STATUS OF THE POWER COUPLERS FOR THE ESS ELLIPTICAL CAVITY PROTOTYPES

C. Arcambal, P. Bosland, M. Desmons, G. Devanz, G. Ferrand, A. Hamdi, P. Hardy, H. Jenhani, F. Leseigneur, C. Marchand, F. Peauger, O. Piquet, D. Roudier, C. Servouin,
Irfu, CEA-Saclay, Gif-sur-Yvette, France
C. Darve, ESS-AB, Lund, Sweden

Abstract

In the framework of the European Spallation Source (ESS) project[1], the CEA Saclay is responsible for the design, the fabrication, the preparation and the conditioning of the couplers used for the Elliptical Cavities Cryomodule Technological Demonstrators (ECCTD).[2] This work is performed in collaboration with ESS and the IPNO. This paper describes the coupler architecture, its different components, the main characteristics and the specific features of its elements (RF performance, dissipated power, cooling, coupler box test for the conditioning). The status of the fabrication of each coupler part is also presented.

INTRODUCTION

The linear accelerator of the ESS is composed of a superconducting section comprising two kinds of cavities called "medium beta cavity" (beta=0.67) and "high beta cavity" (beta=0.86) [3]. All these cavities will be equipped with couplers (see Fig.1) and in the end 120 couplers will be mounted on the accelerator. In a first step, we are developing 6 couplers to equip a prototype medium beta cavity (+2 spares). That shall allow validating the RF thermo-mechanical design of the coupler, its integration in the cryomodule and its manufacturing processes.

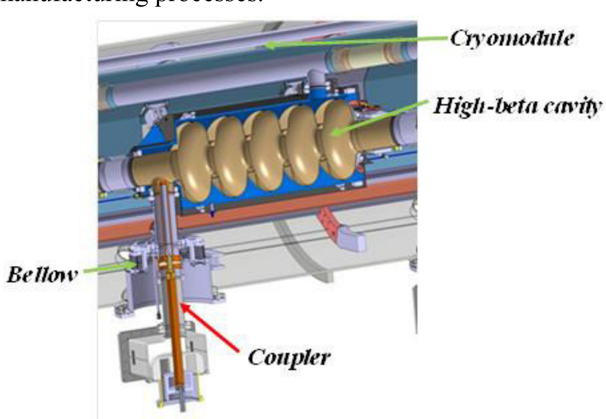

Figure 1: Coupler mounted on a high beta cavity.

COUPLER ARCHITECTURE AND CHARACTERISTICS

The ESS prototype power coupler is composed of three main parts:

*a window with its antenna to allow RF power coupling to the cavity and isolate the cavity vacuum from atmosphere thanks to an alumina disk,

*a cooled double-wall tube to keep a coaxial configuration between window and cavity and allow thermal transition between ambient and cold cavity temperatures,

*a doorknob transition to allow RF matching between the coupler and the RF power source.

The couplers mounted on the medium beta cavities are the same as the couplers of the high beta cavities; it means that the window and the doorknob are identical. Only the length of the double-wall tube changes; that allows obtaining a different antenna penetration inside the cavity and assures the correct external quality factor.

The ESS coupler is based on the coupler developed in the framework of the program HIPPI [4]. Thus, its architecture is very similar to the HIPPI one. Some elements have been modified e.g. the bellow has been removed from the double wall tube to allow an easier cleaning, the bellow is now on the ESS cryomodule. Other elements have been added such as the high voltage DC bias for the antenna and a photomultiplier port at the air window side. (see Fig. 2).

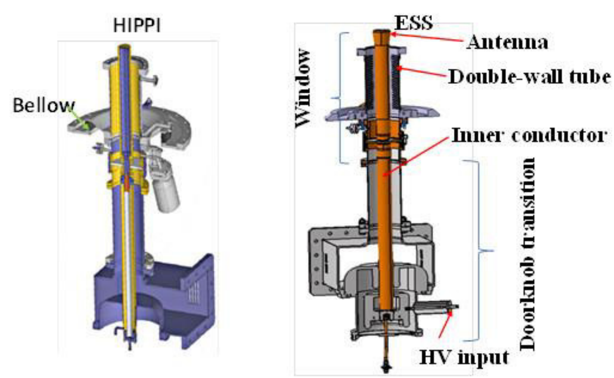

Figure 2: HIPPI coupler and ESS coupler.

In 2009 [5], the HIPPI coupler was tested until 1.2 MW for 17 minutes and at 1.1 MW for several hours, duty cycle 10%. (see Fig. 3) This last value of power is the one retained in the ESS requirements.

