RF SUPERCONDUCTIVITY ACTIVITIES OF PEFP*

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Abstract

Radio Frequency (RF) superconductivity activities of the Proton Engineering Frontier Project (PEFP) aim to develop a superconducting RF linac to accelerate a proton beam above 80 MeV at 700 MHz. In the past two years, the preliminary design of a low-beta cryomodule has been completed. A low-beta (beta=0.42) cavity, a higher-mode coupler and a fundamental power coupler for the PEFP cavities have also been designed. The dies, fixtures and coining rings, as well as the dumbbell tuning sets of the low-beta cavity have been designed and fabricated. Also a warm tuner for PEFP cavities has been designed and fabricated for tuning the PEFP cavity field flatness. Two prototype copper cavities are under production and testing. An overview of the RF superconductivity activities of PEFP in the coming two years is presented.

INTRODUCTION

Proton Engineering Frontier Project (PEFP) was launched by the Korean government in 2002 to develop a high-current proton linear accelerator to supply 100 MeV 20 mA pulse proton beams and to construct beam line facilities, with which the users can access the proton beams with wide ranges of energies and currents for their research and development programs. The PEFP host site was selected, in January 2006, to be Gyeongju city located in the south-eastern part of Korea. In the first phase of the project, we have successfully developed a 20 MeV proton linac, which consists of a 50 keV proton injector, a 3 MeV RFQ, and a 20 MeV DTL I. A DTL II, which is under construction, will increase the energy of the proton beam to 100 MeV. Two user facilities are to be installed to utilize the 20 MeV and 100 MeV proton beams at the end of the 20 MeV and 100 MeV accelerating structures, respectively [1].

A superconducting RF Linac (SCL) is being considered for accelerating a proton beam at 700 MHz for the following options: 1. from 80 MeV to 100 MeV in PEFP; 2. from 100 MeV to 1.0 GeV in the PEFP extension project; 3. from 100 MeV to 200 MeV as an injector of a rapid cycling synchrotron (RCS) with an extraction energy 1-2 GeV for a post-PEFP plan [1,2]. A room has been reserved for the SCL to accelerate a proton beam from 80 MeV to 100 Mev and for testing the SCL in the PEFP tunnel. The schematics of the PEFP linac and beam line facilities are illustrated in Fig. 1. For any of the options, the first section of the PEFP SCL is a low-beta SRF linac. A reasonable geometrical beta (β_g) and a good accelerating energy range for the low-beta linac are 0.42 and from 80 MeV to 178.6 MeV, respectively. Following sections could be medium-beta SCL (β_g =0.61) and highbeta SCL (β_g =0.81), that depends on the post-PEFP plan. Table 1 lists the primary parameters of the PEFP SCL.

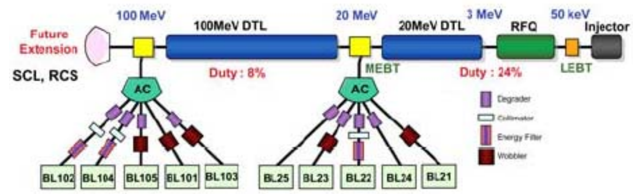

Figure 1: Schematics of the PEFP 100 MeV linac and beam line facilities.

Table 1: Primary parameters of the PEFP SCL accelerator

Operation frequency (MHz)	700
Operation model	Pulse
Pulse width (ms)	0.1~1.33
Peak current (mA)	1~20
Max. beam duty (%)	8
Average beam current (mA)	0.1~1.6
Max. repetition rate (Hz)	60
Energy range (MeV)	≥ 80
Possible beta sections	0.42, 0.61, 0.81

The research and design (R&D) work of the PEFP superconducting RF (SRF) project started in September, 2005. In the past two years, a preliminary design of the PEFP low-beta cryomodule has been completed; a PEFP cavity design, the cavity dies have been achieved; the prototype copper cavity is under production; the PEFP HOM coupler and fundamental power coupler (FPC) have been designed. In this paper, the above activities are introduced, a PEFP Superconducting RF Lab is pictured; and the status and future plan of the PEFP SRF project have been described.

DESCRIPTION OF PEFP LOW-BETA CRYOMODULE

A PEFP low-beta cryomodule consists of three low-beta elliptical cavities, three FPCs, three tuners, a cooling system, a magnetic shielding, and a series of sensors for the temperature and vacuum [3]. The PEFP cryomodule design is based on the successful design of the SNS cryomodules.

