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RF STRUCTURES FOR LINAC4

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Abstract

Linac4 is proposed to replace the existing proton linac at CERN (Linac2). Using an increased injection energy of 160 MeV instead of 50 MeV, Linac4 is expected to double the beam intensity in the PS Booster (PSB) and will thus be the first step towards higher brightness beams in the LHC. In this paper we re-assess the choice of RF structures for Linac4. Different accelerating structures for different energy ranges are compared in terms of RF efficiency, ease of construction and alignment, and necessary infrastructure. Eventually we present the final choice for Linac4.

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Linac4 is proposed to replace the existing proton linac at CERN (Linac2). Using an increased injection energy of 160 MeV instead of 50 MeV, Linac4 is expected to double the beam intensity in the PS Booster (PSB) and will thus be the first step towards higher brightness beams in the LHC. In this paper we re-assess the choice of RF structures for Linac4. Different accelerating structures for different energy ranges are compared in terms of RF efficiency, ease of construction and alignment, and necessary infrastructure. Eventually we present the final choice for Linac4.

INTRODUCTION

Linac4 is a low duty cycle machine (2 Hz), which will provide H^- beam pulses of 0.4 ms with an average pulse current of 40 mA to the PSB [1] (see Table 1). At the same time this machine is designed to be the front-end of a superconducting H^- linac (SPL), which will provide a 4-5 GeV beam at repetition rates between 2 and 50 Hz [2, 3]. For this reason, all accelerating structures are designed for a duty cycle of $\approx 5\%$, even if Linac4 will only operate with a maximum duty cycle of 0.1% when injecting into the PSB. In this paper we present the “old” reference design [1] and a revised “new” design, which was recently adopted including changes in the mechanical design of the DTL.

Table 1: Main parameters of Linac4.

Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. rep. rate	2 Hz
Beam pulse length	400 μ s
Source current	80 mA
Chopping factor	62%
Linac current	40 mA
Max. beam power	5.1 kW

DESIGN PHILOSOPHY

The RF frequency of Linac4 is determined by the existence of klystrons, wave-guides and circulators at 352 MHz from the decommissioned LEP machine at CERN. After the RFQ and the chopper line, three different structure types accelerate the beam from 3 to 160 MeV. The “old” reference design used three Drift Tube Linac (DTL) tanks with permanent magnet quadrupoles (PMQs) up to an energy of 40 MeV, followed by a Cell-Coupled DTL (CCDTL) up to 90 MeV and a Side-Coupled Linac (SCL) at 704 MHz up to the final energy of 160 MeV. The reasoning behind the choice of transition energies and accelerating structures in the “old” and “new” design is explained

in the following. Due to the compact size of the drift tubes (a consequence of using PMQs), the DTL has a very high shunt impedance as shown in Fig. 1. Since PMQs do not offer any means of adjusting the transverse focusing for different beam currents we prefer not to extend its energy range and instead to switch to a CCDTL after three DTL tanks. Each CCDTL module consists of three coupled 3-cell DTL-type cavities, which are operated in the $\pi/2$ mode. The quadrupoles are outside the tanks, which simplifies their alignment and relaxes the positioning tolerances of the drift tubes inside the cavities. At ≈ 100 MeV it becomes more efficient to use structures with a period length of $\beta\lambda/2$, rather than $\beta\lambda$. In the “old” design an SCL was used as the last section and the transition energy of 90 MeV was chosen such that four modules of five 21-cell cavities (11 accelerating cells and 10 coupling cells) can be driven by four 4 MW klystrons at 704 MHz. The SCL cells operate in the stable $\pi/2$ -mode and five cavities are coupled by 3-cell bridge couplers. In the “new” design we replace the SCL by a 7-cell π -mode structure (PIMS) at 352 MHz, which is a scaled version ($\propto$ to the relative particle velocity β) of the normal conducting LEP accelerating structure [6], that was used successfully at CERN until the decommissioning of the LEP accelerator in the year 2000.

