BEAM PROFILE MEASUREMENT IN MTA BEAM LINE FOR HIGH PRESSURE RF CAVITY BEAM TEST

M. R. Jana*, A. Bross, M. Chung, S. Greer, C. Johnstone, T. Kobilarcik, G. Koizumi, M. Leonova, A. Moretti, M. Popovic, T. Schwartz, A. Tollestrup, K. Yonehara, Fermi National Accelerator Laboratory, Batavia, IL - 60510, USA
B. Freemire, P. Hanlet, Y. Torun, IIT, Chicago, IL – 60616, USA
G. Collura, PDT, Torino – 10129, Italy

Abstract

Recent High Pressure RF (HPRF) cavity experiment at MuCool Test Area (MTA) has used 400 MeV Linac proton beam to study the beam loading effect. When the energetic proton beam passes through the cavity, it ionizes the inside gas and produces the electrons. These electrons consume RF power inside the cavity. Number of electrons produced per cm inside the cavity (at 950 psi Hydrogen gas) per incident proton is ~ 1200. The measurement of beam position and profile are necessary. MTA is flammable gas (Hydrogen) hazard zone so we have developed a passive beam diagnostic instrument using Chromox-6 scintillation screen and CCD camera. This paper presents quantitative information about beam position and beam profile. Neutral density filter was used to avoid saturation of CCD camera. Image data is filtered and fitted with Gaussian function to compute the beam size. The beam profile obtained from scintillation screen shall be compared with multi-wire beam profile.

INTRODUCTION

High intensity, low emittance muon beams are essential requirements for Muon Colliders and Neutrino Factories. Low emittance muon beams can be produced by Ionization Cooling process. This consists of passing muon beams through low-Z ionization absorber material (H), to reduce all components momentum and replacing only longitudinal momentum using RF cavity. In the same time to keep muon beam focused, both the absorbing material and RF cavity are placed inside strong magnetic field provided by superconducting solenoid. One of the beam cooling schemes is under development at MuCool Test Area (MTA), Fermilab using highly pressurized hydrogen gas RF cavity. This technique has two advantages: first, the energy absorption and energy regeneration occur simultaneously rather than sequentially. Secondly, higher RF gradient in external magnetic field is achieved due to breakdown suppression by Paschen Effect. Experiment has been done at MTA to study the Beam loading effect in High Pressure RF (HPRF) cavity with 400 MeV proton beam. Beam-induced plasma electrons are produced in the cavity and consume large amount of RF power. It has been shown that the number of electrons produced per cm inside the cavity (at 950 psi Hydrogen gas) per incident proton is ~ 1200 [1]. It is to be noted that before entering into HPRF cavity, proton beam has to be passed through 4 mm diameter collimator. Therefore measurement of beam position and profile are essential requirements of this experiment to obtain the information how many protons are entering into the HPRF cavity. MTA is flammable has (hydrogen) hazard zone. No energized beam monitor device can be use when superconducting solenoid magnet is ON due to safety reason. Another important point is to be noted, toroid (current transformer) used for beam monitor purpose is made up of ferrite so when SC magnet is turn ON then it does not work because of saturation of ferrite material. Looking into these requirements, we have developed a passive beam diagnostic instrument using Chromox-6 scintillation screen and CCD camera. Scintillation screens are widely used for beam profile monitoring device in many particle accelerators [2-5]. In our application, Chromox-6 scintillation screen was kept in air and incident beam of intensity ~ 10^{12} ppp. We obtain horizontal (σ_x) and vertical (σ_y) beam size from Gaussian fitted horizontal and vertical beam distribution respectively. Results are compared with multi-wire grid [or Secondary Electron Monitor (SEM) grid] beam profile data. We have also estimated beam transmission efficiency through second collimator and found good agreement with beam toroid data.

