STATUS OF BEAM DIAGNOSTICS AT KHIMA FACILITY

Tae-Keun Yang*, Dong Hyun An, Ga Ram Hahn, Heejoong Yim, Ji-Gwang Hwang,
Chang Hyeuk Kim, Seon Yeong Noh, and Chawon Park
Korea Institute of Radiological and Medical Sciences (KIRAMS), Seoul, South Korea

Abstract

The Korea Heavy Ion Medical Accelerator (KHIMA) is the cancer therapy facility based on a synchrotron which can accelerate up to 430 MeV/u for carbon beam and up to 230 MeV/u for proton beam. The facility has 4 sectors Low Energy Beam Transport (LEBT) line from ECR-IS to radio-frequency quadrupole (RFQ) and interdigital H-mode drift-tube-linac (IH-DTL), Medium Energy Beam Transport (MEBT) line from IH-DTL to synchrotron, synchrotron ring, High Energy Beam Transport (HEBT) line from the ring to irradiation rooms, 3 treatment rooms and 1 research room. For the beam diagnostics at the KHIMA, 17 type monitors with total number of 88 are considered and planned including the related instruments such as slit, stopper, stripper and etc. This proceeding introduces specifications of each diagnostic devices and shows test results of several devices.

INTRODUCTION

The Korea Heavy Ion Medical Accelerator (KHIMA) is a project to develop a heavy-ion therapy machine based on a synchrotron. The conceptual design report for each part of the facility has been completed and fabrication of some equipments has been started. The facility can be divided as 4 sectors according to the transferred beam energy; Low Energy Beam Transport (LEBT), Medium Energy Beam Transport (MEBT), synchrotron ring, and High Energy Beam Transport (HEBT) line [1]. A detail information for an ion beam at each sectors are important to transfer well and confirm a beam to a patient with high intensity by minimizing a beam loss. The various monitors are required to measure beam specification such as the beam current, spatial distribution, spill structure, and energy. The beam diagnostic devices can be classified as a destructive or a non-destructive device. The Faraday-cup(FC) is the most famous destructive device and the current transformer(CT) is the most famous non-destructive one to measure the beam current. The DC FCs are installed at the LEBT and AC FCs are the LEBT and MEBT line. The AC current transformers(AC CTs) are installed at the LEBT and MEBT and the DC current transformer (DCCT) is installed at the syncrotron ring. The combination of slit and wire scanner in LEBT line or wire grid monitor in MEBT line, and the pepper-pot device in LEBT line are considered for measuring the beam emittance, which is a significant beam parameter in the accelerator. The transverse beam profile is also measured by the scintillation screen in the synchrotron and HEBT line. Two capacitive pickup devices are installed in the MEBT line to measure the beam energy by the time-of-flight (TOF) method. Linear-cut beam position monitor, which has the wide linear region, and stripline kicker are adopted to measure the beam position and to use as a RF exciter for tune measurement and RF-KO, respectively. For the interlock, the beam stopper, collimator, and slit is also installed at the each section. In this paper, the beam diagnostics contained at each sectors of the KHIMA facility is introduced.

* ytk@kirams.re.kr

LOW ENERGY BEAM TRANSFER LINE

The LEBT line is the region of ECR-IS to an entrance of radio-frequency quadrupole (RFQ), see Fig. 1. It has two ECR-IS for producing $^{12}C^{4+}$ and H_3^+ beams. The extraction voltage of the ECR-IS is 24 kV and the required maximum current are 285 euA for $^{12}C^{4+}$ and 765euA H_3^+, respectively. The extracted ion beam is bent by 90° analyzing magnet for ion selection and then the selected beam is transferred into RFQ to accelerate the beam up to 7 MeV/u through the optical components, like solenoid, steering magnet, quadrupole magnet, and electrostatic chopper.

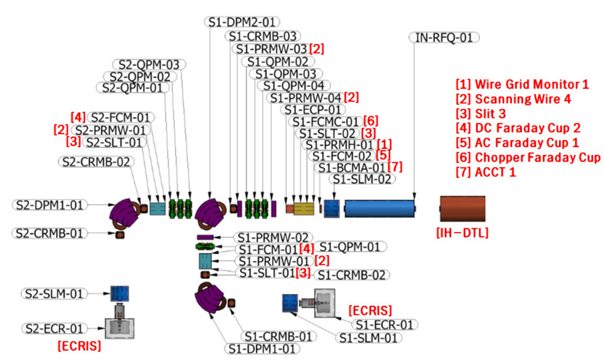

Figure 1: Layout and position of beam diagnostics in LEBT line.

