THE LINAC4 DTL PROTOTYPE: THEORETICAL MODEL, SIMULATIONS AND LOW POWER MEASUREMENTS

F. Grespan, CERN, Geneva, Switzerland; Università degli Studi di Milano, Milano, Italy
G. De Michele, F. Gerigk, S. Ramberger, CERN, Geneva, Switzerland

Abstract

A one meter long hot prototype for the Linac4 DTL at CERN was built in collaboration with INFN, Legnaro. After machining of parts at CINEL s.r.l., Vigonza, the drift tubes were welded and the cavity was copper plated at CERN. Following mechanical assembly and low power measurements, the cavity is presently being prepared for high power tests.

2D and 3D simulations as well as first RF low-power measurements were performed to verify the electromagnetic properties of the cavity and to tune it before high-power RF tests. In particular, the influence of the post couplers was studied in order to achieve stabilization of the accelerating field during operation. An equivalent circuit model of the DTL is presented, along with a comparison of simulation and measurement results for the prototype.

INTRODUCTION

A 1034 mm long prototype [1] has been built for an operating frequency of 352.2 MHz and an average field of 3.3 MV/m (Fig. 1). It consists of 13 cells with a tank diameter of 520 mm and a drift tube (DT) diameter of 90 mm. The cell length increases along the prototype corresponding to beam energy going from 3 MeV to 5.4 MeV. One post coupler (PC) every three DTs is placed at the longitudinal position of the 2^{nd}, 5^{th}, 8^{th} and 11^{th} DT for field stabilization. The PC diameter is 20 mm.

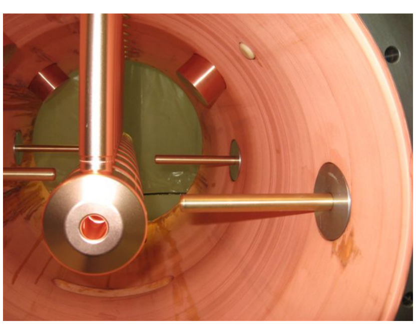

Figure 1: DTL hot prototype, internal view with PCs.

With the objective of better understanding the PC stabilization mechanism and in order to define a tuning strategy for longer Linac4 DTL cavities, an equivalent circuit model was developed for the prototype. Principal ingredients for a representative circuit are its equivalent circuit elements including their interdependence expressed by connections and mutual inductances.

2D and 3D simulations, measurements and circuit analyses, in particular on coupling effects, have been undertaken to obtain a circuit model, its discrete elements and the circuit topology. The correspondence between measurements and the circuit model are verified on Brillouin diagrams by consistently fitting the principal resonator bands in the cavity: TM_{01n} band, stem band and PC band [2].

SIMULATIONS AND MEASUREMENTS

The main electromagnetic properties of the prototype cavity simulated with Superfish [3] compare well with 3D simulations using HFSS [4]. Table 1 shows the simulated cavity parameters, including the frequency change of 3 tuners when fully inserted (r=45mm, h=50mm). The effect of tuners in frequency and power dissipation is estimated for 2D simulations applying the Slater perturbation theorem to field data. Figure 2 shows the simulated average electric field on axis E_0, including a case where PCs are introduced in the 3D simulation.

Table 1: Cavity Parameters

	Superfish	HFSS
Freq (Stems) [MHz]	351.7	350.6
Freq (Stems+PCs) [MHz]	351.9	350.8
ΔF of 3 tuners [MHz]	1.13	0.95
Q0 (Stems+PCs incl.)	41300	41640
Q/Q0 (tuner effect)	97%	98%

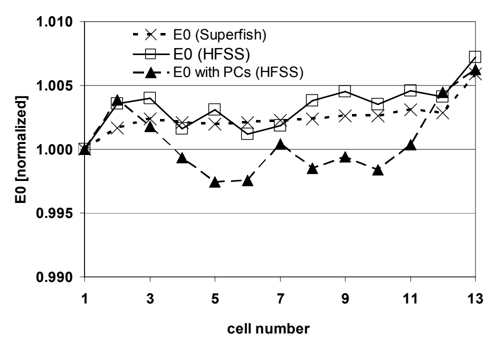

Figure 2: Average E field on axis as computed by Superfish and by HFSS, without and with PCs.

The prototype was first assembled without the waveguide coupler and without vacuum gaskets in the end-covers. The frequency without PCs and with tuners at 50 mm penetration was 351.9 MHz. Outfitting the cavity with vacuum gaskets raises the frequency to 352.1 MHz and increases the Q-value from 22’480 to 34’700.

Post Couplers

PCs are used in DTL cavities to create a secondary coupled resonator system, which is then coupled with the main resonator system, formed by the accelerating cells

(DT cells) resonating in the TM_{01} mode. The purpose of the PC resonator system is to stabilize the accelerating field in case of local frequency errors. Furthermore PCs increase the slope (group velocity) of the dispersion curve in correspondence of the accelerating mode and consequently the power flow in transient conditions. At nominal cavity dimensions the deviation from the nominal field due to the PC insertion should be small [5]. This is confirmed by 3D simulations of the whole prototype performed with different PC lengths (Fig. 2). The system, composed by two chains of coupled resonators, has two bands of frequencies: the TM band and the PC band. Since the DTL prototype has four PCs, in the PC band there are four resonating modes (Fig. 3).

