DEVELOPMENT OF A CELL-COUPLED DRIFT TUBE LINAC (CCDTL) FOR LINAC4

Y. Cuvet, F. Gerigk, G. De Michele, M. Pasini, S. Ramberger, M. Vretenar, R. Wegner, CERN, Geneva, Switzerland
E. Kenzhebulatov, S. Kryuchkov, E. Rotov, A. Tribendis, BINP, Novossibirsk, Russia
M. Naumenko, VNIITF, Snezhinsk, Russia

Abstract

The 352 MHz CCDTL will accelerate the Linac4 beam from 50 to 102 MeV. It is the first structure of this kind that will be used in a proton linac. Three short DTL-type tanks, each having two drift tubes, are connected by coupling cavities and form a chain of resonators operating in the stable π/2 mode. The CCDTL section is made of 7 such 5-resonator chains, each fed by a 1.3 MW klystron. Focusing quadrupoles are placed between tanks, easing their alignment with respect to a conventional DTL thus making the structure less sensitive to manufacturing errors. In order to validate the design and to develop the production technology, two prototypes have been constructed and successfully tested. The first prototype, built at CERN, consists of two half-cavities and one coupling cell, whereas the second, larger one, having two full cavities and one coupling cell, was built at VNIITF and BINP in Russia within the frame of an R&D contract funded by the ISTC Organisation. Both prototypes have been tested at CERN slightly beyond their nominal power level, at the design duty cycle of 10%. In this paper we present the results of high-power tests, the results of the technological developments prior to production, and the final design of the CCDTL.

INTRODUCTION AND BASIC DESIGN

The Cell-Coupled Drift Tube Linac (CCDTL) was originally developed at LANL as a structure providing higher shunt impedance than conventional Drift Tube Linacs (DTL) for intermediate-velocity particles [1]. In the original design the CCDTL was used at twice the basic linac frequency (800 MHz) and when the principle was tested on a CW prototype it appeared that surface power density was too large for stable operation. To avoid these problems, CERN started to develop a CCDTL at the basic linac frequency of 352 MHz and for applications as the Superconducting Proton Linac (SPL), limited at a duty cycle of less than 10% [2]. Different combinations were analysed and tested, to finally adopt for the Linac4 project [3] the CCDTL configuration shown in Fig. 1. This CCDTL is made of 3-gap DTL-like accelerating tanks, connected by off-axis coupling cells bridging the focusing quadrupoles. Whereas the shunt impedance of this CCDTL configuration remains similar to that of a DTL with permanent quadrupoles, its main advantages are the easy access, alignment and cooling of the quadrupoles and the simpler construction and alignment of the tanks, the drift tube alignment tolerances being no longer dominated by the tight requirements of the quadrupoles.

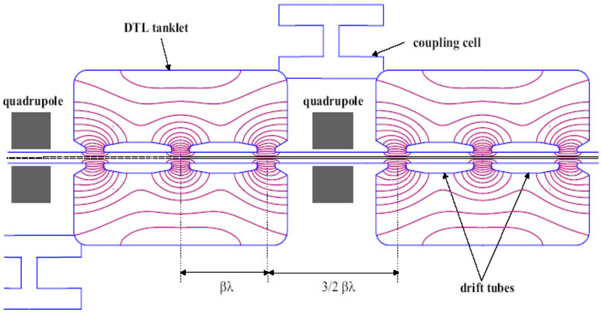

Figure 1: Linac4 CCDTL structure with indication of the electric field lines.

The RF configuration of Linac4 limits the peak power per resonator to about 1 MW. For this reason, the CCDTL tanks are grouped in modules of 3 tanks connected by two coupling cells (Fig. 2). The basic Linac4 CCDTL resonator is therefore made of 5 coupled cells operating in the π/2 mode. The CCDTL starts at 50 MeV, an energy that allows placing quadrupoles within the 3/2 βλ distance between neighbouring gaps. The geometry of the coupling cell and coupling slot is kept constant for all modules to simplify construction. This is achieved by shifting the end-walls of the tanks.

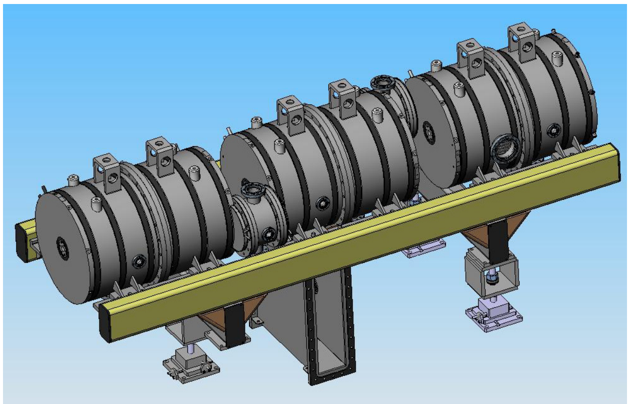

Figure 2: 3D view of a Linac4 CCDTL module with support structure and rectangular RF port.

