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EDMS NO.	REV.	VALIDITY
1898179	**1.0**	**RELEASED**

REFERENCE
PSB-OP-EP-0001

Date: 2018-02-16

PARAMETERS

Beam Requirements for Linac4 Connection to the PS Booster

ABSTRACT:

The aim of this document is to list the main requirements in terms of Linac4 beam quality and operational flexibility that are needed before the connection of Linac4 to the PSB.

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HISTORY OF CHANGES

REV. NO.	DATE	PAGES	DESCRIPTIONS OF THE CHANGES
0.1	2018-01-30	-	First version for approval
1.0	2018-02-16	All	Comments implemented from A. Lombardi, R. Scrivens and after discussions in LIU beam performance meeting of 15/02/2018. Summary table of requirements added.

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1. Introduction

The aim of this document is to list the main requirements in terms of Linac4 beam quality and operational flexibility that are needed before the connection of Linac4 to the PSB.

2. List of Requirements for LINAC4 for Connection to the PSB

Below the main beam quality requirements for Linac4 are listed as well as operational requirements, which should guarantee reaching post-LS2 target beam parameters and at the same time maintaining the current operational flexibility.

Energy painting has been added separately at the end of the list, as it is not absolutely necessary in order to be able to provide all beams after LS2, but it would be a very elegant tool to improve the performance of high-intensity beams.

1) Minimum peak current of 40 mA before chopping[1] for 400 μs pulse length [1]. This will guarantee reaching 1.6e13 particles/ring (ISOLDE target intensity), neglecting losses (no margin); see Note 1 below the list

2) Flat Linac4 pulse shape in terms of intensity and x/y position at the PSB stripping foil (for variable pulse length between 100 ns to 600 μs)
   a) Intensity flatness along the pulse of ±2% for LHC beams (up to ~160 μs pulse length) and ±5% for higher intensity beams (longer pulse length)
   b) Position (x/y) variations along the pulse should be negligible, ±1 mm[2] for position to reach LHC target parameters ('All matched' optics for dispersion and beta [2] at the injection foil position, no longitudinal painting); see Note 2 below the list
   c) From simulations and calculations [3] the error on the x/y injection angle should be ±<4 mrad
   d) Including when changing the number of turns for one specific cycle, also in the case of by-ring interlocks (RF space charge compensation)

3) Stable current (±2%) shot-by-shot
   a) Including when changing between low- and high-intensity cycles

4) Normalized transverse emittances at PSB entrance ≤0.4 mm mrad

5) 160 MeV beam energy at the end of the linac with desired energy spread (BSM)

6) Debuncher commissioned
   a) Energy spread adjustable pulse-to-pulse between ~80 and ~450[3] keV rms (measured with 2nd BSM during LBE line commissioning, then extrapolated to PSB injection point) [4 (page 4)]
      i) Provide to OP measured operational plots/tables of energy spread vs. debuncher amplitude setting for beam preparation (+debuncher phase variation as additional useful information)

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[1] Nominal chopping factor: Between ~60-65% without longitudinal painting. 40 mA current should be used for space charge simulations.

[2] Backtracking of position variation at stripping foil to pickups in L4T for verification.

[3] After preliminary studies it might be beneficial to have an increased energy spread up to ~600 keV.

7) Chopper operation consolidated
   a) Demonstrate chopper operation at 2 MHz
   b) Confirm a chopper extinction factor of 10E-4 for different chopping frequencies (in particular for the nominal chopping pattern) and the optimized LEBT/MEBT optics. This is mainly for loss minimization both at the vertical injection septum and for out-of-bucket beam)
   c) With beam-based measurements confirm min. chopper OFF time (show full beam transmission; design value: 15 ns[4]) and min. chopper ON time (100% beam extinction; design value: 25 ns)

