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Yerevan Synchrotron Injector Electron Beam Transversal Scan with Vibrating Wire Scanner

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Abstract—We have developed extended-aperture (20 mm) vibrating wire scanner (VWS) for transversal scanning of electron beams with large transversal size. Test experiments were performed in open atmosphere on the 40 MeV electron beam of the Yerevan synchrotron injector with the 4–10 μA at outlet. A construction of VWS is elaborated for scanning beams with larger transversal size. This elaboration is a new precision tool for diagnostics of beams in accelerators, which may be successfully employed, because of universality of the used operation principle, for profiling of as well large-aperture proton and ion beams.

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Keywords:

1. INTRODUCTION

Principle of operation of vibrating wire scanner is based on the dependence of the frequency of eigenmodes of wire vibrations on its tension [1]. We used in our preceding developments the scheme of direct pass of the measured beam through the vibrating wire. For excitation of wire eigenmodes the interaction between the wire and the field of a permanent magnet has been used. For matching of the wire length with parameters of beam scanning a rather convenient scheme was proposed: the two end portions of the wire were in the magnetic field, while the middle part was left free for scanning the beam. The wire length is usually chosen to be in the range of tens of millimeter (30–60) and the central free part of the wire amounts to nearly one third of the wire length, i.e., 10–20 mm. For beams with millimetric transverse size this scheme operates satisfactory. However, for beams with a size larger than the VWS aperture or at measurements of the beam halo region, some particles of the beam hit the parts of VWS (magnetic system, wire clips, holders, screws, etc). This effect has been noted in [2] where VWS was used for measuring halo of proton beam on the accelerator PETRA. View of VWS in park-position is demonstrated in Fig. 1. Every step in tonal gradation corresponds to an order of magnitude drop of the beam density.

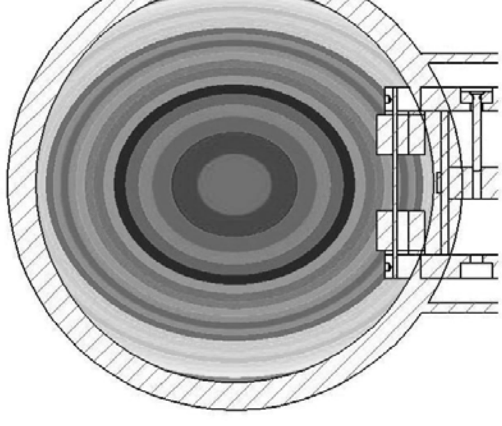

Fig. 1. VWS in park-position on the accelerator PETRA.

2. EXPERIMENT

2.1. Sensor

The purpose of the experiment was to measure the vertical profile of a beam of 40 MeV electrons from the injector of ANL (Alikhanyan National Laboratory, former YerPhI) synchrotron. The beam current was up to 10 μm and the estimated transverse size of beam was about 20 mm.

Such a beam was supposed to use for production of radioisotopes from photonuclear reaction. The main task was obtaining the ^{99m}Tc isotope by irradiation of molybdenum trioxide with electron beam which was converted into bremsstrahlung photon flux in a tantalum plate [3].

The magnets of the optimum magnetic system are placed in the centers of half-waves of the second harmonic. For a 38 mm long wire the distance between the magnets was 11 mm. For enlarging the scanner aperture up to 20 mm the magnets were shifted towards the clips of wire ends, but this led to loss in optimality of the scheme of excitation of vibration generation. We developed a special shock-scheme of excitation of eigenmodes of electromechanical resonator, which compensated for this shortcoming.

As compared with previous experiments we elaborated new electronic schemes: electronics placed in the Ring Hall of accelerator contained only a scheme which excited wire vibrations and amplified the sinusoidal signal up to the amplitude of 3 V. Supply for this electronics and for the step motor, as well as transfer of information signals were realized by means of a 60 m long multicore cable with 3.4 Ω resistance of each core. Power was supplied via paired wires. Information signals were transferred via twisted pairs: this suppressed electric noises caused by operation of high-current accelerator devices.

2.2. Temperature Dependence of VWS

The sensing element of VWS contains many constituent parts. The specific values of characteristic time constants of each part depend on temperature. These values depend on the heat capacity and heat conduction of the material, as well as on the sizes of the specific part. It is also essential where VWS is placed, in vacuum or in atmosphere. Thermal inertia is minimal for the thin vibrating wire and maximal for the bearing base of VWS. So, the response of periodic thermocycling of VWS depends strongly on the rate of variation of the sensor temperature. Figure 2 shows results of such thermocycling with following parameters: temperature rise up to 70°C at the rate of 0.5 deg/min, dwell time 40 min, temperature drop down to 30°C at the rate of 0.5 deg/min, and dwell 40 min. The loop in Fig. 2 runs in time counter-clockwise. The hysteresis behavior is caused by the above-indicated distinctions in thermal characteristics of VWS parts. The slow dependence of VWS on the environment temperature is estimated to be nearly –4 Hz/deg.

