ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB049

DESIGN STUDY ON THE SUPERCONDUCTING HWR FOR SECONDARY PARTICLE GENERATION AT KOMAC*

Han-Sung Kim†, Hyeok-Jung Kwon, Seung-Hyun Lee, Jeong-Jeung Dang, Hae-Seong Jeong, Yong-Sub Cho, Korea Multi-purpose Accelerator Complex of KAERI, Gyeongju, Korea

Abstract

A 100-MeV proton linac has been operated since 2013 at KOMAC (Korea Multi-purpose Accelerator Complex) and provides the accelerated proton beam to various users from the research institutes, universities and industries. To expand the utilization fields of the accelerator, we have a plan to develop a secondary particle utilization facility including a pulsed neutron source and radio-isotope beam based on the 100-MeV linac. According to the preliminary analysis, the neutron yields can be increased by about 2.5 times if the incident proton beam energy increases from 100 MeV to 160 MeV. Therefore, we carried out design study on the SRF linac based on half-wave resonator to increase the proton beam energy. Baseline design parameters include 350 MHz operating frequency, 2 K operation temperature, and peak electric field and magnetic field less than 35 MV/m and 70 mT, respectively. The available space at existing accelerator tunnel was also taken into consideration. Details on the design study on the SRF linac based on HWR cavity for the secondary particle utilization facility at KOMAC will be given in this presentation.

INTRODUCTION

A 100-MeV proton linac at KOMAC is being used for various application fields including bio/medical research, material test, basic science and space technology [1]. The utilization of the l00-MeV linac, however, is limited mainly to the direct proton beam irradiation on various specimen. It is well-known that energetic proton beam on target can be used to generate secondary particles.

Secondary particle utilization facility based on 100-MeV proton linac is under consideration at KOMAC. Currently, a pulsed neutron for neutron science and application and Li-8 beam for beta-NMR application are good candidates for such facility as shown in Fig. 1.

In addition, slight energy upgrade from 100 MeV can improve the yield of the secondary particle generation greatly. For example, pulsed neutron yield is more than doubled if the proton beam energy is increased to 160 MeV. The technology of choice for beam energy upgrade is SRF (Superconducting Radio-Frequency). The existing accelerator tunnel has room for linac extension up to roughly 180 MeV based on 350 MHz superconducting accelerator.

Several types of SRF cavity structure are currently used for acceleration of the low-beta proton beam such as quarter-wave resonator (QWR), half-wave resonator (HWR), spoke cavity, and so on. For example, two-gap spoke structure is chosen as a baseline design for European Spallation Source (ESS). Though spoke structure has some advantages over HWR and intensive study has been given to that structure, there is no operating accelerator based on spoke structure mainly due to its technological difficulty. In this study, we chose HWR structure as shown in Fig. 2 and performed preliminary design study on the HWR suitable for accelerating proton beam from 100 MeV to 180 MeV. Once the proton energy is increased up to about 180 MeV, a well-developed elliptical structures can be used thereafter.

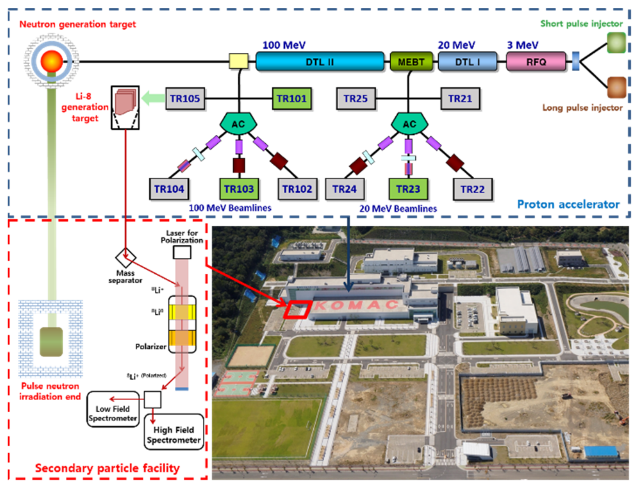

Figure 1: Layout of secondary particle facility.

