HIGH POWER RF COUPLER FOR ADS ACCELERATING CAVITIES*

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Abstract

An accelerator driven system (ADS) requires a high-power CW proton accelerator with proton beam energies near 1 GeV. High-gradient superconducting TEM-cavities are a natural choice for the front end of the linac. This paper presents the design of superconducting low-beta half wave resonators operating at 162 MHz frequency for ADS, as well as, a new 75 kW power coupler. This coupler would permit operations with an accelerating voltage of 3.0 MV per cavity with a beam current of 25 mA. The coupler includes a cold RF window which cools the antenna by conduction and a variable bellows section to adjust the coupling factor. The importance of these features for reliable operation will be discussed in detail.

INTRODUCTION

Argonne National Laboratory is developing a concept design of ADS that would provide a 5 MW, 1 GeV proton beam [1]. A near-term goal of the Argonne initiative is to establish a credible path forward for a pre-engineering study phase. One of the steps towards this goal is the development of SRF accelerating cavities including RF power couplers that will be used in the low-energy section of the linac.

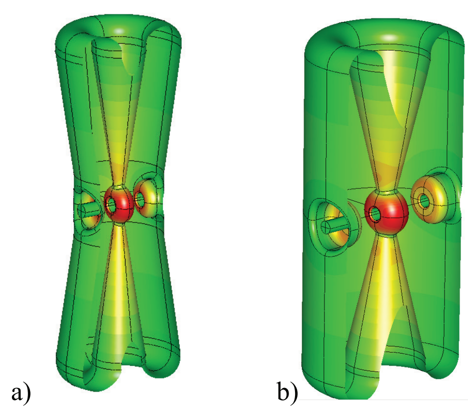

Figure 1: Electric field distribution in β=0.12 (a) and β=0.24 (b) cavities.

ACCELERATING CAVITIES

The RFQ used in the proposed accelerator is designed to accelerate protons to energy of 3 MeV. Beam dynamics simulations demonstrated that 162.5 MHz cavities with optimal β=0.12 and β=0.24 used in the front-end of the linac provide good performance. The accelerating cavities design (see Fig.1) is based on the SRF half-wave resonators (HWR) that have been recently developed at Argonne [2].

To improve the parameters of the cavities such as R/Q, G-factor and minimize peak surface electromagnetic fields, the cavity shape was optimized. During the optimization the following parameters were varied: gap width, inner and outer conductor diameters and blending radii. Table 1 summarizes the RF parameters achieved after optimization of both cavities.

Table 1: Cavity RF Parameters

Parameter		
$\beta_{optimal}$	0.12	0.24
R/Q, Ω	279.0	317.4
G, Ω	48.0	71.5
B_{peak}/E_{acc}, Gs/MV/m	63.0	60.5
E_{peak}/E_{acc}	5.0	4.72

RF COUPLER DESIGN

To provide 75 kW RF power to the cavities we are proposing to use a coaxial capacitive coupler with a design similar to the 4 kW RF coupler developed by ANL for FRIB [3]. To increase the power handling capability, the outer diameter was scaled to 6 1/8'' (see Fig.2a). Material thicknesses remained the same.

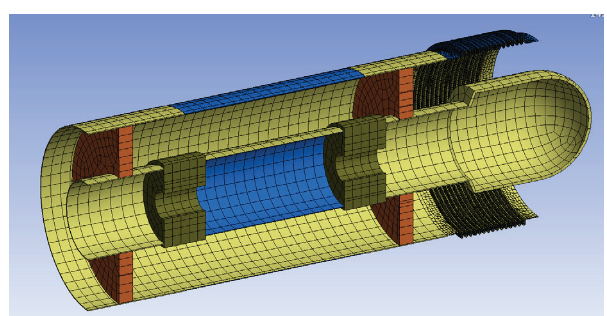

Figure 2: RF power coupler design after the optimization.

The primary components of the RF coupler shown in Figure 2 are as follow (from left to right):

- A 300 K alumina window serving as a vacuum break between the cryomodule vacuum and the atmosphere;
- A thermal transition from 300 K to 55 K made of stainless steel with a 20 microns layer of plated copper to reduce the heat load into the cryostat;
- A 55 K RF alumina window needed to cool the central conductor. It also provides a clean seal of the cavity RF volume after high-pressure rinsing in a clean room;

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- A bellows section required for adjustment of the inner conductor depth inside the cavity which determines the external Q-factor. This section serves as a thermal transition between the 2 K cavity flange and the 55 K cold window thermal intercept.

