SPL-based Proton Driver for a nu-Factory at CERN.

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Abstract
The conceptual design and feasibility studies for a nu-Factory Proton Driver based on the CERN Superconducting Proton Linac (SPL) have been completed. In the proposed scenario, the 4 MW proton beam (H- beam) is accelerated with the upgraded High Power (HP)-SPL to 5 GeV, stored in an accumulator ring and finally transported to a compressor ring, where bunch rotation takes place, in order to achieve the specific time structure. We here summarize the choices in terms of lattice, magnet technology and RF manipulations in the two rings. The possible critical issues, such as heating of the foil for the charge-exchange injection, space-charge problems in the compressor and beam stability in the accumulator ring, have been addressed and are shown not to be show-stoppers. The analysis focuses on the baseline scenario, considering 6 bunches in the accumulator, and preliminary studies are discussed for the option of 3 or a single bunch per burst.

1 Introduction

Following the specification of the International Scoping Study [1], the Proton Driver for a Neutrino-Factory must deliver multi-MW of beam power at a few GeV, with a small number of short bunches at a target where the intense muon beam is produced. The CERN–proposed scenario [2] is based on the Superconducting Proton Linac in its 5 GeV High Power version (HP-SPL) which can deliver 4 MW of beam power, thus 10^{14} protons at a repetition rate of 50 Hz [3]. Two additional fixed-energy rings are needed to transform the long linac pulse to the required time structure at the target. In the foreseen scenario, the H$^-$ beam from the HP-SPL is injected and stored in an accumulator for about 400 μs, to create the 6 (or 3)–bunch structure, and then sent to a compressor ring where longitudinal bunch rotation is applied to reduce the bunch length to 2 ns rms. The ratio between the two rings is such as to guarantee the correct positioning of the 3(2) bunches inside the compressor without energy changes.

The accumulator and compressor design for the baseline option, which assumes 6 bunches spaced by 12 μs per burst, is documented in [4]. A first analysis of a 3–bunches and 1–bunch scenario is reported in [5]. In the cited documents, the issues related to the H^- injection and the space charge in the compressor are also addressed, while the beam–stability studies in the accumulator are presented in [6].

2 Accumulator and compressor design

Figure 1 shows the lattice of accumulator and compressor for the 6–bunches scenario. The accumulator is designed to be isochronous, to freeze and keep the energy spread as small as possible, and no RF cavities are installed, to reduce the machine impedance. On the other hand, the compressor needs a large slippage factor and RF voltage to perform a rapid phase rotation. Table 1 summarizes the main parameters for the two rings. A transverse emittance of 3πmm mrad is defined by the competing issues of injection-foil heating, aperture and space charge, while the longitudinal parameters are set by the phase–rotation dynamics and the requirements at the target, leading to a momentum spread of 0.863×10^{-3} rms and a total bunch length of 120 ns before rotation. Variable chopping of the linac beam is used to obtain a flat profile, with smooth edges to minimize longitudinal space-charge effects.

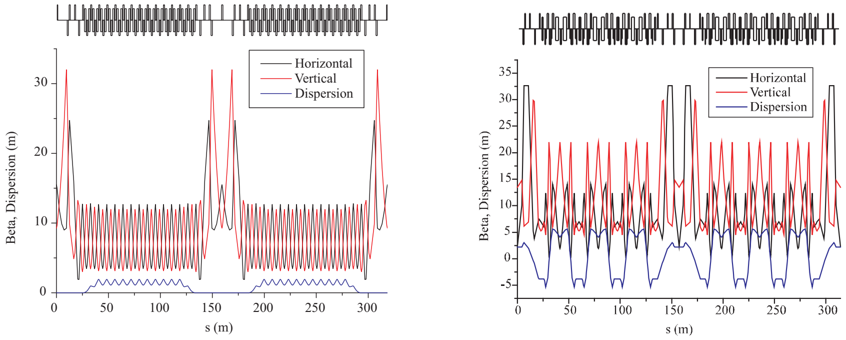

Fig. 1: Accumulator and compressor lattice for the 6–bunches scenario

Table 1: Main parameters

Parameters	6–bunches	3 / 1–bunches
Accumulator circumference (m)	318.5	185.8
No. of accumulation turns	400	640 / 1920
Accumulator transition gamma	6.33 (isochronous)	6.33 (isochronous)
Accumulator working point	(7.77, 7.67)	(7.37, 5.77)
Accumulator magnet type	NC	SC
Compressor circumference (m)	314.2	200
No. of compression turns	36	86
Compressor rf voltage (MV)	4	1.7
Compressor transition gamma	2.3	2.83
Compressor working point	(10.79, 5.77)	(4.21, 2.74)
Compressor magnet type	SC (bending)	NC
Output bunch spacing (μs)	12	30/-

3 Analysis of critical issues

In the charge-exchange injection process, a two–dimensional (H/V) painting is used to keep the maximum stripper-foil temperature below 2000 K. For the 1–bunch accumulation scheme, it is necessary to apply a moving vertical orbit bump to the H^- beam in addition to horizontal painting [4]. The minimum emittance achieved in this case is 5πmm mrad, instead of the nominal 3πmm mrad.

