TURN-KEY BEAMLINES FOR THE 15 – 30 MeV MEDICAL CYCLOTRON AT VECC

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Abstract

Turn-key beamlines built by Danfysik are to be installed at the medical cyclotron facility VECC in Kolkata, India. The beamlines will transport a 500 µA beam of 15 – 30 MeV protons to the target stations where they will be used for research and development. A raster scanning system is used to generate a uniform dose distribution in a square or circular pattern.

The beamline components, collimators, diagnostics, and helium cooled HAVAR separation foils protecting the beamlines and cyclotron from possible contamination from the targets are designed for up to 15 kW beam power.

INTRODUCTION

A medical cyclotron facility is being installed at VECC in Kolkata. The cyclotron will feed five beamlines. Three of these are dedicated for the production of radioisotopes for radiopharmaceuticals. The 4th beamline is for carrying out materials science related activities such as damage studies, production of radioactive isotopes as positron sources, for charge particle activation analysis etc. The 5th beamline is for carrying out activities related to liquid metal lead bismuth eutectic (LBE) target. BARC and IGCAR will operate the 4th and 5th beamlines. Danfysik has designed and fabricated the 4th and 5th beamlines. The beamlines have undergone a Factory Acceptance Test at Danfysik without beam.

The high DC beam power puts significant constraints in the beam optical design as well as on the beam diagnostics, which have been designed to withstand this beam power.

4TH BEAMLINE

Figure 1 shows the 4th beamline which is designed to feed two target stations. A five-port dipole magnet initially either deflects the beam towards the low-power station or lets the beam pass straight through to the high-energy station.

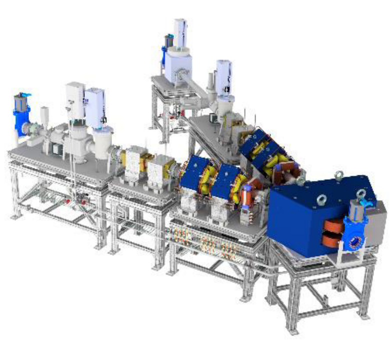

Figure 1: Physical layout of the 4th beamline.

The assembled beamline is shown in Figure 2. The switching dipole is seen to the far left. The high power beamline is seen in the front, and the low power beamline is located behind this.

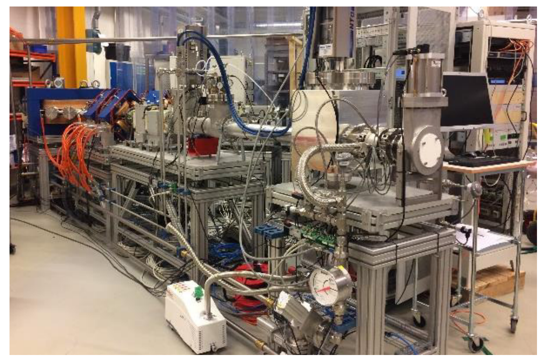

Figure 2: 4th beamlines installed for Factory Acceptance Test (December 2016) at Danfysik.

Beam Optics

Key beam parameters are given in Table 1.

Table 1: Beam Parameters in the 4th Beamline

Ion	H+
Energy	15 – 30 MeV
Hor. emittance at 30 MeV (norm.)	10 π mm mrad
Vert. emittance at 30 MeV (norm.)	5 π mm mrad
Energy spread	< 600 keV
Beam current, high-power beamline	500 µA
Beam current, low-power beamline	50 µA
Beam spot on target, FWHM	10 – 12 mm
Scanned beam	30 mm × 30 mm
Beam uniformity	+/- 10%
Scanner frequencies	20 – 200 Hz

The beam optics is shown in Figure 3 and Figure 4, which show the beam optics all the way from the beam extraction at the cyclotron and to the target. The delivery of Danfysik only includes the last half of the beamlines, i.e. from the last dipole and to the target station.

