PETRA PROTON BEAM PROFILING BY VIBRATING WIRE SCANNER

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Abstract

A vibrating wire scanner (VWS) based on the strong dependence of the wire oscillation frequency on temperature was developed and used in the 15 GeV/c proton beam of the proton accelerator PETRAII at DESY. The results show an enormous sensitivity of the scanner and the possibility to use it for weak particle beams and beam halo profiling. Details of the measurements and the results are given. Some investigations of the frequency and the Q-factor of the vibrating wire oscillations dependence on vacuum level are presented.

INTODUCTION

Vibrating wire scanners are based on the extremely sensitive dependence of the wire natural oscillations frequency on its temperature [1-6]. On the other hand, the wire temperature depends on the number of interacting particles/photons with the wire.

In this paper experiments with the vibrating wire scanner on a 15 GeV/c proton beam at PETRA are presented. The dependence of Q-factor of the wire on the vacuum pressure is also discussed. This method might give some additional measuring potential to the VWS.

EXPERIMENT IN PETRA

The experiments in PETRA were done on the proton beam in the bypass, where the electron and proton beams are separated in different beam pipes. Such place was chosen to avoid electromagnetic disturbances induced by electromagnetic wake-fields on the wire, which are much larger for short electron bunches than for long proton bunches.

The vibrating wire resonator consists of a quartz support with a coefficient of thermal expansion of a few $10^{-7}\,K^{-1}$ and a beryl-bronze vibrating wire with a coefficient of thermal expansion of $17.5\times10^{-6}\,K^{-1}$ [7]. Such a ratio of coefficients provides sensitivity to both surrounding media temperature variations and wire heating by the beam. The beryl-bronze vibrating wire passed preliminarily thermal treatment. More details of the experimental setup can be found in [6].

Park Position

The wire of the VWS in its parking position had a distance to the beam center of 6.7 σ. Beam parameters: I = 10 mA, σ_x = 0.6 cm, σ_y = 0.5 cm. The short term frequency stability was 0.01 Hz at a stable room temperature and at absence of the beam.

Fig. 1 represents the typical picture of the scanner frequency change in park position during 30 hours. The proton and electron beams currents in PETRA are also presented. Note that during an absence of both beams the frequency changed smoothly connected with the temperature changes of the whole pickup while during operation of electrons and protons the variations are much larger. The temperature change in the chamber without beam can be estimated from the data to about 7 °C. In the presence of proton beam current the frequency behaviour depends on current intensity. At currents less than 50 mA the wire frequency changes are proportional to the beam current while at higher currents probably the electromagnetic disturbances also have influence on the frequency/temperature by absorbing some modes.

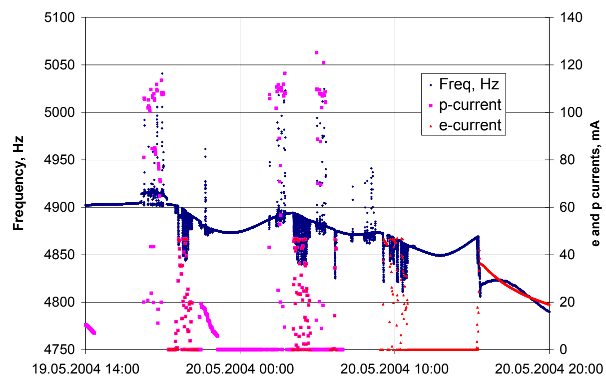

Figure 1: Dependence of VWS frequency on time in park position. Available values of proton beam and electron beam currents are also presented.

Conclusion: Even at a distance of 6.7 σ from the proton beam the VWS has a sensitivity of about 1 Hz/mA.

Scanning

The main mechanism of heat transfer is the thermal conductivity along the wire. The thermal equilibrium time τ can be roughly estimated from the equality of the power scattered due to thermal conductivity $4\lambda S(T-T_0)/l$ (T is the temperature in the middle of the wire, λ is the coefficient of thermal conductivity, S and l are the cross-section and length of the wire) and power, necessary to maintain the wire at given temperature $\rho Slc(T-T_0)/(2\tau)$ (ρ is the wire material density, c is the thermal capacity). From this equality we obtain $\tau = c\rho l^2/8\lambda$. For beryl-bronze wire of total length 36 mm this time is about few sec. In these experiments the scanning was done at speed 0.5 mm/sec.

Before the scans some vertical and horizontal corrections of the beam position at the scanner were done.

