DESIGN OF HOM COUPLER PROTOTYPE FOR THE APT SUPERCONDUCTING RF CAVITIES *

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Abstract

Beam dynamics calculations for the Accelerator Production of Tritium (APT) proton linac suggest that wakefields, which are excited during beam operation, would not lead to beam-breakup instabilities. However, in the superconducting (SC) radio-frequency (RF) cavities of the APT linac, higher-order modes (HOMs), whose frequencies are below the beam tube cut-off frequency, can be sufficiently excited by the beam to add significantly to the heat load removed by the helium refrigerator. In this paper, we present a design of an HOM coupler for the APT RF cavities that will remove this power to a resistive load at room temperature.

1 INTRODUCTION

The present design of the APT proton linac is based on two types of 700 MHz, five-cell niobium SCRF cavities: medium-beta ($\beta = 0.64$), and high-beta ($\beta = 0.82$) [1]. During beam operation, higher-order modes may be excited in these cavities by the traversing proton beam. Extensive beam dynamics calculations have been performed to assess the danger of the HOM excitation for beam break-up (BBU) in the APT linac. Results of these calculations demonstrated that, because of a substantial external transverse focusing force present in the design of the APT linac, these modes will have no detrimental impact on beam dynamics that would have resulted in the BBU phenomenon [2].

Detailed analysis of HOM excitation in the APT SCRF cavities was performed by Krawczyk [3]. In Table 1 the spectra of such modes are reproduced for the two types of cavities, including loss factors. From this table the total HOM power that would be dissipated into SCRF cavities by the proton beam with the average current I and the bunch repetition rate f_{rep} can be estimated using the following formula:

$$P_{HOM} = k_{loss}I^2/f_{rep}$$

where :

k_{loss} = total HOM loss factor (sum of all HOM),
f_{rep} = the bunch repetition frequency, and
I = qf_{rep} is the average beam current.

In the case of the APT proton linac at the average current of 100 mA with a 350 MHz bunch repetition frequency, the estimated total power from all higher-order modes dissipated into the cavity walls is 5–6 W per medium-beta cavity and 7–17 W per high-beta cavity. HOM frequencies above beam-tube cut-off frequency will propagate out of the cavity and deposit their power in the warm sections of the accelerator. Even though these power dissipation levels tend to be overestimated, a substantial power may be deposited into the 2K refrigerator because of the large number (~400) of SCRF cavities in the APT linac, thus increasing capital and operating costs.

Table 1A. Lowest higher order monopole modes in the five-cell, medium-beta (β=0.64) APT SCRF cavity [3]

Mode	$\Delta\Phi$	f (MHz)	k_{loss} (V/pC)	R/Q (Ω)
TM$_{01}$	$\pi/5$	681.59	0.0001	0.105
	$2\pi/5$	686.54	0.0015	1.396
	$3\pi/5$	692.64	0.0011	1.014
	$4\pi/5$	697.56	0.0041	3.733
	π	699.53	0.2033	185.00
TM$_{02}$	$\pi/5$	1396.82	0.0023	1.034
	$2\pi/5$	1410.73	0.0045	2.049
	$3\pi/5$	1432.74	0.0002	0.106
	$4\pi/5$	1458.80	0.0059	2.596
	π	1481.02	0.0004	0.172

Table 1B. Lowest higher order monopole modes in the five-cell, high-beta (β=0.82) APT SCRF cavity [3]

Mode	$\Delta\Phi$	f (MHz)	k_{loss} (V/pC)	R/Q (Ω)
TM$_{01}$	$\pi/5$	674.20	0.0001	0.049
	$2\pi/5$	681.16	0.0018	1.666
	$3\pi/5$	689.94	0.0006	0.577
	$4\pi/5$	697.19	0.0047	4.381
	π	699.92	0.3161	287.38
TM$_{02}$	$\pi/5$	1357.69	0.0009	0.415
	$2\pi/5$	1367.65	0.0100	4.671
	$3\pi/5$	1384.50	0.0018	0.830
	$4\pi/5$	1409.56	0.0227	10.252
	π	1439.37	0.0016	0.727

In this paper we present a design of a demountable HOM coupler for the APT SCRF cavities.

