CERN LINAC4 DRIFT TUBE LINAC MANUFACTURING AND ASSEMBLY

S. Ramberger*, P. Bourquin, A. Cherif, Y. Cuvet, A. Dallocchio, G. Favre, J.-F. Fuchs, J.-M. Geisser, F. Gerigk, J.-M. Giguet, J. Hansen, M. Polini, S. Sgobba, N. Thaus, M. Vretenar, CERN, Geneva, Switzerland

Abstract

The manufacturing of the Linac4 Drift Tube Linac (DTL) components has been completed and the assembly of the structures is in its final stages. 3 tanks of 3.9 m, 7.3 m, and 7.3 m, designed to accelerate a 40 mA average pulse current H^--beam from 3 to 50 MeV, are being assembled from 2, 4 and 4 segments of about 2.0 m length, containing each from 22 drift tubes at the low energy end, down to only 6 at the high energy end. Due to its peculiar design avoiding adjustment mechanisms on the drift tube, tight tolerances have to be maintained in the production. This paper discusses the assembly stages that are used to achieve the tolerances over the full length of the structures. Metrology results on the assembled DTL Tank1 confirm the required precision.

INTRODUCTION

The mechanical design of the DTL has been undertaken with reliability and ease of assembly in mind from the beginning. A list of basic design decisions lead to a straightforward design that is implemented with the required quality assurance procedures in order to make sure that the final RF, vacuum and beam parameters can be achieved. All parts have been followed in production with metrology verifications so that the required positioning tolerances of drift tubes and their permanent magnet quadrupoles (PMQs) are obtained in the completed assembly, and that the quality of inner surfaces and interfaces provide the required vacuum and RF environment.

The manufacturing of the main Linac4 DTL components has been completed and assembly is currently on-going in the CERN workshops (Fig. 1). The first DTL tank has been completed and installed in the Linac4 tunnel, and it has successfully undergone first beam tests. Each of the four segments of Tank3 has been assembled individually and they are currently being assembled together.

Table 1: Linac4 DTL Mechanical Design Parameters

Parameter	Tank 1 / 2 / 3
Drift tubes per tank	38 / 41 / 29
Number of segments	2 / 4 / 4
Length of tank	3.90 / 7.34 / 7.25 m
Tuners per tank	12 / 20 / 17
Post-couplers per tank	12 / 20 / 29

* Suitbert.Ramberger@cern.ch

MECHANICAL DTL DESIGN

The main body is made of self-supporting 304L stainless steel cylinders of 50 mm thickness doing away with any additional tank reinforcement. The material thickness is sufficient for integrating cooling channels, flanges and inter-segment interfaces without the need for welding except for the RF ports; this choice keeps deformation of the tank segments to a minimum. A maximum length of 2 m was chosen in order to facilitate the procurement of the raw material, to allow manufacturing with standard industrial equipment, and to ease the assembly with drift tubes.

Girders have been designed in EN AW-5083 aluminium to follow the shape of the tank segments. They are aligned by a groove in the tank segment providing precise vertical and lateral positioning. Their main purpose is to position drift tubes precisely along the tank. Drift tubes have been designed without the requirement for wires descending the stem as beam instrumentation and steering magnets are in areas on the beam adjacent to the tanks. PMQs in vacuum are used as focusing elements in the drift tubes. Before installation their outgassing rate is checked. Precise manufacturing of drift tubes is reported in [1].