ISBN 978-3-95450-178-6

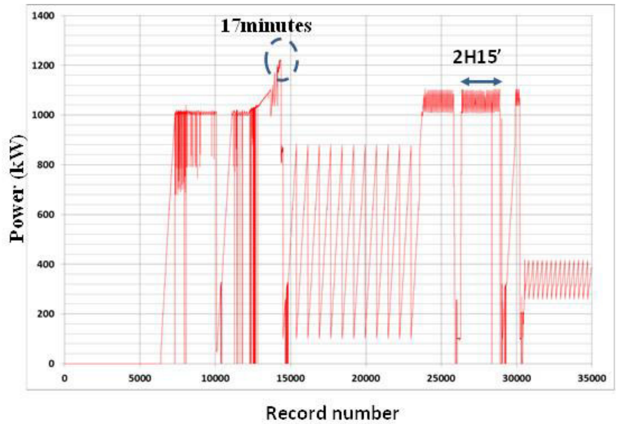

Figure 3: Power test on the HIPPI coupler.

General Features

Taking into account the performance of the HIPPI coupler and the ESS needs, the following requirements have been defined for the ESS couplers (see Table 1).

Table 1: Main Requirements of the ESS Coupler

Quantity	
High beta couplers	84
Medium beta couplers	36
RF Pulse Features	
Nominal frequency	704.42 MHz
Maximum peak power	1.1 MW
RF length pulse	defined to obtain a nominal voltage pulse length of 2.86 ms in the cavity
Nominal and maximum repetition rate	14 Hz
External Quality Factor	
Medium beta couplers	Qext $\in [5.9\times10^5; 8\times10^5]$
High beta couplers	Qext $\in [5.6\times10^5; 7.6\times10^5]$

Some electromagnetic simulations with HFSS from Ansys have been performed to determine the antenna penetration inside the cavity in order to reach the desired external quality factors. (see Fig. 4) By simulation, we calculate Qext as a function of the distance between the antenna tip and the cavity axis for the 2 kinds of cavities. (dist=61.26 mm for the medium β cavity and 64.41 mm for the high β cavity). As explained previously, this penetration difference of 3 mm will be obtained changing the double-wall tube length between the medium and high β cavities.

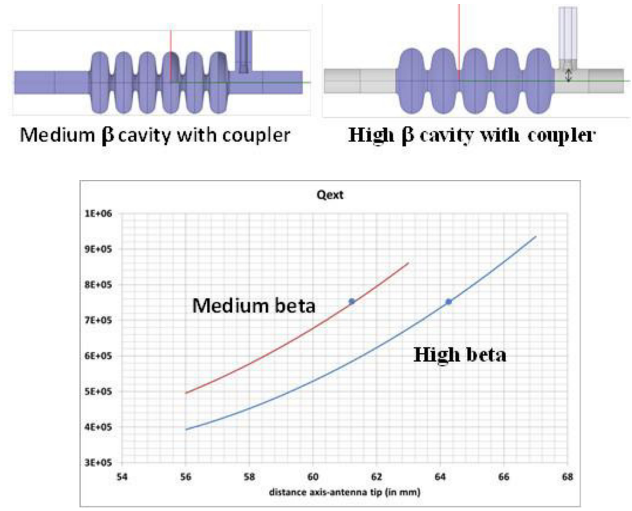

Figure 4: Simulation of the “antenna-cavity” coupling.

Specific Characteristics

Different diagnostic ports are available on the coupler to insure good operating security: (see Fig. 5)

* 2 flanges to put photomultipliers on the coupler in order to detect the possible appearance of arcs (on the vacuum window side and on the air window side).

*1 flange to put an electron pick-up to detect multipactor phenomena and to control the RF power at the window ceramic level.

*1 flange for vacuum monitoring.

For the maximum power (i.e. the maximum peak power 1.1 MW and for a duty cycle close to 5%), we have estimated with analytical considerations and simulations with HFSS the power dissipated in the window ceramic and the inner conductor (i.e. the part from the doorknob until the antenna tip). Assuming 3×10^{-4} for loss tangent, the RF losses into the ceramic are 33 W in standing wave (SW) (in the worst case) and 9.3 W in travelling wave (TW). The inner conductor RF losses are 58 W in TW. To dissipate these powers, the couplers will have different cooling circuits:

* a water cooling circuit for the inner conductor. The water flow will be around 2 l/min corresponding to a water ΔT=0.97 °C,