PEFP low-beta SRF cavity

A PEFP low-beta SRF cavity is a 5-cell elliptical cavity with geometrical beta β_g=0.42 operating at 700 MHz. The low-beta cavity is regarded as the lowest beta elliptical

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cavity operating at a pulse mode so far. Generally, lower beta cavities have a stronger Lorentz force detuning than higher beta cavities. For pulse SRF accelerators, a Lorentz force detuning is a more serious problem than that for CW accelerators. In order to efficiently control the Lorentz force influence on the low-beta cavity, double stiffening rings are used for the cavity. After a cavity shape optimization for its electromagnetic properties, a multipacting calculation, a HOM analysis and a mechanical analysis and design, a low-beta cavity has been designed [4, 5], as shown in Fig. 2. The primary parameters of the low-beta cavity are listed in Table 2.

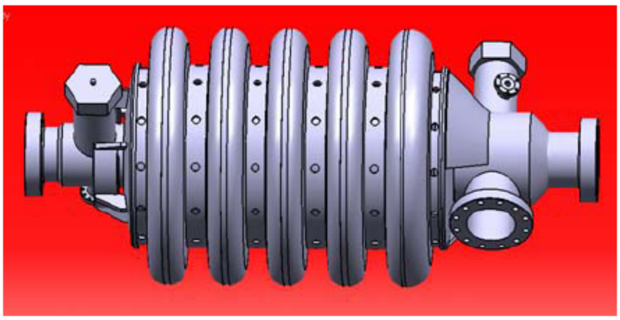


Figure 2: A PEFP low-beta cavity.

Table 2: Primary parameters of the PEFP low-bate SRF cavity.

Frequency (MHz)	700
Cavity type	Elliptical
Cavity geometrical β_g	0.42
Cavity effective β	0.45
Cell-to-cell coupling (%)	1.41
Cavity length (cm)	86.0
Number of cells	5
E_{pk}/E_{acc}	3.71
B_{pk}/E_{acc} [mT/(MV/m)]	7.47
R/Q (Ohm)	102.3
G (Ohm)	121.7
Stiffening structure	Double-ring
Min. K_L [Hz/(MV/m)^2]	-1.1
Field flatness sensitivity (%/MHz)	49.1
Frequency sensitivity (KHz/mm)	188
Tuning sensitivity (N/mm)	4498
Maximum Von Mises stress (MPa)	12.6

PEFP HOM Coupler

For the PEFP low-beta cavities, the HOM analysis has shown that the HOM coupler's external Q (Q_{ext}) of a dangerous HOM is lower than 3×10^5, thus reducing the influence of the dangerous modes on the beam instabilities and the HOM-induced power [2].

Two faults for a TTF-type HOM coupler on the SNS cavities have been identified: notch frequency shift and copper feed-through tip melting of a capacitive coupling [6], and these faults caused the 2 SNS SRF cavities to become unpowered, 10 SNS SRF cavities operating at a reduced gradient [7]. In order to satisfy the PEFP HOM damping requirements, to control the notch frequency shift easily and to avoid a feed-through tip melting, a new type of coaxial HOM coupler has been designed for the PEFP cavities [8].

The PEFP HOM coupler design is based on the TTF type coaxial HOM coupler, as shown in Fig. 3. The feed-through of the coupler is directly installed on the inner conductor to avoid a feed-through tip melting. Two stubs are used to match the capacitors of the notch filter and the coupling feed-through, and to optimize the electro-magnetic distribution in the coupler. The stick of the inner conductor is used to couple the electric components of the HOMs, and a hook is used for coupling the magnetic components of the HOMs. A notch frequency filter is used for tuning a notch position. To tune the notch frequency easily and to control the notch frequency shift, we designed a nut notch frequency tuner, which can tune a notch frequency shift in both directions.

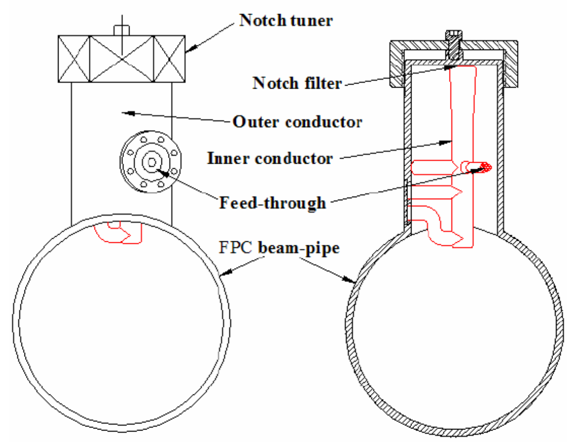


Figure 3: PEFP HOM coupler and cross-section on the FPC beam-pipe.

This coupler has a good filter property, low lectromagnetic fields on the inner conductor ends, and it is easy to tune and control a notch frequency. Two HOM couplers are installed on a PEFP SRF cavity with a relative azimuthal angle of about 90 degrees to ensure a damping of both polarizations of the dipole modes. One coupler is attached to each end of the cavity.