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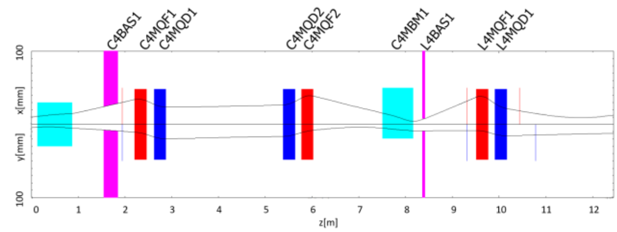

Figure 3: Beam optics for the 4th beamline, low energy branch. Effect of vacuum isolation system not shown.

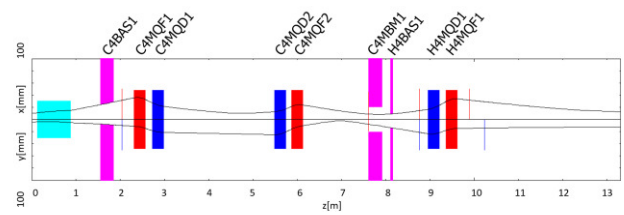

Figure 4: Beam optics for the 4th beamline, high energy branch. Effect of vacuum isolation system not shown.

The Danfysik beamlines consists of a short common part with a beamline selecting dipole followed by two sub beamlines. Each of the sub beamlines (high and low power) consists of a quadrupole doublet, which focuses the beam onto the target, and a set of scanner magnets which scan the beam in a raster fashion over the target, see Fig. 5.

The vacuum of the beamlines is isolated from the target stations with a dual foil system. The scattering of the beam particles is significant and has been included in the beam optical design. The dual foil system is designed to withstand the power deposited by a scanned beam, where the power is distributed over a large part of the foil.

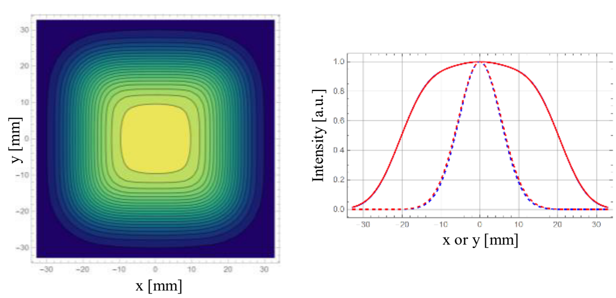

Figure 5: Transverse beam profile on target. The profile on the right shows the scanned profile as well as the profile without scanning.

Beam Diagnostics

The beam diagnostics for the 4th beamline is listed in Table 2 and Table 3. The Faraday cups and slit blades are made of graphite-like material to minimize the activation caused by the beam. As shown in Table 2 and Table 3, the viewing screens, slits and BPMs cannot sustain the full 15 kW beam power. The control system protects these devices from damage by limiting their use to a safe power range.

Table 2: Beam Diagnostics, Low Energy Branch

1.5 kW Faraday cup
2 kW viewing screen
1 kW rotating wire BPM
Adjustable slits, 100 W per blade

Table 3: Beam Diagnostics, High Energy Branch

15 kW Faraday cup
2 kW viewing screen
1 kW rotating wire BPM
Adjustable slits, 1 kW per blade

5TH BEAMLINE

Figure 6 shows the 5th beamline. The 5th beamline will deliver a proton beam to a liquid metal target (not Danfysik scope) in the basement of the complex.

Figure 6: Physical layout of the 5th beamline.

Beam Optics

Key beam parameters are given in Table 1.

Table 4: Beam Parameters in the 5th Beamline

Ion	H+
Energy	15 – 30 MeV
Hor. emittance at 30 MeV (norm.)	10 π mm mrad
Vert. emittance at 30 MeV (norm.)	5 π mm mrad
Energy spread	< 600 keV
Beam current (15 MeV)	200 μA
Beam current (30 MeV)	350 μA
Spot on target, FWHM	40 mm
Scanner frequencies	20 – 200 Hz

The beam optics is shown in Figure 7.

