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THE DRIFT TUBE WELDING ASSEMBLY FOR THE LINAC4 DRIFT TUBE LINAC AT CERN

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Abstract

The fabrication of the Linac4 Drift Tube Linac (DTL) required the welding assembly of 108 drift tubes (DT) which has been undertaken at the CERN workshop. The design of the DTL is particular in that it was purposely simplified to avoid any position adjustment mechanism for drift tubes in the tank. In consequence, drift tubes have been designed with tight tolerances and parts have been assembled with an optimised welding procedure. Two re-machining stages have been introduced in order to compensate for welding distortions. This paper discusses the various assembly stages with a view on the final precision that has been achieved.

INTRODUCTION

The Drift Tube Linac [1] for the new linear accelerator Linac4 at CERN will accelerate H^- ions of up to 40 mA average pulse current from 3 to 50 MeV. It is designed to operate at 352.2 MHz and at duty cycles of up to 10 %. Permanent magnet quadrupoles (PMQs) are used as focusing elements. The three DTL cavities are equipped with 38, 41 and 29 copper DTs respectively (see Fig. 1). The design aims at reducing the complexity of the mechanical structure doing away with adjustment mechanisms like screws or bellows for drift tube positioning [2]. In consequence, DTs have been designed with tight overall tolerances in the order of 100 µm. The Electron Beam Welding (EBW) technology has been chosen to minimise welding distortion and limit heat input that could damage the PMQ. The duration of the project starting from R&D to the end of the assembly stage was eight years (2005 to 2013).

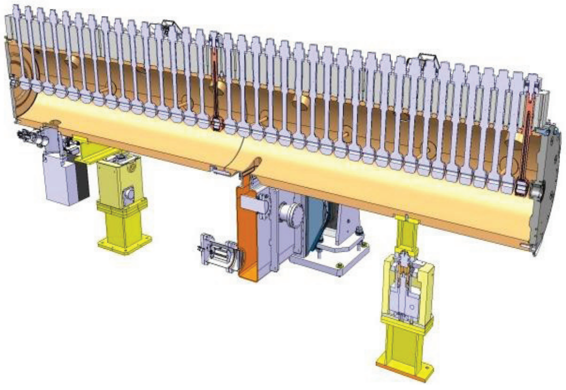

Figure 1: View of a DTL tank equipped with 38 DTs.

MATERIAL

High quality 3D forged OFE copper (99.99 % min. Cu) in half-hard temper was used, having a fine (max. 90 µm) and homogeneous grain size, low content of oxygen (5 ppm) and specific limits in ppm for sixteen additional elements. The main benefits are improved weldability, better mechanical stability, and increased yield strength allowed by the half-hard temper. Ready weldability by EBW was proven. Welding tests were performed with 3D forged OFE copper conform to ISO standard 13919-2, level B, with limited risk of porosity inducing so-called virtual leaks for the vacuum system.

The raw material (multidirectional forged and for some components finished by ring rolling) complies with the stringent requirements of CERN specifications in terms of composition, microstructure, tensile properties, hardness and ultrasonic examination criteria. The ultrasonic (frequency 4 MHz) testing procedure and acceptance criteria, which include a stringent requirement imposing a maximum acceptable loss in ultrasonic back wall echo equal to 20 % screen height, allow a fine and homogeneous microstructure to be indirectly guaranteed on all supplied forgings.

MANUFACTURING OF COMPONENTS

Nearly 1000 components are required to manufacture 108 DTs. Each DT is unique and is assembled using nine components (see Fig. 2) with four EB welds.

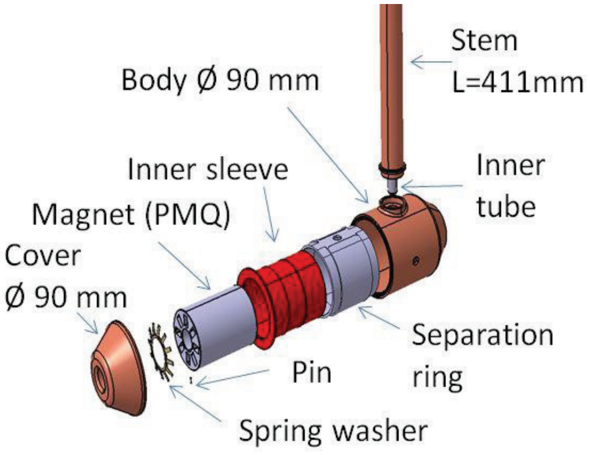

Figure 2: View of the DT's nine components.