Fig. 2 shows a scan started at a distance of 40 mm from the vacuum chamber center.. Two scintillators with photo-multipliers PM1 and PM2 were installed in the vacuum chamber to registered protons which are scattered on the wire (and on other parts of the scanner).

The signal from the VWS sensor changes practically from the beginning of movement, while the signals from scintillators start to increase first at distances of 27 mm from the vacuum chamber center.

The scanner was moved from its park position towards the vacuum chamber center up to 20 mm. In this experiment the proton beam was shifted towards the scanner park position by a distance of 4 mm by means of a local beam bump.

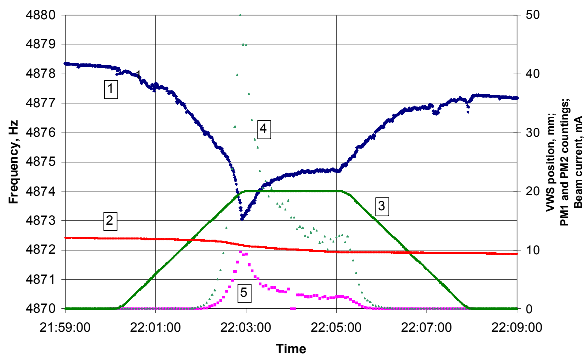

Figure 2: Scan of the proton beam: 1- frequency of the VWS, 2 – beam current, 3 – VWS position relative to the vacuum chamber center, 4 and 5 – PM1, PM2 signals.

As seen from 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 might occur from the influence of electromagnetic higher order modes accompanying the proton beam. These electromagnetic components might be able to heat the wire by absorbing some modes (see [8]). Clarification of this problem and corresponding modifications of VWS require additional efforts.

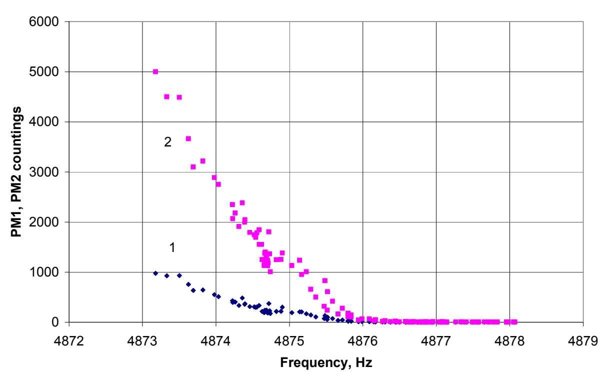

Figure 3: Correlation between signals from VWS and PM1 (curve 1) and PM2 (curve 2).

Despite this effect, the signals from PM1 and PM2 strongly correlate with frequency signal from VWS starting from some scanning depth (Fig. 3). There was some small hysteresis observable connected with different directions of the VWS movement.

The largest shift of the wire oscillation frequency due to heating was about 150 Hz at the distance between the wire and beam center of x slightly less than 20 mm. This value is about a factor 2 less than the calculated value. Three effects might contribute to the uncertainty: 1) the uncertainty of the absolute beam position at the VWS of ±1.5 mm; 2) non-gaussian beam tails; 3) electromagnetic background.

VWS QUALITY FACTOR

In the experiments at PETRA a strong dependence of frequency on the vacuum pressure was observed.

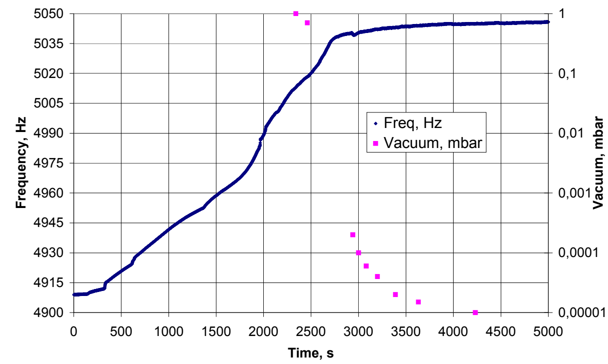

Figure 4: Dependence of frequency of VWS at PETRA chamber vacuum level.

As seen from Fig. 4 the frequency increased with decreasing pressure. The main increment by about 120 Hz occurs in pressure interval 1bar - 1 mbar. At pressures below 0.01 mbar the frequency rate changes its slope and seems to saturate.

The structure of resonant curves was studied by amplitude-frequency characteristics. Fig. 5 represents some such curves for 0.4, 10, 30, 100 and 1000 mbar. The Experiments were done at energomassanalizer EMAL-2 in YerPhI.

