Design and Fabrication of the Wire Scanner

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1. Introduction

A 20-MeV proton accelerator is operating by Proton Engineering Frontier Project (PEFP) at Korea Atomic Energy Research Institute (KAERI). At the end of the 20-MeV accelerator, a beam line was installed which consists of quadrupole triplets, gate valve, Faraday cup, vacuum box and beam window [1]. A wire scanner type beam profile monitor was designed and fabricated to measure the beam profile at the beam line. By measuring the beam profile, the beam characteristics depending on the quadrupole magnet strength could be compared with the simulation results and the beam emittance could be calculated through quadrupole magnet scan method. In this paper, the design and fabrication of the wire scanner for the beam profile measurement of the PEFP 20-MeV beam line are presented.

2. Design and Fabrication

2.1 Wire Scanner Design

The wire scanner would be installed 2152.5mm apart from the interior surface of the DTL24 end plate to the downstream of the beam line. The beam diameter was about 30mm when all the quadrupole triplets were turned off. In this case, the wire scanner should not interrupt the beam to supply it to irradiation sample. The wire scanner would be used to measure the focused beam to measure the beam emittance using quad scan method during beam test period. In this case the maximum beam diameter would reach the 40mm. The diameter of the beam pipe at which the wire scanner would be installed was 134mm. With these conditions, the beam conditions during measurement and design criteria of the wire scanner are as follows;

- Beam energy: 20MeV
- Peak beam current: 1mA
- Beam pulse width: 50us
- Beam repetition rate: 1Hz
- Fork aperture: 50mm
- Stroke: 40mm
- Number of wire: 2 (vertical: 1, horizontal: 1)

During the measurement, the wire temperature increases because it intercepts the beam. Therefore, it is necessary to estimate the wire temperature under the measurement conditions. Two things should be considered in thermal point of view when we design the wire scanner. A) Wire break due to thermal heating, B) excessive thermionic emission current from the wire due to high temperature. A 120um in diameter tungsten was selected as a wire material.

The heat balance equation to estimate the ultimate wire temperature under the measurement conditions is described as follows.

$$\frac{dT}{dt} = \frac{4}{\rho \pi d c}(P_{den} - \pi \sigma \varepsilon T^4)$$

Here P_{den} is the beam power density, ρ is the tungsten density, d is the wire diameter, c is the tungsten heat capacity, σ is the Stefan Boltzmann constant, ε is the tungsten emissivity. In the calculation, the heat source was the beam power and only the radiation heat transfer was considered as cooling mechanism. The energy loss of the 20MeV proton beam in the 120um tungsten wire was calculated by using SLIM code. The calculation result is shown in Figure 1. The temperature was saturated after 12 second up to the 900°C which was far below the melting temperature of the tungsten.

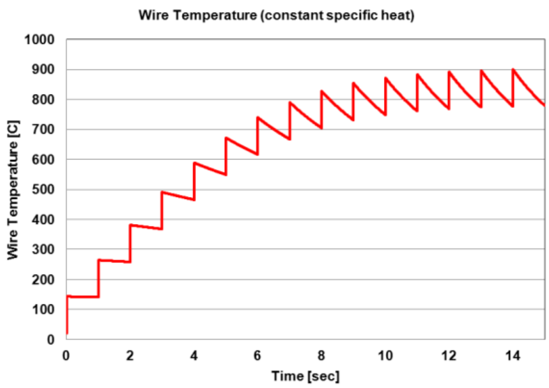

Fig. 1: Tungsten wire temperature change during beam profile measurement.

