First 20 MeV Proton Beam Transport to TR102 for Space Applications and Associated Diagnostic Challenges at KOMAC

Seunghyun Lee*, Seok Ho Moon, Sang-Pil Yun, Young-Gi Song, Gye-Ryung Kim, Han-Sung Kim, Hyeok-Jung Kwon
Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 38180
**Corresponding author: shl@kaeri.re.kr*

1. Introduction

A 20 MeV proton beam is a crucial tool for evaluating Displacement Damage (DD) in space-qualified electronic components. Utilizing this beam for space applications requires strict control over proton flux and irradiation uniformity within ± 10 %. Because the existing 20 MeV beamline setup at the Korea Multi-purpose Accelerator Complex (KOMAC) was not originally configured to meet these specific requirements, a novel operational strategy was implemented. The 20 MeV proton beam was transported through the Drift Tube Linac 2 (DTL2) section of the KOMAC proton linac and ultimately into the TR102 beamline. Prior to the experimental trial, comprehensive beam dynamics simulation studies were performed to verify transport feasibility and determine the optimal operational parameters for the DTL and transport magnets. Based on these numerical foundations, this paper reports on the first successful beam transport of the 20 MeV proton beam to the TR102 target room. While the physical transport and operational settings of the beam optics were successfully validated, initial beam characterization attempts revealed technical challenges caused by the low energy and shallow penetration depth of the 20 MeV protons. The existing diagnostic instrumentation exhibited insufficient sensitivity, yielding only marginal and faint responses that fell short of the requirements for precise quantitative flux and uniformity measurements. In this paper, we present the results of the 20 MeV proton beam transport to TR102 at KOMAC and highlight the importance of characterizing low-energy proton beams.

2. 20 MeV Proton Beam Transport Simulation

Target Room 102 (TR102) is connected to a low-flux beamline 102 (BL102), as illustrated in Fig. 1. This specialized beamline, BL102 is engineered with two primary functional components: a collimator assembly for beam intensity reduction and a dedicated magnet lattice for generating uniform beam profiles.

To satisfy the strict low-flux requirements for space parts testing, the collimator reduces the incident proton flux by a factor of 1/10,000. Fabricated from high-purity graphite, the collimator features a 5 mm diameter aperture that physically intercepts the outer edges of the beam. Consequently, the vast majority of the primary beam power is thermally dissipated within this graphite block. Following the collimation stage, a dedicated beam optics system—consisting of a quadrupole magnet and a pair of octupole magnets—is employed to transform the standard Gaussian beam distribution into a uniform, flat-top profile at the target.

For real-time beam monitoring, the beamline is equipped with diagnostic instrumentation, including an Alternating Current Transformer (ACCT), a stripline-type Beam Position Monitor (BPM), and a Faraday cup. Furthermore, a two-dimensional (2D) array ionization chamber is slated for installation at the final target position to precisely map the transverse beam profile. In this section, we present the numerical simulation results for transporting the 20 MeV proton beam to TR102, and the beam uniformity calculation result.

2.1 Design Specifications

At the TR102 target position, the beamline is designed to produce a large-area exposure field of 100 mm × 100 mm with an irradiation uniformity better than ±10%. The initial design specifications of this beamline—originally optimized for standard high-energy operations—are summarized in Table 1.

Table I: Key design specification of the TR102 at KOMAC

Parameter	Design value
Beam Energy at target	33 MeV ~ 100 MeV
Max. average power at collimator	800 W
Max. average beam current at target	10 nA
Beam size at target	100 mm × 100 mm
Beam uniformity at target	< ±10 %

As indicated by the design parameters in Table I, the beamline was inherently engineered for higher operating energies ranging from 33 to 100 MeV. Because transporting a significantly lower energy 20 MeV proton beam to TR102 represents an unprecedented operational regime at KOMAC, a thorough feasibility study was required and presented in the following subsection.

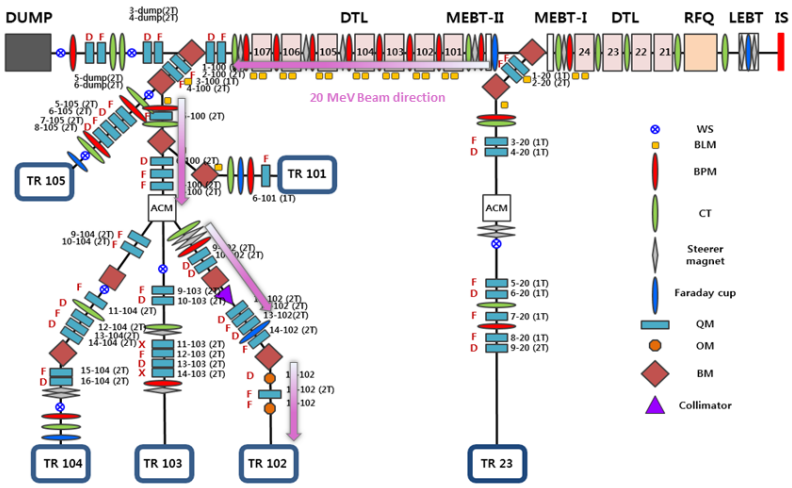


Fig. 1. Schematic of the 20 MeV proton beam transport scheme in the KOMAC linac, with pink arrows indicating specific components

