FZJ HIPPI SC TRIPLE-SPOKE CAVITY

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Abstract

The paper describes the design, fabrication and test results of the superconducting triple-spoke cavity (resonant frequency 352 MHz, β=0.48) developed at Forschungszentrum Juelich in the frame of High Intensity Pulsed Proton Injector (HIPPI) project. The cavity has 5 cm diameter beam aperture, a transverse radius of 21.7 cm and the whole length of 78 cm. Intense cavity RF and structural analyses have been conducted and the further prospective on cavity developments are presented. Construction of the niobium cavity prototype has been completed; the cavity has been chemically processed. Results of initial cold test are discussed.

CAVITY DESIGN

A cavity electrodynamics design aims to optimise the cavity geometry to minimize values of peak electrical and magnetic fields on the cavity surface relative to the accelerating electrical field on the cavity axis (B_{pk}/E_{acc} and E_{pk}/E_{acc}). The detailed cavity RF analyses have been published many times elsewhere [1]. Additionally, making cavity RF design, fabrication technology and structural parameters have to be taken into account. The whole our RF design has been greatly adapted to two main goals - the simplest technology of cavity manufacture and to the prime goal of the project to achieve the best possible structural parameters (Lorenz force frequency shift and frequency pressure dependence). In our case, racetrack/elliptical spoke base shapes have been also under consideration [2] but found to be more complicate for manufacture and the circular conical shape have been accepted. Also, the cavity square cross section [3] is much less rigid rather cylindrical and requires very complicate stiffening structure. The final geometry and parameters of the cavity are shown in Fig.1 and Table.1.

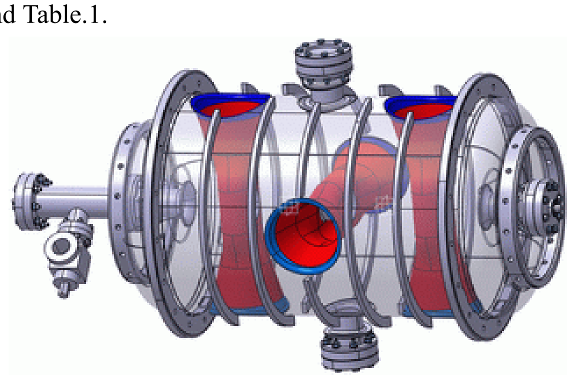

Figure 1: 3D view of triple-spoke cavity.

The strategy of cavity structural design should include the integrated simulations of RF and mechanical properties. The conducted coupled analyses resulted in the understanding of the cavity frequency dependence on the external pressure and Lorentz forces [4], cavity modal analyses, the proper cavity mechanical design and experimental result interpretations. The uncertainty with the cavity final wall thickness changes the results of the structure optimisations. The cavity structural behaviour can be accurately generalized to the case of arbitrary boundary conditions, characterized by its longitudinal stiffness K_{ext}, [5] (Fig.2). The final thickness of 4 mm of cavity walls for calculations is supposed.

Table 1: Some parameters of triple-spoke cavity.

Frequency	MHz	352
β=v/c		0.48
$R_{aperture}$	mm	25
βλ	mm	408.8
R_{cavity}	mm	217
R/Q	Ohm	420
QR_s	Ohm	93
E_{pk} / E_{acc} *)		4.65
B_{pk} / E_{acc} *)	mT/MV/m	10.97
*) L_{cav} = N_{gaps} * βλ/2, where N_{gaps}=4 – number of gaps		

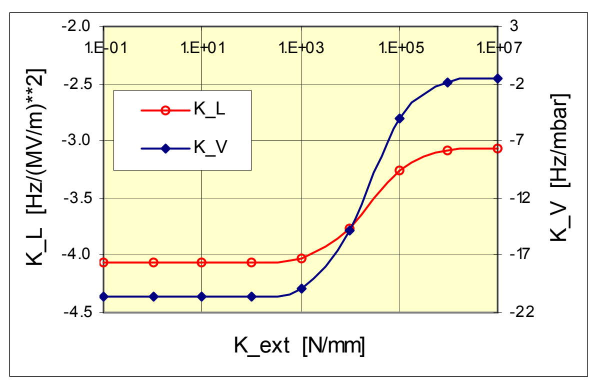

Figure 2: Cavity structural analyses results.

CAVITY FABRICATION

The Central Department of Technology (ZAT) of Forschungszentrum Jülich was essentially involved in design, construction and fabrication of the cavity. The niobium walls and spokes are formed of 4 mm thick Nb sheets, end cups of 5 mm. Significant efforts were made to work out the technology of EB welding of 4 mm niobium sheets. The spokes were formed in halves and seam welded together. Transition rings were machined from bar stocks and welded to the ends of spokes to provide a transition to the cylindrical housing with a blend radius of 5 mm. The cavity walls also have been manufactured from two halves and longitudinally welded.

During fabrication of the end cup the wall thickness has been changed but still stayed within acceptable distribution from 3.9 to 4.9 mm. Different cavity components are shown on Fig.3.

