HIGH POWER RF TESTING OF A CELL COUPLED DRIFT TUBE LINAC PROTOTYPE FOR LINAC4

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Abstract

A Cell-Coupled Drift Tube Linac (CCDTL) accelerating structure at 352 MHz has been adopted for the energy range 40 to 90 MeV of Linac4, the new 160 MeV injector linac for the CERN accelerator complex. With regard to a conventional DTL in this energy range this structure presents the advantages of lower construction cost and easier access, cooling and alignment of the focusing quadrupoles placed between tanks.

A full-scale high-power prototype representing 1/3 of a complete module has been designed and built at CERN. It is fed by a waveguide input coupler of novel conception.

This paper summarizes the main mechanical features of the prototype and reports the RF tuning procedure and the results of high-power RF testing.

THE CCDTL PROTOTYPE

A CCDTL module, in the geometry adopted for Linac4 [1], consists of three DTL-type tanks containing two drift tubes each, connected by off-axis coupling cells. Between tanks are placed electromagnetic quadrupoles and diagnostic equiment whose installation, alignment and access is greatly simplified with respect to a DTL. The module resonates at 352 MHz in the π/2 mode, leaving the couping cells unexcited. Figure 1 shows an open 3D view of a module, together with its support and the short-circuited WR2300 waveguide coupled to the central tank.

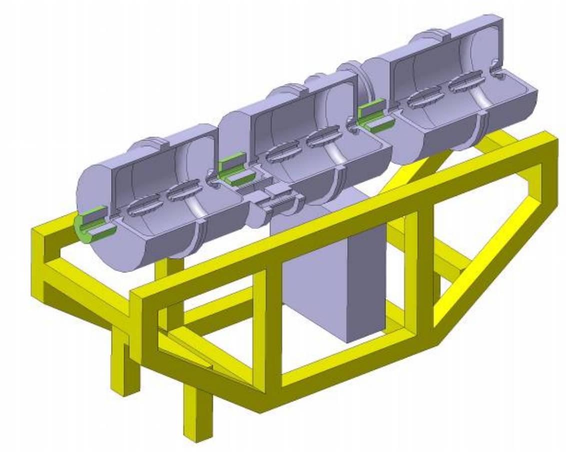

Figure 1: open view of a CCDTL module.

A CCDTL prototype consisting of two half accelerating cells connected by a coupling cell (Fig. 2) has been recently designed and built [2]. The chosen geometry is the smallest presenting the same electric field and thermal distribution as the final CCDTL structure. The half-tanks are made of copper-plated stainless steel, with cooling channels directly machined in the external part of the tank cylinder. Each half-tank contains a drift tube made in copper and cooled via the supporting stem. The half-tanks are connected via coupling slots to a coupling cell and are closed by disc covers, to provide the correct boundary conditions for the electric fields. In the final CCDTL configuration, two half-tanks are connected to form a complete tank. Vacuum and RF tightness between half tanks and covers and between the coupling cell elements are provided by "Helicoflex" type contacts. The end walls are EB welded to the tank cylinder, as well as the coupling cell end wall. Table 1 summarises the geometrical dimension of the prototype cavity.

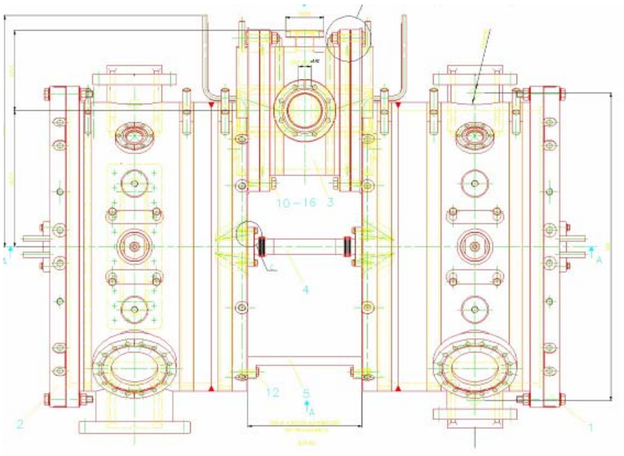

Figure 2: View from top of the CCDTL prototype. The coupling cell is off-axis; the quadrupole is replaced by a tube.

