DESIGN OF 352.21 MHz RF POWER INPUT COUPLER AND WINDOW FOR THE EUROPEAN SPALLATION SOURCE PROJECT (ESS)

E. Rampnoux#, S. Bousson, S. Brault, P. Duchesne, P. Duthil, G. Olry, D. Reynet,
CNRS/IN2P3, IPN Orsay, France

Abstract

The future European Spallation Source will be built to Lund in Sweden and will consist of a superconducting linac which will contain a SRF SPOKE cavities section with its associated high power RF couplers. In this framework, IPN Orsay is in charge of studying, designing and of conditioning four power couplers at nominal operations conditions by 2015. Studies and preliminary design of the ESS Spoke cavity power coupler are presented.

INTRODUCTION

The high-power RF coupler is the connecting part between the RF transmission line and the RF cavity and provides the electromagnetic power to the cavity and the particle beam. In addition to this RF function it also has to provide the vacuum barrier for the beam vacuum. High-power couplers are one of the most critical parts of the RF cavity system in an accelerator. A good RF and mechanical design as well as high quality fabrication are essential for efficient and reliable operation of an accelerator.

ESS accelerator high-level technical objectives are:

- 5 MW of average beam power
- 125 MW of peak power
- Beam current of 50 mA
- A repetition rate of 14 Hz
- Pulse length of 2.86 ms
- High reliability, > 95%
- Flexible design for future upgrades
- SRF Spoke cavities section operating at 352.21 MHz

The others parameters of the ESS layout are detailed in [1] and are now being optimized to meet the cost objectives. The prototyping phase of the project is under progress and will provide key elements and more specifically high power coupler to be tested under nominal operation conditions.

This paper discusses the design characteristics of the ESS Fundamental Power Coupler (FPC), the sizing relative to multipactor phenomenon, and the RF design.

SPOKE RF COUPLER DESCRIPTION

Each of the 352.21 MHz SRF Spoke cavities of the ESS accelerator will be powered via a coaxial FPC containing of a planar ceramic window separating the cavity vacuum side from air side. The ceramic is an alumina disk with a purity of 97% at minimum and a permittivity value of 9.2 with a loss tangent of 0.0002, values taken in the HFSS program for the RF design.

rampnoux@ipno.in2p3.fr

The design is based on the coupler developed for the superconducting SPOKE cavities in the framework of the EURISOL Design Study [2]. To adapt that design to the ESS power coupler requirements, a water cooling system is integrated in the inner antenna and the water cooling system of the ceramic window has been modified to direct the water flow more effectively.

The window assembly (Figure 1) has three instrumentation ports: one for ultra-high vacuum gauge, a second for electron pick-up antenna and the last will be a sapphire optical view port for arc detector.

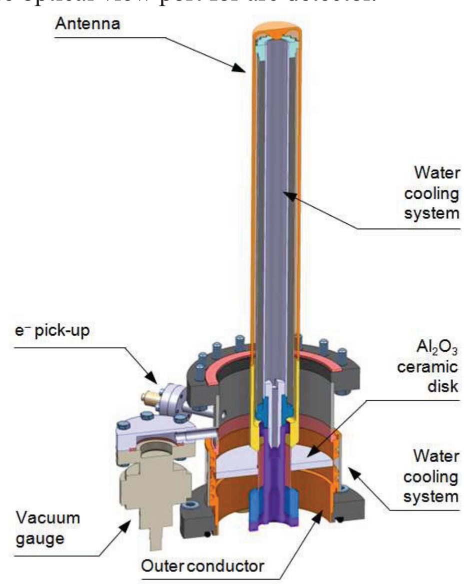

Figure 1: FPC for the ESS Spoke superconducting cavities.

Figure 2 show the general assembly drawing.

