# CONSTRUCTION, TUNING AND ASSEMBLY OF THE BETA=0.12 SC LADDER RESONATOR AT LNL

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*Abstract*

The Ladder resonator is a 4-gap full Nb cavity suitable for the 0.1< β <0.2 range of high current proton linacs. A beta=0.12 Nb prototype of this cavity has been built by E. Zanon SpA (Schio, Italy) on the basis of LNL design. In this paper we describe the construction procedure of such cavity, as well as the tuning steps, aimed at the achievement of the target frequency of 352.2 MHz and the desired field uniformity along the four gaps. Related results of RF simulations and room temperature tests are presented. The preparation of the SC test at LNL is at an advanced stage.

## THE LADDER RESONATOR

The 4-gap Ladder resonator has been proposed [1] for the very low beta section (β =0.1÷0.2) of high current proton linacs in a variety of applications: production of exotic ion beams, transmutation of nuclear wastes, spallation neutron sources, neutrino factories, and technological neutron irradiation tools. Attractive features of such cavity are the relatively high real estate gradient due to the four gap acceleration occurring in a very short space and the possibility to equip the resonator with two large flanges, allowing easy internal inspections, surface treatments, and possible repairs. In Figure 1 a photo of the β=0.12 full Nb prototype of the Ladder resonator is shown.

Figure 1: Inner view of the full Nb prototype of the β=0.12 Ladder resonator, after completion of the construction procedure.

As a case study, the first section of the EURISOL [2] driver (CW, 5 mA) was considered. Eurisol is a being designed European facility for the production and reacceleration of exotic nuclear species. A total of twelve Ladder resonators ($\beta_{opt}$ = 0.12 and $\beta_{opt}$ = 0.17) cover the energy range from 5 to 20 MeV, immediately following the RFQ. The main nominal parameters of the $\beta_{opt}$ = 0.12 resonator are indicated in Table 1

Table1: Ladder main parameters

| **Parameter** | **Value** |
|---|---|
| frequency | 352.2 MHz |
| Energy gain at $\beta_0$ =0:12 | 1.15 MeV |
| $B_s$ | 0.065 T (set as a limit) |
| $E_{s,p}$ | 20 MV/m |
| rf coupling | 1.2% |
| Internal length | 196 mm |
| Gap length | 25 mm |
| Beam bore diameter | 25 mm |
| Stem height | 450 mm |
| $Q_0$ @4 K (assumed) | $5*10^8$ |

## CONSTRUCTION PROCEDURE: ASSEMBLY AND ELECTRON BEAM WELDING (EBW)

After the encouraging results obtained upon construction of the aluminum model [3] the construction of the full Nb prototype started in early 2005. The tuning of the Ladder cavity has been carried on together with the assembly and construction steps, namely the following

1) Construction and plastic deformation of each half-stem.
2) Welding of each couple of half-stems.
3) Construction of the plates, equipped with stiffening ribs and flanges.
4) Welding of the stems onto the top and bottom plates.
5) Welding of the lateral plates onto the top and bottom plates.
6) Construction of the head flanges.
7) Welding of the head flanges on the body of the cavity.
8) Construction of the beam ports
9) Welding of the beam ports

All welding seams were made from the inside of the cavity volume, with the exception of stem bases and beam ports, which were welded from the outside.

The stems, made out of a 3 mm thick Nb sheet, are hollow and filled with liquid helium, so as to provide efficient cooling of those areas where more intense rf currents flow. The same holds true for the four cavity walls shown in fig.1. All these plane surfaces needed to be stiffened with either ribs or pins, in order to stand the pressure difference between the liquid He and the vacuum volumes.

The large lateral flanges, which allow large access to the inner cavity volume and which are not shown in fig.1, are made of full Cu with a Nb layer sputtered on the cavity side. The joint between these flanges and the cavity body is by pure bolt pressure.

## TUNING STEPS: SIMULATIONS AND EXPERIMENTAL RESULTS

The rough tuning procedure has been carried out with the aims of obtaining, in the final operating conditions at 4 K: the target frequency of $f_0$= 352.2 MHz within $\pm\Delta f$ (where $\Delta f$ is the slow tuner range); a field uniformity along the four gaps within ±5%. Fine slow tuning is obtained by pushing and pulling both end plates of the resonator.

