PROGRESS IN THE DESIGN OF LINAC4, THE SPL NORMAL-CONDUCTING FRONT-END ($<$180 MEV)

F. Gerigk, R. Garoby, K. Hanke, A.M. Lombardi, M. Pasini, C. Rossi, E. Sargsyan,
T. Sieber, M. Vretenar, CERN, AB Department, Geneva,Switzerland

Abstract

The SPL is a high-power superconducting H^- linac designed to cover the needs of future experimental programs at CERN. Its normal conducting front-end comprises an RFQ, followed by a low-energy beam chopper, an Alvarez Drift Tube Linac (DTL), a Coupled Cavity DTL (CCDTL), and a Side Coupled Linac (SCL) and can be built in a first stage as Linac4. The design is based on achieving smooth transitions between the different sections and on avoiding emittance exchange via space charge resonances. Following a collaboration agreement for the construction of a prototype DTL tank the original design was changed in order to reduce costs and to increase efficiency. This paper outlines the design approach for the normal conducting SPL front-end and reports on the recent changes in the reference design.

INTRODUCTION

Linac4 is designed for two different applications: 1) as a new (low duty cycle) injector for the PS booster, replacing the ageing Linac2, and 2) as front-end for the SPL [1], a high power (high duty cycle) H^- linac replacing the PS booster and injecting directly into the CERN PS or into a new accumulator ring. For this purpose Linac4 will be relocated into a new tunnel and extended to 180 MeV. From this energy onwards the superconducting cavities of the SPL will continue to accelerate the beam up to its final energy of 3.5 GeV. While the initial average beam power of Linac4 is relatively modest (5 kW) the machine is designed to deliver an average beam power of 205 kW as part of the SPL. The main parameters for both applications are given in Table 1.

The CERN management is expected to take a decision on the construction of Linac4 by the end of 2006. The case of the SPL will be considered in 2010-2011, as one of the possible options for the upgrade of the CERN proton accelerator complex.

DESIGN PHILOSOPHYY

The basic design consists of RFQ, a Medium Energy Beam Transport line (MEBT) with a beam chopper at 3 MeV, an Alvarez type Drift Tube Linac (DTL) up to an energy of 40 MeV, a Coupled Cavity DTL (CCDTL) up to 90 MeV, followed by a Cell Coupled Linac (SCL) accelerating the beam to its final energy of 160 or 180 MeV, respectively (Fig. 1). At 90 MeV after the transition from CCDTL to SCL, the frequency changes from 352.2 MHz to 704.4 MHz in order to profit from higher accelerating gradients, higher efficiency and a more compact accelerating structure. The choice of structures and basic beam dynamics have already been analysed in some detail (see e.g. [2], [3], [4], [5]). The front-end test stand preceding the construction of the full Linac4 already in preparation [6].

Table 1: Main linac parameters

	Phase I (Linac4)	**Phase II (SPL)**	
ion species	H^-	H^-	
length	80	88	m
beam energy	160	180	MeV
beam power	5.1	205	kW
bunch frequency	352.2	352.2	MHz
repetition rate	2	50	Hz
source current	80	80	mA
peak current	64*	64*	mA
chopper beam-on	62	62	%
chopping scheme	133/355	3/8	
av. pulse current	40	40	mA
av. current	0.032	1.14	mA
beam pulse length	0.4	0.57	ms
beam duty cycle	0.08	2.85	%
particles p. pulse	1.0	1.42	$\cdot 10^{14}$
particles p. bunch	1.14	1.14	$\cdot 10^{9}$
$\varepsilon_{tr,rms}$	0.29	0.35	π mm mrad
$\varepsilon_{l,rms}$	0.45	0.50	π mm mrad

The current planning foresees Linac4 to be installed in the PS south hall at CERN where only limited space is available. Since the RF equipment for the 352.2 MHz part of the linac is already available (recuperated from LEP), this new design concentrates on raising the electric gradients and optimizing the lattice for the shortest length possible.

In order to achieve a low loss design, Linac4 follows the standard design rules for high-intensity hadron linacs: a) zero current tune per period below 90 deg (Fig. 2), b) smooth variation of the focusing forces across all transitions between accelerating structures (Fig. 3), and c) avoiding emittance exchange between the longitudinal and transverse planes by keeping the ratio of the depressed longitudinal over transverse tunes in the stable areas of Hofmann's stability charts [7] (Fig. 4). The resulting beam envelopes are plotted in Fig. 5.

