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DOUBLE-WIRE VIBRATING WIRE MONITOR (DW-VWM) FOR BEAM HALO MONITORING IN HIGH-INTENSITY ACCELERATORS

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Abstract

Double-Wire Vibrating Wire Monitor (DW-VWM) for beam halo monitoring in high-intensity accelerators is developed and manufactured. Compared with previously developed monitors, we increased the ratio of aperture to wire length by using small size magnets and shifting them to the ends of the wire. Besides, two vibrating wires are positioned on the same frame. The first wire is placed in the beam halo region for measurements, and the second wire, which is separated from the beam by a screen, is used to subtract background signal caused by ambient temperature shifts. Electronics of the DW-VWM consists of autogenerator unit placed near the monitor and frequency measurement unit placed in control room (100 m distance operation was tested). The nearest goal is to install the DW-VWM in the accelerator AREAL (Candle SRI) for profiling ~pA mean beam current.

INTRODUCTION

The operating principle of Vibrating Wire Monitor (VWM) is based on the measurement of the change in the frequency of a vibrating wire, which is exposed to the beam. The heat transfer from beam to wire depends on particles and wire material parameters. Corresponding accuracy of resulting wire temperature is less than 1 mK [1]. In the proposed Double-Wire Vibrating Wire Monitor (DW-VWM) we introduced a second wire that can be separated from direct beam deposition by a screen. This wire is used to subtract measurement background. We also increased the ratio of aperture to wire length by using 5 mm x 5 mm magnets. After optimizing the parameters of the DW-VWM and selecting the proper material of the wire, we intend to install the sensor in the electron accelerator AREAL (Candle SRI) with 5 MeV of energy [2, 3] and measure the beam in range of pA.

DESIGN AND DISTINCTIVE FEATURES

The DW-VWM is installed inside the vacuum chamber of accelerator AREAL (see Fig. 1a). A schematic view of DW-VWM is presented in Fig. 1b.

Below we specify the distinctive features of DW-VWM.

Magnetic System and Wires

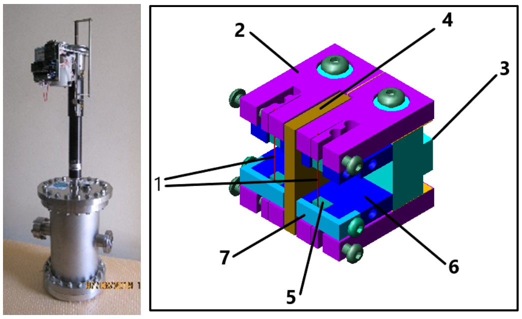

Figure 1: (a) Vacuum chamber of AREAL with step motor feed. (b) Main view of DW-VWM. Two wires (1) are tightened by four clips (2). Clips are fastened on the same frame from stainless steel (3). Between two wires inserted a removable screen (4) with thickness up to 4 mm. Magnetic field system consists of four assemblies of magnet poles and permanent magnets. The core of the system are permanent magnets (5) covered by magnetic steel (6 and 7). The bearing poles (6) are mounted on the bed (3).

Aim of magnetic system is to generate oscillations on the second harmonic of natural frequency. Wire length is 22 mm. Optimal assembly of magnets is presented on the left side of the Fig. 2 - the distance between centers of the magnets should be half of the wire length, i.e. 11 mm. For 5 mm size magnets the aperture in this case becomes only 6 mm. To enlarge the aperture, we shift magnets to the clips by 2.5 mm (right side of the Fig. 2). Distance between centers of magnets becomes 16 mm and aperture increases up to 11 mm.

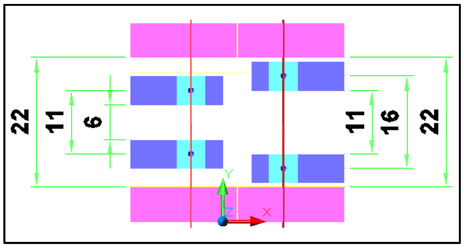

Figure 2: Two types of magnetic system for DW-VWM.

