DESIGN AND DEVELOPMENT OF RF STRUCTURES FOR LINAC4

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Abstract

Linac4 is a new 160 MeV H^- linac proposed at CERN to replace the 50 MeV Linac2 as injector to the PS Booster, with the goal of doubling its brightness and intensity. The present design foresees after RFQ and chopping line a sequence of three accelerating structures: a Drift Tube Linac (DTL) from 3 to 40 MeV, a Cell-Coupled DTL (CCDTL) to 90 MeV and a Side Coupled Linac (SCL) up to the final energy. The DTL and CCDTL operate at 352 MHz, while in the SCL the frequency is doubled to 704 MHz. Although the injection in the PS Booster requires only a low duty cycle, the accelerating structures are designed to operate at the high duty cycle required by a possible future extension to a high-power linac driver for a neutrino facility. This paper presents the different accelerating structures, underlining the progress in the design of critical resonator elements, like post-couplers in the DTL, coupling slots in the CCDTL and bridge couplers for the SCL. Prototyping progress for the different structures is reported, including the RF design of a DTL tank prototype and results of low- and high-power tests on a CCDTL prototype.

LINAC4

In the frame of an improvement and consolidation programme of the CERN proton accelerator complex, the construction of Linac4, a new linac injector for the CERN PS Booster (PSB), has been proposed recently. Linac4 will accelerate a 40 mA H^- beam up to 160 MeV using RF cavities at 352 and 704 MHz, replacing the present 202 MHz 50 MeV proton Linac2 [1]. The higher energy will reduce the space charge induced tune spread at PSB injection by a factor of 2 and charge exchange injection will reduce beam losses, thus removing the two main PSB limitations towards higher beam brightness in the LHC injector chain. With Linac4 operation will be simplified, the beam brightness required for the LHC ultimate luminosity could be obtained at PS ejection and the increase in the number of protons per pulse from the PSB will improve statistics for the ISOLDE experiments. In a longer term, the new linac constitutes an essential component of any of the envisaged LHC upgrade scenarios and is also designed to be extended to a 3.5 GeV, multi-MW superconducting linac (SPL) [2].

LINAC4 ACCELERATING STRUCTURES

After an RFQ and a chopping line at 3 MeV, the accelerating part of Linac4 (3-160 MeV) is divided into three different structures: a DTL at 352 MHz, a CCDTL again at 352 MHz, and a SCL at 704 MHz. The main parameters of the three accelerating structures are reported in Table 1. Figure 1 shows the general layout of Linac4 together with the RF power distribution scheme. A large fraction of the Linac will make use of recuperated 352 MHz 1 MW klystrons from the LEP collider, used here in pulsed mode, while the SCL section will be powered by new 704 MHz 4 MW pulsed klystrons.

Table 1: Main Parameters of Linac4 Accelerating Sections

	DTL	CCDTL	SCL	
Output Energy	40	91.7	163	MeV
Frequency	352.2	352.2	704.4	MHz
Gradient E_0	3.3/3.5	2.8/3.9	4	MV/m
Synchr. Phase	-30/-20	-20	-20	deg
Lattice	FFDD/FD	FD	FD	
Aperture Radius	10	14	16	mm
Diameter	0.52	0.52	0.30/0.31	m
N. of resonators	3	8	4	
Tanks per res.	1	3	5	
Gaps per tank	28/33/24	3	11	
Drift tube diam.	90	85	-	mm
Length	12.9	25.2	28.0	m
Max. El. field	1.7/1.4	1.4/1.7	1.2/1.2	Kilp.
Peak RF Power	3.82	6.4	12.5	MW
N. of klystrons	5	8	4	

The main constraints and guidelines in the design of Linac4 accelerating sections were:

- the structures should be able to operate in both low duty cycle mode for Linac4 (2 Hz, 400 µs beam pulse length) and high duty cycle mode (50 Hz, 700 µs) for the SPL. The cooling circuitry is dimensioned for high duty, while in Linac4 most of the cooling pipes will not be connected. Comfortably large beam apertures have been chosen (7 to 8 times the rms beam size) to minimise beam losses in the SPL operation mode. Tuning is provided by movable pistons at low duty and by control of cooling water temperature at high duty.

