DRIFT TUBE LINAC DESIGN AND PROTOTYPING FOR THE CERN LINAC4

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Abstract

The Drift Tube Linac (DTL) for the new linear accelerator Linac4 at CERN will accelerate H$^-$-ion beams 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 %, if required by future physics programmes. The accelerating field is 3.2 MV/m over the entire length. Permanent magnet quadrupoles (PMQs) are used as focusing elements. The 3 DTL cavities consist of 2, 4 and 4 section of about 1.8 m each, are equipped with 35, 41 and 29 drift tubes respectively, and are stabilized with post-couplers. Several new features have been incorporated in the basic design. The electro-magnetic design has been refined in order to reduce peak field levels in critical areas. The mechanical design aims at reducing the complexity of the mechanical structure and of the adjustment procedure. Drift tubes and holders on the tanks that are machined to tight tolerances do not require adjustment mechanisms like screws or bellows for drift tube positioning. A scaled cold model, an assembly model and a full-scale prototype of the first half section have been constructed to validate the design principles. The results of metrological and RF tests are presented.

INTRODUCTION

The Linac4 DTL will accelerate H$^-$-ion beams of up to 40 mA average pulse current from 3 MeV to 50 MeV in 3 accelerating cavities over a length of 18.7 m. The RF cavities operating at 352.2 MHz and at duty cycles of up to 10% are 520 mm in diameter with drift tubes of 90 mm diameter and 20 mm beam aperture.

The drift tubes are equipped with permanent magnet quadrupoles (PMQ) with an FFDD lattice in cavity 1 and an FD lattice in cavity 2 and 3. PMQs have the advantage of small size at medium magnetic gradients without the need for current supply wires or power converters. To ease matching for beam currents below nominal, electromagnetic quadrupoles are placed in each of the intertank sections. Latest design parameters are shown in Table 1.

ELECTRO-MAGNETIC DESIGN

The electro-magnetic design aims at an acceleration with high constant average field E_0 of 3.2 MV/m over all gaps with a high effective shunt impedance per unit length ZT^2. While it is a typical DTL concept to ramp E_0 in the first cavity in order to adiabatically capture the beam longitudinally [1], the choice of high constant E_0 aims at maximizing the energy acceptance to the incoming beam and leads to a more compact design [2].

Table 1: DTL Cavity Parameters

Parameter	Cavity 1 / 2 / 3
Cells per cavity	36 / 42 / 30
Maximum surface field	1.6 / 1.4 / 1.3 Kilp
Synchronous phase	-30 to -20 / -20 / -20 deg
RF peak power per cavity	0.95 / 1.92 / 1.85 MW
RF beam / peak power	1.88 MW / 4.7 MW
Focusing scheme	FFDD / FD / FD
Quadrupole length	45 / 80 / 80 mm
Number of sections	2 / 4 / 4
Length per cavity	3.63 / 7.38 / 7.25 m

A particular advantage of ramping E_0 are lower peak fields at lower beam energies where earlier designs showed increased breakdowns [3]. Several parameters might be of influence: comparably large surfaces of flat opposing faces on consecutive drift tubes, more outgassing due to larger overall surfaces including the cavity end-wall, an incoming beam with a higher number of stray particles, magnetic fields close to surfaces of shorter drift tubes.

Recent studies for muon cooling where strong accelerating and magnetic fields have to be combined, emphasize the importance of the latter [4]. The PMQs that will be used for the DTL design have a peak magnetic surface field of 0.5 T which in the shortest drift tubes falls close to the area of peak electric fields.

In order to reduce breakdown probability in the first cells, the peak electric field therefore has been reduced by 30% by increasing the gap length. The cells are tuned by the face angle. At longer drift tubes the peak electric field can be ramped to values that allow for optimum effective shunt impedance (Fig. 1). In this way, the same advantage of lower peak fields in the first cells is achieved as when ramping E_0.

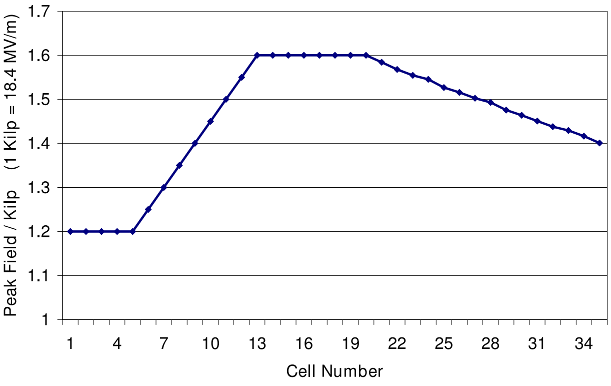

Figure 1: The peak field is reduced in the first cells.

