PRODUCTION DESIGN OF THE DRIFT TUBE LINAC FOR THE CERN LINAC4

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Abstract

The design of the Drift Tube Linac (DTL) for the new linear accelerator Linac4 at CERN has been made ready for production: H^--ion beams of up to 40 mA average pulse current are to be accelerated from 3 to 50 MeV by three RF cavities operating at 352.2 MHz and at duty cycles of up to 10%. In order to provide a margin for longitudinal matching from the chopper line, the longitudinal acceptance has been increased. The synchronous phase starts at -35 deg in Tank1 and ramps linearly to -24 deg over the tank while it went from -30 to -20 deg in the previous design. The accelerating gradient has been reduced to 3.1 MV/m in Tank1 and increased to 3.3 MV/m in Tank2 and Tank3 for a better distribution of RF power between tanks that is compatible with a mechanical design. To make the transverse acceptance less sensitive to alignment and gradient errors, the focusing scheme is now FFDD over all 3 tanks. Design features that were demonstrated in earlier reports have been improved for series production. Results of high power RF tests of the DTL prototype equipped with permanent magnet quadrupoles (PMQs) are reported that test the voltage holding in the first gaps in presence of magnetic fields.

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INTRODUCTION

The design of the DTL has been completed studying quasi in parallel the electro-magnetic, the beam-dynamics and the mechanical design. This approach is required as design issues are multidisciplinary and interdependent. Prototypes were used for mechanical and electro-magnetic design verifications.

Considerable modifications have been introduced to make the design more robust, fully compatible with manufacturing requirements, and easier to assemble, test and operate. The final design parameters are shown in Table 1.

Table 1: DTL cavity parameters

Parameter	Cavity 1 / 2 / 3
Cells per cavity	39 / 42 / 30
Average accel. field	3.1 / 3.3 / 3.3 MV/m
Maximum surface field	1.49 / 1.40 / 1.44 Kilp
Synchronous phase	-35 to -24 / -24 / -24 deg
RF peak power per cavity	0.99 / 2.00 / 1.93 MW
RF beam power	0.36 / 0.78 / 0.75 MW
Focusing scheme	FFDD
Quadrupole length	45 / 80 / 80 mm
Number of segments	2 / 4 / 4
Length per cavity	3.90 / 7.34 / 7.25 m

ELECTRO-MAGNETIC AND BEAM-DYNAMICS DESIGN

The electro-magnetic and the beam-dynamics design have evolved in unison, maintaining the ideas presented earlier on limiting breakdown field in the first cells [1, 2], and compact design with high gradient [3]. Manufacturing capabilities relating to the drift tube and tank segment sizes have been studied early and used as constraints during the design phase:

- The average accelerating field E_0 has been optimised in order to use available power over the predefined maximum segment length effectively.
- The RF phase in the first cells of cavity 1 has been lowered in order to increase input phase acceptance and tolerance to error from the chopper. Sensitivity to RF phase errors is decreased.
- The focusing scheme in cavity 2 and 3 is now FFDD as this leads to a design that is more tolerant to quadrupole errors. Also the gradient is smaller.
- The matching between cavities is smoothed over 4 to 6 cells. The lower phase in the end-cells requires higher power in the electro-magnetic design.
- The diagnostics and steering in the inter-tank areas has been optimised to fit within $3\beta\lambda$ between cavities 1 and 2 and $2\beta\lambda$ between cavities 2 and 3.
- The size of the drift tube nose flat has been optimised in cavities 2 and 3 to achieve higher shunt impedance.

MECHANICAL DTL DESIGN

A considerable number of improvements in the mechanical design have been undertaken based on the experience gained in the manufacturing, assembly and tests of the pre-prototype and prototype DTL cavities.

The final mechanical DTL design is based on the following decisions:

- Self-supporting structure of steel cylinders

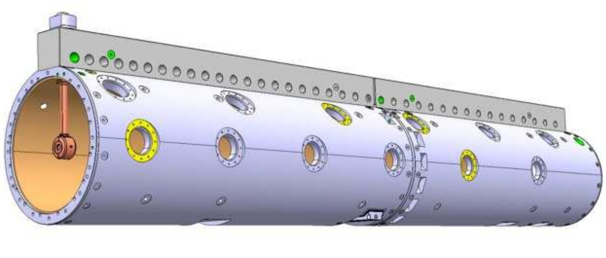

Figure 1: Vessels and girders of the DTL Tank1.

