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PLAN FOR THE KOMAC PROTON LINACP UPGRADE TO 200 MeV*

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Abstract

A 100 MeV proton linac has been operated for over 10 years at KOMAC and used for proton beam services. We are planning to upgrade the linac energy to 200 MeV. By increasing the linac beam energy, we expect the machine to be capable of serving wider application fields including space radiation tests of semiconductor devices and material tests by using high-energy neutrons generated by bombarding a proton beam to a solid target. For the energy upgrade, we consider the SDTL structure for the 200 MeV section. The structure of SDTL is relatively simple so we may reduce the risk and time of development. In addition, we can avoid complex cryogenic systems by choosing a normal conducting approach. For the beamline, two separate target rooms (one for proton, and the other for proton and neutron irradiation) are under design. Details of the planning activity for the KOMAC linac upgrade will be reported in this presentation.

INTRODUCTION

Since its commissioning in 2013, the 100 MeV high-power proton linear accelerator (linac) at the Korea Multi-purpose Accelerator Complex (KOMAC) has been employed to provide proton beam irradiation services for a broad spectrum of applications and research fields, including materials science, biomedical research, semiconductor device testing, nuclear physics, and fundamental science.

In recent years, there has been a notable increase in demand from the semiconductor industry for high energy proton and fast neutron sources, particularly for evaluating soft error rates (SER) and single event effects (SEE) in semiconductor components. Currently, KOMAC provides pilot-scale irradiation services utilizing pulsed white-spectrum neutrons (with maximum energies up to ~100 MeV), which are produced at a copper beam dump, as well as 100-MeV proton beam. However, to satisfy international testing standards such as ISO 26262-11:2018, JEDEC/JESD89B, IEC62396-1 and AEC-Q100 for terrestrial radiation test and JEDEC/JESD234 and ESCC/No. 25100 for space radiation test, proton and neutron energies exceeding 200 MeV are required.

To address this need, a preliminary design study has been undertaken for upgrading the linac energy to 200 MeV. The study encompasses the conceptual design of a separated type drift tube linac (SDTL) based on normal conducting RF technology, beam transport line including matching section between 100 MeV DTL and 200 MeV SDTL as well as two target rooms to support advanced irradiation capabilities and beam service. The overall layout of the linac energy upgrade is shown in Fig. 1.

In previous study, we reported linac energy upgrade scheme based on half-wave resonator (HWR) adopting SRF technology [1]. In this study, we focused on the alternative upgrade pathway based on normal conducting SDTL. With this accelerating structure, we can take advantage of the experience and knowledge gained during the 100 MeV linac development and reduce the development risk coming from a low-beta SRF cavity development and cryogenic system complexity.

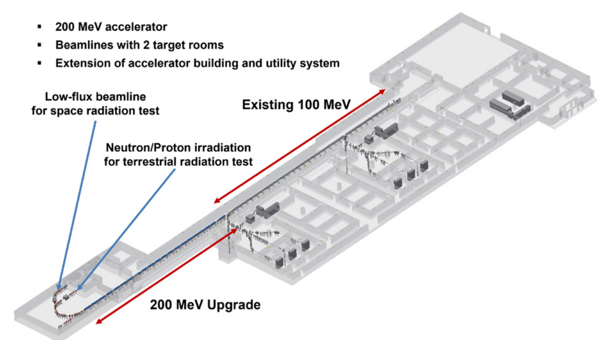

Figure 1: Overall layout of 200 MeV linac upgrade.

LINAC UPGRADE STUDY

We performed design study for linac energy upgrade including basic beam dynamics study, SDTL structure design with accelerating structure optimization, and beam transport line for guiding accelerated proton beam to beam service target room area.

Beam Dynamics Study

The basic beam dynamics study was performed by using TraceWin code. Focusing lattice is based on quadrupole doublet located between SDTL tanks as shown in Fig. 2, where distance between two tanks was $2\beta\lambda$. The quadrupole strength for matched beam condition was 32 T/m, which resulted in zero current phase advance less than 90.

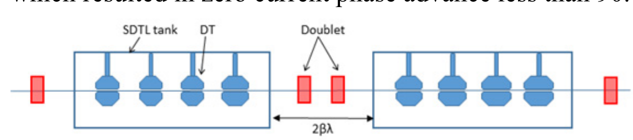

Figure 2: SDTL doublet structure.

The structure configuration comprising 5 accelerating cells and 4 drift tubes (DTs) per SDTL tank was adopted. A total of 20 tanks are required to reach an energy of 200 MeV. The individual tank lengths range from 187 cm to 242 cm. The total RF power required per tank is in the range of 680 kW to 930 kW for a beam current of 20 mA, and 775 kW to 1030 kW for a beam current of 40 mA. The

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overall length of the SDTL section is 60.7 meters. Figure 3 shows the variation of the effective shunt impedance from 3 MeV (after RFQ) to 200 MeV. The beam envelops and beam distribution is shown in Fig. 4 and the input and output beam parameters of SDTL is summarized in Table 1.

