HIGH POWER RF COUPLER FOR THE CW-LINAC DEMONSTRATOR AT GSI

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Abstract

The planned super-heavy element (SHE) research project investigates heavy ions near the coulomb barrier in future experiments [1]. A superconducting (sc) continuous wave (cw) CH-LINAC Demonstrator was developed and installed behind the High Charge State Injector (HLI) at GSI Darmstadt, Germany. In future the advanced cw-LINAC setup, including several CH-cavities, will accelerate the heavy ion beam from HLI with an energy of 1.4 MeV/u up to 3.5–7.3 MeV/u. The RF power of several kW will be coupled capacitively into the CH-cavities with minimal reflection at an operation frequency of 216.8 MHz. Two ceramic windows (Al_2O_3) are installed inside the RF coupler, to reduce the premature contamination of the cavity and as an additional vacuum barrier. The CH-cavity will be operated at cryogenic temperature (4 K) and will be increased to room temperature along the RF coupler. The optimally adapted RF coupler design, providing minimal RF losses and simultaneously maximal performance, was optimized by electromagnetic simulations. An RF coupler design with a reflection-free RF adaptor as well as the temperature distribution along the coupler will be presented.

INTRODUCTION

The sc cw-LINAC demonstrator comprises a 216.8 MHz CH-(Crossbar H-mode)-cavity as the main component, surrounded by two sc solenoids. The CH-cavity demonstrator accelerates highly charged ions with a mass-to-charge ratio of up to 6 inside 15 accelerating cells at a design gradient of 5.5 MV/m (Table 1). For an Advanced Demonstrator setup a "standard cryomodule layout" has been is defined, it contains three short CH-cavities, two sc solenoids and a sc rebuncher. The Advanced Demonstrator allows for first SHE-experiments at coulomb barrier for light and medium heavy ions.

After successful RF-test the demonstrator is currently in preparation for the first beam test at GSI. A helium vessel surrounding the cavity provides a closed helium circulation; a precooled area with a N_2 thermal shield (77 K) surrounding the helium vessel has been installed. Further, a μ-metal layer suppresses the earth magnetic field and as an additional thermal isolation the cryostat will be evacuated (superisolation). As shown in Fig. 1 the high power RF-coupler for the CH-cavity (Fig. 1) has a direct connection between the room temperature and the cryogenic section (4.2 K). The main design challenge is to minimize the thermal load in the sc cavity.

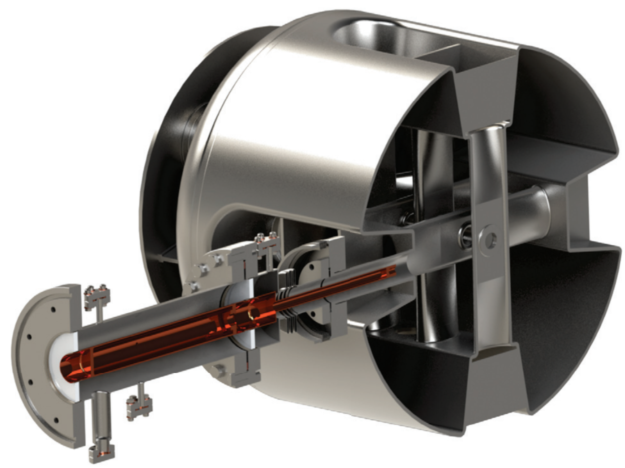

Figure 1: CAD-model of the high power coupler connected to the demonstrator CH-cavity [2].

Table 1: Design-parameters of the Demonstrator CH-cavity [3]

Parameter	Unit	Value
Frequency	MHz	216.816
A/q		≤ 6
Max. Current	mA	≤ 1
β (v/c)		0.059
Accelerating cells	#	15
Effective length ($\beta\lambda$)	mm	612
Cavity diameter	mm	409
E_a (design)	MV/m	5.5

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HIGH POWER COUPLER

The design of the presented high power coupler for sc cavities was inspired by the already successfully tested coupler from Fermilab [4]. The coupler has two ceramic windows for a separation from the vacuum section, an increase of the cleanliness and for a thermal separation. A standard 3 1/8" rigid line (RF-support) is scaled down with a RF-jump inside of the coupler to a CF 40 flange at the CH-cavity. This jump is necessary because of the small distance between the stems of the CH-cavity. The best position for capacitive power coupling is between the stems due to the high electric fields along the beam axis.

