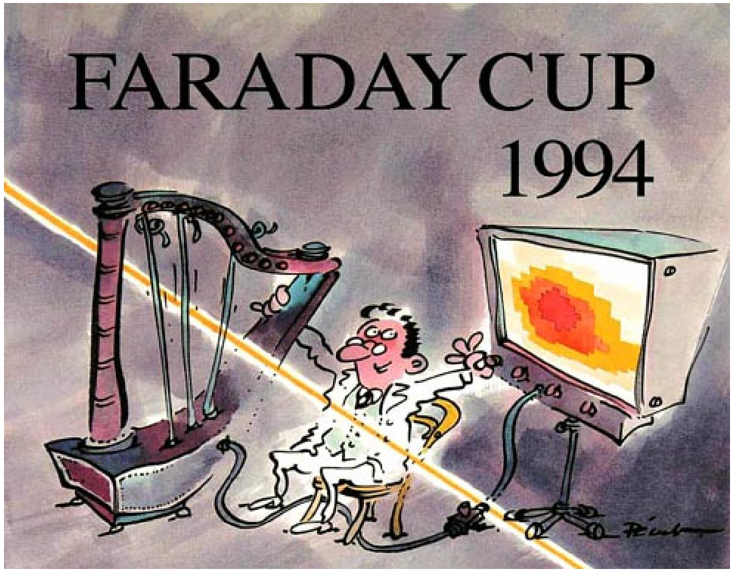
VIBRATING WIRE SENSORS FOR BEAM INSTRUMENTATION

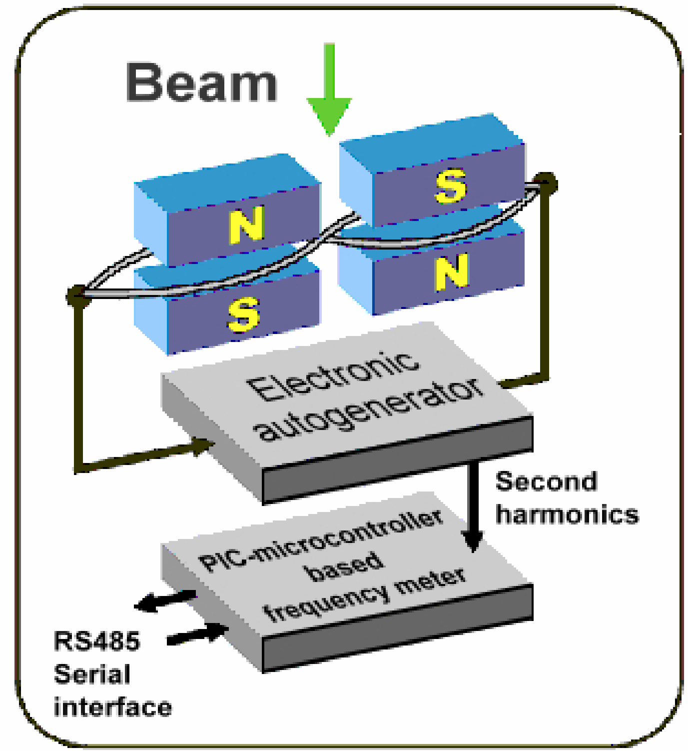
Suren Arutunian

Yerevan Physics Institute

Conceptual idea

Vibrating wire scanner - dream of 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?

ρ	**material density**
σ	**wire strain**
l	**wire length**
E	**modulus of elasticity**

$$F = 1/l \bullet \sqrt{\sigma/\rho}$$

$$\Delta F / F = E/2\sigma \bullet \Delta l/l$$

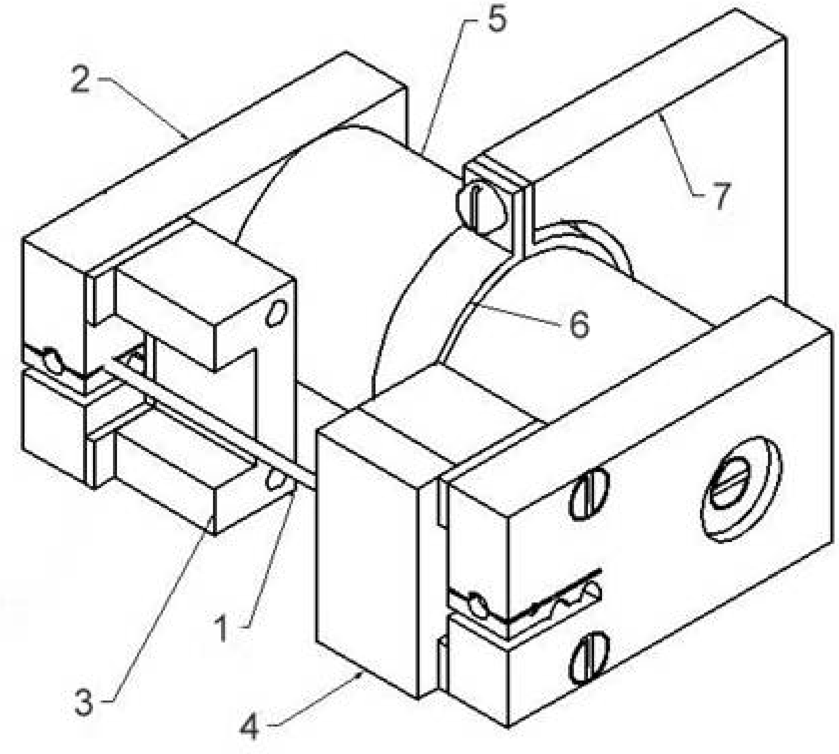
$$\Delta F / F = -E/2\sigma \bullet \alpha_S \Delta T$$

$$E = 200 GPa$$

$$\sigma << tensile - strenght = 500 - 800 MPa$$

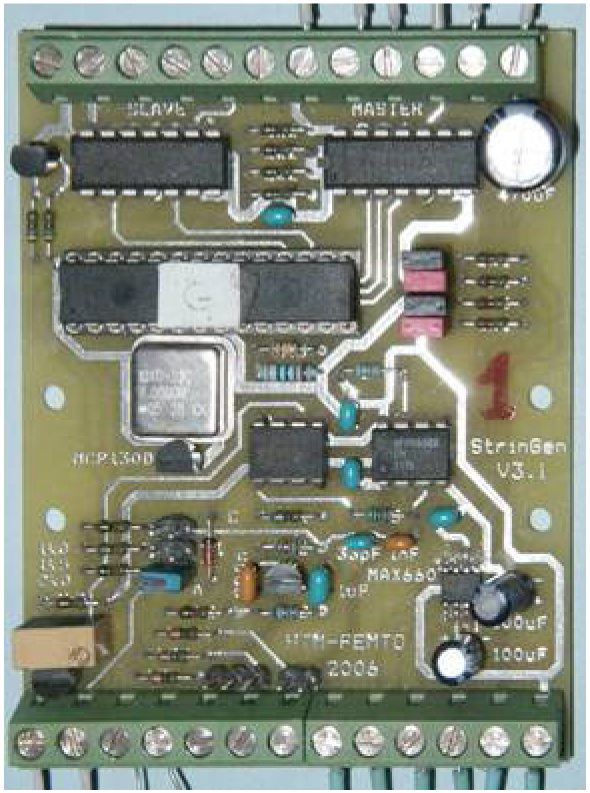
$$E / \sigma \approx 500$$

Single wire VWS (DESY, PETRA)



