IMPACT OF ENVIRONMENTAL VARIABILITY ON VIBRATING WIRE MONITOR OPERATION

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Abstract

The Vibrating Wire Monitor (VWM) was developed for precise transversal profiling/monitoring of charged particle/photon beams. The extremely high sensitivity of VWM is achieved by sensitivity of wire natural oscillation frequency to wire temperature. Due to the rigidity of the wire support structure, the VWM is also sensitive to the environmental parameters. In this paper, it is shown that the main parameter of influence is the ambient temperature. The magnitude and character of this influence is investigated along with the effect of electromagnetic interference on the VWM electronics in an accelerator environment.

INTRODUCTION

VWMs for accelerator beam instrumentation are based on the change in the natural oscillations frequency of a vibrating wire depending on the temperature of the wire and environment in which oscillations take place [1]. During operation these conditions (VWM sensor and electronics temperatures, electromagnetic interference from high power accelerator elements, hyper-radiation, presence of high electric and magnetic fields etc) can change, leading to shifts in measurements.

In vacuum the dominant effect is the sensor temperature since the resonant frequency in first approximation depends exceptionally on the mechanical properties of resonator and weakly depends on electronics.

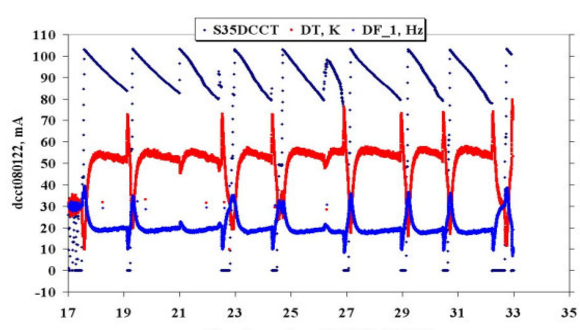

Figure 1: VWM005 reacts to the current change in APS.

Experiments at the APS ANL [2], [3] showed that a five-wire VWM005 reacts to electron beam current even in the case when beam synchrotron radiation does not touch the vibrating wire. In this experiment, a VWM was mounted at terminating flange of APS storage ring. We explained this behaviour by shifts of copper flange temperature. In Fig. 1 we present the time dependence of the VWM005 first wire frequency shift (right axis) that correlates with beam current (left axis). At right axis we also present the calculated wire temperature with shifts of about 2 K and 30 min relaxation time.

EXPERIMENTS

VWM Dependence on Ambient Temperature

To decrease VWM dependence on ambient temperature normally we choose wire material and housing material with the same thermal expansion coefficients. But to accent the question we analyze a sensor with wires and housing made by different materials (housing – bronze, first wire – Kanthal, second wire – stainless steel). As a reference thermometer we used Platinum resistive temperature detector Pt100 (RTD) with 0.03 °C accuracy. Measurements were done by Eurotherm model 2416 PID controller. Calibration of VWM is presented in Fig. 2.

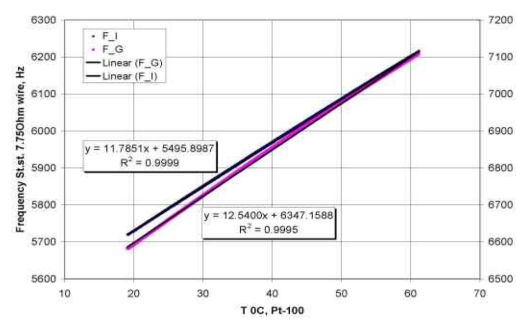

Figure 2: Calibration of two-wire VWM: magenta – Kanthal, blue –stainless steel.

The mean dependences on ambient T are 12.540 Hz/K (in range 6600-7100 Hz) for Kanthal wire and 11.785 Hz/K for stainless steel wire. The frequency measurement accuracy was about 0.01 Hz corresponding to 0.8 mK temperature drift. This value is extremely small so the long-term temperature measurements require detailed investigations to determine the stability of the VWM measuring system. Measurements with VWM and with Pt100 have some essential differences:

- The sensitive element of VWM has a mass of about 2 mg that is less massive than Pt100 (about 50 mg) although VWM contains housing of about 100 g surrounding the wire.

- The autogenerator current for VWM does not exceed 1 mA so the self dissipative power for VWM is about 10 mW which is at least one order smaller than for Pt100.
- The VWM frequency measurement scheme in fact is numerical in contrast to analogue scheme of measurements via Pt100.
- In case of air usage VWM wire is affected by air pressure and humidity and it seems that this problem is less essential for Pt100.

Mercury Thermometer Regulated Thermostat

For long-term drift measurements we prepared a thermostat on the basis of a mercury contact thermometer that regulates the absolute level of temperature. By tuning of the power supply driving the heater on/off control, we achieved reasonable oscillation of the temperature about 0.6 0C by Pt100 thermometer. The oscillation amplitude measured by VWM was 0.1 0C because of greater thermal inertia. The typical temperature paths collected by Pt100 and VWM are presented in Fig. 3.