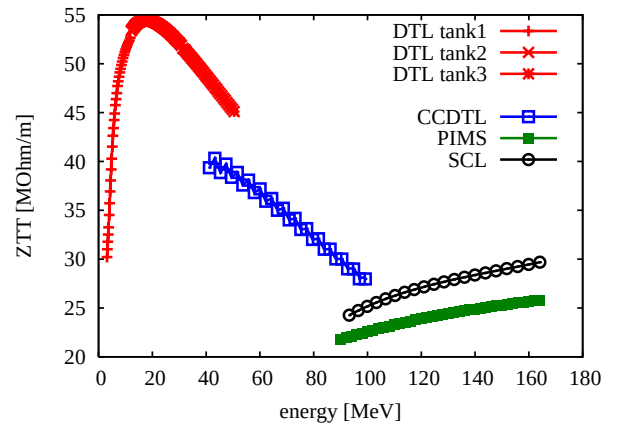


Figure 1: ZT^2 for all structures in Linac4, 80% of Superfish, losses for end-walls, stems, tuning rings are included.

In the first stage, Linac4 structures will be fed by 1.3 MW CW klystrons stored after the decommissioning of the LEP accelerator. However, at the end of the stock of LEP klystrons it is foreseen to replace pairs of 1.3 MW klystrons by single 2.5 MW klystrons designed for pulsed operation. In the present layout with a single frequency for the whole linac it is convenient to use some of the new pulsed klystrons from the beginning in order to reduce the overall number of klystrons and to simplify the feeding

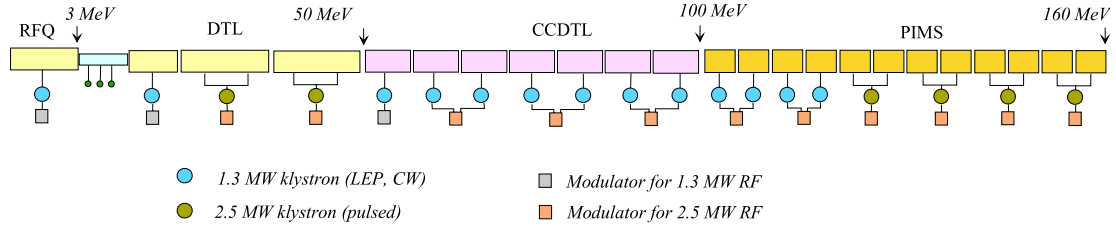


Figure 2: Revised linac layout and klystron partitioning.

of DTL tank2 and 3, which are designed for 2 MW peak power (see Fig. 2).

All accelerating structures in Linac4 use iris-coupling from a tangential waveguide to feed the cavities with RF power. Matching is achieved by adjusting the short circuit position at $\approx \lambda/4$ from the iris. A commercial wave-guide window separates the coupler from the wave-guide. A coupler set-up has been tested successfully with a CCDTL prototype up to a peak power of 300 kW (2 Hz, 0.5 ms).

The revision of the Linac4 layout towards a “new” reference design is based on the following guidelines:

- **Safety margins for additional losses in cavities and wave-guides and klystron power:** For all structures we apply a scaling factor of 80% to the values calculated by Superfish, taking into account additional losses for stems, end-walls, tuning rings, and coupling holes. This is considered as conservative (compared with 90% of Q-value measured on the CCDTL prototype or with results achieved at SNS), providing sufficient safety margin for unexpected problems during production. Moreover, it is assumed that the klystrons (peak power 1.3 MW) can reliably operate with 1 MW at the cavity input. This leaves $\approx 30\%$ of additional power losses in wave-guides and circulators ($\approx 5\%$), phase and amplitude controls ($\approx 10\%$), and finally the safety margin for klystron operation ($\approx 15\%$, this margin contributes to a higher life-time).
- **New transition energies:** From the shunt impedances in Fig. 1 it is clear that one can gain in overall efficiency by shifting the output energies of DTL and CCDTL to higher values. Making use of the design klystron power and slightly reducing the gradient in the DTL tanks, the DTL output energy was raised from 40 to 50 MeV. The CCDTL energy was raised from 90 to 102 MeV. CCDTL output energies are limited by the achievable coupling between accelerating cavity and coupling cells. Due to the increasing volume of the cavities (proportional to the relativistic particle velocity β), the coupling decreases with energy while the maximum size of the coupling holes is limited by the need to place quadrupoles between the CCDTL tanks. Between 50 and 100 MeV the coupling factor changes from 0.89% to 0.52%, which is sufficient to achieve the desired field flatness ($< 1\%$).

- **One single frequency (352 MHz):** The SCL was replaced by a π -mode structure even though the latter has a slightly lower shunt impedance (Fig. 1). Nevertheless, the existing operational experience with low-frequency coupled structures at CERN together with the straightforward tuning procedure make the PIMS a preferable choice, with the additional economic advantages coming from standardisation of all RF components to a single frequency. Other structures that are used for this energy range were considered not suitable [4] for our purpose.

