DESIGN OF THE SUPERCONDUCTING LINAC FOR KOMAC

S.H.Kim, Y.H.Kim, H.S.Kim, K.O.Lee and K.H.Chung
Department of Nuclear Engineering, Seoul National University, Seoul 151-742, Korea

Abstract

KOMAC (KOrea Multi-purpose Accelerator Complex) is the 1 GeV, 20 mA proton linac. The superconducting linac for the high energy part acceleration from 100 MeV to 1 GeV is selected as a main candidate. As is well known, the superconducting linac has advantages for high current, high energy acceleration such as a large bore size, short accelerator length, and the RF efficiency. In this energy range, the velocity of proton increases from β=0.43 to β=0.87. For the design and fabrication simplicity, the cavity β stages are divided into 3 parts. The maximum electric field in the cavity is designed below 20 MV/m. To determine the cavity parameters, the electromagnetic and mechanical analyses are performed with 2D & 3D FEM codes. And the plans for the fabrications and tests of the superconducting cavities are also reported.

1 INTRODUCTION

The purposes of KOMAC (KOrea Multi-purpose Accelerator Complex) are energy amplification, medical application, and basic science research such as physics, biology, chemistry, material etc. Among these applications, the energy amplification using the fertile material is the main issue. It is well known that the efficiency of the neutron yield around the proton energy 1~1.5 GeV is maximum. The current of 20 mA is chosen so that it may provide the neutrons for the commercial size k~0.95 sub-critical reactor.

KOMAC is composed of normal conducting accelerating section that accelerates proton beam to energy of 100 MeV and superconducting (SC) linac.

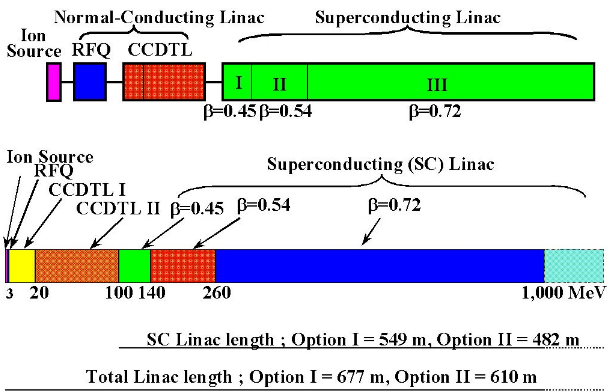

Figure: 1 KOMAC accelerator schematics (up), KOMAC scaled length (down)

Figure 1 is the schematics of KOMAC accelerator. The superconducting linac is selected as a main candidate for the high energy part acceleration. The superconducting linac for high energy acceleration has many advantages such as saving the operation cost, reducing the beam loss, and shortening the linac length that result in the saving the area. Of course acceleration around the energy of 100~200 MeV have no particular advantage compared with normal conducting coupled cavity linac. But in KOMAC, whole high energy acceleration from the end of CCDTL (Coupled-Cavity Drift Tube Linac) is designed with superconducting linac for the machine simplicity. The SC linac is divided into three beta regions for design and fabrication simplicity. The geometric betas of each section are 0.45, 0.54, 0.72. In this paper the design concept, design guideline for main components, cavity specifications and R&D plan for the cavity development are introduced.

2 DESIGN GUIDE

Generally the beam dynamics in the transition region is complex due to the difference of periodic condition. To minimize this effect focusing periodic condition is designed to be same along the whole SC linac, i.e. the same transverse beam dynamics periodicity (figure 2). Concerning the lattice, the doublet is selected, which is located outside of the cryostat. FODO lattice is excluded due to the stray magnetic field problem that can degrade the performance of SC cavities.

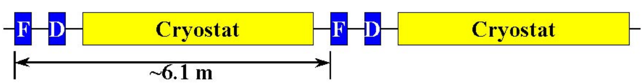

Figure: 2 Focusing period of KOMAC SC linac; same for all three beta regions

For hand-on maintenance, the beam loss must be limited to the certain level [1]. Especially in the high power above 100 MeV proton accelerator, the relative losses ($\Delta I/I$) should be kept below in the range ~10^{-8}/m to 10^{-9}/m. In KOMAC SC linac, the design value of beam loss is below 0.05 nA/m at 1 GeV.

3 CAVITY DESIGN

Superconducting multi-cell cavities in a π mode operation is designed with SUPERFISH code. The number of cavities per cryostat is four for all beta regions. To satisfy the above mentioned periodic condition the number of cells per cavity for each beta are 6, 5, 4 respectively.

Table 1 shows the major parameters of the KOMAC SC linac.

