THE SPL FRONT END: A 3 MeV H$^-$ TEST STAND AT CERN

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Abstract

In the frame of the SPL (Superconducting Proton Linac) study at CERN, a new 160 MeV proton injector for the CERN PS Booster is presently under development. This linear accelerator (Linac4) would not only be a first step towards a future, multi-MW superconducting linac, but would also improve in the medium term both the beam availability and beam quality for CERN's proton users. Within the framework of the Linac4 study and with the support of the EU funded Joint Research Activity HIPPI (High Intensity Pulsed Proton Injectors), a 3 MeV test stand is under construction at CERN. This test stand will explore some of the most critical issues of the linac, such as the beam dynamics at low energy, with special emphasis on the chopper line that has been designed to generate the required time structure of the beam, to clean the beam halo, and to match it to the subsequent RF structures. In this context, a new Beam Shape and Halo Monitor is under construction. The beam acceleration will be performed by an RFQ that is being developed in France within the IPHI collaboration between CEA and CNRS. Moreover, the test stand will be equipped with an additional 1 MW RF klystron to test different 352 MHz RF structures that are being developed for the Linac4.

INTRODUCTION

During the setting up of the LHC injector chain (Linac2-PSB-PS-SPS) it has been demonstrated that the intensity in the PS ring for the 25 ns LHC beam is limited to 1.5×10^{11} ppb, slightly more than nominal, mainly because of space charge effects at 50 MeV injection into the PS Booster (PSB). This is why the proposal has been made to build the low energy part (160 MeV) of the SPL and use it as an upgraded PSB injector, calling it Linac4 [1], [2]. The charge exchange injection that will be used in the PSB, combined with the higher injection energy, will substantially increase the intensity and brightness of the PSB beam. As a result, the intensity per bunch within the nominal transverse emittances is expected to reach 2.0×10^{11} ppb at the PS exit.

The technology and the beam dynamics issues at low energy, up to 3 MeV, are critical for the performance of Linac4, especially in its potential role as an SPL front-end. The halo formation mechanism has to be accurately studied and the techniques for chopping the beam with the appropriate time structure have to be validated. For these reasons a 3 MeV beam test stand is being built and installed in the position where it will later operate as the Linac4 front-end.

3 MEV TEST STAND LAYOUT

The 3 MeV test stand is designed to become the low energy part of Linac4. As a test stand, its main goal will be to validate the chopper line and to characterize the beam parameters and halo at low energy.

The preliminary layout is shown in Fig.1, integrated in the building where it will be assembled, the PS South Hall Extension.

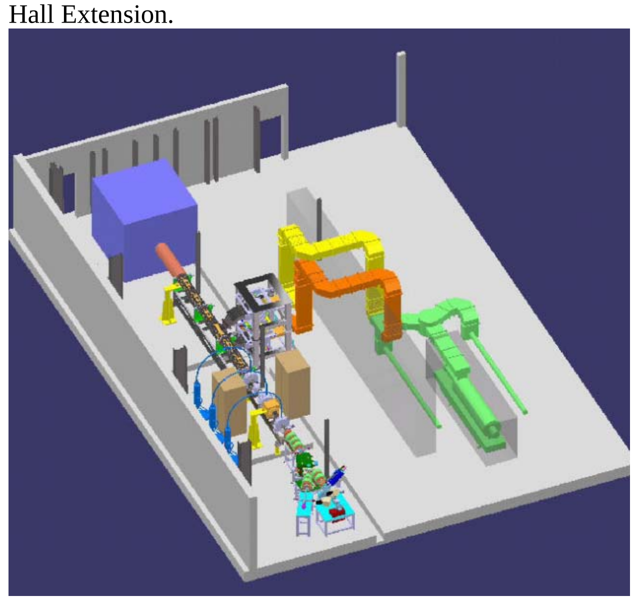

Figure 1: Layout of the 3 MeV test stand.

The test stand is composed of four areas, described below.

Ion Source and LEBT

A high intensity, high performance, micro-wave driven source is presently under development at CERN. It is designed for the requirements of the SPL, that can be considered as a long term development of the less demanding Linac4 H$^-$ source.

In Table 1 the parameters for the two cases are listed.