The resulting linac layout is shown in Fig. 2.

DRIFT TUBE LINAC

A new mechanical design for the DTL is being developed at CERN, which uses the rigidity of thick tank walls (50 mm) to provide the necessary precision to align the structure and the drift tubes. The “old” design featured an independently supported girder from which the drift tubes were suspended and which was used as alignment reference. It also made use of an elaborate alignment mechanism, designed by VNIIEF, Sarov, for the positioning of the drift tubes (see [1]). Since drift tubes are usually aligned only once we have chosen a new approach that relies on machining tolerances to position the drift tubes. In case of alignment errors the drift tubes can be re-positioned by re-machining the stem holders on top of the tank. This new approach will be tested with a hot prototype (see Fig.3), which is under development at CERN.

COUPLED CAVITY DRIFT TUBE LINAC

The CCDTL is under development at CERN since 1997. Cold test results of a hot model constructed at CERN, with two half accelerating cells and one coupling cell have been reported in [7]. Meanwhile, this prototype has been tested with high power and within 2 days the nominal accelerating voltage of 4 MV/m could be reached [5]. A second prototype was constructed in Russia by VNIITF Snezhinsk and BINP Novosibirsk and delivered to CERN in March 2007, consisting of two full accelerating cavities and one coupling cell as shown in Fig. 4. In April this device was tested at low power at CERN, finding a Q-value of 36200 (90% of the theoretical value), a coupling factor of 0.9% and a field

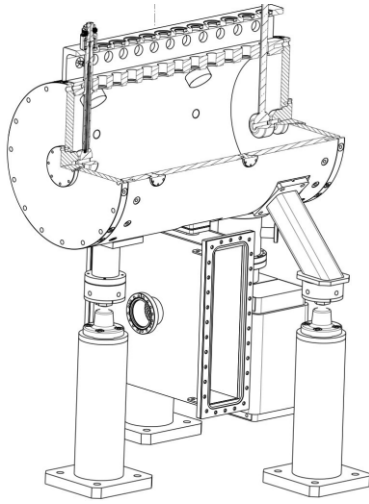


Figure 3: DTL prototype at CERN.

flatness error below 1%. The prototype is presently under vacuum and high power tests are expected to take place in the coming months.



Figure 4: CCDTL prototype from BINP Novosibirsk and VNIITF Snezhinsk.

PIMS

The π -mode structure is based on the LEP expertise and makes use of all mechanical solutions developed for the LEP cavities. The structure consists of discs and cylinders which are machined out of solid copper blocks. About 40% less copper is needed for the PIMS with respect to the SCL. Cooling channels are drilled from the outside into the discs, preventing any risk of water leaking into the vacuum of the cavity. After the brazing of tubes for RF pick-ups, power coupler, and tuners onto the cylinders the structure will be electron-beam welded. The welded cavities are tuned by five fixed and two movable tuners to provide the necessary field flatness. Figure 5 shows a sketch of the foreseen 7-cell structure at 100 MeV. The cells are coupled by two cou-

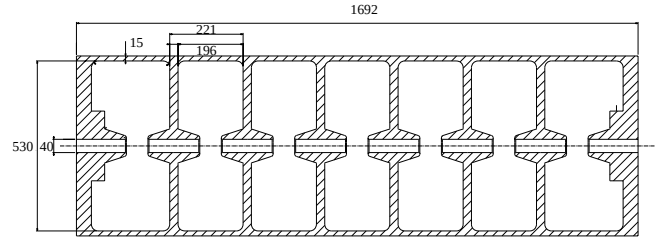


Figure 5: 7-cell pi-mode structure at 160 MeV.

pling slots, which are turned by 90 deg from cell to cell to minimise the 2nd neighbour coupling. A minimum coupling factor of 3%, which provides the same field stability as in the case of the 5-cell LEP cavities (1.5% coupling), is easily achieved. The design of a cold model has already started and the construction of a hot prototype is foreseen in 2008.

Table 2: Main structure parameters

	DTL	CCDTL	PIMS
output energy [MeV]	50	100	160
cavities	3	7×3	12
peak power [MW]	4.7	7	11.3
peak field [KV]	1.6	1.7	1.7
movable tuners	8	9	24
length [m]	18.7	25	22

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