RF Power Requirements for PEFP SRF Cavity Test

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1. Introduction

For the future extension of the PEFP (Proton Engineering Frontier Project) Proton linac, preliminary study on the SRF (superconducting radio-frequency) cavity is going on including a five-cell prototype cavity development to confirm the design and fabrication procedures and to check the RF and mechanical properties of a low-beta elliptical cavity. The main parameters of the cavity are like followings [1].

- Frequency: 700 MHz
- Operating mode: TM010 pi mode
- Cavity type: Elliptical
- Geometrical beta: 0.42
- Number of cells: 5
- Accelerating gradient: 8 MV/m
- Epeak/Eacc: 3.71
- Bpeak/Eacc: 7.47 mT/(MV/m)
- R/Q: 102.3 ohm
- Epeak: 29.68 MV/m (1.21 Kilp.)
- Geometrical factor: 121.68 ohm
- Cavity wall thickness: 4.3 mm
- Stiffening structure: Double ring
- Effective length: 0.45 m

For the test of the cavity at low temperature of 4.2 K, many subsystems are required such as a cryogenic system, RF system, vacuum system and radiation shielding. RF power required to generate accelerating field inside cavity depends on the RF coupling parameters of the power coupler and quality factor of the SRF cavity and the quality factor itself is affected by several factors such as operating temperature, external magnetic field level and surface condition. Therefore, these factors should be considered to estimate the required RF power for the SRF cavity test.

2. RF System for Vertical Test

The quality factor of the SRF cavity at low temperature is extremely high such that the bandwidth is just several tens of Hz range. Therefore the fixed frequency RF system is not suitable for SRF cavity test. The RF system for the vertical test is based on the PLL (Phase Locked Loop) to maintain the cavity on resonance and to minimize the reflected RF power [2]. The schematic diagram of the RF system is shown in Fig. 1. The vector signal generator is used as VCO (voltage controlled oscillator) and phase comparator which generates voltage signal proportional to the phase difference between the forward RF power and cavity RF power is used to drive the signal generator FM function.

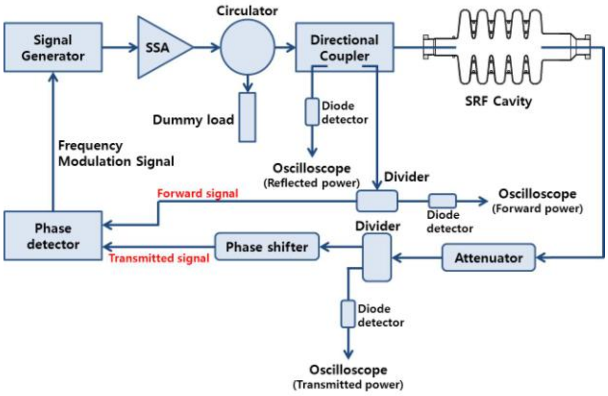

Figure 1. PLL based RF System for Cavity Test

3. Generator Power Requirement

3.1 Surface Resistance Effect

The surface resistance of the SRF cavity should be as low as possible to reduce the required RF power to generate the accelerating field. For the SRF cavity, the surface resistance is composed of three terms; BCS resistance, magnetic resistance and residual resistance. BCS resistance depends on the RF frequency and the operating temperature. If the operating frequency is 700 MHz, the BCS resistances at 2 K and 4.2 K are about 3 nΩ and 154 nΩ, respectively.

During cool down, any magnetic flux present will be trapped as the cavity becomes superconducting and increase the surface resistance. Therefore, the cavity should be shielded from any external magnetic field including the earth's magnetic field to as low a level as practically possible.

Surface resistance, required generator power and average dynamic heat load are summarized in Table 1. Residual resistance is assumed to be about 15 nΩ, which can be obtained through standard surface cleaning process. To calculate the average heat load, the duty factor of 9% is assumed.

Table 1. Surface resistance and RF power

Temperature	2 K		4.2 K	
B field [mG]	10	500	10	500
Sur. Res. [nΩ]	20.7	143.2	171.9	294.4
Q0	5.9E9	8.5E8	7.1E8	4.1E8
RF power [W]	25	174	183	321
Heat load [W]	2	13.9	14.6	25.7

3.2 Coupling Effect

The efficient coupling between the RF power coupler and a cavity is very important to minimize the required RF generator power. Figure 2 shows the required RF power dependency on the coupling beta. As can be seen from Fig. 2, required generator power rapidly increases as the coupling deviates from the critical coupling. Practically, the coupling is adjusted by RF power coupler insertion length into the cavity. Figure 3 shows the external Q variation as a function of the coupler insertion depth. To make the coupling critical, the coupler length should be about 46 mm.