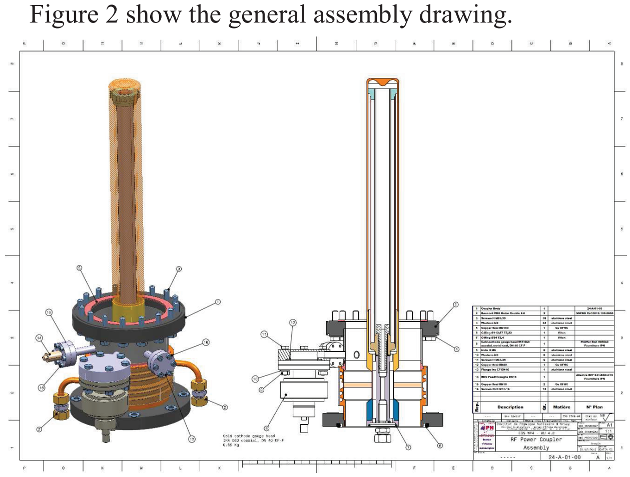

Figure 2: ESS Coupler Window Assembly.

The vacuum side of the ceramic disk window of the ESS FPC will be coated with 10 nm Titanium Nitride (TiN).

The ESS FPC will be matched to a rectangular WR2300 waveguide via a waveguide doorknob transition which is described in this paper.

RF WINDOW SIZING RELATIVE TO MULTIPACTING

Resonant secondary electron emission RF discharge or multipactor can disturb the operation of high power coupler microwave generator and particles accelerators. Multipactor phenomenon can degrade the frequency response of microwave cavities thus reflecting the incoming power back to the power amplifier. Another concern is heating, which is a result of the RF power dissipated to the device walls as the multipacting electrons strike the walls and thus significantly reduce superconducting properties of the accelerating cavities. So it is very important to properly size each accelerator components to avoid this multipactor phenomenon.

In a coaxial waveguide, multipactor phenomenon depends mainly on the operation frequency, the power coupler sizes, the impedance of it and the RF power. The conventional analytical formula is given by the expression:

$$P = (freq * Diam\_port)^4 * Z \qquad (1)$$

In our case, the analytical formula is weighted by a fit corresponding to points of experimental multipacting measurements performed by CERN on the Large Electron-Positron (LEP) RF power coupler. The operation frequency was 352.21 MHz and experimental formula is given by the expression:

$$P = (freq * Diam\_port)^4 * Z * h(1/(n+1)) \qquad (2)$$

The RF power calculation according to the geometrical parameters of the coaxial waveguide and the order of the equation weighting for an application frequency of 352.21 MHz shows that the optimum RF power is reached for the calculation of the second order for a 50 Ohms matching and this for a 100 mm power coupler port diameter.

By sizing the coupler diameter of 100 mm no multipactor phenomenon in the coupler port of the SRF SPOKE cavity will appear.

RF WINDOW DESIGN

Coaxial capacitive power coupler using a single ceramic disk window is suited for handling the RF peak power of 300 kW in TW mode operation. The presence of a ceramic disk inside the coaxial waveguide creates a local mismatch (Figure 3). So, to transmit the maximum of incoming RF power, the area around the ceramic disk was modified and optimized in reflexion Sparameter by adjusting window's dimensions. All electromagnetic computations were realised with HFSS program (Ansys Company).

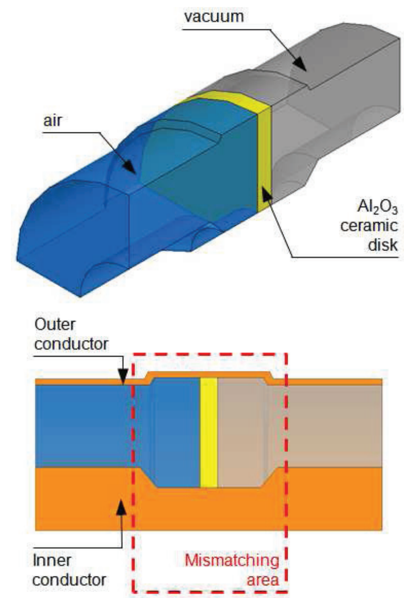

Figure 3: ESS coaxial window layout.

ESS RF window present a minimum of reflexion parameter of -61 dB at a frequency of 352 MHz. Moreover it is interesting to notice that the frequency response of the ESS coaxial planar ceramic shows a large bandwidth like approximately 1 GHz (Figure 4), thereby allowing standard fabrication tolerances.

