DESIGN OF THE PEFP LOW BETA CRYOMODULE*

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Abstract

A low beta elliptical superconducting RF cavity has been designed for the linac of Proton Engineering Frontier Project (PEFP). A double stiffening-ring structure is used to reduce Lorentz force detuning of the low beta cavity. Higher order mode (HOM) analysis has shown, for the low beta cavities, the HOM coupler's Q_{ext} needs to be lower than 3×10^5 for reducing the influence of the dangerous modes on the beam instabilities and HOM-induced power. A coaxial coupler is designed for PEFP cryomodules. The cooling system and the magnetic shielding structures shaped by two coaxial cylinders for the low beta cryomodules are described.

INTRODUCTION

Superconducting RF (SRF) cavity is considered to accelerate a proton beam with repetition rate of 60 Hz at 700 MHz in the PEFP Linac being built at Gyeongju in Korea [1, 2]. The first section of the SRF linac is composed of the low beta cryomodules with three 5-cell elliptical cavities of β_g=0.42, and will accelerate a proton beam from 80 MeV to 178.6 MeV [3].

Generally, the low beta cavities have stronger Lorentz force detuning than the high beta cavities. For pulse SRF accelerators, the Lorentz force detuning is a more serious issue than that for CW accelerators. The PEFP low beta SRF cavity is the lowest beta elliptical cavity operating at pulse mode so far. The Lorentz force detuning control of the PEFP low beta cavity is a big challenge in the cavity design [4].

Although the TTF HOM coupler has been used on many cavities successfully, there are two faults: notch frequency shift and feed-through tip melting of the capacitive coupling, which have been found during SNS cavity VTA, cryomodule testing at JLab and the SNS commissioning at ORNL. In order to satisfy PEFP HOM damping requirements, easily control the notch frequency shift and avoid the feed-through tip melting, a new HOM coupler is needed to design.

In this paper, the low beta cavity design, the HOM analysis of the PEFP low beta linac, the HOM coupler design, the cooling system and magnetic shielding of the PEFP low beta cryomodule have been introduced.

RF CAVITY DESIGN

Cavity design

Considering the cavity field sensitivity and the cavity production difficulty, we chose 5 as the PEFP low beta cavity's cell number, 6 degree as the wall angle α of internal cell, and 4220 as the field sensitivity that corresponds to the cell-to-cell coupling factor of 1.41%.

Based on the present SRF technology at KAERI, our choice was a reduction in the ratio of E_{pk}/E_{acc}, and a realization of the higher *R/Q* in the PEFP low beta cavity optimization.

After optimization design of the cavity shape in RF properties, a multipacting simulation code FishPact developed by Genfa Wu [4] is used to estimate the multipacting risk for the whole cavity. The calculations indicate the occurrence of the multipacting is unlikely, because the electrons can not gain sufficient energy to generate secondary electrons when impacting on the cavity surface. Table 1 lists the RF parameters of the PEFP low beta cavity.

Table 1: Primary parameters of the PEFP Low beta cavity.

Parameters	Value
Frequency (MHz)	700
Geometrical beta β_g	0.42
E_{acc} (MV/m)	8.0
E_{pk}/E_{acc}	3.71
B_{pk}/E_{acc} [mT/(MV/m)]	7.47
R/Q (Ω)	102.30
Cell to cell coupling (%)	1.41
Geometrical Factor (Ω)	121.68

Stiffening-ring structure design for reducing Lorentz force detuning

After optimization design of the stiffening structure regarding to the Lorentz force detuning control, cavity field flatness sensitivity, frequency sensitivity, tuning sensitivity and stability of the cavity mechanical property, a stiffening structure composed of double stiffening ring between inner cells and between Field Probe end cell and end dish, and single stiffening ring between FPC end cell and end dish has been designed for the low beta cavity. This structure can reduce Lorentz force detuning factor to -1.1 Hz/(MV/m)^2 for a wall thickness of 4.3 mm. Frequency sensitivity of the low beta cavity is 187.8 KHz/mm; the field flatness sensitivity of the cavity is 49.1%/MHz; and the tuning sensitivity is 4498 N/mm, and the maximum Von Mises stressin the cavity is 12.6 MPa [5]. Fig. 1 shows the stiffening structure and a PEFP low beta cavity with this structure.