The minimum gap length increases by 40 % from about 8.5 mm to 11.9 mm. As a further advantage also longitudinal mechanical tolerances increase by the same relative amount. The consequences on the effectiveness of the structure remain low. Energy gain in the first cells decreases by 4.1% but only 1% in beam energy over the first cavity is lost.

ALIGNMENT TOLERANCES

The required alignment tolerances were defined by error studies on beam dynamics [5]. Limits for transversal and rotational positioning of quadrupoles are tight (Table 2). The longitudinal magnet position is less critical.

Table 2: Alignment Tolerances Between Drift Tubes

Error Type	Max. Amplitude
Transverse horiz. & vert. (x,y)	±0.1 mm
Magnet rotation, all axes	±3 mrad

The tolerances are tight but following advances in machining quality, they are considered feasible without any further adjustment mechanism. In consequence, all critical parts have to undergo metrology before assembly. Considerable advantage of this strategy is that the assembly becomes straightforward and that positioning cannot degrade by accidental movement of screws. It is worth noting that on other DTLs like the Linac2 at CERN, the drift tube positions have never been corrected after their first alignment even though the design had foreseen this explicitly [6].

MECHANICAL DTL STRUCTURE

The DTL cavities consist of a steel cavity, an aluminium girder, drift tubes assembled from pre-machined copper pieces, and accessories for mounting drift tubes in girders as well as for tuning, stabilization, support, vacuum pumping and alignment of the structures (Fig. 2).

The cavities are made from 50 mm thick mild steel cylinders that provide the rigidity to achieve the required tolerances when placed on supports. The cavity is segmented into 2 sections in the first cavity, and 4 sections in the second and third cavity that are aligned with precisely machined rings after assembly of each section. Mild steel is the material of choice due to its thermal conductivity, mechanical strength, and comparably low price [1].

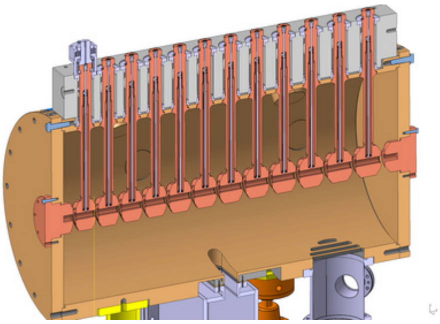

Figure 2: DTL prototype cut along the beam axis.

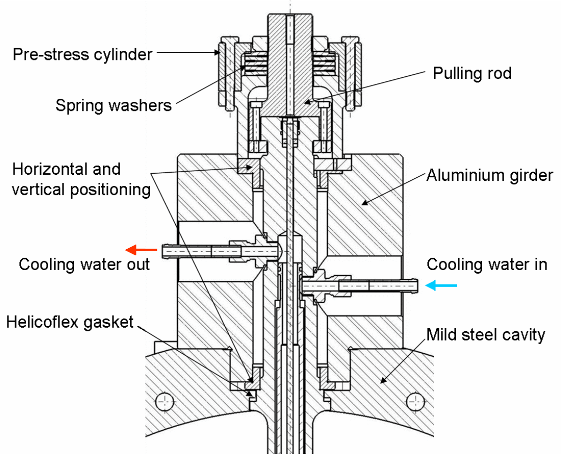

Figure 3: Drift tube mount assembly.

The steel cylinders of about 1.8 m length are precision machined in order to correctly position rectangular aluminium girders on top. The girders are pre-machined for each drift tube and stainless steel rings are inserted into the openings from above and below. The steel rings are remachined for precise drift tube positioning.

DRIFT TUBE MOUNT ASSEMBLY

The completed girder is placed on the steel cylinder and provides the reference for drift tube mounting (Fig. 3). The horizontal position of the drift tube is defined via the lever arm between upper and lower steel rings whereas the vertical position is given by the stop position on the lower ring.