Each accelerating cell is equipped with two ports for tuners and one port for vacuum pumping. One of the accelerating cells has the port for the waveguide input coupler. The coupling cell is equipped with two tuning ports. All cells have a RF pickup port. Figures 3 and 4 show the prototype at different stages of its assembly.

Table 1: Geometrical dimension of the accelerating and coupling cell of the CCDTL prototype.

Accelerating tank diameter	495 mm
Drift tube diameter	85 mm
Full bore aperture	28 mm
Half accelerating cell length	302.5 mm
Gap length	49.05 mm
Coupling cell length	240 mm
Coupling cell nose diameter	93 mm
Coupling cell diameter	233 mm
Coupling cell gap	22.8 mm

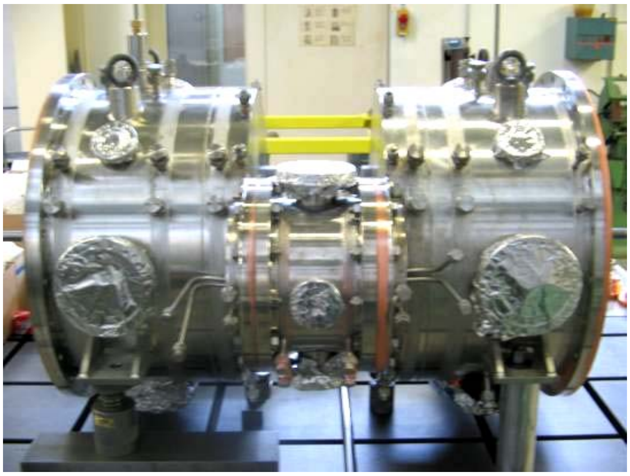

Figure 3: CCDTL during assembly in the workshop.

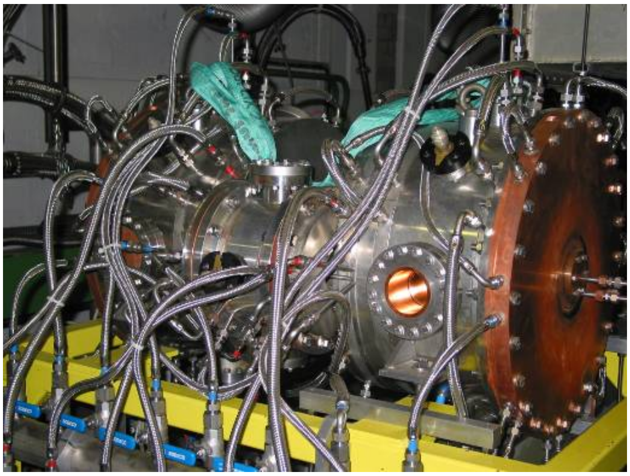

Figure 4: CCDTL cavity assembled, tuned, vacuum tested and with cooling system connected.

RF TUNING PROCEDURE

For the low-level measurements the cavity was first assembled without the waveguide coupler and preliminary measurements were made to characterise each cell. In order to measure the frequency and Q-value of an individual cell, the remaining cells were detuned by insertion of a metallic bar in the beam aperture, or in case of the coupling cell by short-circuiting the gap with a spring contact.

