ESS DTL MECHANICAL DESIGN AND PROTOTYPING

P. Mereu*, M. Mezzano, INFN, Torino, Italy
F. Grespan, A. Pisent, M. Poggi, C. Roncolato, INFN-LNL, Legnaro, Padova, Italy
D. Castronovo, R. Visintini, Elettra-Sincrotrone Trieste, Bosovizza, Trieste, Italy

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.

In this paper the DTL design, thermal and structural simulations are presented, together with the results obtained by the prototypes of the Drift Tubes.

DTL DESIGN

In the ESS accelerator the initial warm linac section is composed by Ion Source, Low Energy Beam Transport line (LEBT), Radio Frequency Quadrupole (RFQ), Medium Energy Beam Transport line (MEBT) and DTL. INFN-LNL is in charge of the design and production of the DTL [1], [2].

Table 1: DTL Design Parameters

	Tank				
	1	2	3	4	5
Cells	61	34	29	26	23
E_0 [MV/m]	3.00	3.16	3.07	3.04	3.13
L[m]	7.62	7.09	7.58	7.85	7.69
RBore[mm]	10	11	11	12	12
LPMQ[mm]	50	80	80	80	80
Tun. Range [MHz]	±0.5	±0.5	±0.5	±0.5	±0.5
Q_0/1.25	42512	44455	44344	43894	43415
PCu[kW] (no margin)	870	862	872	901	952
Eout[MeV]	21.29	39.11	56.81	73.83	89.91
Ptot[kW]	2192	2191	2196	2189	2195

The DTL has a design which is similar to the CERN LINAC4 DTL; it is a 38.8-m long system, divided in five tanks; each tank is a stand alone structure, composed of four 2-m-long modules made of AISI 304L stainless steel with internal electro-copper deposition. The Drift Tubes are positioned in the girder, a precisely machined aluminum alloy structure, which is housed in the upper part of each module. The DTL design parameters are shown in Table 1.

DRIFT TUBES DESCRIPTION

In the DTL the Drift Tubes (DT) are equipped with various components: Beam Position Monitor (BPM), Electro Magnetic Dipole (EDM) and Permanent Quadrupole Magnet (PMQ) [3]. The DTs are made of a Cu-OFE body, with a AISI 304L Cu-electro-plated stem.

The DTs are made by furnace vacuum brazing and are sealed with Electron-Beam-Welding (EBW) after the insertion of the internal components (i.e. BPM, EMD or PMQ) inside the DT body. A prototyping program is ongoing to validate the technological solutions for the productions of different type of DTs [4].

Brazing Joint Compatibility

A sample was prepared in a zone close to the EBW joint (Fig. 1). A simplified model was simulated to check the feasibility of the process due to the small amount of material near the EBW. Fast speed and high power density are necessary to have low temperature at the Brazing Joint (Spot Speed: 12 mm/s, Power Density: 1800 W/mm^3, Single passage, No Thermal Radiation). The brazing joint did not show any leak. The sample was then cut in circular sectors using an EDM machine in order to visually check the brazing joints; the area around the joints was sent to an external company to obtain the micrographs. The analysis reveals that the EBW penetration achieved is smaller than the INFN specification (1 mm).

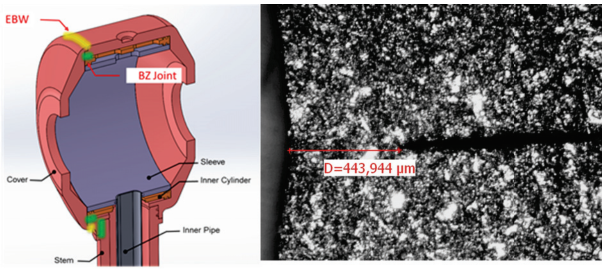

Figure 1: Over brazing joint prototype.

BPM Prototyping

The first BPM has been prototyped (Fig. 2); it is made of Cu-OFE parts, machined and brazed in the INFN workshops. It has been realized with SMA feedthroughs provided by Kaman-Meggit. The process to realize the BPM involves TIG welding, furnace vacuum brazing and Electro Beam Welding. In the prototype the final EBW failed, because it burned the pin of one of the four the feedthroughs. Presently a second prototype is being finalized, in order to tune the EBW.