Estimation of the effect of buffer chemical polishing (BCP) and thermal shrinking of niobium between 300K and 4 K had been done a *priori* with the HFSS code [4]. The first estimation of the effect of BCP was performed assuming that 0.1 mm of materials is uniformly removed from the internal surface of the cavity. The associated volume variation produces a frequency shift of about $\Delta f_{ce}$= -100kHz.

The contraction of niobium, on the other hand, induces a frequency increase of about $\Delta f_{th}$= +480 kHz. The slow tuner acts by pushing or pulling the end plates on a surface of 80 mm radius. Simulations have shown that, for a 0.5 mm deformation of both plates the $\Delta f$ equals to 150 kHz. Therefore our goal was to obtain a frequency equal to $f_1 \pm \Delta f = f_0 + \Delta f_{ce} - \Delta f_{th} \pm \Delta f$ = (351.82 ±0.150) MHz.

In the first step the target frequency $f_1$ was sought by means of adjustment of the stem height h and the cavity length L, following a procedure already experimented with the aluminum model [3]. The simulations vs. measurements curves for h and L variations are shown in Figures 2 and 3.

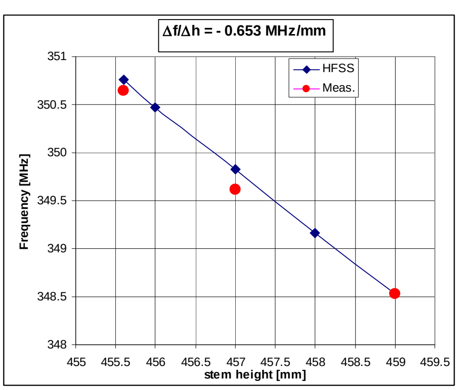


Figure 2: Result of rough frequency tuning by reducing the stem height h @ L=196 mm.

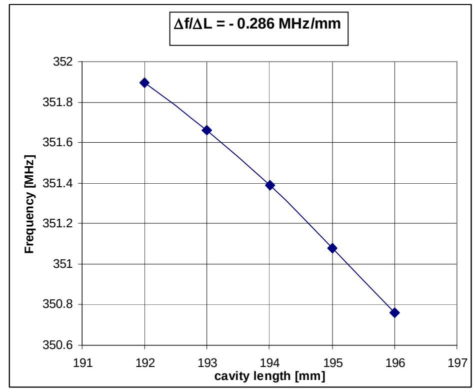


Figure 3: Result of rough frequency tuning by reducing the cavity length L @ h=455.6 mm.

From Figure 2 it is clear that the h reduction causes a decrease of the stem inductance and therefore a frequency increase, and, conversely, the L reduction causes a decrease of the inductance of the end cells and a frequency increase. It has to be noticed that the end cell capacitance (determined by the distance between beam port and end plates) is affected by such variations. On the basis of such results the settings for h and L before welding are L=193 mm and h=455.6 mm and the measured frequency was 351.790 MHz.

In the second step, after welding stems and head flanges, adjustment of the beam port depth and stem deformation were made, with the purpose of recovering the target field uniformity and to compensate the effect on related frequency changes. Of course, this will result in unequal gap lengths and, in principle, in a worsening of TTF and β acceptance. Nevertheless, if we compare this situation with the TTF and β acceptance drop due to perfectly β-tuned gaps and non-uniform field distribution, it can be noted that the former effect is less important than the latter and causes only a slight effect on the above quantities. In conclusion, it is largely preferable to obtain good field flatness at the expense of gap length uniformity (as far as variations smaller than about ±2mm of the gap lengths are considered) than vice versa.

The frequency measured after stem welding was 349.966 MHz and the field uniformity was significantly worse (Figure 4): indeed, the shrinkage of the final gaps due to EBW had been underestimated.

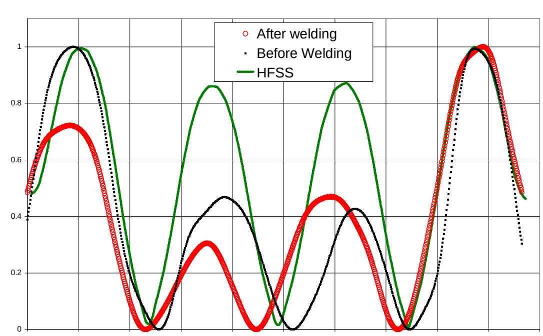


Figure 4: Measured on-axis fields before and after welding process and comparison with HFSS results.