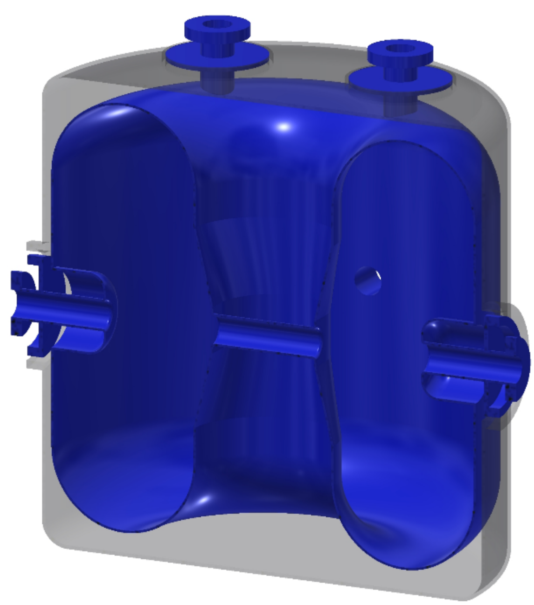

Figure 2: 350 MHz Superconducting half wave resonator for KOMAC proton linac.

* Work supported by KOMAC operation fund of KAERI by MSIP
† kimhs@kaeri.re.kr

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB049

OPTIMUM BETA AND TTF

To design a superconducting HWR for low-beta proton beam, first we have to determine the optimum beta or geometric beta considering the velocity range of the HWR, because the critical dimensions of the HWR and the energy gain heavily depend on the choice of beta.

To determine the optimum geometric beta, we performed a parametric sweep on various beta value and compared the transit time factor and energy gain per cavity as shown in Fig. 3 and Fig. 4. Based on the sweep result, the geometric beta was fixed as 0.58. With this value, we can estimate the output energy of the accelerating cavity. Considering the available space at the end of existing accelerator tunnel, we determined to put 28 cavities, through which the proton beam can be accelerated up to 180 MeV if we assume the E_{acc} of 7.2 MV/m.

Required RF power per cavity ignoring the cavity loss is about 49 kW for 1st cavity and 62 kW for 28th cavity. Because the estimation of the RF power is based on 20 mA peak beam current and the optimum coupling case, RF system should be designed with a lot of margin to be on safe side.

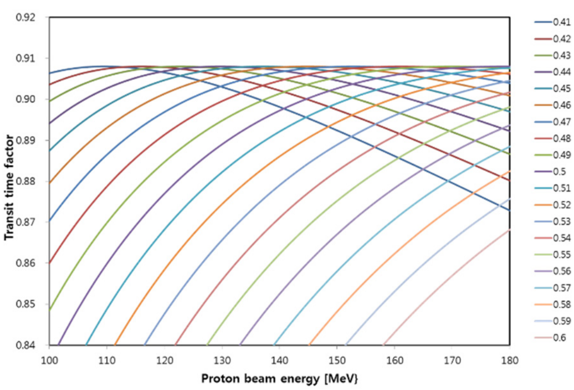

Figure 3: Transit time factor sweep results.

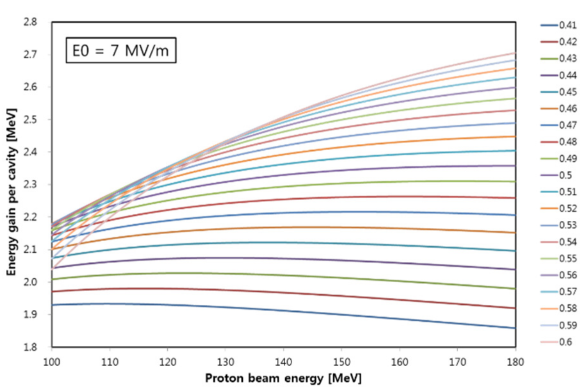

Figure 4: Energy gain per cavity.

ELECTROMAGNETIC ANALYSIS

Preliminary design of the HWR cavity is shown in Fig. 2. The outer diameter and the height of the cavity is about 460 mm and 440 mm, respectively. One of design goals is to reduce the peak field as low as possible. We set the maximum electric field less than 35 MV/m and maximum magnetic field less than 70 mT [2]. According to the CST Microwave Studio simulation as shown in Fig. 5, the peak electric field and the peak magnetic field was 30.25 MV/m and 64.4 mT, respectively. The operating temperature is going to be 2.0 K and the BCS resistance at 2.0 K is about 1 nΩ. If we reduce the surrounding magnetic field as low as 15 mG by using magnetic shield, then the resistance due to magnetic field is estimated about 3 nΩ. Design value of total surface resistance is 20 nΩ assuming conservative residual resistance of 16 nΩ. With 20 nΩ surface resistance, the unloaded Q is estimated to be about 6.19E+09. The main design parameters are summarized in Table 1.