Cu-plated Stainless Steel Stem

One complete stem was fully copper plated as well as several plates to measure the effective deposition rate (i.e.

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* paolo.mereu@to.infn.it

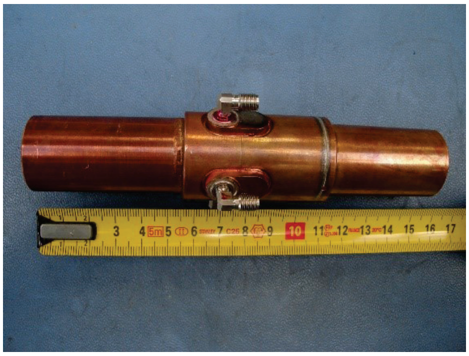

Figure 2: BPM prototype.

the current density) of the process. The cu-plated stem has been brazed on a DT sample. The aim was to test the stability of the copper-plating in the thermal cycle and the deposit with the brazing (Fig. 3).

Figure 3: Cu-plated stem.

EMD Design

A new design of electromagnetic dipoles for beam orbit correction has been done, changing them from continuous to pulsed operation in order to simplify the integration inside Drift Tubes, in particular to avoid water cooled coils. The goal is achieve the 16 G m requested strength, within the given space in the drift tube and following the design guess rule is do not exceed 1A/mm2 of current density.

The EDM is 50 mm long, coils included. Coil section is 7.2 mm^2. It operates with 30% duty cycle, for a RMS current of 7 A and RMS power 0.5 W. Maximum integral field is B_{0L} = 18.5 G m, the uniformity is $\frac{dB_L}{B_{0L}}$(@x=5 mm)= −0.08%, $\frac{dB_L}{B_{0L}}$(@x=10 mm)= −2.3%.

Cooling is guaranteed by the contact of the iron yoke with the stainless steel sleeve of the drift tube. The temperature growth is 2.5 °C (Fig. 4).

TANK MODULE DESIGN

Based on lessons learned from Linac 4 DTL, INFN proposes a new design 2 m module end flange, based on a more "traditional" external flange that accommodates larger number of screws and a better disposition of the water channels, avoiding critical hot spots. The flange is not welded, but made with the 3D forging process of the stainless steel module. The flange is cut and flattened on the upper part in order to accommodate the aluminum girder of the Drift Tubes (Fig. 5). The girder has been modified according to the design of the flange: a pocket was made on the extremities of the girder in order to allow the joining with the tank below.

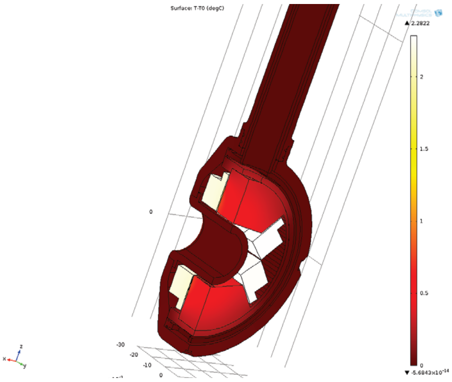

Figure 4: EDM temperature distribution.

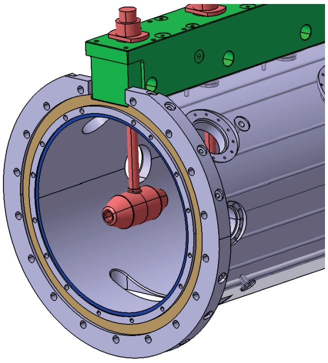

Figure 5: Detail of the tank flange.

SIMULATIONS

All the simulations presented in the following sections are performed using Ansys 15.0 – Workbench.

Structural Simulations

The following analysis was performed to check the deformations of the DTL tank flange due to the loads of the screws used to join modules and provide the necessary tightening force to the spring energized seal, especially in the zone were the girder is positioned. For the simulations, a simplified portion of a generic tank module is considered using as boundary conditions a fixed support located where the spring-energized seal will be mounted and a frictionless support on the sectioned surfaces of the reduced geometry.