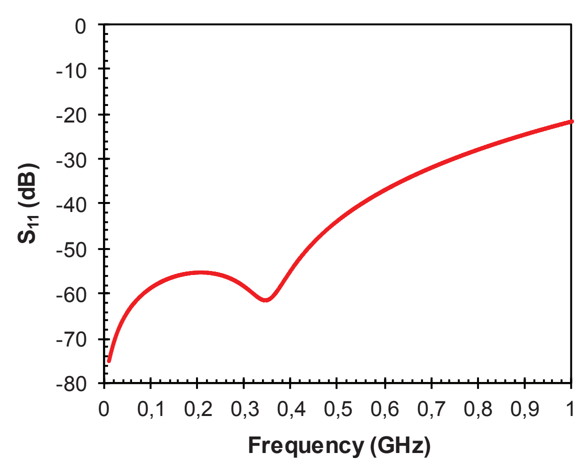

Figure 4: ESS FPC reflexion characteristics computed with HFSS program.

Electric fields were computed with HFSS program for 300 kW RF peak power as on accelerator operation. The maximum of electric field (5.10e+05 V/m) in the coupler window is obtained on the top of the chamfer situated on the inner conductor near the ceramic disk (Figure 5).

The most critical area is the interface between the inner conductor and the ceramic disk where the presence of a high electric field could be damage the ceramic. In our case the value of the electric field in this area is 3.10E+05

V/m for an incoming RF power of 300 kW that it will not allow to activate electric discharges in air.

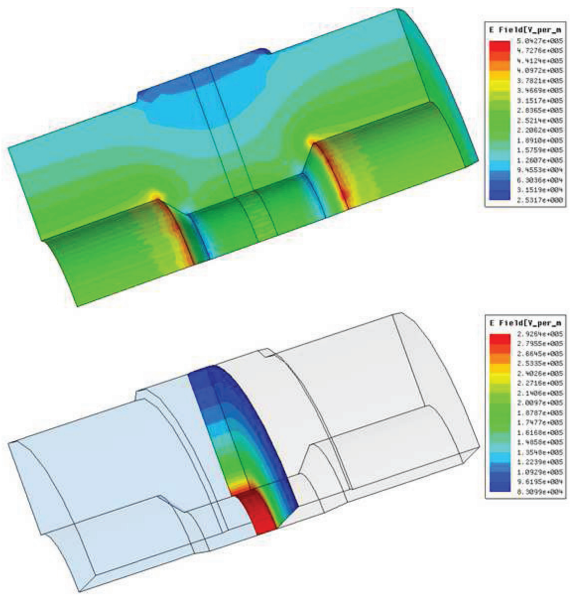

Figure 5: Electric Fields distribution (V/m for 300 kW RF peak power).

To complete the ESS FPC, a RF design of a typical doorknob has been performed for the coaxial to waveguide transition.

DOORKNOB DESIGN

The ESS Fundamental Power Coupler (FPC) is matched to a rectangular WR2300 waveguide via a waveguide doorknob transition shown in Figure 6.

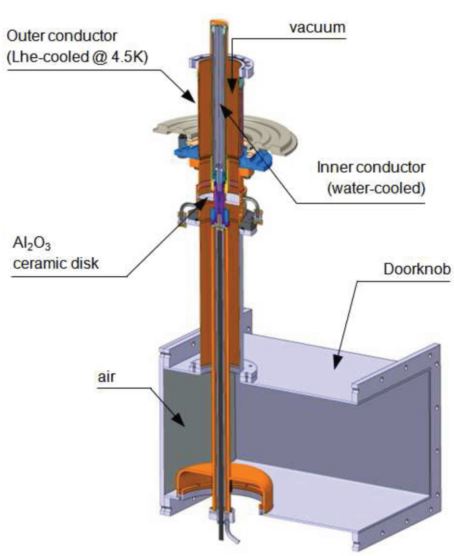

Figure 6: Cross-sectional view of the ESS high power coupler.

The coaxial part of the doorknob, on the air side of the power coupler, is made from copper and the water-cooled inner conductor doorknob is made of stainless steel.

