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STUDY OF AN ENERGY UPGRADE OF THE CERN PS BOOSTER

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Abstract

CERN's LHC injector chain will have to deliver beams with ultimate brilliance as the LHC is heading for increased luminosity in the coming years. In order to overcome bottlenecks in the injector chain, an increase of the beam transfer energy from the CERN Proton Synchrotron Booster (PSB) to the Proton Synchrotron (PS) has been investigated as a possible upgrade scenario. This paper gives an overview of the technical solutions and summarizes the conclusions of the feasibility study.

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INTRODUCTION

One of the outcomes of the 2010 Chamonix workshop [1] was that an increase of beam energy of the existing CERN PS Booster from 1.4 GeV to about 2.0 GeV would ease injection of high intensity and high brilliance beams into the PS [2], and thus help removing bottlenecks in the injector chain. The PSB is a machine composed of four superimposed synchrotrons which was commissioned in 1972. It has already undergone several upgrades during its life time. Given that consolidation of the ageing machine would be required anyway to allow for reliable operation throughout the lifetime of the LHC, the question was raised whether such an energy upgrade could be done, and what resources would be needed in addition to the consolidation program. The task force set up immediately after the workshop has tried to cover the complete accelerator hardware and all aspects of operation, in order to obtain an as complete picture as possible of the technical modifications that would be needed and the impact in terms of resources. The task force was also mandated to evaluate the time lines of such a potential upgrade, taking into account that work in the injectors would be constrained by the long LHC shutdowns.

The findings of the working group have been published in [3]. In the following sections the areas with significant impact will be addressed in detail.

EXPECTED PERFORMANCE GAIN WITH 2 GEV

There is a general consensus that increasing the beam energy will facilitate injection of high intensity beams into the PS. The gain can be quantified by looking at the formulas for the space-charge induced tune spread [4]

$$\Delta \mathrm{Q_x} = \frac{R_p N_b}{2\pi^{3/2}\gamma^3\beta^2\sigma_z} \oint \frac{\beta_x(s)ds}{\sigma_x(s)[\sigma_x(s)+\sigma_y(s)]} \quad (1)$$

and

$$\Delta \mathrm{Q_y} = \frac{R_p N_b}{2\pi^{3/2}\gamma^3\beta^2\sigma_z\sqrt{\varepsilon_y}} \oint \frac{\beta_y(s)ds}{\sigma_x(s)+\sigma_y(s)} \quad (2)$$

Injection at 2 GeV lowers the space charge effect by a factor $(\beta\gamma^2)_{2GeV}/(\beta\gamma^2)_{1.4GeV}$ = 1.63. That is, keeping the same space charge tune spread as present, about 65% more intensity could be injected. Equations (1) and (2) contain also terms $1/\sigma_z$, which means that keeping the longitudinal emittance at the present values the bunch length would decrease which would limit the above quoted gain to about 40%. However, as the PS bucket size will increase at 2 GeV, it is believed that one can allow for larger longitudinal emittance and thus compensate for this effect. Another knob to further increase the injected intensity would be to accept a larger transverse emittance, but recent requests from the LHC for low-emittance beams led us to discarding this option.

In summary, from theoretical arguments the gain in injected intensity is expected to be at least 65%.

IMPACT OF ENERGY INCREASE ON BOOSTER EQUIPMENT AND SYSTEMS

Magnets

The natural first question to be asked is if the Booster main magnets can achieve the field levels required for operation at 2 GeV. Interestingly, the magnets have been sufficiently over designed such that this is not an issue. A concern was however whether mechanical stress would become an issue when pulsing the magnets permanently with 2 GeV cycles. In order to address this issue, a stress test has been performed where a spare magnet has undergone 5000 cycles at a field level corresponding to twice the one at 1.4 GeV (see Figure 1). No degradation of the magnet was found [5]. However, some minor mechanical modifications needed to be implemented before going to high field levels.

Another issue was that the saturation of the outer rings increases even more than it is already the case at 1.4 GeV.

This issue could be satisfactorily solved by changing the present solid retaining plates by laminated ones.

Furthermore, the present water cooling system is insufficient. The requirements on the magnet cooling depend essentially on the magnetic cycle. It was managed to design a 2 GeV cycle where the r.m.s. current remains within 10% of the present one [6]. By staying within this limit it turns out that only minor modifications to the cooling circuits will be required which can be carried out in situ. A higher r.m.s. current would have necessitated a more severe revision of the magnet cooling, which would have probably required removal of the main magnets from the tunnel.

Apart from the main magnets there are a number of auxiliary magnets to be considered. They are mainly used at injection energy and not considered to be an issue. However the study is to be completed. As for the transfer line to the PS, about 15 to 18 out of the 59 magnets will need to be changed. Before this figure can be confirmed, the optics study of the transfer line needs to be completed, which in turn depends on the re-design of the PS injection region (see below). Furthermore the PS injection bumpers and a number of low-energy correctors and quadrupoles need to be checked.

Figure 1: Booster main magnet undergoing tests for operation at 2 GeV.

RF System

The complete renovation of the Booster high level and low level RF is planned in the frame of the consolidation program. On the low-level side this consolidation will include the transverse damper and the RF cables. The main part of the RF consolidation will concern the high-level systems.