2 DESIGN OF A PROTOTYPE OF HOM COUPLER

There is a plethora of HOM coupler designs that have been developed over the years for various accelerators [4]. For the design of the APT HOM coupler, we have chosen a design based on the coaxial line technique that was originally developed for the HERA SCRF cavities and adopted for the TESLA project [5]. Recently, a similar technique was applied in the design of the HOM coupler for the Spallation Neutron Source (SNS) proton linac [6] and for the JAERI/KEK Joint Project [7].

The HOM coupler consists of a central conductor that forms the antenna and two inductive stubs. The coupling capacitor and the inductance of the conductor that extends to the upper stub (length L) determine the filtering frequency of the band elimination filter (BEF) corresponding to the fundamental accelerating mode (π-mode) of the SCRF cavities of 700 MHz. The coupler is tuned to the correct frequency by changing the gap of the coupling capacitor. The HOM output coupling port serves as a conduit for the HOM power to the external load at room temperature.
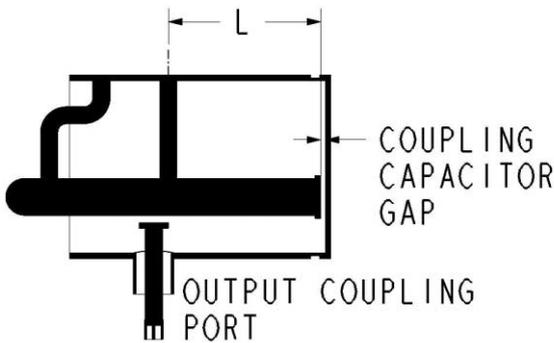
Figure 1: Sketch of the HOM coupler.

2.1 Electromagnetic design

Analysis of the HOM coupler was performed using the HFSS code [8]. Figure 2 shows the HOM coupler model used during simulations. The HOM coupler is attached to a coaxial line with a diameter of 130 mm that corresponds to the beam tube diameter in the APT SCRF cavities.

Three ports are defined in this case: ports 1 and 2 are located at the coaxial line, and port 3 is the HOM output coupling port. A symmetry plane was used to reduce the size of the problem and the computation time.
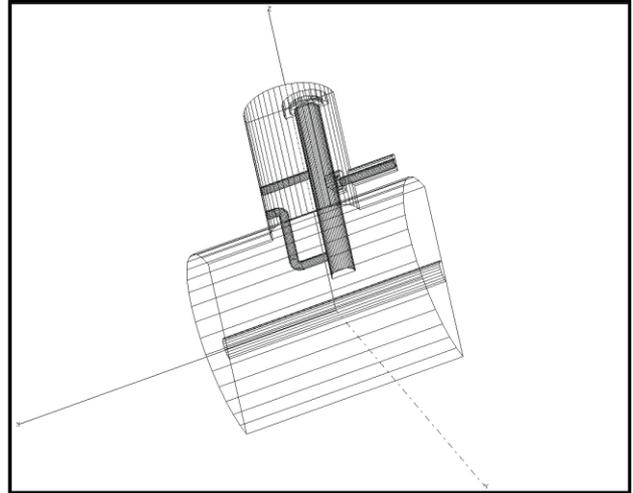
Figure 2: HFSS model of the HOM coupler

Optimization was performed to ensure the frequency of the BEF matches the frequency of the fundamental accelerating mode. A parametric study was performed by varying the antenna inductance and coupling capacitance. Further optimization provided enhancement of the damping at the frequency of ~1,400 MHz (multiple of the bunch repetition frequency). This included varying the diameter of the central conductor (antenna) and the gap of the output coupling capacitor. The results of the optimization are illustrated in Figure 3.
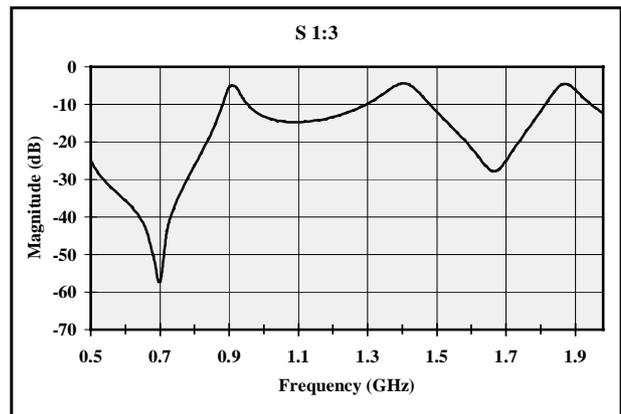
Figure 3: HOM coupler prototype transfer function.

