ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO089

DESIGN DETAILS OF THE EUROPEAN SPALLATION SOURCE DRIFT TUBE LINAC

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Abstract

The Drift Tube Linac (DTL) of the European Spallation Source (ESS) is designed to operate at 352.2 MHz with a duty cycle of 4% (3 ms pulse length, 14 Hz repetition period) and will accelerate a proton beam of 62.5 mA pulse peak current from 3.62 to 90 MeV. This paper gives a detailed overview of the ESS-DTL current mechanical design, and the related driving criteria. It presents also an outlook of the main aspects of the assembly and installation, with related equipments, tooling and procedures.

DTL GENERAL DESIGN

In the ESS accelerator the initial warm linac section is composed by the Ion Source, Low Energy Beam Transport line (LEBT), Radio Frequency Quadrupole (RFQ), Medium Energy Beam Transport line (MEBT) and DTL [1].

The DTL has a partially similar design to the CERN LINAC4: it is a 38.8 m long system, divided in five cylindrical RF cavities (Tanks) [2]. Each tank is a standalone structure composed by four 2 m long modules, made of AISI 304L stainless steel with copper plating on internal surfaces. The Drift Tubes are positioned in the girder, a precisely machined aluminium alloy structure housed in the upper part of each module [3].

The tank is closed at both ends by a closing cover with a half DT on the inner side. Each tank is individually supported by an isostatic mechanical support, which provide also the fine alignment of the tank on the beam line. The space between two consecutive tanks, Inter-Tank (IT), is taken up by a vacuum valve and a stain-less steel vacuum chamber, which houses diagnostic instrumentation such as Faraday Cup (FC), Wire Scanner (WS) and non-invasive Profile Monitor (PM).

COVER DESIGN

The tank covers are composed mainly by an AISI 304L circular plate and a half DT on the inner wall. Depending on the position along the beam line, the cover houses a Permanent Magnet Quadrupole (PMQ) or a Beam Current Monitor (BCM).

The steel plate is 30 mm thick and is copper plated on the inner surface facing the RF cavity. It houses 8 V-shaped cooling channels, 10 mm offset from the inner wall, each one obtained by intersecting two ⌀6 mm holes deep-drilled in the thickness of the material. Two additional ⌀8 mm channels provide the inlet and outlet for the DT cooling circuit.

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The half DT is made by an external copper profile and an internal steel sleeve, both vacuum brazed on the steel plate. The DT cooling circuit is obtained by machining a circumferential channel on the sleeve, in a single or double loop depending on the DT length.

In the cover with PMQ (Fig. 1) the magnets assembly is housed inside the sleeve, while in the BCM version a current transformer is placed in a seat on the outer wall of the cover; in both cases the components are fixed by a flange on the outer side.

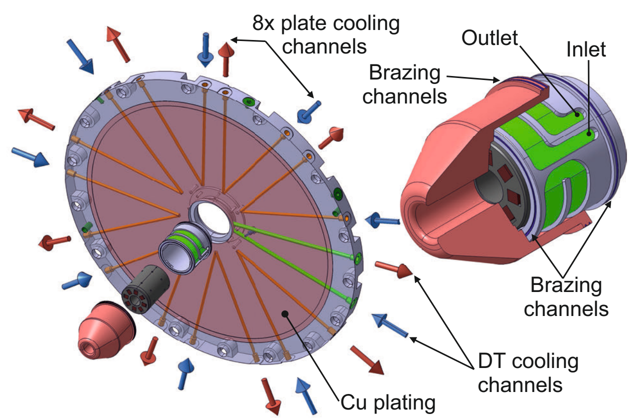

Figure 1: Layout of the cover with PMQ. Plate cooling channels coloured in orange, DT cooling circuit in green, brazing channels in blue.

Table 1: Boundary conditions and results of CFD simulation: inlet mass flow rate ($\dot{m}$) and temperature (T_{in}), average convective heat-flux coefficient (h) and pressure drop (Δp)

Circuit	$\dot{m}$ [kg/s]	T_{in} [°C]	h [W/m^{2}K]	Δp [bar]
DT channel	0.11	30	7350	0.41
Plate channel	0.05	30	6500	0.12

Computational Fluid Dynamics (CFD) and Finite Element Method (FEM) simulations were carried out to validate the design of the cover. For those analysis the maximum thermal load, corresponding to the last cover in tank 5, was set at 3869 W/m^2 on the cover wall facing the RF, and spanning from 154 W/m^2 and 23 520 W/m^2 on the DT (depending on the position). First a CFD simulation was performed in Ansys Fluent on a simplified geometry, in order to evaluate the convective heat-flux coefficient and pressure loss on both DT and plate channels (see Table 1) [4]. On this bases, a FEM thermo-structural analysis was performed in Ansys Mechanical. Figure 2 shows the results obtained from the

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latter: the simulations show a peak temperature of 41.8 °C on the steel plate and 47.9 °C on the DT. The deformation along the beam axis is 49 µm on the DT.

