EURISOL DS Project
Task 8: SC cavity development

Deliverable D3
Spoke cavities study and fabrication (coupler & tuner)

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I. Introduction

Spoke cavities are superconducting accelerating structures which are very promising for accelerating hadrons beams up to 150 MeV/u (and even more). Their main advantages are the natural stiffness, the capability to deliver high accelerating gradients, and the possibility to have multi-cell structures, leading to a high real-estate gradient. For the energy range between 60 and 140 MeV/u, triple-spoke cavities are the most promising solution to achieve an efficient acceleration of protons, deuterons and He3 (2+). An important prototyping work on this accelerating structure has been performed in the EURISOL-DS program. At first, single spoke resonators cavities were studied, fabricated and tested before designing a triple spoke cavity with the required parameters to fit the final EURISOL driver specification.

II. Spoke cavities development at 352 MHz

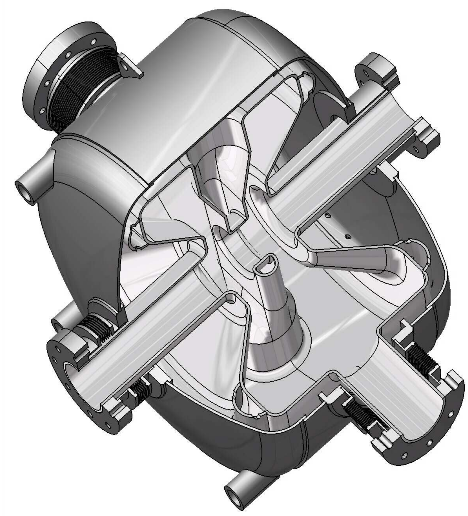

Fig. 1: cut-off view of the β 0.15 single spoke resonator

Two single spoke resonators have been developed at two different beta: 0.35 and 0.15. The high beta cavity was only optimized in terms of RF performances: the mechanical behavior was not studied at that time. The low beta spoke cavity is a more “complete” prototype (fig. 1), including optimized stiffening half-tubes and its helium tank. The spoke bar has a complex shape (racetrack) in order to lower the peak surface fields and to optimize the peak fields over the accelerating field ratio.

One of the difficulties is to optimize the cavity shape, without making the fabrication too difficult, and so too expensive. During the conception with the 3D electromagnetic codes, the fabrication process should be taken into account. On the figure 2, pictures of the cavity fabrication are shown at several fabrication steps.

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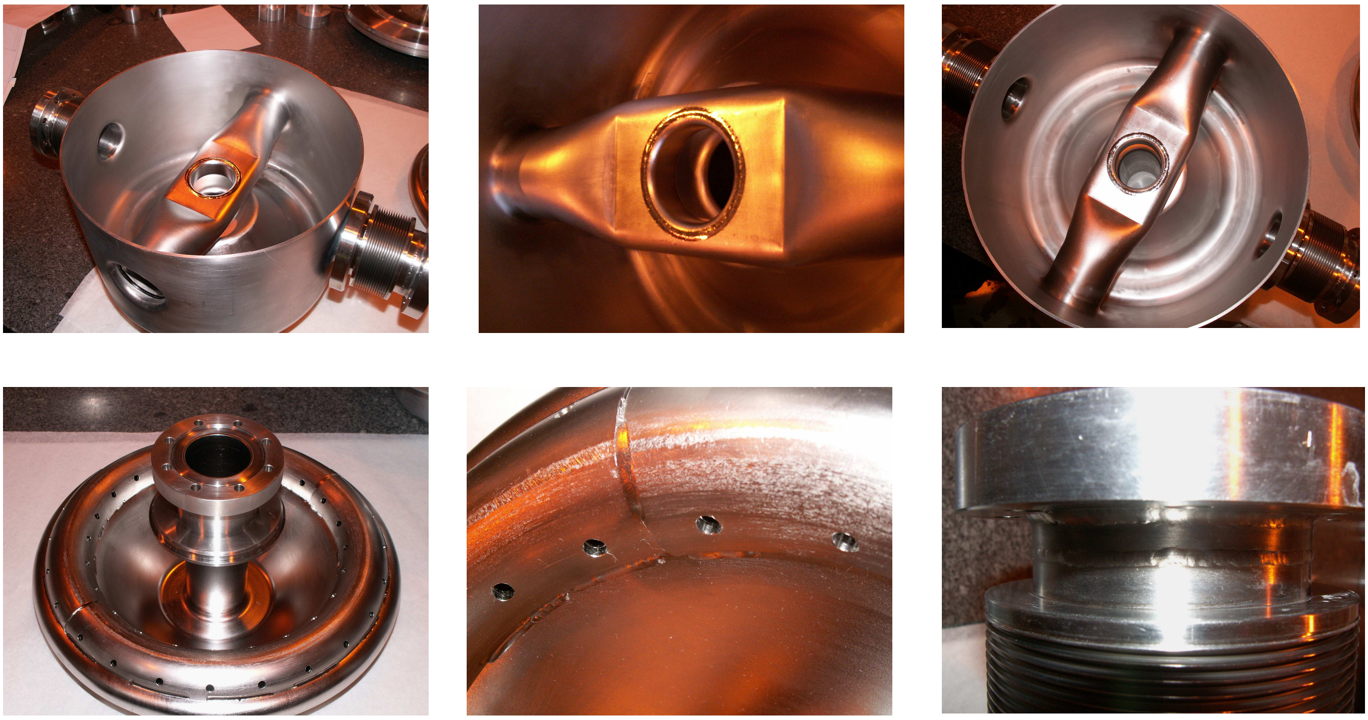

