ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-MOPO124

DETAILS OF THE MANUFACTURING PROCESSES OF THE ESS-DTL COMPONENTS

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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 presents the details of the manufacturing processes with quality control reports reports of the components of the DTL.

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 [1]. The ESS-DTL is a 38.8 m long system, divided in five tanks [2]; each tank is a stand-alone structure, composed of four 2 m long modules made of AISI 304L stainless steel with internal copper electro-deposition. The nominal position of the 168 DTs is demanded to the girder, a precisely machined aluminium alloy structure, which is housed in the upper part of each module. The DTL comprises 4 types of DTs, depending on the beam components integrated in the body: Permanent Magnet Quadrupole (PMQ), Beam Position Monitor (BPM), Electro-Magnetic Dipole (EMD) and Empty body [3]. Figure 1 indicates the main components of a typical DT. The DTs are made by a Cu-OFE body and an AISI 304L Cu-plated stem; internally there are machined steel components which provide the proper cooling water flow around the DT body. DTs are assembled by Vacuum Brazing (VB) and Electro Beam Welding (EBW).

DRIFT TUBES MANUFACTURING

The DT production and assembly, apart the EBW and all DTs-BPM, is made internally at INFN, in Torino (Tanks 1, 2) and in Legnaro (Tanks 3, 4, 5). The production of one typical DT is made of different phases, summarized as follows:

1) Machining of Body, Cover, Stem and internal steel components.
2) Copper plating of stem surfaces, housed in the RF cavity of the DTL.
3) VB of body with stem and relative internal components.
4) For the DT-BPM and DT-EMD, inner-pipe welding on the sleeve (see Brazing section in the following).
5) Machining of the coupling references in the stem for the integration in the girder and laser tracker housing.
6) For DT-PMQ, machining of the references surfaces of the PMQ housing.
7) Integration of the internal beam components (PMQ, EMD, BPM).
8) Sealing of the DT cover with EBW. For BPM and EMD, EBW of the Beam-Pipe on both ends of the DT.
9) Machining to the definitive external profile, by removing the EBW allowance at the Beam-Pipe interfaces with the DT.

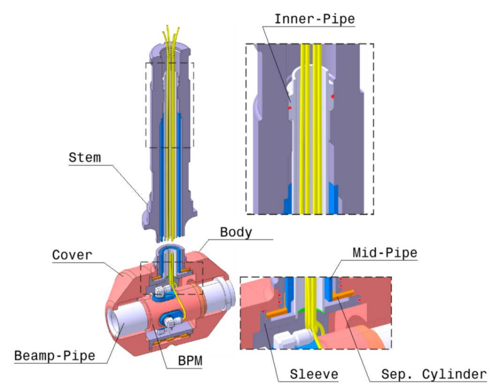

Figure 1: Main components of a DT-BPM. Details show the brazing channels (in red) and press-fit interfaces.

PART PRODUCTION

Mechanical production of bodies and cover is made of different phases, (each one involving different machines and thus different alignment). Referring to Figure 2:

1) Initial rough milling.
2) Lathing of the internal profile. The part is fixed with a classic bracket claw with no pre-alignment.
3) Milling of 90 mm external cylinder. Pre-alignment is made measuring the internal datum plane B and consequently compensating the machine.
4) Milling of 28 mm cylinder for stem integration. Pre-alignment is made with a dedicated alignment block.
5) Lathing of external profile of the angular cone, along with the "nose" plane. The part is fixed on the inner profile with a dedicated alignment as in second picture.

The procedure was continuously improved, in term of production rate, also using feedback from metrology results.

QUALITY CONTROL AND METROLOGY

INFN has developed a quality system in which every single part is designed, producing an executive drawing for each one, then machined and finally measured. This work-flow

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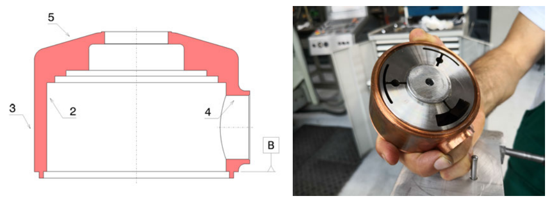

Figure 2: Recap of the different body production phases (left), INFN Alignment blocks for cone profile lathing (right).

allows to highlight immediately anomalies in components or procedures. Both INFN-LNL and INFN-Torino has a Coordinate Measuring Machine (CMM), so parts and assemblies can be measured in parallel in the two workshops. Quality system in DTs production involves the following steps:

1) Marking during production all DTs components.
2) Part metrology with CMM. For every part a summary report is saved.
3) Metrology of the pre-brazing assembly.
4) Metrology of the post-brazing assembly with CMM.
5) Vacuum test, performed at INFN-LNL, of the hydraulic seals in the post-brazing assembly.
6) Test of hydraulic seals at INFN-LNL with He, pressurized N2 or water.
7) Metrology with CMM.
8) Before the integration of the PMQs, each PMQ is characterized by company supplier (Elytt Energy) with rotating probe in order to identify his magnetic axis. After that each PMQ is coupled to the DT with corresponding reference surfaces.
9) Coupling each cover with the corresponding DT.
10) Vacuum packing on each DT for EBW.
11) New test for vacuum seals, performed at INFN-LNL, after welding.
12) Metrology after machining with CMM.

