STATUS OF THE 80 MHZ SC-RFQ DEVELOPMENT AT LNL

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ABSTRACT

First results of the being developed full niobium superconducting RFQ project for the ALPI injector PIAVE at LNL are reported. Two separate cavities, SRFQ1 and SRFQ2, will accelerate heavy ions with charge-to-mass ratio 1/8.5, injected from an ECR source located on a 350 kV platform, from 37.1 keV/u to 587 keV/u.

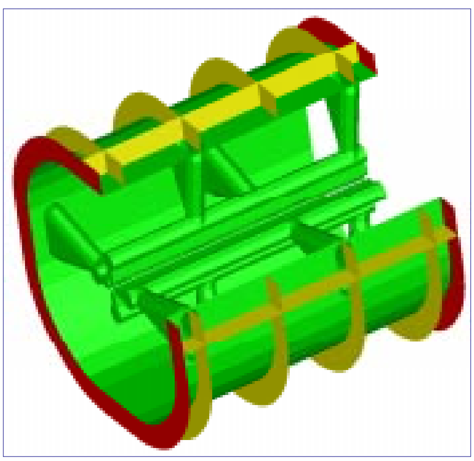
A full scale stainless steel model of SRFQ2 was built, aligned and tested in order to investigate all procedures of manufacturing, electron beam welding, assembly, positioning, mechanical stability, rough and fine frequency tuning of the structure. Beside the room temperature tests, which are being carried out at present, cooling of the structure to liquid nitrogen temperature in a test cryostat is also foreseen.

The paper summarizes the results achieved with the stainless steel model.

INTRODUCTION

PIAVE, the new high current injector of the heavy ion booster ALPI at INFN-Legnaro, is shown in fig.1. It is the first accelerator which will employ superconducting radiofrequency quadrupoles (SRFQ's) as the first accelerating structures. A proof of principle of SRFQ's was made at Stony Brook [1], a very high field - though without modulation - full Nb RFQ was built and tested at ANL as a modification of a Split Loop Resonator [2], while a prototype of a 350 MHz modulated RFQ is being built at ANL, in the frame of the proposed Exotic Beam Facility [3].

The present paper recalls the main construction steps of the full size stainless steel prototype of SRFQ2. A full niobium SRFQ requires several assembly and electron beam welding steps, which must end up in a carefully aligned structure, the frequency of which must lie in the fine tuner range (± 0.1 MHz): the whole construction and EBW sequence was hence tested on a full scale SS prototype, before going to expensive niobium. The low frequency (80 MHz) and the consequent large size of the structure make it extremely frequency-sensitive to even small amplitude mechanical vibrations, both because the lowest natural vibration mode tends to be low and because the content of electromagnetic energy is large, thus requiring significant power to the RF to be able to lock the resonator in phase and amplitude [4][5]. Great attention was hence paid to the mechanical design of the structure, which was stiffened by a titanium jacket on the outside. First RF tests on the model (frequency, Q and unbalance among the quadrants tested by a preliminary bead pull investigation) are reported, as well as accelerometry measurements meant to verify the mechanical frequency spectrum of the RFQ, to be compared with what predicted by the computational code I-DEAS [6].



	SRFQ1	SRFQ2
Resonant Frequency [MHz]	80	80
Length [mm]	763	1347
Diameter [mm]	620	640
Vane voltage [kV]	148	280
Stored energy [J]	2.1	3.6
Capacitance [pF/m]	143	135
Max. surface field [MV/m]	25	25
Max. magnetic field [Gauss]	233	241
Shunt impedance [MΩ] (Cu)	0.276	0.43
Power Loss [kW] (Cu)	79.5	133
Q value (Cu)	13319	13400
Field bump [%]	0.3	0.5

Fig.1: Pictorial view of SRFQ2: it is a four rod structure with 90° apart stems, with a stiffening jacket on the outside. It will eventually be built in 3 mm thick Nb (RRR=250) and the stiffening jacket in Ti. Stems are hollow as well as cylinders on the back of modulated electrodes. The table summarizes the RF features of both SRFQ's, as calculated by M.A.F.I.A. We judge E_p to be achievable and B_p to be not critical. The larger U content and the smaller length of SRFQ2 suggested to prototype this resonator first.

CONSTRUCTION OF A STAINLESS STEEL PROTOTYPE OF SRFQ2.

