CERN-ACC-2014-0243

Thomas.Kramer@cern.ch

Upgrade of the SPS Injection Kicker System for the LHC High Luminosity Operation with Heavy Ion Beam

T. Kramer, J. Borburgh, B. Goddard, L. Ducimetière, L. Sermeus, J. Uythoven, F.M. Velotti
CERN, Geneva, Switzerland

Keywords: LHC, HiLumi, MKP

Abstract

In the context of the LHC High Luminosity Upgrade project a performance upgrade for heavy ions is envisaged. One of the performance limitations is the rise time of the present SPS injection kicker system MKP. A reduction of the rise time for lead ions was studied in line with a modification of the whole injection system. This paper briefly describes the different rise time options studied for an initially proposed dedicated ion kicker system MKP-I, focuses however on a cost effective alternative using the presently installed 12 MKPS magnets connected to a new fast pulse forming line. As only 12 out of the 16 injection kicker magnets would be fast enough to be used in an upgraded system, additional deflection has to be provided by the septa. The beam optics for that variant is highlighted and first requirements for the septum elements are stipulated. The paper concludes with a failure analysis of the proposed scheme.

Presented at: IPAC14, 15-20 June, Dresden, Germany

Geneva, Switzerland
October, 2014

UPGRADE OF THE SPS INJECTION KICKER SYSTEM FOR LHC HIGH LUMINOSITY OPERATION WITH HEAVY ION BEAM

T. Kramer, J. Borburgh, B. Goddard, L. Ducimetière, L. Sermeus, J. Uythoven, F.M. Velotti,
CERN, Geneva, Switzerland

Abstract

In the context of the LHC High Luminosity Upgrade project a performance upgrade for heavy ions is envisaged. One of the performance limitations is the rise time of the present SPS injection kicker system MKP. A reduction of the rise time for lead ions was studied in line with a modification of the whole injection system. This paper briefly describes the different rise time options studied for an initially proposed dedicated ion kicker system MKP-I, focuses however on a cost effective alternative using the presently installed 12 MKPS magnets connected to a new fast pulse forming line. As only 12 out of the 16 injection kicker magnets would be fast enough to be used in an upgraded system, additional deflection has to be provided by the septa. The beam optics for that variant is highlighted and first requirements for the septum elements are stipulated. The paper concludes with a failure analysis of the proposed scheme.

INTRODUCTION

It was identified and outlined in [1] that injection into the SPS will be one of the various limitations towards increased peak luminosity for ions in the LHC. The proposed baseline was to inject ion batches into the SPS with a batch spacing of 50 ns requiring a very fast and new 50 ns injection kicker system. As this would mean increasing the present system performance by more than a factor three beyond existing technology frontiers, a complex and challenging rework of the existing injection layout and equipment had to be studied [2]. The studies concluded to further investigate the feasibility of a dedicated 50 ns ion injection kicker system (MKP-I).

The existing injection scheme in the SPS (Fig.1) uses four MSI septum magnets, twelve MKPS (145 ns rise time) and four MKP-L (225 ns rise time) kicker magnets as well as an injection dump TBSJ [3] and thus currently only allows for a batch spacing of 225 ns.

MKP-I STUDIES

Studies were performed to investigate the feasibility of a 50 ns injection kicker system for ions [4]. The following constraints had to be considered:

- Injection of 17.1 Gev/c/u Pb^{82+} batches (200 ns) with 50 ns batch spacing using the available PS to SPS transfer line. The required rise time is therefore 50 ns and defined as 10%-90% with the aim to use the transverse damper system to damp any injection oscillation due to the 10% mismatch;
- The proton injection system should stay available independently;
- Only a limited contribution to the machine impedance budget is acceptable.

Due to the demanding rise time requirements only a fast transmission line kicker system with short magnets connected to a pulse forming line (PFL) was considered. The magnet was designed in an “open C” shape in order to allow that non-kicked beam can pass to the ion dump and to retract the magnet for proton operation to improve the machine impedance.

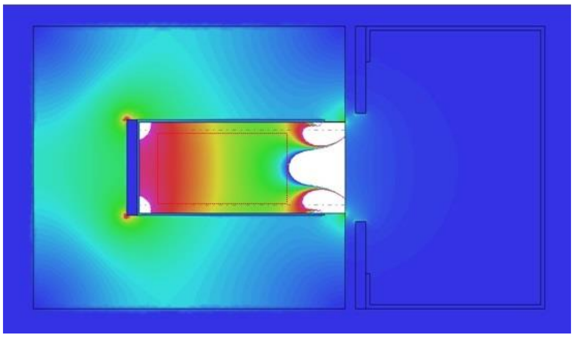

Figure 2: MKP-I simulated B-field with indicated good field region (red line). White areas are outside ±0.5%.

