Vibrating wire scanner/monitor for photon beams with wide range of spectrum and intensity

Aginian M.A., Arutunian S.G., Hovhannisyan V.A.,
Mailian M.R., Wittenburg K.

Developed vibrating wire scanner showed high sensitivity to the charged particles beam intensity (electron, proton, ions). Since the mechanism of response of frequency shift due to the interaction with deposited particles is thermal one, the vibrating wire scanner after some modification can be successfully used also for profiling and positioning of photon beams with wide range of spectrum and intensity. Some new results in this field are presented.

Scanning of proton beam

We developed a new method of beam profiling by means of a vibrating wire [1-6]. The operating principle of such vibrating wire scanner (VWS) is based on high sensitivity of natural oscillations frequency of the strained wire from its temperature. At achieved resolution 0.01 Hz (VWS natural frequency is about 5000 Hz) the corresponding temperature resolution is about $2{\cdot}10^{-4}$ K.

In May 2004 in PETRA, DESY, Hamburg experiments for proton beam halo profiling were done (energy of protons 15 GeV, beam current approximately 10 mA, beam horizontal size σ =6 mm) [6]. A few pA resolution of deposited proton current on the wire was achieved. This experiment was aimed to profile of proton beam periphery. Results of scan at distances 3÷6.5 σ are presented in Fig. 1. Simultaneously with scanning of the beam by our scanner, signals from two scintillator pickups were measured. The scintillators are used in traditional methods for beams profiling with wire scanners, where beam particles scattered on the wire are measured. The scan was started at distance of 40 mm from the vacuum chamber center. It is seen from Fig. 1 that signal from our sensor changes from the start of movement, while the signals from scintillators begin to increase at distances of 27 mm from the vacuum chamber center.

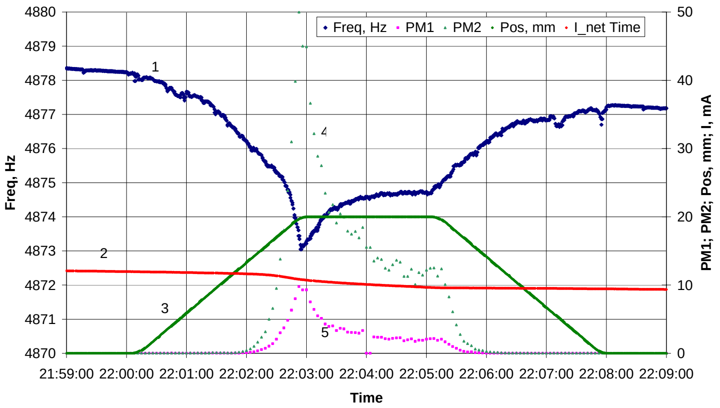


Fig. 1. Scan of the proton beam using VWS: 1- frequency of the VWS, 2 – beam current, 3 – VWS position relative to the vacuum chamber center, 4 and 5 – signals from scintillators.

The scanner was fed from park position toward the vacuum chamber center up to 20 mm. In this experiment the proton beam was shifted towards the scanner park position by distance of 4 mm by means of bump-magnets system.

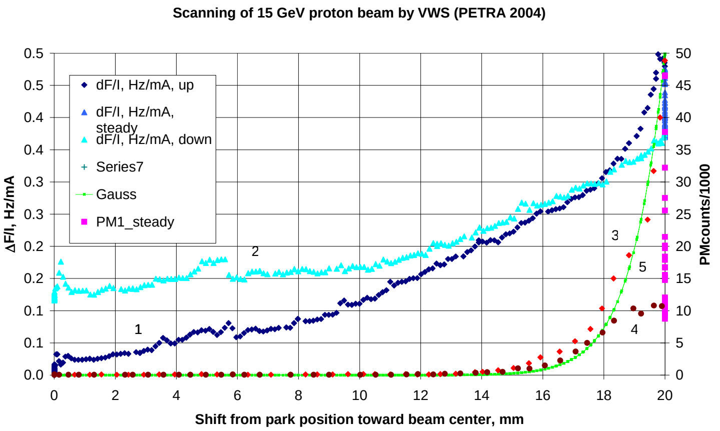


Fig.2 Dependence of frequency shift and scintillator signal on scanner position: 1- frequency at motion toward the beam, 2- frequency at motion from the beam, 3 and 4 – the same for signal from scintillator, 5 – reconstruction of beam profile from Gaussian distribution with σ =6 mm)

