VIBRATING WIRE SCANNER PARAMETERS OPTIMIZATION

S. Arutunian, K. Bakshetyan, N. Dobrovolski, M. Mayilyan, V. Oganessian, A. Soghoyan, I. Vasiniuk, YerPhI, Yerevan,
K. Wittenburg, DESY, Hamburg

Abstract

The vibrating wire scanner (VWS) was experimentally tested [1, 2] on electron beams and showed an unprecedented sensitivity and a huge dynamic range. In this work the experimental results of PETRA proton beam scans are presented. The experiments confirm their excellent suitability for beam halo measurements. A comparison of different materials of the wire is presented and the most suitable materials for different tasks are suggested.

EXPERIMENTAL RESULTS

Two experiments are described in the following:

Ion beam

The vibrating wire scanner (VWS) was tested on the ion beam of the energomassanalyzer EMAL-2. An ion beam with a current of about 1 nA and an energy of 20 keV was obtained. A 90 µm wire from beryl bronze was used and its frequency was measured at center of the beam. A diaphragm of 2 mm × 5.5 mm formed the ion beam with the same sizes and within a 15 second period the beam touched the wire. During that period about 16 pA penetrate the diaphragm. The frequency decrement was about 0.15 Hz (Fig. 1). This result agrees with experimental data [2] within an order of magnitude, where 70 pA electron beam causes a frequency shift of about 1 Hz.

Fig. 1. VWS touched by the ion beam of EMAL-2.

1.2 Proton beam

A series of experiments with the VWS were done at the proton beam of the accelerator PETRA at DESY. The VWS was installed in the proton by-pass to exclude the influences from short electron bunches. During the experiments, the beam consisted of 10 bunches with an initial current about 15 mA and an energy 15 GeV. Two scintillator-photomultiplier pickups (PM1 and PM2) were installed beam-downwards to monitor the rate of scattered protons.

A view of the VWS in its parking position is presented in fig. 2.

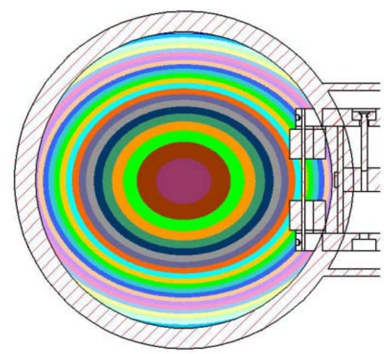

Fig. 2. VWS in parking position, 40 mm from the axis of the vacuum chamber.

In fig. 2 the gradation corresponds to the decrease of beam flux density by 10^{-1}cm^{-2} at the following beam parameters: I = 10 mA, σ_x = 0.6 cm, σ_z = 0.5 cm[1]. The density in the center corresponds to 10^{16}-10^{17} protons/s/cm^2.

Even in the park position the VWS actively reacted to the events in the vacuum chamber, mainly to proton beam turn on/off and to changes of its parameters. Fig. 3 shows a typical picture at currents below 50 mA.

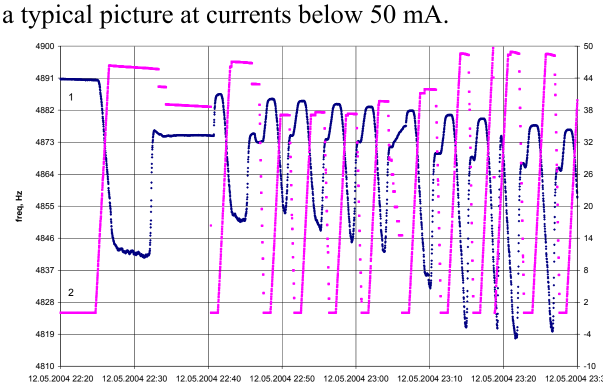

Fig. 3. The VWS output signal in park position (1 – frequency, 2 – beam current).

Turning on and increasing the beam current caused initial wire heating due to interactions of the beam halo with the wire and its support.

---

[1] Τηε βεαμ ωιδτη σ was measured by wire scanners.

6 scans with stable beam positions are presented in fig. 4. The position of the beam according to a BPM nearby is: z = +3 mm, x = -7 mm [2].

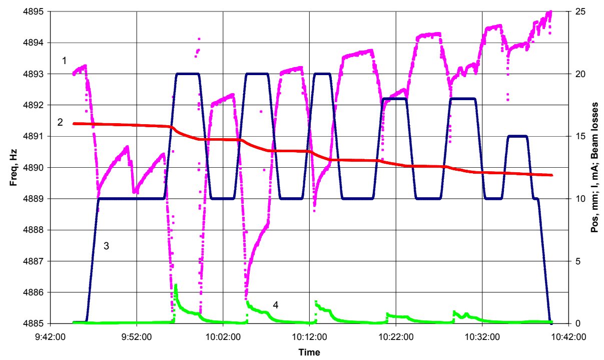

Fig. 4. Scanning of the beam halo. Traces: 1: frequency, 2: current, 3: position, 4: losses (PM1 rate).

