DIAGNOSTICS AND MEASUREMENT STRATEGY FOR THE CERN LINAC 4

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Abstract

Linac4 is a 160 MeV H^- linac which will become the new injector for CERN's proton accelerator chain. The linac will consist of 4 different RF structures, namely RFQ, DTL, CCDTL and PIMS running at 352.2 MHz with 2 Hz repetition rate and 0.4 ms pulse length. A chopper line ensures clean injection into the PS Booster. The combination of high frequency and a high-current, low-emittance beam calls for a compact design where minimum space is left for diagnostics. On the other hand, diagnostics is needed for setting up and tuning of the machine during both commissioning and operation. A measurement strategy and the corresponding choice of the diagnostic devices and their specific use in Linac4 are discussed in this paper.

INTRODUCTION

Linac4, a 160 MeV H^- linac, is the first step in re-building CERN's proton injector complex. The linac will consist of 4 different RF structures, namely a radio-frequency quadrupole (RFQ), a drift tube linac (DTL), a cell-coupled drift tube linac (CCDTL) and a pi-mode structure (PIMS). Figure 1 shows schematically the different sections of the linac. In a first phase, Linac 4 will inject into the existing CERN PS Booster and deliver beams for fixed-target physics and the LHC through the present accelerator chain. In a second phase, Linac4 will become the front-end of a superconducting linac (SPL), which will inject into a new proton synchrotron (PS2). In the operation of a high-power hadron linac as Linac4, beam loss is a critical issue. The specification of the instrumentation has therefore been driven by beam dynamics calculations. We will discuss in the following paragraphs the diagnostics specified for the commissioning of the different stages of the linac as well as for day-to-day operation.

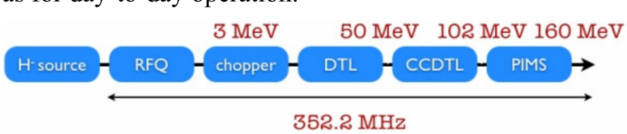

Figure 1: Linac4 layout.

ALIGNMENT, STEERING STRATEGIES AND LOSS CONTROL

After the nominal layout of the machine had been defined, a series of runs (1000-2000) was made in order to evaluate beam losses and emittance growth under the effects of machine and beam errors. The results of these studies are reported in [1]. Starting from these results, a system composed of correctors (dipolar kicks) and diagnostics (beam position monitors) has been integrated in the Linac4 layout in order to minimise losses and to control emittance growth. A procedure has been implemented to find the value of the correctors which minimises orbit excursion at the location of the diagnostics, while maximising transmission. The aim is to have a sufficient number of correctors and monitors to be able to control routine beam loss to less than 1 W/m at the highest possible beam duty cycle (6%, foreseen for future operation of Linac4 as injector for the SPL operated at maximum beam power). These studies show that a correction system made of 15 horizontal and vertical steerers and monitors can correct the effects of quadrupole alignment errors within ±0.1 mm and ± 1 mrad and beam alignment errors of ±0.3 mm and ±0.3 mrad (all values are 1 sigma). The residual losses in the worst case scenario are shown in Figure 2.

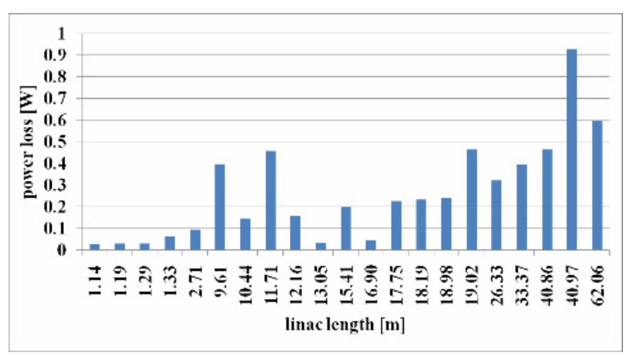

Figure 2: Power loss along Linac4 (40 mA, 6% duty cycle, and worst case out of 2000) for beam and machine alignment errors (quadrupoles 0.1 mm, 1 sigma, beam position ±0.3 mm/0.3 mrad Gaussian) applying the best correction achievable with the given diagnostic and steering system.

