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TUNING ESPERIENCE ON THE ESS DTL COLD MODEL

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Abstract

An aluminum mock-up of the ESS DTL tank 2 was produced to INFN-LNL in December 2017. The tank is 7.1 m long, equipped with movable tuners and movable post couplers. The purpose of this DTL model is to verify the RF design choices (in particular on the first 2 tanks where the Post coupler distribution is irregular) as well as to implement and to debug algorithms and procedure for stabilization and tuning. The preparatory simulation work and the results of measurements campaign are presented here.

INTRODUCTION

The 5 tanks of the ESS DTL are equipped with post couplers (PCs) for field stabilization [1]. The number of post couplers of each DTL tank was fixed following the criterion of the minimum number of PCs per unit length which guarantees to keep the accelerating field E_0 within specifications (±2%) in case of perturbation [2]. The distribution must be compliant with the increasing cell length as well as with the 2 m tank modulation. As a consequence of these boundaries, the distribution of post couplers per number of cells changes along Tank 1 and Tank 2, while it is regular in Tank 3, 4 and 5, as listed in Table 1.

Table 1: PCs Distribution of ESS DTL Tanks

	T1	T2	T3	T4	T5
N Cells	61	34	29	26	23
N DTs	60	33	28	25	22
N.PCs	24	23	28	25	22
PCs/DT	-up to DT 14th: 1/4 -up to DT 32nd: 1/3 -up to end: 1/2	-up to DT 21st: 1/2 -up to end: 1/1	1/1	1/1	1/1

The distance between post couplers is then gradually increasing as βλ in the last three tanks, while is jumping from 4 βλ to 3 βλ to 2 βλ in Tank 1 and from 2 βλ to 1 βλ in Tank 2.

In particular, in Tank 2, looking to the PCs as the second chain of resonators, this is equivalent to say that the period of the PC chain is suddenly changing from 43 cm to 21.5 cm. For this reason – along with the opportunity to test and define hardware and procedures for DTL tuning - it was decided to produce an aluminium model of DTL tank 2, to demonstrate the proper stabilization of a DTL with such irregular post coupler distribution (Fig. 1).

ALUMINUM DTL AND BEAD-PULL APPARATUS

The purpose of the aluminum mock-up is to provide a valid test bench for the bead pulling activities, without duplicating a real DTL tank, for cost and time optimization. The mock-up is geometrically identical to the actual DTL Tank 2; thus the cavity internal diameter, the modularity (i.e. the length of each module), distribution and positioning of the ports for the corresponding components (Drift Tubes, Pick-Ups, Tuners and Post Couplers) are the same as in the real DTL Tank; the vacuum ports and the RF coupler ports were not realized, as they are irrelevant for bead pulling purposes.

The structure is made of a 2-mm-thick aluminum skin bended with 521 mm internal diameter. The proper form of the aluminum skin is given by four ribs, evenly placed along each module. Each rib is machined by milling from a 20 mm-thick solid aluminum sheet. The flexural stiffness of the module is provided by 5 struts made of structural steel beams with rectangular hollow section. The struts provide also the housing for the interfaces of the ports. The module is supported at each rib by a welded structure, which is coupled to a corresponding carriage with longitudinal skid. An isostatic alignment system is provided between the welded structure and the carriage for the proper relative positioning of the modules. The pair of rails for the longitudinal movement during the coupling of the modules is fixed to a substructure made of four aluminum profile beam support, fixed to the ground. The tank is terminated by two covers, which integrate the corresponding half Drift Tube, with a central hole for the passage of the bead. In Fig. 2 an internal view of the DTL mock-up is shown

The alignment of the dummy Drift Tube is reached using a Laser Tracker and is made with an isostatic regulation on top of the upper strut, which permit a complete spatial regulation (6 DOF) of each Drift Tube. The final alignment reached has been with a spatial error from the nominal position less than 0,1 mm.

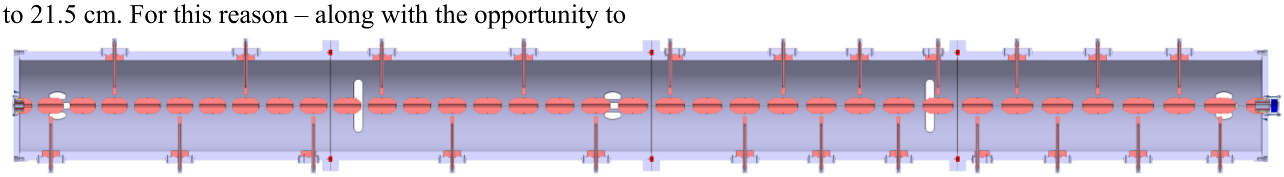

Figure 1: The ESS DTL Tank 2: it is possible to notice the tank subdivision as well as the PC distribution change.