EXPERIMENTAL SETUP

Schematic of HPRF cavity beam test at MTA at Fermilab is shown in Fig. 1. Proton beam of energy 400 MeV, 10μs pulse length, intensity ~ 2×10^{12} ppp form Fermilab linac is used. Before entering into cavity beam has to pass two successive cylindrical collimators. First collimator made up of aluminium has length of 100.6 mm, diameter of 152.4 mm with through hole of diameter 20 mm at centre. A chromox-6 scintillation screen of size 40 mm × 40 mm, thickness of 1 mm is placed in front of first collimator. Second collimator made up of aluminium has length of 203.2 mm and central through hole of diameter 4 mm. To monitor beam intensity during beam operation two toroids are used. One (upstream) is placed in between first and second collimator and other (downstream) one is in between HPRF cavity and second collimator respectively. After traversing through the cavity, finally beam is dumped into solid cylindrical beam absorber of diameter 152.4 mm and length 200.1 mm. The HPRF cavity (filled with 950 psi hydrogen gas), Chromox-6 scintillation screen, collimators, beam absorber all are placed in air and inside Super Conducting (SC) solenoid magnet which can produce magnetic field of ~ 3T. *PixelLINK* USB CCD camera (1.4 Megapixel, 8 bit, S/N > 60 dB) is used to view and record the beam spot on the screen. The camera is placed at a distance of 5804 mm from screen, 2000 mm from beam axis shown in Fig. 1. The angular position of the camera is 19°. We have marked a grid of size 20 mm × 20 mm on scintillation screen to estimate the beam position. To obtain clear view of the scintillation screen, CCD camera is fitted with telephoto lens of focal length 160 mm. Camera is controlled via software and image is viewed, stored in PC. With this arrangement a resolution of ~ 10 px/mm was achieved. To avoid saturation of CCD we have used Neutral Density filter of attenuation of ~ 13%. To obtain reference beam profile (both horizontal and vertical), a multi-wire grid (50μm wire diameter, 1 mm spacing) monitor system was installed at MTA beam line as shown in Fig. 2. The reading from upstream, downstream beam toroid and also image of the beam spot were saved in PC at the same time for offline analysis. Figure 2 shows the photograph of MTA beam line with CCD camera, multi-wire grid and other experimental components for HPRF beam test.

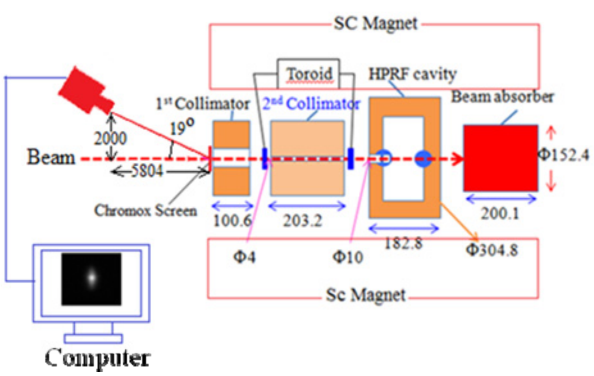

Figure 1: Schematic of HPRF cavity beam test at MTA.

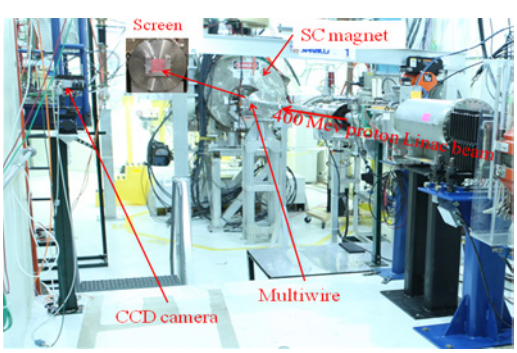

Figure 2: MTA beam line with Chromox-6 screen.

SCINTILLATION SCREEN

In HPRF cavity experiment, we have used 400 MeV proton linac beam of pulse length 10μs. The interval between two consecutive pulses is 1 min and the intensity is ~ 10^{12} ppp. In our case scintillation screen should work in air and compatible with long operation with high intensity beam. Chromox-6 [Alumina: Al_2O_3(99.4%) doped with Cr_2O_3(0.5%)] scintillation screen meets such requirements. It has many important properties e.g. good thermal stability, high radiation resistance, high sensitivity and also UHV compatible. It emits fluorescent light of λ ~ 700 nm and hence normal CCD camera is enough to capture the beam image. The decay time is ~ 100 ms [6].