Table 1. Major Specification of the KOMAC SC linac

Beta	0.45		0.54		0.72	
	case I	case II	case I	case II	case I	Case II
No. of Cavities	16	20	48	48	296	248
No. of Cryostats	4	5	12	12	74	62
RF Power Input	50	40	50	50	50	60
Length (m)	24.4	36.6	73.2	73.2	451.4	372.1
Energy (MeV)	100~140		140~260		260~1,000	
Structure	6cells/cavity		5cells/cavity		4cells/cavity	
No. of Klystrons	1 (x 1MW)		3 (x 1MW)		19 (x 1MW)	
Focusing	Quadrupole doublet (period; 6.1 m)					
Sync. Phase	-30 degree					
Operating Temp (K)	2 K					

Case I : E_0T=5MV/m for all beta regions
Case II; E_0T=4MV/m for beta=0.45,
E_0T=5MV/m for beta=0.54
E_0T=6MV/m for beta=0.72

The major design guidelines of SC cavities are summarized below.

- minimize the use of stiffener
- raise the lowest mechanical resonance frequency; >60Hz
- 10 Hz tuning sensitivity
- Inside or outside welding can be possible

To accomplish the above requirements the cavity shapes are optimized with thick Nb sheet (3.5~4 t), Ti helium vessel, increasing the wall slope. Figure 3 is the cavity shapes for each beta regions and Table 2 shows the major cavity parameters.

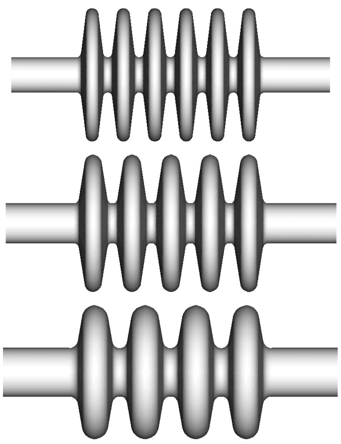

Figure : 3 The optimized cavity shapes for each beta

Table 2. Parameters of KOMAC SC cavities (Case II)

Beta		0.45	0.54	0.72
Energy (MeV)		100~140	140~260	260~1,000
Aperture Dia. (cm)		10	11	14
Cavity Dia. (cm)		40	40	40
Wall slope (degree)		7	9	10
Corner Radius (cm)	Mid	1.64	2.22	3.79
	End	1.51	2.03	3.31
Cell length (cm)		9.64	11.56	15.42
Unloaded Q		6.7e9	8.4e9	1.1e10
ZTT (ohm/m)		1.2e12	1.9e12	3.3e12
Eacc (MV/m)		4	5	6
Ep/Eacc		3.52	3.05	2.54
Hp/Eacc (A/MV)		7411	6289	5434
RF loss/cavity (W) At Rres=10nohm		7.89	7.54	6.76

4 OTHER DESIGN ASPECTS

3.1 Mechanical Analysis

The external pressure and the effect of Lorentz force etc. which result in cavity deformation are considered as frequency shift sources. The considered mechanical tuning range is +/- 1 mm, it corresponds to ~300 kHz, so the allowable deformation due to the external pressure is set ~0.1 mm. And the cavities are designed that max. stresses on the cavity wall are below 40 MPa. The natural mechanical resonance vibration is considered also. The lowest mechanical resonance frequency should be kept above 60 Hz. Table 3 shows the results of FEM analysis.

Table 3. Mechanical properties of KOMAC SC cavities

		Beta=0.45		Beta=0.72	
		Unstiff.	Stiff.	Unstiff.	Stiff.
Max. stress (2bar) (von Mises) MPa		79.3	23.8	37.0	17.3
Max. Deformation (2 bar) mm		0.39	0.06	0.15	0.03
Lowest Res. Freq. (Hz)	Long	56.4	85.8	128.8	186.4
	Trans	18.2	30.1	65.2	141.6

The transverse vibrational resonance frequency of the beta=0.45 cavity is below 60 Hz. Further study is required. It is expected that the change of the stiffener configuration and Ti He vessel structure can enhance the performance.

3.2 Thermal Load

The required cryogenic capacity is estimated from the thermal analysis. The cavity wall losses are analyzed from the SUPERFISH result. In SUPERFISH cavity wall loss is calculated from the Piel semi-empirical formula [2]. The static losses are calculated from the CERN data. Table 4 is the results of thermal load analysis. The required cryogenic capacity is about 8 kW at 2 K with ~30 % margin.