* a helium cooling circuit for the double wall tube,

* a water cooling circuit for the window to cool the ceramic from the outer conductor side. This circuit will be used only if natural air convection is not enough to dissipate the power. (see Fig. 5)

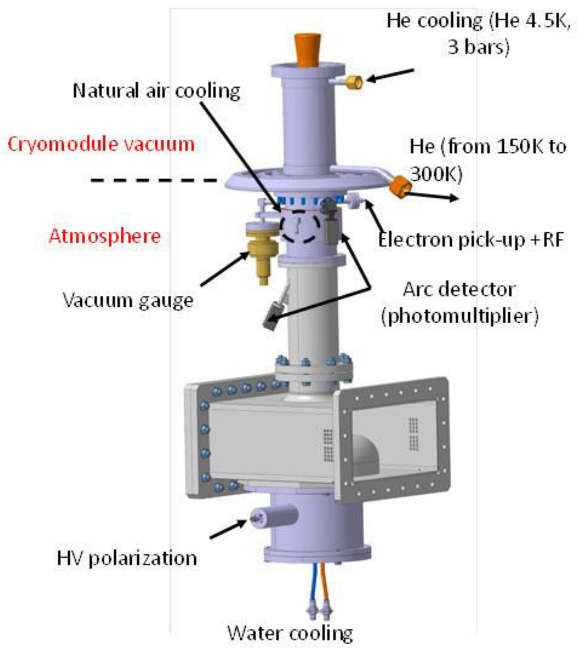

Figure 5: Interfaces and cooling circuits.

The mass of each coupler part is given in Table 2.

Table 2: Coupler Mass

Coupler parts	Approximate Mass (kg)
Window with antenna	6.6
Double wall tube	14.2
Doorknob transition	29.7
Whole coupler	=50.5

WINDOW

The RF performance of the window has been simulated with HFSS (see Fig. 6). The matching frequency is defined to be as close as possible to 704.4 MHz.

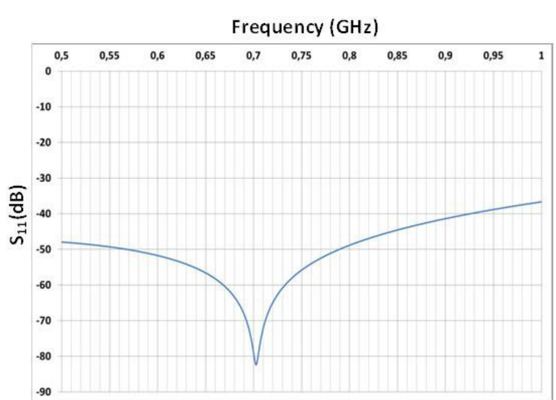

Figure 6: Return losses of the window.

On the vacuum window side, a TiN coating is deposited on the ceramic (10 nm ±5 nm) All metallic surfaces close to the ceramic window will be covered by a copper layer to limit the RF power dissipation (30 µm ± 10 µm).

DOUBLE-WALL TUBE

The 316L stainless steel will be used for the double-wall tube to insure an important temperature gradient between the cavity and the coupler parts at the ambient environment. A copper coating is deposited on the inner surface (thickness: 10 µm, -3µm/+2µm and RRR ∈ [20;40]). The He cooling circuit is realized with 3 helical channels inside the double wall

DOORKNOB TRANSITION

A part of the doorknob transition is a RF trap allowing the insulation between the RF power and the high voltage. The HV injection is performed via a 5 kΩ resistor. A kapton tube between the inner conductor and the doorknob assures the electrical insulation. The dimension of the RF trap and the position of the HV input are determined to obtain a low RF electric field at the HV input. (see Fig. 7)

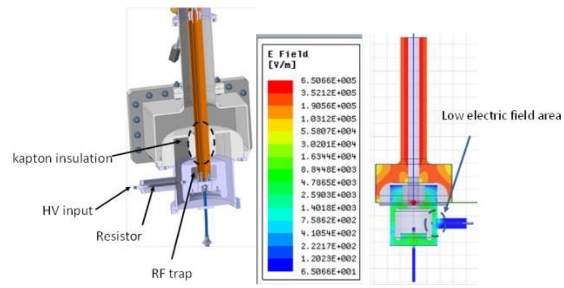

Figure 7: RF trap.

MANUFACTURING STATUS

The first pair of windows is foreseen to be delivered at the end of October 2015. The process of electron beam (EB) welding on the antenna is under validation (two parts of the antenna are EB welded and the weld has to be deep enough to ensure water tightness over time) (see Fig. 8).

Figure 8: Antenna sample.