2.2 Beam Transport Simulation Results

To verify the feasibility of the low energy transport scheme we conducted numerical simulation through DTL2 section in the KOMAC proton linac. In this operation configuration, RF is not applied to all the seven DTL2 tanks and quadrupole magnets in the DTs embedded in the DTL2 are re-adjusted and optimized to transport the beam. The envelope calculation is shown in Fig. 2. The simulation confirms that the 20 MeV beam can be successfully and safely transported through the entire DTL2.

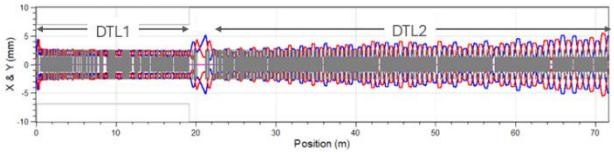
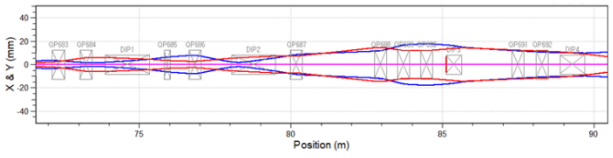
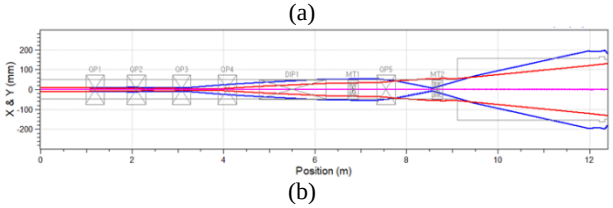


Fig. 2. The envelope calculation of 20 MeV proton beam through DTL2 without acceleration



(a)



(b)

Fig. 3. The envelope calculations of 20 MeV proton beam (a) in the upstream of the collimator and (b) in the downstream of the collimator in the BL102

Following the DTL2 section, the tracking simulation was extended to the TR102 beamline. Because passing through the high-attenuation graphite collimator drastically alters both the beam intensity and the transverse phase-space distribution, the simulation was strategically bifurcated into two distinct phases. Fig. 3(a) illustrates the calculated beam envelope in the region upstream of the collimator, where the primary 20 MeV proton beam is guided into the beamline. Fig. 3(b) displays the downstream simulation tracking the survival parameters after the collimation stage.

The collimator's 5 mm aperture scrapes the proton flux to 10^{-4} of its initial value and abruptly modifying the spatial profile. Consequently, decoupling the calculation into independent upstream and downstream segments was necessary to accurately model the localized beam loss at the collimator block and properly initialize the low-flux beam tracking toward the target.

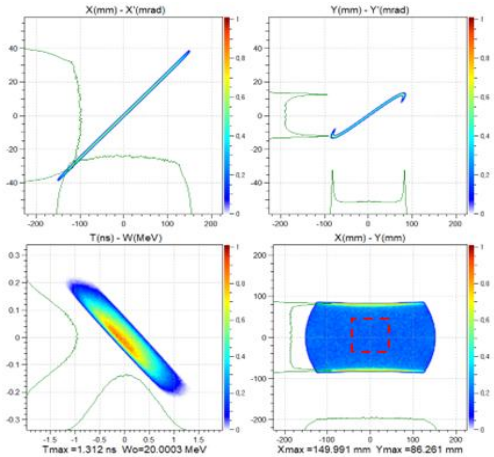


Fig. 4. The beam distribution simulated at the target position in TR102

The transverse beam phase-space distribution at the final target position in TR102, which marks the termination of the downstream tracking shown in Fig. 3(b), was evaluated and is presented in Fig. 4. The real-space transverse projection x–y beam distribution displayed in the bottom-right panel of Fig. 4 was utilized to quantify the beam uniformity. Using this

spatial particle density distribution, the beam uniformity was calculated across the target area. The simulation results confirm that the combined magnetic lattice successfully expands and flattens the beam, satisfying the required 100 mm × 100 mm exposure field with a spatial uniformity well within the design threshold of ±10% shown in Fig. 5.