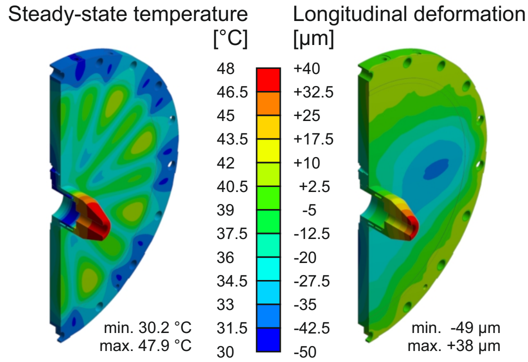

Figure 2: Temperature and longitudinal deformation maps resulting from FEM analysis on the cover with PMQ.

INTER-TANK DESIGN

Along the DTL there are two types of Inter-Tank: IT 1, which is entirely under vacuum and contains only the diagnostic instrumentation, due to the limited space available, and IT 2-3-4, which contain a vacuum valve and a vacuum chamber for instrumentation. Table 2 reports the space available for the ITs, while Figure 3 shows the layout of both IT types.

Table 2: Longitudinal Space Available in Each Inter-Tank Between the Corresponding Covers

Inter-Tank	Between tanks	l [mm]
IT 1	1-2	118.301
IT 2	2-3	178.368
IT 3	3-4	223.482
IT 4	4-5	259.125

The beam box in each Inter-Tank has interfaces for the FC, WS, two PM and three vacuum feed-through.

The beam box is sealed by a FPM elastomer O-ring, on the cover side, and is connected to the valve through a bellow, on the opposite side. Since the O-ring requires a replacement every five years, the Inter-Tanks are designed to be assembled and disassembled directly in the accelerator tunnel without moving the tanks from the beam line. During those operations, the bellow is compressed using a threaded tie-rod, and the beam box is extracted (or inserted) from the side of the DTL. A similar procedure is used for the bellow in IT1.

INSTALLATION PROCEDURE AND EQUIPMENT

Assembly operations are carried out in the DTL Workshop (DTLW) at the ESS site in Lund, with a defined tank sequence. First, each module is assembled independently, with corresponding girder, drift tubes and ancillaries; the four modules are then aligned and coupled together on an assembly table; finally, are installed the tank covers, cooling water manifolds, hydraulic connections and the upper section of the mechanical supports.

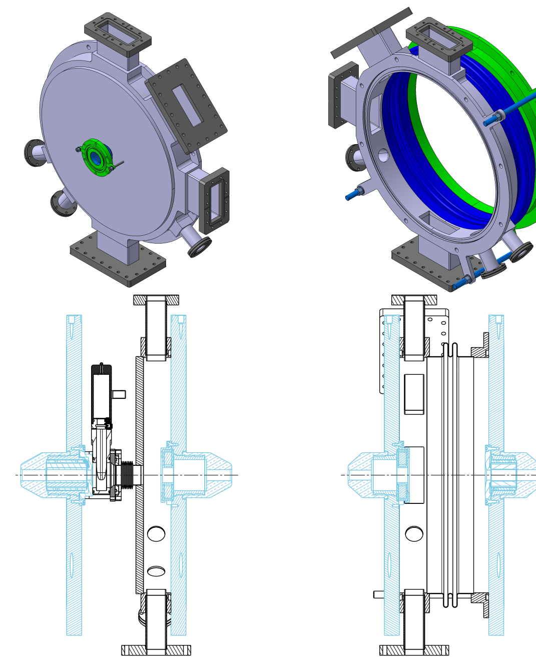

Figure 3: Isometric view (on top) and longitudinal section view (on bottom) of IT 1 (right) and IT 2 (left). Tank covers in section views are coloured in light blue.

A series of tests is performed on each tank in the DTLW after the assembly. These include position measurements, hydraulic tests, vacuum leak tests and bead-pulling measurements.

Installation of the Tanks on the Beam Line

After the tests, the tank is lifted with a crane in the DTLW and positioned on the Tank Handling Trolley (THT), showed in Figure 4. The tank is positioned on the four cradles of the THT (coloured in light blue in Figure 4) and fastened with straps; the THT is adaptable to the different length of the tanks by replacing special sections of beams (coloured in green in Figure 4), so that the cradles interface each tank across the junction of modules 1-2 and 3-4, avoiding any interference with the flanges.

The tank, positioned on the THT, is loaded on a truck and transported up to a loading bay next to the accelerator tunnel, where is unloaded again to the floor. The tank is then moved up to the tunnel by pulling the THT with a manual operated tractor.