DIAGNOSTICS CHOICES

Source and Low-Energy Beam Transport

In order to characterise the H^- source and the 2-solenoid low-energy beam transport (LEBT), measurements of the beam current (transmission), beam profile and emittance are required. During the commissioning phase the source and LEBT will be set up in two different ways: in the spectrometer configuration only one solenoid is used, followed by a diagnostics box which houses a Faraday cup (FC) and a secondary emission monitor (SEM) for profile measurements. Downstream of the diagnostics box there is a slit/spectrometer system followed by a SEM grid and a Faraday cup for measurement of the energy spread. In the emittance configuration, the LEBT is replaced by an emittance scanner consisting of a movable slit and SEM grid. In the operational linac the diagnostics box will be situated between the two solenoids. The beam current is measured by a beam current transformer (BCT) installed between the diagnostics box and the second solenoid.

Chopper Line

The chopper line is equipped with two identical beam current transformers located between the first and the last pair of quadrupoles. Furthermore, there are two wire scanners (WS) upstream and downstream of the chopper structure. These devices measure beam profiles in both planes by scanning two orthogonal wires slowly through the beam. The moving range is large enough in order to measure both the deflected and undeflected beam. For commissioning of the chopper line we have developed a dedicated beam shape and halo monitor (BSHM) to verify the correct functioning of the chopper. The BSHM images secondary electrons generated by a thin carbon target inserted in the beam and is able to detect remaining beam current in chopped buckets down to an intensity of 1E3 particles per bunch. In the transverse plane, the detector can deliver an image of the beam and display simultaneously the beam core and beam halo thanks to its dynamic range of $>10^{-5}$. The detector has been successfully tested with a laser beam and with a 3 MeV proton beam [2].

IPHI Measurement Line

The 3 MeV part of the linac including source, LEBT, RFQ and chopper line will be operated stand-alone and characterised with the IPHI ("Injecteur de Protons à Haute Intensité") measurement line provided by the French CEA and IN2P3 laboratories in the frame of the IPHI-CERN collaboration. This temporary diagnostics line comprises measurement of the beam current, position, profiles, energy (time-of-flight) and energy spread. It has been described in detail in [3].

Drift Tube Linac (DTL)

The Drift Tube Linac consists of three tanks accelerating to beam energies of 12, 32 and 50 MeV. Commissioning of the DTL is planned to take place in stages, where at each stage the beam is characterised using a movable diagnostics bench. This measurement bench comprises beam profile measurement devices (SEM grids), two pick-ups for position and time-of-flight (TOF) measurements, one beam current transformer as well as a spectrometer magnet for measurement of the energy spread, discussed in the following section. The transverse emittance is measured with a scanning slit/SEM device (modified from the source diagnostics) and the longitudinal profile and phase spread is measured by a bunch shape monitor (BSM) based on secondary electrons [4]. In the operational linac, there will be pick-ups after each of the three tanks. These pick-ups are specified to measure beam position, intensity and phase with a resolution of 0.1 deg, 0.1 mm and 0.5 mA. Due to space constraints, the pick-ups will be partly integrated into the magnets between the DTL tanks. At the exit of the last DTL tank a beam current transformer (resolution 0.5 mA) as well as a retractable SEM grid (resolution 0.5 mm) is foreseen.

Spectrometer Line

Beam dynamics studies have been carried out to specify a layout for the diagnostics line on the movable bench and assess the feasibility of a slit/spectrometer/monitor technique for energy spread measurements of the DTL beam at the time of commissioning. Through the dispersion locally generated at the spectrometer magnet, the relative energy spread at the slit is converted into transverse beam size spread at the monitor according to a 1:1 ratio. Two quadrupole magnets are placed immediately after the end of the DTL tanks to produce a parallel beam at the slit. The slit itself needs to be positioned as close as possible to the beginning of the line to avoid an energy spread blowup due to space charge effects which could impair the measurements at low energy. Finally, a third quadrupole is placed after the slit for optical enhancement, followed by a 0.8 m long bending magnet with ρ=1 m bending radius and a magnetic B field varying between 0.5 and 1 T. The results of end-to-end beam dynamics simulations for the three separate DTL tank cases are summarized in Table 1.

Table 1: Results of beam simulations of the spectrometer line. From left to right: average tank output energy, 2.2σ beam energy spread at the tank output, 2.2σ beam size at the monitor and energy resolution.