RF-Simulation

The RF-power coupling in the CH-cavity has to be accomplish with a minimum reflection free power coupler (Fig. 2). For this RF-power should be coupled with minimum losses into the CH-cavity, for elimination of reflected RF-waves and to reduce the cost of the RF-power. After the size of the standard rigid line and the diameter of the inner part was determined, the reflection parameter S_{11} has been reduced by optimization process. The window distance, the gap Δ and the window thickness are the most important and very sensitive parameters to optimize. The optimized parameters of the coupler are summarized in Table 2, technical details of the used window material are presented in Table 3. The associated S_{11} parameter is shown in Fig. 3. The window distance is the main parameter for the frequency shift of the refection parameter. The gap [7] is defined as the distance of the jump position of the inner conductor to the outer conductor; varying the gap the amplitude of S_{11} has been adjusted.

For the used coupler an axial symmetric could be assumed in the simulation to increase the mesh accuracy and to optimize the gap or windows distance. Otherwise the minimum of S_{11} shift to a higher frequency and the distance of the window is too low.

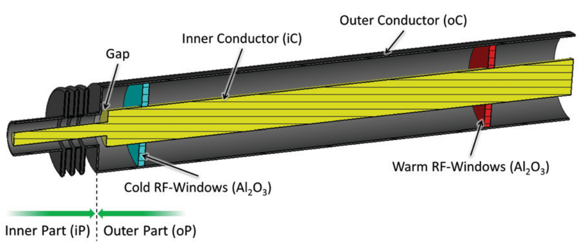

Figure 2: Simulated RF-coupler with a cross-section transition (gap) and two ceramic windows.

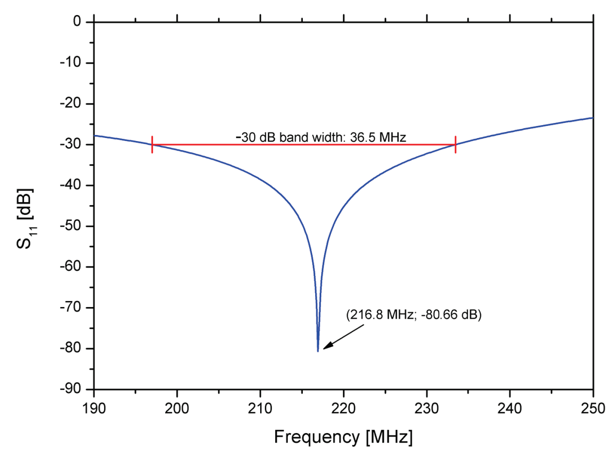

Figure 3: Simulated minimum of the reflection characteristics (S_{11}) of the high power coupler at the operation frequency.

Table 2: Parameters of the High Power Coupler

Parameter	Unit	Value
$R_{iP,iC}$	mm	6.1
$R_{iP,oC}$	mm	16.7
$R_{oP,iC}$	mm	14.0
$R_{oP,oC}$	mm	38.45
Window distance	mm	320.0
Window thickness	mm	6.0
Gap Δ	mm	6.5

Table 3: Parameters of the Window Material (Al_2O_3) [5, 6]

Parameter	Unit	Value
Alumina content	%	99.5
Permittivity ϵ		9.9
Magnetic permeability μ		1.0
Thermal conductivity (20°C)	W/K/m	30.0
Thermal conductivity (70 K)	W/K/m	100-340
Heat capacity	kJ/K/kg	0.88
Thermal diffusivity	m^2/s	8.7×10^{-6}
Thermal expansion coeff.	K^{-1}	7.9×10^{-6}

Heat Distribution

The RF-coupler provides for a direct connection between the cold area (4 K) at the CH-cavity and the room temperature at the outside of the cryomodule (Fig. 4). The heat transport is dominated by conduction along the surface of the outer conductor (Fig. 5). The inner conductor has a direct thermal connection only by the two Al_2O_3-windows and a thermal radiation takes place between the outer and inner conductor. At room temperature the warm window provide for a thermal isolation (Table 3); the cold window is used as thermal conductor and enables for cooling of the inner conductor. The distance between the cold and warm part of the coupler is extended by a bellow in the cold region to increase the way of the heat conduction.