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

Oscillations excitation and frequency measurement unit



Generator is assembled on the base of fast operational amplifier allows to maintain the generation just on the wire natural frequency resonance

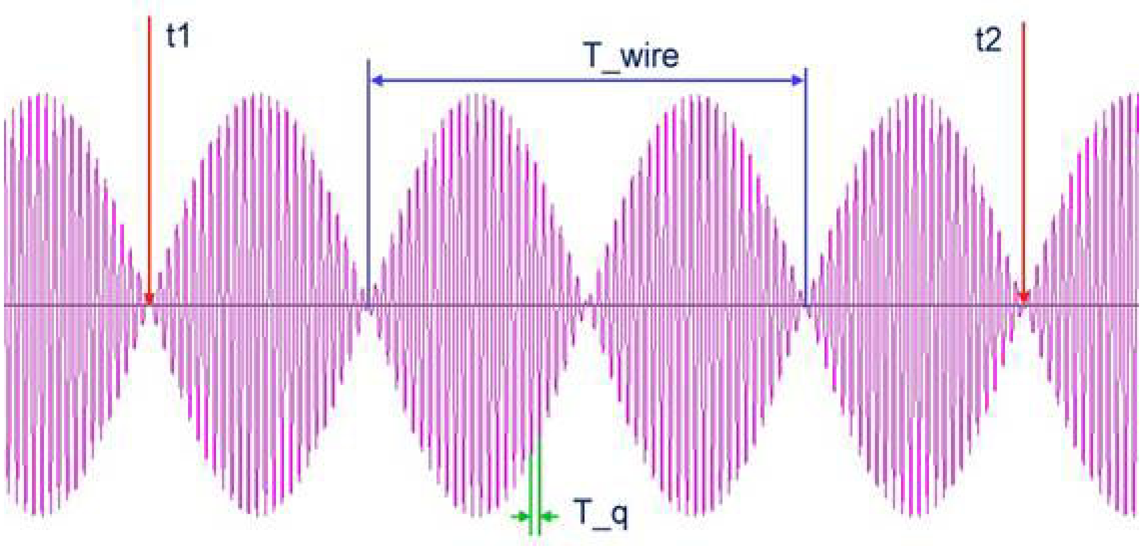
Electronic circuit test (I.Vasiniuk)

Wire is included into positive feedback circuit

Frequency measurement algorithm

Time t1 – wire periods counting start
Time t2 – wire periods counting end

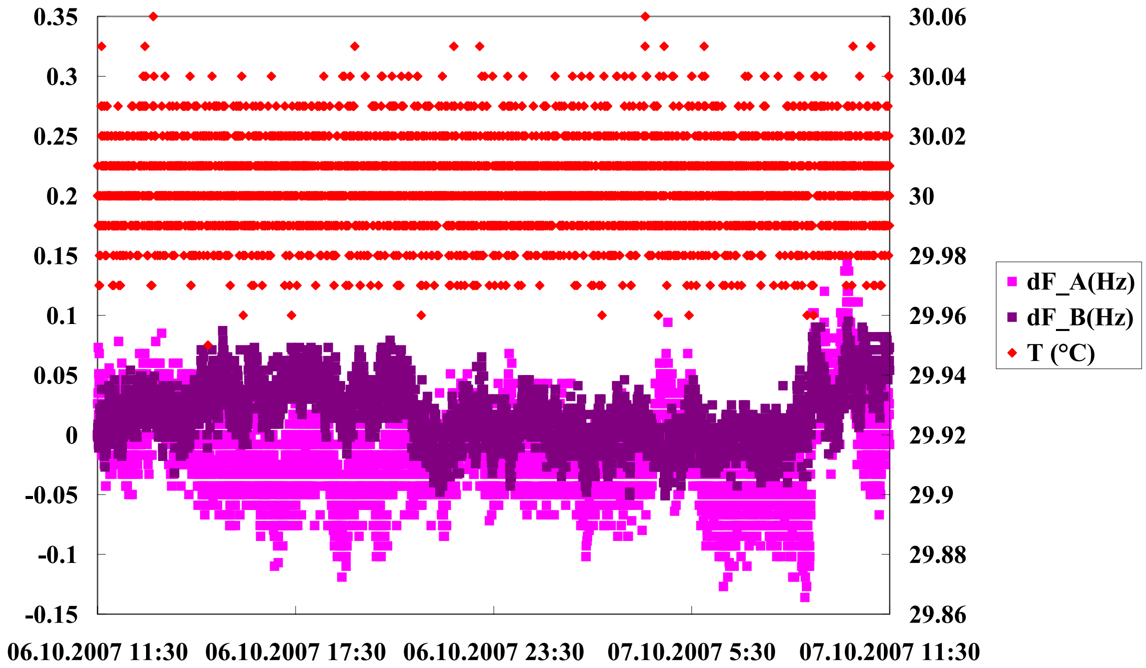
T_wire – wire oscillation period
T_q – quartz oscillation period
F_wire=F_q*N_wire/N_q
t2-t1=gate in range 100 ms-30 s