The thermionic emission current at 900°C was calculated to check the effect of the thermionic emission current on the secondary electron emission current. The thermionic electron emission current density was calculated by using Richardson-Dushman equation as follows [2].

$$J = A_0 T^2 e^{-\frac{e\phi}{kT}}$$

Here, J is the thermionic electron emission current density, A_0 is 1.28×10^6 A/m^{2}K^2 , ϕ is work function that is 4.6eV for tungsten. The calculated current density from the tungsten at 900°C was 3.2×10^{-8} A/m^2. The secondary electron emission current density was estimated from the secondary electron emission yield by using Sternglass theory as follows [3].

$$Y = \frac{Pd_s}{E^*}\frac{dE}{dx}$$

Here, Y is the secondary electron emission yield due to proton collision, P is the probability, 0.5, ds is the average depth from which secondaries arise, 1nm, E* is the average amount of kinetic energy lost by a proton per ionization produced in the wire, 25eV, and the dE/dx is the stopping power, 22.4keV/um. The calculated yield was 0.9 electrons per every incident protons. The calculated secondary electron emission current density due to proton collision was 2200A/m^2, which was far larger than the thermionic electron emission current density. Therefore, we can safely neglect the effect of the electron current from the heated wire.

2.2 Wire Scanner Fabrication

The wire scanner was fabricated. The fork material was 5mm thick aluminum. The insulator was G-10 plate, which isolated the wire from the fork. A copper block was used to fasten the wires. The insulator was aligned with the fork and the wire was aligned with the insulator by using the notch. The wire was attached to the linear motion. The signal lines were connected to the amplifier located outside through the shield cable. The horizontally stretched wire to measure the y direction beam profile was installed in the upstream side and the vertically stretched wire to measure the x direction beam profile was installed in the downstream side. The distance between two wires was 5mm. The wire scanner installed in the beam line is shown in Figure 2.

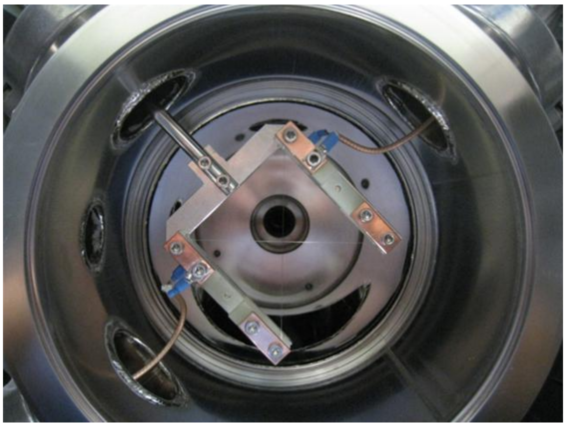

Fig. 2: The wire scanner installed in the beam line. The beam direction is outward from the paper.

2.3 Wire Scanner Test

The wire scanner was tested with 20MeV proton beam. The output signal from the wire scanner was processed through the current amplifier. The typical beam signal from the wire was shown in Figure 3. The signal intensity was obtained from the average value from 35us to 45us during 50us beam pulse width to avoid the initial transient value.

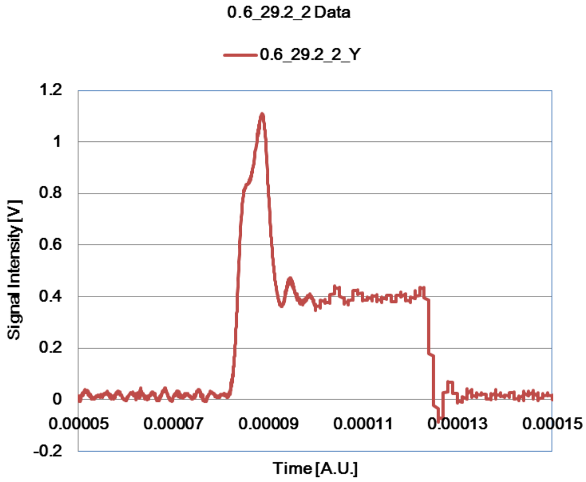

Fig. 3: Typical signal profile from the wire scanner.

3. Conclusions

The wire scanner for beam profile and emittance measurement for the PEFP 20MeV beam was designed, fabricated and tested. Recently, the wire scanner was installed at the 20MeV beam line and used to measure the beam profile depending on the quadrupole triplet operation parameters.

Acknowledgement

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