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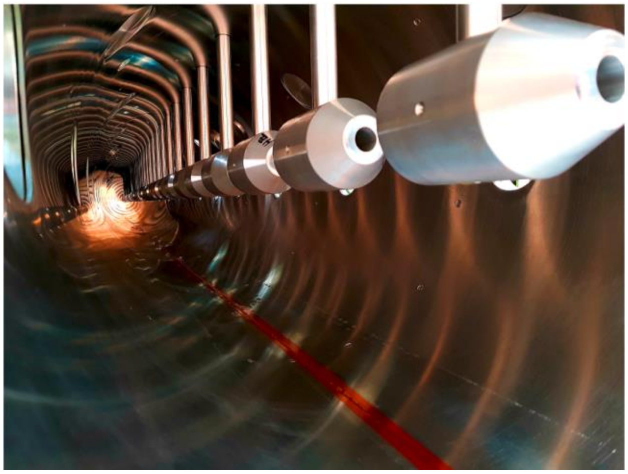

Figure 2: Internal view of the aluminum DTL.

The interfaces of the ports are the same as in the real DTL Tank, duplicating the actual geometry (i.e. diameter of the port, distance of the interfaces surfaces from the tank geometrical axis, position of the screw holes and sealing housing). This was done in order to carry out the bead pulling on the mock-up with the same movable tuner which will be used in the bead pulling of the DTL Tank in the DTL assembly workshop before the transfer and integration of the assembled and tested tank to the ESS accelerator.

The system for bead-pulling mainly consists of 2 aluminum plates directly fixed to the end plates of the DTL tank and supported to the ground by 2 adjustable aluminum bar. A step motor controlled by LABVIEW moves the dielectric thread through a system of pulleys, pulling a metallic bead along the beam axis line of the cavity. The same routine launches the Network Analyzer acquisition. The plates are qualified in CMM, and the precise positioning of the bead wire in the DTL geometrical center is provided by laser tracker references located on each plate. The tension of the thread can be varied by acting on a screw and it is monitored during the measurement by a load cell. The interfaces of this measurements apparatus were studied to be compatible with the real DTL tank geometry (Fig. 3).

Figure 3: Aluminum DTL with bead pull system, movable tuners and post couplers (courtesy of CERN-Linac4) and VNA.

RF MEASUREMENTS : STABILIZATION AND TUNING PROCEDURES

The stabilization procedures for the DTL foresee the consolidated method of the on-purpose perturbation of the cavity at one end of the structure and then to the other one; this provokes a frequency shift Δf and a field perturbation at each DTL cell. Therefore, it makes sense to introduce a Tilt Sensitivity parameter

$$TS_i = \frac{E_{0i}^{(he)} - E_{0i}^{(le)}}{\Delta f}$$

Where $E_{0i}^{(he)}$ and $E_{0i}^{(le)}$ refer to axial field values of the i-th cell in the case of perturbation at the high and low energy end respectively. This parameter is an index of the response of the cavity to perturbations and therefore the stabilization procedure consists of the determination of the set of PC lengths that minimize such parameter. In this case, the perturbing object is a hollow cylinder of 11 mm diameter, whose axis coincides with the beam axis and which is inserted in such a way to have the same Δf at both cavity ends (typically in the order of about -120 kHz). In the initial measurements, all the PCs were set at the length of 190 mm and with all the tuners set at 55 mm insertion. In this configuration, the TM and the PC mode bands are well separated (about 30 MHz) and therefore the TM modes only contribute to perturb the operational one. The TM_{010} frequency is equal to 352.1 MHz and the loaded Q is equal to about 2700, while the 1st upper mode is about 700 kHz higher than the TM_{010} one. The related TS is shown in Fig. 4. As one can expect, the TS is rather large (about ± 50 MHz^{-1}) and it is dominated by the 1st upper TM_{011} mode, moreover the E_0 varies in a range of ±11% about its mean value.

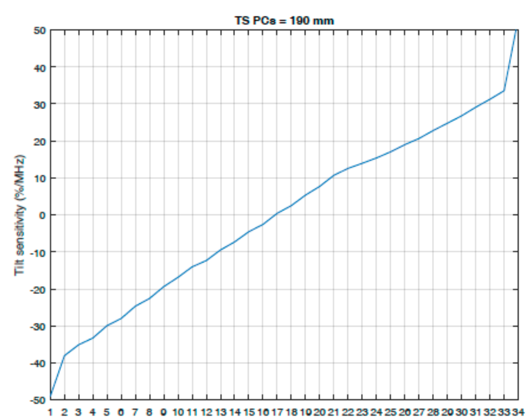

Figure 4: Tilt sensitivity for the initial PC setting.

At first, the optimum PC lengths were sought looking at the $TS_i' = TS_i - TS_{i-1}$, according to [3]: this procedure requires the determination of the resonance length of each PC looking to the discontinuity of resonance TM_{010} frequency. Nonetheless, in our case, the cavity 3dB bandwidth of about 240 kHz is too high to reliably distinguish such resonance. Therefore, it was decided to directly vary the PC lengths in order to reduce the TS, by trials and errors. This step took about 30 successive iterations. The

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best PC settings allowed the tilt sensitivity to reach the minimum value of ± 5 MHz^{-1} (Fig. 5).