The transmission of all the incoming RF power from WR2300 waveguide to the coaxial waveguide is obtained by adjusting the dimensions and the position of the cylindrical part of the doorknob inside the WR2300 waveguide. The response in frequency obtained using with HFSS program (Figure 7) shows an adaptation of -84 dB at 352.2 MHz with a bandwidth of 15 MHz at -20 dB.

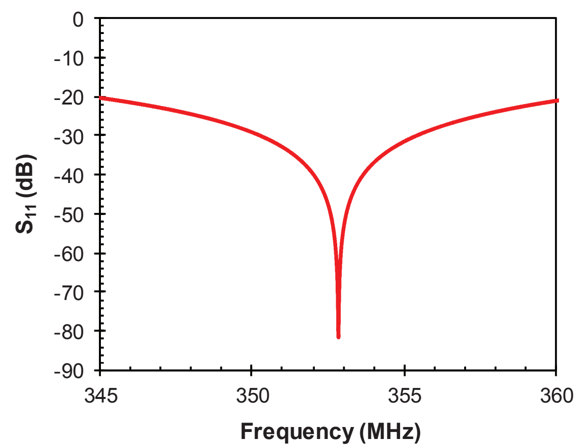

Figure 7: ESS Doorknob reflexion characteristics computed with HFSS program.

Two FPC parts were optimised, the length of the coaxial waveguide of the doorknob and the length of the antenna to minimize the electric field value inside the ceramic disk as shown on figure 8.

The two maximum of electric fields are situated either side of the ceramic disk and the electric field value is minimum in the ceramic. So the ESS FCP is designed to function in all RF power reflected without damage, in theory, the ceramic disk.

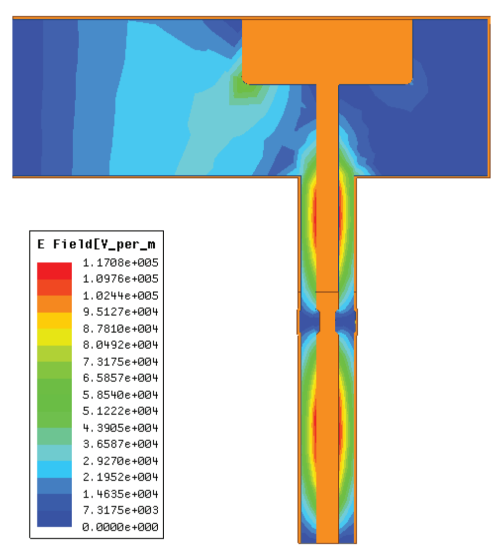

Figure 8: Electric Fields distribution in the ESS power coupler (V/m for 300 kW RF peak power).

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CONCLUSIVE PERSPECTIVES

RF design and mechanical drawings of the ESS FPC are finalized by the IPN Orsay team. Currently, two manufacturers are awarded by the IPN Orsay to fabricated two power coupler each without doorknob. The reception in IPN at Orsay is planned for the beginning of 2014. This putting in competition is going to allow IPN Orsay to validate a manufacturer for the realization of the 30 power couplers for the SPOKE cavities section.

The design of the conditioning cavity is in progress as the supply of high power RF components and instrumentations devices. A first implementation of the power coupler conditioning test stand is shown in Figure 9 [3].

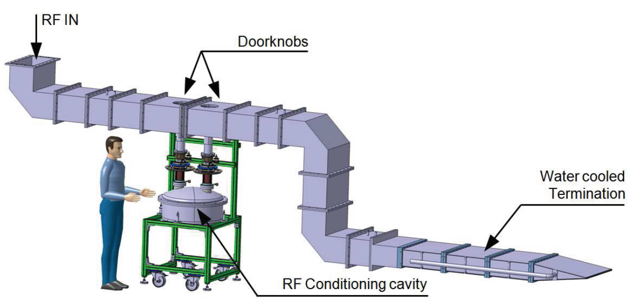

Figure 9: Future ESS RF FPC conditioning test stand layout.

A first power coupler conditioning is planned for the middle of 2014.

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[1] ESS Technical Design Report, (2013), http://europeanspallationsource.se/accelerator-documents
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