HIGH FREQUENCY PERFORMANCE

The electromagnetic design includes several stages: first choosing the dimensions to reduce reflections at the operating frequency and determining the required external Q-factor and the antenna insertion depth to operate at the required coupling strength.

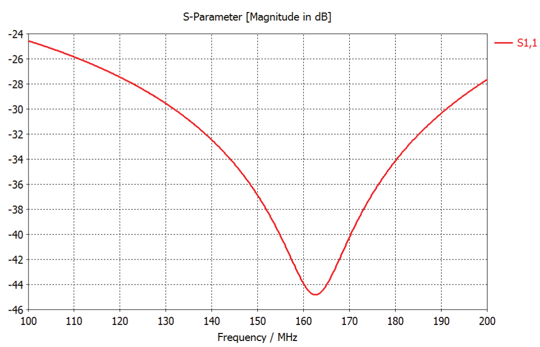


Figure 3: S11 as a function of frequency.

The geometry was optimized to the dimensions of a 50 Ohm 6 1/8'' line as shown in Fig.2b. In this case it is possible to minimize reflections at the operating frequency by changing the length of the thermal transition and the antenna diameter. Figure 3 shows the frequency dependence of the S11 parameter of the coupler working as a 2-port network device. Reflections are as low as -45 dB at 162.5 MHz with a -30 dB bandwidth of 60 MHz.

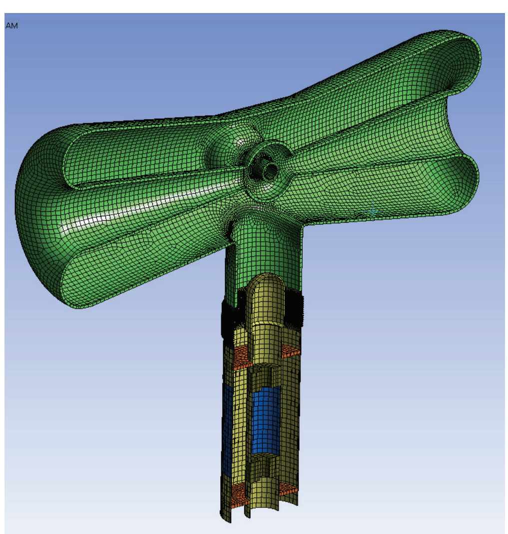


Figure 4: Power coupler connected to the HWR.

Analytical estimations show that an external Q-factor of $4{\cdot}10^5$ is required for optimal operation with a beam loaded cavity. The RF coupler attached to the HWR perpendicular to the beam ports is shown in Fig.4. In this area the electric field is high enough for the required coupling strength. A series of simulations has been done to determine the optimal RF port and antenna lengths for the required regime. The external Q-factor of the coupled cavity can be changed by adjusting the penetration length as shown in Figure 5.

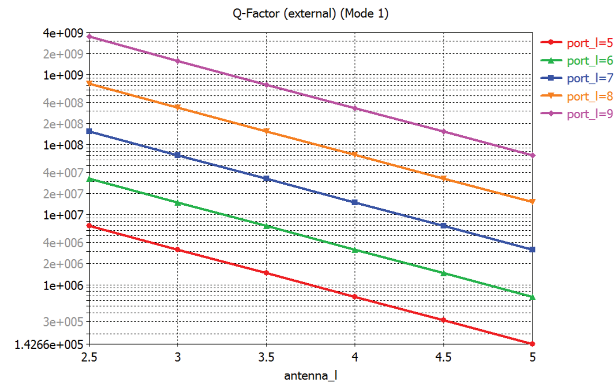
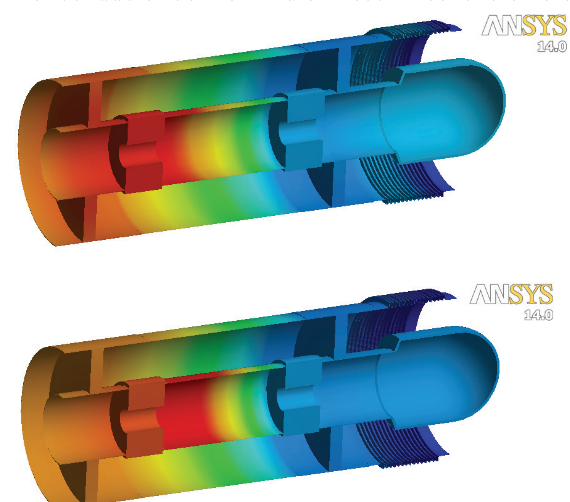


Figure 5: External Q-factor as function of the antenna's length for different RF port dimensions.

