DEVELOPMENT OF SPOKE CAVITIES FOR THE EURISOL AND EUROTRANS PROJECTS.

G. Olry[#], J-L. Biarrotte, S. Blivet, S. Bousson, C. Joly, T. Junquera, J. Lesrel, A.C. Mueller, H. Saugnac, P. Szott, CNRS/IN2P3, IPN Orsay, France.

E. Zaplatin, FZJ, Juelich, Germany.

Abstract

IPN Orsay is strongly involved within the EURISOL and EUROTRANS projects, especially collaborating to the overall design of their linac architecture. Since a few years, main part of the R&D work is dedicated to the development of superconducting spoke cavities and their associated components (RF coupler, tuning system horizontal cryomodule...).

Following the very promising results obtained with our first single-spoke prototype (2-gap, 352 MHz, beta 0.35), a new prototype has been designed and fabricated (2-gap, 352 MHz, beta 0.15) in order to be integrated in a future linac. The mechanical and RF tests, done on this prototype, are presented. Then, an overview of the latest beam dynamics calculations performed to design a linac using spoke cavities will be described.

BETA 0.35 SINGLE-SPOKE CAVITY

This prototype has shown very promising RF performances: Eacc max = 16.2 MV/m at 2 K (which corresponds to a voltage gain of 3.24 MV). More details of the measurements and results done at 4.2 K and 300 K temperatures are presented in the proceedings [1] and [2].

Lorentz force detuning

The static Lorentz force detuning factor has been measured several times during the cold tests. The cavity beam tubes were fixed every time. $K_{Lorentz\ measured}$ (in Hz/(MV/m)^2) = -5.72, -6.94, -6.36, -6.68, -5.60 and -7.30 at 4.2 K and -8.91 at 2 K. Thanks to Evgeny Zaplatin from Forschungszentrum Jülich (FZJ), we have compared these experimental data with the one calculated with ANSYS. He found $K_{Lorentz\ calculated}$ = -5.49 Hz/(MV/m)^2, using the same boundary conditions (i.e. both beam tubes fixed) and a 3-mm uniform thickness for all cavity walls. This result fits well the measurements, as for the other calculations he performed for the beta 0.15 spoke cavity (next §) and the beta 0.12 Quarter-Wave Resonator [3].

BETA 0.15 SINGLE-SPOKE CAVITY

Since 2002, the design of this second prototype has changed thanks to the experience gained on the beta 0.35 cavity. For instance, we chose a new RF port location and a new stiffening system [4, 1, 2]. The cavity has been

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[#]olry@ipno.in2p3.fr

built this year by the Cerca company within 7 months. Figure 1 shows the cavity after the final welding.
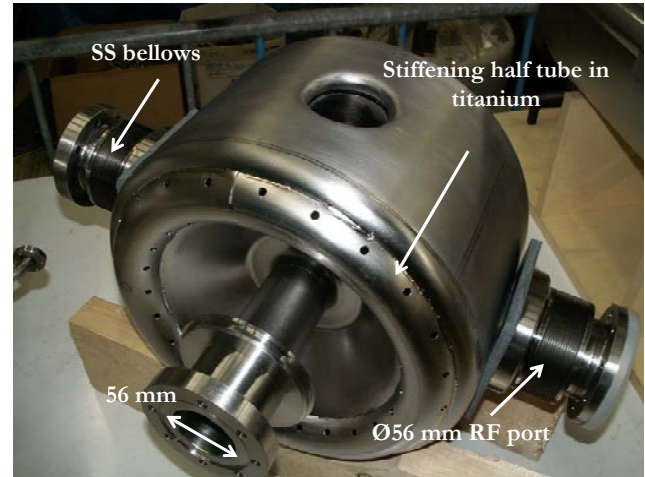

Figure 1: Beta 0.15 spoke cavity made of RRR250, 3-mm thick, niobium sheets from TokyoDenkaï (Japan).

RF parameters

The main RF parameters are presented in Table 1. New calculations have been performed using Microwave Studio (MWS) and have shown some discrepancies as compared to the previous ones performed with MAFIA (for instance, -30% for the Qo value calculated with MWS). We did not yet investigate in details the reason why but it seems that the new modeller of MWS describes more precisely the geometry and gives more accurate values of the peak surface electric and magnetic fields.

