A PRELIMINARY STUDY OF THE VIBRATION WIRE MONITOR FOR BEAM HALO DIAGNOSTIC IN J-PARC L3BT

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Abstract

The existence of beam halo is an important characteristic of high-intensity beams. In the J-PARC 3-GeV Rapid Cycle Synchrotron (RCS), transverse beam halo diagnostic is required to increase the output beam power. For measurement of projected beam distributions to determine the extent of beam halo formation, wire scanners and halo scrapers were employed at the Linac-3GeV Beam Transport line (L3BT). In order to determine more detail of halo formation, Vibration Wire Monitor (VWM) was under consideration by RCS monitor group. After the offline study of the VWM at the test stand with low energy electron gun, the VWM was installed in L3BT to demonstrate the feasibility of the beam halo measurement. The high sensitivity of the VWM makes it a prospective one for investigation of beam halo and weak beam scanning. And the VWM is insusceptible secondary electrons which are one of major noise source for beam monitoring in the RCS. In this paper, we will report preliminary results about feasibility study of the VWM and beam halo measurement at L3BT.

INTRODUCTION

The Japan Proton Accelerator Research Complex (J-PARC) is a high intensity proton accelerator facility aiming to realize 1 MW class beam power [1]. The J-PARC accelerator consists of a linac, a Rapid Cycling Synchrotron (RCS), and a Main Ring (MR). A 181 MeV negative hydrogen ion beam from the linac is injected into the RCS through stripping to a proton beam by a charge stripper foil placed in the RCS injection point. The RCS provides a 3 GeV beam to both the MR and the Material and Life science Facility (MLF) with a repetition rate of 25 Hz. With the current injection energy of 181 MeV, the RCS has successfully demonstrated high intensity beam operation up to 420 kW with a less than 1% beam loss [2].

After the injection energy upgrade to 400 MeV, the RCS will aim at final goal of the 1 MW output. In order to provide such a high intensity beam for routine user program, it is required to improve the quality of the high intensity beam. Space charge dominated high intensity proton beam has various beam instability and beam halo is one of most important behavior of them. In high power proton accelerator as a J-PARC, even small ratio of beam loss such a beam halo cause serious radiation dose. The key issue to evaluate the high intensity beam quality is the suppression of the transverse beam halo.

In generally, the beam halo quantity is less than 10^{-4} of the beam core. Therefore beam profile monitors for halo measurements are required very wide dynamic range, high sensitivity and resolution, and noise rejection techniques of instruments and methods.

The beam transport line between the J-PARC linac and 3 GeV RCS, to which we refer as L3BT, has a transverse collimation system to eliminate a transverse beam tail or halo for the RCS charge exchange injection. For more effective halo collimation, detailed beam profile measurements are required. In the case of the RCS monitor group, beam halo formations are determined respectively by combining various devices and method [3]. However there are some technical issues such as electronic signal noise by secondly electrons or AC power supply for beam halo measurements, and we are developing new beam halo diagnostic system for the high intensity proton beam in J-PARC.

In this paper, we focus on the relevant beam halo diagnostics by new halo monitor in J-PARC L3BT. Hardware details and beam study results for the new beam halo monitor will be appeared.

THE VIBRATION WIRE MONITOR

The principle of the vibration wire monitor (VWM) for beam diagnostic is to pick up its temperature rising-induced frequency shift by irradiating vibration wire with a beam. The novelty of the method is that the wire temperature shift is used as information about the number of particles which interact with the wire. The VWM for beam diagnostic has been proposed around the 2000 [4], and under development by DESY, recently [5]. Figure 1 shows the VWM developed by Bergoz instrumentation for beam profile measurement [6].

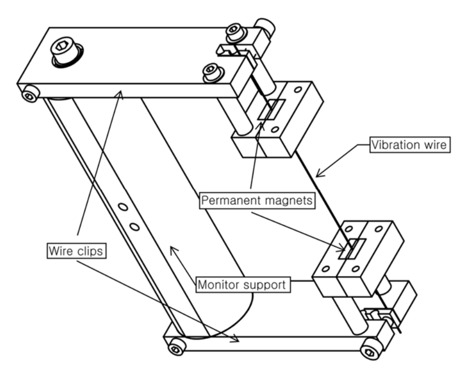

Figure 1: The VWM for beam halo measurement which was developed by Bergoz corporations [6].