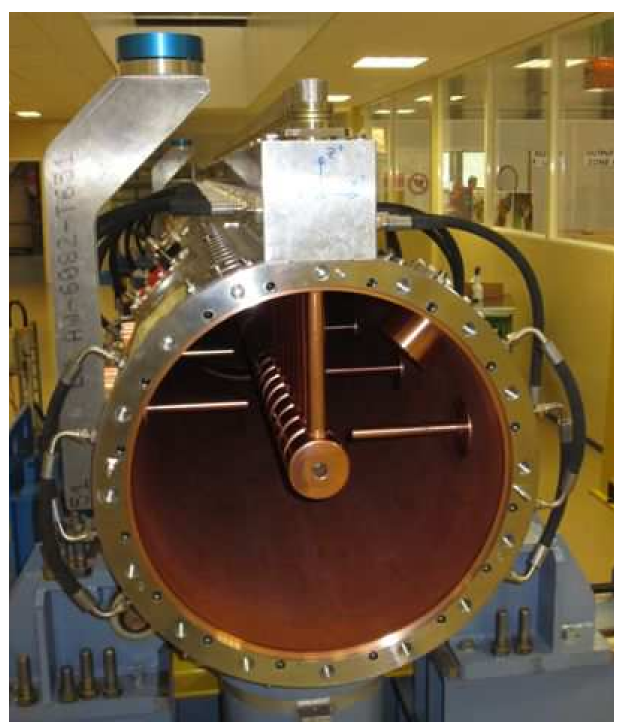

Figure 1: DTL Tank1 assembled.

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All interfaces between drift tubes, girders and tanks are machined with tight tolerances. It has been one of the key issues in the project to define the tolerances and their reference system with great care. Metal seals are used to provide at the same time the vacuum as well as the RF continuity. No bellows nor plastic seals are required in the assembly of the vacuum envelope, making the design robust and reliable. For easier tuning, the gradient of the tanks has been designed flat, and no bends or tuning pads are needed on the post-couplers.

TOLERANCES

The required mechanical tolerances in the DTL are mostly defined by beam dynamics. The positioning of PMQs, transverse horizontally and vertically, and their roll angle are critical. The overall acceptable errors are shown in Table 2 [2]. At the start of the design, the positioning tolerance was split equally between tank manufacturing, magnet manufacturing and tank alignment. Magnet manufacturing achieved tighter tolerances and tank alignment can be compensated by steering the beam giving more margin to manufacturing.

While longitudinal PMQ positioning errors are non-critical for beam dynamics up to a millimetre, the positioning and orientation of drift tubes, affects the distribution of accelerating fields and the beam aperture respectively. In beam dynamics simulations, the DTL has been found to be quite forgiving of tuning errors, and errors up to ±2% can be accepted [2]. It is the low energy end, where longitudinal positioning is most critical due to small gap sizes while it is the high energy end, where orientation errors in the drift tubes have a strong effect due to the length of drift tubes. At short drift tubes, 1% in field error corresponds to 2% error in longitudinal drift tube position thus 0.24 mm on a 12 mm gap. On long drift tubes of almost 200 mm length, a yaw (or pitch) angle of 1 mrad leads to a reduction in aperture of 1% on the 20 mm bore.

TANK AND GIRDER MANUFACTURING

The manufacturing of the 10 tank segments started by deep drilling of cooling channels. After some blank machining, the inner surface of the tanks was finished on a lathe with a surface roughness of $R_a = 0.6\,\mu$m. Rough machining of all openings and the girder groove followed, and a heat treatment at CERN. It was discovered late in the manufacturing that deep drilling had gone out of tolerances and some of the channels got too close to tuner openings.

Table 2: Acceptable mechanical DTL tolerances on PMQ positioning, found in beam dynamics simulations

	transv. (1σ)	roll (1σ)	pitch & yaw (1σ)
Accept. Error	±0.1 mm	±1 mrad	±2 mrad

Three defects were identified by ultrasonic testing, and repaired with welding inserts.

The manufacturer introduced two metrology stages before the final remachining where any alignment errors of previous stages can be compensated and the required amount for final re-machining is defined. Last the reference surfaces supporting the girders and connecting the end flanges are fine machined. All tank segments have been manufactured within or close to tolerances. After delivery at CERN, they are cleaned and copper plated with a nominally 30 μm thick matt copper layer.

In parallel, the manufacturing of girders has been one of the most critical steps in the project. The girders have tolerances of mostly 20 μm. Machining has been undertaken at two companies in parallel that both feature DIXI machines with micrometer precision in a temperature controlled environment. The girders are pre-machined, heat treated, equipped with stainless steel ring inserts at each drift tube position on the top and bottom side and fine machined to the required precision.

SEGMENT ASSEMBLY

First girder segments are installed in the top groove of the tank segments, the key for precise longitudinal positioning is inserted and the girder is bolted down by screws. Next cooling channels are plugged at dead ends, and vacuum tested. The structure is outfitted with blank flanges with temporary rubber seals and vacuum tested. As soon as this starting point has been defined, drift tubes are installed with their copper seal, orientation key and the mounting mechanism as described in [3]. Drift tubes are installed consecutively on both sides from the center and tested by up to four per vacuum test cycle of around 24 h. The completed segment is thoroughly vacuum tested for leak and outgassing rates. After venting, the geometrical position of drift tubes is analysed by laser tracker. So far almost all drift tubes have been positioned within ±50 μm.