The temperature distribution along the outer conductor is dominated by the 77 K inside the thermal shield, caused by the stay thermal conductivity of the material. The cold part at the end of the coupler, close to the CH-cavity, has only a minimum rate of heat flow due to the area of the outer

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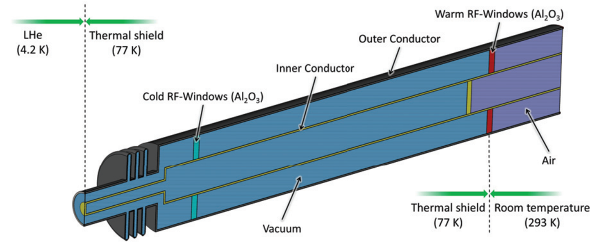

Figure 4: Cross sectional view of the used thermal areas in the simulation of the high power coupler.

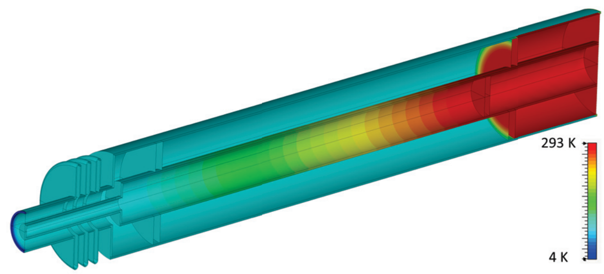

Figure 5: Simulated heat distribution along the high power coupler. The cold part has a temperature of 4 K, whereas the outer part is kept at room temperature.

conductor and a small thermal conductivity of the X-750. The inner conductor has a complete distribution from the outside with room temperature up to the inner part at 4K. So far the simulations have been performed without RF-power. The desired thermal shielding given by the cold RF-window, has been confirmed by the simulations.

The thermal radiation from the outer to the inner conductor of the complete length of this RF high power coupler is less then 1 W and can be neglected.

Mechanical Integration

The module structure of the coupler is built on the part with the 3 1/8" rigid line diameter and the inner part with a down scaled CF 40-size. The inner part has a very complex structure and close tolerances in the area of the gap and the radius jump. The amplitude of S_{11} has been reduced and a frequency shift is achieve without a precise manufacturing at the gap area.

The coupler has three diagnostic ports to monitor several parameters like temperature, RF and multipacting and to evacuate the section between the two ceramic windows (Fig. 6). The ceramic windows is covered by a very thin metalization layer to solder the window into the CF 100 flange. Both windows are fixed with elastic rings, which connects the inner to the outer conductor. These rings are important to reduces the pressure against the ceramic, because of the thermal expansion of both metallic conductors. The elastic rings must be designed for different coupler geometries (depending on diameter and ceramic thickness) separately in a structural mechanics calculation.

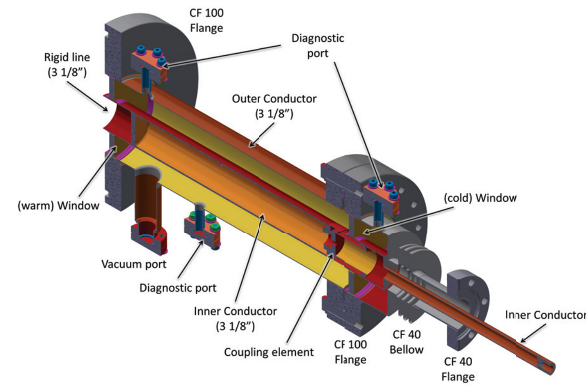

Figure 6: CAD-model of the final design of the 216.8 MHz high power coupler. The standard 3 1/8" rigid line will be scaled down to a CF 40 flange due to the limited space between two stems of the CH-cavity [2].

OUTLOOK

The already delivered RF-couplers will be installed at the test assembly for conditioning. Two couplers condition each other in a 216.8 MHz cavity. During the conditioning temperature measurements are planned at different positions to investigate the relationship of multipacting and temperature into the RF-coupler. After the successful exceed of the multipacting threshold the coupler will be installed inside of a clean room into the CH-demonstrator cavity and the first beam test will be expected in 2017.

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