A full scale stainless steel prototype of SRFQ2 was built, for the sake of understanding the construction, electron beam welding, mechanical assembly, rough and fine tuning techniques of the resonator. The more challenging part of the mechanical construction was performed in the LNL mechanical workshop (machining of the electrodes, extrusion of the cylinder on the back of the electrodes, deep drawing of the stems) whereas the external tank and the stiffening jacket were realized by local companies. Electron Beam Welding (EBW), which is definitely not straightforward because of the complexity of the structure, was also realized at an italian company, supported by LNL on the machine programming of the most difficult welds (e.g. the race-track shaped weld between the stem and the tank, which is an “internal” weld).

Fig.2 shows the disassembled structure before the final EBW steps.

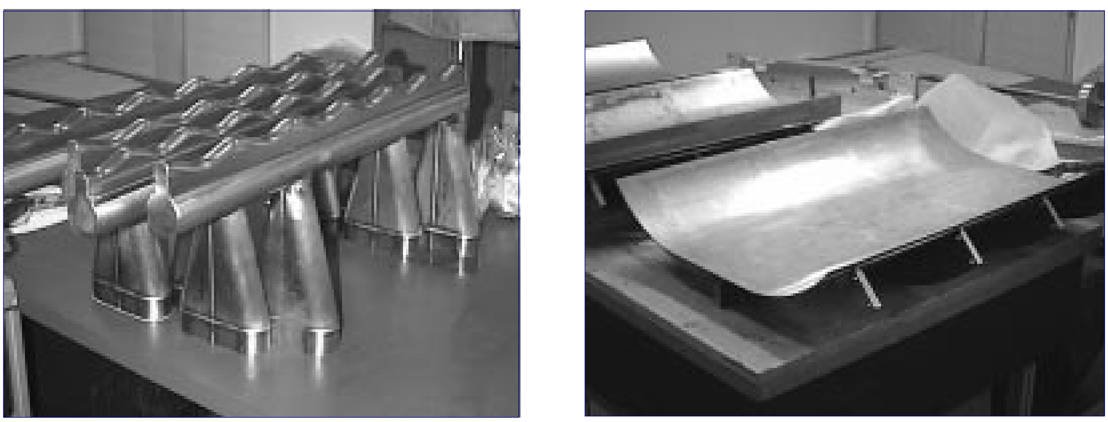


Fig.2: modulated electrodes with stems and stiffened tank quadrants, prepared independently, ready to be EB-Welded to one another

ROUGH FREQUENCY TUNING.

The SRFQ is first of all assembled, without any further welds, into its positioning jig. The electromagnetic frequency is then measured. The resonator was built deliberately larger in diameter, so that the correct frequency can be approached by stepwise reduction in length of all stems by the desired amount. At each step the structure was reassembled and the frequency measured (fig.3). Three such steps were sufficient in our case to reach a good frequency value, that is a value which is expected to be, at 4 K, at 80 $\pm$ 0.1 MHz, $\pm$ 0.1 MHz being the foreseen fine tuning range (fig.4). The final frequency was 79.675 MHz and the quality factor $Q \approx 1500$.

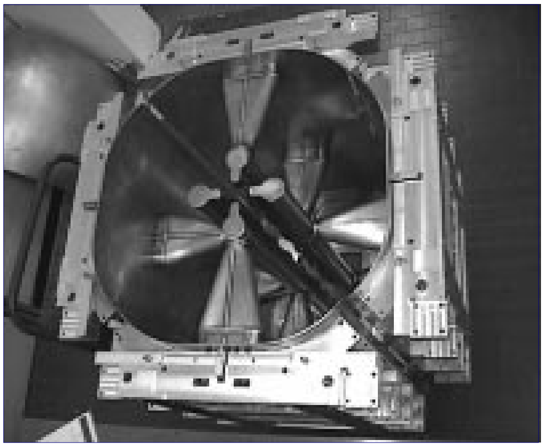
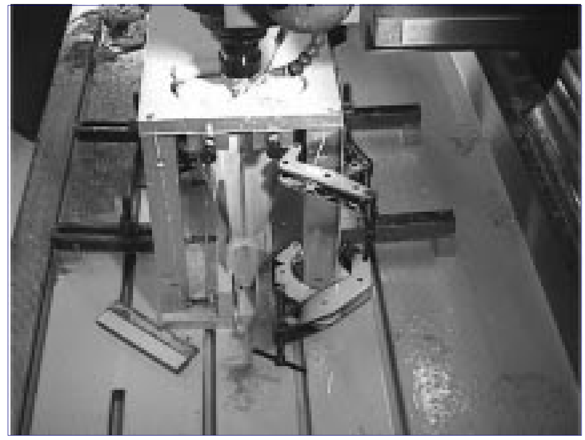



Fig.3: The stainless steel RFQ prototype being assembled in its jig for the first frequency measurement (first image) and one of the stems being cut by milling machine in order to squeeze the cavity and increase the frequency in the following measurement (second image).