Electronics

New electronics of DW-VWM consists of two main boards: autogenerator unit placed near the VWM and frequency measurement unit placed in control room (100 m distance operation was tested). Autogeneration board is equipped with a scheme devoted to excite the oscillation generation by applying a short initiating pulse on the wire. Frequency measurement unit is equipped with FTDI1232C based USB interface (virtual COM port). Minimal measurement time is about 20 ms.

VACUUM DEPENDENCE

The use of VVM in the accelerators makes it interesting to study the dependence of the monitor frequency on the pressure in the vacuum chamber. It is clear that the impact of pressure on the frequency can occur on several reasons. First, the wire tension is determined by its balanced temperature, because even in the absence of other agents of influence, a current of oscillation generation flows through the wire is a source of its heating. Second, the movement of the wire contains a component of viscous friction, depending on the pressure of the atmosphere. In the case of a small difference between the temperature of the walls of vacuum chamber and monitor, the removal of the heat-conducting media initiates slow processes of thermalization of the sensor to new conditions.

Let us consider the first reason in more detail. The wire generation current is about 1 mA. In [4] one can find detailed calculations of the dependence of the frequency of the wire on the power deposited in it. In Table 1, the characteristics of monitors with wires of various materials are presented, as well as a change in the temperature and the frequency of wire when a current of 1 mA passes through it.

Table 1: Parameters of DW-VWM for different wires (SS – stainless steel, T – tungsten, BC – beryllium-copper). Initial frequency is 8000 Hz, length of wires 22 mm. Power deposition is modelled by 1 mA DC current (corresponding deposited power is W_gen).

Material	**SS**		**T**		**BC**	
Condition	**air**	**vac.**	**air**	**vac.**	**air**	**vac.**
diameter, m	**1.0E-4**	**1.0E-4**	**4.0E-5**	**4.0E-5**	**8.0E-5**	**8.0E-5**
W_gen, W	**2.1E-6**	**2.1E-6**	**9.5E-7**	**9.5E-7**	**4.4E-7**	**4.4E-7**
DF/DT, Hz/K	**55.2**	**55.2**	**12.0**	**12.0**	**35.8**	**35.8**
Resp. time, s	**3.53**	**10.64**	**0.71**	**0.88**	**1.39**	**1.91**
DT/DW, K/W	**6.1E+3**	**2.2E+4**	**7.9E+3**	**1.3E+4**	**3.4E+3**	**5.2E+3**
Overheat, K	**1.3E-2**	**4.5E-2**	**7.54E-3**	**1.2E-2**	**1.5E-3**	**2.3E-3**
DF, Hz	**6.97E-1**	**2.46**	**9.03E-2**	**1.44E-1**	**5.45E-2**	**8.10E-2**
Freq. shift, Hz	**1.76**		**5.37E-2**		**2.65E-2**	

The last line presents the shift of the balance frequency in air and vacuum. As one can see this shift is more or less noticeable for a stainless steel wire, and practically negligible for tungsten and beryllium-copper.

The frequency dependences of the sensor equipped with stainless steel wire with a diameter of 100 µm (the first wire) and tungsten wire (40 µm) are shown in Fig. 3 (two sensors were used to measure the vacuum).

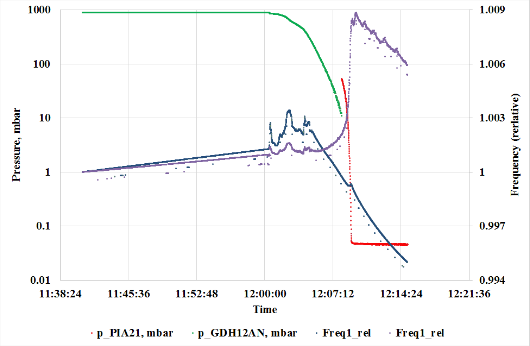

Figure 3: The process of pumping out the vacuum chamber. The frequencies are normalized to the values at the beginning of the experiment (8640.9 Hz for the first wire and 7919.3 Hz for the second wire).