Figure 2: Several steps of the spoke fabrication process

Pictures of the two single spoke prototypes are show in figure 3. On the low beta cavity, the helium tank was welded in a second time (Fig. 4), after having tested at cold temperature the “naked” cavity. The beam port diameter for both cavities is 56 mm. The power coupler port location and diameter was modified between the high and low beta prototype in order to lower the losses (changing from a 45° angle between the port and spoke bar to 90°) and to increase the power coupler RF capabilities (increasing the diameter from 30 mm to 56 mm). The RF parameters are given in the table of figure 5.

Fig. 3: Picture of the two single spoke superconducting cavities: β 0.15 (left), β 0.35 (right)

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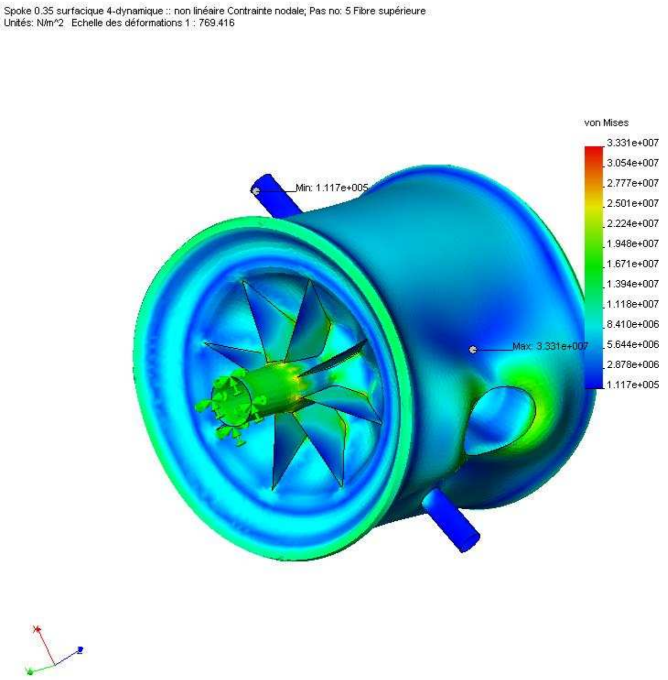
Figure 4:: Low beta spoke cavities after welding of the helium tank

	Parameter	Unit	Single spoke		
			β 0.35	**β 0.15**	**Comment**
Electromagnetic Design	Design frequency	MHz	352.2	352.2	
	Number of acc. gaps		2	2	
	β (optimum)		0.36	0.2	
	Lacc	m	0.297	0.17	Lacc = Ngap.β.λ/2
	Qo (4.2 K)		1.9 E+9	1.3 E+9	with Rres = 10 nΩ
	Qo (2K)		8.8 E+9	6.2 E+9	with Rres = 10 nΩ
	r/Q	Ω	220	88	
	G	Ω	101	67	
	Epk/Eacc		4.56	6.74	with Lacc = Ngap.β.λ/2
	Bpk/Eacc	mT/MV/m	12.33	14.48	with Lacc = Ngap.β.λ/2
	Voltage Gain	MV	1.96	0.63	at Epk = 30 MV/m

Figure 5: RF parameters for the two single spoke cavities

One important part of the design is to calculate the cavity mechanical stress under several conditions. For a differential pressure of 1 bar (vacuum condition) applied to the cavity walls, the maximum stresses are calculated for two boundary conditions: with both beam tubes fixed, and with only 1 beam tube fixed. The results for the beta 0.35 cavity is shown on figure 6.