The LEBT line of KIHMA has two emittance measurement systems, which consists of 4 slits with 2 slits at each x- and y-axis, wire scanner with two perpendicular wires, and DC Faraday cup in a vacuum chamber, for measuring the beam emittance after the beam selection by the analyzing magnet and to control the beam optics by measuring the profiles before and after triplet magnets, and an ACCT for measuring beam current after a chopper system. Especially, the Faraday-cup and slit, which is installed in LEBT line, has the cooling channel with the cooling capacitance of 100 W because the beam power of 30 W is fully deposited on

Copyright © 2015 CC-BY-3.0 and by the respective authors

ISBN 978-3-95450-176-2

the Faraday-cup. The electric potential with the suppression voltage of -1 kV is calculated and the maximum value of the potential barrier is to be 250 V. It is shown in Fig. 2.

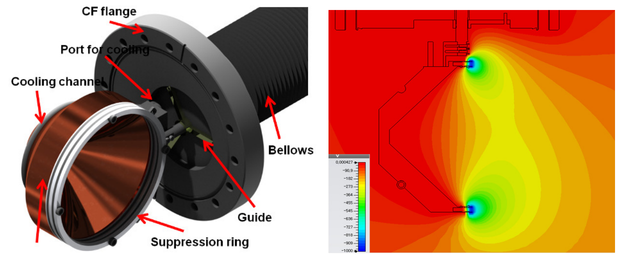

Figure 2: DC Faraday-cup and electric potential map of suppression ring in LEBT line.

Three wire scanners are located near the triplets in the LEBT line for monitoring the beam profile and emittance. For the wire scanner, the device with two wires, which are perpendicular and insulated to each other, is chosen. The actuator is based on a brushless motor to reduce the noise signal from the brush of the motor. Based on the calculation of the heat deposit on the wire, it has moving speed of 100 mm/s and moving range of $\pm$ 200 mm. The diameter of the wire is 0.1mm and the material is tungsten. The emittance measurement is performed by reading current on the wires at each changed positions of slits and wires.

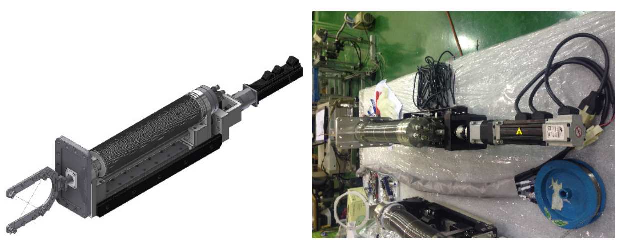

Figure 3: Wire-scanner in LEBT line.

The DC beam from the ECR-IS is changed to be pulsed by an electrostatic chopper. In general, the cylindrical wall typed Faraday-cup was used to collect the beam deflected by the chopper in CNAO and MedAustron [2, 3]. But we choose the DC Faraday-cup on the side of a vacuum pipe to simplify the construction and to lessen the length of the chopper system. The chopper electrodes were designed to be asymmetric so that the deflected beam was well focused at the Faraday cup that is shown in Fig. 4.

After the electrostatic chopper, the emittance of the pulsed beam is measured using x-y slits and wire grid monitor before the RFQ. The wire grid monitor can measure the transverse profile and the central position of a beam. The wire grid monitor consists of horizontal and vertical wire array, 64$\times$64 wires. The active area of it is 105$\times$105 mm^2. The material of wire is tungsten-rhenium alloy and its diameter is 0.1mm. The wire frame is mounted on a pneumatic actuator with 150mm travel range. The pepper-pot device, which consists of mask with the square array

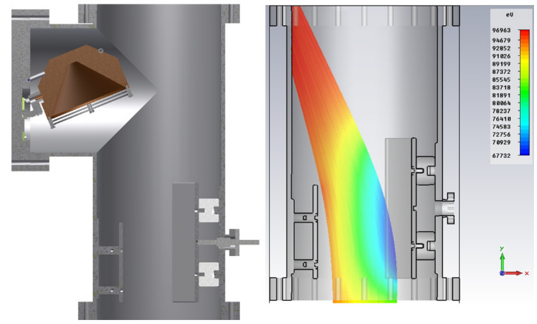

Figure 4: Electrostatic chopper in LEBT line.

holes, microchannel plate (MCP), mirror, and CCD camera, is also considered as a candidate of the emittance measurement equipment. The measurement speed of the device is faster than the combination of the slit and wire-scanner. The design of the pepper-pot device is shown in Fig. 5.