Some options of the cavity end cup stiffening were considered. Ecole des Mines, Evry, Paris (C2P) could successfully coat the outer surface of the end cup using copper plasma spraying (Fig.3). The layer had a maximum thickness of about 19 mm and it took about 8 days of effective spraying work. The end cup was thermal cycled from RT to LN_2 temperature (77K). The end cup has been put very rapidly in a bath filled with liquid nitrogen. As soon as the liquid nitrogen stops boiling (several minutes) the end cup has been cooled down to 77K. After that the end cup was removed from the bath and was dried again to RT. An infrared heating device was used to speed up the drying process. To minimize the condensation and freezing of water on the cold end cup a flow of dry air was used. In an hour the end cup was warmed up to RT. The thermal cycling procedure was repeated six times. To investigate in details the interface region between the copper coating and the niobium plate several probes from the end cup using a water beam-cutting device have been cut. During the water beam cutting there was no additional heat introduced into the components. Three probes were cut from the component. In two cases the copper coating hasn't had any contact to the niobium plate. Still, supersonic echo measurements of end cup thickness before and after thermal cycling allow concluding that the thermal cycling does not destroy the contact between copper and niobium. A series of simulations has been provided to choose an alternative end cup stiffening scheme. The final stiffening with the end cup ring that allows also a cavity vacuum test under RT has been realized.

All cavity welds were EB welded using our in-house EBW machine. The outer cavity stiffening structure was laser welded to the cavity body.

FIRST COLD TEST RESULTS

The triple-spoke cavity received its chemical treatment (BCP) at Saclay. Approximately 60 to 90 µm of Niobium were removed. Two BCP runs were made, each with the cavity in horizontal position, sending the acid in via the lower coupler port, and taking the out coming fluid from all three other openings back to the closed acid circulation system (Fig.4). Filling and emptying took about 8 minutes. Fresh acid circulated for about 70 minutes through the cavity. For the second run the flanges were detached, and the cavity was turned about the horizontal axis by 180 degrees before the flanges were re-attached again. The cavity was subsequently high pressure rinsed at IPN-Orsay. The standard nozzle designed for elliptical cavity was used. All four ports were used for rinsing; the rinsing was done in 4 positions, every time the rinsing water was pumped from the bottom. After the HPR the cavity was dried in a class 10 clean room for several hours and then all auxiliary parts such as blank flanges, input and output probe and pump out port with valve were assembled.

Figure 3: Different cavity components.

Preparation of the cavity for insertion into the vertical bath cryostat included attaching thermo-elements, installing a siphon for removal of He gas from the lower end cap, installing RF lines for (critical) coupling and for the field probe, line for vacuum pump, etc (Fig.5). Cooldown revealed no problems. The first measurements have been provided by 4K. At E_{acc}=5.8 MV/m the test has been stopped by the cavity quench. There was a MP discharge at around E_{acc}=1 MV/m, but it was easily processed. For the second measurement the upgrade of our testing facility for 2K operations has been made. The test has been stopped by a strong MP discharge at about E_{acc}=5 MV/m. Fig.6 shows the Q vs E_{acc} performance of the cavity in both tests at 4.2K and at 2K.

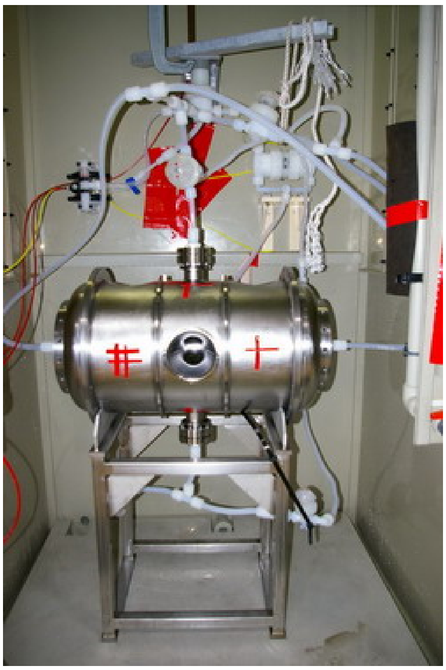

Figure 4: BCP installation at CEA-Saclay.

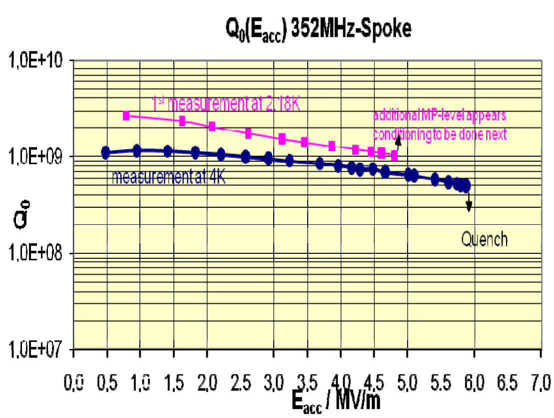

Figure 6: TSR test results.

The sensitivity of the cavity frequency to the pressure in the helium bath is measured $df/dp_{\_exp}$=-31.9 Hz/mbar with estimated $df/dp_{\_calc}$=–21.4 Hz/mbar. The Lorentz force detuning during the high power test at 4.2 and 2K was measured showing the same results K_{L_exp}=–5.5 Hz/(MV/m)^2 with K_{L_calc}=–4.1 Hz/(MV/m)^2.

Figure 5: Triple-spoke cavity at FZJ test stand..

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