Next step was to tune to 352.2 MHz the frequency of each of the three cells constituting the resonator, by means of piston tuners and of end caps inserted via the central aperture in the end covers. After this adjustment, the input waveguide coupler was mounted and matched to the waveguide impedance. The half-height WR2300 waveguide from the RF generator is terminated into a movable short-circuit (a sliding plate) at $\lambda/4$ distance from an iris that couples the waveguide to the resonator. By moving the short-circuit plate, the voltage on the iris can be varied, allowing to change the coupling between waveguide and resonator until the critical coupling, corresponding to zero reflected power, is achieved. The coupling factor $\beta \equiv P_{ext}/P_{cav} = Q_0/Q_{ext}$ was measured for different short-circuit positions and the measured data is reported in Fig. 5. The curve follows the sinusoidal variation predicted by theory, allowing for a maximum coupling of 1.04, above critical coupling. Finally the cavity was accurately tuned to the design frequency, and frequency, Q-values and bead-pull measurements of electric field on axis were taken. The results are reported in Table 2 and Fig. 6. The asymmetry between electric field in the inner and outer gaps is typical of the CCDTL and taken into account in beam dynamics simulations.

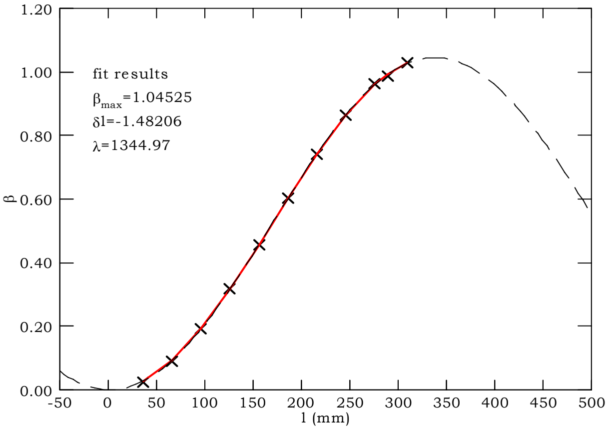

Figure 5: Coupling coefficient as a function of short-circuiting plate position.

Table 2: Results of the low-power measurements.

	Freq. (MHz)	Q_0
0-mode	350.686	
$\pi/2$-mode	352.187	22700
π-mode	353.725	
k (coupling bw. cells)	0.88%	
Field Flatness error	<1%	

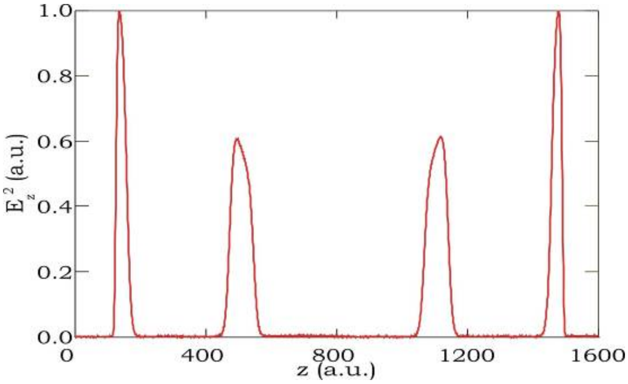

Figure 6: Bead-pull measurement.

Particular effort has been devoted to understanding the reason for the low Q-value (65% of the theoretical one) measured. Computer simulations indicate that this is due to the fact that the grooves housing the vacuum (and RF) joints were not copper-plated. After the first round of high-power tests, it is foreseen to open the half-tanks and apply local plating on the groove surfaces, in order to improve the Q-value.

HIGH POWER MEASUREMENTS

High-power tests started in September 2006. The power source was a LEP-type klystron (1 MW, CW), fed by a power supply that is presently limited to 58 kV. The RF power out of the klystron is therefore restricted to about 300 kW. For the tests the klystron RF input was pulsed, in order to obtain the required duty cycle. A calibrated directional coupler measured the forward power. The cavity voltage was measured at the two pick-ups in the half-tanks. A set of thermocouples was installed to monitor the temperature during the test. The vacuum in the prototype was of the order of 10^{-8} mbar. Figure 7 shows the prototype connected to the klystron waveguide. The circular RF window, inserted in the last section of waveguide, is visible in the front.