For the double-wall tubes, the first pair should be delivered in October 2015. The different parts have been machined; the cooling channels have been realized; the assembly by the shrink-fitting method, the welds, the copper coating remain to be done. (see Fig. 9)

ISBN 978-3-95450-178-6

Figure 9: Flange (Left) and mandrel (Right) of the tube.

The doorknob transitions will be delivered at the beginning of 2016. A mock-up representative of the RF trap parts has been fabricated to validate the dimensions of the seal grooves and the assembly steps (see Fig. 10).

Figure 10: Doorknob RF trap mock-up.

COUPLER VALIDATION

Power couplers will be RF conditioned by pairs. Each pair will be assembled on a RF test box comprising a pumping system (see Fig. 11). These test boxes will be delivered in January 2016.

The box is made out of 316L stainless steel without copper coating inside. Consequently, some fans are set-up on the top of the conditioning bench to cool the box.

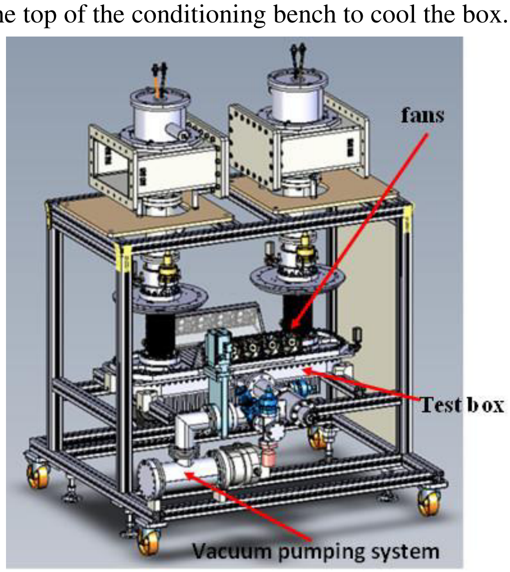

Figure 11: Conditioning bench.

We made some training assembling the HIPPI couplers in real condition (see Fig. 12) in order to define and improve the tools before working with the ESS coupler assembly.

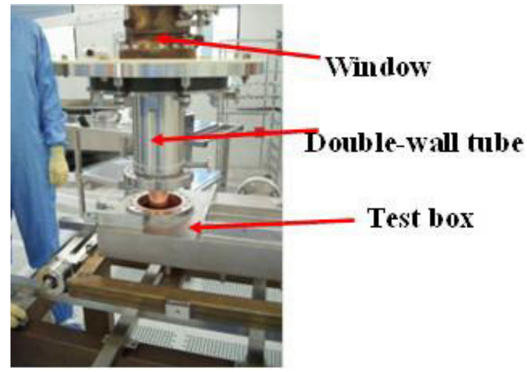

Figure 12: Coupler assembly training in clean room.

The coupler conditioning will be performed at CEA Saclay SupraTech-Cryo-HF facility, first in TW with low power, short pulses and low repetition rate. Depending on the couplers vacuum multipactor effect and arc breakdown diagnosis, the average power will be increased up to 1.2 MW using 3500 µs pulses with a repetition rate of 14 Hz (nominal duty cycle). Then the power will be maintained at nominal value for at least 15 minutes before decreased to check for multipacting zones. In SW RF conditioning, the measurement is rather similar to the TW one. However, the RF will be totally reflected by a movable short circuit allowing the maximum field position sweeping along the coupler and particularly near the ceramic. This process will be handled by an automated control system with HMI supervision.

CONCLUSION

Taking into account the different fabrication steps of the coupler parts, we foresee to begin the conditioning of ESS coupler prototypes at the beginning of 2016. These tests will allow the validation of the coupler architecture and its performance. Afterwards, the call for tender for the 120 series couplers will be launched.

REFERENCES

[1] H. Danared et al.,"Status of the ESS accelerator construction project", Proc. of IPAC2015, Richmond, VA, USA, 2015.

[2] F. Peauger et al.,"Progress in the elliptical cavities and cryomodule demonstrators", Proc. of SRF'15, Whistler, Canada, 2015.

[3] G. Devanz et al.,"ESS elliptical cavities and cryomodules", Proc. of SRF'13, Paris, France, 2013.

[4] G. Devanz et al.,"704MHz high power coupler and cavity development for high power pulsed proton linacs", Proc. of LINAC08, Victoria, BC, Canada, 2008.

[5] G. Devanz et al.,"Cryoenic tests of a 704MHz 1MW power coupler", Proc. of IPAC'10, Kyoto, Japan, 2010.