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# PRELIMINARY BEAM DYNAMICS STUDIES FOR 200 MeV SUPERCONDUCTING LINAC PLANNED AT KOMAC

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## *Abstract*

Korea Multipurpose Accelerator Complex (KOMAC) is planning an energy upgrade of the existing 100 MeV proton linac to 200 MeV using a superconducting Half Wave Resonator (HWR) operating at 350 MHz. A cryomodule is planned to house four HWR cavities with warm doublet focusing lattice structure. Matching between the already existing DTL section and HWR section is designed and studied. We report the preliminary study of the beam dynamics of the 200 MeV superconducting linac carried out at KOMAC.

## INTRODUCTION

Radiation is concerned significantly for semiconductors applied with high reliability and radiation hardness. Such applications are ranging from space-based, remote terrestrial, nuclear facility and medical electronics [1]. Terrestrial applications can be affected by atmospheric neutrons. In case of space electronics, trapped particles (protons, electrons and heavy ions), solar activity and galactic cosmic rays can cause damages to semiconductor devices. Semiconductor technology is continuously advancing with the high density integration, new materials, and new device concepts. Radiation effects (single event effects, total ionizing dose and displacement damage) in a wide variety of electronic devices and circuits, and radiation hardness are required to be evaluated comprehensively. Test methods are based on guidelines in international standards of atmospheric/space radiation effect test on semiconductors such as JEDEC JESD 89A and ESA ESCC 25100. According to these two international standards, space radiation effect tests can be performed within 200 MeV proton beams. And 90% of the atmospheric neutron radiation can be realized using a proton beam of energy till 200 MeV. We concluded that a 200 MeV proton accelerator is suitable for a radiation effect test facility for semiconductors.

Korea Multipurpose Accelerator Complex (KOMAC) is currently operating a 100 MeV proton linac since 2013, and has an energy upgrade plan to 200 MeV proton linac. In this paper, we present preliminary beam dynamics studies for 200 MeV superconducting linac planned at KOMAC.

## SCHEMATICS OF THE 200 MeV LINAC AT KOMAC

### *200 MeV Proton Linac*

Current 100 MeV proton linac operating at 350 MHz consists of a microwave ion source (IS), a low energy beam transport (LEBT), a radiofrequency quadrupole (RFQ), a 20 MeV drift tube linac (DTL I), a medium beam transport (MEBT) and a 100 MeV drift tube linac (DTL II). Superconducting linac will be used to increase the beam energy from 100 to 200 MeV using a half wave resonator (HWR). It requires 9 cryomodules (CM) containing 4 HWRs operating also at 350 MHz and 2 K. To match the output beam between the DTL II and the HWR, a matching section (M) has been designed. The described 200 MeV proton linac schematic is shown in Fig. 1. We have also beamlines for transporting 20 and 100 MeV proton beams to the irradiation target rooms for various proton beam applications.

### *Half Wave Resonator*

Superconducting HWR is employed to increase the beam energy from 100 MeV to 200 MeV. Its geometry is primarily optimized using GenLinWin [2]. GenLinWin generates an analytical form of HWR field profile and transit time factor (TTF) with the given geometric beta, half DT length ($l_1$ in % of the cavity length), central DT length ($l_2$ in % of the cavity length), accelerating gradient ($E_{acc}$) and frequency. $E_{acc}$ is fixed at 7.5 MV/m to keep the

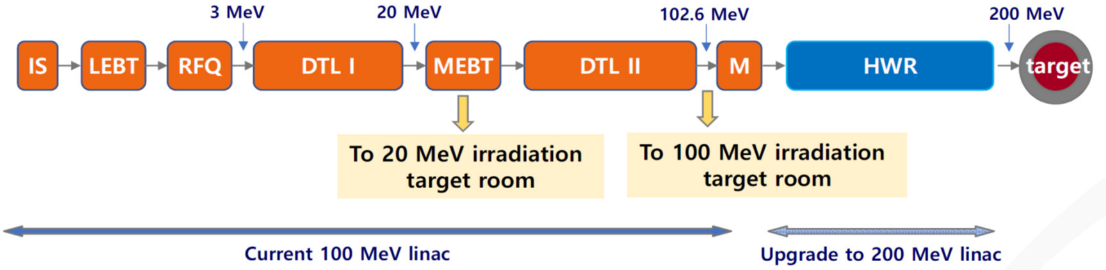

Figure 1: Layout of the 200 MeV proton linac at KOMAC: It consists of currently operational 100 MeV linac part and the half wave resonator (HWR) which is at the planning stage. Orange & blue colour: normal & super conducting.

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phase advance below 90° to avoid any structure and space-charge driven resonance and following emittance growth. Once the field profile and realistic component dimensions and spacings are given, we performed the geometrical beta optimization to obtain the shortest linac length criterion. In case of HWRs, one uses optimum beta ($\beta_o$) rather than $\beta_g$ as the beta optimum is obtained at the maximum TTF. Along with $l_1$ and $l_2$, synchronous beta ($\beta_s$) is used in describing a length between gaps. HWR geometrical parameters are shown in Fig. 2. In order to obtain the final energy ≥ 200 MeV with various combinations of $l_1$ and $l_2$, we performed the $\beta_g$ optimization to get the shorted linac length. The optimal set of geometrical parameters is summarized in Table 1.