Fundamental Power Coupler

Each PEFP SRF cavity has one coaxial fundamental power coupler (FPC) of a KEK-type to transfer the RF power from the klystron to the beam. The design of the PEFP FPC is largely based on the successful design of SNS FPC. The doorknob transition is used to match the impedance of a WR-1150 waveguide to that of a 50 Ω coaxial guide. A coaxial window with chokes at both sides of the ceramic window is used for a vacuum insulation. The chokes are used to match an impendence of both sides of the ceramic window. An optimized design of the window has been completed after calculating its stress distribution and RF fields and simulating its multipacting behaviour. The dimensions of the coaxial guides have been decided after calculating the electromagnetic field distribution near the ceramic window when a standing wave arises and after considering a cryomodule assembly [9], as shown in Fig. 4. A DC voltage of 2500 V between the inner conductor and the outer conductor of the coaxial FPC is used to control the multipacting during a high power conditioning and operation. Table 3 lists the primary parameters of the PEFP FPC.

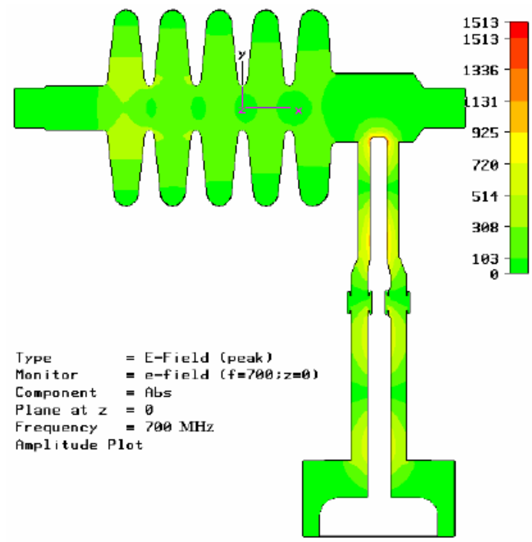


Figure 4: A standing-wave electric field distribution in the PEFP FPC with a low-beta cavity.

Table 3: Primary parameters for the PEFP FPC

Operation frequency (MHz)	700
Coupler type	Coaxial
Max traveling power (kW)	333
Commissioning forward power (kW)	≥650
Pulse length (ms)	1.3 ms
Repetition rate (Hz)	60 Hz
Operating pressure (Torr)	$\leq 5\times10^{-9}$
Outer conductor cooling	Helium stream
Inner conductor cooling	N/A
Window cooling	Water
Outer conductor extension cooling	Air
Inner conductor extension cooling	Water

Tuner

PEFP cavity tuning is achieved by varying the total length of the cavity. Table 4 lists the primary parameters of the tuner for the PEFP low-beta cavity.

Since the PEFP cavity is similar to the SNS cavity, and the operation frequency of the PEFP is very near the SNS operation frequency, the SNS tuner is modified for the PEFP cavities. The tuning system is generally composed of a stepping motor, a gearbox, a screw-and-nut assembly, and a lever arm with a flex mechanism attached. The tuner is attached to the helium vessel and drives the cavity field probe (FP) side to change the cavity frequency. Due to the low Lorentz force detuning coefficient of the PEFP low beta cavity, a Piezo needs not to be assembled on the tuners of the PEFP low beta cavities. This design will be confirmed after a prototype test with a beam. Based on the SNS tuner production and operation experiences, the gear box and the tuner frame are redesigned to meet the requirements of a PEFP tuner for a low-beta cavity.

Table 4: Primary parameters of a tuner for a PEFP low-beta cavity

Operation frequency	700 MHz
Resolution	44 Hz
Maximum load	21000 N
Frequency tuning sensitivity	187.8 kHz/mm
Tuning range	470 kHz
Field flatness tuning sensitivity	49.1 %/MHz

RF control system stabilizes the frequency, amplitude, and phase variations induced by sources such as the RF drive, the beam current variations, the Lorentz force detuning, and the microphonics. The tuner is an active part of the complete RF control system.

Cooling system

PEFP cooling system includes a cryogenic circulation, thermal insulation, a cooling circuit of the FPC, and the detectors for the temperature, pressure and helium liquid level. The design of the PEFP cryomodule cooling system is largely based on the SNS cryomodule cooling system. Table 5 lists the primary parameters of the PEFP low beta cryomodule.

Table 5: 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

*. These items are not finally determined.

1. *Cryogenic circulation*

There are three helium streams flowing in the PEFP cryomodule (see Fig. 5). A primary circuit produces 2.0 K to 4.2 K of helium coolant in 3 helium vessels within the cryomodule. A secondary circuit provides coolant to the flanges and outer conductors of 3 FPCs, and a third circuit provides coolant to the 50 K radiation shield. The heat exchanger, Joule-Thomson (J-T) valves and auxiliary pipes are installed in the End Tank [3].