Table 1: RF parameters of β0.15 spoke cavity

	MAFIA	MWS
Q_0[a] (@ 4.2K)	1.36 E+9	1.76 E+9
(@ 2 K)	6.23 E+9	8.18 E+9
G [Ω]	67	89
Epeak/Eacc	3.32[b]	3.24[b]
	6.74[c]	6.56[c]
Bpeak/Eacc [mT/MV/m]	7.14[b]	6.62[b]
	14.48[c]	13.40[c]
Voltage gain for Epeak=30 MV/m [MeV]	0.63	0.78
Optimal beta	0.20	0.20

[a] Assuming a residual resistance of 10 nΩ
[b] Lacc=iris-to-iris length=0.084 m and
[c] Lacc=βλ length=0.170 m

In general, we found Bpeak values 11% lower with MWS than with MAFIA, which gives a dissipated power value about 21% lower with MWS. Thus, this could be one of the reasons to explain these discrepancies but that must be checked more precisely.

Tests @ 300 K

The cavity was delivered in December 2004 without its Helium tank and firstly tested at 300 K. No leaks were detected under vacuum and we checked the mechanical behaviour of the new stiffening system. As shown in the Table 2, the displacements and the frequency shift of the cavity were in good agreement with those expected.

Table 2: Mechanical parameters of the cavity a under vacuum load.

| | Beam tubes free | | Beam tubes free |
	Ansys[*]	Cosmos	Measurements @ 300K
Max displacement (mm)	0.14	0.18	0.17
Max Von Mises stress (MPa)	43.8	38.7	N/A
Frequency shift (kHz)	-378.7	N/A	-440

[*]Calculations performed by Evgeny Zaplatin (FZJ)

Then, we measured the thickness of the cavity walls (after a chemistry treatment of 140 µm) on 20 points of 16 profiles. The Figure 2 shows the mean value on a profile. One can notice that the thickness is locally close to 2 mm (instead of 3 mm initially)! As we will see, this thickness reduction has a big effect on the static Lorentz force detuning factor.
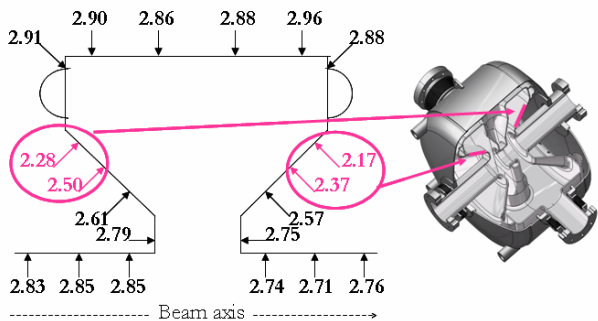

Figure 2: Average thickness in mm.

Test @ 4.2 K and 2 K

The cavity preparation has been done at CEA/Saclay. 140 µm were removed (BCP) and the cavity was rinsed through its 4 ports during 2 hours (HPR of 80 bars).

First test at 4.2 K has needed a 2-hour RF conditioning process to reach 9.6 MV/m (P_{cavity} dissipated max = 15 W). The limitation was due to a quench (Figure 3). Two multipacting (MP) barriers were observed at 1.5 MV/m and around 8 MV/m but easily processed within a few minutes. X-ray emission started from 4 MV/m during the 1st test then nothing after that (during the 2nd and 3rd tests).

We saw also a quench during the test at 2 K for Eacc max = 10.5 MV/m (P_{cavity} dissipated max = 8 W). The same MP barrier at 8 MV/m has been observed but without X-ray emission.

As the quench levels are the same, i.e. for Bpeak ~ 70 mT, one can suspect a big defect (around Ø100 µm) on the RF surface. We plan to remove at least 200 µm more for the next test, hoping to remove this defect.
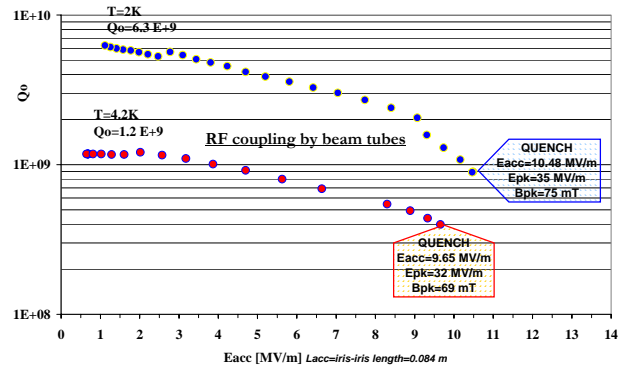

Figure 3: Cold tests results: Qo vs. Eacc

Lorentz force detuning

The cavity was tested in vertical cryostat with its beam tubes "free" (no external stiffening system was used as during the beta 0.35 spoke cavity tests).

