by Instrumentation Technologies
  - Different interfaces for data exchanges are built in the LIBERA.

RS485  Ethernet  Rocket I/O

To corrector power supplies  Configuration and monitoring  Position Data from 119 other BPMs
FOFB Architecture:
Power Supply Control

Overall latency
~360 µs

Libera rack
(7 or 8 units)

Power supply rack (2 planes)

Air-coil magnet
(2 planes)

Copper link

Optic link

RS 485 link

2 conductor copper cable
Data Processing

Beam Position Monitor application
(provided by Instrumentation Technologies)

Communication Controller

Matrix multiplication

PI controller

RS 485

Fast Orbit Feedback application

Position X and Y @ 10 kHz

ΔX, ΔY

RX, RY

ΔIX

ΔIY

IX

IY

C_X

C_Y

Communication Controller: designed by Diamond Light Source
Initial Design of the Fast Orbit Feedback for Diamond Light Source, ICALEPS 2005
FOFB Efficiency (0.01 Hz – 1 Hz)

Effect on the perturbations caused by the insertion devices (vertical position at source points)
Conclusion

• Low cost system
  – Using computing resources of FPGA BPM system

• Global orbit correction
  – Distribution of all BPM data around the ring with a dedicated network

• Air-coil correctors over stainless steel bellows with high cut off frequency

• Flexible
  – Easy change of correction algorithm

• First results are very promising
  – System should be available for user operation in the coming months
The discussion session

• I participated in the discussions on
  – transverse profile measurement
  – emittance measurement
  – digital signal processing (FPGA)

• What I learned
  – the most challenging part of the flying wire monitor is not the detection of secondaries or losses, it is usually the drive. Stepper motors often cause wire vibration. This is the reason servos are used at the Tevatron.
  – Emittance measurement in hadron machines is often a problem due to the lack of a good machine model. The instruments installed around the ring often disagree with each other at the 40% level.
  – FPGA code (and code changes) testing becomes an issue when used in machine protection systems (LHC). Having a dedicated test bench may help.