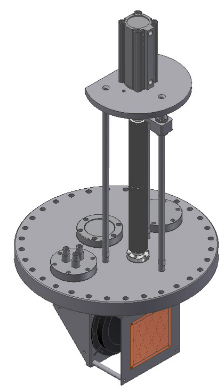

Figure 5: Pepper-pot device in LEBT line.

The pepper-pot mask is made of phosphor bronze and the hole size is measured to be 89.9 $\pm$ 1.29 μm by using the scanning electron microscope.

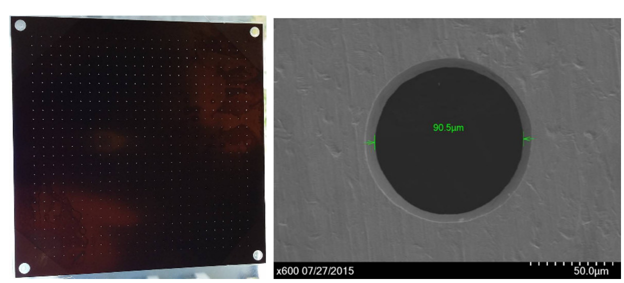

Figure 6: Phosphor bronze pepper-pot mask in Pepper-pot device.

After this wire grid monitor, there are two devices to measure beam current. One is an AC Faraday cup and another is ACCT. The AC Faraday cup has a role of a stopper. Its specification is the same to the DC Faraday-cup except for higher sampling time, $\leq$10 MS/s. The ACCT is non-destructive unlike a Faraday-cup so that it can work as a

ISBN 978-3-95450-176-2

Copyright © 2015 CC-BY-3.0 and by the respective authors

real time monitor during the treatment as well as commissioning.

MEDIUM ENERGY TRANSFER LINE

The pulsed ion beam injected into RFQ is accelerated up to 7 MeV/u by the linac which consists of RFQ and interdigital H-mode drift-tube-linac (IH-DTL). The frequency, repetition rate and duty cycle of the linac are 200 MHz, 4∼5 Hz, and 200 μs, respectively. The accelerated beam is transported to synchrotron through the MEBT line. The layout of the MEBT line is shown in Fig. 7.

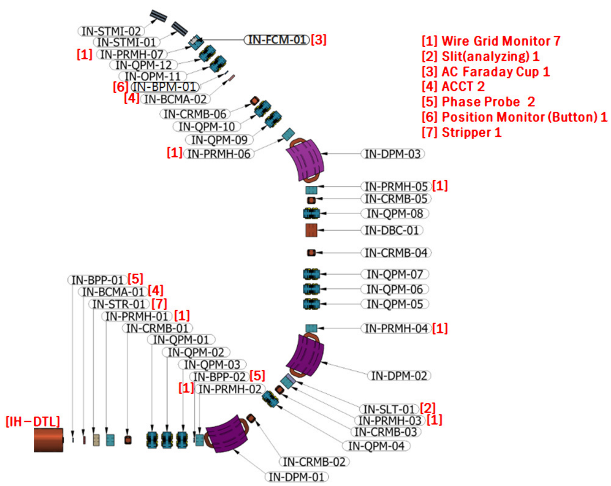

Figure 7: Layout and position of beam diagnostics in MEBT line.