Whenever a change in trajectory is needed, the four screw jacks on the sides of the THT are lowered down, freeing the load from the main wheels (coloured in purple in Figure 4). The wheels are pivoted by a proper angle and the load is charged again by retracting the screw jacks, so the movement can start again. A manual winch is used for minor movements during these adjustments. Reached the tunnel,

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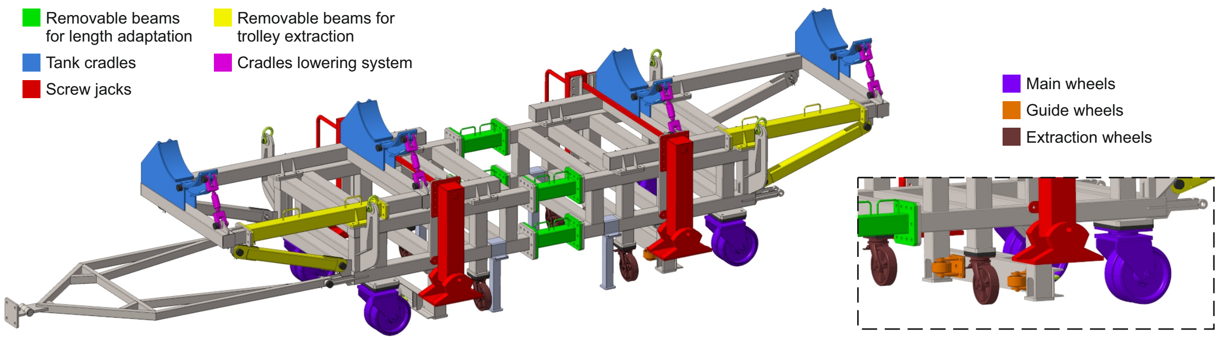

Figure 4: Design of the Tank Handling Trolley (THT).

the tank is moved along the installation corridor, parallel to the beam line, up to the nominal longitudinal position.

The insertion of the tank on the beam line is done by pivoting the wheels by 90°, with the same procedure already mentioned, and pulling transversally the THT using a manual winch. During this operation, the horizontal wheels at the base of the THT (see detail in Figure 4, wheels in orange) engage with a couple of temporary linear guide installed on the floor, which avoid deviations from the right trajectory.

At this stage the tank axis is 50 mm higher than the nominal position. The screw jacks are lowered again, discharging the load from the wheels, which are removed. The screw jacks are retracted until the upper section of the mechanical support, installed on the tank, engages with the lower section of the support, already installed on the floor. In this way, the load of the tank is transferred to the supports and the THT can be removed. The screw jacks are further retracted until the extraction wheels reach the floor (see Figure 4, wheels coloured in brown). Finally, a portion of the THT beam is removed (see Figure 4, yellow coloured beams), and the cradles are opened, allowing the extraction of the THT from the side of the tank.

MECHANICAL SUPPORT DESIGN

Each tank is independently supported by an isostatic support, composed by 2 columns, which interfaces the tank under modules 1 and 4. The column under module 1 has a spherical joint between support and tank, while the other one has a ball-plane and a ball-groove contact. The ensemble of the two column forms a Kelvin isostatic coupling.

Every column is divided in upper and lower section (see Figure 5). The upper section is mounted under the tank during the assembly operation in the DTLW, and is transported in the tunnel together with the tank. From bottom to top, it is composed by: a screw jack, a cylindrical guide, the kinematic coupling mechanism and a plate-plate interface. In case of the double coupling column, the upper section has 2 screw jacks cylindrical guides, one for the ball plane and one for the ball-groove coupling. The screw jacks and the Kelvin coupling provide a fine regulation of the vertical position and yaw-pitch-roll angles, while the plate-plate interface, and a set of driving screws on it, allow the translation on the plane. Vertical and in-plane regulation are decoupled.

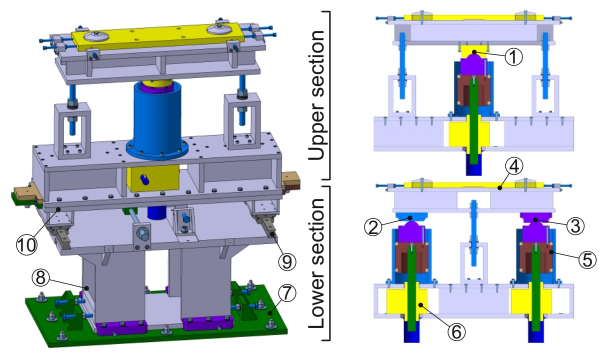

Figure 5: Isometric view of the single joint column (on left), section view of the upper section of single (top-right) and double (bottom-right) joint column. The numbers identify: 1) sphere joint, 2) ball-plane joint, 3) ball-groove joint, 4) plate-plate interface, 5) cylindrical guide, 6) screw jack, 7) floor plate, 8) H-beam, 9) linear guide, 10) interface block.

The lower section is composed by a floor plate, a couple of H-beams and an interface block. The floor plate allows a translation of the support parallel to the floor, by means of screws acting on the H-beams. The interface block provides the coupling with the upper section; moreover, is equipped with 2 linear guides which provide a coarse longitudinal regulation and allow the thermal expansion of the tank.

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