Measurement resolution at F_wire about 5000 Hz and F_q=1.0000 MHz

gate, s	Resolution, mHz
0.1	50
1	5
30	0.16

2 wires VWS long time run in laboratory environment



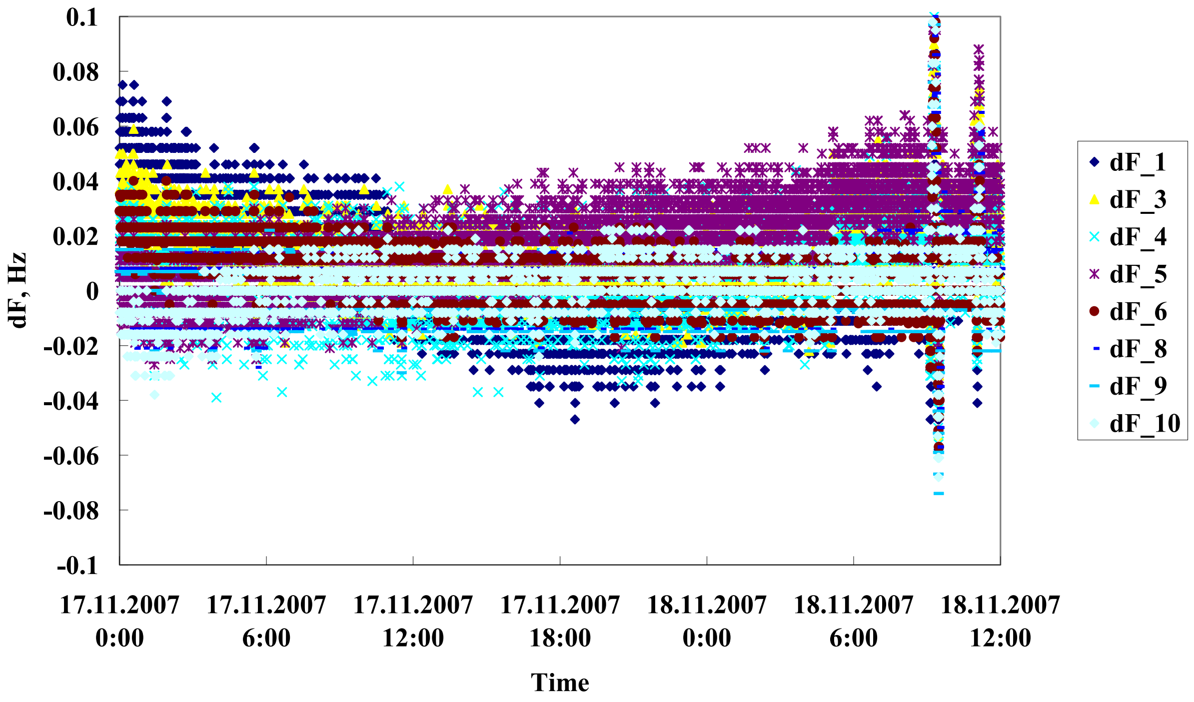
Absolute deviations for 24 hours:

dF_A
0.03 Hz

dF_B
0.02 Hz

T
0.01 ^{0}C

10 wires VWS long time run in laboratory environment

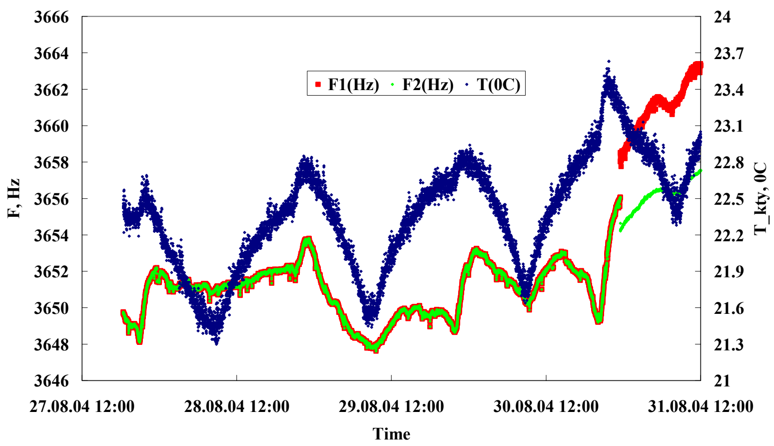


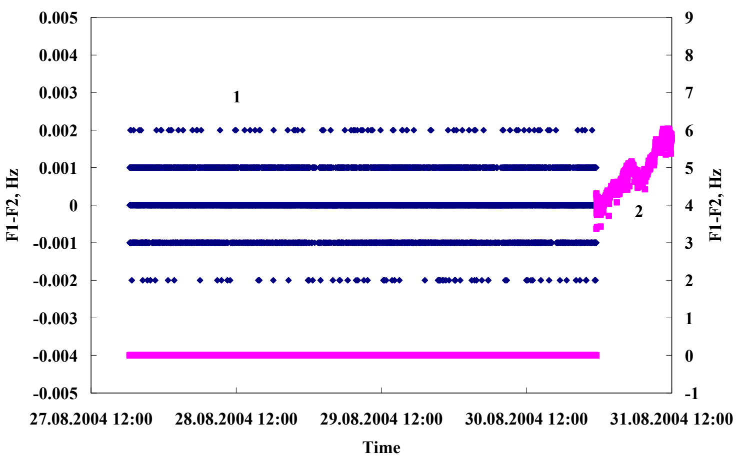
Thermostabilization at 30 ^{0}C with Platinum resistance thermometer

10 wires VWM absolute deviations for 36 hours, Hz

1	0.017
2	0.036
3	0.010
4	0.010
5	0.013
6	0.008
7	0.047
8	0.007
9	0.006
10	0.008

Frequencies resonant capture

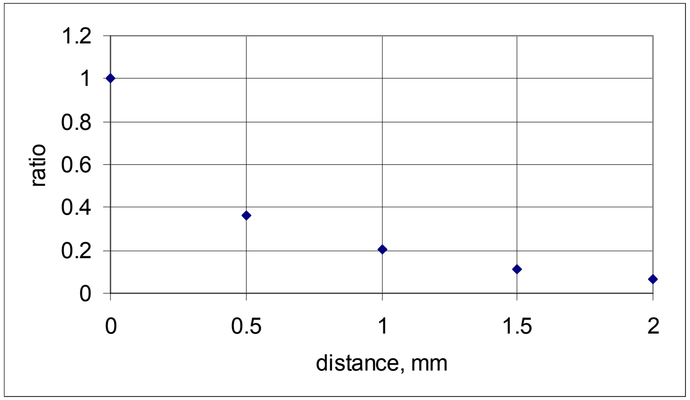




Each frequency was measured by separate electronic unit with proper quartz oscillator.
Measurement gate 30 s (resolution 1 mHz)

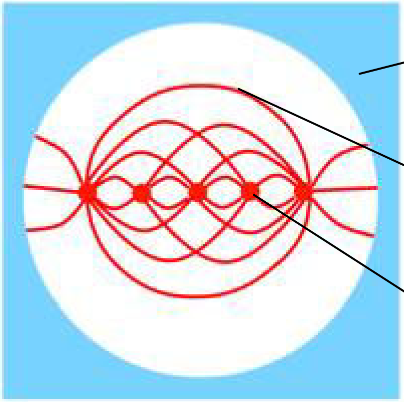
Multiwire sensor wires thermal coupling in air

Wires overheatings when outermost wire was fed by DC current



VWS wires were fed by a DC current (about 10 mA)

wire 1	wire 2	wire 3	wire 4	wire 5
0.255	-	0.052	0.031	0.019
-	-	-	-	-
0.050	-	**0.283**	0.099	0.051
0.029	-	0.101	**0.265**	0.090
0.019	-	0.051	0.090	**0.247**



Multiwire sensor wires thermal coupling in air

heat coupling equations

$$Q_1 = \alpha_{11} T_1 + \alpha_{12}(T_1 - T_2) + \alpha_{13}(T_1 - T_3) + \alpha_{14}(T_1 - T_4) + \alpha_{15}(T_1 - T_5)$$

$$Q_2 = \alpha_{12}(T_2 - T_1) + \alpha_{22} T_2 + \alpha_{23}(T_2 - T_3) + \alpha_{24}(T_2 - T_4) + \alpha_{25}(T_2 - T_5)$$