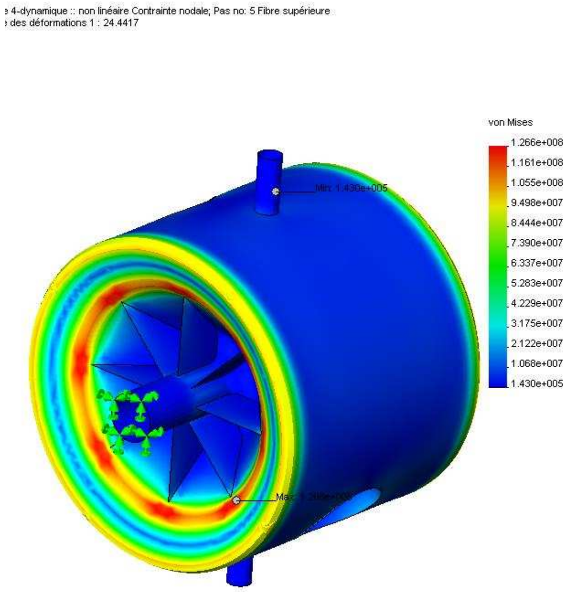
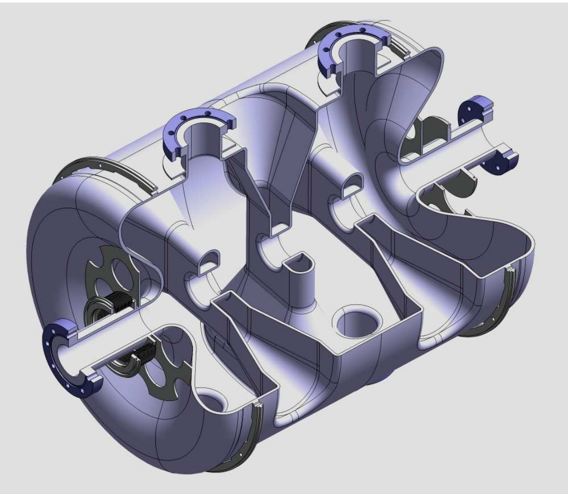


Figure 6: Calculated maximum stress on the beta 0.35 cavity with both beam tubes fixed (left) and only one beam tube fixed (right).

Triple Spoke cavity design at 352 MHz

In order to fit the evolution of the EURISOL driver reference layout, it was decided to develop a new spoke cavity prototype with 4 accelerating gaps (3 spoke bars). A cut view of the cavity is shown on figure 7. The design was adapted from the single spoke two first prototypes, but a full optimization work was performed in order to achieve the best possible RF geometry. The cavity was modeled using the CST Microwave studio RF code: a full 3D model was used, 13 main parameters have been scanned, and representing more than 300 computed cavities to reach the optimum values of peak fields over accelerating field ratio. The final result is Epk/Eacc = 4.1 and Bpk/Epk = 9.0 mT/MV/m. The niobium for the cavity fabrication has been received and the cavity fabrication has started.



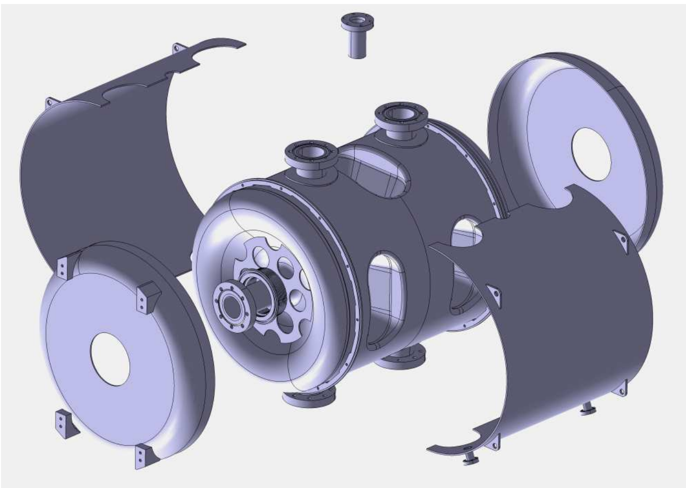


Fig. 7: Cut view of the final geometry of the triple spoke (left) and helium tank assembly (right)