Mechanical measurements confirmed that the four gaps g1, g2, g3 and g4 (numbered from the low energy side) had not maintained the design value (see Table 2). In particular g1 and g4 have become shorter, causing a capacitance increase and the detected frequency decrease.

Table 2: gap lengths before and after welding

| gap | g1 | g2 | g3 | g4 |
|---|---|---|---|---|
| **Meas. Value [mm]** | 22.3 | 24.7 | 24.8 | 22.9 |
| **Design value [mm]** | 25.0 | 25.0 | 25.0 | 25.0 |

We proceeded then with machining the beam ports and providing plastic deformation of the stems in the following way.

First of all, it should be noted that the frequency variation due to machining of the beam port depth is positive, because of the decreasing of the gap capacitance, which also causes a decrease of the fields in the external gaps. It has to be pointed out that, since the field is approximately equal at both beam port locations, the above-mentioned variation is the same for both beam ports. In addition, the deformation of lateral stems by pulling them towards the center causes the capacitance of the internal gaps to increase and the capacitance of the external gaps to decrease again, and therefore a further balancing of the field peaks has to be expected. Moreover, since the field magnitude in the external gaps is significantly higher than that in the internal gaps, this unbalance causes a frequency increase too. Both these effects have been checked with on-purpose HFSS simulations resulting in a frequency variation of +0.364 MHz for a 0.5 mm deformation of both stems and of 0.242 MHz/mm per machining of each beam port.

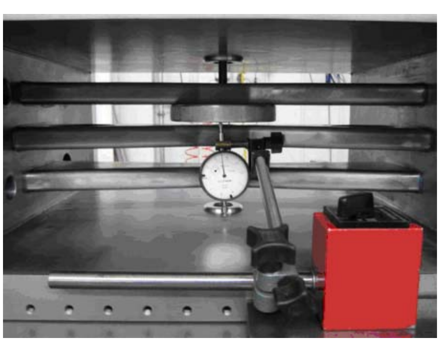

Figure 5: The mechanical device used for stem deformation.

Putting together all these observations, it was decided to machine the beam ports in order to have g1=25.3 mm and g4=25.2 mm i.e. g1+g2=g3+g4=2g0=50mm. This has caused a measured frequency increase of 1.592 MHz (f1=351.558 MHz) and the recovering of the pre-welding field uniformity. After that, the lateral stems were stepwise deformed with the apparatus shown in Figure 5, in order to get the desired field uniformity.

The final settings for the gaps are g1=25.4 mm, g2=24.5 mm, g3=24.4 mm and g4= 25.7 mm, to which a frequency of 351.856 MHz and a field uniformity of ±3% correspond (Figure 6).

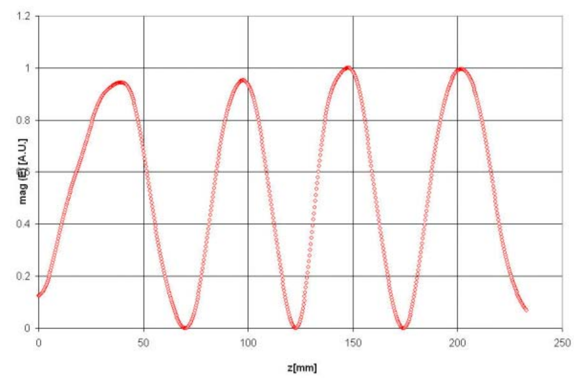


Figure 6: The electric on-axis field after the completion of the tuning procedure.

## CONCLUSIONS

The tuning procedure of the full Nb prototype of the Ladder cavity was completed and the desired specifications of both target frequency and field uniformity were met. Buffer chemical polishing of the cavity is foreseen for July 2006 at CERN and the full power RF SC tests will be performed at LNL in Fall 2006.

## REFERENCES

[1] V. Andreev et al.: Physical Review Special Topics: Accelerators and Beams Vol. **6**, 040101 (2003).

[2] http://www.ganil.fr/eurisol

[3] G. Bisoffi et al., Proc. Of the 2003 RF Superconductivity Workshop, Travemünde (D), September 2003.

[4] HFSS 8.5 distributed by ANSOFT CORPORATION Pittsburgh, PA 15219-1119 USA