Table 1: Main H$^-$ source parameters

Parameter	Linac4	SPL
Instantaneous current	50 mA	>40 mA
Pulse length	0.5 ms	> 2.0 ms
Repetition rate	2 Hz	50 Hz
Extraction voltage	95 kV	95 kV
Duty cycle	1 ‰	15 %

The decision to develop a micro-wave driven source is based on the very satisfying operational experience with

ECR ion sources for heavy ions, especially in terms of reliability and life-time. Different magnetic structures for the source will be tested to maximize the H^- output. At present a multi-cusp structure is under investigation. Although the extracted current is very small (~300 μA), the influence of different source parameters (gas flow, RF power, RF tuning, bias of the plasma electrode, wall materials and additional gases) are being tested to get a better understanding of the H^- production. One of the next steps will be to redo the present tests with a solenoidal field structure. Based on the experience gained from these measurements a new source design will be made before the end of 2004. A test stand will be prepared for a prototype low energy beam transport (LEBT) equipped with a duoplasmatron proton source. The LEBT is based on a two solenoid structure and will contain some beam diagnostics, beam steering and possibly a pre-chopper.

Accelerator System

The core of the test stand is represented by a 6 m long RFQ that is being built within the framework of the IPHI collaboration between CEA and CNRS [3]. The RFQ has been designed to provide a continuous proton beam current of 100 mA for high intensity beam studies. After a one year test period at Saclay, this device will be made available for CERN to use for its new projects. In the 3 MeV test place and in Linac4, the RFQ will be operated at a 1/1000 duty cycle with 0.5 ms pulse length and 2 Hz repetition rate. In the SPL the duty factor will reach 15%.

The RF power source for feeding the RFQ will be a overhauled LEP klystron (352.21 MHz, 1 MW CW) that will be operated in pulsed mode. After some preliminary tests with the original LEP power supplies [4], it has been decided to develop a dedicated pulsed power supply. This will be done in collaboration between CERN and GSI, which also needs such converters to power the LEP klystrons of their future 70 MeV proton linac. According to the present terms of the agreement under negotiation, GSI will provide two HV pulsed power supplies, each capable of driving a 1 MW LEP klystron at full power with 0.7 ms pulse length and 2 Hz repetition rate. The first power supply will be delivered by the end of 2005 and the second by the end of 2006.

Chopper Line

The 3 MeV chopper line is meant to produce the beam time structure required by the different users and perform the delicate matching (transverse and longitudinal) between the RFQ and the DTL. In a high intensity machine, these two operations are crucial to maximize the beam transport and keep the beam losses along the accelerator at the lowest possible level. The line has been kept as compact as possible (3.7 m) and the chopper deflection structures are located inside quadrupoles. The two 500 mm long structures are made of a double meander stripline built on an alumina substrate [5]. With a drive voltage of ±500V between the two parallel meander lines, the chopped beam is deviated by 7 mrad. This results in a 2.0 cm separation between the beam centres at the beam dump, 1 m downstream from the last chopping cavity. The chopper driver must be very flexible and able to provide the required voltage excitation at a maximum repetition rate of 45 MHz, with a pulse length varying from 8 ns to 2 μs while keeping a 2 ns rise/fall time.

The transverse focusing is designed as a five-cell FODO structure and simulations show that a rather wide range of currents (from 20 mA to 60 mA) can be matched from the RFQ to the DTL.

The longitudinal matching of the beam from the RFQ output to the DTL input is assured by three buncher cavities, equally spaced, operating at 352 MHz. Two types of nose-cone equipped pillbox cavities, B30 and B40, have been designed, differing in beam aperture (30 mm for the B30 and 40 mm for the B40). Two B30 are placed at the beginning and at the end of the line, while the B40 is situated in the chopping region (and for this reason needs a larger aperture). A gap voltage of 140 kV is required for the B30s and 100 kV for the B40. Multi-particle simulations indicate transmission of the main beam as high as 98% and the chopped beam is eliminated to better than 0.02%. Under nominal conditions the computed longitudinal emittance growth is limited to 4% and the transverse emittance growth to 8%. Again, the simulations show that this chopper line is rather insensitive to misalignment of its component and that a positioning accuracy of 0.2 mm and 1 mrad is sufficient to achieve the required performance.