It can be seen that at the beginning of the pumping (time interval 12:00:34 - 12:04:45) the frequencies behave in a correlated manner, but not have been regular. Apparently, strong air flows arising due to fast pumping impact on the wire oscillations. After this stage, the process becomes regular, but proceeds differently for the first and second wires. In any case, the scale of frequency changes is much larger than the frequency shift due to the tuning of the balance frequency. This matter requires further consideration.

DW-VWM Long Runs

In Fig. 4, results of running the monitor under conditions where both pressure and temperature in the vacuum chamber changed are shown.

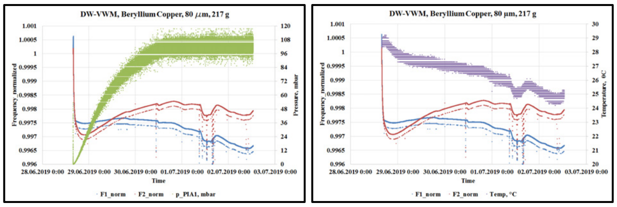

Figure 4: Long run of DW-VWM installed into vacuum chamber and assembled with Beryllium Copper wires with diameter of 80 µm. Frequencies were normalized on the initial values (for wire #1 6045.16 Hz, for wire #2 7030.61 Hz). (a) Dependence on pressure. (b) Dependence on temperature.

A correlation is seen with both temperature and pressure. The next experiment (Fig. 5) was carried out when the temperature was kept stable and the pressure was changed slightly (from 10 to 60 mbar).

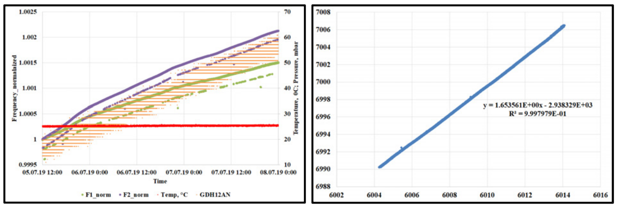

Figure 5: (a) Plots of frequencies, pressure and temperature vs time. (b) Correlation of frequencies after post-processing the experimental data.

In the experiment, a 100-meter communication line between two boards was used. This led to the random outliers in the frequency counting algorithm (which were interpreted as a frequency shift by roughly an integer number of Hz). The entire experiment contains 150750 points and there were 5379 outliers (for both channels). Extracting these points, we obtained a frequency interdependence (Fig. 5b) with a good degree of correlation and a coefficient F2/F1 = 1.65

Excitation of Oscillations

The quality factor of VWM is determined by various dissipative processes in the resonator, in particular, by the viscous friction of the wire in the atmosphere, which is completely determined by the pressure in the vacuum chamber. A corresponding increase in the quality factor in a vacuum leads to a change in conditions of oscillation excitation. For example, see Fig. 8, where the wire oscillation process was initiated by a short triggered pulse of capacitor discharge. The monitor contained two wires: the wire #1 is the stainless steel with a diameter of 100 microns and the wire #2 is tungsten (40 microns). The oscillation frequency of the second wire was noisier, which we explain by the specification of the magnetic system, which poorly determines the number of harmonic oscillations. For larger diameter of the wire, the system becomes stiffer and the impurity of the fourth harmonic against to the main second is lower (see Fig. 6). It is seen that the duration of the start of generation in air is longer than at low pressures (of the order of 1 mbar).

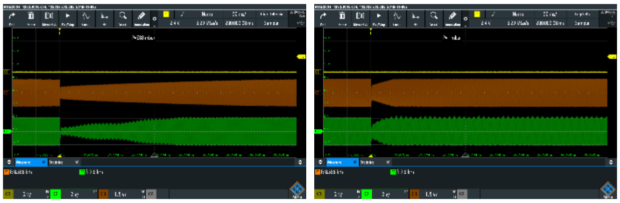

Figure 6: Oscillation generation process. Wires: #1(brown) – stainless steel D100 µm; #2 (green) – Tungsten D40 µm. (a) pressure 888 mbar, (b) pressure 1 mbar.