HOM analysis [3]

Two main HOM related issues of the superconducting RF linac are the beam instabilities and the HOM-induced power. In order to understand the HOM issues regarding to beam stabilities and induced power in the PEFP low beta SRF linac, we have analyzed a normalized HOM-induced voltage, an induced power and a time-averaged

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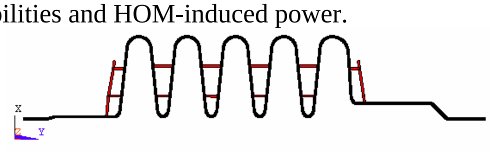
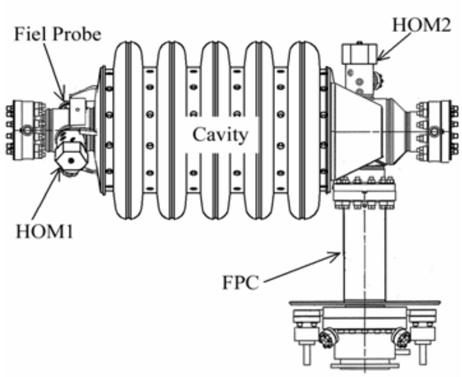
induced power especially from the TM monopole modes. The HOM trapping possibility has been established by considering a manufacturing deviation of the HOM frequency and by studying the spectra of the monopole, dipole and quadrupole modes in the low beta SRF cavity. The HOM-induced power in the PEFP cavity has been calculated for different Q_{ext}. The discussion about beam instabilities has shown the beam instabilities both in transverse and longitudinal directions are not issues in the PEFP low beta SRF linac. For the low beta cavities, the HOM coupler's Q_{ext} is lower than 3×10^5 for reducing the influence of the dangerous modes on the beam instabilities and HOM-induced power.



a. A 2-D PEFP low beta cavity with stiffening structure.



b. a low beta cavity with stiffening structures, HOM couplers, Field Probe and FPC.

Figure 1: PEFP low beta cavity and its stiffening structure.

HOM COUPLER AND FUNDAMENTAL POWER COUPLER

It has been designed a coaxial coupler with two stubs, one hook and one feed-through tip, which is directly installed on the inner conductor for the PEFP cryomodules, as shown in Fig. 2. The stick of the inner conductor is used to couple electric components of the HOMs, and the hook is for coupling magnetic components of the HOMs. The stubs are used to match capacitors of the notch filter and coupling feed-through, and to optimize the electromagnetic distribution in the coupler. The notch frequency filter is for tuning the notch position.

In order to control notch frequency shift, the frequency sensitivity has been reduced, and a nut tuner is designed.

PEFP Fundamental Power Coupler (FPC) is an antenna coaxial coupler, which is planed to copy and scale SNS FPC for PEFP cavities.

COOLING SYSTEM

PEFP cooling system includes cryogenic circulation, thermal insulation, cooling circuit of FPC, and detectors of temperature, pressure and helium liquid level. The design of the PEFP cryomodule cooling system is largely based on the SNS cryomodule cooling system. Table 2 lists the primary parameters of the PEFP low beta cryomodule.

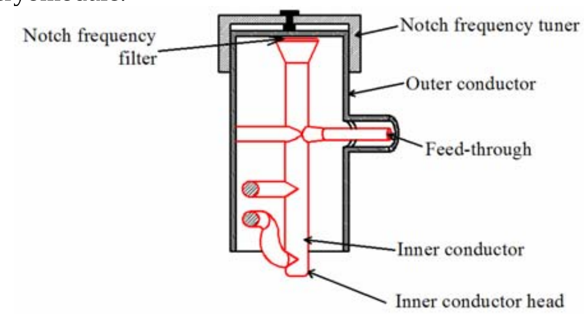


Figure 2: PEFP HOM coupler and its notch frequency tuner.

Table 2: Primary parameters of the PEFP low beta cryomodule cooling system.

Parameter name	Value
Cavities per cryomodule	3
Helium vessels per cryomodule	3
Primary circuit static heat load	24.8 W
Primary circuit dynamic heat load*	16.2 ~ 101.2 W
Pressure in Helium vessel*	0.032 ~ 1.0 Bar
Temperature in Helium vessel*	2.0 ~ 4.2 K
Pressure of the primary circuit helium liquid supply	3 Bar
Temperature of the primary circuit helium liquid supply	5 K supply
50 K shield heat load	163 W
Pressure of the 50 K shield supply	4.0 Bar
Temperature of the 50 K shield supply	35 K
Pressure of the 50 K shield return	3.0 Bar
Temperature of the 50 K shield return	55 K

Cryogenic circulation

As shown in Fig.3, there are three helium streams flowing in the PEFP cryomodule. A primary circuit produces 2.0 K to 4.2 K helium coolant in 3 helium vessels within the cryomodule. A secondary circuit provides coolant to 3 FPC flanges and outer conductors, and a third circuit provides coolant to the 50 K radiation shield. According to the testing and operating experience of the SNS cryomodules, the PEFP End Tank performs the function of the supply end tank and return end tank of the SNS cryomodule. The heat exchanger, Joule-Thomson (J-T) valves and auxiliary pipes are installed in the End Tank. The End Tank is not welded on the vacuum space, but sealed. This design is for easily repairing the cryomodule.