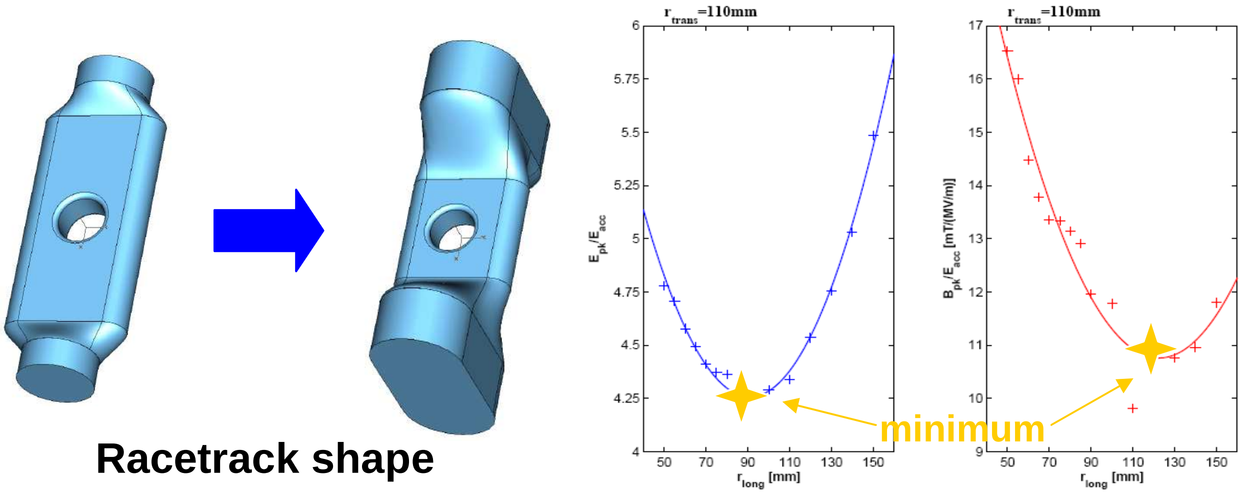


Fig. 8: Optimization of the cavity spoke bar geometry and consequences on the peak fields

III. Spoke cavity cold tuning system (CTS)

The spoke cavities CTS is an adaptation of the CTS we have developed for the elliptical 700 MHz 5-cell cavities. Its design is based on the system developed by the CEA for Soleil cavities. The CTS consists in a mechanical system (fig. 9) driven by a cold stepping motor operating under vacuum and a moto-reductor. The motor drives a ball screw, linked to a double lever arm mechanism which can act on four rods attached to the cavity. The design was optimized to obtain high rigidity, lowest possible weight and cost. The system includes also the possibility to use piezoelectric actuators for the fast compensation of frequency shifts.