8) RF HW modifications implemented and new LL-RF FESA class available and tested
   a) All RF LL parameters in LSA to allow comprehensive ppm RF parameter copy between cycles
   b) Decision on how to use the RF feed-forward algorithm; show that strategy works
      i) for different beam types (ppm operation with cycles of min. and max. intensity)
      ii) and simulating a by-ring interlock on one selected cycle (e.g. a typical parasitic TOF/EAST cycle)

9) Define max. allowable high-loss threshold per watchdog (define damage level)

Energy painting:

10) Characterization of energy swing potential for longitudinal painting
   a) Possible methodology to map working region for longitudinal painting:
      i) Measure energy spread variation with BSM for different energy swings ($\Delta E_{0,max}$) and swing rates ($\Delta E_0/dt$), 1 full sweeping period
         (1) Analyse (plot) energy spread vs. time (normalized by sweeping period length)
         (2) Deviations of relative energy spread could give indication of a limitation in debuncher cavity power and provide thresholds for control for longitudinal painting
   b) Expected performance at PSB injection point:
      i) Debuncher ON (80-450 keV rms):
         (1) $\Delta E_{0,max}$ = ±1.2 MeV at min 40 + 40 PSB turns [5]
         (2) $\Delta E_{0,max}$ = ±0.8 MeV at min 20 + 20 PSB turns [4 (slide 3)]
      ii) Debuncher OFF ('natural' energy spread 250 keV rms at PSB inj. point):
         (1) $\Delta E_{0,max}$ = ±1.6 MeV - energy sweep limitations related to line acceptance (+ PIMS cavity power reach) [4 (slide 5)].

Note 1 (Linac4 current):

The BI.DIS10 pulse-forming network was modified to allow for **600 μs** long pulses to compensate for a reduced Linac4 current with respect to the original design. If the average current at the BI line will be of the order of **26 mA**, it will be possible to reach a total accumulated intensity a **factor 2.5** higher than the present one (e.g. 9e12 protons per ring; injection losses are neglected).

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[4] 50-100 ns of min. chopper OFF time are required for beam commissioning.

As a reminder, the original goal, assuming 40 mA at the PSB, was of increasing the intensity by a factor 3) if a 600 μs flat pulse (flat within ±1%, BCT resolution) can be produced by the linac. In case of limitation to 400 μs the gain will be of the order of 70%.
No gain in terms of number of injected particles at all will be achieved if the current at the BI line will be of **15 mA** and the flat pulse will be limited to **400 μs** (+60% if possible reaching 600 μs).

Note 2 (pulse flatness):

No transverse deflection along the pulse is **important for the direct tailoring of LHC/BCMS beam emittances and intensity** during injection into the PSB.

In fact, simulation of the LHC25ns standard beams showed 3 mm injection steering tolerance to achieve a target transverse emittance of 1.2 μm (see [6] Fig. 7.15 at page 128). If the incoming intra-bunch position variation is already in the order of 3 mm, this gives no margin for injection mis-steering. The problem gets amplified for the direct tailoring (during injection) of BCMS bunches due to the smaller transverse emittances.

3. Summary Table

Table 1 below summarizes the requirements at the location of the PSB injection stripping foil.

Table 1: Linac4 beam requirements at PSB stripping foil location for 40 mA peak current.

Min. peak current (before chopping)	40 mA
Intensity flatness along the pulse for pulse lengths up to 160 μs	±2%
Intensity flatness along the pulse for pulse lengths >160 μs	±5%
Horizontal/vertical position variations along the pulse	±1 mm
Horizontal/vertical injection angle error	±<4 mrad
Current stability shot-by-shot	±2%
Normalized transverse emittances	≤0.4 mm mrad
Beam energy	160 MeV
Ppm energy spread	~80-450 (600) keV
Nominal chopper operation	See 7)
Energy painting	See 10)

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[6] V. Forte, 'Performance of the CERN PSB at 160 MeV with H- charge exchange injection', 03/06/2016, CERN-THESIS-2016-063, https://cds.cern.ch/record/2194937/files/CERN-THESIS-2016-063.pdf?subformat=pdfa&version=1.