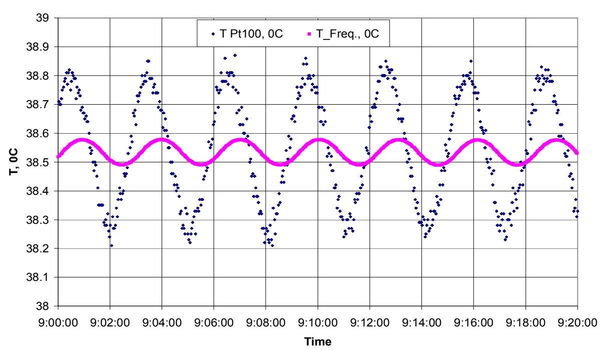

Figure 3: Thermostat on mercury thermometer base: signals from Pt100 and VWM are presented.

Temperature oscillation period was about 3 min and because of different thermal inertia the phase shifts between Pt100 and VWM readings are seen.

Dependence on the Electronics Temperature

To compare measurements of temperature via VWM and Pt100 we placed the sensors in mercury thermometer controlled thermostat and put both electronic units in a box that slowly thermocycled in range 10 ^{0}C...65 ^{0}C. The time resolved signals are presented in Fig. 4. Notable is the difference in temperature scales. The Pt100 readings show mean temperature shifts about 1 ^{0}C when mean temperature of the VWM readings remain stable. We also calculated the differences in subsequent readings of Pt100 and VWM. Because of very slow drift of mean temperature these values represent the measurements errors. Ninety three % of all readings for the VWM lies in range ±0.0015 K while the same fraction for Pt100 lies in range ±0.06 K. The dependences of Pt100 and VWM temperature measurements on the temperature of sensor electronics are presented in Fig. 5. The drift of VWM measurements is essentially absent and for Pt100 we have about -0.02 K_of_readings/K_of_electronics.

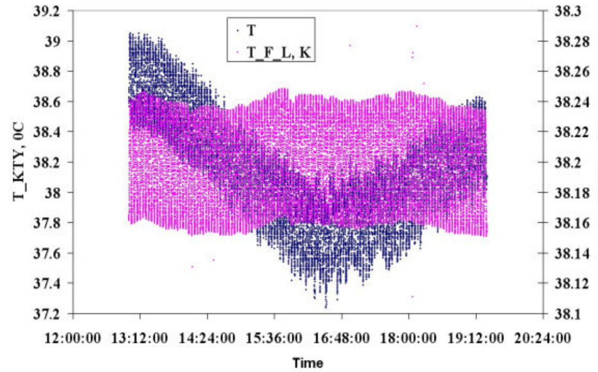

Figure 4: Thermometers are in mercury thermostat and the electronics are thermocycled.

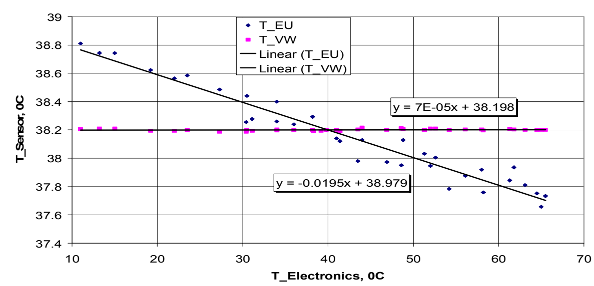

Figure 5: Comparison of the Pt100 and VWM readings dependences on electronics temperature.

Same VWM Sensor and Few Electronic Units

To investigate how large is VWM temperature dependence on the electronic unit components we prepared the following experiment. We placed the VWM005 in mercury thermostat and used one of the wires as reference. The measurements of frequency we provided by 3 electronic units with different essential components (the operational amplifier in autogeneration circuit was chosen from OP37 and NE5534 with different slew rate, the field-effect transistors used in amplitude stabilisation scheme were chosen from 2N3819, 2N5459 and КП305E). The electronic units were thermocycled in the range 20 ^{0}C...60 ^{0}C. Each electronic unit contains a separate quartz generator IQXO-22C 4.0000M type. Measurements were provided subsequently by specially developed PC controlled multiplexer. For each unit switch on new generation of oscillations by autogeneration scheme about 1 s was needed so for every polling 8 s was chosen. This time was enough to prepare 4-6 correct 1 s measurements. Readings were written to a file every second with a special program that extracted unwanted points. The results of the experiment are presented in Fig. 6. In red the box temperature that contained electronic units is marked. As one can see, very small shifts between units are observed. The readings from the fourth (magenta) unit were shifted at 0.1 Hz in room temperature but this shift remained constant at units heating compared to the fifth unit (green). The shift 0.1 Hz can be explained by the different quartz generators. And vice versa the readings of the fifth unit at temperatures near 60 ^{0}C decreased compare to the third one (blue).

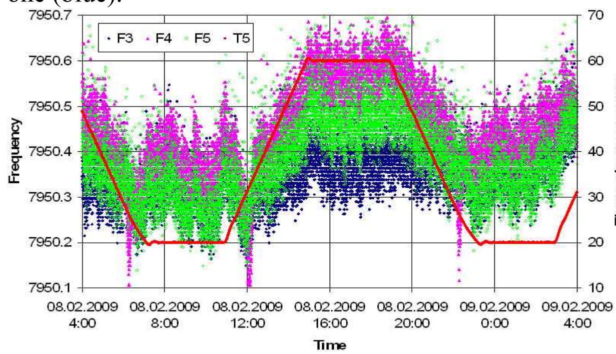

Figure 6: Comparison of the different electronic units with the same VWM sensor.