The beam current decrement steps are obviously correlated with the scanning. During the inward scanning, the frequency increased up to a value of 5070 Hz. During the period at 20 mm (≈ 13 mm from beam center) the frequency fell slightly and after reaching the initial position the frequency recovered. Note that the recovered frequency is correlated with the absolute value of the beam current. Also the signal from PM1 and the frequency changes are strongly correlated. The uncertainty of the frequency at position 10 mm was about 0.012 Hz (rms), the corresponding uncertainty of wire mean temperature is 0.0005 K.

The results of scanning with 12 mm amplitude are presented in fig. 5. The beam position was slightly optimized to: z = +3.1 mm, x = -7.6 mm. As a result, no correlation between beam current decrease and scanning processes were observed.

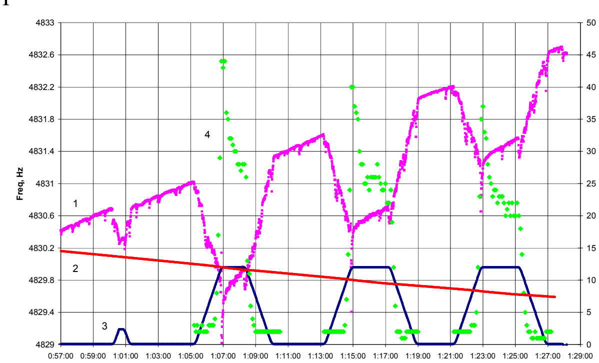

Fig. 5. Some shallow scans. Traces: 1 = frequency, 2 = current, 3 = position, 4 = PM1 rate.

Fig. 5 shows that the signal of pickup PM1 starts only at approaching to the position 10 mm due to its limited sensitivity while the change of the frequency is already observable at the beginning of the scan. In accordance with the overall fall of the current, a monotonic raise of the frequency of the scanner occurs. An interesting pattern appears on the curves corresponding to the maximum shifted position of the scanner. Note that a similar behavior (more blurred) is observed in data obtained from pickup PM1. Therefore it seems to be an effect of real beam-VWS interactions.

Fig. 6 shows a 20 mm scan in more detail (BPM: x = -4.7 mm; scan from 5.9 σ to 2.6 σ from beam center) together with the readings of PM1 and PM2. The signals from PM1 and PM2 are strongly correlated with the frequency signal from the VWS (see fig. 7). Note that the signals should depend linear on the beam halo. However, especially the frequency shows a nongaussian increase at distant positions. This behavior is not well understood yet.

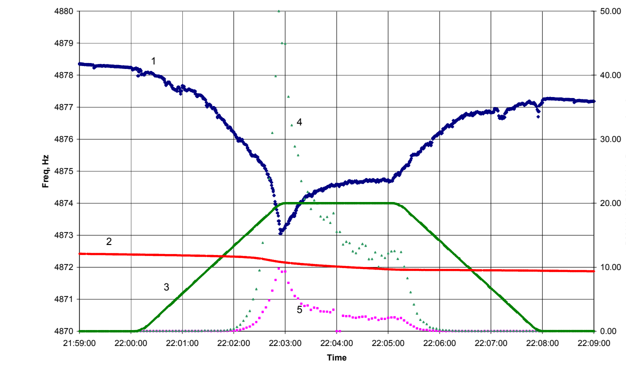

Fig. 6. Frequency, PM1 and PM2 readings in detail. Traces: 1-4 as in fig. 5, 5 - PM2 rate.

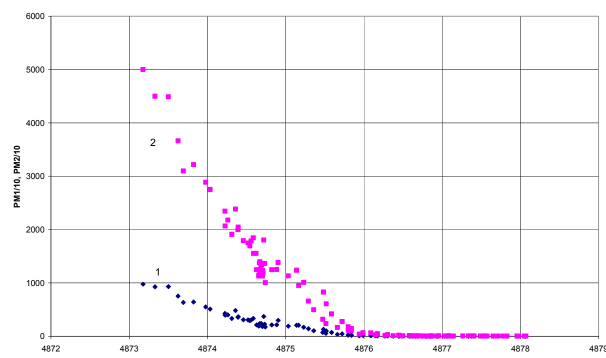

Fig. 7. Correlation between VWS and PM1 and PM2.

SOME PRELIMINARY ANALYSIS

Wn only the temperature of the wire is changed, the oscillations frequency shift is defined by the expression:

$$\frac{\Delta f_1}{f_1} = -\frac{\Delta\rho}{2\rho} + \frac{\Delta\sigma}{2\sigma} = -\frac{3}{2}\alpha_s \Delta T + \frac{1}{2}\frac{E}{\sigma}\alpha_s \Delta T\,, \quad (1)$$

where α_s is the coefficient of thermal expansion of the wire material, E is the elasticity modulus, ΔT is the change of the wire temperature, σ is the wire tension. The wire tension is much less than the factor E (the maximum value of the σ does not exceed a few thousandth of E), so the first term can be neglected. The power Q_s heating the wire is: $Q_s = q_1 I_s$. Due to thermal losses on thermo conductivity (the main cooling mechanism at room temperature) Q_s causes the wire

[2] Note that a negative beam position indicates a shift towards the wire.

heating with respect to environment temperature by the value

$$T_{mean} = 0.594 \frac{Q_S l}{8\pi r^2 \lambda}, \quad (2)$$

where λ is the coefficient of thermal conductivity of the wire, $q_1 = k(dE/dy)(\pi/2)$, k - transformation ratio of ionization losses into heat, dE/dy- particle ionization losses, r - wire radius, I_s - current of particles in vertical gap between magnet poles heating the wire, form-factor 0.594 determines the difference between the triangle model of temperature profile and exact solution.

