# PEFP HOM COUPLER DESIGN*

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*Abstract*

A new type of coaxial higher-order mode (HOM) coupler with one hook and two stubs has been designed for PEFP SRF cavities to satisfy the HOM damping requirements of the superconducting RF (SRF) linac of the Proton Engineering Frontier Project (PEFP), and to overcome the notch frequency shift and feed-through tip melting issues. This paper presents details on the PEFP HOM coupler's structure, structure optimization, filter characteristics, electro-magnetic field distribution and a coupler installation tool.

## INTRODUCTION

A superconducting RF (SRF) cavity is being considered to accelerate a proton beam after 80 MeV at 700 MHz in the PEFP Linac being built at Gyeongju. The first section of the SRF linac is composed of nine low-beta cryomodules with three 5-cell elliptical cavities of $\beta_g$=0.42, and it will accelerate a proton beam from 80 MeV to 178.6 MeV [1]. A low-beta cavity and a low beta cryomodule have been designed [2-4].

The function of the HOM coupler is to damp the higher-order modes to prevent a resonant buildup of the beam-induced fields that may make the beam unstable or a cavity quenching.

For the PEFP low-beta cavities, the HOM analysis has shown that the HOM coupler's external $Q$ ($Q_{\text{ext}}$) of a dangerous HOM is lower than $3\times10^5$, thus reducing the influence of the dangerous modes on the beam instabilities and the HOM-induced power [1]. Table 1 lists the PEFP HOM coupler's specifications.

Table 1: HOM coupler specifications of the PEFP low beta cavity

| Parameter | Value |
|---|---|
| HOM damping modes | M23, M31, M32, M 33, D11, D32* |
| HOM damping mode $Q_{\text{ext}}$ | $\leq 3\times10^5$ |
| HOM average RF load | ≤ 1.0 W |
| TM010 π mode $Q_{\text{ext}}$ | $\geq 6.26\times10^{10}$ |
| TM010 π mode RF load (in the macro-pulse) at $E_{\text{acc}}$=8 MV/m | ≤ 10 W |

* Here, 'Mm' and 'Dm' mean the m-th mode of the monopole and the dipole of MAFIA calculation, respectively.

TTF (Tesla Test Facility) HOM coupler has been used for many cavities successfully, Fig.1 shows a TTF coaxial HOM coupler for SNS cavities. During the SNS (Spallation Neutron Source) cavity VTA (Vertical Test Area) testing, the cryomodule testing at JLab and the SNS commissioning at ORNL (Oak Ridge National Laboratory), two faults were identified: notch frequency shift and copper feed-through tip melting of a capacitive coupling [6]. These faults caused the 2 SNS SRF cavities to become unpowered, 10 SNS SRF cavities operating at a reduced gradient [7]. JLab tried to change the copper feed-though into a niobium feed-though in the Renascence Cryomodule. The test results were that a quenching happened instead of a melting [8]. In order to satisfy the PEFP HOM damping requirements, to control the notch frequency shift easily and to avoid the feed-through tip melting, a new type of coaxial HOM coupler has been designed for the PEFP cavities.

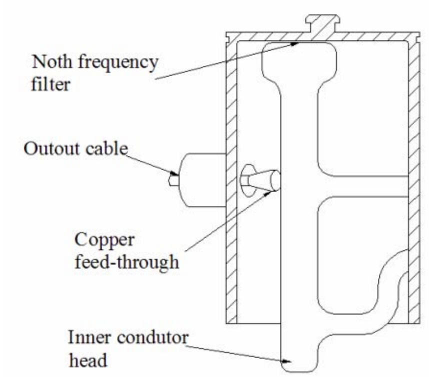


Figure 1: A SNS HOM Coupler schematic [5,6].

In this paper, the PEFP HOM coupler's structure, structure optimization, filter properties, and its electromagnetic field distribution on the crucial parts of its structure have been introduced. A special tool to install the feed-through has also been designed.

## HOM COUPLER STRUCTURE

The PEFP HOM coupler design is based on the TTF type coaxial HOM coupler, as shown in Fig. 2. 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,

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we designed a nut notch frequency tuner, which can tune a notch frequency shift in both directions.

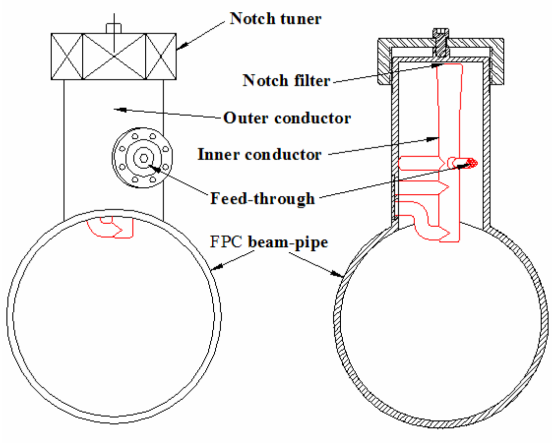


Figure 2: PEFP HOM coupler and cross-section on FPC beam-pipe.

## HOM COUPLER OPTIMIZATION

The basic rules to optimize the HOM coupler are:

- The cavity operating frequency is a notch frequency.
- Notch of the operating frequency should be as deep as possible.
- Filter notch frequency sensitivity should be as low as possible.
- Uniform electric field or magnetic field in the coupler.
- Notch frequency can be easily tuned and controlled.