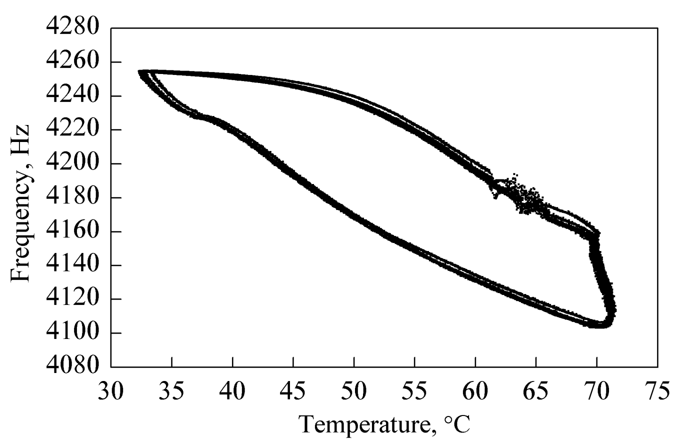

Fig. 2. Thermocycling of VWS with the period of 240 min.

2.3. Scanning

In the above-mentioned studies of methods for producing radioisotopes an electron beam from linear accelerator has been used. For this problem the beam size was an important parameter; since the irradiated material was a pellet of 18 mm diameter, the size and position of the beam had to suit this condition. Thus the VWS aperture should exceed 20 mm.

In order to make possible observation of beam interaction with individual parts of VWS, these parts were phosphor dye covered. The image was visualized by a video camera. The scanning process is shown in Fig. 3. The central bright spot on the screen of target input corresponds to the beam profile. The slide (A) shows the park-position of VWS with the sensor aperture marked by thick lines. The slide (B) shows the situation where the beam touches magnetic poles of the sensor (touching points are indicated by arrows). It is seen in slide (C) that the beam-exposed region increases essentially with continuing scan. The last slide (D) shows how the beam exposes, together with magnetic poles, also the bearing base of VWS (up-to-down arrow).

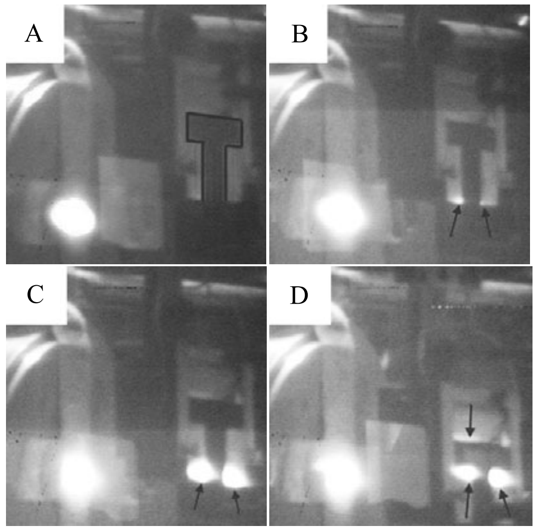

Fig. 3. It is seen in slides B, C, and D how phosphor-coated parts of VWS are visualized at their continuous exposure by the beam.

Figure 3 demonstrates that the horizontal size of beam is actually larger than 20 mm (size of VWS aperture). Thus, a large number of electrons hits the VWS parts and heats them. The beam hits first the outer parts of magnetic system and at the end of scanning it can intersect the VWS bearing base too. Each heated part stimulates in its turn two different processes of influence on the frequency. First, a shift occurs of the wire pinching points because of mechanical links in the heated part, second, different heat transfer mechanisms influence temperature of vibrating wire. In our experiments the main mechanism of heat transfer was convective motion of air. Expansion of the wire pinching points leads to increase in frequency, whereas heating of wire leads, in contrary, to decrease in the frequency of vibrating wire. Balance between these two processes is dynamical and depends essentially on the scanning rate. The results of two such scans to the same depth at the rates of 5 mm/min and 10 mm/min are given in Fig. 4.