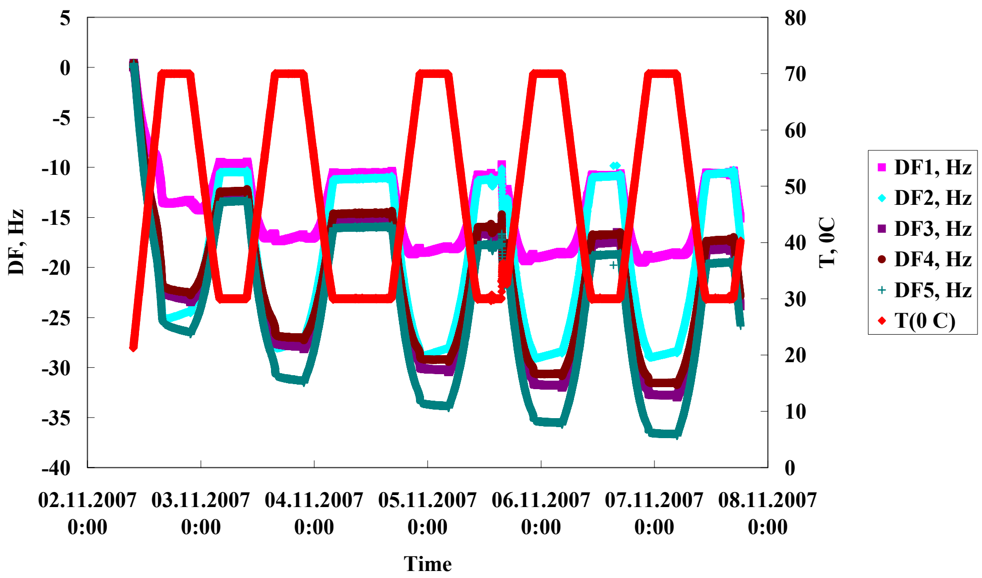
$$Q_3 = \alpha_{13}(T_3 - T_1) + \alpha_{23}(T_3 - T_2) + \alpha_{33} T_3 + \alpha_{34}(T_3 - T_4) + \alpha_{35}(T_3 - T_5)$$

$$Q_4 = \alpha_{14}(T_4 - T_1) + \alpha_{24}(T_4 - T_2) + \alpha_{34}(T_4 - T_3) + \alpha_{44} T_4 + \alpha_{45}(T_4 - T_5)$$

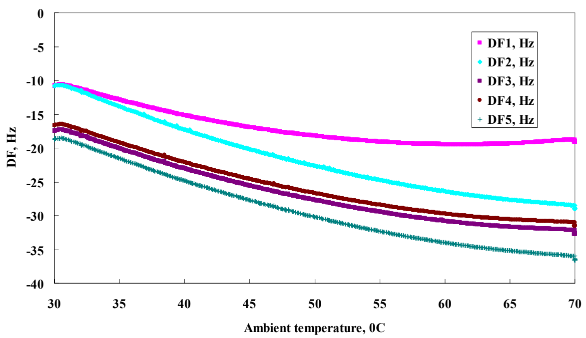
$$Q_5 = \alpha_{15}(T_5 - T_1) + \alpha_{25}(T_5 - T_2) + \alpha_{35}(T_5 - T_3) + \alpha_{45}(T_5 - T_4) + \alpha_{55} T_5$$

T_i **wire with index i overheating**

Frequency dependence on ambient temperature



VWM005 behavior immediately after sensor assembling



	1	2	3	4	5
dF2/dT, Hz2/K	-5.50E+03	-8.73E+03	-7.47E+03	-7.35E+03	-8.35E+03

Compare with -3.38E+05 Hz^2/K for single wire

Technical characteristics

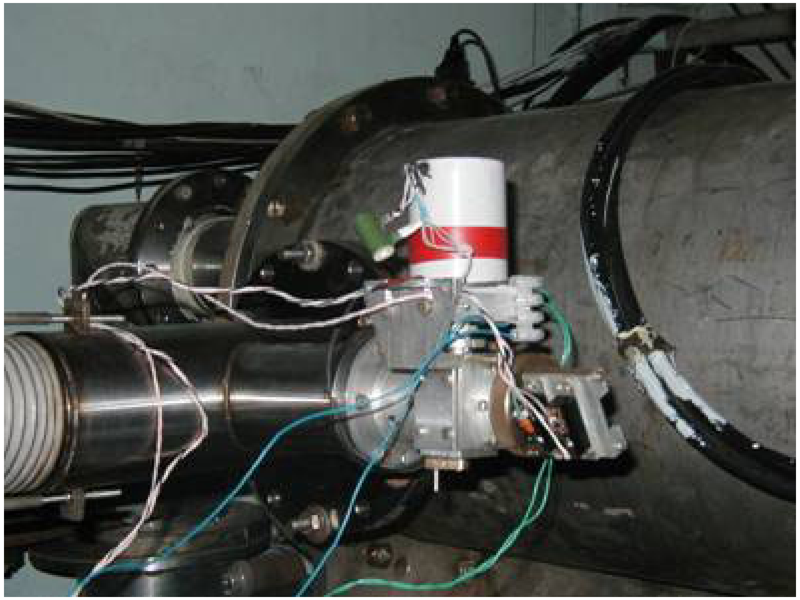
Material, conditions	A316 Vacuum	A316 Air	Tungsten Vacuum	Tungsten Air
DTmean/DQ, K/mW	19.4	0.23	3.0	0.23
DF/DTmean, Hz/K at F0 = 4200 Hz	-40.2	-40.2	-8.8	-8.8
DF/DQ, Hz/mW	-779.6	-9.3	-26.4	-2.0
response time, s	20.2	0.26	1.8	0.15

Technical characteristics of 5 wire VWM in case of usage in air
resolution of frequency measurement is 0.01 Hz
measurement accuracy (1 hour) ± 0.01 Hz (± 0.00025 K)
(24 hour) ± 0.04 Hz (± 0.001 K)
response time 0.26 s
deposited on the wire power ± 1 μW (1 hour) ± 4 μW (24 hour)
Nonlinearity of the pickup in operational range 0-100 mW is 0.01 %