The dependence of the signals on the scanner position is presented in Fig. 2. The signal from the scanner was presented as shift of the frequency from the value in park position, normalized to the mean proton beam current. Some hysteresis effect during the backward movement was observed. As seen from the Fig. 2 the signal from VWS appears at distances 27-40 mm from the vacuum chamber center while there is no signal from the scintillators here. Some contribution in wire heating can be added from the influence of electromagnetic background accompanying the proton beam[1]. The electromagnetic component also can heat the wire. For separation of two mechanisms of heating two wires can be used with materials having strongly different absorption factors for proton and electromagnetic components. Clarification of this problem and corresponding modifications of VWS require additional efforts.

Scanning of photon beam

Photon beam passing through the material will also cause heating of the wire material with the advantage of no additional electromagnetic component. Thus the photon beam also can be measured by method of vibrating wire. Some estimates of absorption parameters for different materials and photon energies are presented in Table 1.

Table 1. Absorption parameter μ^{-1} for photon beams with different energies.

Material	**10^2 eV**	**10^3 eV**	**10^4 eV**
Tungsten	3.5 10+5	7.6 10+4	1.8 10+3
Molybdenum	5.0 10+4	5.0 10+4	8.0 10+2
Silicium	7.4 10+4	3.7 10+3	7.3 10+1

To estimate the wire frequency shift under irradiation of photon beam we numerically solved the model task of thermal conductivity along the wire allowing finding the temperature profile along the wire for different photon beam parameters, wire materials and geometry.

For example we consider the photon beam with parameters of XFEL TESLA [7]:

Wavelength, 1-5 A

Average power, 210 W

Photon beam size (FWHM), 500 μm at distance 250 m from source

---

[1] It seems that this should be also seen by the scintillator but background's influence on heating processes and scintillator detection can differ essentially.

Photon beam divergence (FWHM), 0.8 μrad
Bandwidth (FWHM), 0.08 %
Average flux of photons $1.0\times10^{+17}$ ph/s
Average brilliance, $4.9\times10^{+25}$ ph/(s mrad^2 mm^2 0.1 % bandwidth).

Taking into account that here the beam diameter is less than 6 mm beam of PETRA it is reasonable to take a wire of less length and diameter. We have an experience with wires of length about 10 mm and diameter 20 μm, these sizes we take for further calculations. Wire initial frequency set (the second harmonics) - 5000 Hz

Fig. 3 represents the temperature profiles of wires from Molybdenum and Silicium at different time moments. It is seen that wire transition time for temperature balance of the beam with the wire is about 1 sec. Also, because the beam size is much less of wire length the temperature profile is almost a triangle.

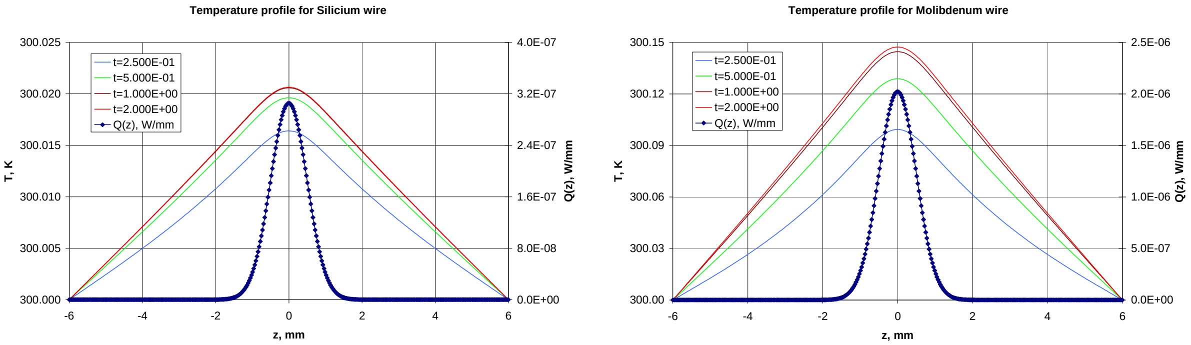


Fig. 3. Dynamics and profile of temperature along the wire from Silicium and Molybdenum. Parameters of the photon beam are the same and the VWS in both cases is placed at distance 2.5 mm from the beam center.