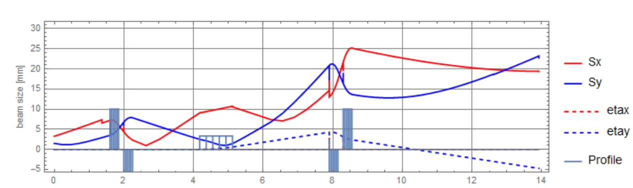

Figure 7: Beam optics for the 5th beamline.

The beamline consists of a quadrupole doublet, a 90° dipole, and a second quadrupole doublet. A set of scanner magnets allow the beam to be scanned in a circular pattern over the target area.

The vacuum of the beamline is isolated from the target stations with a dual HAVAR foil system. The layout of the target has prevented that the dual foil system can be placed close to the target. Instead the dual foil system is placed near the scanner magnets. Because the beam is not distributed over a large transverse area at this location, the allowed beam current is reduced to 200 µA – 350 µA as compared to the 500 µA in the 4th beamline. Figure 7 shows the effect of the emittance increase in the dual foil system: the emittance grows significantly at the foil system right before the last quadrupole doublet, and the beam remains broad through the long transport line to the target.

Beam Diagnostics

The beam diagnostics for the 5th beamline is listed in Table 5.

Table 5: Beam Diagnostics in the 5th Beamline

15 kW Faraday cup
2 kW viewing screen
Fixed slits, 100 W per blade
Adjustable slits, 100 W per blade

CONTROL SYSTEMS

The 4th and 5th beamlines are controlled from individual but identical control systems. The main task of the control system is to control and monitor devices such as power supplies and vacuum equipment and to acquire and present data from beam diagnostics such as Faraday cups, slits, viewing screens and beam profile monitors.

The control system receives information about the extracted beam (beam energy) from the cyclotron control system and issues beam permit signals based on this.

The control system interfaces with the existing control system for the cyclotron and exchanges interlock signals with this.

VACUUM ISOLATION

A vacuum isolation system is installed between the target chamber and the beamline. The aim of the vacuum isolation system is to protect the beamline and the cyclotron from possible contamination from the target. The vacuum isolation system consists of two 10 µm HAVAR foils which are cooled by a high velocity helium flow at 0.5 bar. The vacuum isolation system is shown in Figure 8.

The vacuum isolation system has been designed in a trade off with the beam optical design. On one hand, it is desirable to focus the beam onto the foils in order to have as small an emittance growth as possible. On the other hand, it is desirable to spread out the beam on the foils for cooling reasons.

The vacuum isolation system has been designed to withstand a 15 MeV – 30 MeV beam with 500 µA protons. The foil temperature should be below 500 °C to maintain a high enough strength to withstand the pressure from the He side of the foil. Computational Fluid Dynamics (CFD) analysis has been carried out to estimate the foil cooling. Energy deposition from various Gaussian beam profiles has been used as input for the CFD. The analysis has shown that the maximum temperature of the foils will remain below 500°C if the 1σ beam radius is larger than 9 mm. The energy loss is lower at higher energy, so an even smaller beam can be allowed at 30 MeV.

Table 6: Energy loss, scattering angles and allowed beam radii for protons through the two 10 µm HAVAR foils.

	15 MeV	**30 MeV**
Energy loss	348 keV	205 keV
Relative energy loss	0.24%	0.12%
Energy spread	0.12%	0.06%
Scattering angle	8.5 mrad	4 mrad
Minimum beam radius	9 mm	7 mm

Figure 8: Vacuum isolation system consisting of two HAVAR foils.

CONCLUSION

Two beamlines have been designed and fabricated by Danfysik for the 15-30 MeV high current proton cyclotron at VECC. The design has addressed important issues such as beam losses and scattering of particles. A control system is supplied which ensures smooth operation of the beamlines and basic machine protection.

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