Diagnostics

In order to monitor the correct functioning of the chopper and to precisely measure the beam distribution in all three planes, a dedicated “Beam Shape and Halo Monitor” (BSHM) is being developed. This monitor has to fulfil two tasks: 1.) to measure the time structure of the beam and detect the remaining beam in chopped bunches down to 10^3 particles in the vicinity of a bunch populated with 10^8 particles; 2.) to provide a transverse image of the beam, allowing observation and study of the beam halo (diameter 4 cm, 10^3 particles/cm^2), and the beam core (diameter 1 cm, 10^9 particles/cm^2). The monitor is based on a thin carbon foil, which is inserted into the beam to generate secondary electrons. These electrons are accelerated towards a multi-channel plate (MCP), where they are transformed into light, which is transported via a fibre optics bundle to a CCD camera. Fast gating and a high-quality CCD camera provide the required dynamic range of 10^5-10^6. Further diagnostics will come from the IPHI installation and includes beam current transformers upstream and downstream of the chopper, as well as a set of devices following the chopper line, including a wire scanner, beam position monitors, pick-ups for beam energy measurement by means of the time of flight technique and a spectrometer magnet.

MEASUREMENT PROGRAMME

The purpose of the 3 MeV test stand is threefold. The primary goal is to validate the whole 3 MeV injector, including the chopper system, the second one is to study the beam dynamics in the line and verify the simulation codes, and the third one is to measure the real beam parameters at 3 MeV so that the design of the downstream accelerator can be optimised. After a series of "routine" measurements (transmission, energy and energy spread) during setting up, we will concentrate on characterising the chopper and the matching to a DTL.

Validation of the Chopper

The chopper system is composed of three elements: the chopper itself, which provides the kick to the beam; the quadrupole after the chopper structure, which magnifies the kick; and the dump which collects the deviated beam. Each component will be tested individually. The effective kick received by the beam will be measured on a screen downstream, with a pencil beam and the quadrupole switched off. Two spots will be observed, corresponding to the main and the chopped beams. In the absence of quadrupole, the distance between them is proportional to the effective chopper voltage. The current in the quadrupole will then be progressively increased until the second spot on the screen disappears; in this condition we will be sure that the centre of the chopped beam is on the dump and that the main beam goes through the line. The rise and fall times of the chopper will then be estimated with the BSHM, both for the pencil beam and for the full beam. At the end of that series of measurements, the chopper line itself as well as all its components will be fully characterised.

Beam Matching and Halo Studies

The transverse emittance will be estimated from a series of profile measurements at varying quadrupole strength and the longitudinal emittance will be derived from energy spread measurements at varying buncher voltages. This method should be applied carefully in presence of space charge. In our case [6], we can achieve accuracy of the order of 10%. This method will also provide a good estimate of the flexibility of the line to meet different requirements for matching at the entrance of the next accelerator. After having assessed the envelope properties of the beam we will make use of the 2D readout system of the BHSM to study the halo. The halo will be measured (shape and intensity) for various settings of the source, the RFQ and the line and the results will be compared to simulations. Finally these parameters will be used to optimise the performance of the collimation system.

PLANNING

The start of such a rich scientific program is foreseen in 2007, when the IPHI RFQ and diagnostic line will have completed their testing phase at Saclay under continuous beam conditions. To avoid interference with the work of LHC installation, the preparation of the test place has started early, in 2003, and the design phase will be completed in the first half of 2005. The fabrication of all the major components is advancing and should be finished by the end of 2005. In the meantime, during the second half of 2005, the technical infrastructure will be fully prepared and a first RF system will be installed in order to make tests of prototype RF structures in 2006. The integration of the 3 MeV test stand (SPL Front End) project into the Linac4 realization and the possible SPL construction is shown in Fig.2.

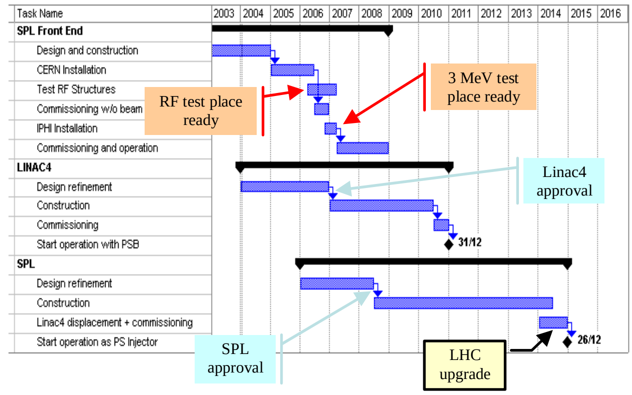

Figure 2: Integrated planning of the 3 MeV test stand (SPL Front End), of the Linac4 and of the SPL.

ACKNOWLEDGMENTS

The progress reported is the result of the commitment and enthusiasm of numerous scientific and technical contributors from many different teams at CERN, who managed to support this realization while fulfilling at the same time their responsibilities towards the LHC project. The active assistance and collaborative spirit of the members of the CEA-CNRS is also gratefully recognized. We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395).

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