ANALYSIS AND RESULTS

Fig. 3 depicts 400 MeV proton beam (~ 10^{12} ppp) spot on the scintillation screen recorded by monochrome USB CCD camera. Quantitative analysis of the beam spot was performed by image processing software IMAGEJ [7] and Wolfram Mathematica [8]. Beam profiles obtained from the beam spot both at horizontal and vertical plane are shown. Characterization of the projected beam was done by calculation of beam centre (X_0, Y_0) and beam width (σ). This has been done by filtering (background noise subtraction) the CCD raw data and Gaussian fit of the same. From the Gaussian fit we obtained horizontal beam width σ_x = 2.5 mm and vertical beam width σ_x = 4 mm respectively. Fig. 4*(a)* depicts values of σ_x and σ_y at different beam shot number. Scintillation screen has a grid of size 20 mm × 20 mm w.r.t origin (O) is shown in Fig. 3. The coordinate of the centre (X_0, Y_0) the grid is (10, 10) and aligned with collimator hole centre (shown in Fig. 1) with an accuracy of less than 1mm. Fig. 4*(b)* illustrates the position of the beam centre w.r.t the centre of the collimator hole. We have estimated the beam transmission through the second collimator in the following way: first we have constructed 2D Gaussian surface [Fig. 5(a)] from the beam spot on scintillation screen and contour plot of the same is shown in Fig. 5(b). Integration over the whole surface would give us an area which is equivalent to number of incident protons (N_1) from linac and is confirmed the number obtained from upstream beam toroid (Fig. 1). Again we know the both locations of collimator centre and beam centre. Now integrating over a collimator hole area w.r.t the beam centre we obtain number of protons (N_2) are passing through the second collimator. The ratio (N_2/N_1) of these two numbers would give us the beam transmission efficiency. Results are compared with downstream toroid and found agreement within 4% shown in Fig. 6(a). The above mentioned results are based on beam test done on 2011 summer. Again in 2012 summer further beam test has been done with new installation of Multi Wire (MW) at a distance of 1.1 m from the screen (Fig. 2). We have observed that linac beam size has small difference than

ISBN 978-3-95450-115-1

the previous one. The detailed analysis shall be reported elsewhere. For the sake of comparison, in this paper we have reported the preliminary results on beam size obtained from CCD image and MW as shown in Fig. 6(b). There are 25% difference in σ_x and 10% in σ_y respectively. These may be due to poor spatial resolution of MW.

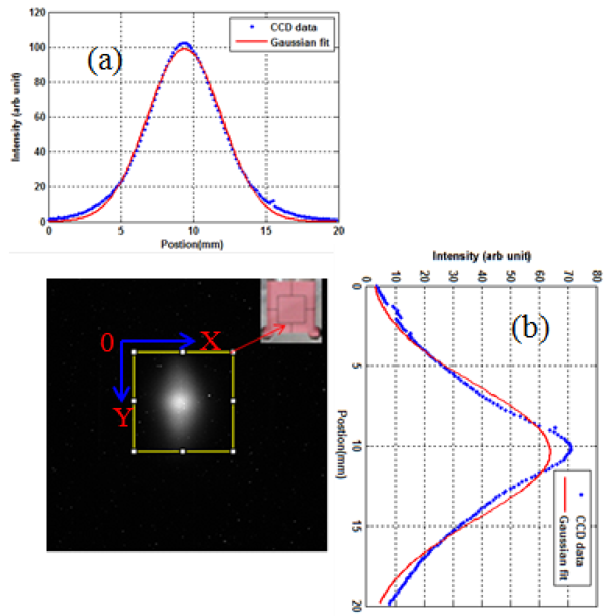

Figure 3: Beam image on Chromox-6 scintillation screen taken with CCD camera for 400 MeV proton beam. Horizontal (a) and vertical (b) beam profiles with Gaussian fit are also shown.