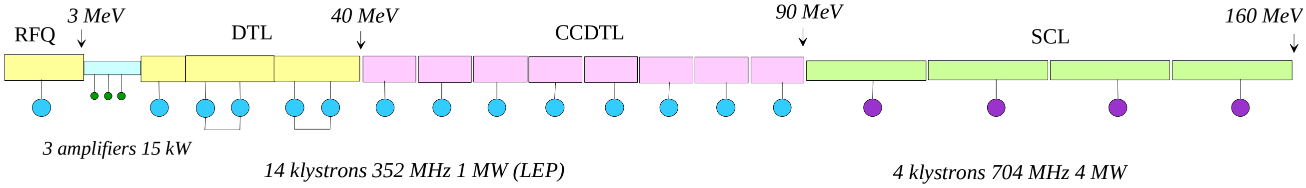

Figure 1: Linac4 RF scheme

- the resonator lengths are optimised for the 1 MW LEP klystrons at 352 MHz and for new high power (4 MW) klystrons at 704 MHz.
- high reliability and simplified maintenance have been the guidelines for the selection of mechanical and RF solutions. For example, rubber vacuum joints and knife-edge RF contacts have been banned from the resonators.
- relatively high accelerating gradients could be selected, because using recuperated klystrons moves the cost optimum towards higher fields. This allowed keeping the overall linac length to about 80 m, fitting in the space available in an existing experimental hall.
- in the resonator design, a 20% safety margin has been kept with respect to the maximum klystron power, to account for waveguide losses and phase-amplitude control, and another 20% for additional cavity loss with respect to the Superfish power (with stems and slots).

DRIFT TUBE LINAC

The DTL design resulted in a quite compact structure (37 MeV acceleration in 13 m) thanks to: i) avoiding a field ramp in Tank1 (for maximum acceptance), ii) a high synchronous phase of -20º, and iii) a high electric gradient of E_0=3.5 MV/m. The focusing with Permanent Magnet Quadrupoles (PMQ) made possible a small drift tube diameter (90 mm), with a consequent increase in RF power efficiency. Face angles on the drift tubes increase even further the efficiency, still keeping the peak surface field below 1.7 Kilpatrick. For the resulting average shunt impedance of 43 MΩ/m, the DTL can be fed by five 1 MW klystrons, leading to a quite logical splitting of the structure into 5 mechanical sections each about 2.6 m long and fed by one klystron. However, in order to minimise the number of intertank transitions the last 4 sections are coupled in pairs to form 2 tanks fed by 2 klystrons each.

The DTL will be stabilised by post-couplers, and a consequence of the small drift tube diameter is that the distance between tank and drift tube is as high as 1.01λ/4, a value considered at the upper limit for obtaining an effective stabilisation. However, a set of 3D simulations of Tank1 with post-couplers indicates that even for the selected configuration of one post every three drift tubes confluence of tank and post bands can be obtained with about 0.5 mm accuracy in post length (Fig. 2). For this configuration, computations show that the tilt sensitivity of the tank can be reduced by a factor of ~10 [3].

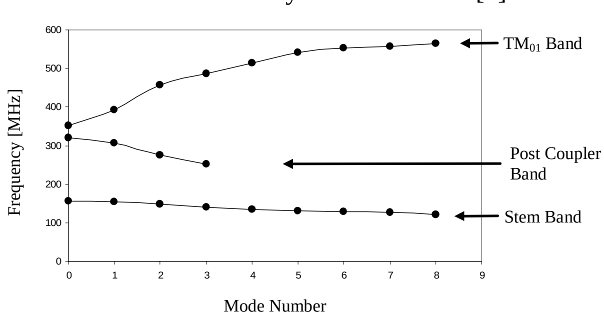

Figure 2: Computed mode frequencies in 1/3 of Tank 1.