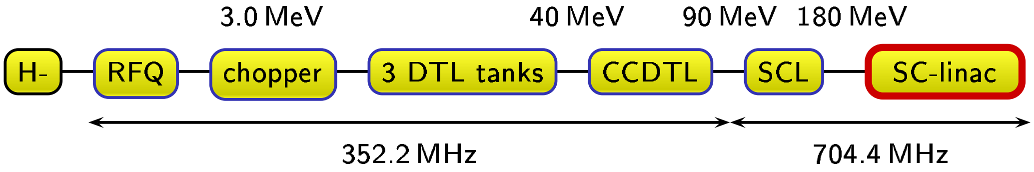

Figure 1: SPL layout.

DESIGN PROGRESS

The base line design of the DTL and CCDTL sections of Linac4 [8] was recently re-assessed resulting in major changes for the DTL. At the same time the overall design of Linac4 and the SPL evolved, yielding new values for peak current, synchronous phases and electric field gradients.

peak current

The most recent change in the design of Linac4 concerns peak current, pulse length, and chopping ratio. Linac4 now uses the same chopping ratio (38 % instead of 25 %) as the SPL, leading to equal requirements for peak current (64 mA in the linac), average current (40 mA), and numbers of particles per linac bunch ($1.14 \cdot 10^9$). This choice also yields less injection turns into the booster and provides a larger safety margin for low-loss H^- injection [9]. It also implies equal space charge forces for the beam transport and equal RF peak power.

DTL PMQs

A major change in the hardware design is the use of permanent magnetic quadrupoles (PMQs) in the DTL. Due to the low starting energy of 3 MeV it is very challenging to construct electromagnetic quadrupoles which are small enough to fit inside the first drift tubes of DTL tank 1. Even though the electro-formed JPARC electromagnetic quadrupoles might be adapted for the use in Linac4, PMQs offer a number of additional advantages: a) they are cheaper to construct, require less cooling, and need only little maintenance, b) the smaller drift tube diameter

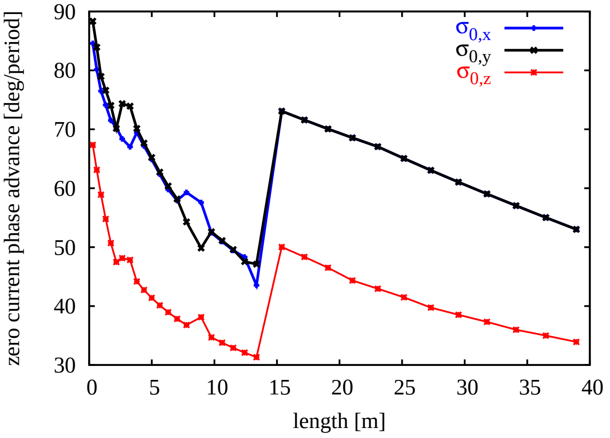

Figure 2: Zero current tune per period along Linac4.

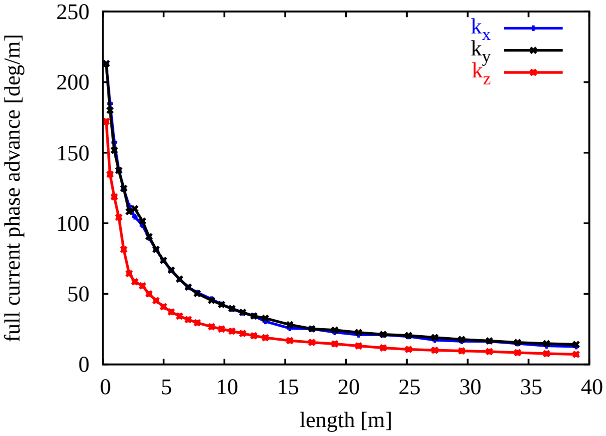

Figure 3: Full current tune per metre along Linac4.

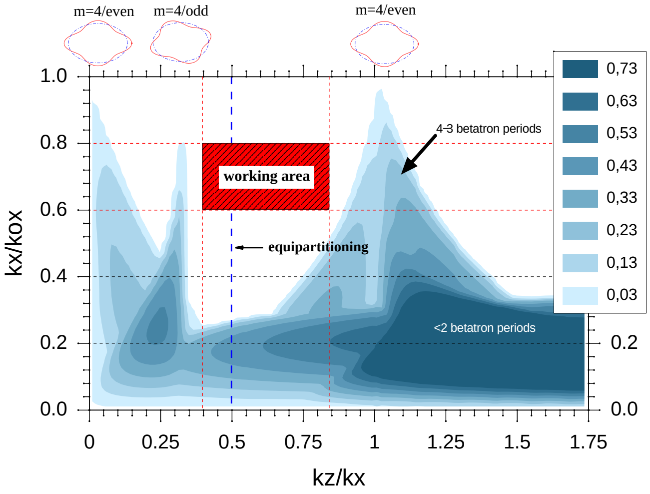

Figure 4: Hofmann's instability chart for space charge resonances.