The both ends of conductor wire are fixed at monitor arms and through between the two pairs of permanent magnetic fields. The wire length L is twice the length between permanent magnets, because second harmonics

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oscillation of the wire is excited efficiently. The connector for amplifier circuit is the lower arm of the divider. As a result of the Lorentz-force interaction between the oscillating current through the wire and magnetic field, wire oscillations of the VWM arise. When the wire of the VWM is connected in a positive feedback circuit, the natural oscillation of wire is excited by an electric amplifier.

The wire heating is caused by interaction of the beam with the wire. Thus, the frequency of natural oscillations of the wire provides information about its temperature. After long term irradiation by the beam, the wire temperature will reach a condition of thermal equilibrium. From the wire frequency with thermal equilibrium condition, we can estimate the mean temperature of the wire and the number of irradiating particles per unit time.

In principle, the VWM is insusceptible secondary electrons which are one of major noise source for beam monitoring in high intensity accelerator such as J-PARC RCS. And we assume that the VWM potential dynamic range of 10^{-5} will be achieved. Therefore, we focus this novel beam monitor for beam halo diagnostic, and carrying out research and development about the VWM.

FREQUENCY SHIFT OF THE VWM UNDER BEAM IRRADIATION

The wire oscillation of the VWM can be described as a support with a strained vibrating wire which is the rigidly fixed wire ends. The frequency F_0 of second harmonic of natural wire oscillation is

$$F_0 = \frac{1}{L}\sqrt{\sigma_0 / \rho} \,. \tag{1}$$

The distance between points of wire ends fixation is L, σ_0 is wire initial tension, ρ is wire material density. Due to temperature stress, the oscillation frequency of a vibrating wire has strong temperature dependence. The relative oscillation frequency shift $\Delta F/F_0$ is defined by the expression,

$$\frac{\Delta F}{F_0} = -\frac{E\alpha}{2\sigma_0}\Delta T \,, \tag{2}$$

α is wire material coefficient of thermal expansion, E is module of elasticity. The wire temperature shift ΔT is an average value along the wire.

Heat transfer quantity by the interaction of the beam with the wire depends on particles species, its energy, material of wire and wire geometry. The main parameter of energy transfer from charged particles is the particle ionization losses dE/ds in wire material. The average heating quantity q_h from one particle passing though the wire is,

$$q_h = k\frac{dE}{ds}\frac{\pi}{2}r \,. \tag{3}$$

Where r is wire radius and a heat transfer coefficient k is defined what part of energy losses converted into the wire heat [7].

Equilibrium temperature of irradiated wire in vacuum is determined by the balance between the heating power from the charged particles and two heat removal effect of wire. One of heat removal is thermal radiation through the wire surface, and the other is thermal conductivity of the wire material through the ends of wire.

FIEASIBILITY STUDY OF THE VWM IN L3BT

The place for the VWM location was installed in L3BT downstream. Figure 2 is a picture of the installed VWM.

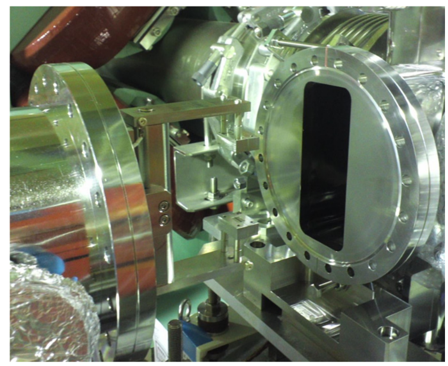

Figure 2: A picture of the installed VWM in L3BT.

The installed VWM which is product of the Bergoz corporations is accommodated with a Multi Wire Profile Monitor (MWPM) for calibration of the VWM. The wire material of installed VWM is SUS316L, wire diameter is 0.1mm and a length between wire ends fixation is 120mm. A distance between permanent magnets which is physical aperture of the VWM is 60 mm. In order to measure the beam profile, the VWM is attached to the movable rod with stepping motor, and driven toward to the vacuum chamber center in horizontal direction. A beam loss monitor of scintillator–photomultiplier pickup

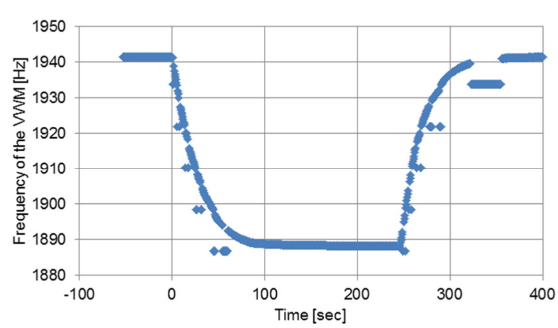

Figure 3: The VWM frequency shift at 1.3mm of distance from beam center. The wire was irradiated only in a period between 0 sec and 247 sec.