Beam Intercepting Devices

The Booster dump has been subject to investigations since the question came up whether it would support beam intensities expected with Linac4. The option to dump these beam intensities at an energy of 2 GeV came then as an additional constraint. It became clear that the present Booster dump needs to be replaced by one adapted to the expected beam parameters, and that a spare dump is needed. This activity is covered by the consolidation project and is well under way. Removal of the existing dump is being planned with participation of the radiological protection group.

A second intercepting device which potentially needs replacement is the beam stopper in the transfer line to the PS. It remains to be confirmed whether it can operate at 2 GeV beam energy. If this is not the case, a new design and production of two units will be required.

Power Converters

The biggest impact of a 2 GeV upgrade would be for the power converters, notably the Booster Main Power Supply (MPS). The present Booster MPS can neither deliver the r.m.s. nor the peak current required for 2 GeV operation. The present 1.4 GeV is a hard limit, and the present MPS cannot pulse at any higher value than that.

Increasing the peak power using traditional thyristor technology would have an unacceptable effect on the electrical network. Therefore, it is proposed to replace the MPS by a POPS-type [7] power supply using a capacitor bank (Figure 2). The available voltage increases and would allow for faster ramping, thus reducing the r.m.s. current. The capacitor bank totally absorbs the peak power. This would at the same time allow dividing the machine into two circuits (inner and outer rings) thus making the trim power supplies used for rings 1 and 4 obsolete. The new main power supply would require a new building for which a location has already been identified. Apart from the MPS a number of smaller power supplies cannot operate at 2 GeV and need to be replaced.

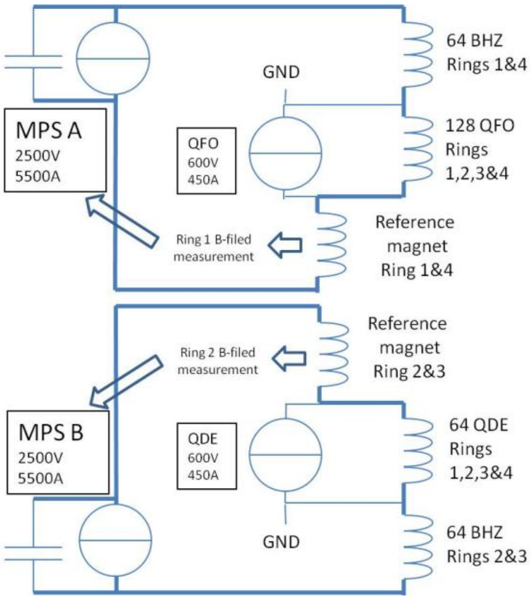

Figure 2: Lay-out of new POPS-type main power supply.

Extraction, Transfer and PS Injection

A number of extraction elements can operate at 2 GeV without modifications. However, notably the extraction kickers and recombination septa need to be re-designed and re-built. Some other elements, like the extraction septum, would require modification (re-inforcement of the cooling).

A critical issue is the PS injection septum. The septum would need to be replaced by a longer one for 2 GeV injection, which in turn requires the whole PS injection region to be re-designed. A solution has been found where the injection point remains in PS straight section 42 (SS42) as presently the case. The PS injection kickers have been confirmed to work for low-intensity beams at 2 GeV if operated in short-circuit mode. This will result in a small, but acceptable emittance growth [8]. An additional kicker and modifications to the transfer line are needed to inject also high-intensity beams [9].

Electrical Systems

The present power consumption of the Booster is around 10 MVA. The main consumers of electrical power are the power converters and the cooling and ventilation systems. As for the power converters, an increased request of about 100% is expected for the transfer line power supplies, which will be compensated by a 25% decrease estimated for the new MPS. For the cooling and ventilation systems, the required electrical power will be 15-20% above the present one. There is no more power available from the transformers for general services, and the 18 kV "cubicles" cannot be extended. Furthermore the whole electrical system on the Meyrin site needs consolidation. A re-design has started, which includes the increased power needs of a 2 GeV Booster in the frame of a global re-design of the electrical network on the Meyrin site.

Cooling and Ventilation

As for the electrical network, the future design of the cooling system will depend on the needs, mainly the ones of magnets, power converters and RF. So far there is no evidence for any increase in the cooling needs. Therefore, a refurbishment of the cooling station and some distribution piping is considered sufficient.

As for the ventilation system, no specific needs have been identified. Therefore a complete refurbishment of the existing plant, while keeping the same functionalities, is planned. However, new buildings (e.g. the one for the new MPS) need to be included. Furthermore RP aspects need to be considered when the ventilation system is refurbished.

RESOURCES AND TIME LINES

The resources in terms of budget and manpower have been detailed and published in [3].

The time lines of the upgrade project are constrained by the long LHC shutdowns. While the exact dates and durations of the long LHC stops are still under discussion, it remains our goal to complete the upgrade and re-commission the Booster during the second long LHC shutdown.

CONCLUSIONS

We have confirmed that an upgrade of the CERN PS Booster from the present beam energy of 1.4 GeV to 2.0 GeV would be beneficial for the production of LHC-type beams with ultimate specifications, as well as for the fixed-target physics program.

We have found that there are no technical show stoppers to do such an upgrade. In particular the main magnets can withstand the higher field levels with only minor modifications. We have however identified equipment that needs to be changed, in particular the main power supply and a number of extraction elements. Provided the project is launched rapidly, it can be completed by the second long LHC shut-down.

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