Electron beam

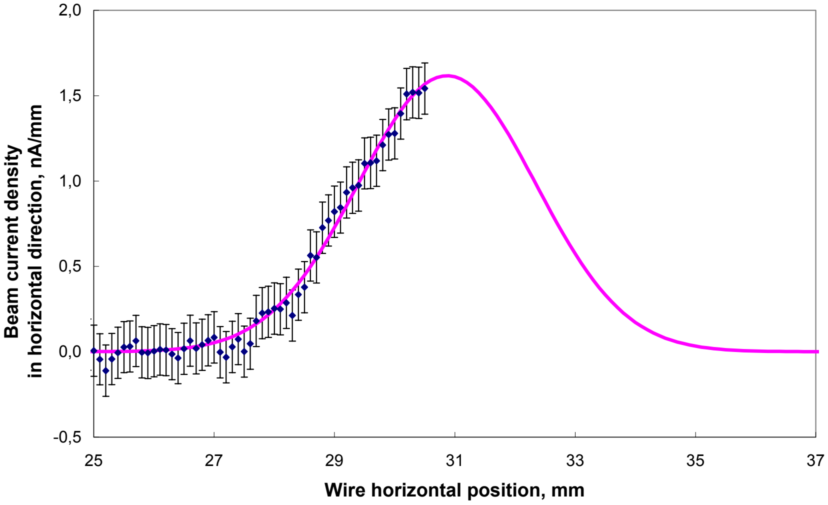
VWS installing in 50 MeV Injector of Yerevan Synchrotron (N.Dobrovolsky, M.Mailian)

VWM incut into vacuum chamber



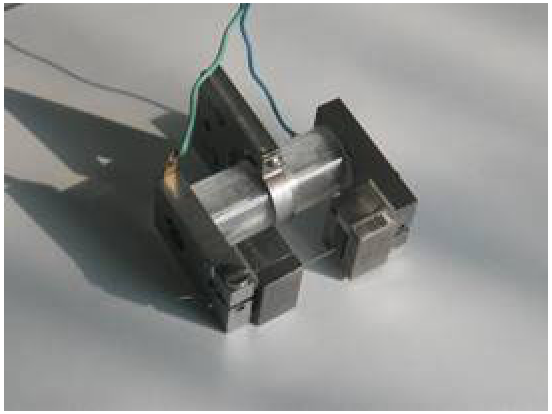
Electron beam

VWS mounted on the vacuum below with 1 μm 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

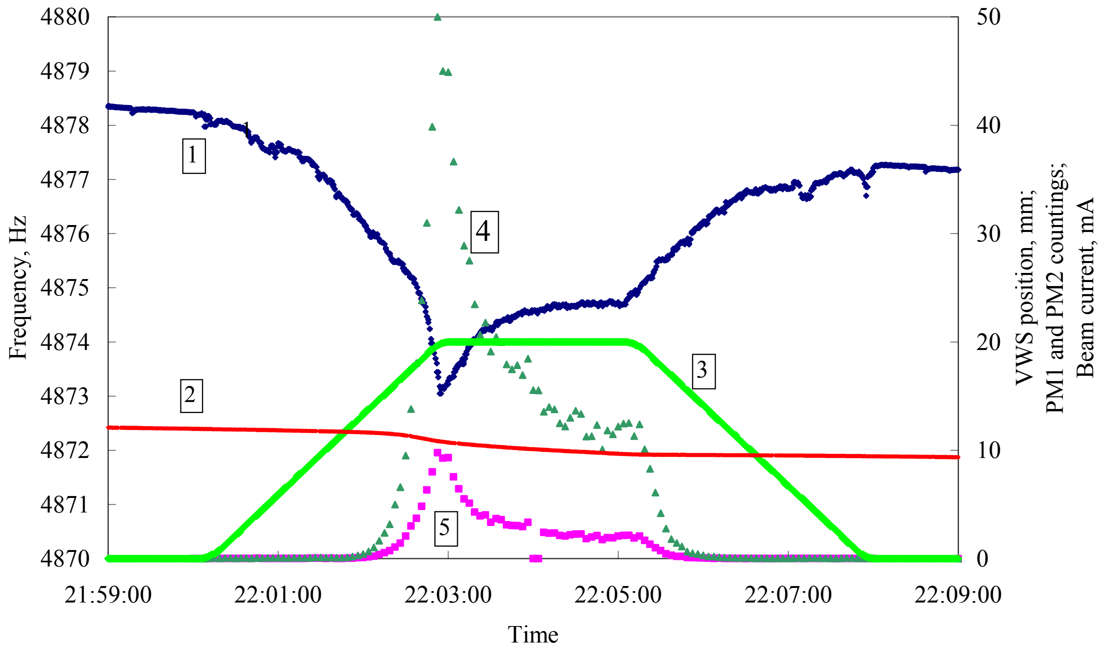


VWS for PETRA experiment, one beryl bronze wire of diameter 90 μm

VWS mounted on tube with below and step motor

VWS installing into PETRA proton bypass (R.Boespflug, left and K.Wittenburg)

Proton beam



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

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

Ion beam

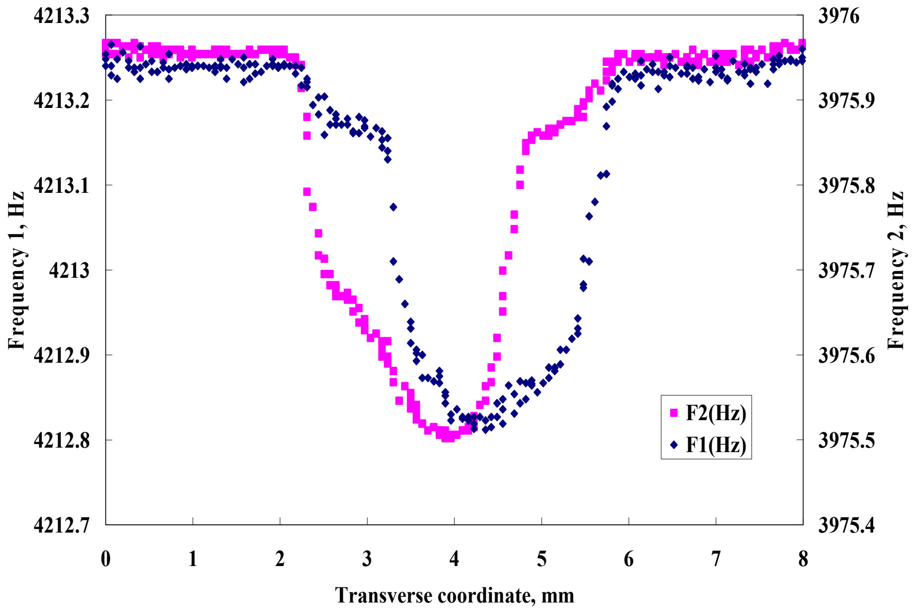
Energo-mass-analyzer EMAL-2 a device with laser source of ions for mass-spectral analysis of solids. Fe ion beam with current about 1 nA and energy 20 keV passes through the gap with sizes 2 mm × 5.5 mm and fall on the wire

Approximately 16 pA of beam current interacted with the wire, frequency decrement about 0.15 Hz