The lower limit of the sensitivity of the VWS to temperature changes is defined by electronics and the method of signal measurement and is about 0.01 Hz, which corresponds to temperature 2×10^{4} K. The temperature determines the upper limit, when the wire oscillation generation broke out (approximately 2000 Hz, corresponding temperature shift is about 30 ^{0}C). Estimates show that sensitivity of our scanner allows scan of beams of energies 10^{2}-10^{4} eV at distances 1.9 mm - 3.1 mm. The spatial resolution of VWS depends on flux of photons falling on the wire and improves at distances close to the beam center and decreases in beam periphery. Fig. 4 represents the dependence of the spatial resolution of the scanner depending on distance from the beam center. The beam parameters are the same as for the XFEL TESLA [5]. The assumed wire material is Molybdenum.

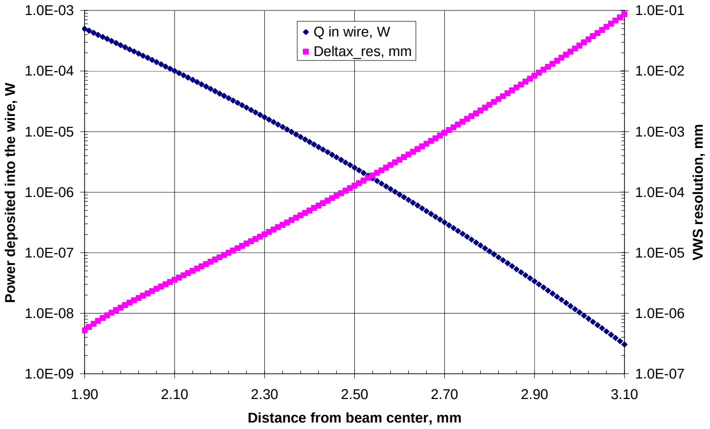


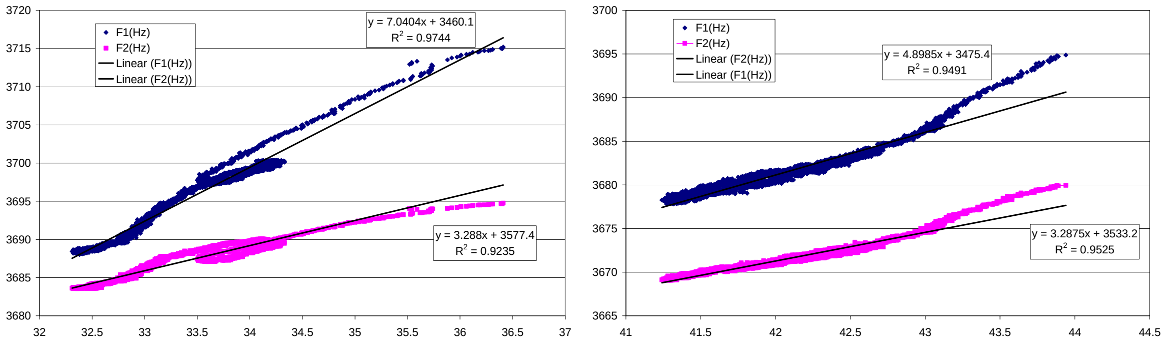
Fig. 4. The power from the photon beam deposited into the wire and VWS spatial resolution depending on the VWS position from the beam center.

As seen from the Fig. 4 the spatial resolution of the scanner strongly depends on its position and at scanner's limit positions is less than 0.01 μm (x=1.9 mm) and 0.1 mm (x=3.1 mm). The lower limit 0.01 μm of resolution has a formal meaning since the diameter of the wire is much more than this value and such resolution can be reconstructed by VWS signal derivation only if the measured beam has known structure of profile.

Experiment with X-ray source: material science perspectives

To investigate the influence of the penetrative radiation on vibrating wire characteristics we have done an experiment using X-ray apparatus RUP-200-15. For the experiment we chose a two-wire modification with second harmonic frequencies 3680 and 3670 Hz. The second wire was screened by 2-mm lead plate, which allowed to neglect the influence of X-rays and compare its signal with irradiated one. The base of the pickup was made of low absorbing glass fiber plastic.

