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ESS DRIFT TUBE LINAC MANUFACTURING, ASSEMBLY AND TUNING

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Abstract

The Drift Tube Linac (DTL) for the ESS Linac will accelerate H+-beams of up to 62.5 mA peak current from 3.62 to 90 MeV. The structure consists of five cavities. The first cavity (DTL1) is a 7.6 m long tank containing 60 drift tubes, 23 fixed tuners, 3 movable tuners and 24 post-couplers, operating at a frequency of 352.21 MHz and an average accelerating field of 3.0 MV/m. The cavity is now assembled at ESS, the results of alignment and tuning are here presented. The DTL1 "as-built" has been analysed from the beam dynamics point of view. The manufacturing of DTL4 and DTL3 is completed, and they are now under assembly at ESS. DTL2 and DTL5 manufacturing will be completed within 2021. The paper describes the production and assembly stages, with a focus on the statistics of quality check in terms of metrology, alignment and leak tests.

ASSEMBLY OF DTL1

Figure 1: DTL1 on the bead pull station at ESS Lund.

DTL1 (Fig. 1) is composed of 4 stainless steel modules, containing60 copper Drift Tubes (DTs) [1]. The assembly of the tanks is performed in the DTL Workshop at ESS (Fig. 2), a space that has been equipped to:

1. Assemble/align/leak-test the DTs in the DTL modules in the Module Assembly Tables (MAT);
2. Join the 4 modules (2m each) to compose/align/leak test the Tank (8m each) in the Tank Assembly Table (TAT);
3. Bead pull and tune the tank in the bead pull station;
4. Mount and test the cooling system making the tank ready for installation in the tunnel, on the Tank Handling Trolley (THT).

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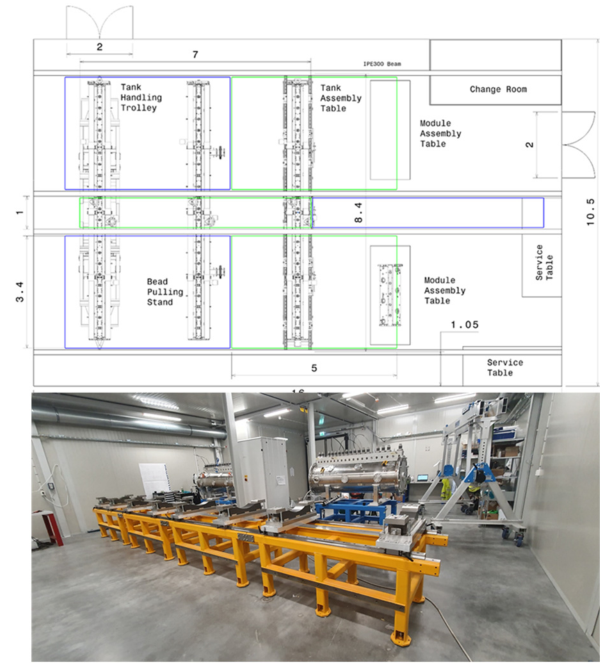

Figure 2: Sketch and picture of DTLW at ESS-Lund.

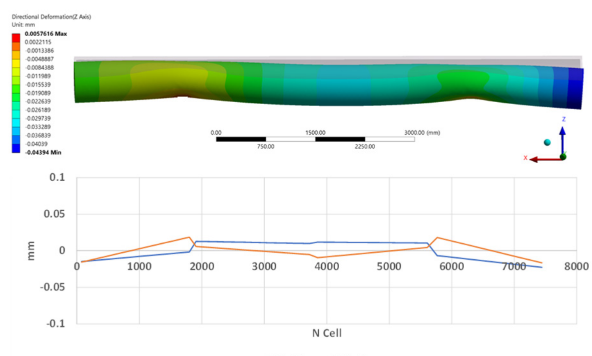

Figure 3: Simulated and measured deformation when the DTL is moved to 2 supports.

At ESS Lund, from September 2019 to January 2020 all DTs where assembled, leak tested and aligned in the modules, except 6 DTs equipped with beam position monitor (BPM), which arrived in February 2020 because of an issue with cable procurement. After 6 months of travel stop due to COVID pandemic, the assembly activity restarted in Lund in October 2020. In 3 weeks the INFN team installed the 6 DTs-BPM, connected, aligned and leak test the 4 DTL1 modules, installed the end plates and the bead pull equipment.

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The deformation of the entire tank due to the movement from the TAT (8 supports) to the BP station (2 supports as in the tunnel) has been measured and compared with mechanic calculation shows a good agreement (Fig. 3).