Figure 2 presents the results of ORBIT [7] simulations of the bunch rotation in the compressor. Transverse space-charge will be tolerable, partly because of the rapidity of the rotation and partly because of the horizontal beam size increase (thanks to the dispersion contribution) which keeps the Laslett tune shift small enough to avoid integer resonance crossing.

Transverse and longitudinal fast instability may be an issue in the isochronous accumulator, since the damping mechanism provided by synchrotron motion is not available. Analytical estimations and HEADTAIL [8] simulations indicates that they are under control. In particular, for what concerns the

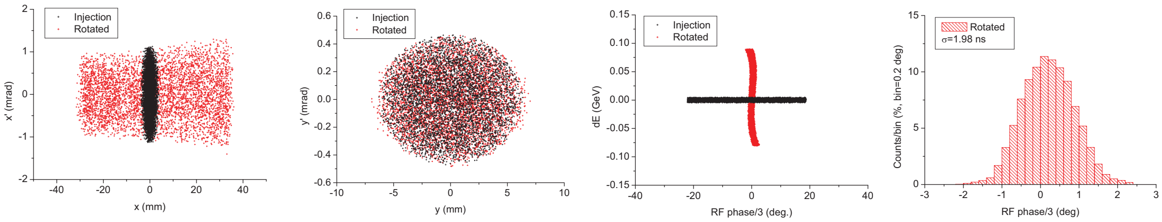

Fig. 2: Phase-space plots before and after the longitudinal bunch compression

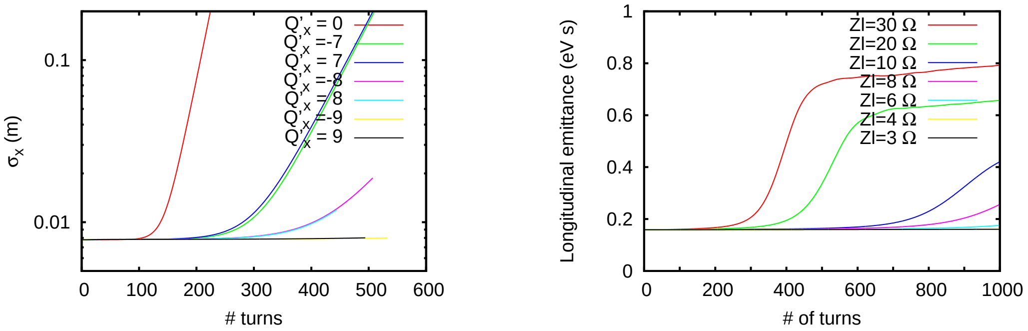

Fig. 3: Broad-band resonator impedance simulations. Left: Horizontal beam size evolution, for different values of chromaticity and a transverse impedance of 1 MΩ/m, Q_R=1, f_R=1 GHz. Right: Longitudinal emittance evolution for different values of longitudinal BB impedance.

machine impedance, the narrow-band component can be neglected due to the absence of RF-cavities and the resistive-wall is not considered an issue, since the rise-time τ ~8.2 ms is long compared to the accumulation time. Simulations were done for the broad-band (BB) component, with the pessimistic assumption of having full-intensity beam for the entire accumulation time. Figure 3 (left) shows the transverse beam size evolution for different values of chromaticity, considering a BB impedance of 1 MΩ/m, 1 GHz and $Q_R = 1$. A chromaticity of $|Q'|$=10, and, in general, a betatron tune spread of $\Delta Q \sim 0.02$ either from chromaticity or from octupoles detuning with amplitude, is enough to cure the instability. Threshold scales linearly with the impedance value. As shown in Fig. 3 (right), a longitudinal broad-band impedance value of a few Ω, easily achieved in modern machines, is tolerated. The electron-cloud related instability as well should not be an issue, due to the long and flat bunch profiles that are not favorable to the electron-cloud build up in the vacuum chamber. Same considerations and similar numbers are obtained for the 3-bunches accumulator. The 1–bunch scenario has not been studied in details, but one could assume values twice as much stringent, since the bunch intensity is double.

4 Conclusions

There is no show-stopper for a multi-MW proton driver based on a 5 GeV SPL delivering 6 or 3 bunches of 2ns rms length at 50 Hz. The single-bunch options is more challenging, although not impossible. A conceptual design is in hand, but the accumulator and compressor have to be designed in details, for what concerns RF system, beam–losses minimization, eventual collimators, injection and extraction systems.

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