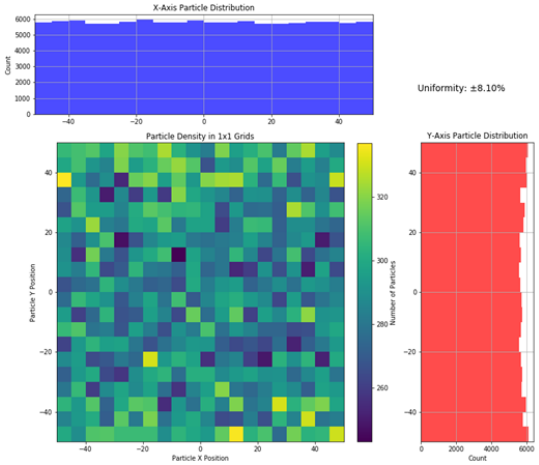


Fig. 5. The beam distribution of the new beamline at the

3. Results of 20 MeV Proton Beam Transport

The proton beam current was monitored starting from an ACCT after the DTL24 at the end of the DTL1 section as 13.35 mA. Beam energy after the DTL24 is 20 MeV. As the 20 MeV proton beam propagated through the unpowered DTL2 cavities, the current measured at DTL107 slightly dropped to 11.70 mA. corresponding to a transmission efficiency of 87.6%. We believe that this beam loss can be minimized by optimizing DT quadrupole magnet strengths. There are two ACCTs located in upstream (BL100) and downstream in the beamline (BL102). Beam currents at CTs are summarized in Table 2.

Table 2. Input beam parameter used in the simulation

ACCT position	Beam Current [mA]
DTL24 in DTL1	13.35 mA
DTL107 in DTL2	11.70 mA
BL100 in beamline	11.07 mA
BL102 in beamline	11.00 mA

4. Beam Profile Measurement Attempts and Diagnostic Limitations at TR102

Following the successful transport confirmation along the beamline, transverse beam profile measurements were attempted at the TR102 target station using a commercial two-dimensional (2D) ionization chamber (IC) array. However, initial attempts yielded no detectable beam profile. Concurrently, the upstream octupole magnets were intentionally deactivated to prevent beam widening, focusing the raw, un-broadened proton beam directly toward the target to maximize localized particle density.

Even under these highly concentrated beam conditions, the 2D IC array registered an extremely faint absorbed dose of only approximately 10^{-4} Gy (Fig. 6 and 7). This negligible response stood in stark contrast to the diagnostic nodes located upstream; for instance, the Faraday cup at the BL102 station simultaneously recorded a robust signal exceeding 9 V, confirming that a high-intensity proton flux was physically present right before entering the target room.

The Octavius 1500XDR array requires particles to penetrate at least 9.0 mm to reach the active detector center from the housing surface (7.5 mm of housing depth + 1.5 mm half of the detector thickness). However, the range of a 20 MeV proton beam is only 4.26 mm. Consequently, the incoming protons are completely stopped within the detector housing before reaching the active volume.

Numerical evaluations show that a minimum energy of 30.3 MeV is required to penetrate the window, and 33 MeV is needed to fully cross the detector. This perfectly validates the beamline's original design minimum of 33 MeV and proves that this 2D IC array cannot be utilized for direct profiling at 20 MeV.

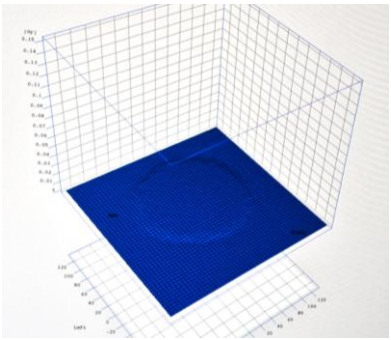


Fig. 6. Beam profile measured using the 2D IC array at TR102

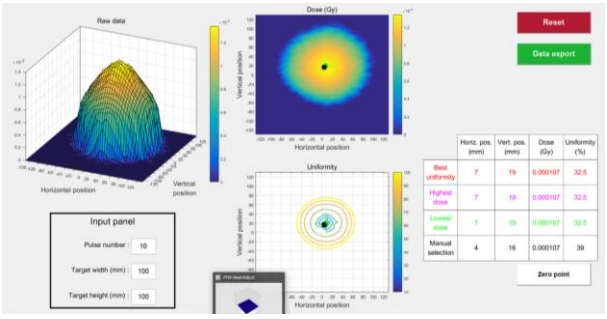


Fig. 7. Beam flux and beam uniformity analysis

5. Conclusions

A 20 MeV proton beam is essential for Displacement Damage (DD) testing in space electronics, requiring strict control over flux and irradiation uniformity (±10 %). Because KOMAC's standard 20 MeV setup

cannot meet these criteria, a novel strategy was implemented to transport the beam through the unpowered DTL2 section into the TR102 beamline. Beam dynamics simulations first verified transport feasibility and optimized magnet parameters, leading to the first successful physical beam transport to TR102. However, the existing diagnostic instrumentation failed to characterize the beam accurately due to the shallow penetration depth of 20 MeV protons. This paper presents the transport results and highlights the necessity of developing low-energy beam profiling methods.

REFERENCES

[1] Lee, S., Yoon, SP., Kim, HS. *et al.* Improvement of beam uniformity for radiation effect test on electronic devices for space applications at KOMAC. *J. Korean Phys. Soc.* **83**, 743–750 (2023). https://doi.org/10.1007/s40042-023-00915-6