# STATUS OF THE UPGRADE OF THE CERN PS BOOSTER

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*Abstract*

The CERN PS Booster (PSB) is presently undergoing an ambitious consolidation and upgrade program within the frame of the LHC Injectors Upgrade (LIU) project. This program comprises a new injection scheme for H- ions from CERN's new Linac4, the replacement of the main RF systems and an energy upgrade of the PSB rings from 1.4 to 2 GeV which includes the replacement of the main magnet power supply as well as the upgrade of the extraction equipment. This paper describes the status and plans of this work program.

## INTRODUCTION

In order to enable CERN's proton injector chain to deliver beams beyond today's specifications to the LHC and to operate reliably throughout its lifetime, CERN has put in place the LHC Injectors Upgrade (LIU) project [1]. In this framework the upgrade of CERN's 40-year-old PS Booster has been launched. It can be divided into two main activities: the upgrade of the Booster injection in order to enable the machine to inject 160 MeV $H^-$ ions from CERN's new $H^-$ linac (Linac4), and the energy upgrade of the Booster, its extraction and transfer lines to a top energy of 2 GeV. Work has started both in the fields of beam physics and machine studies, as well as on the design, manufacturing and commissioning of hardware. This paper reports on the results that have been achieved until present, installations planned during the first long LHC shutdown (LS1) and on-going studies and developments.

## RESULTS ACHIEVED DURING 2012 RUN

Constant optimisation of the LHC-type beams in the PSB has resulted in beam parameters in excess of the original specifications [2]. The intensity and normalised emittance values for the multi-bunch 50 ns and 25 ns beams as achieved in 2012 are given in Tab. 1 [3]. Studies and experimental work have also progressed in order to build up an optics model of the machine [4] and in order to evaluate the performance in presence of space charge [5].

On the machine hardware side the outstanding achievement in 2012 was the commissioning of the first cells of the new wideband RF cavities. With a set of 5 prototype cells 4.6E10 protons could be captured and accelerated [6]. The existing 2 MHz cavity was used in parallel to attain the full RF voltage required for acceleration. Figure 1 shows the Finemet® cells installed in Ring 4 of the PSB.

Table 1: Specified and Achieved Beam Characteristics for the Multi-bunch LHC-type Beams at PSB Extraction

| Beam | prot./bunch [$\times 10^{11}$] | $\varepsilon_{h/v}$ [$\pi$ mm mrad] | batches | bunches |
|---|---|---|---|---|
| 25 ns (spec.) | 2.4 – 13.8 | $\leq 2.5$ | 2 | 6 (4+2) |
| 25 ns (as in 2012) | 16 | 2 | 2 | 6 (4+2) |
| 50 ns (spec.) | 1.2 – 6.9 | $\leq 2.5$ | 2 | 6 (4+2) |
| 50 ns (as in 2012) | 12 | 1.35 | 2 | 6 (4+2) |

Figure 1: Prototype wideband cavity cells installed in Ring 4 of the PSB.

## INSTALLATIONS DURING FIRST LONG LHC SHUTDOWN

The first long LHC shutdown provides a time window for a number of hardware modifications and upgrades. Besides standard maintenance work, activities comprise a partial clean-up of old cables, renovation of a number of




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beam instrumentation systems, controls renovation, machine interlocks, modifications of the main magnet connections, upgrade of multipole power supplies, upgrade of the low-level RF and transverse feedback systems and installation of additional wideband cavity cells. In view of the future energy upgrade to 2 GeV, some modifications of the extraction septum are also planned. The main activity planned for LS1 is the exchange of the PSB dump, as the present one is inappropriate for beam parameters expected with Linac4 and 2 GeV. The dump design is simple and robust and aims at maintenance-free operation during a time span of approximately 25 years. The dump core is an air-cooled copper C18150 (CuCrZr) cylinder. Appropriate shielding has been designed and procedures for the removal of the old dump and the installation of the new dump elaborated [7].

## PREPARATIONS FOR NEW INJECTION SCHEME

A new injector for the PSB, a 160 MeV $H^-$ Linac (Linac4), is presently under construction at CERN [8]. It will replace the 50 MeV proton linac presently in use. The changes with regard to the present injection scheme are twofold: the increased injection energy requires a number of elements in the injection line to be upgraded or replaced, and the change from proton injection to charge-exchange injection requires a complete re-design of the injection period of the PSB.

### *Injection Line*

In the injection line notably the system employed to split up the incoming beam into the planes of the four Booster rings is being rebuilt. This system consists of the distributor, a system of five pulsed magnets, which give an initial deflection to the beam slices destined to the different rings, followed by a vertical septum, which further increases the deflection angle. Both devices will be replaced by new ones that can operate at 160 MeV beam energy. The hardware is presently under construction at CERN. Figure 2 shows the new distributor ready for installation.

Figure 2: New distributor ready for installation.

After the septum the stack of vertical dipole magnets which bend back the beams into the horizontal plane and two stacks of corrector dipoles have to be replaced. The stack of vertical dipoles has been ordered, and the correctors have been designed.