THERMAL SIMULATIONS

It is known [4] that the electromagnetic field patterns in couplers operating in the overcoupled regime are different for on or off resonance operations. In the first case, the magnetic field is maximal at the tip of the antenna, in the second case it is electric field. Due to this fact, it is necessary to check that there is no overheating in either regime. Fig. 6 demonstrates a temperature map of the coupler working at 75 kW forward power for both cases. No significant temperature rise occurs and the heating of the inner conductor both on and off resonance is tolerable.



a)

b)

Figure 6: Temperature maps of a coupler operating at resonant frequency (a) and off resonance (b) (red – 356 K, blue -2 K).

Table 2 summarizes the thermal data for a coupler operating at the resonant frequency. The values of heat flows to 55 K and 300 K are defined by the losses in the alumina windows. They can be reduced by a factor of ~ 2 by making these windows thinner. Another option to reduce RF losses is to use a material with a lower dielectric loss tangent. Such a material is available from Morgan Technical Ceramics [5] and can be used in the coupler to produce alumina windows of the required dimensions.

Table 2: Thermal performance of the RF coupler (on resonance)

Parameter	Value		
Material	AL 300	AL 300	AL995
Loss tangent	$3.8{\cdot}10^{-4}$	$3.8{\cdot}10^{-4}$	$2.9{\cdot}10^{-4}$
Thickness, in	0.5	0.25	0.25
Max temperature, K	316.9	303.9	302.0
Heat to 2K, W	7.8	7.2	6.6
Heat to 55K, W	72.5	54.0	47.6
Heat to 300K, W	24.1	11.2	3.0

Although, thin windows reduce the RF losses and heat flows and can sustain the stresses caused by thermal expansion, they may be damaged by the excessive force caused during the cavity assembly.

MULTIPACTING DISCHARGE

One of the problems in coupler operation is the multipacting discharge which may lead to significant heating. We used CST Particle Studio, Mult-P 3D [6] and analytical estimations [7] to analyse if a multipactor discharge is possible at various power levels. All three methods predict a growth of secondary particles number at 15 kW forward power which remains significant up to 75 kW (see Fig.7). For power levels less than 15 kW, the effect is of 3rd order and higher. Starting at 15 kW, it becomes a second order effect. At 52 kW, the first order multipacting starts.

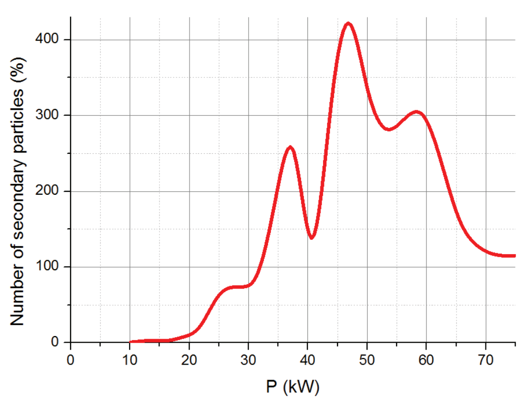


Figure 7: Relative counter function for RF coupler.

Simulations also show that the discharge is mostly one-point multipacting and power dissipation on the alumina windows is at least 10 times lower than on copper. There is also no sign of two-point multipactor between the bellows convolutions as the electric field carries the particles away.

Among the ways to suppress multipacting, we can apply a voltage bias between the inner and outer conductor, or treat the copper surface to reduce its SEY, or redesign the coupler for higher impedance. Our experience shows that though a severe multipacting discharge was predicted by simulations to occur in a similar 2 inches coupler design [8] at the same frequency, it was never observed during the power tests.

SUMMARY

A new high-power coupler for application with SC cavities has been designed. The coupler would provide 75 kW of RF power to 162.5MHz HWR cavities. A cold window reduces the temperature of the central conductor and thus the power which can be otherwise radiated to liquid helium. A variable bellows section allows adjustments of the coupling factor to the cavity. Even ath this high power this feature may be useful, especially during conditioning through multipacting, cavity pulsed conditioning with high RF power and optimal support of accelerator operation at different values of the beam current.

Non-linear thermal simulations were performed using ANSYS and show no excessive heating in the bellows section and reasonable temperature regime both on and off resonance. Multipacting discharge simulations indicate a concern, especially for power levels higher than 15kW. This can be avoided by using a bias voltage or surface treatment if necessary.

ACKNOWLEDGMENTS

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