VWM Regulated Thermostat

To improve the mercury thermometer thermostat we prepared a thermostat on the VWM basis. The 2-wire VWM was used and PID (proportional, differential, differential) control was applied according to one of the VWM wires signals. Simultaneously the second wire frequency was measured and for reference the temperature by Pt100. Sensor Pt100 was mounted on the top side of VWM housing.

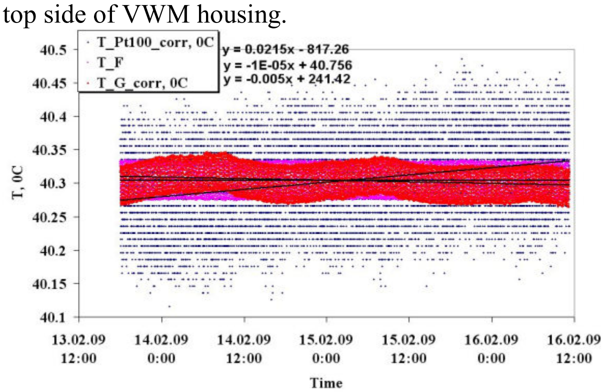

Figure 7: Results of thermostat regulated by VWM thermometer.

The results of 2.5 days of data collection are presented in Fig. 7. Since the readings from first VWM wire (magenta) was used in control by PID-algorithm as reference the time drift of this signal is absent. The second wire measurements show small drift about -0.005 K/day as compared to 0.02 K/day for Pt100 measurements.

Electromagnetic Interferences

For an experiment at the APS in Jan 2008, the electronics of the VWM was placed in the accelerator tunnel in immediate vicinity of magnets. The algorithm for frequency calculation in the VWM is based on the counting of periods of oscillation inside of a one second interval. Count of periods by PIC family microcontroller was provided by external interrupts of measuring signal edge rising. Electromagnetic interferences can create signal edges counted as additional period of oscillations. Each error produces a constant shift of about 1 Hz in frequency measurement. This produced divisible to 1 Hz jumps in data. Effect also depends on specific microcontroller parameters. Typical situation for VWM005 is presented in Fig. 8. The problem can be solved mathematically by special software that past together split data (see Fig. 9). It is preferable to solve this problem by dividing the electronic units of the VWM into two parts: an autogenerator unit and a measurement unit. The first one must be placed in tunnel in which the sinusoidal amplified signal is produced and transfer to the control panel. At the input of measurement unit with microcontroller a special block of low frequency filters must be installed to remove high frequency disturbances.

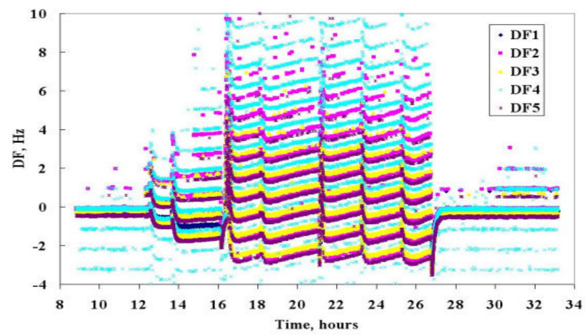

Figure 8: Electromagnetic disturbances 1.04 Hz steps.

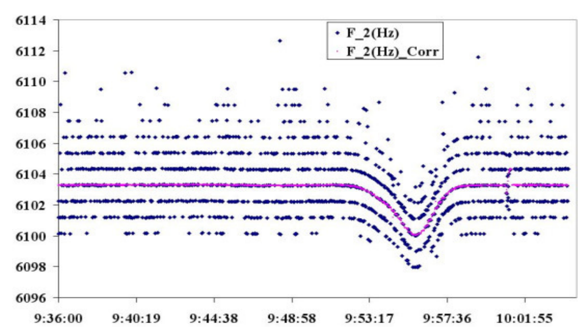

Figure 9: Mathematical treatment of split signal.

CONCLUSIONS

Experiments show that the parameters of absolute stability of VWM temperature measurements are superior to RTD so the VWM can be used not only for beam diagnostics but also for precise and stable thermometry, e.g. for precise measurement of the magnet cooling water temperature with a resolution of 0.01°C [4].

REFERENCES

[1] S. Arutunian, Vibrating wire sensors for beam instrumentation, BIW08.

[2] G. Decker, S. Arutunian, M. Mailian, G. Rosenbaum, First vibrating wire monitor measurements of a hard x-ray undulator beam at the Advanced Photon Source, DIPAC07.

[3] G. Decker, S. Arutunian, M. Mailian, I. Vasiniuk, Hard x-ray synchrotron measurements at the APS with vibrating wire monitor, BIW08.

[4] T. Fukui et al., High precision temperature measurement system, ICALEPCS99.