The static Lorentz force detuning factor was measured twice: $K_{Lorentz\ measured}$ = -55 and -47 Hz/(MV/m)². As illustrated in Figure 4, Evgeny Zaplatin has shown the effect of a thickness reduction of the spoke cavity walls. One can see a good correlation with these calculated values for a cavity walls thickness between 2 and 2.5 mm.
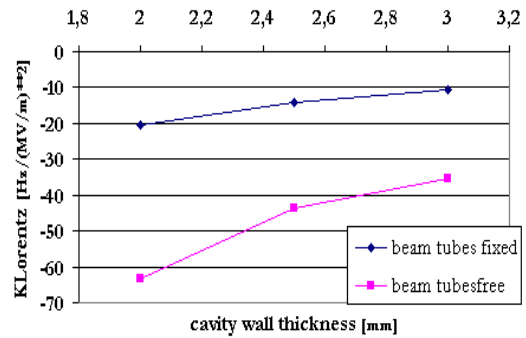

Figure 4: The static Lorentz force detuning factor vs. the spoke cavity walls thickness.

BEAM DYNAMICS CONSIDERATIONS

Spoke cavities can be very efficient in a broad intermediate velocity region, from roughly β=0.1 to β=0.6. Moreover, these cavities are short and modular, and can be very attractive, when independently powered, to accelerate several q/A ions in the same linac, like in the EURISOL case [5], or to improve the linac global

reliability using a fault-tolerance strategy, like in the EUROTRANS case [6].

Spoke cavities for EURISOL

The EURISOL driver accelerator has to accelerate protons up to 1 GeV, but must also exhibit a strong heavy-ions capability, especially to accelerate deuteron beams [7]. In this respect, 2-gap 352 MHz spoke cavities (β=0.15 & β=0.35) are proposed to cover the 5-100 MeV proton energy range while ensuring a 50 MeV/u output energy for deuterons. In the case where the EURISOL injector operates at 176 MHz (this choice is presently under discussion), still the second spoke section (352 MHz, β=0.35) would perfectly fit to the linac design.

Concerning the EURISOL post-accelerator, which has to accelerate radioactive beams in a very large q/A range up to 100 MeV/u, 264 MHz, 2-gap, β=0.38 spoke cavities are also good candidates for the high-energy section of such a machine, as shown in Table 3.

Table 3: Possible layout for the EURISOL post-accelerator using 264 MHz 2-gap spoke cavities.

$^{132}Sn^{25+}$	Section 1	Section 2	Section 3	Section 4	TOTAL
Cavity Freq.	88.05 MHz	88.05 MHz	176.1 MHz	264.15 MHz	-
Cavity β	0.07	0.12	0.24	0.38	-
# cav./ lattice	1	3	6	9	-
# cavities	12 cav	27 cav	60 cav	126 cav	225 cav
Length	13.3 m	21.6 m	41.7 m	84.7 m	161.3 m
Beam energy	0.67 MeV/u 2.8 MeV/u	2.8 MeV/u 14.3 MeV/u	14.3 MeV/u 39.2 MeV/u	39.2 MeV/u 100.1 MeV/u	0.67 MeV/u 100.1 MeV/u

Spoke cavities for EUROTRANS

The EUROTRANS project aims at demonstrating the technological feasibility of a high-power proton driver for an ADS.

The main challenge here is to reach the reliability requirement, which is extremely stringent: beam trips in excess of 1 second duration should not occur more frequently than 5 per year. To reach this goal, the proton superconducting linac must be "fault-tolerant": any individual cavity failure must be handled "on-line" at all stages without loss of the beam. This is done using the local compensation method, which principle is illustrated in Figure 5: with an appropriate retuning, beam dynamics simulations show that in every case of RF cavity failure, the beam can be transported up to the high-energy end without any beam loss. At least 30% margins on RF power and accelerating fields are needed to carry out such a compensation [8]. In order to practically implement such a strategy, fast recovery scenarios (milli-second range) have to be set up. The use of adequate diagnostics and fast digital LLRF control systems with pre-tabulated set-points is mandatory.

The feasibility study of these transient scenarios is presently starting within the EUROTRANS project, with expected results before 2007.
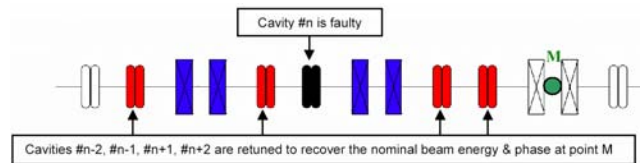

Figure 5: The "local compensation" method.

CONCLUSION

Following these good results, we will test, in 2006, the beta 0.15 spoke cavity, equipped with its Helium tank and its RF coupler, inside a horizontal cryostat, presently under development at IPN. We also plan to fabricate two new spoke-type prototypes for EURISOL and start the design of their dedicated cryomodule with a preliminary LLRF control system.

ACKNOWLEDGEMENTS

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