- Maximum segment length of 2 m
- PMQs instead of EMQs for focusing
- PMQs in vacuum
- Precise machining without adjustment mechanisms
- Stainless steel AISI 304L for cavities
- Vacuum grid design with integrated cooling channels
- Stainless steel magnet holders
- Interlocking on water flow and thermal probes
- Additional lower cost seals for leak testing

The basic design principle of the Linac4 DTL, using bolted steel cylinders supporting precisely machined aluminium girders with shrink-fitted stainless steel positioning rings for drift tube mounting, and the absence of any adjustment mechanism has been reported earlier including relevant design tolerances [1]. The cavity material now is ring forged stainless steel AISI 304L in order to reduce risks in manufacturing and operation with several advantages. The cavities will be copper plated only on the inside, and precise reference surfaces do not need protective layers when left bare. In case of problems in plating, the plating layer can be removed without damage to the base material. In addition, the 12 mm diameter deep-drilled cooling channels for demineralised water can be linked in series with channels in copper drift tubes and do not require a separate cooling circuit.

A downside of using stainless steel instead of mild steel is its 4 times lower heat conductivity. It becomes critical on the vacuum port, where large openings for pumping within a DN150 flange area lead to a concentration of surface currents and thus power loss ($\sim$90 W) on the remaining grid bars (Fig. 2). While the additional power loss due to the grid is negligible, heat flow has to follow these bars as no other path for heat evacuation exists, and results in a temperature rise easily exceeding 100 K at 10% duty cycle without active cooling. The pumping grid thus has been redesigned with just two 20 mm wide and 25 mm thick bars with integrated cooling channels reducing the temperature rise to 10 K. While larger openings increase RF leakage, thicker bars reduce it. A peak power loss of 1.1 W was simulated on a reference surface where the vacuum pump is connected to a 200 mm long manifold sleeve.

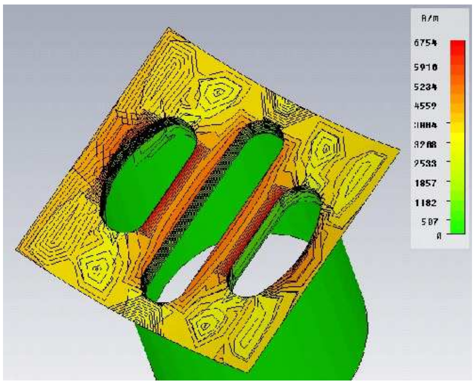

Figure 2: Current density distribution around the vacuum port (arbitrary scale).

DRIFT TUBE MOUNT ASSEMBLY

The mounting mechanism has been considerably improved using fewer parts that require less machining (Fig. 3). Spring washers are slid on a sleeved bushing that is inserted into the base plate, the sleeve preventing the washers from misaligning and obstructing the common opening. The assembly is tightened with a pre-stress socket on a press and fixed by a pre-stress screw on either side.

A stainless steel mounting screw instead of the earlier extension rod is installed without force through the sleeve directly into the drift tube. A stop on the screw abutting on the drift tube prevents too tight mounting, and leaves the required exact clearance for the Helicoflex® seal. When releasing the pre-stress screws, the compression force of the spring washers of about 20 kN is transferred uniformly onto the drift tube through the mounting screw.

A recently added flat 3 mm wide channel through the steel vessel passes just above the Helicoflex® seal and extends into the drift tube. It provides a way of measuring a reference temperature of the drift tube core with external industrial thermal probes. The same channel allows for injecting helium to check the leak tightness of the seal on a residual gas chromatograph.

Additional slightly compressed seals for leak testing between the girder and the vessel impede the helium from propagating to neighbouring drift tubes. The channels may also be used for evacuating an accidental water spill within the drift tube opening. A patent on the assembly has been filed and the technology can be licensed from CERN.

HIGH POWER TESTS

A full-scale prototype with 12 drift tubes corresponding to about half a tank segment has been built as a proof of concept of the design, and tested in various configurations (Fig.4). In order to separate the tank and drift tube development, the original 12 drift tubes do not contain PMQs and their cooling circuit just consists of a stub. Verification of the mechanical design and tolerances has been reported

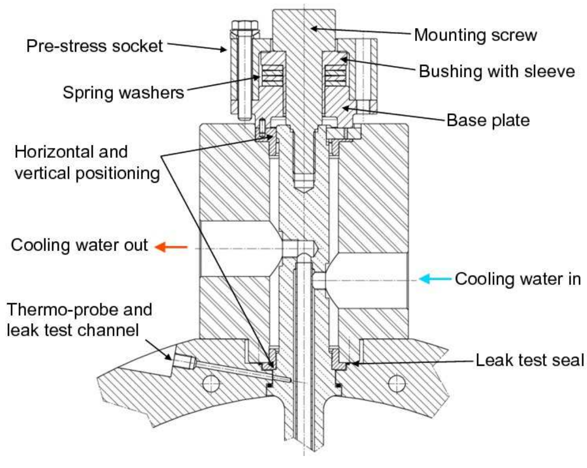

Figure 3: Drift tube mount assembly.

earlier [1]. The structure has then been equipped with movable tuners and post-couplers in order to develop and test a new stabilisation strategy based on a spectral measurement and fitting an equivalent circuit reported in [4]. The final post-couplers and tuners have been manufactured and installed on the prototype.