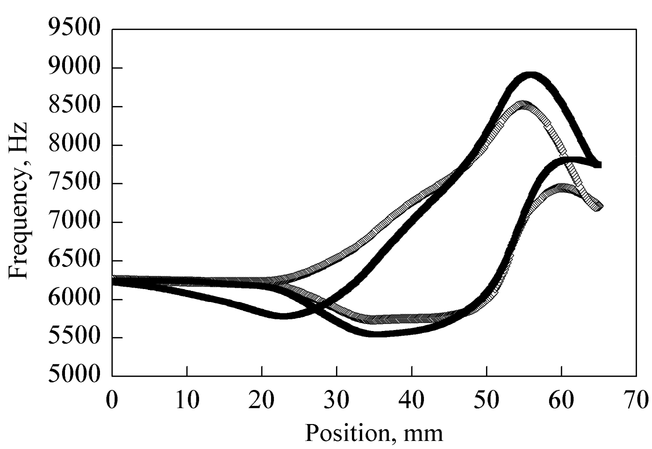

Fig. 4. Two scans with the depth of 65 mm at different rates (rhombs – 10 mm/min, black squares – 5 mm/min).

The process becomes the more complicated the larger number of VWS parts exposed by the beam. Frequencies higher than 6240 Hz in the plot should be considered as overheating of the VWS base. This occurs at scanning to the depth exceeding 50 mm. It is apparent that the influence of overheating is very strong, more than 2500 Hz.

In both scans the process was initiated from the first impact of the electron beam with the wire (position 20 mm), when VWS was still in the state of thermal balance. In order to use this circumstance, we performed two unidirectional scans (forward and backward) to the depth of 50 mm with preliminary thermobalanced VWS sensor. Corresponding data are demonstrated in Fig. 5.

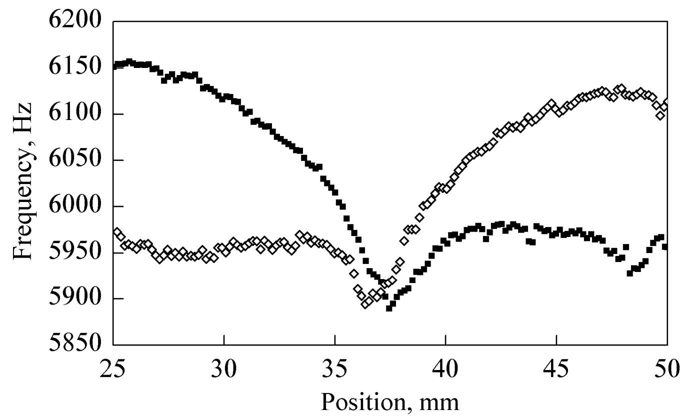

Fig. 5. Results of two unidirectional forward and backward scans at the rate of 10 mm/min (forward – black squares, backward – rhombs).

Using the data of these scans it is possible to restore the beam profile. In Fig. 6 this is performed by averaging the frequencies of the two scans in the same position (bright rhombs). Description of this behavior by the Gaussian distribution is depicted by dark squares (Fig. 6): the peak position is 37.24 mm and the standard deviation 3.1 mm.

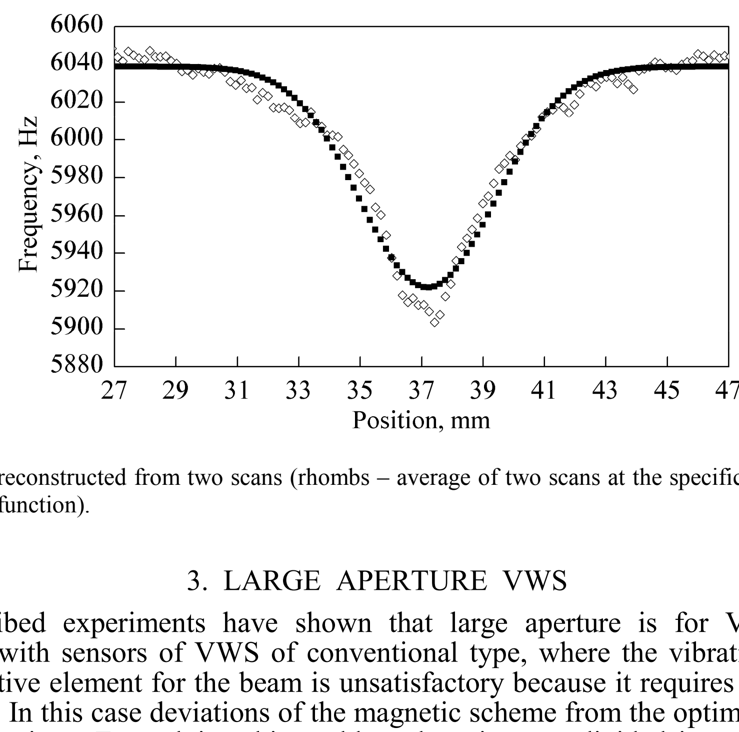

Fig. 6. Beam profile reconstructed from two scans (rhombs – average of two scans at the specific point, black squares – fitting by a Gaussian function).