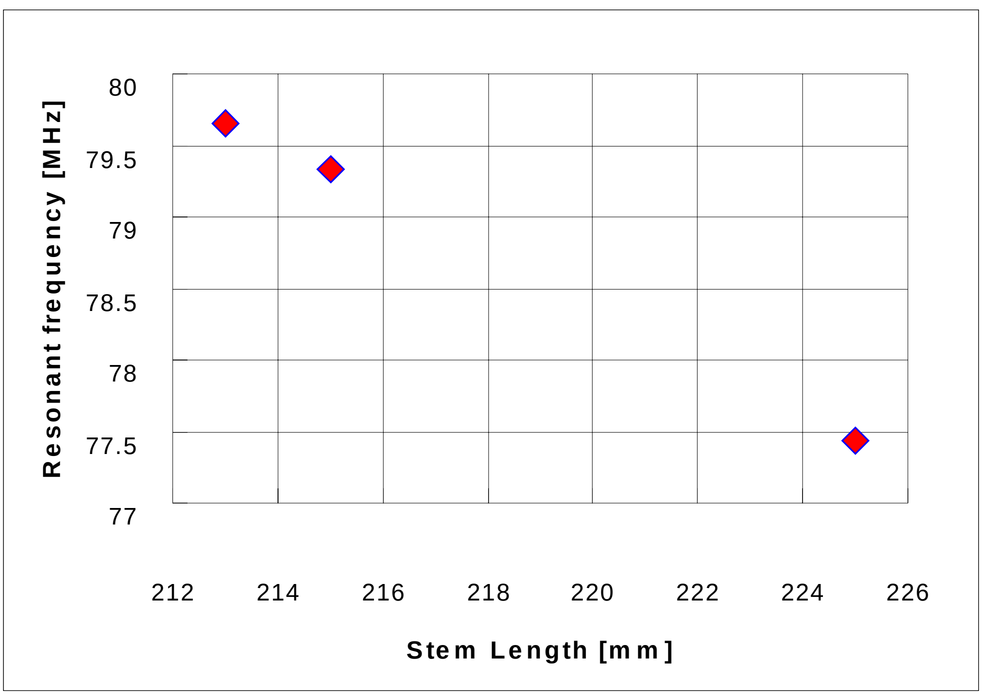


Fig.4: The result of the rough tuning frequency measurements is shown. The frequency sensitivity to the length reduction of the stems is Δf/Δl~180 kHz/mm. Taking thermal shrinkage (from 300 to 4 K) into account, and the consequent frequency increase, the target frequency is f_0 = 79.75 MHz at room temperature for stainless steel.

SS-SRFQ ALIGNMENT CHECKED BY BEAD PULL MEASUREMENTS.

A properly shaped bead was precisely positioned between couples of quadrants and in four points along the SS-RFQ structure. The bead was properly shaped so as not to be influenced by the large modulation and to reveal the effect of relative mispositioning of electrodes. The result of such bead pull measurements between couples of electrodes, in four points along the SS-RFQ structure, is shown in fig.5. The field bump due to mispositioning of the electrodes is within ± 2%.