The ACCT and wire grid monitor are located at the exit of IH-DTL to measure beam intensity and to measure the transverse profile of a beam, respectively. The accelerated carbon beam is fully stripped and the H_3^+ beam is changed to proton beam by a thin carbon foil. The equilibrium thickness of the carbon foil for the 7 MeV/u carbon beam is calculated to be 87.8 μg/cm^2 by using code LISE^{++} [4, 5]. The equilibrium thickness means the thickness which does not more change the charge state ratio of transmitted ions. The thickness of carbon foil is chosen to be 100 μg/cm^2. The population of $^{12}C^{6+}$ beam is about 98 % in the case of 100 μg/cm^2 carbon foil. The energy loss and rms angular straggling for the 100 μg/cm^2 carbon foil are 16.1 keV/u and 0.314 mrad, respectively. The five stripper foils are mounted on one ladder and two ladders with step motor are installed in the beam line that is shown in Fig. 8.

The phase probe monitor in a straight section after IH-DTL is used to estimate the spatial beam structure of the accelerated beam by measuring induced current on its electrode as a function of time. The energy of the beam is also determined by applying time-of-flight (TOF) method with output signals from two phase probes. The distance between two probes is about 3 m. The designed phase probe is shown in Fig. 9.

The impedance of the pick-up probe is matched to 100 ohm due to the two passage of the signal. The outer conductor is applied to reduce the signal decay during the signal propagation along the long connector and to prevent the noise signal from surroundings [6]. The performance of the phase probe is confirmed by measuring the signal response on the wire test bench and TOF experiment with the proton beam in the KIRAMS. The result is shown in Fig. 10.

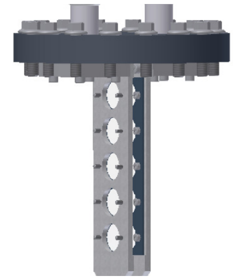

Figure 8: Carbon charge stripper foil mounted on ladder.

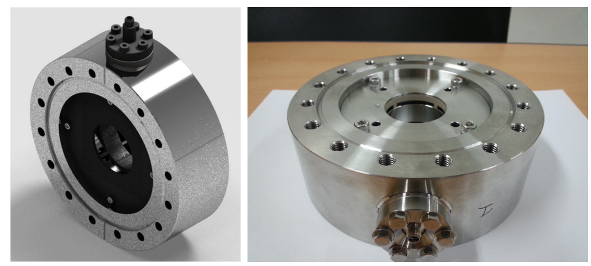

Figure 9: Capacitive beam phase probe in MEBT line.

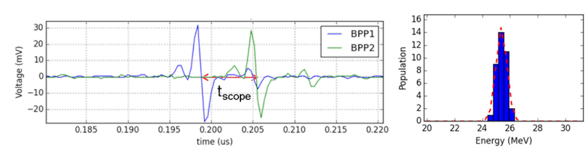

Figure 10: Energy measurement by TOF experiment.

The measured energy is 25.38 ± 0.39 MeV. It is smaller than the extraction energy due to the energy loss in the aluminum window and air. After first bending magnet in the MEBT line, a horizontal slit is installed to select only a targeted ion with proper charge state, $^{12}C^{6+}$ or H^+, among various ion beams and charge states produced by the stripper. Seven wire grid monitors will be installed to measure the transverse profile of a beam in MEBT. Its specification is similar to one in LEBT with the active area of 70×70 mm^2. Before the injection point, the ACCT and button type beam position monitor are installed to verify the beam current variation and orbit jitter before the injection on the synchrotron, respectively.

SYNCHROTRON RING

The injected beam with the energy of 7 MeV/u is accelerated up to 430 MeV/u for carbon beam and 230 MeV for proton beam in the synchrotron. In order to accelerate beam without the significant beam loss, the monitoring of

Copyright © 2015 CC-BY-3.0 and by the respective authors

ISBN 978-3-95450-176-2

the central orbit, betatron tune, phase stability and synchronization of frequency ramping of the low level RF system for magnetic alloy cavity are important. The layout and position of the beam diagnostics in the synchrotron is shown in Fig. 11.

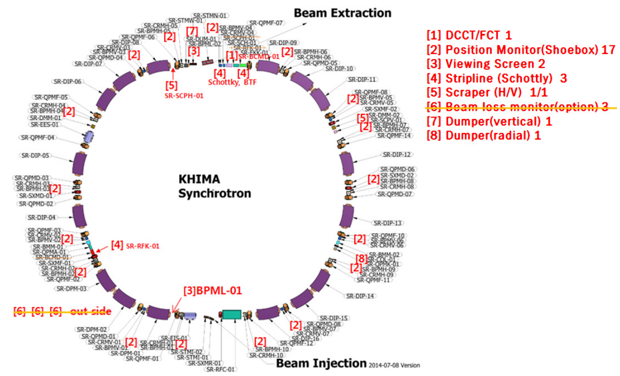

Figure 11: Layout and position of beam diagnostics in synchrotron.