The pickup was located at minimal distance from radiation source, where the intensity was about 2000 Roentgen/min. The estimates showed that radiation density at this distance was less than resolution of wire pickup by 2-3 orders. Indeed, in experiment no change of frequency was observed at switching on/off of the X-ray source. However, dose-depending increase of the frequency of first wire was revealed. The incline of the first wire time-frequency graphs was increased twice at the X-ray apparatus voltage switch from 100 kV to 165 kV at 15 mA current. The frequency of the second wire kept the same. At the end of irradiation (total radiation time was 45 min.) the difference between 2 frequencies from 10 Hz increased to 18 Hz. Fluctuation of frequencies during the measurement was less than 0.15 Hz. The X-ray radiation also resulted in change of temperature dependence of irradiated wire from 7.03 Hz/K (before irradiation) to 4.7 Hz/K (after), while for the non-irradiated wire this value changed negligibly (3.26 and 3.1 Hz/K, correspondingly). The results are presented in Fig. 4. The temperature was measured by a semiconductor thermoresistor (type- KTY).



a b

Fig. 4. Frequency-temperature dependence of wires before (a) and after (b) irradiation.

Thus, already small doses of radiation can influence the mechanical tensions and/or redistribution of dislocations, and this was fixed by our pickup. Method of irradiation of the wire by X-rays can also be used for studies of radiation quenching and aging of materials. Note, that investigations in this area by traditional methods require long-term experiments, while high sensitivity of the vibrating wire pickup allows to fix the changes practically on-line.

The presented ideas and results show that measurement of photon fluxes by means of a vibrating wire scanner has a good perspective. Unmovable sensor can also be used for photon beam position monitoring. Preliminary experiments show that vibrating wire electromechanical resonators can be used for express analysis of characteristics of materials, irradiated by photon and particles beams in wide range of parameters.

References

1. Arutunian S.G., Dobrovolski N.M., Mailian M.R., Sinenko I.G., Vasiniuk I.E. Vibrating wire for beam profile scanning. - Phys. Rev. Special Topics. - Accelerators and Beams, 1999, v. 2, 122801.
2. Arutunian S.G., Avetisyan A.E., Dobrovolski N.M., Mailian M.R., Vasiniuk I.E, Wittenburg K., Reetz R., Problems of Installation of Vibrating Wire Scanners into Accelerator Vacuum Chamber. - Proc. 8-th Europ. Part. Accel. Conf. (3-7 June 2002, Paris, France), pp. 1837-1839.
3. Arutunian S.G., Dobrovolski N.M., Mailian M.R., Vasiniuk I.E., Vibrating wire scanner: first experimental results on the injector beam of Yerevan synchrotron.- Phys. Rev. Special Topics. - Accelerators and Beams, 2003, v. 6, 042801.
4. Arutunian S.G., Bakshetyan K.G., Dobrovolski N.M., Mailian M.R., Soghoyan A.E., Vasiniuk I.E., First experimental results and improvements on profile measurements with the vibrating wire scanner.- Proc. DIPAC'2003, (5-7 May, Mainz, Germany 2003), pp.141-143.
5. Arutunian S.G., Werner M., Wittenburg K. Beam tail measurements by wire scanners at DESY.- ICFA Advanced Beam Dynamic Workshop: Beam HALO Dynamics, Diagnostics, and Collimation (HALO'03) (in conjunction with 3rd workshop on Beam-beam Interaction) (May 19-23, 2003 Gurney's Inn, Montauk, N.Y. USA)
6. Arutunian S.G., Bakshetyan K.G., Dobrovolski N.M., Mayilyan M.R., Oganessian V.A., Soghoyan A.E.., Vasiniuk I.E., Wittenburg K., Vibrating wire scanner parameters optimization. – EPAC’2004.
7. The Superconducting Electron-positron Linear Collider with an Intagrated X-Ray Laser Laboratory.- TESLA Technical Design Report, Part V The X-Ray Free Electron Laser.- DESY 2001-011, ECFA 2001-209, TESLA Report 2001-23, TESLA-FEL 2001-05.