Table 5. Thermal load of KOMAC SC linac

	Beta=0.45	Beta=0.54	Beta=0.72
RF loss*	189.4 W	362 W	1,650 W
Static loss	190 W	330 W	1,580 W
Sub-total loss	379.4 W	692 W	3,230 W
Total cavity loss	4.3 kW		
Transfer loss	1.2 kW		
Total loss	5.5 kW		

* Rres= 10 nano-ohm

3.2 Input Coupler

The maximum required rating of input coupler for KOMAC SC linac is about 60 kW. This power level is achieved in the operating SC accelerators in the several facilities. Since the operating frequency is relatively high, there's no the multipacting problem. In KOMAC dual window is adopted for low thermal leak and easy maintenance (figure 4).

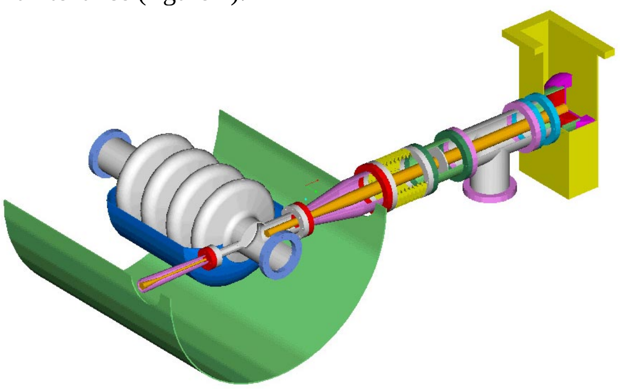

Figure : 4 Conceptual layout of KOMAC input coupler

3.3 Magnetic and Thermal Shielding

In case of Nb SC cavity, it was revealed that the 100 % magnetic flux is trapped in the field smaller than 3 Gauss. This trapped magnetic flux degrades the performance of SC cavity. The TESLA criterion is adopted [3]. The max. allowable remanent magnetic flux density is below 20 mGauss. The shielding scheme is hybrid type that uses a high permeability material and Helmholtz coil. Figure 5 show the concept of magnetic and thermal shielding.

5 R&D PLAN

For the development of SC cavity, KOMAC program has a plan of proto-type module like below.

- one single-cell Cu cavity for each beta
- three single-cell Nb cavity for each beta
- one multi-cell Cu cavity for each beta
- three multi-cell Nb cavities for each beta
- complete components for the test of SC cavity.

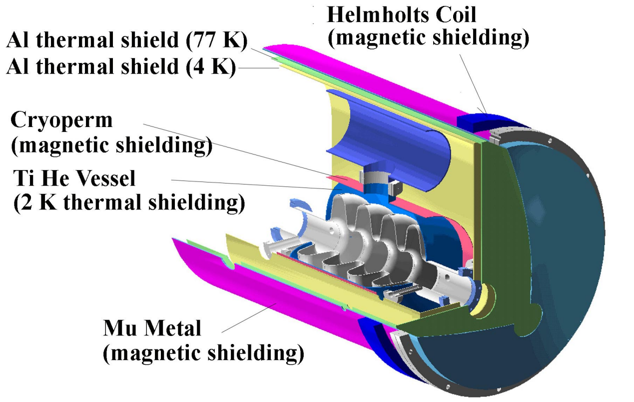

Figure : 5 Conceptual layout of magnetic and thermal shielding

For development of the SC cavity, the on-line facility like below layout (figure 6) is to be built. The cryogenic facility, power supply, machining shop, and other miscellaneous facilities are to be built outside of KOMAC SC cavity R&D facility (KSCF).

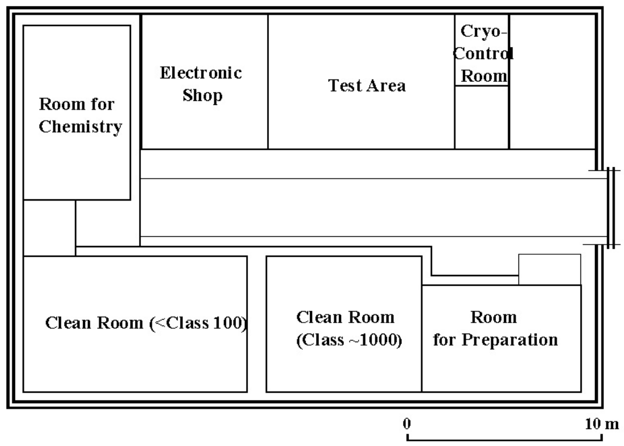

Figure : 6 Layout of KOMAC SC cavity R&D facility

6 CONCLUSION

Preliminary design of the KOMAC SC linac is done. The design guidelines and requirements of the major components are set. And the R&D activity plan for the development of SC cavity is introduced.

7 REFERENCES

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