Laser beam

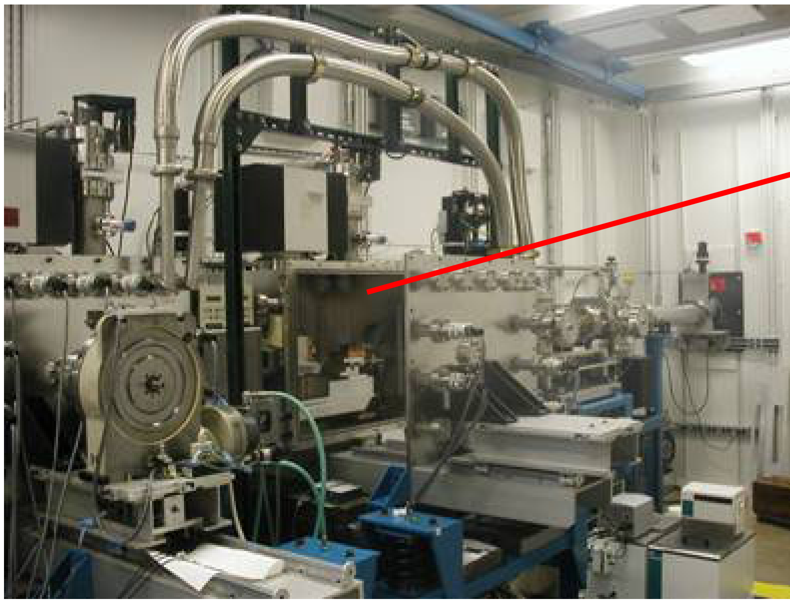
Laser beam scan experiment layout. 1- Commbox measurement unit, 2 – measuring microscope, 3 – stepper motor feed system, 4 – stepper motor control board, 5 - laser, 6 - VWM

Laser beam



Sensitivity 20 Hz/K
Frequency accuracy 0.01 Hz
Temperature resolution 5 ×1E-4 K
Laser radiation power density resolution
in air
3×1E-6 W/mm^2
in vacuum
5×1E-8 W/mm^2

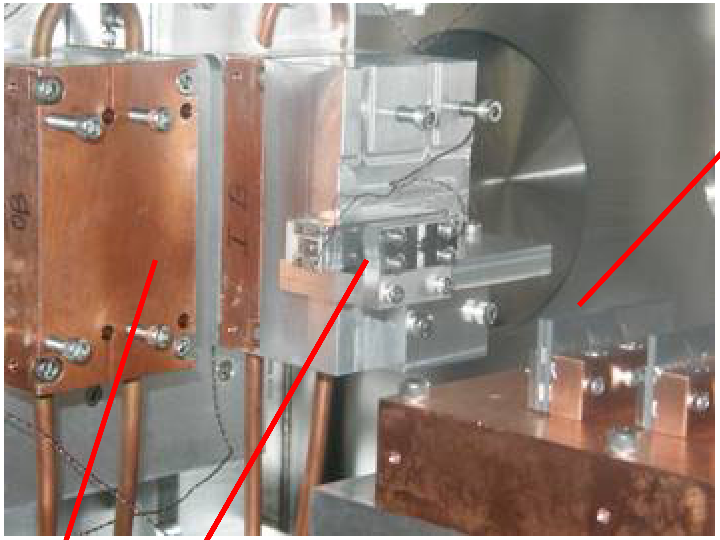
APS 2007



Beamline SBC-CAT-19-ID:
Source Undulator A
Energy Range 6.5-19.5 keV
Flux (photons/sec)1.4 x 10^13 @ 12 keV

VWS installing in vacuum test chamber of beamline (G.Rosenbaum)

APS 2007

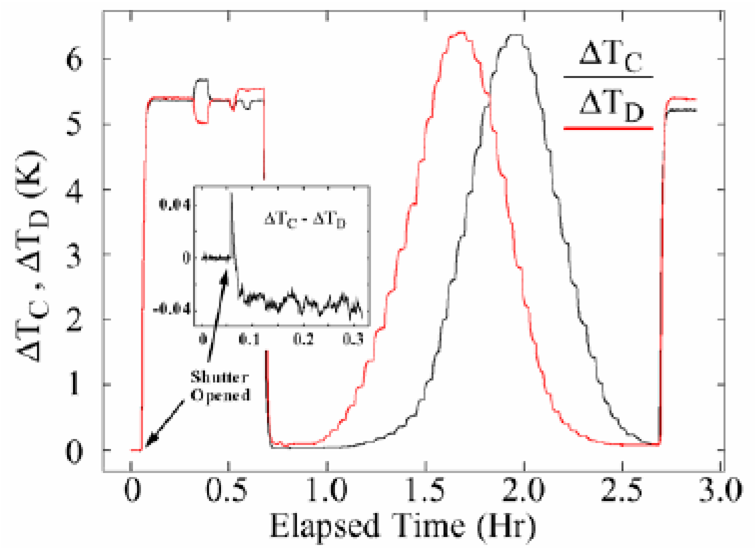


Beryllium filter

VWS mounted on the water-cooled plates

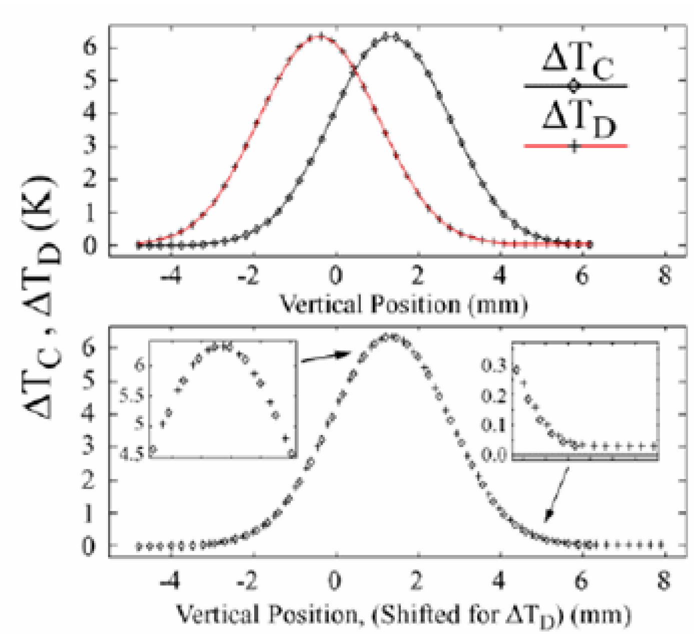
Alignment procedure to assure that both wires were symmetrically placed above and below the midplane with a clear line of sight to the source (G.Decker)

APS 2007



Data collected at a 1-Hz sample rate during a scan of the particle beam's vertical angle in range 100 microradians with 5 microradian steps