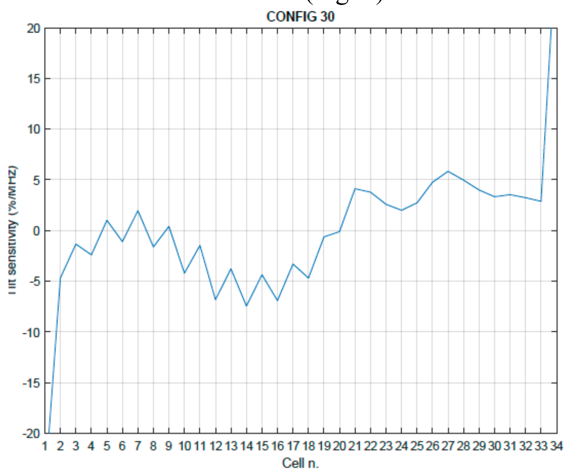

Figure 5: Tilt sensitivity for the final PC setting.

In correspondence to this result, the mode-free zone about the accelerating mode is such that f0-fPC1=2.4 MHz and f0-f1=-2.4 MHz. The PC lengths vs the PC number are shown in Fig. 6.

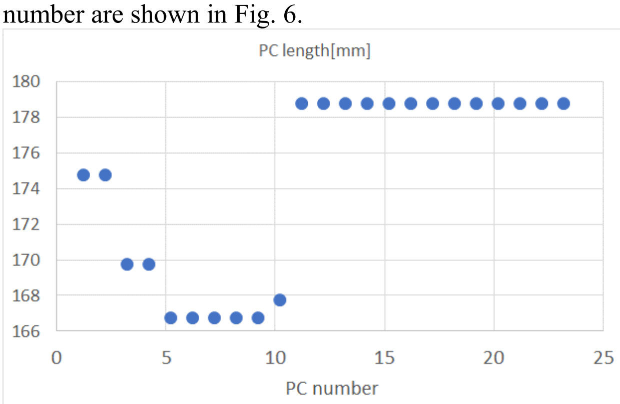

Figure 6: PC lengths vs PC number corresponding to the minimum TS.

The next step was the tuning of the DTL field by moving the 20 slug tuners of 50 mm diameter. The algorithm followed for such procedure is the same of [3], with an eventual correction of the first three tuners in the low energy part of the DTL. In the following Fig. 7 the field distribution after tuning procedure is shown, in which the field uniformity is ±3%. It should be noticed that the large field dip at Cell 27th corresponds to the interface between module 3 and 4 of the tank, and it adds a 2 % error to the field flatness.

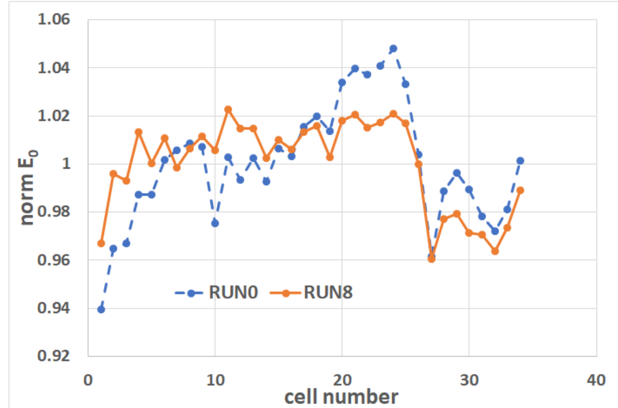

Figure 7: Axial Field distribution before (RUN0) and after (RUN 8) tuning.

The frequency obtained after this tuning operation is 352.196 MHz. In the following Fig. 8, the tuner corresponding tuner height distribution is shown.

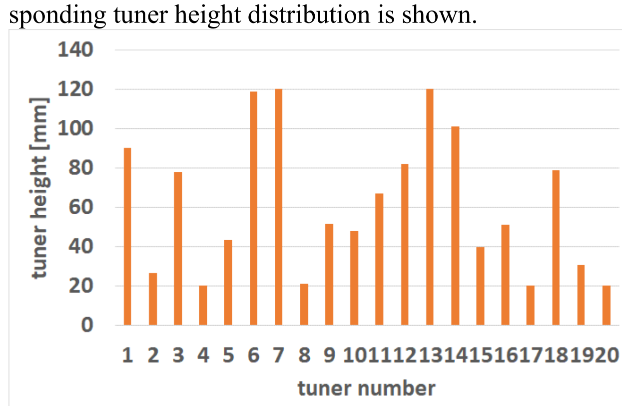

Figure 8: The actual tuner height distribution.

CONCLUSION

The experience on the DTL Tank 2 aluminum model has demonstrated the stabilization and tuning of a tank with PCs irregular distribution, even if the RF discontinuity between module did not allow to reach the goal of ±2% field flatness and to apply the stabilization by resonance PC length. Moreover the hardware and procedures for DTL bead pulling has been debugged and the personnel trained to measurements.

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