In our case, where the second harmonics is excited, the change of the frequency f can be written as

$$\Delta f = -0.25 f (E/\sigma) \alpha_S T_{mean}. \quad (3)$$

In the present experiment: $l = 36$ mm, $r = 0.045$ mm, $f = 4900$ Hz (this frequency corresponds to the wire strain 2.801×10^8 Pa, the ratio $E/\sigma = 464$), $\lambda = 0.17$ W/K/mm, vertical gap between magnet poles is 14 mm. For protons of energy 15 GeV, current $I_0 = 10$ mA and $\sigma_x = 6.083$ mm, $dE/dy = 1.3$ MeV/mm (in bronze), and therefore $q_1 = 27.57$ keV, $\alpha_s = 1.9\ 10^{-5}$.

Table 1 presents the results of the estimation of I_s, Q_s, T_{mean} and frequency decrement Δf at different positions of the wire with respect to beam center.

Table 1.

x, mm	Is, A	Qs, W	Tmean	Δf, Hz
13	5.066E-06	1.395E-01	3.45E+02	
17	1.001E-06	2.760E-02	6.82E+01	1.473E+03
20	2.238E-07	6.160E-03	1.52E+01	3.287E+02
25	1.069E-08	2.945E-04	7.28E-01	1.572E+01
30	2.592E-10	7.169E-06	1.77E-02	3.825E-01
35	3.214E-12	8.869E-08	2.19E-04	4.736E-03
40	2.020E-14	5.587E-10	1.38E-06	2.984E-05

The largest shift of the wire oscillation frequency due to heating was measured to about 150 Hz, at a distance between the wire and beam center of x slightly less than 20 mm. This value is less than the value given in Table 1. Two effects might explain this: 1) the uncertainty of the absolute beam position at the VWS of ± 1.5 mm; 2) nongaussian beam tails.

The linear correlation between the PM rates and the frequency indicates that no other reason than ionization losses contributes to the wire heating. The heating of the wire by electromagnetic component of the proton beam seems to be negligible, which might not be the case for the short bunches of an electron beam. To determine this effect additional experiments are required.

OPTIMIZATION OF SOME PARAMETERS OF VWS

The operating range of the measured temperatures in fact is defined by the preliminary tension of the wire, and the wire oscillations break when the temperature is increased. For maximal tension of the wire we choose the value of $\sigma_{0.2}$ (residual deformation after removal of the load is 0.2 %). The temperature range of the sensor is equal to

$$\Delta T_S = \sigma_{0.2} / \alpha_s E$$

In Table 2 these values for different materials are presented.

Table 2

Material	*E, GPa*	*α_s, 1/K*	*$\sigma_{0.2}$, GPa*	*ΔT_S, K*
Beryl Bronze hard	130	1.90E-5	0.9*	482
Wolfram recrystal.	400	4.70E-6	0.5*	433
Titan, therm., 99.6%	110	9.86E-6	0.3	577
Platinum, therm.	160	9.70E-6	0.07	341
SiC, fibre	400	4.50E-6	2.0*	856
SiO_2, fibre	550	6.25E-6	1.38*	702

One can see that Titan alloys and SiC threads hold much promise (* - the half of the breaking point is taken as $\sigma_{0.2}$). The main parameter of determining the temperature profile for equal beam parameters is the coefficient of thermal conductivity. To increase the sensitivity of the VWS materials like Titan are preferable. The development of new sensors on basis of dielectric strings (e.g. SiC) has a good perspective.

CONCLUSION

Experiments show the ultra high sensitivity of VWS even at a distance of more than 5 σ from the beam center. The accuracy of the frequency measurements achieved 0.01 Hz, which corresponds to wire temperature measurement accuracy about 0.0005 K. Comparison of the signal from VWS with the loss rate showed a linear correlation indicating that the VWS can be successfully used for very sensitive halo measurements.

The application of VWS is not only restricted to halo measurements. In the future we will also study its use for profiling and positioning of high brilliant photon beams.

ACKNOWLEDGMENTS

The authors are grateful to the PETRA staff for their enthusiastic help during the experiments on PETRA.

REFERENCES

[1] Arutunian S.G., Avetisyan A.E., Dobrovolski N.M., Mailian M.R., Vasiniuk I.E, Wittenburg K., Reetz R. - Proc. 8-th Europ. Part. Accel. Conf. (3-7 June 2002, Paris, France), pp. 1837-1839.

[2] Arutunian S.G., Dobrovolski N.M., Mailian M.R., Vasiniuk I.E.- Phys. Rev. Special Topics. - Accelerators and Beams, 2003, v. 6, 042801.