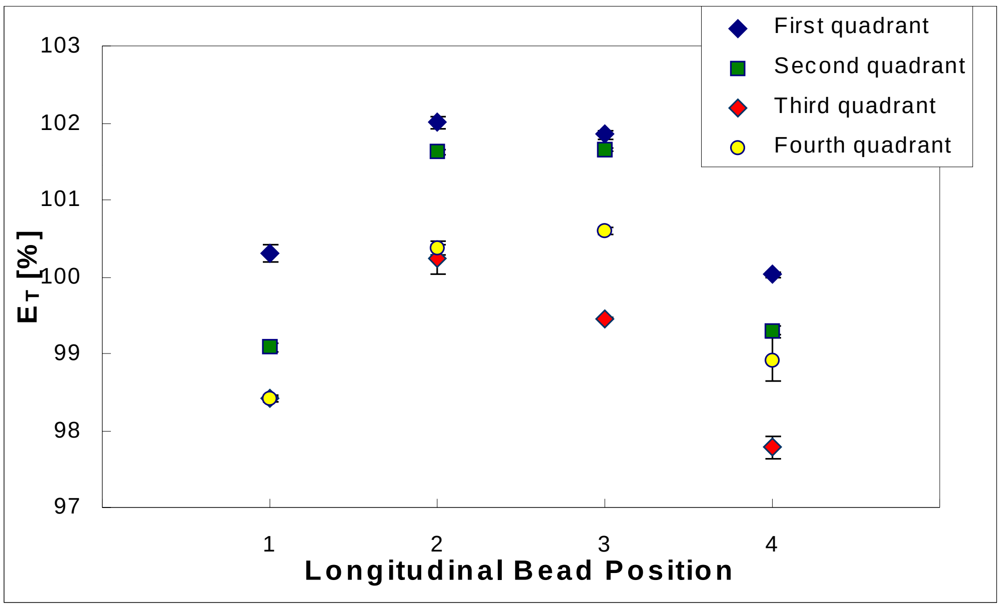


Fig.5: . Bead measurements in the four quadrants of SRFQ2: field bumps are within ± 2%. The positioning of the electrodes, when the measurements were taken, was with ± 0.3 mm with respect to the nominal position. Positioning was better after completion of the construction and the final welds.

ANALYSIS OF MECHANICAL VIBRATION MODES

The shape of the stems and the stiffening jacket geometry was optimized, in order to increase the frequency of the lowest modes of mechanical resonances in the RFQ [7]. Both the single electrode (with its stems) and the whole structure were simulated using a 3D FEM code and the first vibration modes were computed. An experimental check of these results was made on the single electrode so far (fig.6).

Measurements were done trying to approach, for the single electrode, the boundary conditions, imposed to the code, of infinite stiffness at the basis of the stems. The amplified signal from a piezoelectric sensor was viewed on a spectrum analyser. While 200 Hz is electromagnetic noise, the experimental peaks at 224 Hz and 262 Hz correspond to the computed 244 Hz and 349 Hz respectively, as calculated by the code for a single electrode in stainless steel.

The discrepancy is most probably explained by the boundary condition of infinite stiffness at the basis of the stems which, though carefully approached through proper fixation on the bench of the milling machine, cannot be obviously fully obeyed in practice.

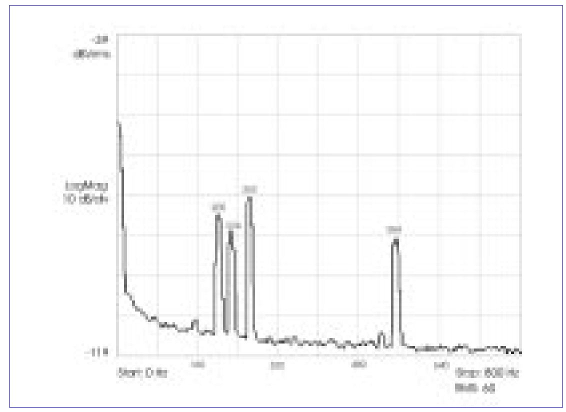


Fig. 6: experimental setup and frequency spectrum of the mechanical eigenmodes of the single electrode. The experimental values of the two lowest eigenmodes are lower than the estimated ones, by 8% and 25% respectively.

REFERENCES.

[1] I. Ben-Zvi, A. Jain, J.W. Noé, P. Paul, H. Wang And A. Lombardi, Nuclear Instruments & Methods B79 (1993) 711-713

[2] J.R.Delayen and K.W. Shepard, Appl. Phys. Lett. 57 (5), 30 July 1990, 514-516

[3] K.W. Shepard, W.L. Kennedy and K.R. Crandall, Proc. of the 1993 IEEE Particle Accelerator Conference, Washington, 1042-1044

[4] I. Ben-Zvi, M. Birk, C. Broude, G. Gitliz, M. Sidi, J.S. Sokolowsi, J.M. Brennan, Nuclear Instruments & Methods A245 (1986) 1-12

[5] G. Bassato et al., Nuclear Instruments and Methods A328 (1993) 195-198

[6] I-DEAS Finite Element Modeling, Structural Dynamics Research Corporation, 2000 Eastman Drive, Milford, OHIO 45150, USA

[7] G. Bisoffi, G. Algise and A. Lombardi, Proc. of the 7th Workshop on RF-Superconductivity, Gif-sur-Yvette 1995, 677-681