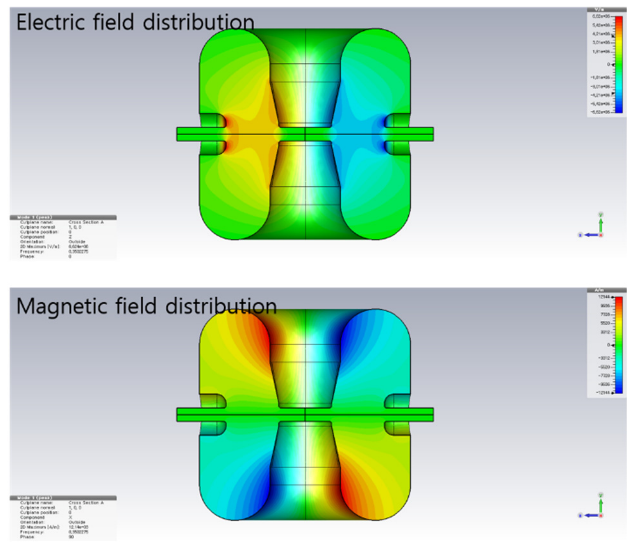

Figure 5: CST MWS results for HWR cavity.

Table 1: Summary of EM Analysis

Parameter	Unit	Value
Frequency	MHz	350.0
Optimum beta	-	0.64
Geometric beta	-	0.58
Stored energy	J	17.728
Vacc @ β_{opt}	MV	3.336
Eacc	MV/m	7.212
E0	MV/m	8.200
Ep	MV/m	30.252
Bp	mT	64.392
Ep/Eacc	-	4.195
Bp/Eacc	mT/(MV/m)	8.928
R/Q @β_{opt}	ohm	285.2
G @ 20 nΩ	ohm	123.8
Q_0 @ 20 nΩ	-	6.19E+09
Loss @ 20 nΩ	W	6.38
Aperture	mm	35
L_{eff}	m	0.4625

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB049

MECHANICAL ANALYSIS

By using a sensitivity analysis feature in the eigen mode solver in CST MWS, we performed a Lorentz detuning analysis based on the procedure shown in Fig. 6. First, radiation pressure load is extracted from electric field and magnetic field calculated in unperturbed cavity as shown in Fig. 7, then through structure solver in CST MPhysics, displacement data due to radiation pressure are obtained as shown in Fig. 8. For the material properties of niobium at 2 K, we used 110.9 GPa for Young's modulus and 0.393 for Poisson's ratio. Re-running the eigen mode solver with displacement data as a sensitivity parameter calculate the resonant frequency shift by using a perturbation analysis. When the cavity wall thickness is 2.5 mm, the Lorentz detuning coefficient was estimated to be about 2.2 $Hz/(MV/m)^2$. This result may be varied depending on boundary conditions used in structural analysis. Therefore, the actual value should be determined through experiments.

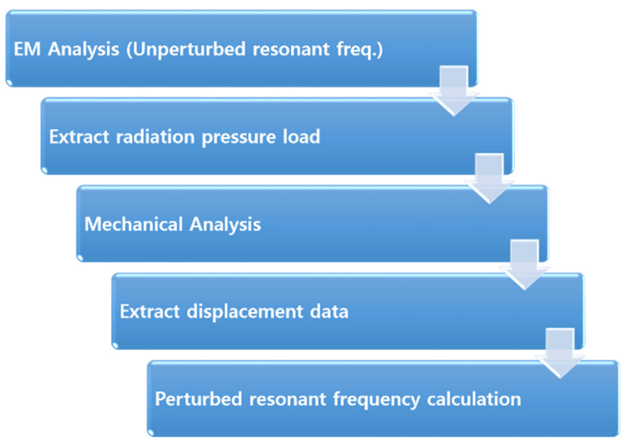

Figure 6: Lorentz force detuning analysis procedure.