A preliminary mechanical design of the DTL has been developed by ITEP Moscow and VNIIEF Sarov (Russia), in the frame of a collaboration agreement with CERN [4]. It is based on a girder-bellow configuration for supporting of the drift tubes, which are aligned outside of the tank and then blocked in place by pouring a fixing material. PMQs are in air, the drift tube being sealed by laser welding. The collaboration will result in the construction of a prototype of Tank1, to be tested at CERN in the second half of 2007. The prototype is shown in Fig. 3.

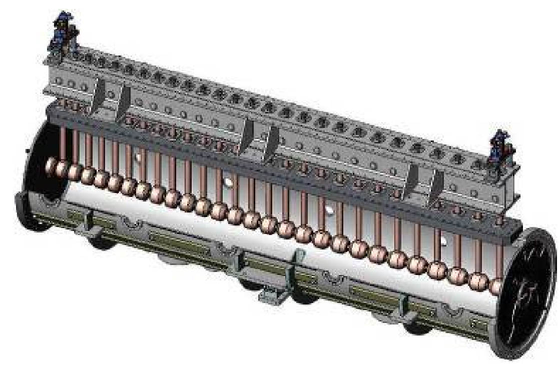

Figure 3: 3D open view of DTL Tank1 prototype [4].

CELL-COUPLED DRIFT TUBE LINAC

A particular type of CCDTL accelerates the beam from 40 to 90 MeV. At a frequency of 352 MHz, it is composed of a sequence of 3-gap DTL-like tanks, divided into modules of three tanks connected by coupling cells. Electromagnetic quadrupoles are placed between the tanks. The main advantages of this structure are the lower construction cost as compared to the DTL, the easy access and cooling of the quadrupoles and the simple alignment. An open view of the first module (40 - 45.5 MeV), including support, waveguide coupler and quadrupoles is shown in Fig. 4.

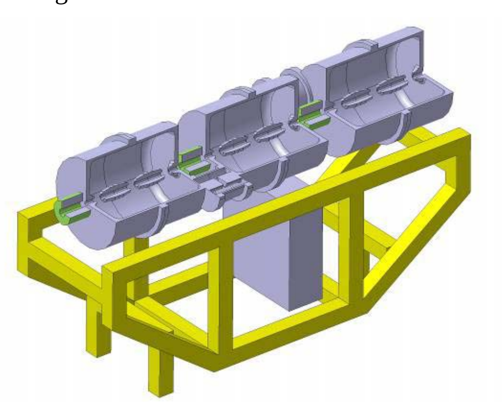

Figure 4: 3D cut-away view of the first CCDTL module.

The development of this structure was started at CERN in 1997, and resulted in the design and construction of a hot prototype made of two half tanks connected by a coupling cell [5]. Recently, the prototype was assembled and prepared for high-power conditioning. The three resonators have been easily tuned by means of dummy tuners to a π/2 mode frequency of 352.2 MHz. The inter-cell coupling provided by a nearly elliptical slot of 102 mm × 48 mm between tank and coupling cell was 0.88%, in perfect agreement with the simulations. The measured Q-value was 22’700, only 65% of simulations, the reason for the low Q being the decision not to copper plate the surfaces holding the Helicoflex joints. In the final configuration these surfaces will be plated too. Figure 5 shows the bead-pull measurement of the field on axis after tuning of the cells, and Fig. 6 shows the model at the high-power RF test stand. The RF power is coupled into the tank via an iris into a waveguide tangential to one of the tanks which is closed by a short circuit at λ/4 from the iris. The RF conditioning of the prototype is presently starting at the SM18 test stand at CERN.