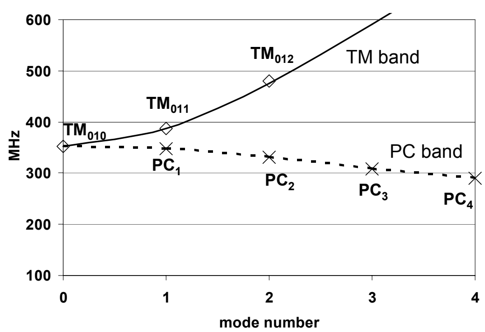

Figure 3: TM and PC modes nomenclature.

Since PCs only have a negligible effect on the nominal accelerating field, the TM_{010} frequency shift due to PC insertion can be estimated with the Slater perturbation theorem, using the field distribution computed by Superfish. The calculated change in frequency as function of PC length is shown in Figure 4, together with measurements. The deviation from the simulated curve [6] has been investigated with a more accurate measurement over the range of PC lengths from 155 mm to 180 mm (Fig. 5), indicating that in this range the 3 highest modes of the PC band cross the TM_{010}, and couple with it.

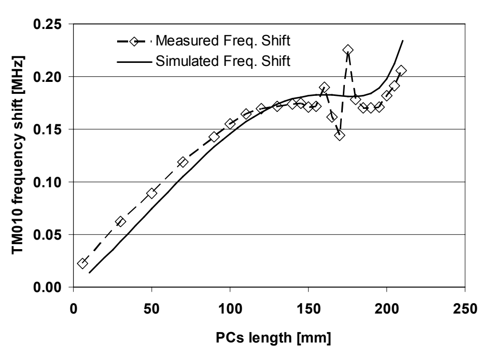

Figure 4: Simulated (Superfish) and measured TM_{010} detuning as function of PC length.

3D simulations and bead-pull measurements have been undertaken on the four PC modes. PC modes are easily recognised in simulations by a characteristic field pattern with E field between PCs and drift tubes and H field around PCs. Simulated axial fields correspond well with the bead-pull measurements performed on the PC modes close to confluence. Figure 6 shows the highest PC mode (PC_1 mode), which presents the same axial field pattern of the TM_{011} mode. For this reason the perturbation effect on the accelerating field is minimized if PC_1 and TM_{011} modes are symmetrically tuned in frequency respect to TM_{010} mode.

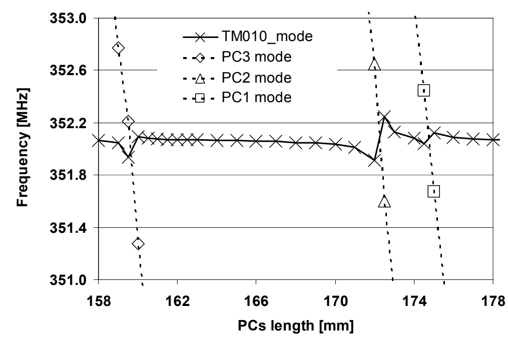

Figure 5: Measurements showing PC modes crossing TM_{010} mode.

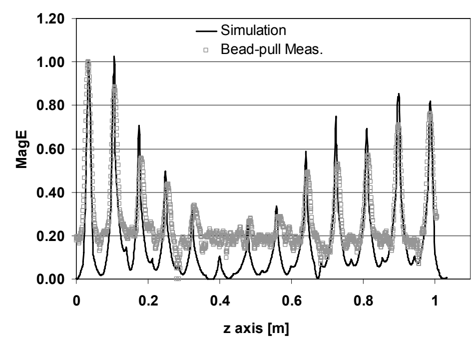

Figure 6: Simulated and measured field on axis for the highest PC mode (PC_1 mode).

Stems

Stem modes can be distinguished in RF measurements because of the much lower frequencies with respect to the operating mode and because of the low sensitivity to gap displacements.

3D simulations show that the presence of DT stems weakly affects the field pattern of the PC modes (Fig. 7): the electromagnetic energy is concentrated around the PCs, with a slight deviation of the H field around the stems, and the change in mode frequency can be estimated using the Slater perturbation theorem. The same behaviour can be noticed for the stem modes in relation to the presence of PCs.

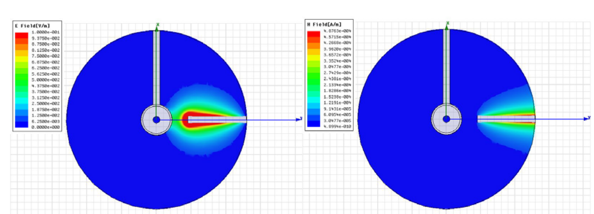

Figure 7: E and H field magnitude of the PC_1 mode.