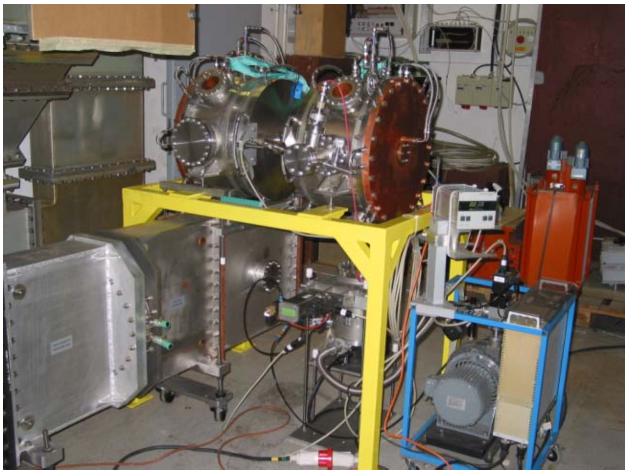

Figure 7: The prototype at the high-power test stand.

The initial conditioning of the cavity went almost unnoticed. Using a 100 µs long pulse at a repetition frequency of 5 Hz (higher than the Linac4 repetition frequency of 2 Hz), within few hours it was possible to reach in the cavity the maximum power delivered by the klystron, and no multipactoring was observed during the conditioning process. The corresponding gradient in the cavity was $E_0 = 4$ MV/m, slightly above the maximum gradient foreseen in the Linac4 CCDTL design.

In the continuation of the test it was observed that at high power levels the frequency of the cavity was continuously drifting. The thermal measurements showed an abnormal heating of one of the two drift tubes, and a water test indicated that the cooling circuit inside the tube was blocked. As a consequence, it was not possible to increase the repetition rate up to the SPL value of 50 Hz, as was foreseen in the original plan. After this series of high-power tests, the drift tube will be dismounted, the cooling will be repaired and the tests will resume.

Finally, the prototype was extensively measured at the Linac4 limiting operating mode, corresponding to 2 Hz repetition rate and 500 µs pulse length. With a reduced cooling of the drift tubes, the frequency was stable. The maximum RF power measured at the cavity input was 305 kW, corresponding to an effective voltage of 1.1 MV and a peak field on the drift tube of 32.4 MV/m (1.76 Kilpatrick). The mean electric field inside the cavity was E_0= 4 MV/m, calculated for a length of 306.4 mm. The present CCDTL design foresees a mean electric field ranging between 2.8 and 3.9 MV/m. The maximum gradient achieved during the tests, limited by the klystron power supply, was about 2% higher than the maximum CCDTL gradient foreseen for Linac4 operation.

Figure 8 shows a plot of the power level in the cavity measured at the input directional coupler (forward power) and at the output pick-up in one of the half-tanks. The two measured powers are identical over all the measurement range, indicating that no dark current was present during the test and hence that the voltage was still far from the breakdown limit [3].

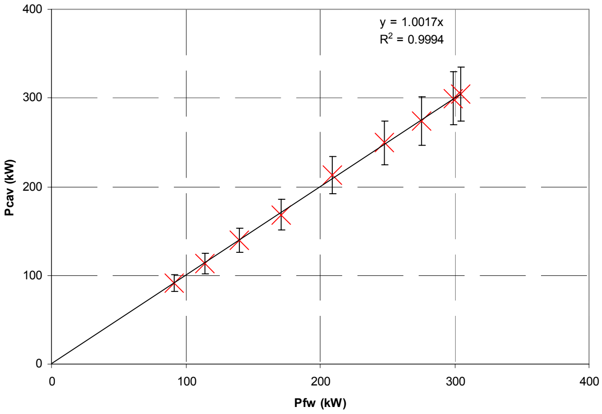

Figure 8: Power in the cavity vs. Power forward from the klystron.

The tests have now been temporarily interrupted to allow the repair of the drift tube cooling channels. During the time required for the repair, the test stand measurement equipment will be improved and the two end covers will be copper plated, in order to improve the Q-value.

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