VWM data corrected for thermal drift and beam current decay



Plot of ΔTD shifted by 1.730 mm

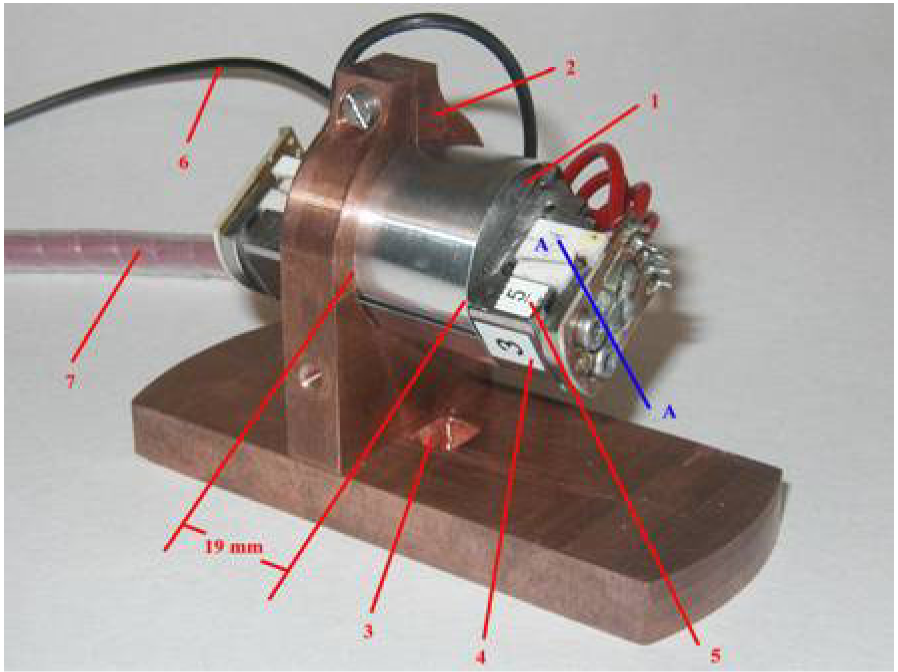
APS 2007

Total of 7 mm of Beryllium was placed in the beam path, both to limit the power striking the wires and to assure that only hard x-rays were being detected

Incorporation of such a device into the design of water-cooled beamline apertures (“smart aperture”, G.Decker) is another interesting concept

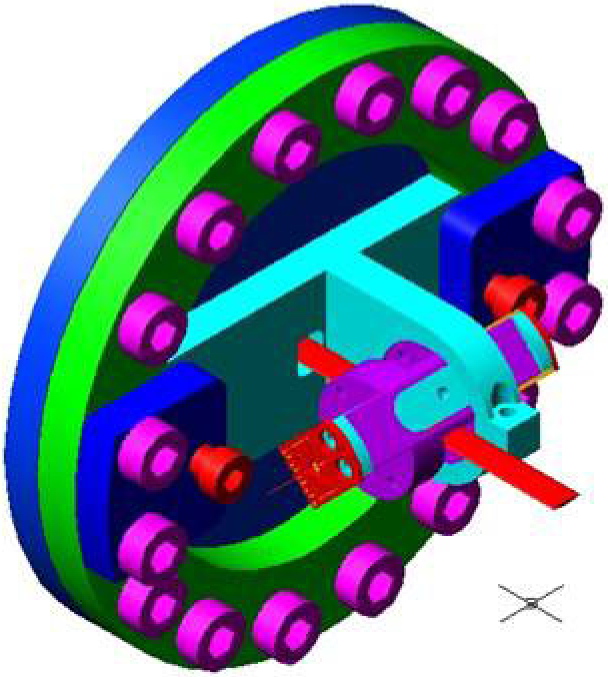
A very successful shift (G.Rosenbaum, M.Mailinan, S.Arutunian, G.Decker)

APS 2008



Five-wires VWM005 details:
(1) sensor, (2) surface of the vertical plate, (3) rectangular window for synchrotron beam accept with VWM005 aperture, (4) number of the sensor, (5) numbers of the first and fifth wires, At one side of the sensor all wires are connected together (6), other wires are assembled in a harness (7). The wires are shifted along the line AA