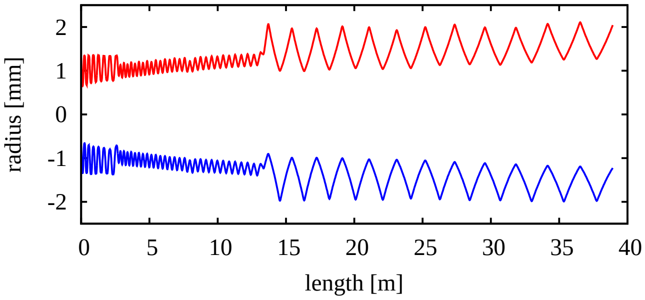

Figure 5: Rms envelopes along Linac4.

raises the shunt impedance and therefore allows to raise the field gradient while maintaining the same number of klystrons for the same output energy, c) the higher magnetic gradients may allow to use FD focusing instead of FFDD from the first tank onwards, depending on the PMQ technology used. This choice would yield a stronger focusing and a smaller beam size. The clear disadvantage is that PMQs do not allow to change the focusing settings in the DTL. Nevertheless, in the case of Linac4, this choice is considered viable since the whole DTL is only 13 m long and profits from a dedicated matching section at the transition from the MEBT into the DTL. Adapting the elements of the matching section for different currents, multi particle simulations (TRACE_WIN [10]) confirmed that beam currents between 20 and 60 mA can be matched into a DTL with PMQs without any degradation in beam quality.

synchronous phase & field ramp

The previous DTL [8] design employed a phase and field ramp in the first tank from -42 deg to -25 deg and from 1.5 to 3 MeV, respectively. In the new design the first drift tubes are slightly longer in order to reduce the transit time factor. Additionally the starting phase was raised from -42 deg to -30 deg. Both measures lower the longitudinal focusing and thus the field ramp can be eliminated without major changes in the evolution of the longitudinal focusing. Furthermore the field level was raised from 3 MV/m to 3.5 MV/m, taking advantage of the higher shunt impedance due to the smaller drift tubes. Another optimization was done with respect to the maximum synchronous phase in the DTL and throughout Linac4. The new design features a maximum synchronous phase of -20 deg instead of -25 deg, which slightly raises the acceleration per metre and thus shortens the structure. This rise, however, might yield two problems: a) more filamentation and possibly emittance blow-up in longitudinal phase space, and b) a rise in phase and energy jitter due to statistical errors in the RF system. The effect on the emittance was analysed by simulating the two linac versions: a) -42 to -25 deg and b) -30 to -20 deg with a range of longitudinal emittances (0.07π deg MeV to 0.35π deg MeV instead of the nominal value of 0.18).

Figure 6 shows the output versus input longitudinal emittance for the two cases. Both versions are close to the theoretical 45 deg line, meaning that the different phase settings have little influence on the longitudinal dynamics. An additional outcome of this study was that larger longitudinal input emittances increase the transverse emittance growth.

To test the influence of different synchronous phase settings on the development of phase and energy jitter a simple drift-kick code was written to evaluate large sets of statistical errors [11]. Figure 7 shows the energy jitter evolution along the present linac design for an rms error of 0.5 % and 0.5 deg.

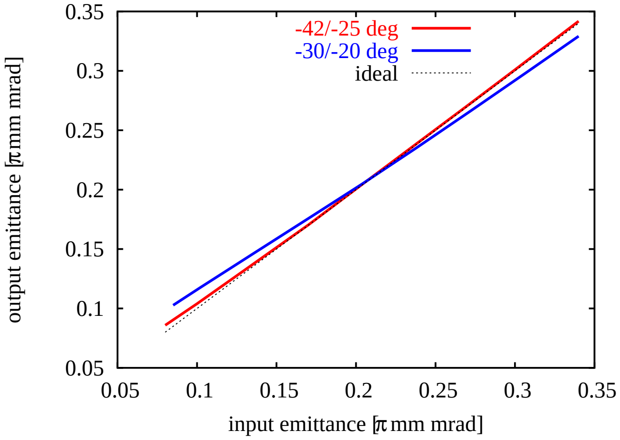

Figure 6: Longitudinal rms output emittance versus input emittance in the DTL.