At the top, the copper drift tube is extended by a stainless steel pulling rod as the length of the drift tube shaft that can be installed in the cavity is limited by the diameter of the cavity. The Helicoflex® gasket rests on a stop on the drift tube and provides for vacuum tightness and RF continuity towards the copper plated mild steel cavity. Spring washers at the top of the drift tube provide the required force via a nut to compress the Helicoflex® gaskets.

For the installation of the spring washers a pre-compression socket is assembled in advance with the lower support socket. This pre-assembly is placed over the pulling rod and rests on the upper stainless steel ring. The nut is placed on the extension rod and just locked on the spring washers. The pre-compression cylinder is released in a way that the compression force is transferred uniformly to the drift tube through the nut and the extension rod.

MANUFACTURING PROCEDURE

The manufacturing procedure for drift tubes is critical in order to reach the required high precision at assembly:

- Machining of drift tube parts with main references
- Assembly of drift tube with stem by e-beam welding
- Vacuum test of cooling circuit
- Final machining of magnet holder and references
- Insertion of PMQ

- Closure of drift tube by e-beam welding
- Metrology

After assembly of each cavity section, the position of drift tubes to reference surfaces is checked by a laser tracker.

THE PROTOTYPES

A full-scale pre-prototype with two drift tubes has been built to test the mount assembly. Laser tracker measurements compared to dimensional metrology data show that the vertical positioning is within 0.01 mm. The horizontal positioning is within 0.1 mm longitudinally and within 0.05 mm transversally with respect to the cylinder axis.

Currently a full-scale prototype of a half section with 12 drift tubes without PMQs is being constructed at CERN (Fig.4). The purpose is to gain a small representative statistic sample on drift tube mechanics and to test technologies such as copper plating, e-beam welding, vacuum sealing, as well as tuning, stabilization, and operation at high RF power. At a later stage, few drift tubes with PMQs will be installed. All the prototype component machining has been provided by INFN/LNL, a contribution in view of a possible application for a radioactive ion beam facility driver in the SPES project [7].

A scaled cold model has been manufactured in order to study stabilization with post-couplers considered to be critical because of the drift tube to tank distance of $1.01\,\lambda/4$ and the 1 in 3 post-coupler scheme in the first cavity [8]. The model could be easily stabilized. Figure 5 compares bead-pull measurements with and without post-couplers after detuning by shifting the half drift tubes at either end.

CONCLUSIONS

The DTL design for the Linac4 at CERN incorporates new features in a basic design: Peak fields are ramped in the first cavity in order to reduce probability for breakdown while the accelerating field E_0 is kept constant over the whole structure. A new mounting mechanism is described that does not require any adjustment after assembly. Both features aim at a robust and reliable construction and operation. First results of metrological and RF tests demonstrate the current progress of prototyping.

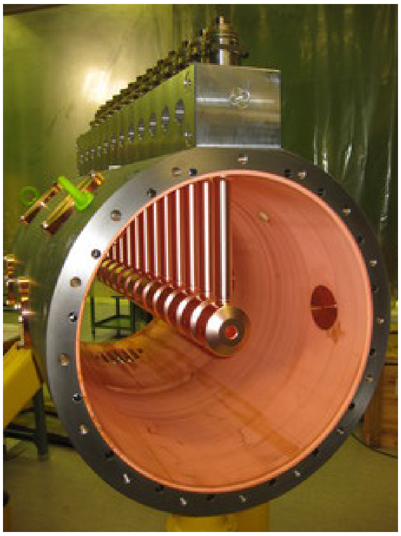

Figure 4: DTL prototype in the assembly stage.

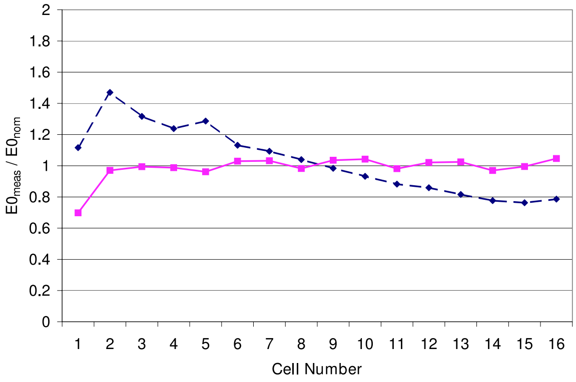

Figure 5: Accelerating voltage per cell in the cold model without (dashed) and with post-couplers (continuous).

ACKNOWLEDGEMENT

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