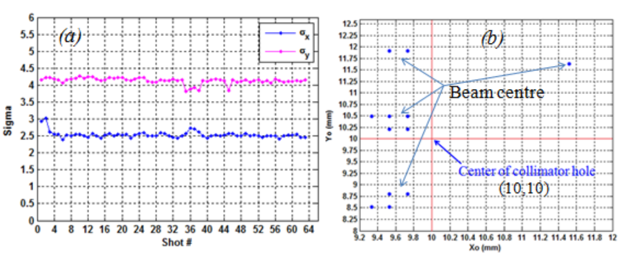

Figure 4: *(a)* horizontal beam width (σ_x) and vertical beam width (σ_y) at different beam shot number, *(b)* position of beam centre w.r.t centre of collimator hole at different beam shot.

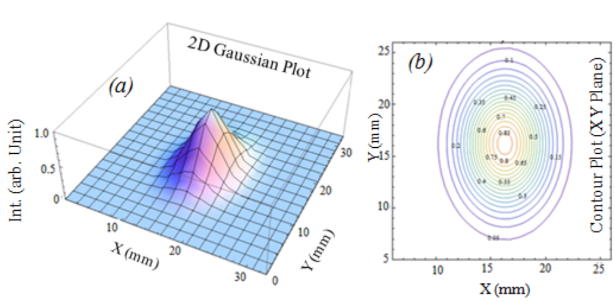

Figure 5: Two dimensional Gaussian distribution plot (left) of the beam image shown in Fig. 3 and its contour plot on X-Y plane (right).

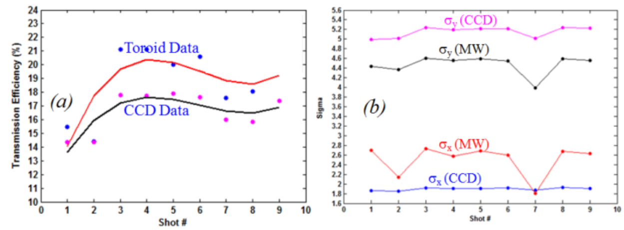

Figure 6: *(a)* Comparison of beam transmission efficiency calculated from CCD data and toroid, *(b)* comparison of beam between CCD data and multi-wire data during beam test done on summer 2012.

CONCLUSIONS

The present paper have reported passive beam diagnostic instrumentation using chromox-6 scintillation screen and CCD camera in flammable gas (hydrogen) hazard MuCool Test Area (MTA) at Fermilab. High intensity (~ 10^{12} ppp) linac proton beam of energy 400 MeV is used for HPRF cavity beam team test. The beam has to be passed through 4 mm diameter collimator hole before entering into cavity. Another important point, when superconducting magnet is on then no energised beam monitor device can be used for safety reason. In this situation combination of Chromox-6 scintillation screen and CCD camera works very well to monitor both beam position and profile. This was the only online tool available to guide the beam operator at Fermilab's Main Control Room to tune the beam during the experiment. Techniques developed for estimation of beam transmission through second collimator hole is well agreement with toroid data. Preliminary analysis of second beam test data shows large variation in σ_x when compared with newly installed multi-wire data. Detail analysis is in progress and shall be reported elsewhere.

REFERENCES

[1] K. Yonehara, "HPRF beam tests", MAP Weekly meetings, 23rd September 2011, https://indico.fnal.gov/conferenceDisplay.py?confId=4661

[2] B. Walasek-Hohne, "Scintillating screen application in beam diagnostics", Proceedings of DIPAC 2011, Hamburg, Germany, p. 553 (2011)

[3] E. Gutlich et al., "Scintillation screen investigation for high current ion beams", IEEE Transaction on Nuclear Science 57 (2010) 1414

[4] J. Harasimowicz et al., "Scintillating screens sensitivity and resolution studies for low energy ion intensity beam diagnostics", Rev. Sci. Instrum. 81 (2010) 103302

[5] E. Bravin, "Scintillating screens use at CERN", Workshop on Scintillating screen applications in beam diagnostics, GSI, Darmstadt, Germany (2011), http://www-bd.gsi.de/ssabd

[6] P. Strehl, "Beam Instrumentation and Diagnostics", Springer (2006) p.120

[7] W.S. Rasband, "ImageJ", U.S. National Institute of Health, Bethesda, Maryland, USA, http//rsb.info.nih.gov/ij (1997-2010)

[8] Wolfram Research, Inc. USA, www.wolfram.com