	W [MeV]	ΔW/W [%]	Δx [mm] I=65mA	resol. [keV/mm]
Tank 1	12.2	0.7	7.7	11
Tank 2	31.8	0.5	4.0	37.5
Tank 3	50.0	0.3	2.7	61

As shown by the last two columns, the performance of the scheme is rather satisfactory, though a 0.5 mm sampling monitor resolution might be needed to have better measurement sensitivity. The energy resolution per mm is also comparable to the precision that is required for the DTL tanks RF field and phase characterization at a 1%-1 deg level RF tolerance as specified in error studies [5]. The spectrometer diagnostics could hence complement TOF measurements when determining the RF set points. In conclusion however, despite a favorable assessment from the beam dynamics point of view, a few caveats remain on the suitability of such a beam diagnostics solution. Apart from cost considerations, the practicality of such an important installation for a temporary, movable bench is at present being evaluated, and has prompted a research into possible alternative solutions for comparison.

Cell-Coupled Drift Tube Linac (CCDTL)

The cell-coupled drift tube linac consists of a total of seven modules accelerating the beam from 50 to 100 MeV. Its commissioning is planned to take place as a whole, where the beam is characterised using the diagnostics installed in the linac for operation. Furthermore, additional devices installed in the beam line between the end of Linac4 and the beam dump can also be used. In operation, the CCDTL will be equipped with two wire scanners (after modules 2 and 6), two SEM grids (after modules 4 and 7) and pick-ups after each of the seven modules. At the exit of the CCDTL there will be a beam current transformer.

Pi-Mode Structures (PIMS)

The pi-mode structure linac consists of 12 cavities which accelerate the beam to the final energy of 160 MeV. For the PIMS we have foreseen a total of six pick-ups for measurement of position, intensity and phase after cavities 2, 4, 6, 8, 10 and 12. Measurement of the beam profile is accomplished by two wire scanners after cavities 3 and 9 as well as by two SEM grids after cavities 6 and 12. A beam current transformer at the exit of the linac provides an absolute measurement of the beam current. As the CCDTL, the PIMS will be commissioned using the diagnostics in the dump line.

Dump Line

The beam line between the exit of the PIMS and the linac dump houses a number of diagnostics. Most of the equipment is located in a "diagnostics box" at the exit of the PIMS, which houses a transformer, a SEM grid and a pick-up. Furthermore diagnostics for the transverse and longitudinal emittance is required. As for the longitudinal plane, this will be accomplished by the bunch shape monitor [4]. For the transverse emittance, various techniques are currently being studied. The beam line will also contain two pick-ups and a beam current transformer. The whole linac will hence be commissioned stand-alone.

Transfer Line and Booster Injection

A new transfer line will connect Linac4 with a part of the old Linac2 injection line. The transfer line will house a number of standard diagnostics tools according to Table 2. In order to characterise the beam emittance and energy before injection into the PS Booster, two existing measurement lines will be upgraded for Linac4 beam parameters. The Booster injection section is being redesigned for H^- injection. The region around the stripping foil will also require dedicated diagnostics. It is proposed to use a radiation hard camera to monitor the injected and circulating beam size on the foil; foil temperature surveillance is also desirable. The dump behind the foil should be segmented in 2 parts to allow separate measurement of the H^- and H^0 current via a resistance and will give an indication on potential foil degradation. View screens (VS) glued onto the dump will show the beam profiles. Matching could be optimized by installing SEM grids capable of multi-turn acquisition in the Booster ring; multi-turn acquisition is also a condition for the new pick-ups in the ring foreseen to measure the bump closure. Transformers and pick-ups will be used for beam current measurement and steering. In addition, beam loss monitors (BLMs) will be distributed along Linac4 and the transfer lines and installed preferably at positions with high dispersion, high potential losses and with a small aperture to beam size factor.

Table 2: Diagnostics Overview for Linac4 Operation

Section	PU	BCT	FC	SEM	WS	VS
Source/LEBT	-	1	1	1		
Chopper line		2			2	
DTL	3	1		1		
CCDTL	7	1		2	2	
PIMS	6	1		2	2	
Dump Line	3	2		1		
Transfer Line	15	11		4		2

SUMMARY

The diagnostics specifications and choices for the new CERN Linac4 have been driven by beam dynamics simulations. Error studies have been performed to identify the measurement precision needed as well as the optimum location of beam monitors with respect to the correction elements. The results have been used to specify the beam instrumentation adapted to the Linac4 needs and to integrate it into the overall machine lay-out.

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