FIRST EXPERIMENTAL RESULTS AND IMPROVEMENTS ON PROFILE MEASUREMENTS WITH THE VIBRATING WIRE SCANNER

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Abstract

The paper presents the first experimental results of transverse profile scans using a wire scanner based on a vibrating wire (vibrating wire scanner - VWS). The measurements were performed at the injector electron beam (10 nA) of the Yerevan synchrotron. The beam profile information is obtained by measuring the wire natural oscillations that depend on the wire temperature. This first experiments on weak electron beam proved this new method as a very sensitive tool, even suitable for very sensitive tail measurements.

Additional, improvements were tested to overcome problems connected with signal conditioning and signal transfer in the presence of electromagnetic noise. As a result the noises were clearly separated and reduced. A mathematical method for rejection of distorted data was developed. Experiments with the scanner at the PETRA accelerator at DESY are planned for measurements of beam tails.

INTRODUCTION

First experiment on scanning of weak electron beam of the injector of Yerevan synchrotron proved the possibility of beam profiling by the vibrating wire scanner (VWS) [1]. The profile of a low intensity electron beam (average current of the beam was few nA) was measured by using the vibrating wire scanner technique. The experimental results show that the sensitivity of vibrating wire scanners is optimal for extended measurements of beam tails.

The experiments have also shown, that the scanner was sensitive to external electromagnetic noise. It was observed that the level of distortion of frequency from the wire correlates with turn-on of high frequency accelerating klystrons independent of whether the electron beam fell on the wire. Analysing the noises allowed marking out the most sensitive parts of the readout system. The improvements were tested during the autumn 2002 experimental session. As a result the noises could be clearly separated and reduced. A mathematical method for rejection of distorted data was developed. Taking into account this experience a special board is developed for planned experiment with the scanner on the PETRA accelerator at DESY.

SCANNING EXPERIMENTS

The principle of operation of the vibrating wire scanner is based on the dependence of the wire natural frequency f_0 on the beam intensity at the given location. The energy deposition of the beam particles in the wire causes heating of the wire. Hence the stretched wire temperature can be obtained by measuring its natural oscillations frequency by an autogenerator electronic circuit with a positive feedback loop.

Initial experiments on profiling were done using laser beams [2, 3]. The effective temperature precision was estimated to be about 10^{-4} degrees C (without noise).

In this experiment the profile of the low intensity (after collimation to about 10 nA) electron beam of the injector of the Yerevan synchrotron was scanned (bunches with RF of 2797.3 MHz with pulse duration of 2 μs). The repetition rate of pulses was 50 Hz. A beryllium-bronze wire of 90 μm diameter as vibrating wire was used. Fig. 1 represents the result of the reconstruction of the beam profile for the first scanning. Fig. 1 also presents the profile of the beam approximated by a normal distribution with σ = 1.48 mm and beam central position at 30.87 mm. The overall current of the beam was set to $I_0 \sim$ 10 nA. Only half of the beam could be scanned because of the short throw of the scanner.

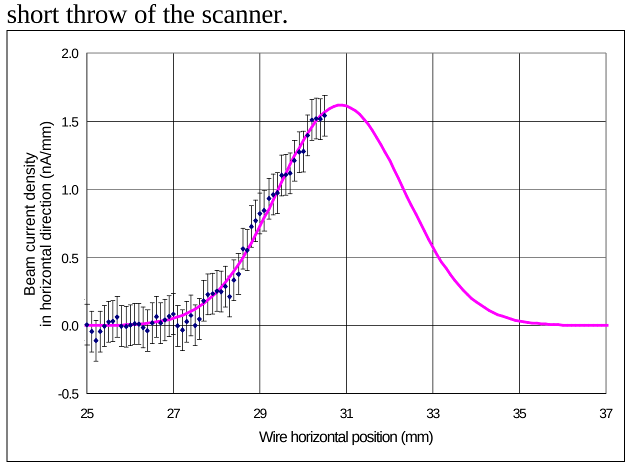

Fig. 1 Reconstructed horizontal profile of an electron beam with a current of about 10 nA. The reconstruction was done after a detailed noise analysis (see "noise studies").