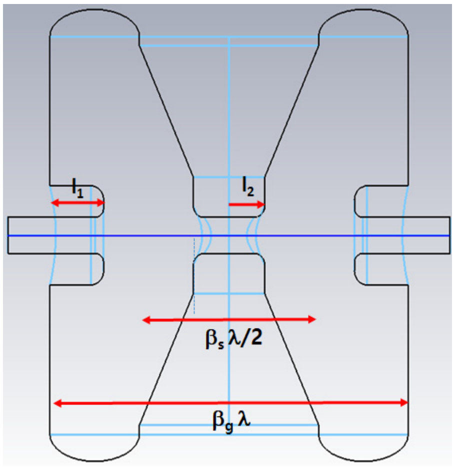

Figure 2: HWR geometrical parameters for the optimization.

Table 1: HWR Optimization Result

| | |
|---|---|
| $\beta_g$ | 0.47 |
| $\beta_s$ | 0.52 |
| $\beta_o$ | 0.56 |
| $E_{acc}$ ($V_{acc}$) | 7.5 MV/m (3.6 MV) |
| $l_1$ | 10% |
| $l_2$ | 15% |
| Number of HWRs | 36 |
| Number of CM | 9 |

Corresponding cavity field profile and the transit time factor from the optimization are plotted in Fig. 3. Further detailed studies of optimization and electromagnetic characteristics are done by CST program. It is presented in IPAC'21 [3].

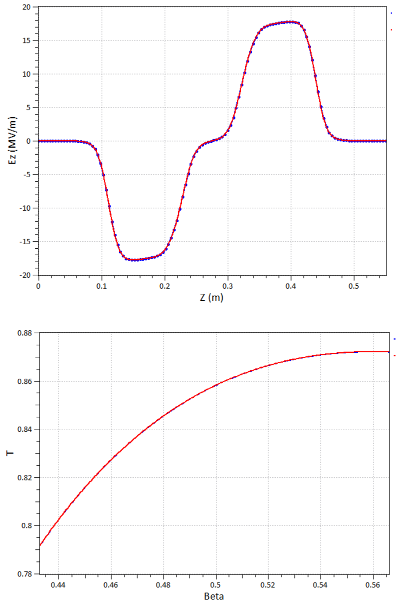

Figure 3: Optimized HWR field profile (up) and transit time factor (bottom).

## BEAM DYNAMICS CALCULATIONS

### *HWR Lattice Structure*

The HWR lattice accommodates two quadrupole magnets and a cryomodule containing 4 HWRs, which makes a doublet focusing type structure. Each HWR cavity (450 mm) is 200 mm-separated (distance between cavity centres = 650 mm). Doublet centre to centre distance is 5.01199 m with the quadrupole effective length of 200 mm as shown in Fig. 4.

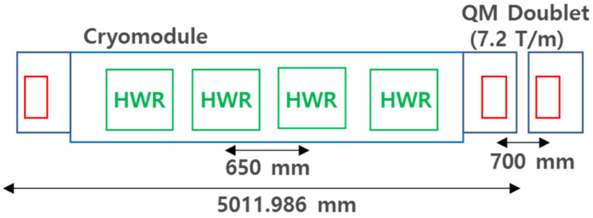

Figure 4: Layout of the HWR lattice.

The matched beam parameters (zero current) are found, and the beam envelopes in X and Y are plotted in Fig. 5.

Till the beam energy ≥ 200 MeV, 9 CMs are required. Beam distribution (zero current) at the exit of the 9th CM is also plotted in Fig. 6. Quadrupole magnet is set at 7.2 T/m for the minimum beam radius through the envelope.

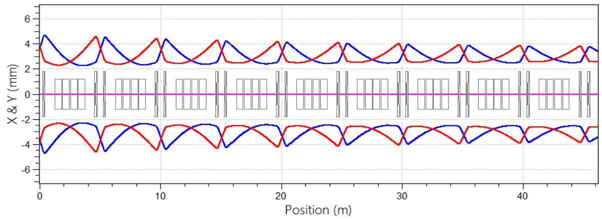

Figure 5: Envelope calculation of the HWR lattice.