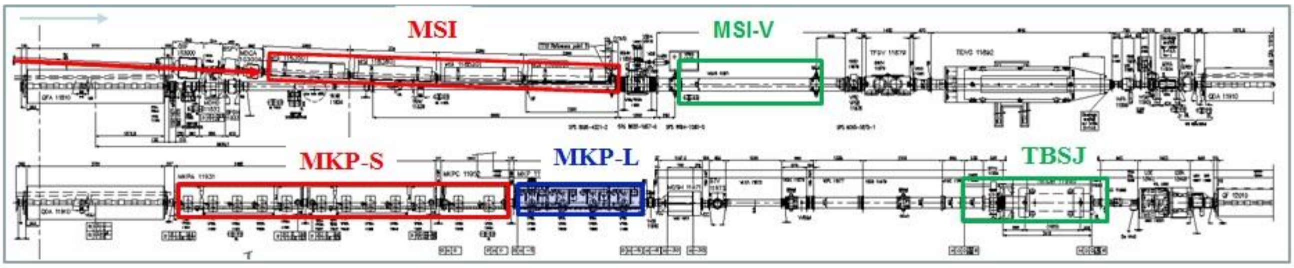

Figure 1: SPS LSS1 injection line Layout: Present: MSI, MKP-S (red) and MKP-L (blue); Proposed ion Layout: MSI (red), MSI-V (green), MKP-S (red) and TBSJ (green).

Preliminary finite element calculations have been performed to verify the ferrite yoke saturation and the field uniformity in the requested good field region (Fig.2). Whilst there is no evidence of saturation in the yoke the open C shape impacts on the field quality. Two 1 mm high “noses” had to be introduced to establish the ±0.5% field quality over the required good field region (hor.: -40 mm/+30 mm vert.: ±17 mm).

PSpice simulations of the magnetic field for a 50 Ω 5 cells magnet are shown in Fig. 3 and summarise in Table 1. Detailed system analysis showed that the rise time has to be even smaller (40 ns) due to a finite bunch length (5 ns) and an up to 5 ns jitter from Thyratrons and electronics.

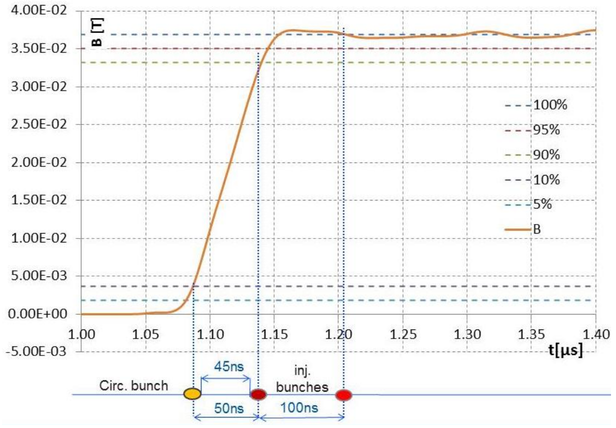

Figure 3: Simulated B-field for a 50 Ω 5 cell magnet.

It transpired that at the 10% (respectively 90%) point in the ramp up of the magnetic field the change in field seen by the bunch over its 5 ns length is not negligible and might contribute to instabilities. Also the present transverse feedback system can only damp oscillation amplitudes in the range of 10% with substantial emittance blow up and it is not optimised to handle head-tail oscillations. Subsequently it was necessary to redefine the rise time definition to a 2% to 98% value which again increased the challenge for the kicker system rise time.

An iterated version with increased aperture was studied considering the additional beam impedance added by the integration of almost 5 m new kicker magnets to the SPS. Whilst the increased aperture improved the situation impedance wise, the introduced ceramic plate with a 30 nm Ti-coating did not yield the desired effect. A thicker coating was at that stage of the study not further considered, as it would perturb the field too much during ramp up. It was concluded that no feasible solution for a 40 ns (2%-98%) system could be ensured, even with investing major R&D efforts. An intermediate alternative was chosen instead, using the existing (faster) MKPS magnets together with a faster Pulse Forming Line (PFL) in parallel with the presently installed Pulse Forming Network (PFN). The PFL solution would allow to improve the rise time to 100 ns (2-98%) at relatively moderate costs.