At higher energies the shunt impedance of the CCDTL falls considerably, together with the coupling factor between CCDTL cells, inversely proportional to the stored energy per tank. Both these factors impose an upper energy limit of about 100 MeV for this structure.

The main parameters of the seven CCDTL modules are given in Table 1. The calculated copper power takes into account the effect of stems and slots and is then increased by a safety factor of 20%. Adding the beam power gives the values quoted in Table 1. The overall length of the CCDTL section is 23.38 m.

Table 1: Linac4 CCDTL Modules

	E_{out} [MeV]	G_{acc} [MV/m]	P_{RF} [MW]	length [m]	E_{max} [Kilp.]
1	57.1	4.00	0.96	2.64	1.6
2	64.6	4.10	1.0	2.82	1.6
3	72.1	4.20	1.0	2.98	1.6
4	79.9	4.30	1.0	3.14	1.7
5	87.8	4.23	1.0	3.29	1.7
6	95.6	4.16	1.0	3.43	1.6
7	102.9	4.10	1.0	3.57	1.6

RF AND MECHANICAL DESIGN

The diameter of the cells has been optimized for maximum shunt impedance and is fixed for all cavities at 520 mm [4]. Each cavity is then tuned by changing the ratio of gap length over βλ. The gradient has been adjusted to keep the total RF power per cavity at a level of ~1 MW and the maximum surface fields below 1.7 Kilpatrick. Similarly all other geometric parameters were analyzed and the RF properties of the cavities were fully parameterized as a function of the geometric β and the accelerating gradient.

A circuit model of a single module has been analysed with PSpice [5] to estimate the voltage errors in the cells due to frequency deviations. These errors can be classified in two types: the first one is caused by residual tuning errors and can be considered as static error; the second one (dynamic errors) comes from, for example, the change of the external temperature or variation of the cooling water temperature or flow speed.

For static errors, we consider the worst case of the CCDTL section, i.e. the last module with a coupling coefficient of k=0.59%. We assume a residual frequency error of ±20 kHz in the cavities using various distribution functions [5]. For this case the tilt sensitivity with respect to the average voltage has been calculated as 10.55%/MHz yielding a maximum field error of 0.2%.

For dynamic errors, the frequency variation due to the maximum expected temperature variation of ΔT=10 K is estimated to be lower than 50 kHz. This variation is compensated with a movable tuner in the central accelerating cavity, requiring a tuner range of 150 kHz. In this condition the maximum voltage error in the accelerating cavities can rise up to 0.4%, which is fully acceptable for beam dynamics. In conclusion only one motorized tuner is necessary for each CCDTL module.

The prototype half-tanks were made by welding (electron beam or TIG) steel cylinders onto the end walls. Two half-tanks are then joined by a Helicoflex® gasket, which provides the RF contact and ensures vacuum tightness. For the series production the half tanks will be made of pre-shaped steel pieces, thus avoiding the welding step, improving the material properties, and speeding up construction. Since the alignment of drift tubes is not as critical as in a DTL, the drift tubes of the prototypes were welded to the tank walls while being fixed into position by a bar penetrating the drift tubes. Since every circular weld has an overlap in the start/end-point, there is a risk of deformation after the alignment bar is taken out. Therefore, for the series production will be adopted an alignment mechanism similar to that of the Linac4 DTL, which relies on the machining tolerances of a “stem holder” in a girder above the tank as shown in Figure 3 [6]. The RF and vacuum contacts between stems and tank are made with Helicoflex® gaskets, which are compressed by the spring-loaded “stem holder”.

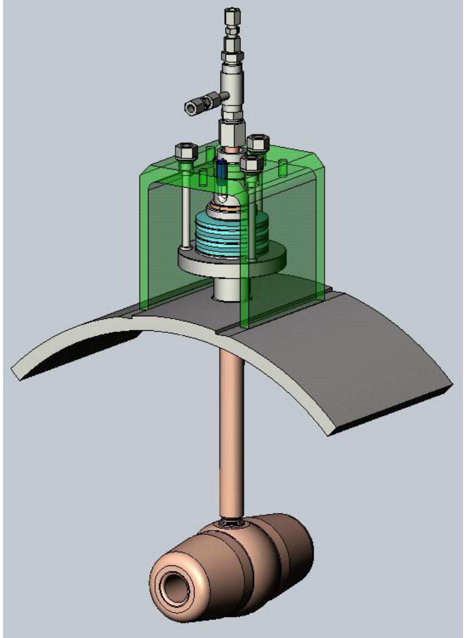

Figure 3: Drift tube fixation on the tank.

A critical point is the vacuum tightness of the rectangular iris, which connects to a rectangular wave-guide stub, and which is used to feed RF power into the central tank. The connection has been studied at VNIITF on a mock-up with HN and HNV type Helicoflex® gaskets using flanges with and without copper plating. The flanges were rectified to a roughness of Ra≈0.3 and cleaned, and after a series of vacuum leak tests it was concluded that the best solution is to use HN type gaskets on non-plated surfaces.