TANK ASSEMBLY

When completed segments are available, they are aligned on a special purpose rotational assembly rig that had been used in LHC cryo-magnet fabrication earlier. Segments are connected by an inter-segment ring, oriented by a key, using the respective spring loaded seal (Fig. 2). Sealing surfaces on segments are copper plated and the inter-segment seals have a copper lining. Nuts on lubricated bolts are tightened by a torque of 200 Nm making sure that interfaces on a full structure supported at both ends would not open even under such extreme conditions. Transport points are in the optimal locations for reducing the structure sag.

The alignment of the assembled segments is verified by laser tracking again (Fig. 3) and the vacuum sealing is tested by closing all flanges. In the case of Tank2 and Tank3, the assembly procedure is repeated with the two one-by-one subassemblies for building a four-segment tank. As soon as the tank is complete with segments, the alignment, the

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magnet polarities and the vacuum are checked, and the tank is outfitted with the final end-covers machined at CERN, as well as temporary tuners and post couplers. Tuning and stabilisation is undertaken in order to equalise the average field levels and to make the structure insensitive to local variations in temperature. The tuning and stabilisation of Tank1 is reported in [4]. Once the final length of tuners and post-couplers is known, pre-fabricated pieces are re-machined to the correct length.

VACUUM

All components are carefully cleaned and tested before installation. Spring loaded seals have been chosen with care to fit to the forces applied on flanges. Copper seals have been preferred on copper surfaces to avoid the possibility of corrosion due to electro-chemical potential. Leak testing channels have been foreseen on all flanges. Sealing surfaces are treated manually. Screws are silver plated.

Inspite of the precautions taken, installation of copper seals turned out to be demanding. 8 out of 10 seals were leaking at the first attempt and a considerable test series was started. 3 techniques to get the seals tight developed out of the experience collected on other vacuum structures over the last years:

- Heat treatment of seals to render the copper soft and malleable,
- Baking of seals in-situ under compression such as to ease their plastic deformation,
- Diamond filing of fine machined smooth surfaces to create the required roughness profile that leads to the plastic deformation of the seal upon compression.

Baking is considered an option in case that leak tightness is not fully achieved. Why a heat treatment in this sealing application is required has not been fully clarified with the manufacturer yet.

For drift tubes a seal with a delta shaped knife edge has been chosen that fits with the low forces that need to be applied to the OFE copper drift tube. Smooth and defect free sealing surfaces are prepared for these seals to become leak tight. In addition, a lower quality metal seal has been inserted between the girder and the tank in order to reduce cross-talk in He leak testing between adjacent drift tubes.

Figure 2: Interface between segments T3S1 and T3S2 before closure with inter-segment ring and key.

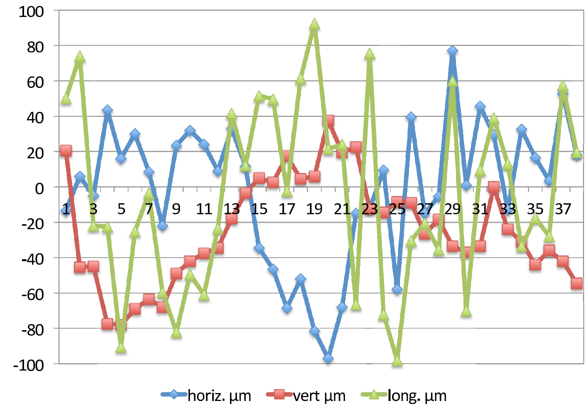

Figure 3: Alignment errors of drift tubes over the whole tank. The interface between the two segments is between drift tube 22 and 23.

CONCLUSIONS

The LINAC4 Drift tube Linac has been designed with the aim of making manufacturing and assembly straightforward while matching the alignment and field tolerances needed by a high power accelerator. This choice entails meticulous preparation and strict application of assembly and quality assurance procedures. The successful assembly of Tank1 and the recent beam tests have validated the design choice, the assembly procedure and the testing sequence.

ACKNOWLEDGEMENT

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