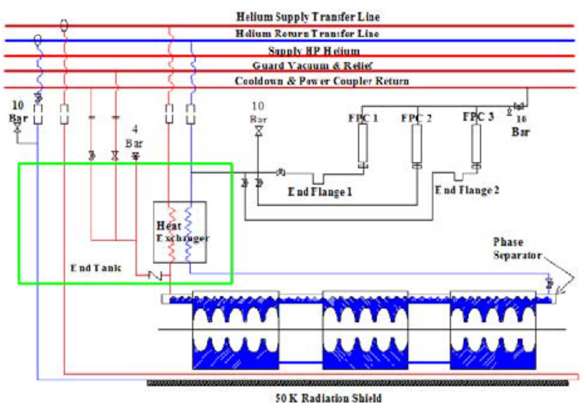


Figure 5: Cryogenic circulation schematic of the PEFP Low beat cryomodule. The blue colour means the supply coolant or cold helium liquid; and the red colour means the return coolant.

2. *Thermal insulation*

The thermal radiation shield is used to prevent the vacuum space and the other parts from transferring the thermal radiation to the primary circuit. The thermal insulation structures in the PEFP cryomodule are comprised of four parts: thermal radiation shield (50K Shielding), multilayer insulation, space frame and vacuum space (see Fig. 6). This multilayer insulation mitigates a heat conduction, a heat convection and a heat radiation to a cold surface. The space frame reduces the heat conduction 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.

3. *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°C with a flux of 1 Gal per minute. The outer conductor extension is cooled by air.

4. *Detectors of temperature, pressure and helium liquid level*

There are four kinds of detectors for the cooling system in the PEFP low beta cryomodule. Temperature detectors employ a temperature diode and a thermocouple to pickup the temperature signal of the helium liquid and the helium gas within the cryomodule and on the FPC for the control system; helium liquid level detectors send a signal of the helium liquid level in the 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

The magnetic shielding structures of the PEFP cryomodules are shaped by two coaxial cylinders. The Amumetal inner shield is attached to the helium vessels and covers the beam pipes between the cavities and the end cavities. The Amumetal outer magnetic shield is attached to the outside of the support frame and the end covers of the cryomodule. If a Q_0 degradation due to a trapping of a magnetic flux is found during the prototype testing, we will choose a three-layer structure.

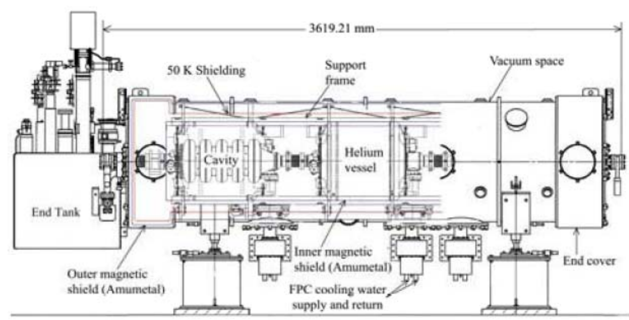


Figure 6: PEFP low beta cryomodule assembly.

STATUS OF THE PEFP SRF PROJECT

Based on the goal and schedule of the project, in the past two years, the status of the PEFP SRF project is described as follows:

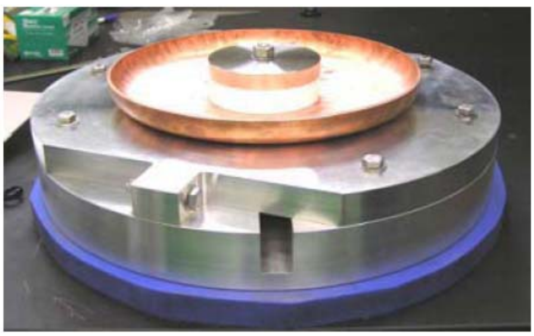
A preliminary design of a PEFP low-beta cryomodule has been completed. The low-beta cavity has been designed. The dies, the trimming fixtures and coning rings of a low-beta cavity have been fabricated, as shown in Fig. 7. Two copper prototype cavities are under production, as shown in Fig. 8. The Nb disks have been ordered, and are been shipping.

Figure 7: A female die and a male die for the central cells of the PEFP Low-beta cavity.

A PEFP HOM coupler and a Fundamental power coupler have been designed [8, 9], and are under production. The FPC baking system has been designed, and is under construction.

Figure 8: Half cells and a dumbbell of the PEFP prototype copper Low-beta cavity.

In order to control and to tune the cavity frequency, a set of dumbbell frequency & length control tuners and a cavity warm tuner have been produced [10], as shown in Fig. 9.



A. The dumbbell length tuning set.

B. The warm tuner.

Figure 9: A dumbbell length tuning set and a warm tuner of cavity field flatness for the PEFP Low-beta cavity.

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