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The machining was particularly challenging in respect to the tolerances demanded. All the copper components were manufactured by Desarrollos Mecánicos de Precisión (DMP), a company that is part of the EGILE group. DMP specialises in high precision machining for the aeronautical industry. The dimensions of bodies and covers are different for each drift tube requiring a dedicated CNC program to be created for each part. Every component was verified using precise CMM machines in clean and temperature controlled areas (20±0.1 K). The CMM reports from DMP were verified at CERN's metrology service. Several challenging developments by DMP were needed in order to reach the 20 µm straightness required on the 411 mm long hollow OFE Cu stems or the smooth transition between milling and turning on the body of less than 10 µm with a surface roughness better than Ra = 0.4 µm. Bespoke tooling and diamond tools have been used in order to obtain the best results. All pieces were laser marked ensuring the mandatory traceability. A range of manufacturing and control files designed for each reference have been produced in order to ensure quality and repeatability. Special handling and cleaning procedures were developed and agreed with CERN in order to ensure ultra-high vacuum (UHV) compatibility

ELECTRON BEAM WELDING

The assembly of the DT requires three assembly stages (see Fig. 3).

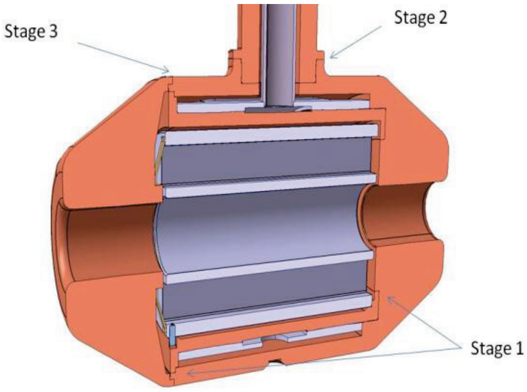

Figure 3: View of the four electron beam welds (three stages).

All parts are degreased and chemically etched, scraping (oxide layer removal) and wire brushing of the weld surfaces are performed immediately before each welding operation.

The first stage concerns the assembly of the water circuit inside the drift tube body (see Fig. 4). Two leak tight welds of 2 mm depth are required. To minimise the welding distortion, a tooling fixture has been used to clamp the parts together and to absorb the heat input. In addition, the tack and welding cycles have been optimised to limit heat input (the welding parameters used for these two welds are around 100 kV, 12 mm/s, 2 kW). The component part remains under vacuum for 20 minutes after the welding operation in order to reduce oxidation.

The deformation of the DT body is in the order of 60 µm in cylindricity after these two welds. A first re-machining stage by turning is performed to create the locating diameter for the cover. To validate the tightness of the welds, a helium leak test is performed systematically.

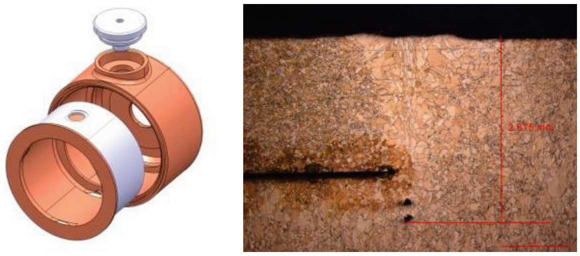

Figure 4: Stage 1: assembly of the water circuit inside the drift tube body.

As can be seen in the cross-section in Figure 4, the weld is defect free over the 2 mm depth required; the cavities inherent to the EBW process are located in the backing support foreseen for this purpose. This concept avoids the risk of any virtual leaks.

The second stage concerns the assembly of the stem to the body. To ensure the required perpendicularity between the axis of the drift tube and the stem of ±1 mrad, a specific tooling fixture is used to hold and position the two elements (see Fig. 5). An original design of the welded joint has been developed to drastically minimise welding distortion. The peculiarity of this design enables a large contact surface (surfaces A & B) while maintaining an independent weld joint with a deformable lip. A 30 µm gap (compatible with EBW process) ensures that the pressure exerted by the fixture is transferred to the contact surfaces (see Fig. 5). The resulting perpendicularity measurements were within tolerance (±1 mrad) for a weld penetration of 2.5 mm (welding parameters 100 kV, 12 mm/s, 2 kW).

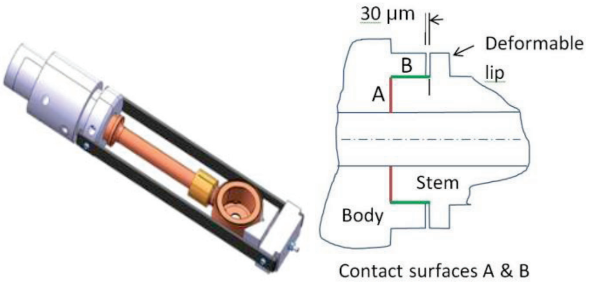

Figure 5: Stage 2: view of the contact surfaces and the welding fixture.

