OVERVIEW OF THE CERN LINAC4 BEAM INSTRUMENTATION

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Abstract

The CERN LINAC4 will represent the first upgrade of the LHC injection chain, by accelerating H⁻ ions from 45 KeV to 160 MeV for charge-exchange injection into the PS Booster. In order to provide its safe and efficient commissioning and operation, a wide variety of beam diagnostics devices has been designed for installation at convenient locations all over the accelerator length and in the transfer line to the PS Booster. This paper gives an overview of all instrumentation devices, including those to measure beam position, transverse and longitudinal profile, beam current and beam loss. The well advanced status of the system design and the main instrument features are discussed

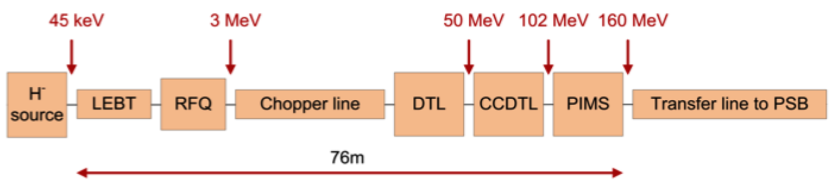


Figure 1: LINAC 4 schematic layout

INTRODUCTION

The LINAC4 schematic layout is shown in Fig. 1. All machine elements from the source to the exit of the chopper line at 3 MeV will be installed and tested with beam in the laboratory where the source is presently commissioned. A movable diagnostics bench [1] will be used to characterize the beam at the end of the RFQ and the chopper line at 3 MeV.

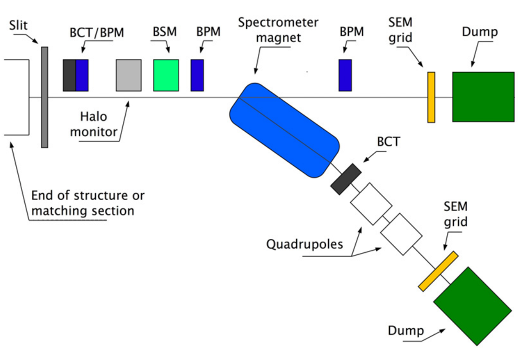


Figure 2: Movable diagnostics bench layout.

The movable test bench layout is shown in Fig. 2. During the machine installation in the tunnel, the bench will be re-used at the same two stages and then at the exit of the first DTL tank at 12 MeV. After this, the permanent LINAC4 instrumentation will be installed and used for both commissioning and operation. Given the different beam parameter scenarios, as shown in Table 1, the LINAC4 diagnostics must cover a wide operational range. Details about the diagnostics functional specifications can be found in [2].

Table 1: LINAC 4 Beam Parameters

Parameter	Commissioning	Operation
Energy [MeV]	3 - 12	0.045 – 160
Peak current [mA]	7 – 80	65-80
Avg. current (after chopping) [mA]	~3.5 – 40	40
Pulse length [μs]	100	400
Repetition rate [Hz]	1	1
Transv. emit. [mm mrad]	0.25-0.4	0.25-0.4

BEAM CURRENT AND POSITION

During commissioning, the beam current at the source exit will be monitored by a retractable Faraday cup, coupled to a 1 MHz sampling ADC readout allowing a 1 μs time resolution. Along the linac the beam intensity will be continuously monitored by means of Beam Current Transformers (BCT) with a maximum sampling rate of 10 MHz. The devices need a magnetic shielding to avoid electro-magnetic coupling with the pulsed magnets that may be close to the detectors. The first two detectors have been already installed in the chopper line in the laboratory without beam and the shielding effectiveness verified.