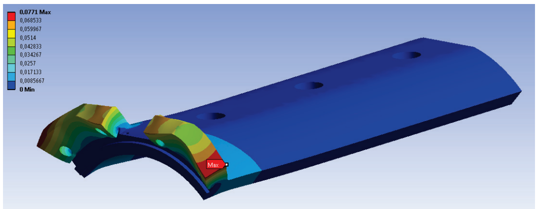

Figure 6: Deformation profile (mm).

The values of the loads applied are 12000 N for each M20 screw and 300 N/m applied in the housing of the energized metal gasket. No gravitational forces are considered. The analysis showed that the most important deformations (0.08 mm) are on the external diameter of the flange which does not lead to particular issues (Fig. 6).

Thermal Simulations

Preliminary analytical calculations shows a negligible temperature increment of the water flow (0.6 K) so, in the simulations, the water temperature is considered to remain constant along the length of the module. The heat transfer coefficient h was then calculated using the Dittus – Boelter correlation. The parameters used for this calculation are shown in Table 2; the value of heat flux used, is the maximum and it's conservative to consider it constant along the tank.

Table 2: Simulations Parameters

Parameter	**Value**
Water flow rate[kg/s]	0.134
Re	11751 - turbolent flow
Heat flux [W/m^2]	15000
T_{WATER}[K]	293
h[W/m^{2}K]	4825.28

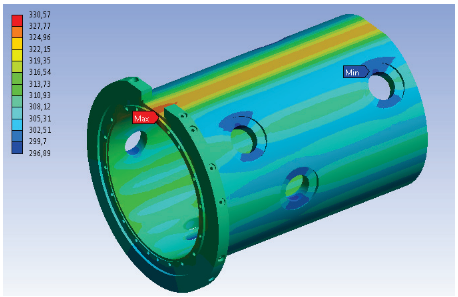

Figure 7: Temperature distribution simulation 1 (K).

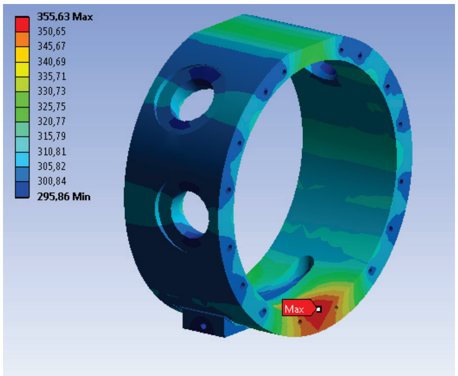

Figure 8: Temperature distribution simulation 2 (K).

Two simulations are then performed, one in correspondence of the vacuum port and one in correspondence of the RF port, with the RF flange with its cooling system attached. For the RF flange cooling system the same considerations of the tank cooling system are used. For the first simulation the temperature distribution shows no particular issues with the temperature maximum reached on the top of the module (330 K) (Fig 7). For the second simulations the resulting temperature profiles shows no criticalities with a reasonable maximum (355 K) near the RF port (Fig. 8).

CONCLUSION

In June 2015 the ESS DTL design passed the Critical Review which authorized the procurement start with some recommendation. In order to meet the ambitious ESS general schedule (first beam in 2019), a first set of tenders have been prepared in 2015, to be launched in mid 2016: tender for all the 20 stainless steel modules 2-m long, tender for Tank4 and Tank3 machining and tender for 90 PMQs.

The structural simulations on the flange does not show critical deformations with the bolts load conservatively higher with respect to the load required by the energized metallic gasket.

Thermal simulations performed on some expected critical zones (i.e. vacuum and RF port) shows a temperature distributions with a reasonable maximum value proving the efficiency of the cooling system: in the thermal simulation of the void port the temperature maximum (330 K) is reached on the top of the tank, in a zone where will be placed the girder with its Drift Tubes with a dedicated cooling system each, for this reason we can suppose that the temperature in the considered zone of the tank will be lower. Regarding the vacuum port, no significant criticalities in terms of temperature distribution and deformations are spotted; as for the thermal simulations of the RF port the temperature maximum (355 K) is reached in the zone between the RF port itself and the tank flange, a portion of the tank with no cooling channels; however the temperature value is not to be considered critical.

ACKNOWLEDGEMENT

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