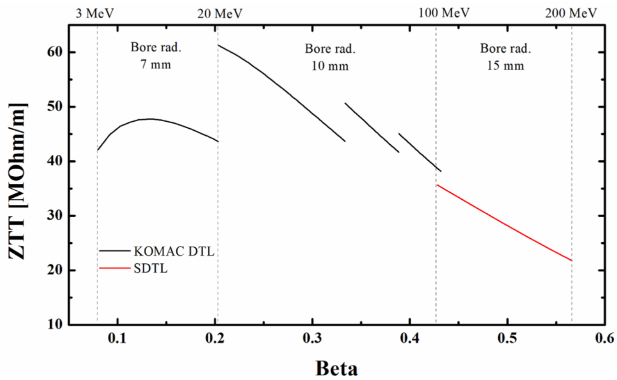

Figure 3: Effective shunt impedance (3 MeV to 200 MeV).

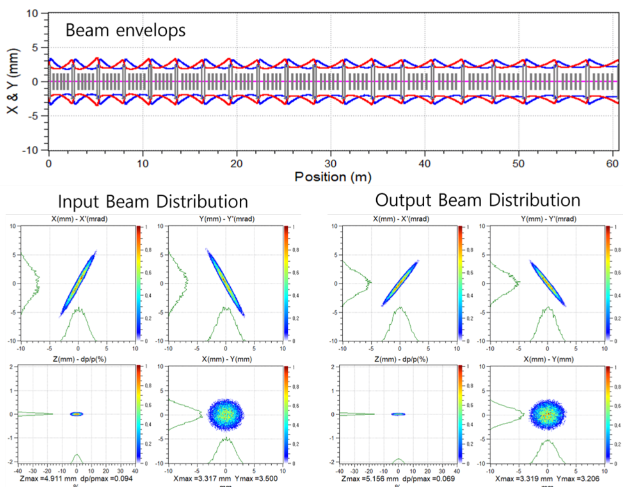

Figure 4: Beam envelops and beam distributions.

Table 1: Beam Parameters at Input and Output of SDTL

Inlet	ε norm. rms [π mm mrad]	α	β [mm/π mrad]
x	0.224	-5.609	3.180
y	0.226	6.103	3.470
z	0.295	-0.002	5.312
Outlet	**ε norm. rms [π mm mrad]**	**α**	**β [mm/π mrad]**
x	0.225	-5.762	4.721
y	0.227	5.432	4.428
z	0.302	-0.014	9.554

SDTL Tank Design

We performed design study of SDTL guided by following criteria [2].

- Number of accelerating cells: 5
- Maximize the effective shunt impedance
- Kilpatrick less than 1.5
- Peak RF power per tank less than 1.2 MW

We optimized the tank diameter and drift tube geometric parameters to maximize the effective shunt impedance and minimize the Kilpatrick by using SUPERFISH code. To reduce the beam loss, we enlarged the drift tube bore diameter from 20 mm (for 100 MeV DTL) to 30 mm. The accelerating field gradient (E0) of 3.8 MV/m was chosen considering Kilpatrick and acceleration efficiency.

For baseline design purpose, we set the number of cell per tank and the synchronous phase as 5 and 30°, respectively. In this case, total 20 SDTL tanks were required to achieve 200 MeV proton beam. As an alternative design, if we chose 6-cell SDTL structure with 28° synchronous phase, only 16 SDTL tanks are enough to achieve 200 MeV proton beam. In 6-cell case, the peak RF power per tank was still below 1.2 MW but with reduced RF control margin. The designed SDTL tank and cell parameters were summarized in Table 2. Figure 5 shows the designed first two SDTL tanks with a quadrupole doublet. The required peak RF power is shown in Fig. 6.

Table 2: Tank and Optimized Cell Design Parameters

Parameters	Values
Frequency [MHz]	350
Number of cells per tank	5
Energy range [MeV]	102.6~200
Max. Kilpatrick	1.4
Accelerating gradient [MV/m]	3.8
Tank diameter [mm]	475
Tank length [mm]	1870~2420
Total length [m]	60.7
Drift tube diameter [mm]	140
Face angle [°]	70
Outer nose radius [mm]	18
Inner nose radius [mm]	45
Flat length [mm]	1
Corner radius [mm]	1
Bore radius [mm]	15
Stem diameter [mm]	36

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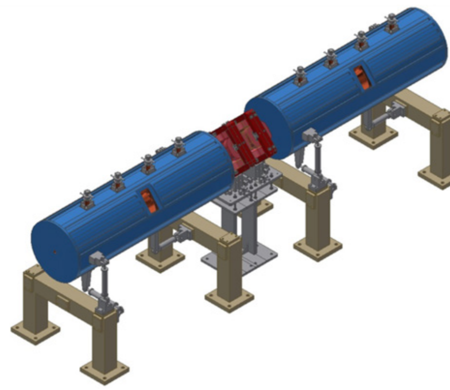

Figure 5: First two SDTL tanks with a quadrupole doublet.

