

# LARGE APERTURE ELECTRON BEAM SCAN WITH VIBRATING WIRE MONITOR IN AIR

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## Abstract

The Vibrating Wire Monitor (VWM) with aperture 20 mm was developed for scan of electron beam with large transversal sizes. Test experiments with VWM placed in air were done on the 20 MeV electron beam of Yerevan Synchrotron Injector with 4-7  $\mu\text{A}$  at outlet. A new design of VWM is proposed for scan of the beam with even greater transversal sizes.

## INTRODUCTION

The principle of operation of the vibrating wire scanner is based on the dependence of the wire self-resonant frequency on the tension of the wire [1]. In our previous developments we used a scheme of direct penetration of the measured beam into the vibrating wire. To generate wire oscillation we utilized the interaction of current through the wire with the field of permanent magnets. To dedicate some wire length to beam scanning a convenient scheme was found. Two areas of magnetic field are placed at each wire end, and a free zone for beam scanning is left in the middle. Normally the length of the wire is about few tens of mm (30-60) and the free zone can be about one the middle third of the wire length, i.e. 10-20 mm. For beams with transverse size in few mm range, this scheme works appropriately. But for beam sizes more than VWM aperture or for beam halo measurements some particles of the beam also intersect with the VWM components (magnet system, clips, holders, screws etc). This effect was noted at [1] when VWM was used for PETRA proton beam halo measurements. A view of the VWM in parking position here is presented in Fig. 1.

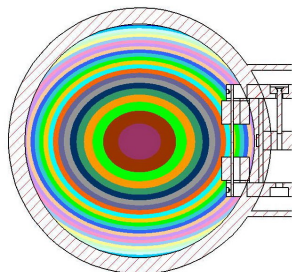


Figure 1. VWM in parking position in PETRA.

Each colors gradation corresponds one decade of beam flux density. As one can see the magnet system is situated in a denser flux zone than the wire.

## EXPERIMENT

### Sensor

The aim of the experiment was to measure the vertical profile of 20 MeV electron beam of Yerevan Physics

Institute Synchrotron Injector. It features a mean current about few  $\mu\text{A}$  and assumed transverse size about 20 mm. The optimal magnet system placement for wire with length 38 mm is depicted on Fig. 2a. Magnets are placed in loop of wire oscillations so that the distance between magnets is 11 mm. Magnets were shifted as shown in Fig. 2b to increase this distance but this resulted with loss of generation optimality. Thus special excitation scheme for autogenerator was developed to compensate this loss.

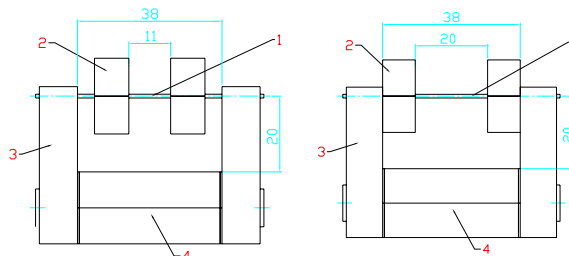


Figure 2. VWM two modifications for the same wire length.

By this modification it was possible to enlarge the aperture the VWM to 20 mm in both transverse directions.

### Electronics

A modified electronics module was used: front-end electronics contains only autogeneration scheme that excited the wire oscillation and provided amplified sine-signal with 3 V amplitude. Power for front-end electronics, for step motor and signal transfer were provided through 60 m long cable with 3.4 Ohm wire resistance. Power wires were doubled. In this way we avoided all types of electrical disturbances that aroused from accelerator high power units.

### VWM temperature dependence

VWM consists from many components. Each of them depends on temperature and has its own characteristic time constant. This value depends on heat capacity and thermoconductivity of component's material and also on component's geometry and sizes. The situation is different depending on VWM placed in vacuum or in atmosphere. The lowest thermal inertia is obtained with thinnest vibrating wire and largest VWM housing. So at VWM dynamic thermocycling frequency response depends very much on temperature rate of change. In Fig. 3 we present results of thermocycling of modified VWM with following scenario: ramp rate 0.5 K/min to 70 °C, dwell 40 min, ramp rate 0.5 K/min to 30 °C, dwell 40 min. Loop in Fig. 3 is turned around in CCW direction. The hysteresis behaviour of graph is determined by above-mentioned thermalization characteristics. The slow

environmental temperature dependence of VWM can be calculated about  $-4 \text{ Hz/K}$ .