The viewing screen, which is coated P43 scintillation material on Al substrate, is installed at the injection and extraction position to identify the injection beam orbit and profile during first turn in the ring. It is adopted as the beam profile monitor in the HEBT line. The spatial structure of macro-pulse and the beam orbit of the ion beam is monitored by using linear-cut beam position monitor, see Fig. 12. The number of beam position monitor is 10 for horizontal direction and 7 for vertical direction. The position of the position monitor is determined based on the amplitude of the betatron oscillation.

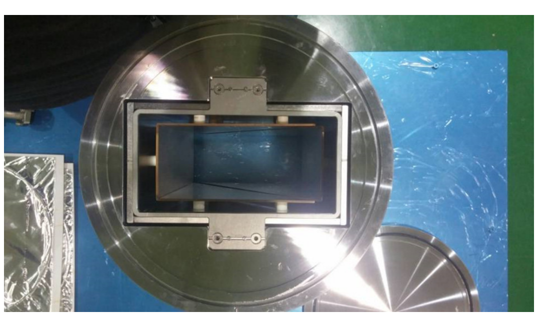

Figure 12: Linear-cut beam position monitor in synchrotron.

It was fabricated based on the design values and the laboratory tests, such as the vacuum leakage test by He leak detector, the measurement of the cross-talk by the Vector Network Analyzer and linearity measurement by the wire test bench, were performed to confirm the performance. The measured cross-talk is less than -40 dB in the operation frequency from 0.48 MHz to 3 MHz, see Fig. 13. The calibration coefficients is measured and it agrees well with the designed parameter calculated by using code CST-MWS [7].

Two stripline kickers are installed to excite the beam

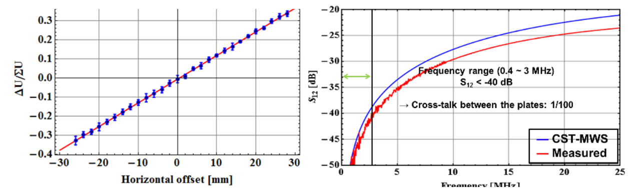

Figure 13: Measurement result of linearity and S-parameter of Linear-cut BPM.

for measuring the betatron tune and to manipulate the spill structure of the extracted beam, respectively. It is also used to measure the beam position and energy spread for the coasting beam. The concave shaped plates are oriented horizontally and vertically to form the capacitors in respective planes. Figure 14 shows the mechanical structure and the field profile of stripline kicker and Schottky pick-up.

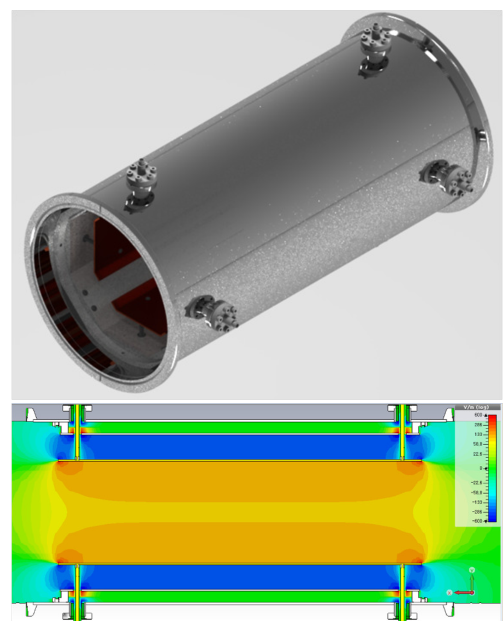

Figure 14: Stripline kicker in synchrotron.

The DCCT and FCT are installed to measure the beam current variation during the injection and extraction cycle. The scraper is also used to control the beam emittance in the ring by removing the halo particles.