### *Injection Period*

The injection period of the PSB will be completely re-built for charge-exchange injection from Linac4 [9]. The horizontal injection septum, present main bottleneck and source of beam loss at injection, will be replaced by a stripping foil unit. Four chicane dipoles will generate the injection bump, and four painting kickers will provide horizontal phase space painting. In addition there are dumps for the partially stripped and unstripped ions, diagnostics and vacuum equipment. Figure 3 shows the PSB injection period modified for the new injection scheme.

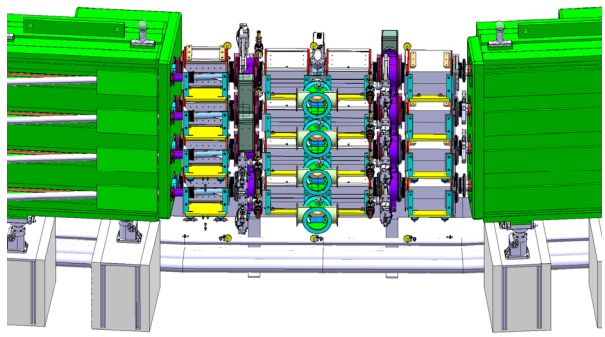

Figure 3: Injection period modified for injection of 160 MeV $H^-$ ions from Linac4. In-between two main dipole magnets there is a system of 4 chicane dipoles, with the stripping foil unit in its center. Every ring is equipped with its proper injection hardware.

The status of the new injection hardware is summarised below:

- Distributor: magnets ready, pulse forming network being tested.
- Vertical distribution septum: magnet design finished, sub components being manufactured; power converters being installed.
- Painting kickers: Ceramic chambers ordered, all other mechanical parts delivered and assembly of 1st magnet about to start; prototype power supply successfully tested.
- Chicane dipoles: magnet design on-going; generators being integrated.
- Stripping foil unit: development on-going.
- Diagnostics: conceptual design phase.
- Injection dumps: conceptual design phase.
- Vacuum system and integration well advanced.

## PREPARATIONS FOR 2 GEV UPGRADE

The upgrade of the Booster rings, extraction and transfer line to the Proton Synchrotron (PS) to a top

energy of 2 GeV is presently planned for the second long LHC shutdown (LS2), presently scheduled for 2018. Development of hardware is presently on-going in various areas.

### *Magnets*

The main magnets can operate at field levels corresponding to 2 GeV operation (30% above today's field levels). Some modifications on the main magnets connections are already being done during LS1. Further modifications of the cooling circuits, the shimming and the retaining plates are planned for LS2 at the latest, but could possibly be advanced to a shorter, intermediate shutdown. Saturation reduction studies and measurements are underway in order to reduce the differences between outer and inner rings which are already present at 1.4 GeV and will become more important at 2 GeV.

In the Booster to PS transfer line a preliminary estimate yields that about 20% of the magnets will need to be exchanged. In order for this figure to be confirmed and the hardware to be defined, the optics of the transfer line must be fully settled. Beam optics studies are presently on-going and a conclusion is expected for Q2 2013.

### *Power Supplies*

The existing main power supply (MPS) can neither provide the rms nor the peak current needed for operation at 2 GeV. An increase of the peak power using traditional thyristor technology would result in inacceptable perturbations of the 18 kV network. The design choice is therefore to use DC capacitors to store the energy for the pulsing load. Some civil engineering work is also required to house the new MPS.

In the extraction, recombination and transfer lines a number of power supplies have enough margins to operate in the new regime, while others need to be modified or replaced.

### *RF Systems*

The renovation of the low-level RF system of the PSB is planned to be completed during LS1.

The baseline choice for the high-level RF system is the replacement of the present h=1 and h=2 systems by wideband Finemet® cavities [6]. During 2013 five more cells will be installed in ring 4 which will bring the available RF voltage up to 7-8 kV. The system will then be used with beam throughout the 2014 and 2015 run periods in order to make the final decision on the complete exchange of the RF cavities by mid-2015. In case of a positive outcome, the hardware will be produced as from 2016 and the full replacement of the present h=1 and h=2 cavities by Finemet® cavities will take place during LS2.

### *Extraction and Recombination*

While the extraction bump kickers are able to operate at 2 GeV, the present extraction kickers have been identified as equipment that needs to be replaced by a new design. The extraction septum can operate with modifications on the cooling and interconnections, which are planned already for LS1. In the recombination line, where the four rings are merged to a single beam line, the existing kickers can remain unchanged while the septa need to be replaced by longer ones.

### *Beam Instrumentation*

A large program to renovate the beam instrumentation has been launched. While most items are either consolidation of ageing equipment or related to the setting up of the charge-exchange injection, the pure energy upgrade is mostly transparent in terms of beam instrumentation.

## SUMMARY

The upgrade of the CERN PS Booster is a major work program, which comprises the complete reconstruction of the injection line and the injection region as well as the upgrade of the Booster rings, extraction and transfer lines to 2 GeV. Work is constrained by the long LHC shutdowns and only very limited work can be done during the long operation periods in-between. Significant work is already on-going, and design and manufacturing of components is in progress. The upgrade program is presently planned to be fully implemented during LS2.

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