Thermal insulation

The thermal radiation shield is used to prevent the vacuum space and the other parts from transferring the thermal radiation to primary circuit. The thermal insulation structures in the PEFP cryomodule are comprised of four parts, namely, thermal radiation shield (50K Shielding), multilayer insulation, space frame and vacuum space (see Fig.4). The multilayer insulation mitigates the heat transmission, heat convection and heat radiation to cold surface. The space frame reduces the heat transmission from the vacuum space to the primary circuit system. The vacuum space is used to decrease the heat convection in the cryomodule. The insulation is comprised of materials suitable for being used in a high radiation environment.

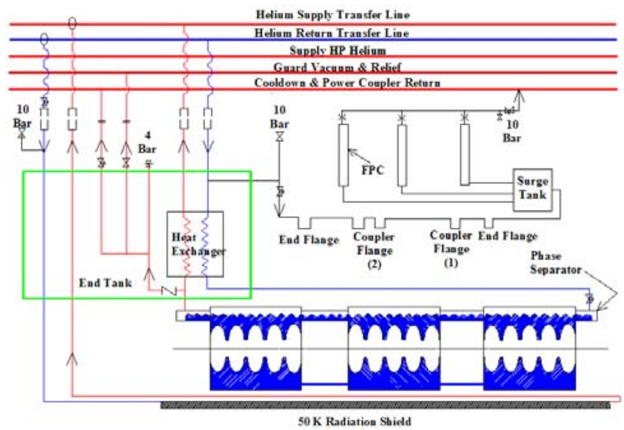


Figure 3: Cryogenic circulation schematic of the PEFP Low beat cryomodule. The blue color means the supply coolant or cold helium liquid; and red color means the return coolant.

FPC cooling circuit

The FPC flange and outer conductor are cooled by the secondary circuit. The inner conductor transfers the RF heat load to the inner conductor extension, which is cooled by DI water of 30^{o}C with flux of 1 Gal per minute. The outer conductor extension is cooled by air.

Detectors of temperature, pressure and helium liquid level

There are four kinds of detectors for cooling system in the PEFP low beta cryomodule. Temperature detectors employ Temperature Diode (TD) and Thermocouple (TE) to pickup the temperature signal of helium liquid and helium gas within cryomodule and on FPC for control system; helium liquid level detectors send signal of the helium liquid level in helium vessel to the control system; pressure detectors transfer the helium stream pressure signal to the control system; and vacuum gauges measure the vacuum in the vacuum space, FPC vacuum side, and beam-pipe for the control system.

MAGNETIC SHIELDING

Because we did not find the serious cavity intrinsic quality factor Q_0 degradation due to trapped magnetic flux in the SNS cryomodules' testing and commissioning, we are going to copy and scale the SNS magnetic shielding for PEFP cryomodules (see Fig.4). The magnetic shielding structures of PEFP cryomodules are shaped by two coaxial cylinders. The Amumetal inner shield is attached on the helium vessels and covers the beam pipes between cavities and the end cavities. The effective working temperature of the inner shield is 9.2 K. The Amumetal outer magnetic shield is attached on the outside of the support frame and the end covers of the cryomodule. Its working temperature is almost the room temperature. If the Q_0 degradation due to trapped magnetic flux is found during prototype testing, we will choose the three-layer structure. The shielding effectiveness of the low beta cryomodules is: transverse shielding attenuation S_T=111.3 and axial shielding attenuation S_A=24.2.

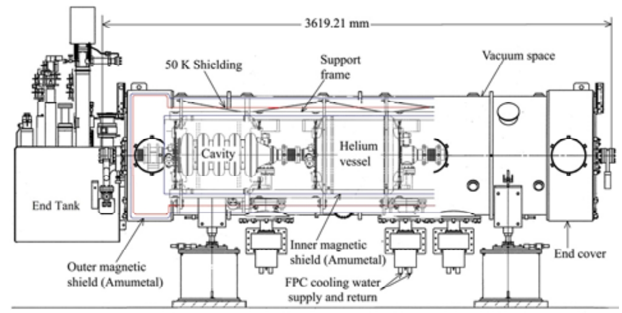


Figure 4: PEFP low beta cryomodule assembly.

CONCLUSION

The design of the PEFP low beta cryomodule is largely based on the successful design, construction and commissioning experience of the SNS project at JLab and ORNL. The comprehensive and competent analysis has been done for the fundamental electromagnetic and mechanical designs. Overall design is technically feasible.

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