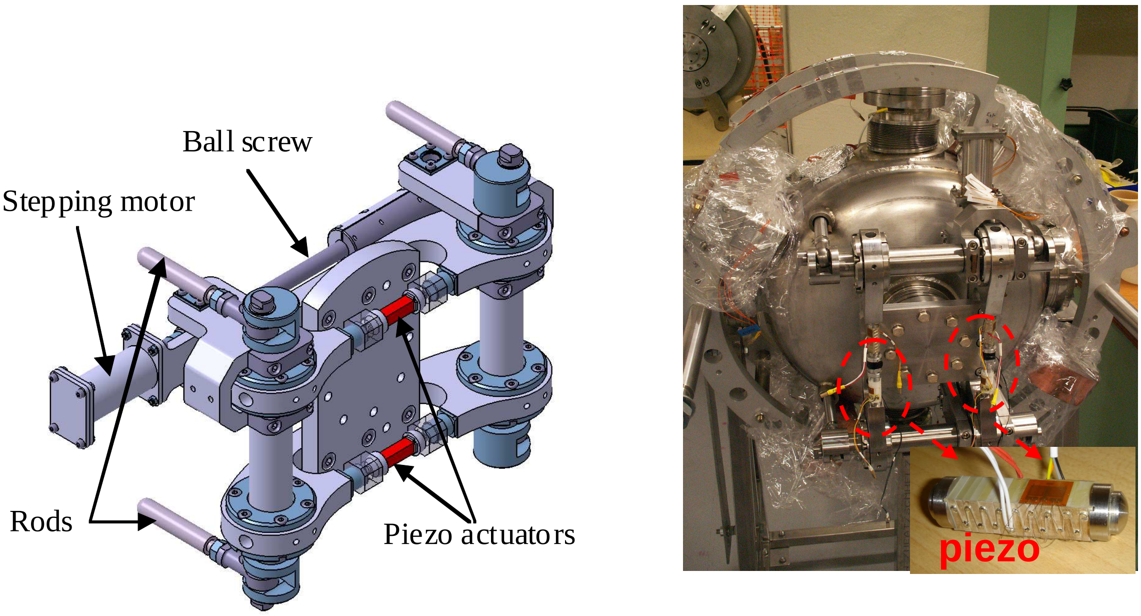


Fig. 9: Cold tuning system for spoke resonators

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The theoretical resolution of the system is 1 nm per micro-step, giving a frequency resolution of 1 Hz. Another important requirement is the CTS mechanical rigidity that should be much higher than the cavity rigidity in order to keep all the longitudinal displacement available for the cavity deformation. The β 0.15 spoke cavity axial rigidity was estimated at 6 kN/mm. Calculations performed with CATIA give a CTS rigidity estimation of 162 kN/mm. This high value allows 96 % of the CTS longitudinal displacement to be effectively seen by the cavity

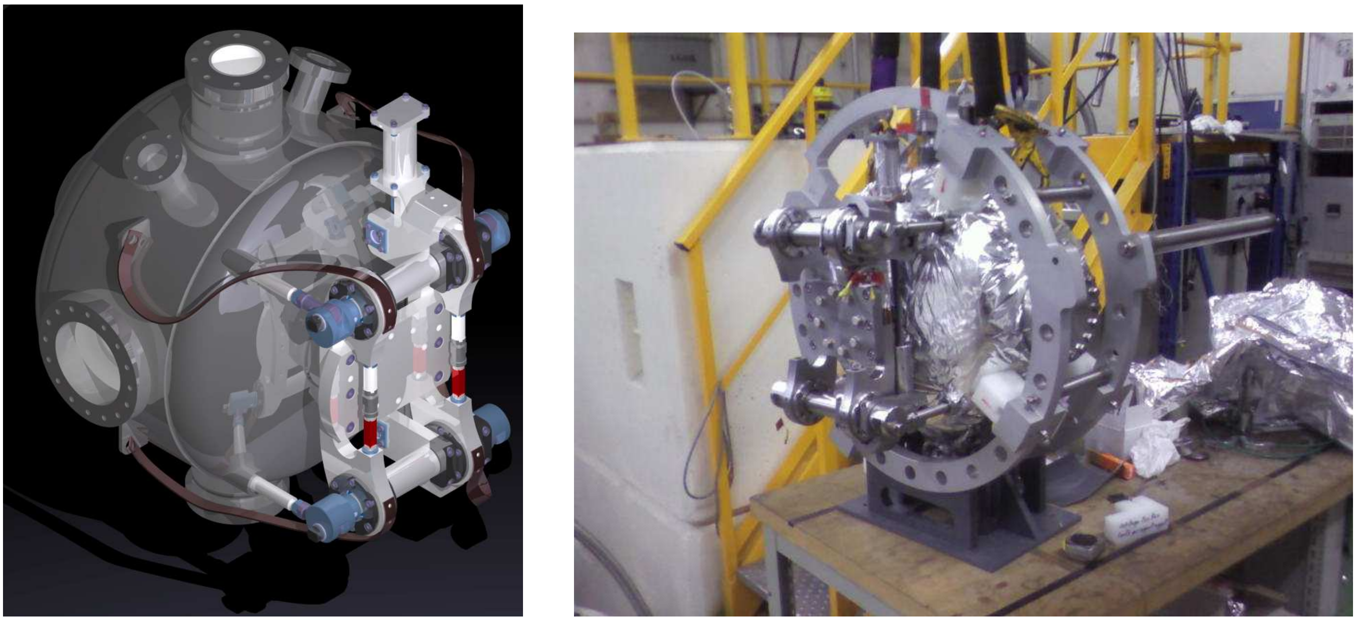

Fig. 10: Cold tuning system for spoke resonators

IV. Spoke cavity power coupler

A 352 MHz capacitive power coupler has been developed for the 2-gap spoke cavities to be mounted on the 56mm diameter port. The same coupler is also suitable for the 352 MHz Half-Wave resonator, providing that a specific RF transition is used to manage the differences in the cavity power couper port diameter difference.