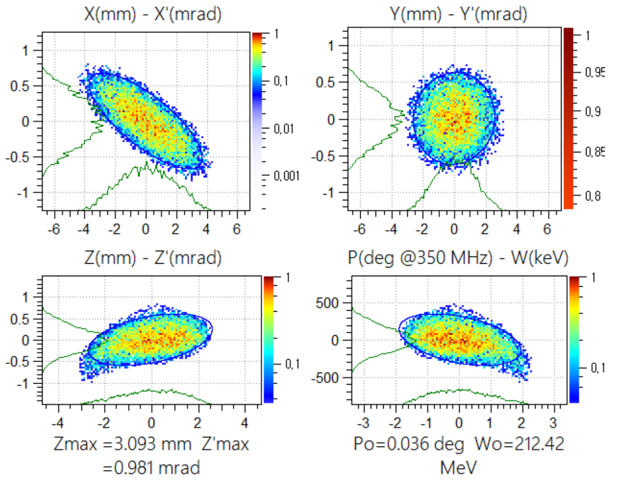

Figure 6: Beam distribution (zero current) at the exit of the 9th CM of the HWR lattice.

### *Matching Section*

To match the 100 MeV beam from the DTL II to the 1st HWR cryomodule, we designed a matching section. In the 100 MeV proton linac, we are currently giving beam services to users through the beamline extending from the linac using two quadrupole magnets and a 45° bending magnet (BM). With such constraint, the matching section is designed with two DTL type bunchers. The buncher has 4 gaps to have a reasonable gap voltage to operate. Distance between two bunchers and distance between the 2nd buncher and the 1st HWR CM are optimized to lower the gap voltage. The envelope calculations of the matching section are shown in Fig. 7.

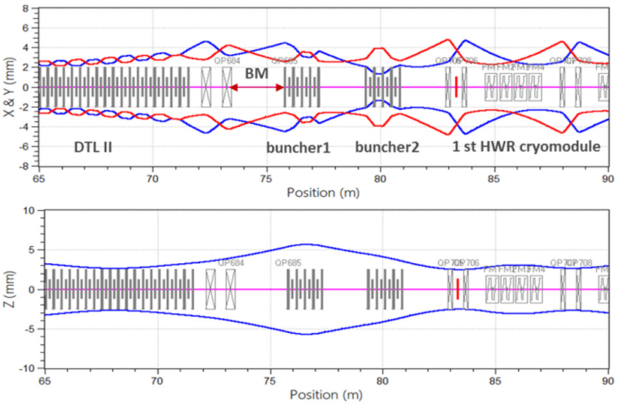

Figure 7: Envelope calculation in the matching section between the DTL II and the 1st CM of the HWR lattice.

### *Beam Dynamics Calculation Results*

Beam dynamics simulation results such as beam sizes in X, Y and Z and particle density diststribution are presented throughout the linac as shown in Fig. 8.

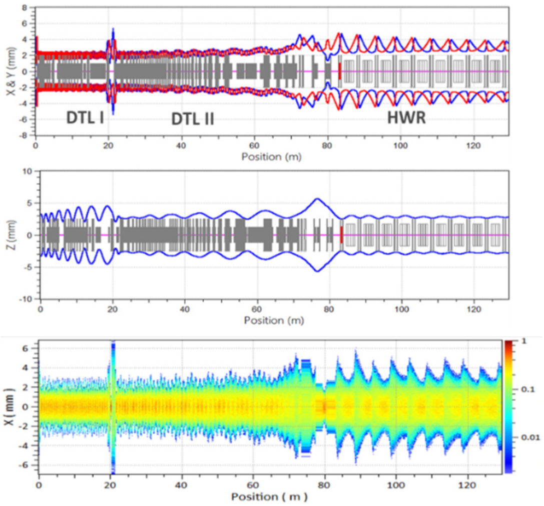

Figure 8: Envelope in X, Y and Z and the particle distribution through the linac are plotted.

The phase advance per meter is kept as smooth as possible through the linac to minimize any mismatch and to ensure a current-independent lattice structure [4-6]. Quadrupole magnets in the drift tubes in the DTL I and DTL II are adjusted to make the phase advance per meter to fall smoothly. However, the increase in the envelope of DTL I and II is unavoidable. Figure 9 is a graph of the phase advance per meter of X, Y and Z throughout the linac. The x and y phase advances per meter have smooth changes. But the z phase advance per meter, $k_{z0}$ in the DTL I is comparatively lower than that in the DTL II. This is because the entire DTL I of 4 DTL tanks is powered by a klystron only, which is our structural characteristics.

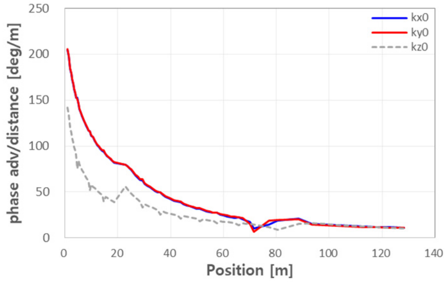

Figure 9: The phase advance per meter of the linac is plotted.

## CONCLUSION

At KOMAC, we are planning an energy upgrade of our proton linac from 100 to 200 MeV using superconducting HWRs. HWR is optimized with the geometrical parameters for the shortest linac length. HWR's doublet focusing lattics and the matching between the DTL and the HWRs are designed. We present the beam dynamics simulation results of the 200 MeV proton linac based on our design.

## ACKNOWLEDGEMENTS

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