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The second and final re-machining stage is the milling of the PMQ housing with respect to the upper portion of the stem with a precision of 50 µm. This re-machining operation is of fundamental importance as it ensures the precise positioning of the DT inside the cavity without the possibility of future adjustments. The machining is carried out on a five-axis CNC milling machine, using a specific fixture maintaining the DT in position without any constraints (see Fig. 6).

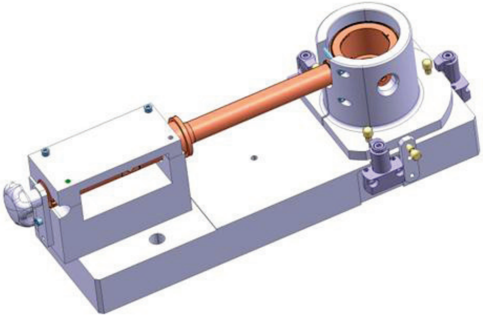

Figure 6: Machining fixture.

A dimensional control is performed to verify the machining operation and ensure the exact position of the PMQ housing before the ultimate welding operation. A final cleaning operation is performed, degreasing and chemical etching, before the last welding operation.

The third and final stage concerns the assembly of the cover to the body (see Fig. 7), carried out after the insertion of the PMQ. The welding parameters have been developed to guarantee that the temperature does not exceed 80 °C at the surface of the PMQ to avoid potential demagnetisation. Particular attention is paid to the weld seam surface, as a smooth regular surface is required for RF reasons. To contain the magnetic field of the inserted magnet, the body is covered with a magnetic shielding foil (Ni 80-81 % Fe 14-15.5 % Mo 4-4.5 %) close to the vicinity of the weld joint. The operation aims to preserve the stability of the electron beam direction, ensure a balanced fusion and regular weld shrinkage. The final assembly undergoes a pressurised helium leak test at 8 bar and is then packaged in a plastic bag under argon protection. The welding parameters used for this weld of 2 mm in depth are in the range of: 70 kV, 12 mm/s, 1.8 kW.

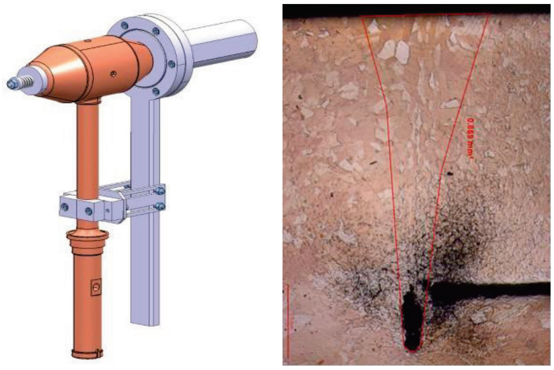

Figure 7: Stage 3: tooling for the cover welding and weld cross section.

METROLOGY

From the beginning of the project, the metrology laboratory was involved in all steps of the process, from the design to the final inspection after the last welding operation. The measurements were done on a CMM with a maximum permissible error (MPE_E) = 2+L/500 (L in mm). To achieve these measurements on 108 different parts of three families for the covers and for the bodies, the idea was to find a common and invariant reference for the measurement on the coordinate measuring machine (CMM). Once achieved, a complex programme was written and efficiency increased by 75 %.The original support structure falsified the measurements (10 µm) due to the effect of gravity. These errors were confirmed by the mechanical design office with a finite element method (FEM) analysis. The support structure was redesigned (see Fig. 8).

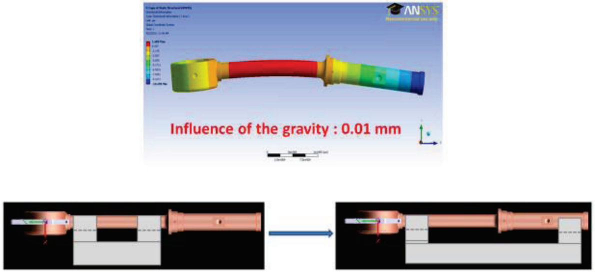

Figure 8: FEM results and redesigned support structure.

During the manufacturing phases, 29 geometrical tolerances were inspected for each body. As the parts are all different, each of them has a dedicated CAD file. Consequently, two parts cannot be measured with the same CMM program because of the different CAD file.The pre-series components were measured at 100 % sample rate and the series at 20 %. The final measurements for all the DTs were within the required tolerances.

CONCLUSION

The development of an extremely stringent procedure made possible the successful manufacture of 108 DTs and has proved the feasibility of a design concept that excludes the possibility of future adjustments. The challenging and tight tolerances have been achieved thanks to the use of an optimised EBW procedure, high quality 3D forged OFE copper, high precision machining, and the use of specific tooling and multistage metrological control. The characteristics of the weld seams obtained met the highest requirements; a defect free weld and good surface quality required for RF applications.

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