CMM accuracy, according to EN ISO 10360-2 over a temperature band of 18–22 °C, is:

$$MPE_E[\mu\text{m}] = 3.00 + 4.00 \cdot L[\text{mm}]/1000 \qquad (1)$$

Where MPE_E is the CMM maximum permissible error of indication for size measurement and L is the measurement length. Both bodies and covers were measured in the external and then in the internal side, for the VB coupling, in two separate routines. The dedicated clamping system, shown in Figure 3 (left and centre), was developed internally at INFN for a fast and accurate part alignment. Histograms in Figure 4 shows the measured deviation from the nominal value. Dotted lines corresponds to the prescribed dimensional tolerances. Most results are within the machining tolerances. Concerning the DT length graph, there are 10 Drift Tube out of tolerance about 20 µm; those parts was not rejected since they correspond to non-consecutive DT and thus the RF profile along the cavity is not affected by the cell geometry.

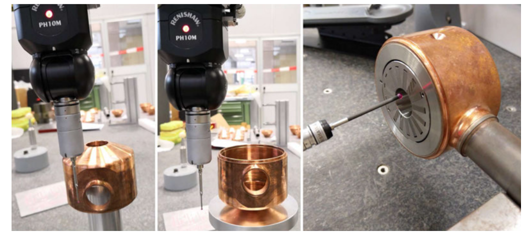

Figure 3: Setup for a DT body metrology at INFN.

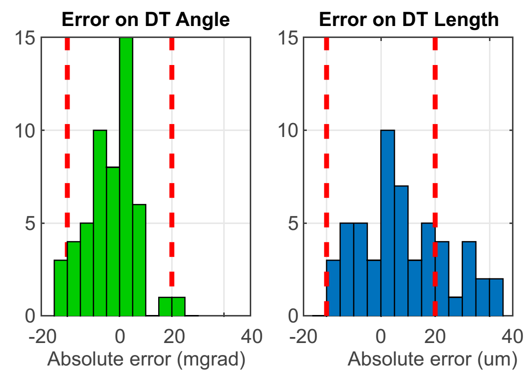

Figure 4: Absolute error histograms for DT bodies.

DRIFT TUBES BRAZING

The SS sleeve is brazed in both ends to the body as it must provide sealing of different interfaces. The Separation Cylinder is inserted in the sleeve's pad with a *H7/g6* coupling [4]. The Mid-pipe is inserted in the stem with interference coupling $\varnothing 20H7/r6$ for a press-fit coupling between stem and pipe in 4 mm length.

The inner pipe has 11 mm internal diameter, used to route the BPM and EMD cables outside the RF cavity to the controller. The inner pipe is integrated in the DT with a VB joint with the stem in his upper end, and with a GTAW joint in the sleeve in the lower end (Figure 1).

The VB phase has been prototyped at INFN-LNL along the project in order to optimize positioning, tooling and thermal cycle and demonstrate the possibility of brazing after Cu-plating of the stems. All prorotypes were succesfully brazed. For the production phase DTs are brazed inserted in 8 elements batches in order to optimize spacing and thermal distributions (left picture in Figure 5). The Oven thermal cycle (right picture in Figure 5) allows a proper thermalization of the DT main components and the complete removal of chrome oxides from all steel surfaces. The temperature of different components is monitored by dedicated thermosensors. First 8 DTs batch has been brazed at end of July 2018: 7 DTs, more precisely 3 DT-PMQ, 2 DT-EMD and 2 DT-Empty, has been successfully brazed and passed vacuum (10^{-9} mbar l/s) and pressure test (1 hour test with water at 8 bar). One DT-Empty presents a leak on the internal sleeve brazing joint. It will be repaired with a dedicated oven cycle after a small machining.

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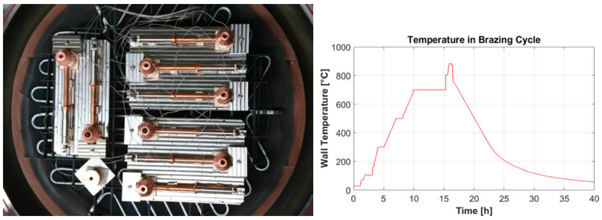
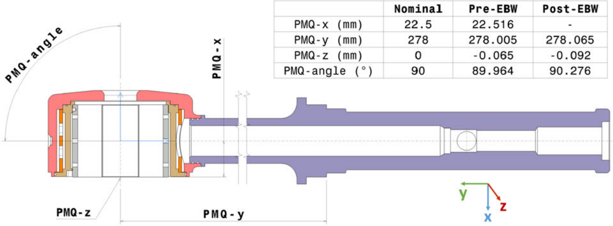


Figure 5: 8 DTs batch inside INFN-LNL brazing furnace (left) and his thermal cycle (right).