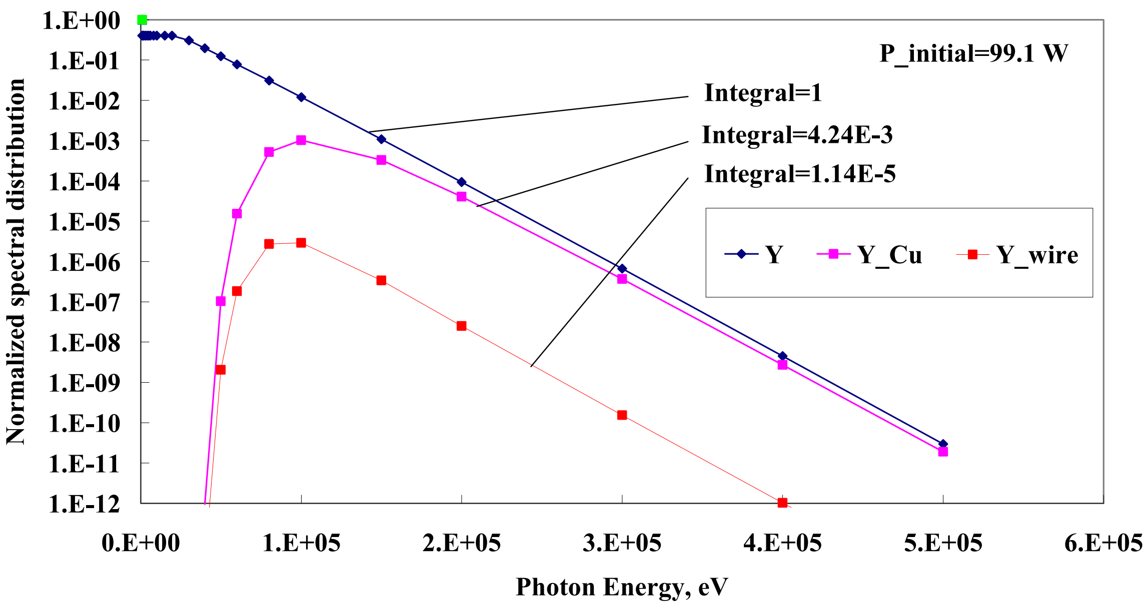
APS 2008



Main view of VWM005 mounting on the flange

VWM is mounted on the 6 inch flange

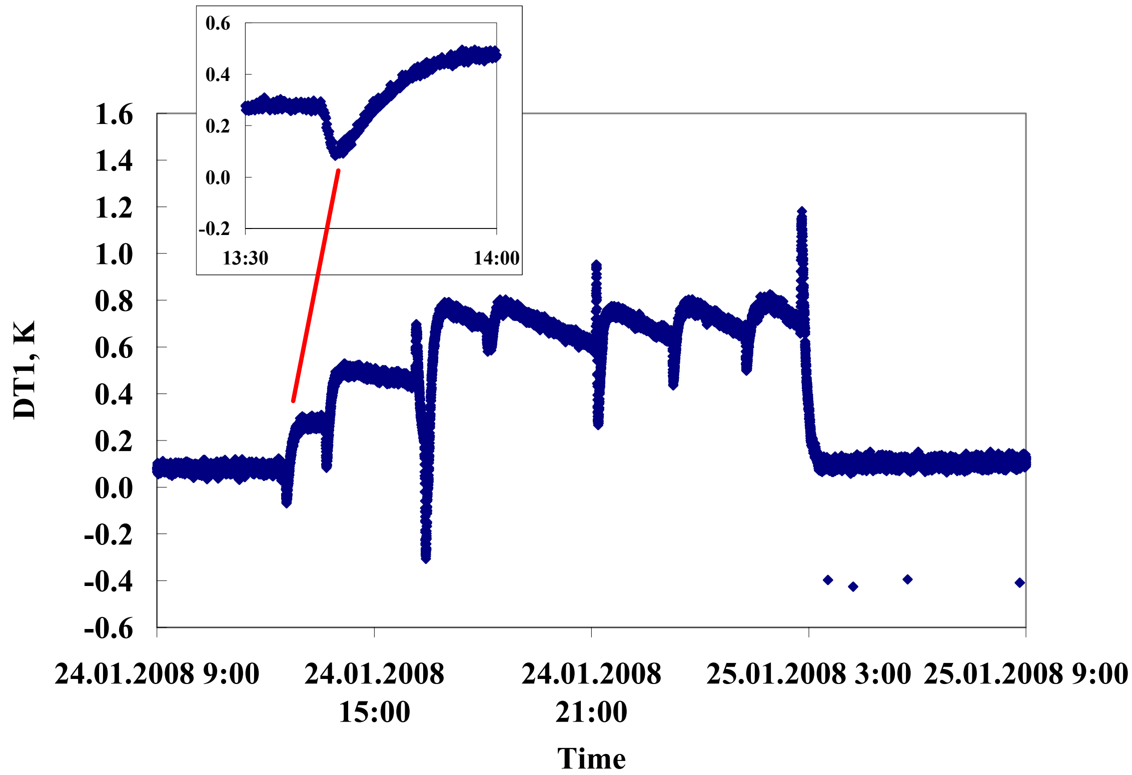
APS 2008



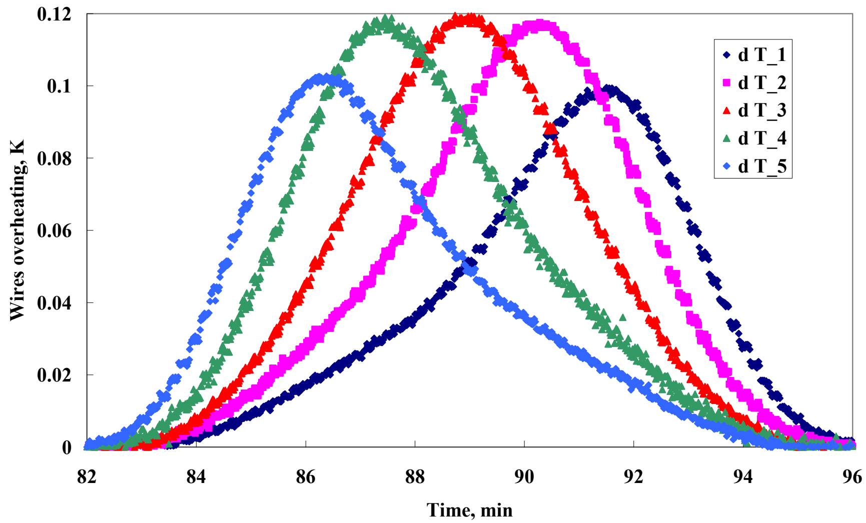
Normalized spectral distribution of initial synchrotron radiation (Y), passed through the Cu flange (Y_Cu) and deposited into the wire (Y_wire). Spectral maximums for Y_Cu and Y_wire are about 100 keV

APS 2008

VWM data dependence on the ambient T. Synchrotron radiation do not touch the wires of VWM. Data show the change of the flange temperature during APS operation



APS 2008

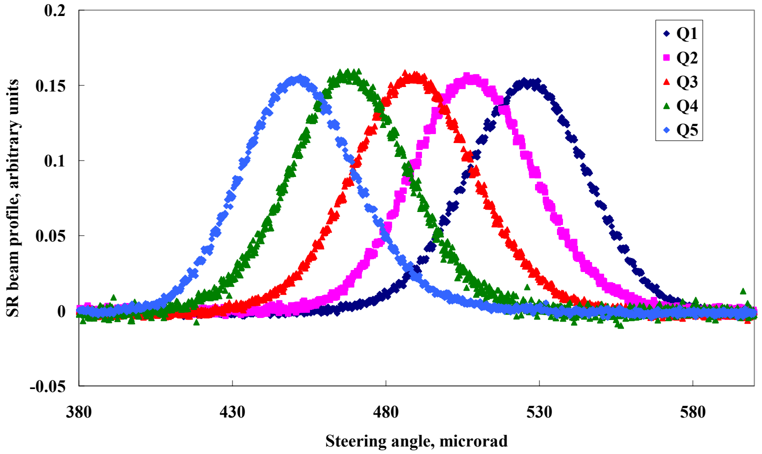


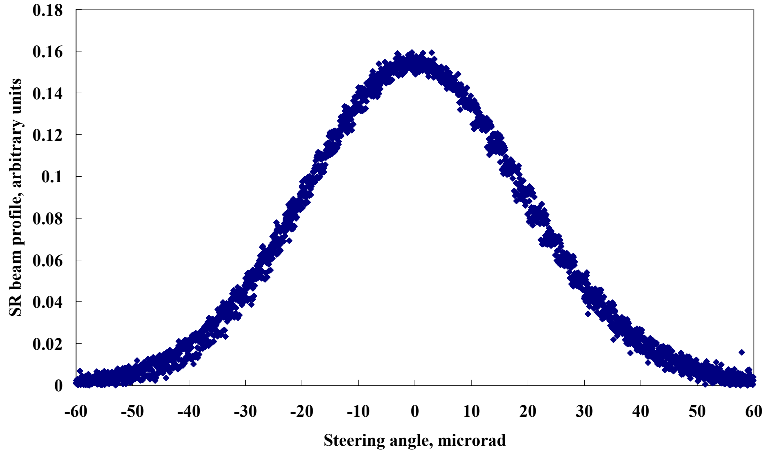
VWM when the electron beam angle was scanned vertically through a range of 300 microradians with 125 steps Electron beam scanned vertically from minus 350 to minus 650 microradian angle with 125 steps

Scan result presented by wire overheating temperatures. Electron beam was scanned vertically through a range of 300 microradians with 125 steps

Profiles asymmetries arise from mentioned above wires thermal coupling and some inequality placement of wires relative to sensor housing

APS 2008





Using a statistical data treatment, the heat coupling coefficients were found and accordingly the profiles of the source were recovered

United profile from all wires (curves are shifted according to value of maximum)

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)

Acknowlegments

Author is grateful to all his co-authors with whom he worked many years. Many thanks to the YerPhI, PETRA and APS ANL stuff for their friendly help during the experiments. Special thanks to R.Reetz and J.Bergoz for permanent interest and essential support