A study of the tuning sensitivity of the HOM coupler was also performed. For a given length of coaxial line (~50 mm in the study case), the gap distance was varied to determine tuning sensitivity of the HOM coupler. Figure 4 illustrates the tuning sensitivity of the designed HOM coupler.

HOM Coupler Prototype
Tuning Sensitivity for Optimized L = 50.5 mm
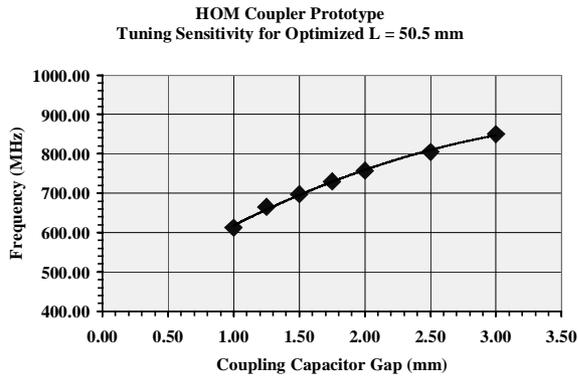
Figure 4: Tuning sensitivity of the designed HOM coupler.

2.3 Mechanical design

During the engineering development and demonstration phase of the APT project, six five-cell, medium-beta SCRF cavities were fabricated, as well as single-cell copper and niobium cavities and one five-cell copper cavity. Each cavity is equipped with two HOM coupler ports with stainless steel 2.25-inch ID Conflat™ flanges. Therefore, the design of the HOM coupler incorporates the corresponding 2.25-inch ID Conflat™ flanges to interface with the APT cavities.

Figure 5 is a computer rendering of the solid model of the HOM coupler. It includes a preliminary concept of a tuning mechanism attached to the top of the coupler. The tuning mechanism consists of a threaded rod and two nuts that provide plunger displacement in both directions, with an amplitude of 0.1 mm per 180° rotation. In the present version, the tuning mechanism may be removed after completion of the tuning.

The output coupling capacitor is mounted on the Cerameseal™ RF feedthrough with a 1.5-inch Conflat™ flange interface.
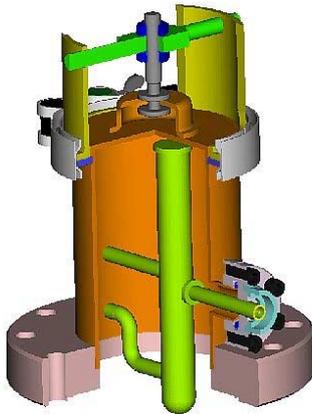
Figure 5: Mechanical design of the HOM coupler (computer rendering of the solid model).

3 FUTURE DEVELOPMENT

It is advisable to fabricate several copper models of the HOM coupler, which can be tested on the copper medium-beta cavity. Farther plans should include fabrication and testing of niobium versions of the HOM coupler.

Experience accumulated at DESY during many years of successful operation of welded HOM couplers on SCRF cavities at the HERA accelerator suggests that such a solution may provide a cost- and maintenance-effective alternative. A welded version of the HOM coupler can be installed on the beam tube during cavity fabrication, thus reducing the danger of the cavity interior surface contamination. The present design of the HOM coupler for the APT SCRF cavities can be easily modified to the welded version by eliminating the 2.25-inch ID Conflat™ flange.

4 CONCLUSIONS

We have developed a design of a demountable HOM coupler for the APT SCRF cavities. This design is based on the concept of a coaxial transmission line that recently was successfully applied to a variety of accelerator projects. A demountable version of the present design provides the flexibility required for prototype testing on an existing copper models of the medium-beta APT cavity.

5 ACKNOWLEDGEMENT

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