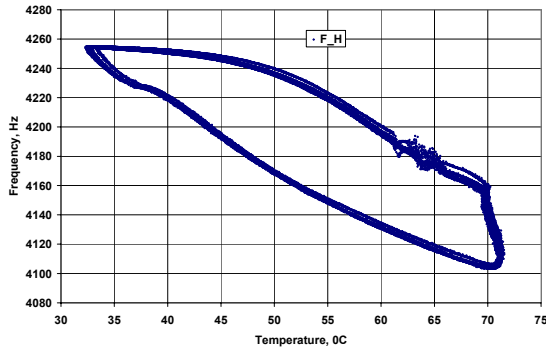


Figure 3. VWM thermocycling with 240 min period.

**Scan**

In these shifts the electron beam was used for test production of radio-medical isotopes [3] so beam was prepared with about 3 cm in horizontal direction and 2 cm in vertical direction. So it was clear that beam should be greater than VWM 20 mm aperture. VWM components were covered by phosphor pain to observe the beam interaction with components. The process was visualized by camera. The view of the process scan is presented in Fig. 4. Slide (A) shows VWM set in parking position and aperture of VWM is depicted by red lines. Slide (B) shows the beam touched the magnet poles of VWM (arrows). Next slide (C) shows that exposed area is substantially large. Last slide (D) shows that, besides the magnet poles the VWM base is also exposed (arrow from up down).



Figure 4. On slides B, C, D the VWM components exposed to the electron beam are highlighted. by the luminophor.

Fig. 4 shows that the horizontal size of beam was really much greater than VWM 20 mm aperture. So a large portion of beam electrons hit and heat the VWM components. At first beam hits the magnet system and at the end of scan it intercepts the VWM base. Each component heating in turn stimulates two different

processes. First it shifts the pinning points of the vibrating wire, then by different heat transfer mechanism it changes the temperature of the wire. In our experiments the main process was convection motion of the air. The pull out of pinning points leads to frequency increase, wire heating, on the contrary decrease the frequency. The balance of these two processes is dynamic and strongly dependant on the scan speed. Two scans of same depth with speed 5 mm/min and 10 mm/min are presented in Fig. 5.

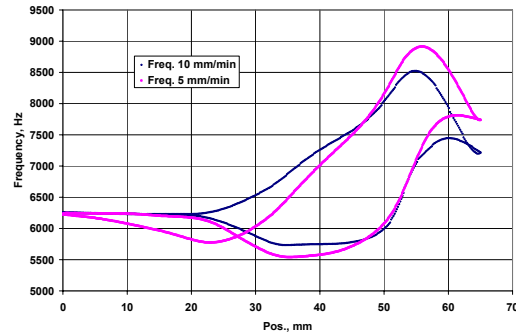


Figure 5. Scans of 65 mm depth with different speed (same in forward and backward directions for one scan).

The whole process becomes very complicated when more VWM components are exposed. The frequency data with values more than 6240 Hz must be interpreted as VWM base overheating. It happened at scan depth more than 50 mm. The impact of such heating was very large – more than 2500 Hz.

In both scans the process starts at first hit by the electron beam to the wire (position 20 mm) when VWM remained as yet in thermalization state. To use these circumstances we prepared 50 mm one-direction scans (forward and back) with initially thermalized VWM. Corresponding data is presented in Fig. 6.

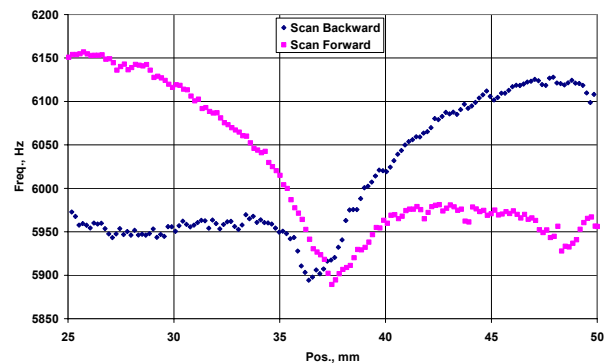


Figure 6. Forward and backward one-direction scans with 10 mm/min speed (forward – magenta, backward – blue).

With help of these scan data it is possible to reconstruct the beam profile. In Fig. 7 the mean value of two scans frequency on the same position is shown (blue dots). A Gaussian fit is presented by magenta (Fig. 7): peak position 37.24 mm, sigma – 3.1 mm.