Considerable effort went into the vacuum testing of the structure to levels of 10^{-7}mbar. It was found that during installation, copper filings had impaired the vacuum tightness of several vacuum seals. In addition, lack of access to the seal area made it difficult to test the vacuum tightness of drift tubes one by one. In consequence, a strategy for clean drift tube mounting had to be developed and tested on the prototype. The prototype was then equipped with a waveguide coupler, conditioned and tested at high RF power.

The prototype is designed for a nominal average accelerating field level of 3.3 MV/m. The unloaded Q-value was measured to 33700 which corresponds to 80% of the Q-value found with Superfish. At nominal field, a power of 220 kW is required. The structure was conditioned within 15 days to a 7.5% duty cycle with 1.5 ms pulse width and 50 Hz repetition rate, the highest expected for operation in a Superconducting Proton Linac (SPL) [5]. Cooling was tested at CW operation at a power level equivalent to the 10% maximum design duty cycle at nominal power.

In parallel to the manufacturing and assembly of the prototype cavity, the design of a drift tube with PMQ was developed and tested. Several test assemblies were built to optimise the assembly procedure by e-beam welding. Thin shielding with mu-metal sheets was used to limit beam deflection in the magnetic field of the PMQ. Magnetic measurements on a PMQ after welding confirmed that the magnetic properties of the Sm_2Co_{17} blocks had not changed due to excessive heat. Finally a complete drift tube equipped with PMQ and cooling circuit was built and tested at high RF power. The drift tube has been installed in the cavity using the new mounting mechanism.

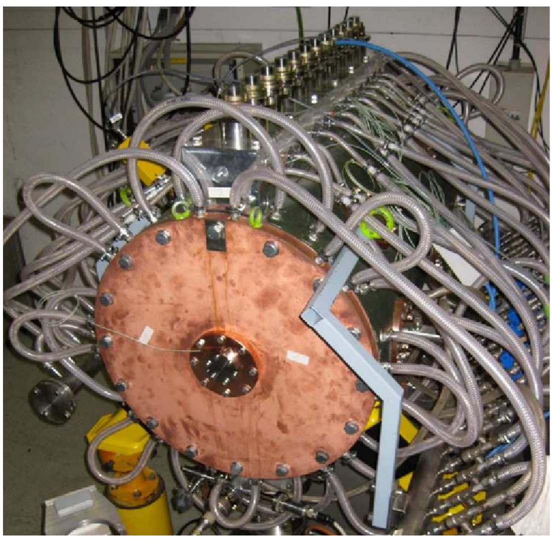

Figure 4: DTL prototype at the high power test stand.

Reconditioning to a 3% duty cycle after insertion of the drift tube has been achieved within four days using an automated procedure. To further test the voltage holding in presence of magnetic fields, it was decided to equip the half drift tube in the end wall with a second PMQ. The exchange of the magnet is minimally invasive as after venting with nitrogen, the cavity becomes exposed to air only through the 20 mm diameter aperture in the half drift tube.

Following corrosion during the assembly stage of an aluminium holder in a copper drift tube, PMQs with holders in anodised aluminium, stainless steel, and titanium were tested in the end wall and reconditioned within two days. No issue with voltage holding in the presence of magnetic fields has been discovered. Concerning the corrosion problems, use of anodised aluminium on a large scale was excluded due to outgassing. Stainless steel was retained as its expansion coefficient is closest to the one of copper and lower heat conduction will help to avoid damage on Sm_2Co_{17} blocks during welding.

CONCLUSIONS

Based on the experience from the prototype structures, the DTL design has been completed such that it is consistent between electro-magnetic and beam-dynamics simulations, with design parameters and constraints, and in cell and tank distribution. It is manufacturable in segment size, drift tube dimensions, and post-coupler positions. It is integrated with RF supply, vacuum and cooling, and optimal with respect to the chosen design parameters. And finally it is complete in tuning, stabilisation and compensation, and ready for manufacturing, assembly and testing.

The manufacturing of the DTL is currently being started.

ACKNOWLEDGEMENT

Construction of the DTL relies on CERN workshops for assembly and finishing technologies. Manufacturing of drift tubes has been started in collaboration with ESS-Bilbao.

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