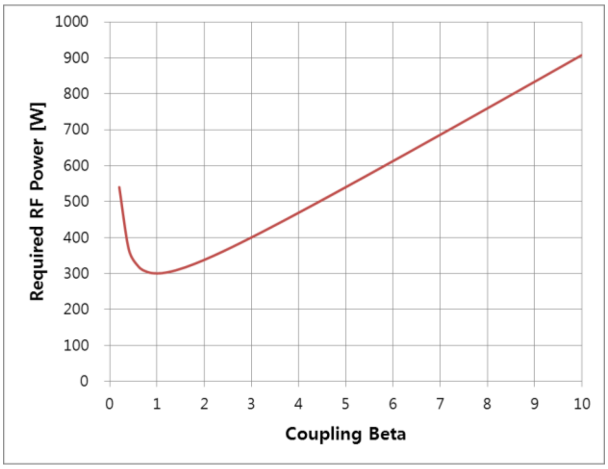

Figure 2. RF pwer dependency on coupling

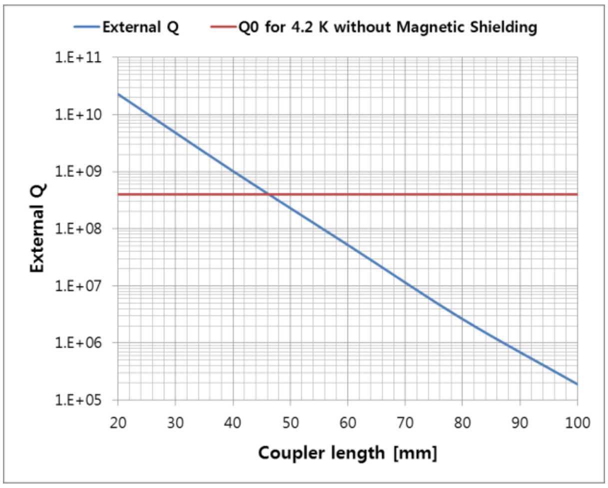

Figure 3. External Q and coupler length

3.3 RF Power Combiner

In case a single SSA (Solid State Amplifier) cannot deliver sufficient RF power, RF power output from two SSA can be combined to drive the cavity [3]. A coaxial type two-way RF power combiner is under development for that purpose. Figure 4 shows the 3D calculation model for RF power combiner. The inner conductor of the coaxial line is split into two splines and impedance matching is done by quarter wave transformer. Return loss (S11) and insertion loss (S21, S31) are shown in Fig. 5. Due to symmetry, S21 and S31 are same. The calculation result is far from the ideal behavior of the RF power combiner and further optimization process is required.

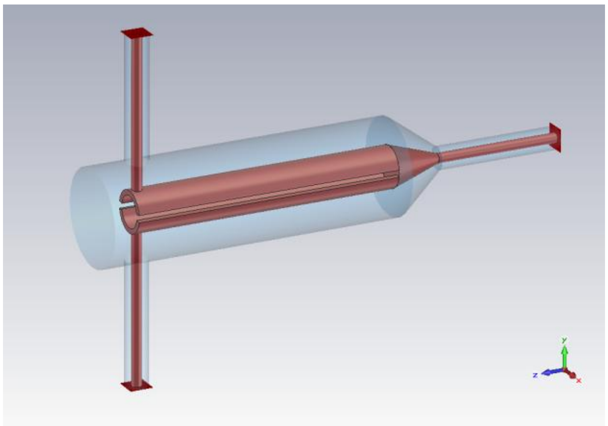

Figure 4. RF combiner calculation model

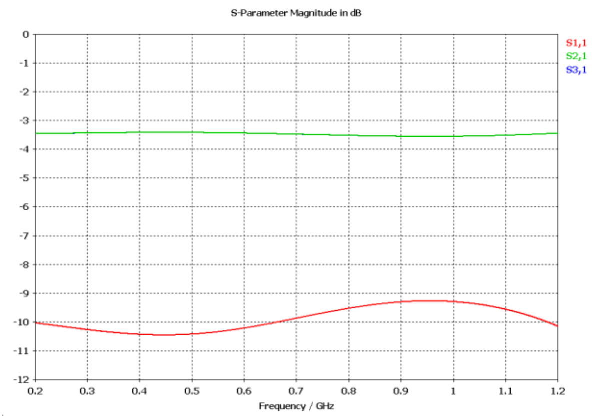

Figure 5. S parameters of RF combiner

4. Summary

A prototype SRF elliptical cavity has been developed for the future extension of PEFP proton linac. To test the cavity at low temperature, RF system based on PLL has been prepared. Required RF power for testing the cavity depends on many factors such as cavity-coupler coupling efficiency, operating temperature, the external magnetic field level and so on. If there is no magnetic shielding and operating temperature is 4.2 K, the required RF power to generate 8 MV/m accelerating field is estimated to be about 321 W at critical coupling case.

This work was supported by the MEST of Korean Government.

REFERENCES

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