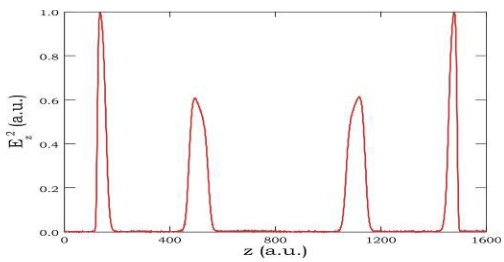

Figure 5: Bead-pull measurement of electric field distribution in the prototype (2 gaps + 2 half gaps).

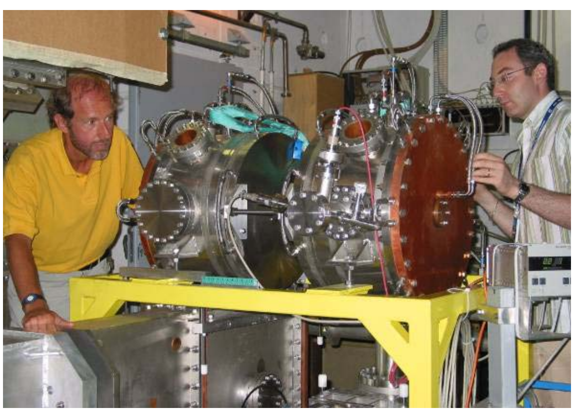

Figure 6: The CCDTL prototype (2 half-tanks with coupling cell) ready for high-power RF testing.

SIDE-COUPLED LINAC

The shunt impedance of 0-mode (CCDTL or DTL) structures rapidly decreases with energy, and from ~90 MeV onward π-mode structures at twice the RF frequency can provide higher efficiency. A preliminary comparison of possible structures at 704 MHz led to the choice for Linac4 of the classical Side-Coupled Linac structure, because of its inherent stability properties, its moderate machining cost on modern CNC machines and because of the experience at many Laboratories, including CERN, in the construction and tuning of this type of structure.

The Linac4 SCL reaches 160 MeV with 20 tanks of 11 accelerating cells, grouped in 4 modules of 5 tanks. Each module is fed by one 4 MW klystron. The tanks are connected by 3-cell bridge couplers, and RF power is coupled via an iris in the central bridge coupler cell. Calculations of field stability in presence of remaining errors after tuning led to the choice of 3% cell-to-cell coupling.

Presently, a cold model of the first SCL tank is under construction at the LPSC Laboratory in Grenoble, within an EU-sponsored Joint Research Activity. The optimised cell profile for this model is shown in Fig. 7. In parallel, BINP Novossibirsk is building a technological model, to test brazing of SCL cells, in collaboration with CERN.

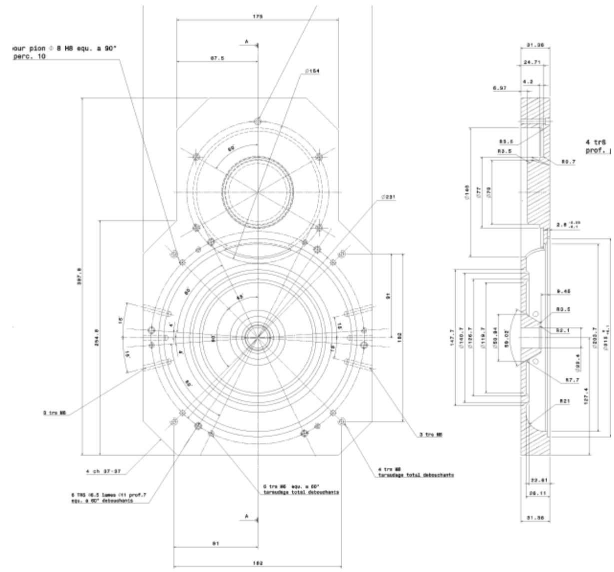

Figure 7: Basic SCL cell.

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