Calculations of "tail sensitivity"

Let's estimate the sensitivity of VWS with respect to the lower limit of beam intensity. In this case radiational losses of wire temperature are negligible and the balance of temperature is determined by the thermal conduction along the wire. Let the temperature of the wire near its fixation points be T_0 and at the middle T_0+T_m (triangular profile of the temperature along the wire). Thermoconductive losses $P= 4\pi\lambda r_w^2 T_m/l$, where λ is the thermoconductivity of the wire with the radius r_w and length l. Total power deposited on the wire $Q=(\pi/2)^{0.5}(r_w^2/\sigma_x)\exp(-x^2/2\sigma_x^2)(I_0 kdE/dy/e)$, where σ_x is the beam size, x is the wire location with respect to the beam center, dE/dy are the ionization losses, k is coefficient transition ionization loss to heat of the wire. Usually k is approximately 0.3* . From the thermal balance follows that:

$T_m = (1/4(2\pi)^{0.5})(l/\sigma_x)\exp(-x^2/2\sigma_x^2) \quad (I_0 k dE/dy/e)/\lambda$.

Note that there is no dependence of T_m on the wire radius.

For beryllium-bronze wire and 100 mA proton beam with σ_x = 0.6 cm (PETRA conditions) the value T_m of about 0.01 K (vibrating wire thermal sensitivity at presence of electromagnetic noises) is achieved at x = 5.7 σ.

The following estimation agrees well with this calculation: At the present experiment a significant increase of the temperature was achieved at about 2 σ. At that wire position, the wire was hit by 1.8 $\cdot 10^8$ e/s. For a 100 mA beam with a width of σ = 0.6 cm this amount is reached at about 6.1 σ. Note that dE/dy for electrons and protons at ultra high energies is about identical.

NOISE STUDIES

Some problems connected with signal conditioning and transfer are discussed in the following. These problems were absent in test experiments in laboratory conditions and arise with RF power switch-on in the real experiments on accelerator beam scanning. The noise was caused by the klystron station of the Yerevan synchrotron injector.

Fig. 2 presents graphics of measured frequency signal before and after the klystrons turn-on in Injector (they were turned on approximately at 13:43).

A scheme of multiplying the vibrating wire frequency by factor 32 was used to increase the processing speed of the frequency measurements. The electronic multiplication of the wire oscillation results in a frequency of about 7963x32 Hz. It is transferred through a 50 Ohm coaxial line of length 70 m in form of a sequence of alternating-sign rectangular pulses with amplitude ± 10 V and with a recurrence rate of about 254.8 kHz. With the powered klystron, the signal became distorted (see Fig. 2)

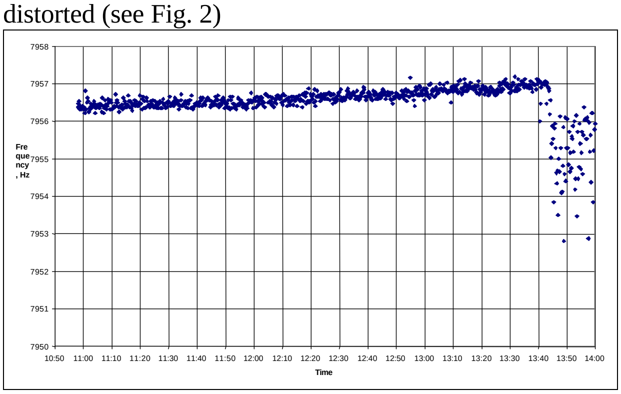

Fig. 2. Noise trace of the signal. At 13:43 the high frequency system was switched on and the noise appeared. Note that the beam was not present.

* about 70% of the energy disappears due to secondary particles emitted from the wire

The generation of various types of noise was studied in laboratory conditions afterwards. Voltages of different form (artificial noises, similar those observed during the experiments) were applied between the common point of the electronic circuit and metallic frame of the scanner to model the noise. Frequency registration was done by the same scheme as during the experiment

The most sensitive unit to electromagnetic noise was found to be the frequency multiplying circuit while the generator, the amplifier and the trigger circuits had no influence on the noise figure. Therefore a new method for frequency measurement was developed. The frequency measurement was carried out by gating the high frequency f_h pulses by one signal period. In the case frequency periods are applied during the time *gate* the relative accuracy of this method is described by the formula ? $f_0/f_0= 1/(gate*f_h)$. At f_h about 6 MHz the gain in the measurement accuracy becomes $f_h/(k*f_0)=30$. That means that the measurement accuracy is on the level of 0.03 Hz within the time interval of 30 ms. The two advantages of this method are i) the reduction of measurement time (therefore below we will name it as fast method); ii) the elimination of frequency multiplication block. This procedure will be done in the interface board inside the computer in the control panel far from noise source.

As a result of the new circuit, the frequency signal splits into several parallel traces (see Fig. 3a, in this example four traces) in the present of strong noise. The lowest trace is the non disturbed signal. As the trace level increases the number of points in it decreases, and there is only one point in the forth stripe. The distance between the traces is about 7.7 Hz at the main signal level of 7765 Hz, i.e. is equal to 1/1000 part of the main frequency. This shows that the noise affects the pulse counting by 1/1000 of the main frequency or 0.1 % only.