(BLM at the VWM location) was installed additionally to measure particles scattered on the wire.

For the feasibility test of the VWM, the proton beam was specially prepared for this purpose. In this experiment, mean beam power is about 1.5 kW, bunch length is 50 μsec, beam energy is 181 MeV, and repetition rate is 25 Hz. The transversal beam sizes at the VWM installed position were σ_x = 1.442 mm, σ_y = 2.968 mm which ware measured by the MWPM.

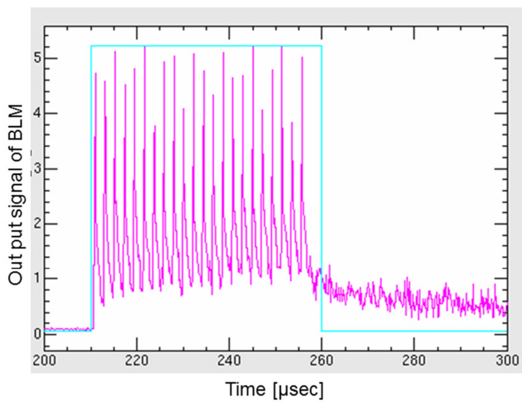

Figure 4: Output signal of the BLM at 1.3mm of distance from beam center.

Figure 3 presents the typical picture of the VWM frequency shift at 1.3 mm of distance from beam center. The natural frequency of the VWM without beam irradiation was about 1942 Hz. The proton beam hit the wire only in a period between 0 sec and 247 sec. A frequency decrement of about 53.13 Hz was measured and a length of time before temperature equilibrium is about 120 sec. At the same time, we take a signal of the BLM to compare the frequency shift of the VWM (Fig. 4).

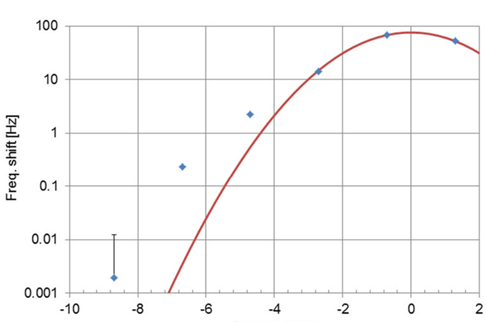

Figure 5: The result of the beam profile measurements for the scanning at the horizontal axis by the VWM.

Figure 5 shows the result of the beam profile measurements for the scanning at the horizontal axis. The solid line represents the profile of the beam approximated by the mean square method of a gaussian function with a standard deviation of σ_x = 1.498 mm. When the VWM position is -8.7 mm, frequency shift of the wire oscillation was not observed, and BLM signal too. The beam profile measured by the VWM is almost consistent with the MWPM results.

The integrated BLM signals are shown in Fig. 6. When position of the VWM was around beam core, BLM signals ware saturate in this beam power. However, qualitative trend of profile measurement by BLM is in good agreement with VWM results.

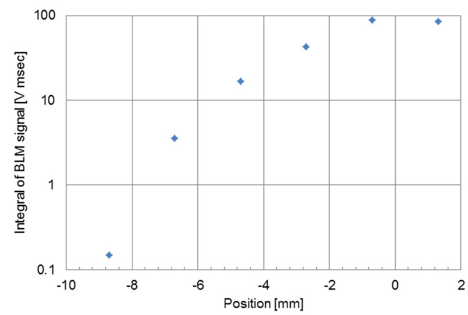

Figure 6: The result of beam profile measurements by integrated BLM signals at each the VWM position.

The feasibility of the VWM for beam halo diagnostic is confirmed by these experiments. On the basis of these results, we will make a detailed study of beam halo measurement by the VWM.

SUMMARY

The VWM has a potential for beam halo measurement, because its dynamic range is wide and the VWM is insusceptible secondary electrons. The VWM was installed in L3BT, and its feasibility for halo monitor has been studied. The beam profile measured by the VWM is almost consistent with MWPM and BLM results. The feasibility of the VWM for beam halo diagnostic is confirmed by test experiments. On the basis of these results, we will make a detailed study of beam halo measurement by the VWM.

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