The coupler geometry is coaxial, at 50 Ω using a warm disk ceramic window. The coupler is designed to be able to transfer 20 kW of RF power to the cavity. Two pipes located on the window outer diameter give the possibility to water-cool the ceramic.

Several window geometries were studied: cylindrical, disk (with and without chokes), travelling wav. For each geometry, the HFSS software was used to calculate the RF parameters, the surface field on the ceramics, the bandwidth, and the RF losses. Finally, the design based on a disk ceramic without choke was chosen because it was the best compromise between good RF performances and simplicity, leading to a reliable and cost-effective design. The computed S11 parameter is shown on Fig. 11: a value of – 57 dB is obtained at the nominal frequency. The coupler exhibits a very large bandwidth, allowing having standard fabrication tolerances.

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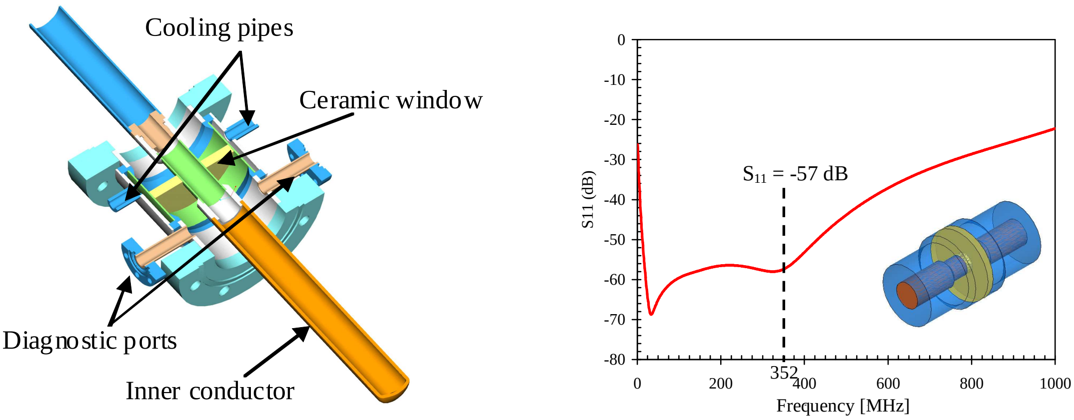

Figure 11: Overall drawing of the 352 MHz power coupler (left) and computed S11 parameter (right).

Two ceramic windows prototypes have been ordered to the SCT Company (Fig. . They have been characterized at low power (measurement of RF parameters) before the antenna welding.

Figure 12: RF ceramic windows before the antenna welding

After reception of the two complete power coupler prototypes, the assembly of the conditioning test bench has been achieved after at careful cleaning and final assembly (Fig. 13a and 13b) of the important parts (RF ceramic windows, coaxial part between the cavity and window, conditioning cavity) in the IPN Orsay clean room

Figure 13a: Evaluation of the Power coupler cleaning procedure efficiency by performing a particle counting