Table 2: LINAC 4 Diagnostics Overview

Location	E [MeV]	BPM	BCT	SEM GRIDS	WS	BTV	BLM
Diagn. Bench	3-12 MeV	3	2	2H+1V	-	-	-
LEBT	0.045	-	1	2H+1V	-	-	-
MEBT	3	-	2	-	2	-	1
DTL	50	2	-	-	-	-	2
CCDTL	102	7	1	2H+2V	2	-	4
PIMS	160	6	1	2H+2V	2	-	3
TL to PSB	160	12	7	3H+3V		3	11
DL	160	-	1			1	-

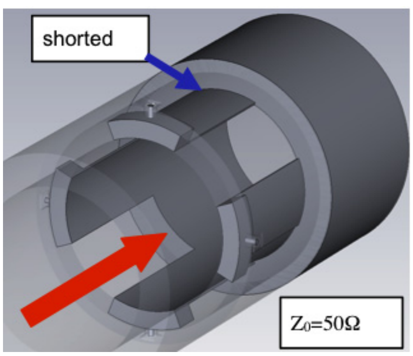


Figure 3: BPM model used for CST MS simulations

Beam Position Monitors (BPM) will measure i) the absolute beam position, ii) the relative beam current among monitors, iii) the absolute beam current after calibration with the BCTs, and iv) the average beam energy via the time-of-flight between two monitors. The systems are based on strip line detectors. The CST Microwave Studio suite has been used to study the expected signal induced by the LINAC 4 bunch trains and the detector model is shown in Fig. 3. The simulations show that, after applying a low pass filter at each electrode signal, the first beam harmonic at 352 MHz is always well detectable, even at the end of the transfer line to the PSB, where the beam is partially de-bunched. The filtering is achieved by means of a capacitor between the electrode and the surrounding beam pipe. The electronics design foresees a down mixing that provides an IF signal at 17 MHz, samples at 70 MHz and will allow extracting the beam position and intensity averaged over a minimum of 55 bunches. Simulations and laboratory tests predict a resolution of 0.1 mm on the beam position, 0.1 mA on the beam intensity and 0.1 % on the relative time-of-flight between two monitors. The first BPM devices will be installed in 2011 on the diagnostics bench.

TRANSVERSE PROFILE AND EMITTANCE

A slit-grid system has been studied for measuring the emittance at the different stages where the diagnostics bench will be installed during commissioning [3]. The slit must stand high power deposition densities in a very short time. It has been decided to use graphite plates mounted with a 15° angle with respect to the beam axis in order to dilute the energy deposition. The slit operation will be limited to a maximum pulse length of 100 µs, unless relaxed beam dynamics schemes will provide bigger beam sizes at the slit location. A detailed study of the emittance measurement accuracy [4] allowed establishing the wire grid design and the emittance scan parameters in order to guarantee an emittance reconstruction error within few percent.

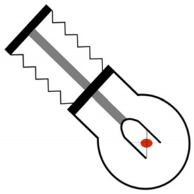
A Beam Halo monitor [5] will be used in the MEBT line at 3 MeV to detect unchopped or partially chopped bunches and to characterize the beam transverse tails.

As shown in Table 2, a number of SEM grid and Wire Scanner (WS) monitors will be installed at different LINAC4 locations. Those are retractable devices, permanently installed and will be used to measure beam profiles. Wire grids will consist of carbon or tungsten wires spaced at 0.5 mm. Dedicated studies are presently conducted for establishing the wire material at the different locations, in order to have enough signal and guarantee the wire survival [6].

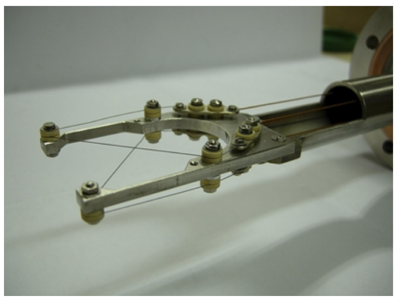
As shown in Fig. 4, the WS detectors will consist of single forks equipped with 2 wires separated by 45 degrees. As the fork will move into the beam at 45 degrees with respect to the beam axis, the horizontal and vertical profiles will be recorded with a single scan. The typical movement step size is 10 µm.

A total of 4 retractable scintillating screens coupled to optical and imaging systems (BTV) will be installed in the dump line and in the transfer line to the PSB (both at 160 MeV).

At present, it is foreseen to use Al_2O_3:Cr (Chromox) 1 mm thick foils and thermal calculations for the DL locations predict their survival with a 100 μs, 65 mA H^- pulses and beam sizes as estimated by nominal beam dynamics. The same should apply for the transfer line monitors, even though detailed calculations have not been performed yet.



a)



b)

Figure 4: Wire scanner a) schematic drawing and b) photo.