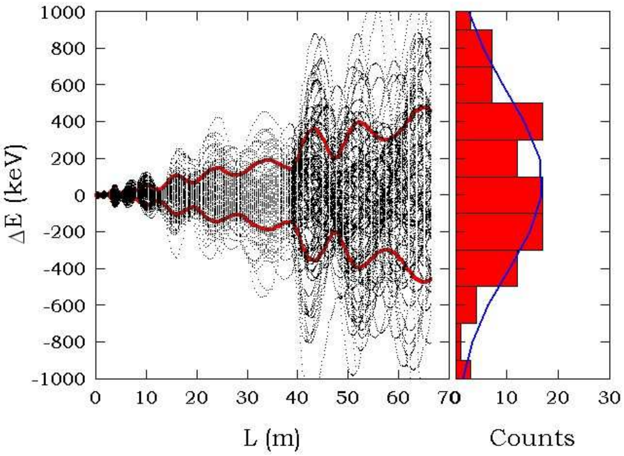

Figure 7: Energy jitter in Linac4 for 0.5 % / 0.5 deg (rms) errors in all RF systems.

Due to the frequency jump at 90 MeV at around 40 m the energy and phase variations double. Using a Gaussian error distribution and 100 different error sets the two settings for the synchronous phase were simulated. Table 2 shows the results of these simulations and confirms that the difference between the "old" synchronous phase settings and the new one is marginal.

Table 2: Energy/phase jitter in Linac4 for 0.5 % / 0.5 deg (rms) errors in all RF systems.

	"old" Linac4	**"new" Linac4**
$\boldsymbol{\phi_s}$	-42 to -25 deg	-30 to -20 deg
$\boldsymbol{\Delta E_\sigma}$	612 keV	678 keV
$\boldsymbol{\Delta\phi_\sigma}$	8.9 deg	7.3 deg

SUMMARY

In the latest iteration of the Linac4 design several changes were implemented: the use of PMQs in the DTL, the field ramp in the first DTL tank was eliminated, raising the maximum synchronous phase from -25 to -20 deg without degrading longitudinal phase space, raising the electric gradient in DTL and CCDTL. All these measures resulted in a length reduction of 3 m (out of 16.4 m) for the DTL, and a reduction of ≈ 7 (out of 58 m) for CCDTL and SCL. At the same time the influence of smaller/larger longitudinal input emittances was tested as well as the effects of RF errors on the development of phase and energy jitter.

ACKNOWLEDGMENTS

We want to thank all HIPPI/CARE contributors to Linac4 (CEA/DSM, CNRS/IN2P3, RAL) and all our international partners [CAT, BARC (India), IHEP (China), ITEP, VNIIEF, IHEP, BINP, VNIITF (Russia)] for the technical progress in Linac4, especially our colleagues at ITEP Moscow for their contribution to the DTL design.

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" program (CARE, Contract No. RII3-CT-2003-506395).

REFERENCES

[1] K. Hanke et.al., "Superconducting proton linac development at CERN", this workshop

[2] R. Garoby et.al., "Design of Linac4, a new injector for the CERN booster", in Proceedings of the XXII International Linear Accelerator Conference (2004).

[3] M. Vretenar et.al.,"Development of a 352.2 MHz cell-coupled drift tube linac prototype", in Proceedings of the XXII International Linear Accelerator Conference (2004).

[4] C. Rossi et.al.,"Linac4, a new H^- linear injector at CERN", in Proceedings of the XIX Russian Particle Accelerator Conference (2004).

[5] F. Gerigk et.al.,"Beam Dynamics for a new 160 MeV H^- linac at CERN (Linac4)", in Proceedings of the XXII International Linear Accelerator Conference (2004).

[6] C. Rossi et.al.,"The SPL front-end: a 3 MeV H^- test stand at CERN", in Proceedings of the XXII International Linear Accelerator Conference (2004).

[7] I. Hofmann, "Stability of anisotropic beams with space charge", Phys.Rev. E **57**, 4713 (1998).

[8] F. Gerigk and M. Vretenar "Design choices for the SPL normal conducting front-end", CERN-NUFACT-NOTE NF 110 (2002).

[9] M. Martini, C.R. Prior, "High-intensity and high-density charge-exchange injection studies into the CERN PS booster at intermediate energies", in Proceedings of the IX European Particle Accelerator Conference (2004).

[10] N. Pichoff and D. Uriot, TRACE_WIN, DSM/DAPNIA/CEA 2004/45.

[11] M. Pasini, "Phase and amplitude error study for the Linac4 RF system", CARE-HIPPI Document-05-006