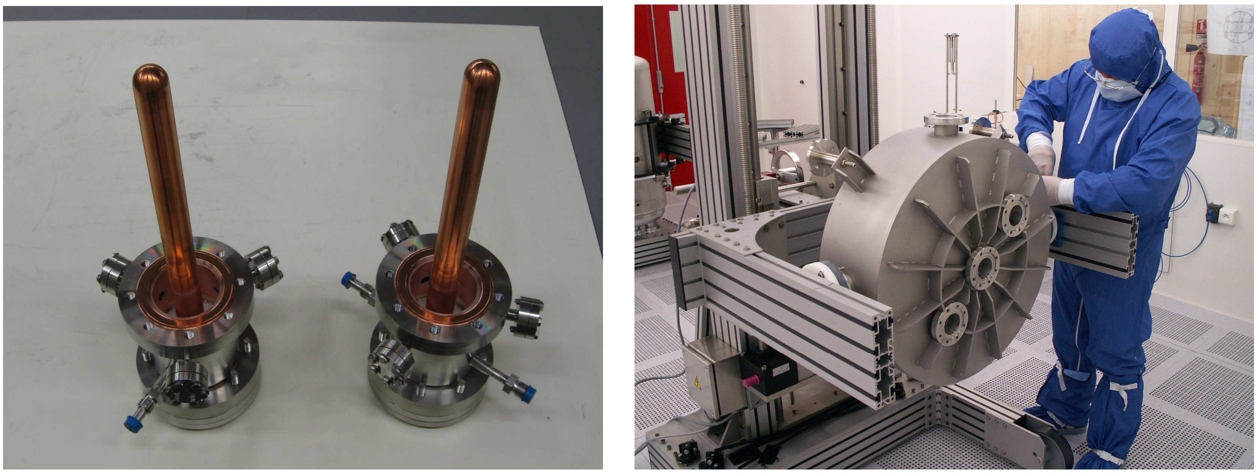

Figure 13b: The two power coupler prototypes (left) and the conditioning cavity assembly in the clean room

A test bench was conceived at IPN Orsay in order to perform the RF conditioning of two couplers at the same time in the travelling wave mode (Fig. 14). For this, a coupling cavity was designed (Fig. 15)

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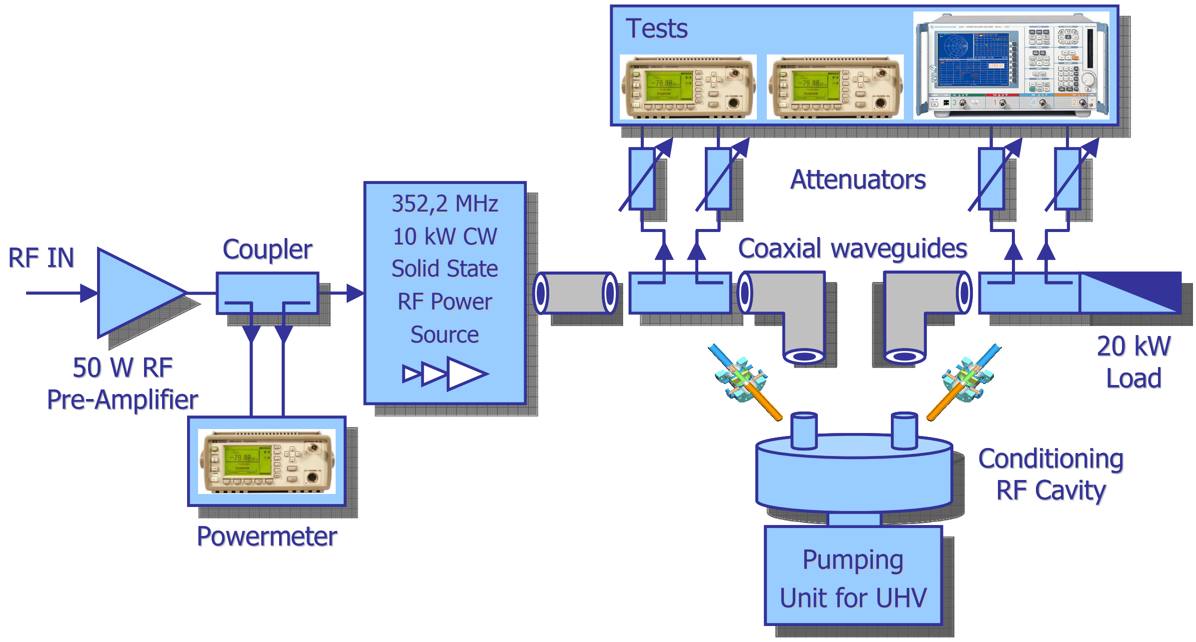

Figure 14: Schematic of the 352 MHz power coupler conditioning test stand.