One can see a big difference in case of atmosphere pressure (888 mbar) and 1 mbar (a further drop in pressure did not lead to a significant change in the picture). The oscillations of the first wire always had a good sinusoidal shape, while the form of vibrations of the tungsten wire was curved, which can be explained by the presence of the second and fourth harmonics in the vibrations simultaneously.

SCAN EXPERIMENTS

Test experiments of scanning a laser beam with different speeds were done. Monitor feed was prepared by bellows system equipped with a step motor. Each step corresponds to 2.775 µm shift of monitor in vertical direction. As a laser, a 532 nm laser (GMD) with <200 mW output power was used. The one direction scan distance was 8.33 mm.

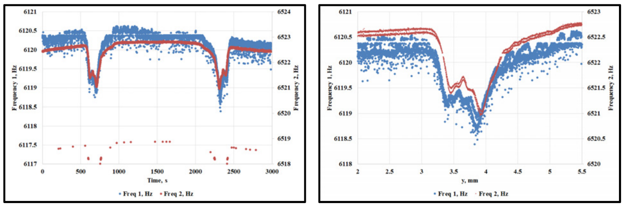

Figure 7: Scan speed of 0.01 RPS (5.55 µm/s). (a) Time dependence, (b) Recovered beam profile.

For scan speed of 0.01 RPS (5.55 µm/s) the total time of the forward or backward scan was about 3000 s (see Fig. 7). Actually, beam size was about 1 mm.

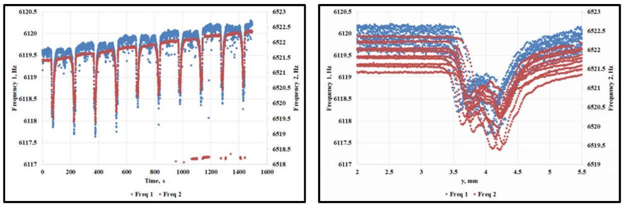

Figure 8: Scan speed of 0.1 RPS (55.5 µm/s). (a) Time dependence, (b) Recovered beam profile.

The cases of increasing the speed up to 0.1 RPS and 0.25 RPS are presented in Figs. 8 and Fig. 9, respectively.

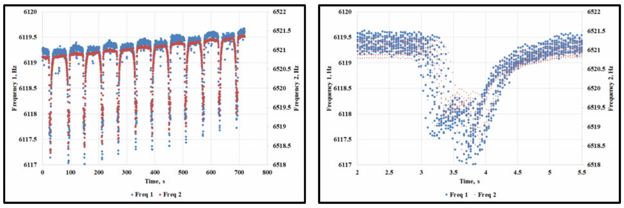

Figure 9: Scan speed of 0.25 RPS (138.75 µm/s). (a) Time dependence, (b) Recovered beam profile.

TEST CHAMBER

In order to test the DW-VWM in a real beamline, we also envision a kind of a test bed. To move the DW-VWM in a vacuum chamber, we decided to use the magnetic manipulator manufactured by 'UHV TRANSFER' which adopts magnets to provide linear motion inside the vacuum chamber without harming vacuum. A magnetic manipulator, with 6 inch (15.24 cm) moving range, was installed for a 100 mm diameter 6-way cross chamber. In addition, special components have been fabricated to mount the DW-VWM to the end of the manipulator. To perform tests in vertical and horizontal directions, two adjacent pipes of the 6-way cross were made as 20 cm long. Preliminary experiments have shown that the accuracy of the magnetic manipulator is better than 0.1 mm, and the 6-way cross can achieve vacuum levels below 10E -9 atm without leakage.

CONCLUSION

Preliminary experiments showed that a new monitor with two wires and enlarged aperture is operational in a wide pressure range. The wires of various diameters and materials were tested (stainless steel with a diameter of 100 µm, beryllium bronze with a diameter of 80 µm, tungsten with a diameter of 40 µm and 20 µm). Based on the results of vacuum studies for proposed magnetic system, we selected beryllium bronze wires as working wires that had good ability to generate oscillations with high stability both in the air and in the vacuum.

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