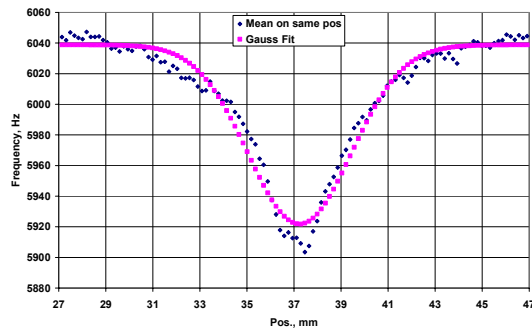


Figure 7. Beam profile reconstruction by two scans.

## LARGE APERTURE VWM

Experiments described above have shown that large aperture for VWM sometimes is very desirable. Simple scaling of common type VWM where vibrating wire simultaneously serves as sensitive to beam element is not suitable because it requires widening the magnet system. The deviation away from optimal magnetic scheme also leads to difficulties in oscillation generation. To solve the problem we separated the wire in two specialized segments: A wire segment (2) sensitive to the beam wire, and a segment vibrating in the magnetic field [4]. In Fig. 8 the main view of VWM prototype with large aperture (here 50x80 mm) is presented (VWM\_LA).

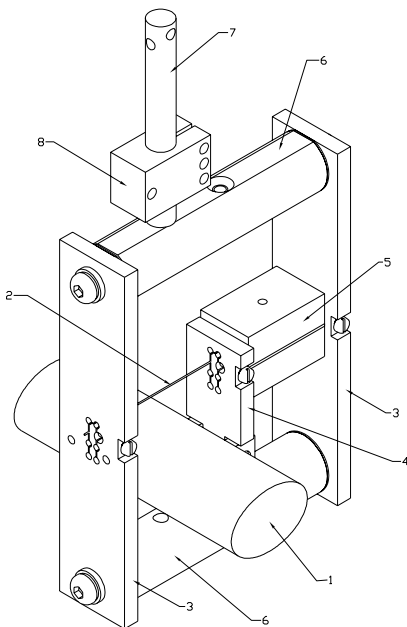


Figure 8. By numbers: 1 – measured beam, 2 – sensitive to temperature scanning wire, 3 - supporting plates with wire pinning, 4 – arm on the bearing axis, 5 – magnet system, 6 – rods from Invar, 7 – finger for VWM\_LA support, 8 – brick for finger location.

This engineering solution provides the possibility to use wires for vibrating and for sense from different materials, even use dielectric wire as sensitive one. In our planned experiments we intend to apply VWM\_LA in the air so

here it is suitable to use hardened Stainless Steel with good mechanical properties for both wires. The sensitive wire is almost free from great thermal contacts from VWM other components, so we used Invar for VWM rods. Consequently we minimized the impact of environmental temperature drifts on the VWM massive components. Daily variation of VWM\_LA frequency was approximately 1 Hz. To avoid direct convection disturbances VWM\_LA was covered by Al foil. Fig. 9 presents the preliminary 150 mm scan forward and back (10 mm/min) as mounted in accelerator tunnel VWM\_LA without electron beam. To compare the VWM behaviour at rest and in motion, the data of VWM in park position is also presented (red).

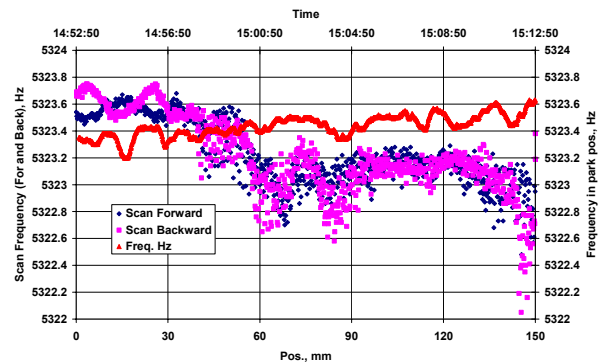


Figure 9. Scan 150 mm without beam.

Note that self-made actuators lead to arms vibration and therefore to noise in frequency signal.

## DISCUSSION

The experiments showed that VWM can be used for large aperture beam profiling. The new type of VWM with two separate wires was developed that allows to reach 50x100 mm aperture for VWM. In this scheme sensitive wire can differ from vibrating wire by material and even can be dielectric.

## ACKNOWLEDGMENTS

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