3. LARGE APERTURE VWS

The above-described experiments have shown that large aperture is for VWS sometimes very desirable. Scanning with sensors of VWS of conventional type, where the vibrating wire serves at the same time as a sensitive element for the beam is unsatisfactory because it requires essential extending of the magnetic system. In this case deviations of the magnetic scheme from the optimum lead to difficulties in generation of vibrations. For solving this problem the wire was divided into two segments [4]: the beam sensitive segment (2) and the segment vibrating in magnetic field (see Fig. 7). Figure 7 shows the general view of the prototype of VWS with large aperture (VWS_LA). In our case the sensor aperture was 50×100 mm. The yoke is seen which divides the wire into vibrating and measuring parts. Placed in the bottom is the vibrating wire in the magnetic system.

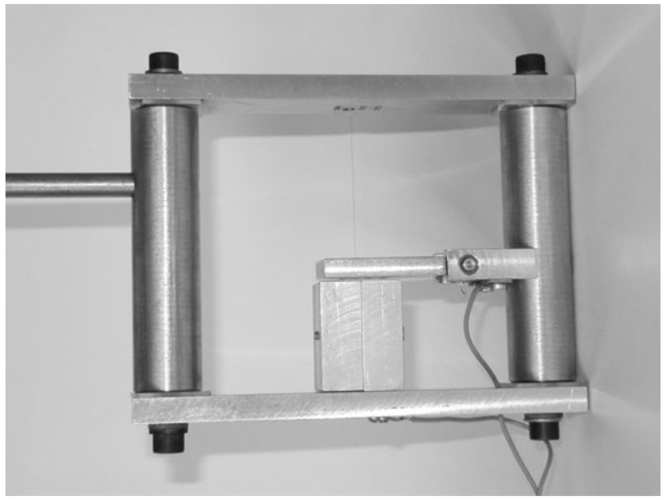

Fig. 7. Photograph of VWS_LA mounted at the beam outlet of the Yerevan synchrotron injector.

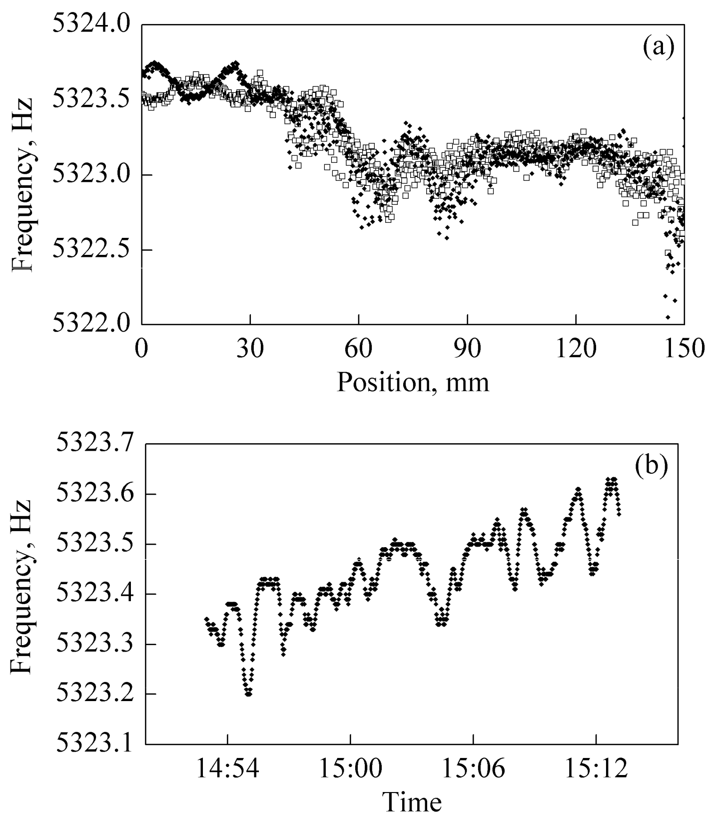

Fig. 8. (a) Scan without beam at the rate of 10 mm/min to the depth of 150 mm (black squares – forward, rhombs - backward). The observed noise in the scan signal is explained by vibration of the scanner feed; (b) Behavior of the frequency of VWS_LA in park-position during 20 min.