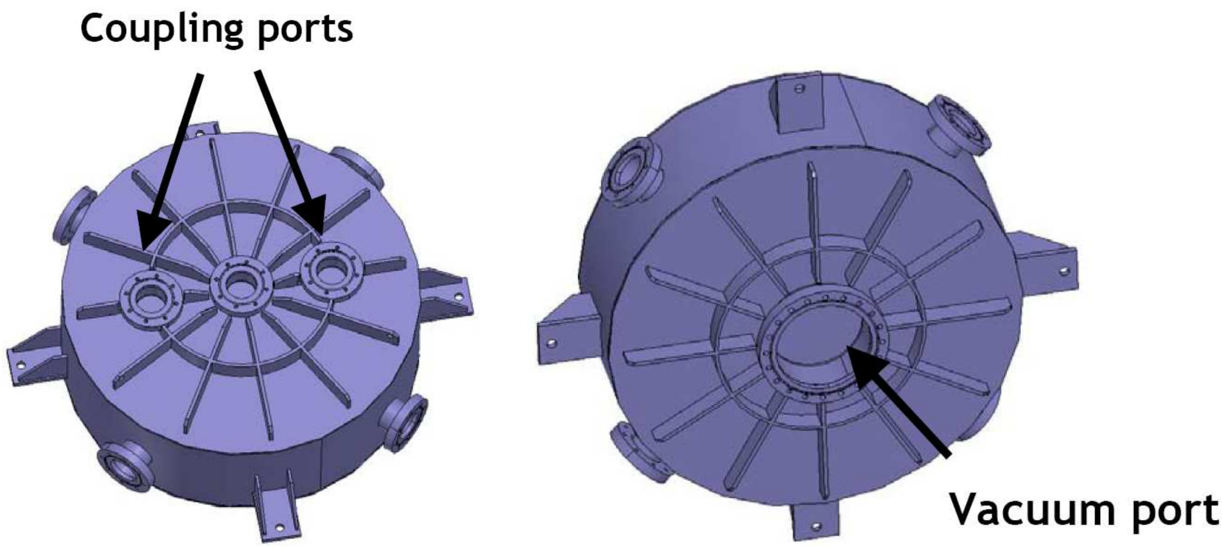

Figure 15: Drawings of the both side of the conditioning bench coupling cavity. It allows the RF power transition from one coupler to another and has ports for vacuum pumping and frequency tuners.

The conditioning of the power coupler has started on the warm test bench (Fig. 16). This important stage consists in feeding the 2 power couplers mounted in series with an increasing RF power, from 0 to 10 kW, step by step. The aim is to condition the RF surface to get rid of any electron emission or multipacting in the coupler. After a few hours, the couplers succeeded in transmitting the 10 kW of RF power, and a stable operation point was reached.

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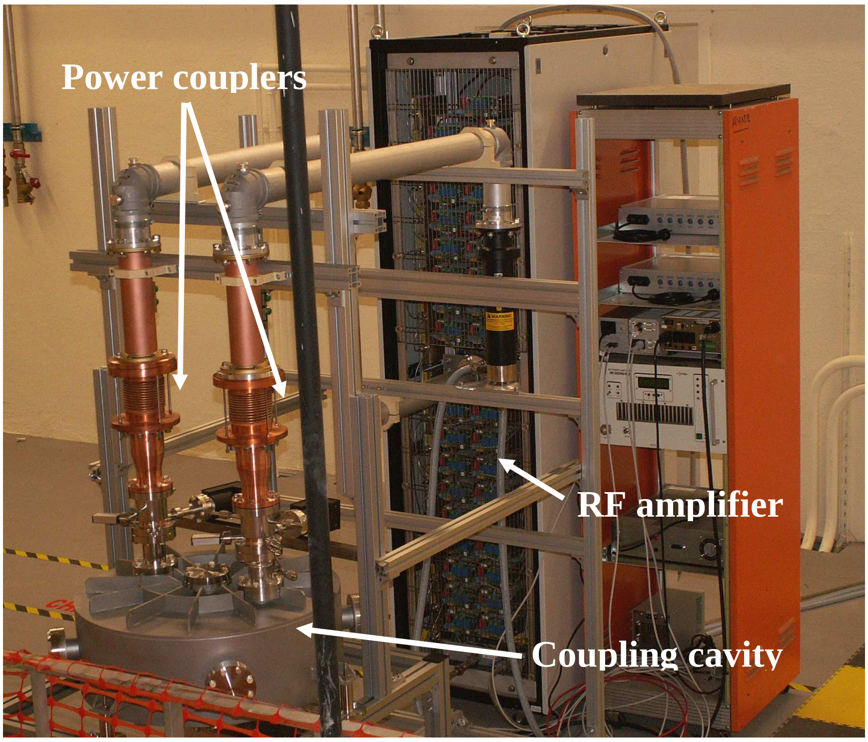

Figure 16: Power coupler conditioning bench during operation at 10 kW

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