EQUIVALENT CIRCUIT

The basic equivalent circuit model of a DTL cell structure used in the following is shown in Figure 8 [7, 8]. In this circuit the series inductor L0 represents the inductance of a half DT, the series capacitor C0 corresponds to the capacitance of a gap, the shunt capacitor C summarizes the capacitance of a DT to the tank wall represented by the ground conductor. The fundamental mode frequency for this circuit is given by $\omega_0^2 = 1/(2L0C0)$. The circuit parameter values numerically fitted from simulations and measurements for the DTL prototype are: $\omega_0 = 352.2$ MHz, $C_0 = 9.0$ pF, $C = 1.9$ pF.

Stems are represented by inductors L_s in parallel with the shunt capacitance C. Each inductor is magnetically coupled with the next one by means of the mutual inductance M_s (Fig. 8). PCs are included in the circuit by C_p and L_p in series, where C_p is the capacitance between PC and DT and L_p the inductance of the PC. M_p represents the nearest neighbour magnetic coupling between PCs at the opposite sides of the tank (Fig. 8). The next nearest neighbour magnetic coupling between PCs located at the same side of the tank is omitted for the present analysis.

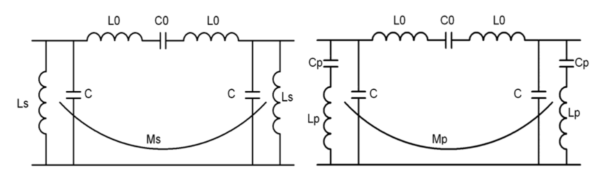

Figure 8: Equivalent circuit of a basic DTL cell with stems (left) or PCs (right).

As mentioned earlier, parameter fitting for stems and PCs can be considered separately in the equivalent circuit, because of the weak coupling observed in the 3D simulations. The equivalent circuit for the stems has been solved by applying Floquet's theorem for periodic structures. The circuit parameters have been calculated by using the measurements of TM_{010} and TM_{011} frequencies, and the modes number 0 and 4 of the stem band.

Because of the imperfect periodicity of the PC arrangement inside the cavity, for the PC circuit a matrix form solution has been preferred to Floquet's theorem. The eigenvalues of the matrix correspond to the mode frequencies and the eigenvector components correspond to the currents through the gap capacitances C_0 and the PC capacitance C_p. The parameters have been fitted using the TM_{010} and TM_{011} frequencies and the PC_1 mode and PC_4 mode as reference values for the matrix eigenvalues.

A comparison between dispersion curves measured on the DTL prototype and dispersion curves calculated with the equivalent circuit is shown in Figure 9. In a next step the circuit model will be used to estimate the tilt sensitivity and to compare it with measurements. Further improvement is expected from introducing next nearest neighbour couplings.

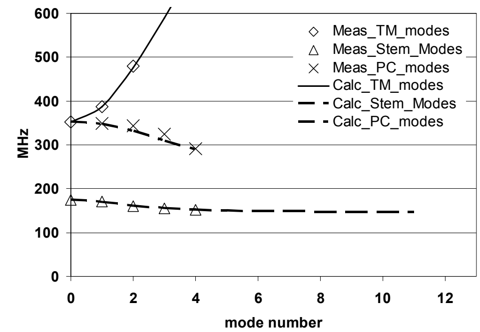

Figure 9: Calculated and measured dispersion curves for TM modes, PC modes and stem modes (PC length = 178 mm).

CONCLUSIONS

The RF measurements performed on the DTL prototype equipped with PCs confirmed the results of 2D and 3D simulations. TM_{010} mode detuning versus PC length corresponds well with the estimation done using the Slater perturbation theorem together with field data from straightforward 2D simulations. Distorted measurement patterns of the same curve can be clearly attributed to interfering PC bands. Based on these investigations, an equivalent circuit model was demonstrated that reproduces the dispersion curves for TM_{01n}, stem and PC modes and that can serve as a starting point for the development of a tuning strategy.

ACKNOWLEDGEMENTS

The authors would like to thank M. Vretenar and R. Wegner for helpful discussions.

REFERENCES

[1] S. Ramberger et al., "Drift Tube Linac Design and Prototyping for the CERN Linac4", Proc. LINAC08.

[2] G. Dôme, "Review and survey of accelerating structures", in "Linear Accelerators" (ed. by P. Lapostolle and A Septier) North-Holland Publ.Co., 1969.

[3] Los Alamos Accelerator Code Group, Poisson Superfish.

[4] Ansoft Corporation, HFSS 10.1.

[5] T. Wangler, "RF Linear Accelerators", John Wiley & Sons, Inc. 1998, par.4.14.

[6] S. Machida, T. Kato, S. Fukumoto, "Stabilizing characteristics of post-couplers", Transaction on Nuclear Science, 1985, Vol. 32.

[7] H.J. Hereward, "Some Examples of Energy Flow in the Alvarez Structure", CERN Internal Report MPS/DL Int. 65-1, 1965.

[8] M.K. Ke, B.R. Cheo, J. Shmoys, "Continuous transmission line modelling of a DTL including beam loading and other perturbations", Particle Accelerators, 1994, Vol. 48.