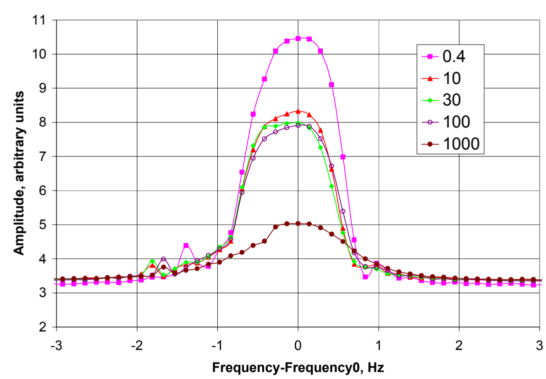

Figure 5: Few amplitude-frequency characteristics for different vacuum levels.

Widths of resonant curves for vibrating wire resonators of different constructions (named A1, A2, A3) are presented in Fig. 6. In all resonators a beryllium bronze wire is oscillating, but different types of wire fixation on the support were used. The above described method requires sweeping of the frequency near the resonance and takes long time. To reduce the time a method for estimation of Q-factor was developed based on measurement of the signal amplitude in a feedback scheme of the wire oscillations excitation. The voltage on the wire depends on its Q-factor; thus, the magnitude of the feedback signal to support constant amplitude in the generator output can be used for the estimation

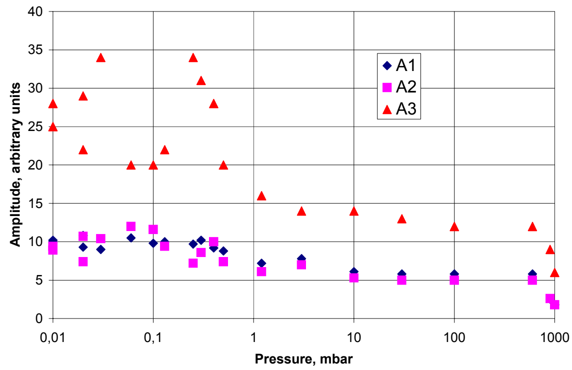

Figure 6: Q-factor measurements of three different resonators depending on vacuum level: A1, A2, A3 different types of VWS construction.

Results of such measurements are presented in Fig. 7. The measurements were done in range of pressures between 0.4-1700 mbar.

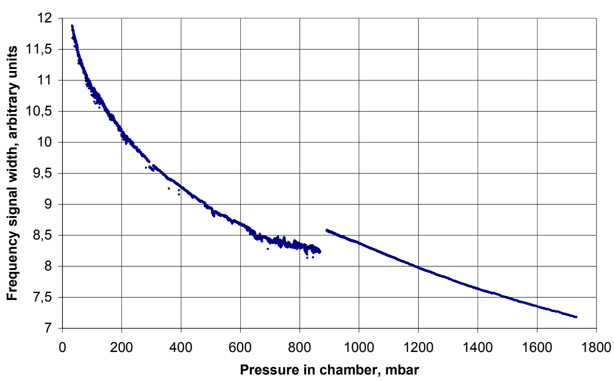

Figure 7: VWS resonator quality dependence on pressure in vacuum chamber.

Experiments in the low pressure range (left part of curve) and at high pressures (right curve) were done at slightly different environmental conditions.

CONCLUSION

Experiments with the VWS show that the system is sensible to changes of the beam current even in park position even at distance of 6.7 σ (here 40 mm) from the beam center. The scans show a strong correlation between scanner position and frequency signal. The accuracy of the frequency measurements achieved 0.01 Hz which corresponds to wire temperature measurement accuracy less than 0.001 K. Comparison of the signal from VWS with a scintillating counter system registering secondary particles/radiation showed that the signal from VWS appears at least 10 mm farther from the beam center than mentioned scintillators.

The obtained data show that the VWS can be used for beam diagnostics in accelerators. Some improvements of the scanner construction to increase the wire operating zone and to diminish the sizes of the wire support of the VWS will be necessary. At very large distances from the beam, the heating of the wire due to higher order mode coupling disturbs the signal. Some more developments are necessary to get rid of this effect. Very perspectives will be the development of sensors on basis of dielectric strings, including new type of oscillations exciting and data acquisition. The area of VWS applications can be enlarged, including profiling and positioning of photon beams from synchrotron light sources and laser beams. In this case the electromagnetic coupling does not exist.

ACKNOWLEDGMENTS

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