RF LOW POWER TUNING OF DTL1

The DTL cavities are equipped with tuners, used to recover frequency and accelerating E0 field flatness, and with Post Couplers (PCs), used to stabilize the field against perturbation [2, 3]. The process of RF tuning of the DTL must guarantee resonant frequency, accelerating field and field stability (Tilt Sensitivity, TS) within specification.

The first funing campaign of DTL1 was held in November 2020. DTL1 transferred from the assembly table to the bead pulling station, proving that field and main flanges are maintained after the movement. The resonant frequency (~1 MHz tuning range) and the Quality Factor (~40000) presented the expected values. Moreover, RF simulations including measured errors well reproduces the measured field. Before starting stabilization, the field was easily tuned within ±2%. An issue occured at the end of the campaign: the DTL is well stabilized by Post Couplers (sensitivity to errors reduced by a factor of 30), but field excursion increased from ±2% to 20%. Since the field was stabilized, it was very difficult to recuperate the homogeneity with tuners.

A second tuning campaign was held in December 2020. We substituted the 2 Post Couplers corresponding to the RF couplers position with special posts prepared at INFN-LNL, modified with a thicker aluminium cylinder with 50 mm extra length and a tuner diameter. Moreover, since one of the PC is eccentric (PC19), we rotated it by 180° to simulate a change of PC position. We tested some hundreds of configurations of Tuners and PCs. The candidate field has finally been obtained with E0<±2% and TS<100%/MHz, by using the rotation of the eccentric post. So, we decided to "sacrifice" some stability to have better field.

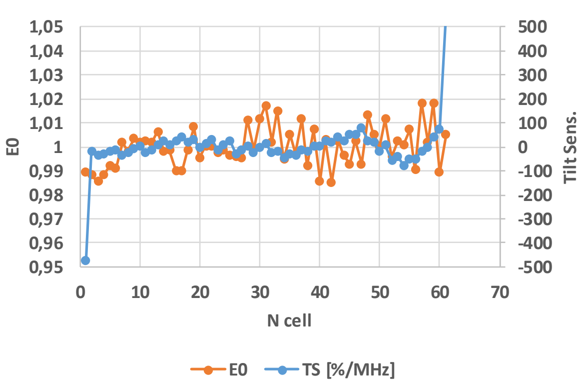

Figure 4: E0 and TS as obtained in April 2021 after the replacement of all copper tuners and PCs.

During the third tuning campaign held in January-February 2021, a further improvement of the field flatness was possible, based on the Singular Value Decomposition (SVD) analysis of the tuner sensitivity matrix, proposed by Beam Physics Group of ESS. E0 field and TS, shown in Fig. 4, have been obtained after the substitution of aluminium adjustable Tuners and PCs with fixed copper elements. To minimize the effect on E0 and TS, the length of CU-PCs has been finely calibrated, approaching the final dimension with more than one machining steps. Table 1 reports a summary of the main RF parameters of the cavity.

After the complete vacuum leak test and the installation of the cooling system, the DTL1 will be moved to the tunnel to be conditioned and commissioned.

Table 1: DTL1 Main RF Parameters

Parameter	**Design**	**Measured**
Frequency [MHz]	352.21	352.131 (in air, no RF power, 22 °C)
Coupling factor [β]	2.01	2.01
Q0 (Superfish/1.25)	42512	40800
ΔFreq. 1st upper/lower mode [MHz]	N.A.	2.13 /-1.70
E0 uniformity [%]	±2	±1.65
Tilt Sens.[%/MHz]	N.A.	±77%

BEAM DYNAMICS CHECK

Since the result of the assembly presents few DT positions marginal respect to specifications (<0.1 mm positioning error), the DTL1 "as built" has been analysed from beam dynamics point of view.

Table 2: Errors Study Setup

Error type	**Max value (or 3σ)**	**Distribution type**
PMQ and gaps transverse misalignment	± 0.15 mm	Uniform
Gap E0 (tuning)	± 2%	Uniform
Gap phase (simulates as long. displacement of gaps)	± 1 deg	Uniform
Klystron stability E0 (applied to whole tank)	± 1%	Gaussian
Klystron stability Phase (applied to whole tank)	± 2 deg	Gaussian
BPM uncertainty	± 0.2 mm	

BD has checked the acceptability of the "as built" DTL1 with respect to the acceptance criteria described in the Requirements. The assigned emittance growth to the entire DTL section (5 cavities) including all errors is <30%

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(=10% by design + 20% by errors for 90% of cases). The permitted whole linac emittance growth is below 150% (=5 sections ×30%) [4].

Inputs for the «as-built» DTL1 are the RF and alignment results, that includes E0 (Fig. 4), PMQ alignment and gap errors (Fig. 5). Table 2 lists the errors considered for the rest of the DTLs.