This measurement method in a real experiment was tested in autumn 2002 on the injector of the Yerevan synchrotron. A smooth trace with nearly no noise was registered when the klystron in the Injector were turned off. The picture changed when the klystrons turn on. As it was in laboratory experiment the main frequency trace is split into 4 levels (see fig. 3b): the main (lowest) trace contains over 90 % experimental data. About 7.3 % of all values are shifted by about 2.56 Hz and 3 % by 5.13 %. The frequency in the main trace is 2560 Hz, i.e. as in laboratory experiment the split is about 1/1000 of the main frequency. Actually the mentioned splitting allows rejecting the frequency spikes programmatically. This enables beam scanning experiments with a considerably signal-to-noise ratio.

PREPARATION FOR EXPERIMENTS AT PETRA

In 2003 it is planned to test the beam scanning system based on vibrating wire in the PETRA proton accelerator at DESY. Due to high sensitivity of vibrating wire scanners the interesting measurements of beam tails will be performed [4, 5]. The electronic schemes were tested under laboratory conditions and are prepared for experiments at PETRA. The effect of the cables were tested for up to 100 m.

Thus, all the units of the PETRA beam scanning system by a vibrating wire are prepared for installation into the accelerator.

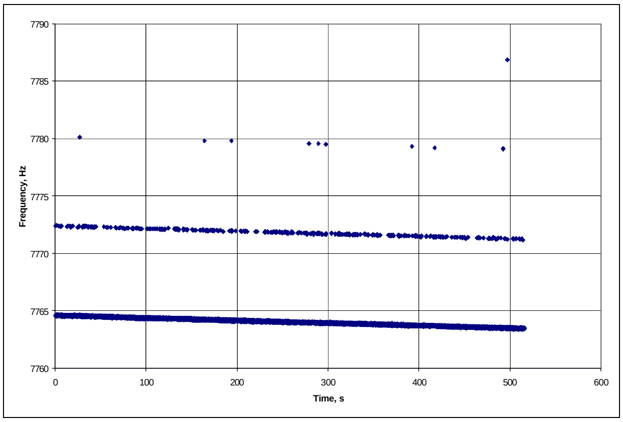

Fig. 3a Registration of frequency signals obtained by the fast measurement method under laboratory conditions in the presence of artificial noise.

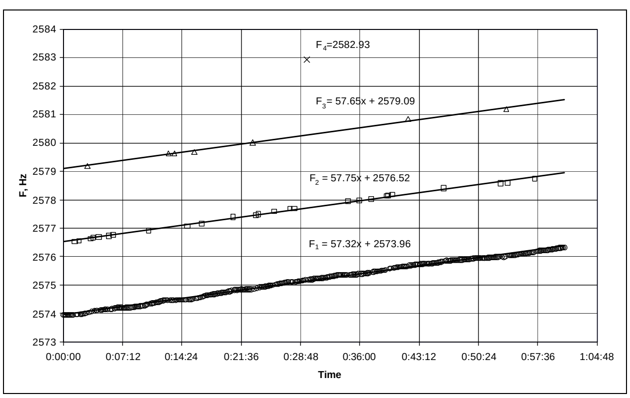

Fig. 3b Typical dependence of frequency on time, obtained by fast method in the presence of electromagnetic noises, associated with the RF klystron.

In the experiments the frequency measurements were done with a time gate of 1 s, i.e. averaging the time structure of the beam (bunches and pulses). In the case of low beam intensities this does not cause any problem. But for more intensity the problem of short-time heating of the wire can arise. The characteristic time of the wire heating in transverse cross-section is of order of $cr_w^2/\lambda \sim (2\div5)(r_w/m)^2$ s. Thus in case of $r_w>10$ μm one can neglect the bunch structure of the beam. However, the pulse duration is much more than the mentioned times, so the short time heating may reach the destruction limit. This problem is mentioned e.g. in [6, 7]. Note that the fast method of frequency measurement for VWS is sensitive to the pulse structure of the beam but not to the bunch structure.

SUMMARY

Experiments confirmed our expectation on the possibility of using a vibrating wire scanner (VWS) for charged particle beam transverse profile measurements. These measurements are particularly useful for low current beams. Specifically, it was confirmed that:

– Interaction of the beam with the wire does not quench the wire oscillations;
– The change in the natural oscillation frequency of the wire during interaction with the beam is a reliable method of measuring the transverse profile of extremely low intensity beams.
– The vibrating wire scanner can be a valuable tool for measuring low intensity beam profiles, and also for beam halo and beam tail measurements at several σ.

In these experiments the accelerator RF system induced noise in the measurement system. This problem was solved by standard engineering techniques.

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