PROTOTYPE TESTING

Two CCDTL high-power prototypes have been designed and built, both for the critical tanks at low energy (50 MeV). The first prototype, designed and built at CERN, was made of two half tanks closed by flat covers, connected by a coupling cell. This is the minimum configuration required to study RF and thermal properties. The second prototype (see Fig. 4), made of two complete tanks connected by a coupling cell, has been built in Russia by VNIITF (Snezhinsk) and BINP (Novossibirsk) within the frame of an R&D contract funded by ISTC. The mechanical design has been adapted to the production capabilities of the two laboratories. Construction and copper plating of the tanks was done in Snezinsk whereas construction and welding of drift tubes and final assembly and tuning were done in Novossibirsk.

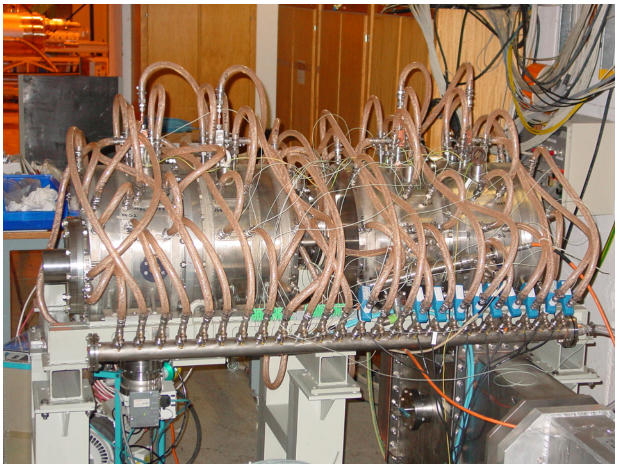

Figure 4: Second CCDTL prototype (VNIITF-BINP).

Both prototypes were tested at CERN, at low power and at high-power at the SM18 Test Stand. Table 2 reports the result of the low-power measurements. The Q-value of the first prototype is lower because the flat covers increase considerably the losses. For the second prototype, the Q-value was about 82% of the calculated one. Field flatness was in both cases within the measurement precision.

Table 2: Results of low-level measurements.

	CERN prototype	**ISTC prototype**
frequency [MHz]	352.35	352.14
coupling factor [%]	0.86	0.90
unloaded Q	27281	36700

High-power conditioning up to the Linac4 operating condition was straightforward for both prototypes, and increasing the duty cycle from the Linac4 value (0.1%) to the SPL duty cycle (10%) was relatively easy. No multipacting activity was observed in the first prototype, and only very limited activity was observed in the second one. Conditioning of the first prototype to 290 kW, corresponding to 1.09 times the design voltage, and to the Linac4 duty cycle took less than a day, and extending the duty cycle to 10% took 2 days. The temperature was measured in different critical positions on the tanks by means of thermocouples. The temperature of the drift tube holder, coupling iris and plunger tuner reached 58, 76 and 80 degrees, respectively. Conditioning of the second prototype took about a week. Power levels in excess of 330 kW at both Linac4 (0.1%) and SPL duty cycle (5%) were measured in the cavity, corresponding to 1.03 times the nominal operating level. The temperature monitoring indicated that at 5% duty cycle the temperature on the external part of the drift tube increased by 40 degrees, while the tuners in the accelerating cell (which were not equipped with cooling circuits) went up to 100 degrees. It was possible to stabilize the temperature at 330 kW power level at 11% duty cycle. For a duty cycle of 2.5% the measured temperatures have been compared with ANSYS simulations from VNIITF/BINP and an excellent agreement was found for 10 out of 12 thermocouples.

CONSTRUCTION PROCEDURE AND PLANNING

It is planned to build the complete CCDTL in the frame of two ISTC projects, one funded entirely by CERN and the other one funded by the ISTC. As for the prototype, tanks and support will be built at VNIITF. After copper plating and pre-assembly the modules will be shipped to BINP. BINP will manufacture and install the drift tubes and take care of the RF tuning. The tuning will be checked after transportation to CERN together with vacuum tightness and a pressure test of the cooling channels. RF conditioning for all the 7 modules will be done at CERN, and installation in the Linac4 tunnel is foreseen from January 2011. Construction is foreseen to start in January 2009, with the first module being delivered to CERN in December 2009. The subsequent 6 modules will be delivered in batches of 2 with the last batch arriving at CERN in December 2010.

ACKNOWLEDGEMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number FII3-CT-2003-506395). We further acknowledge the support of the ISTC for the construction of a CCDTL prototype under contract number 2875.

REFERENCES

[1] J. Billen et al, “A new RF structure for intermediate-velocity particles”, LINAC’94.
[2] F. Gerigk (Ed.),”Conceptual Design of the SPL II”, CERN-2006-006.
[3] http://www.cern.ch/linac4
[4] M. Pasini, “CCDTL design update for LINAC4”, CARE/HIPPI Document-2005-009.
[5] M. Vretenar et al. “CCDTL section for Linac4”, CARE/HIPPI Document-2008-020.
[6] S. Ramberger et al, “Drift tube linac design and prototyping for the CERN Linac4”, LINAC’08.