10000 runs with perfect nominal input beam have been considered. Steerers are used for correction of beam centroid. The beam is composed of 200000 macroparticles, 6D ellipsoid Gaussian distribution and 3D s.c. routine.

Figure 6 shows that in 90% of the cases the emittance growth for all the three planes is lower than 10% with respect to the input emittance. The maximum steerer strength applied considering 99.9% of the cases is 13 mT*m. All runs are without losses.

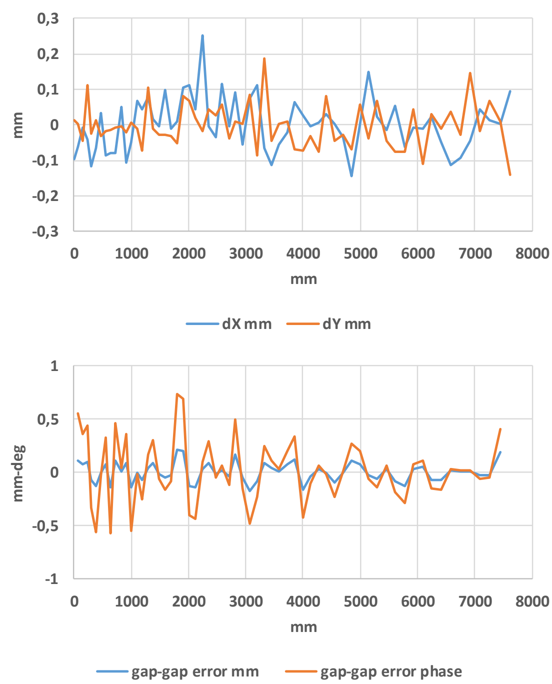

Figure 5: Gap to gap errors and PMQ transverse alignment as result of assembly of DTL1.

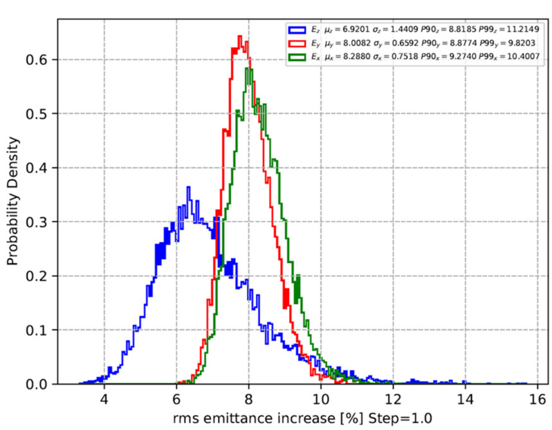

Figure 6: Emittance increase distribution at the end of the 5 DTLs with respect to nominal input beam.

STATUS OF PRODUCTION AND ASSEMBLY OF DTL2 TO DTL5

After DTL1, the installation sequence of the DTLs will be 4-3-2-5.

All 25 DTs of DTL4 have been assembled and vacuum tested in February 2021 (Fig. 7). The Laser Tracker Survey of the 4 modules and DTs is done by ESS-SAM group, with remote support and remote analysis by INFN. A 3 weeks' mission of INFN is planned for June 2021 to complete assembly of DTL4 and make it ready for RF tuning.

About the next tanks:

- DTL3 is composed of 26 DTs: the machining of DT parts is completed, 2 DT-BPM are ready, 23/24 DTs are brazed, 22/23 are welded, the last is ready for welding. The expected delivery at ESS is 15/06/2021. The 4 modules are cu-plated and already delivered to ESS.
- DTL2 is composed of 33 DTs: the machining of DT parts is completed, 3 DT-BPM are ready, 15/30 DTs are brazed. Expected delivery at ESS 30/07/2021. The 4 modules are cu-plated and already delivered to ESS.
- DTL5 is composed of 22 DTs: machining of DT parts is completed, 2 DT-BPM are ready, 15/20 are brazed. Expected delivery at ESS 30/10/2021.

2020 has been also the year when the DTL cooling system has been delivered to ESS and installed as well as the 5 racks of the DTL Local Control System. The commissioning of these subsystem is scheduled for 2021.

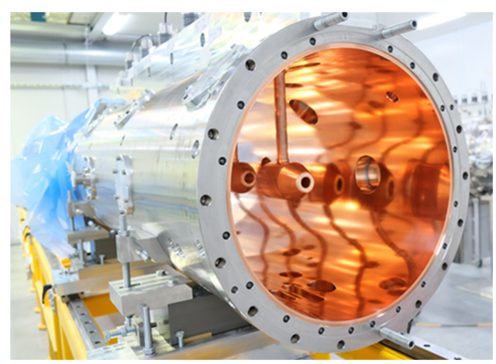

Figure 7: DTL4 - Module4 assembled at ESS Lund.

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