This engineering solution enables applying different materials for the sensitive and vibrating wires; for the sensitive part even wires of dielectric materials may be used. In the scheduled experiments we used the sensor of VWS_LA in open atmosphere, therefore we employed for both segments of wire hardened stainless steel with good mechanical characteristics.

The sensitive wire in the design of VWS_LA is almost free of considerable heat contacts with other parts of the sensor, therefore in order to minimize the ambient temperature dependence we used invar rods as bearing racks. Diurnal frequency drifts of the sensor were approximately 1 Hz. For avoiding direct convective disturbances the VWS_LA sensor was packed into aluminum foil.

Figure 8a shows the result of preliminary scanning by VWS_LA to the depth of 150 mm without electron beam. For comparing behavior of VWS_LA at rest and in motion Fig. 8b depicts the time dependence of the frequency of sensor in park-position.

A typical scan of electron beam with energy 40 MeV and current 10 μA is demonstrated in Fig. 9.

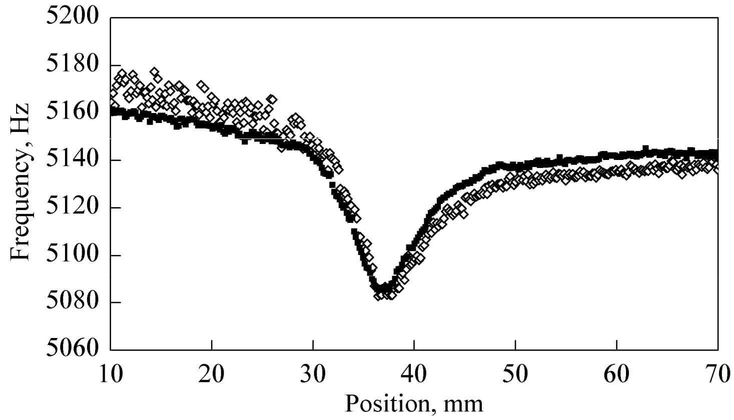

Fig. 9. Frequency signal from the VWS_LA sensor at forward (rhombs) and backward (black squares) scanning.

During scanning the electron beam passes initially the lower invar rack (lower part in Fig. 7), then it gets to free space before the sensitive wire. At this time the process of sensor thermalization takes place leading to the increase in noise in the frequency signal. Taking into account this fact, we perform reconstruction of the beam profile from the data of backward scanning. After subtraction of distribution "tails" the differential signal was multiplied by a factor 0.0195 μA/mm/Hz. The result of this operation is shown in Fig. 10

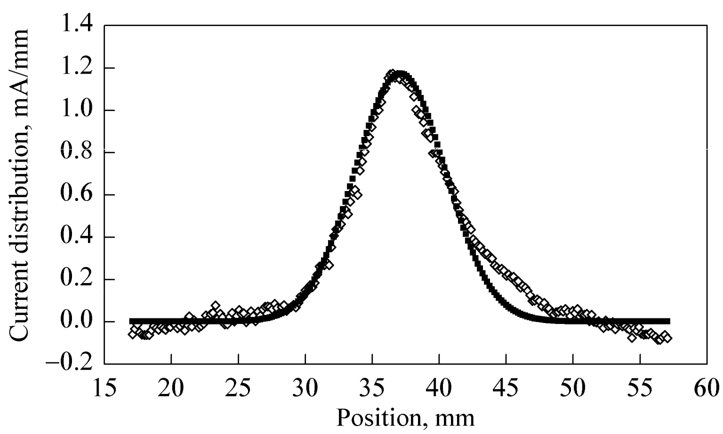

Fig. 10. Reconstruction of the electron beam profile from the differential signal of VWS_LA sensor (rhombs). Fitting with Gaussian distribution with parameters $\sigma = 3.4$ mm and mean value 37.1 mm is given by black squares. The distribution is normalized to the total beam current of 10 μA.

4. CONCLUSION

Experiments have shown that scanners with a vibrating wire may successfully be used for profiling large aperture beams. We developed a new type of VWS with two separate wires which allowed achieving the aperture 50×100 mm. In this case the vibrating and sensitive wires can be fabricated of different materials and the latter may even be dielectric. We actually elaborated and tested a novel technique of beam diagnostics in accelerators, which is aimed at precision measurement of beams with large transversal sizes including the region of beam halo. The method may have wide application, in particular, for profiling beams in new high-current proton accelerators where measurements in the halo region by means of conventional wire scanners are impossible because of their insufficient sensitivity.

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