DT PROTOTYPE METROLOGY

After brazing each DT has to be machined for nominal positioning and alignment, using the same coupling references of the stem with the girder. For DTs-PMQ, also sleeve pads must be machined at PMQ nominal diameter, assuring that the PMQ magnetic axis is close to the theoretical value with allowable deviations around 5 µm.

In order to study the EBW induced deformation observed in a previous prototype, a second DT-PMQ prototype, was brazed and machined 2018, machined in July and then qualified with CMM. The measuring routine identifies the key housing position in the stem, dimensions and position of sleeve pads for PMQ coupling. After this first routine, a 45 mm prototype PMQ was inserted in the Drift Tube. The measuring routine was performed a second time, with a carbon fiber non-magnetic stylus, measuring the PMQ internal cylinder of the PMQ. A third routine was performed on the welded prototype, in order to detect deviations in the PMQ position due to the EBW: the magnetic axis position was thus qualified (Figure 6).



	Nominal	Pre-EBW	Post-EBW
PMQ-x (mm)	22.5	22.516	-
PMQ-y (mm)	278	278.005	278.065
PMQ-z (mm)	0	-0.065	-0.092
PMQ-angle (°)	90	89.964	90.276

Figure 6: Measured PMQ axis position.

BPM AND EMD INSERTION, EBW

BPM and EMD have power and control cable, housed in the central part of the DT body, in air. The vacuum tightness is guaranteed by a Copper Beam-pipe, with EBW at both DT ends. The welding area is then finished by milling at nominal geometry (right details in Figure 7). For BPMs the beam pipe is EBW on the BPM body before the integration in the DTs. The prescribed tolerances during the BPM production, assembly and welding to the two pipe ends guarantee a correct positioning in the DT.

The proper EMD angular reference is given by a slot in the magnet coil, coupled with a corresponding reference in the sleeve (green in Figure 7); the sleeve longitudinal reference is shown in cyan in Figure 7. Beam-pipe in inserted independently before EMD.

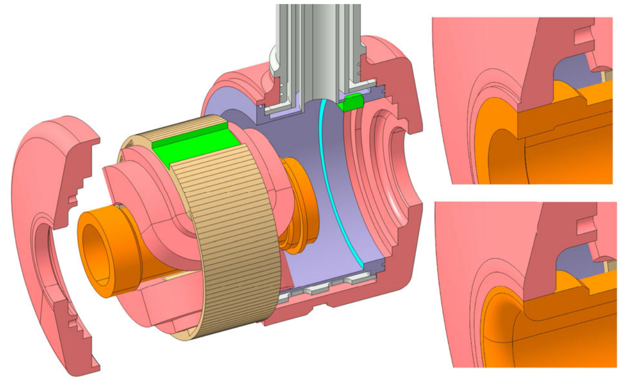


Figure 7: EMD insertion in corresponding DT assembly.

DTL PRODUCTION STATUS

At September 2018, the status of production of the various parts of ESS DTL cavity is the following.

- All the 4 modules of Tank 4 and Tank 1 module 1 and relative girders are delivered to INFN by CINEL (Figure 8);
- Tank 4-Module 1 has been Cu-plated at GSI;
- The other modules are under production by Cinel Strumenti Scientifici;
- DT Bodies and Covers were produced and measured for Tank 1 and 4;
- DT internals were produced for Tank 4, outsourced to 3rd party supplier for Tank 1;
- All the stem production were outsourced to UMAS. 50 Stems have been delivered to INFN;
- All 30 EMDs have been designed, produced and delivered to INFN by DANFYSIK;
- 15 DTs-BPM were outsourced to 3rd party supplier (CINEL);
- The PMQs supply for Tanks 1, 3 and 4 is already delivered to INFN by Elytt Energy. PMQs of Tank 2 and 5 are under production;
- VB for DTs in Tank 4 is started in July. First batch of 8 DTs have been brazed (see Section Drift Tubes brazing);
- All EBW is outsourced to Zanon SPA.

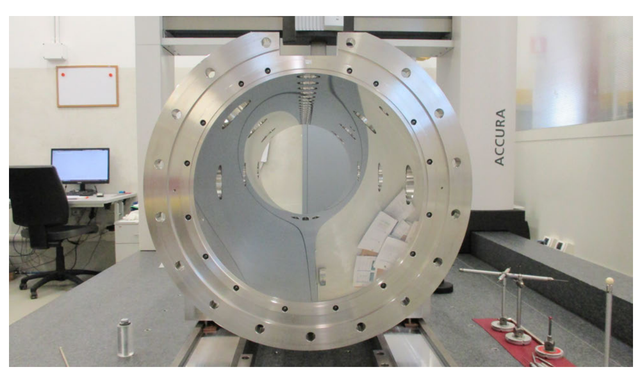


Figure 8: T1-M1 under CMM qualification.

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