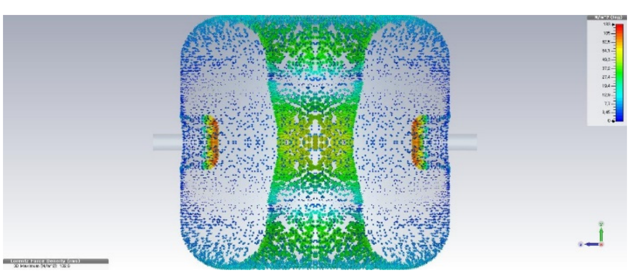

Figure 7: Radiation pressure distribution.

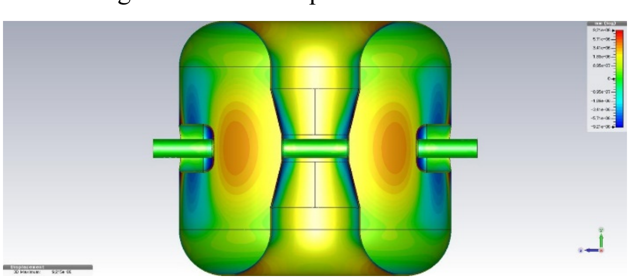

Figure 8: Displacement due to radiation pressure.

Through similar procedure, the frequency sensitivity on helium pressure fluctuation was obtained and it turned out to be about 5.13 Hz/torr.

RF POWER ISSUES

Estimated maximum peak beam power is about 62 kW. If 100 % of RF power margin considering transmission loss and feedback control, peak RF power of 120 kW is required. This RF power is not too demanding for modern solid state amplifier. By using solid state amplifier, we can avoid a vacuum tube or a klystron and high voltage power supply. Basically same type of digital low-level RF system for existing 100-MeV machine can be used for SRF cavity.

Figure 9 shows the required RF power as a function of cavity detuning. Even though the optimum external Q is about 6.37E+05, we may increase the band-width of the cavity by choosing lower external Q at the cost of increased RF power. If the external Q is set to be about 3.50E+05, large detuning up to ±450 Hz can be covered with 100 kW RF power source. In addition, exact tuning of external Q is not necessary because RF power requirement is rather insensitive to external Q with given detuning frequency range. In that case, we may use fixed type RF coupler and can avoid troubles due to adopting an adjustable tuner.

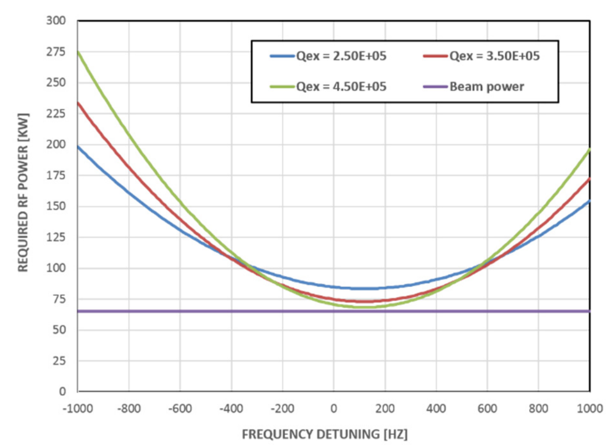

Figure 9: Required RF power as a function of detuning.

SUMMARY

For the secondary particle utilization facility at KOMAC, HWR based SRF linac is under consideration. Preliminary design and several analysis such as field distribution, Lorentz detuning and RF power requirement were carried out. For the next step, detailed engineering design work and prototyping are planned. We think that it is possible to accelerate the proton beam from 100 MeV to 180 MeV by using 28 HWR cavities and these additional accelerating section can be fitted into the existing linac tunnel at KOMAC.

REFERENCES

[1] Y. S. Cho, "Operation Experience at KOMAC", in *Proc. 57th ICFA High-Brightness Hadron Beams (HB2016)*, Malmo, Sweden, July 2015, paper THAM2X01, pp. 468-473.

[2] P. N. Ostroumov, Z. A. Conway, R. L. Fischer, S. M. Gerbick, M. P. Kelly, and A. A. Kolomiets, "Beta=0.285 Half-Wave Resonator for FRIB", in *Proc. SRF'11*, Chicago, USA, July 2011, paper MOP057, pp. 132-134.