Based on the above rules, after simulating the different angles between two stubs, and by varying the distance between the stubs, between the up-stub and filter end, between the down-stub and inner conductor head, and by testing the different hook shapes, as well as by varying the outer conductor diameter and the inner conductor positions and diameters, and by considering the cavity room and fabrication difficulty, we obtained a optimized HOM coupler structure by using a 3-D MicroWave Studio (MWS) simulation, as shown in Fig. 3. The filter notch sensitivity of the coupler is 105MHz/mm that is 46% of the filter notch sensitivity of the SNS HOM coupler (226MHz/mm).

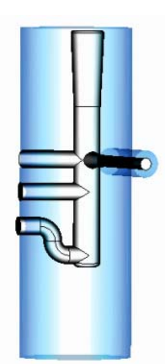

Figure 3: A MWS mode of the PEFP HOM coupler.

### *Filter characteristics*

Figure 4 shows a filter curve of the PEFP HOM coupler. By comparing it with an SNS HOM coupler filter curve, we found that the PEFP HOM coupler has only one deepest notch, and the same out-coupled power as that of the SNS HOM coupler. The cause of the low frequency with a low out-coupled power, is the cut-frequency limit of the circular waveguide in the simulation.

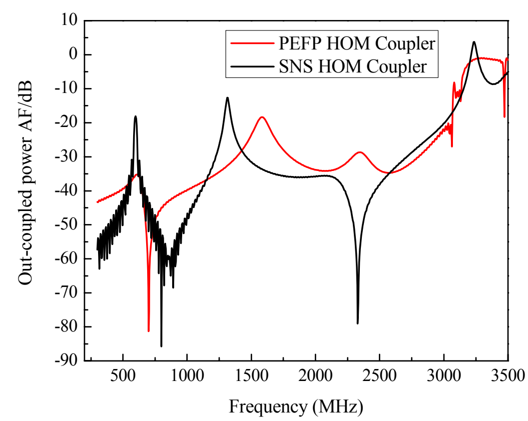


Figure 4: Out-coupled power comparison between a PEFP HOM coupler and an SNS HOM coupler.

### *Field distribution*

We should pay special attention to the electromagnetic (EM) field distribution of the TM010 $\pi$ mode in the HOM couplers, which could induce a strong electric field emission on the inner conductor, and a multipacting and an electron load in the coupler. The results could cause an SRF cavity quenching or unpowered.

A 3-D MWS cavity with two HOM couplers, a fundamental power coupler (FPC) and a field probe is used to simulate the EM field distribution in the cavity and the couplers. 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, as shown in Fig. 5.

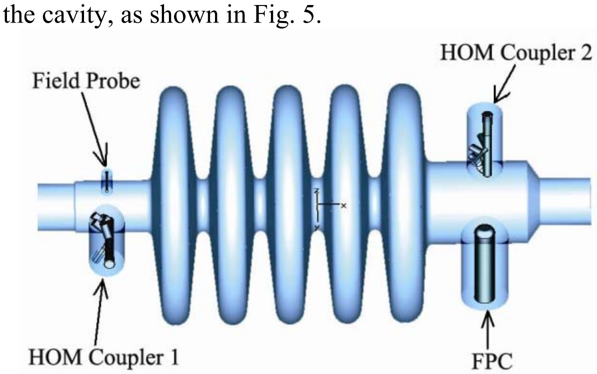


Figure 5: A 3-D MWS mode of a PEFP low-beta cavity with two HOM couplers, an FPC and a Field Probe.

Table 2 lists the simulation results of the maximum EM fields on the cavity surface, on the FPC head and on


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different parts of the HOM couplers of a PEFP SRF low-beta cavity and an SNS medium-beta cavity. The results show that, at the same peak surface electric field on the cavities, the maximum EM fields in the PEFP HOM coupler are approximately one tenth that of the fields in the SNS medium-beta cavity.

Table 2: EM fields in a PEFP low-beta cavity and in a SNS medium beta cavity at the same surface peak electric field.

| Position | SNS HOM coupler | | PEFP HOM coupler | |
|---|---|---|---|---|
| | E (V/m) | H (A/m) | E (V/m) | H (A/m) |
| Cavity surface | $1.00\times10^7$ | $1.85\times10^4$ | $1.00\times10^7$ | $1.51\times10^4$ |
| FPC head | $8.65\times10^5$ | 697 | $4.54\times10^5$ | 946 |
| Inner conductor head | $3.29\times10^6$ | 1863 | $5.30\times10^5$ | 575 |
| Inner conductor top | $1.25\times10^6$ | 0 | $9.93\times10^4$ | 0 |
| Feed-through tip | $5.81\times10^4$ | 1128 | N/A | N/A |

## HOM DAMPING RESULTS

The frequencies and $Q_{ext}$ of the fundamental modes and HOMs have been calculated with the 3-D MWS cavity mode. The simulation results show that the PEFP HOM couplers can meet their specification and damping requirements.

## NOTCH TUNER

Based on the tuning and operating experiences of the SNS HOM couplers, a nut type notch tuner has been designed for the PEFP HOM couplers. This tuner can tune a notch frequency in both directions, and is made of NbTi alloy.

## HOM COUPLER FABRICATION

The outer conductor, the inner conductor and the feed-through are made of a high RRR niobium, the notch tuner is made of NbTi alloy. The flange of the feed-though is made of NbTi alloy. A special tool has been designed to install the feed-through.

## CONCLUSIONS

A new type of HOM coupler has been successfully designed for PEFP SRF cavities. This coupler has a good filter property, low electromagnetic fields on the inner conductor ends, and it is easy to tune and control a notch frequency.

## ACKNOWLEDGEMENTS

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