HIGH ENERGY TRANSFER LINE

The extracted beam is delivered to the treatment room or research beam line. One horizontal and two vertical treatment room and one horizontal research beam line is planned in the KHIMA facility. The quality of beam extracted from the synchrotron is monitored by the qualification monitor, which is installed between the chopper magnet, to obtain the safety for the therapy. The qualification monitor observes the beam spill structure and profile before the treatment room to confirm the dose on patient. When the stability of the beam intensity and profile is confirmed,

ISBN 978-3-95450-176-2

Copyright © 2015 CC-BY-3.0 and by the respective authors

the beam is delivered to the treatment room or research beam line. The layout and position of the beam diagnostics in the HEBT line is shown in Fig. 15.

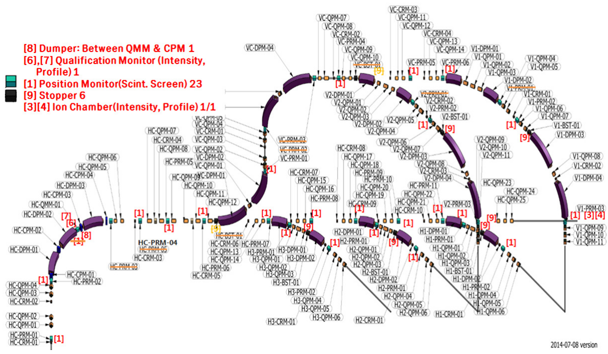

Figure 15: Layout and position of beam diagnostics in HEBT line.

For the optics tuning, the beam profile at the HEBT line is monitored by using the scintillation screen monitor. Since the beam intensity is low, $\sim 5 \times 10^8$ particles/spill, in the HEBT line, the P43 material, which has high light yield, is determined as the scintillation material to obtain the high light output. The thickness of the coating is chosen to be 50 μm with the grain size of 10 μm.

Figure 16: Scintillation screen monitor in synchrotron and HEBT line.

The screen monitor is fabricated and the calibration for the correction of the optics distortion is performed based on the linear mapping. The control and data acquisition system based on the compact single board is under developing. The profile reconstruction and analysis included the suppression of effects of noise and death pixel and the background noise subtraction is done. The beam test with proton beam were performed to confirm the performance that is shown in Fig. 17.

CONCLUSION

The conceptual design of KHIMA facility is completed and we have a plan to construct the 88 beam diagnostics until end of 2017. The beam diagnostic devices such as

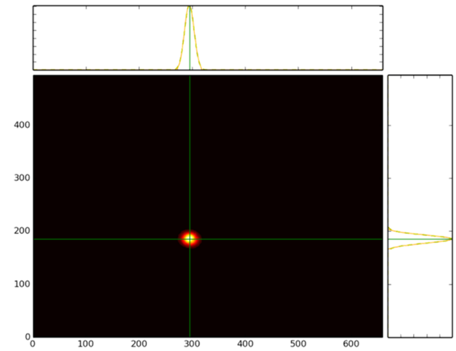

Figure 17: Beam test result with proton beam.

wire-scanner, Faraday-cup, pepper-pot device, electrostatic chopper, capacitive phase probe, linear-cut BPM, stripline kicker, and scintillation screen monitor, is under developing by collaborating with PAL, GSI, RCNP and KEK.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (no. NRF-2014M2C3A1029534)

REFERENCES

[1] KHIMA Handbook of Beam Optics for Accelerator System, private communication.

[2] G. Balbinot et al., ”A NOT-INTERCEPTIVE FARADAY CUP IN THE CNAO LOW ENERGY INJECTION LINES”, DIPAC09, Basel, Switzerland (2009), TUPD21.

[3] F. Osmic et al., ”OVERVIEW OF THE BEAM DIAGNOSTICS IN THE MEDAUSTRON ACCELERATOR: DESIGN CHOICES AND TEST BEAM COMMISSIONING”, IPAC2012, New Orleans, USA (2012), MOPPR002.

[4] O. Tarasov, D. Bazin, Nucl. Instr. Meth. B **266** (2008) 4657.

[5] D. Bazin et al., Nucl. Instr. Meth. A **482** (2002) 307.

[6] Peter Forck, *Lecture Notes on Beam Instrumentation and Diagnostics*, Joint University Accelerator School (JUAS), Geneva, Switzerland (2011).

[7] CST-MWS and PS website : https://www.cst.com/.

Copyright © 2015 CC-BY-3.0 and by the respective authors