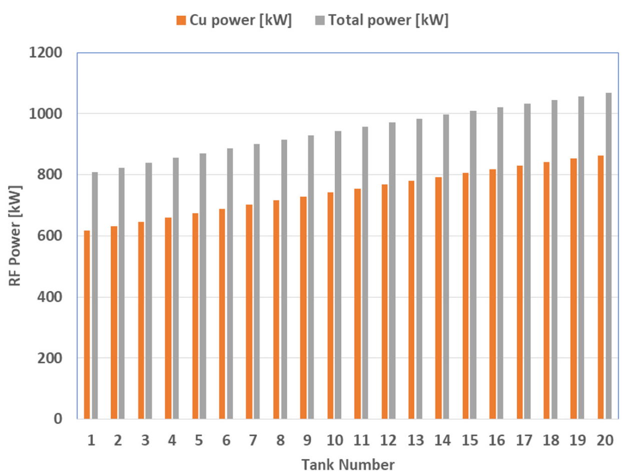

Figure 6: Peak RF power for each SDTL tanks.

Beam Transport and Target Room

We are planning to construct two target rooms; one is a low-flux target room with reduced intensity proton beam for space radiation test and the other is proton/neutron irradiation target room for the terrestrial radiation test for semiconductors and electronic equipment. The layout of beam transport and target room is shown in Fig. 7.

The low-flux target room can be used as well for bio and medical applications, where the low intensity (as low as ~10^6 p/cm^{2}s) beam with exact irradiation dose control is crucial. To make unform beam as large as 200 mm by 200 mm in area, two octupole magnets will be used. Preliminary nonlinear optics calculation with octupole magnets shows that we can make square beam profile with uniformity better than 10% in 150 mm by 150 mm area.

For the proton/neutron irradiation target room, we have plan to install movable neutron generation target, made of tungsten or aluminium. Preliminary neutronics calculation was performed and the angular distribution along with neutron yields is shown in Fig. 8.

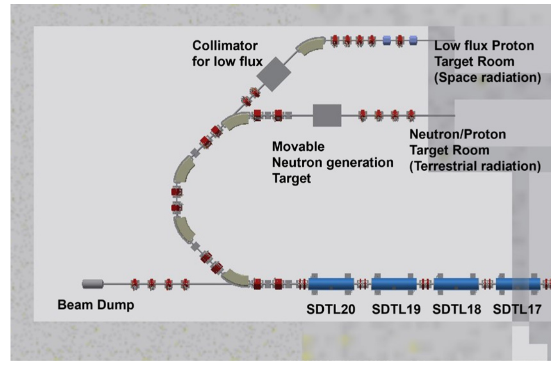

Figure 7: Beam transport and target rooms.

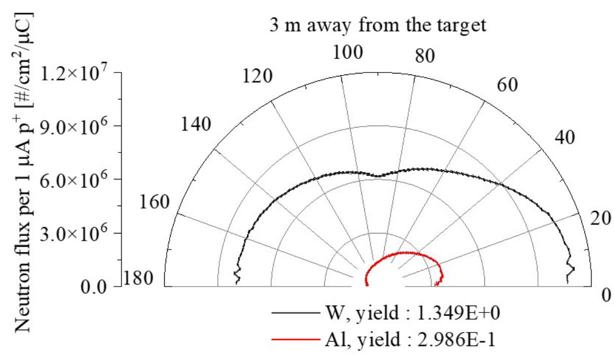

Figure 8: Angular distribution of neutron.

SUMMARY

To broaden the application scope of the high-power proton linear accelerator at KOMAC, an upgrade plan has been initiated to increase the beam energy to 200 MeV. As part of the linac upgrade, a comprehensive design study was conducted, encompassing preliminary beam dynamics simulations and structural optimization of the SDTL. The results indicate that it is feasible to accelerate the proton beam from 100 MeV to 200 MeV using 20 SDTL tanks, each consisting of five accelerating cells. The proposed linac upgrade is expected to significantly extend its utility across a wide range of disciplines, including fundamental science, biomedical research, space technology, and the semiconductor industry.

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