The screens will be beam-destructive and three-profile measurements for emittance estimations will be possible only over multiple shots. Concerning the optical system for imaging the scintillating light on the camera, even if the final compromise between magnification and acceptance has not been studied in detail yet, it is expected to have an optical resolution of about 10 μm.

LONGITUDINAL DISTRIBUTION

The bunch shape monitor (BSM) has been developed by Feshenko at INR in Russia [7]. It consists of a wire which can be inserted into the beam. Secondary electrons created through the interaction of the H^- beam with the wire are accelerated by a HV polarization voltage applied to the wire. The electrons pass through an input collimator and are deflected by an RF deflector whose RF pulse is in synchronism with the accelerating RF. The deflected electrons pass through an output collimator and are detected by an electron detector. The phase of the deflecting field can be shifted to scan the longitudinal intensity distribution of the incoming beam. The BSM will be used on the diagnostics test bench for the beam characterization at low energy and then permanently installed at the exit of the PIMS modules at 160 MeV.

The BSM will be able to monitor the full 400 μs pulse and the maximum peak current (80 mA after the RFQ), with a phase resolution of 1° covering the full phase range (180° at 352 MHz). The background due to stripped electrons should be less than 1% of the total secondary emission from H^- and the phase scan will provide 1 point per beam pulse.

BEAM LOSSES

Beam Loss Monitoring (BLM) system will be included to observe beam losses between the 3 MeV and 160 MeV regions. Above 50 MeV, it is foreseen to use LHC type monitors, i.e. ionization chambers with similar electronics. At lower energies such detectors have very low sensitivity and other solutions, like scintillators coupled to photo-multipliers, are being investigated.

The exact detector number and location is currently under study (see Table 2 for latest numbers and locations).

This configuration is expected to provide multiple integration history windows between 2 μs and 1.2 s, and a dynamic range covering the maximum losses (i.e. 4E13 ions) expected when the full 400 μs pulse is injected.

The BLM system will be included into the beam interlock system granting safe beam permits or block injections if the predefined thresholds get exceeded.

Additionally, on some locations along the transfer to the PSB for observation and measurement reasons, e.g. during commissioning, faster monitors will be installed, for which Aluminum Cathode Electron Multiplier (ACEM) detectors are being considered.

OTHER DIAGNOSTICS

The instrumentation discussed above regards all LINAC 4 devices that will be installed upstream the linac connection to the last piece of transfer line to the PSB, presently used by LINAC 2. This line, as well as the PSB injection region will be refurbished with instrumentation coping with the LINAC 4 beam parameters. In particular 17 BPM, 3 BTV and 6 BLM systems of the same type described above. The PSB injection region will be equipped with a BTV monitor for measuring the beam position and shape at the stripping foil and the stripping foil integrity. After the stripping foil, the dump block designed to absorb unstripped ions will be equipped with Aluminium (or Tungsten) plates aiming at measuring such ions and therefore the stripping efficiency.

REFERENCES

[1] G. Bellodi, "User specifications for LINAC4 test bench diagnostics", CERN EDMS L4-B-EP-0002.

[2] K. Hanke, A. Lombardi,"Beam measurements for LINAC 4 and its transfer lines", CERN EDMS L4-B-ES-0002.

[3] B.Cheymol et al., "Design of the Emittance Meter for the 3 and 12 MeV LINAC4 H- Beam", Proceedings of IPAC 2010, Kyoto, Japan.

[4] F.Roncarolo et al., "Accuracy determination of the CERN LINAC4 emittance measurements at the test bench for 3 and 12 MeV", these Proceedings.

[5] M. Hori and K. Hanke, "Spatial and temporal beam profile monitor with nanosecond resolution for CERN's Linac4 and SPL", Nucl.Instr.Meth. A, 588(2008) 359-374.

[6] F.Roncarolo et al., "Wire grid and wire scanner monitors design for the CERN LINAC 4", these Proceedings

[7] A.V. Feshenko, "Methods and Instrumentation for Bunch Shape Measurements", Proc. of the PAC 2001, Chicago, IL, June 2001.