NEW PFL FOR MKPS MAGNETS

The required flat top for Pb-ions will be much shorter than for protons thus allowing the existing shorter (faster) MKPS magnets to be powered via a PFL providing a kick of ~2 mrad and a rise time of 100 ns (2-98%). Dedicated ion injection septa are needed to compensate the missing kick angel of the not used MKPL magnets. No new machine impedance from kicker magnets will be added.

Table 1: Injection System Parameters for B$\cdot\rho$=60 Tm.

	MKP-I	**MKPS/PFL**	**MSI-V**
Impedance [Ω]	50	16.67	-
Rise time [ns]	46 (10-90%)	100 (2-98%)	10^{-5}
Voltage [kV]	65	40	0.2
Current [kA]	1.3	1.2	28.2
Vert. gap [mm]	44	61	60.4
B-Field [T]	0.037	0.025	0.586
Total length [m]	4.25	9.2	2.5
Deflection [mrad]	1.33	2	13

PSpice simulations have been carried out and show that a fast rise time of 100 ns (2-98%) is feasible using the present MKPS magnets (16.67 Ω) connected via the present cables (six 50 Ω RG220U in parallel) to a PFL (six parallel cable drums). The PFL will be charged by a Resonant Charging Power Supply (RCPS) and discharged using a CX1175 Thyratron switch. Figure 4 shows the simulated pulse with a 2-98% rise time of 94 ns but an undershoot of 5% is present. The injected batch, indicated by the orange and yellow dot would not be affected provided the bunch spacing at injection remains at 100 ns. The circulating beam profits from the 5 ns faster rise time by seeing a residual field far below the specified 2%, also the field change over the 5 ns bunch length is minimized regarding all three affected bunches.

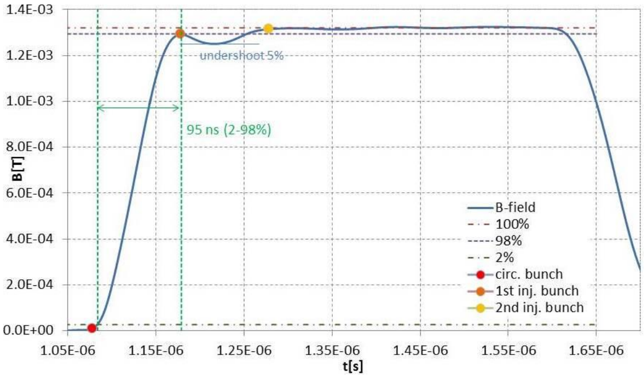

Figure 4: B-field of MKPS magnets connected to a PFL.

FEASIBILITY OF NEW ION INJECTION LAYOUT WITH PFL DRIVEN MKPS

The new ion injection layout (Fig.1) comprises not only the present MKPS connected to a PFL but also requires the already installed magnetic septa MSI and new ion septa MSI-V to compensate for the missing kick from the MKPL kicker magnets. A new ion injection dump with an additional BTV in front is also required [5].

Beam Optics

The beam trajectory for the new ion injection system (Fig. 5) will be substantially different. In order to keep the required deflection from the kicker system as low as possible, the MSI-V will provide 13 mrad additional deflection. In addition a closed orbit bump (using three existing correctors) is introduced. The horizontal acceptance of the injection region was checked by applying random static and dynamic errors to the main active elements showing that the minimum acceptance for the injected ion beam is located as expected at the exit of the MSI-V (5.0σ). Considering the largest injected SPS beam (ε_x = 12 π.mm.mrad), the limitation introduced by the MSI-V is not critical. The smallest aperture in the injection channel will remain at the existing MSI (~3σ).

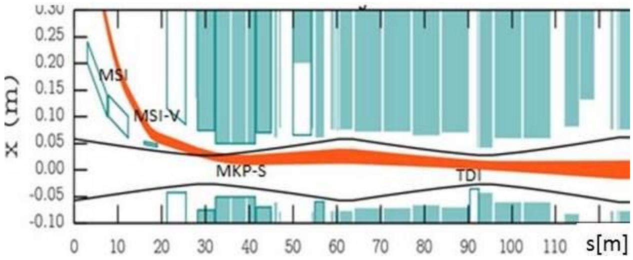

Figure 5: Apertures and beam envelope (orange).

Injection Kicker System Integration

The presented concept does not require any changes to the injection kicker magnets nor their layout in the tunnel. The only changes to be made are in the surface building (BA1): a PFL, its main switches and an impedance preserving changeover switch have to be added as well as the associated controls system upgrade.

Septa

To investigate the feasibility of the injection concept preliminary studies on the MSI-V have been carried out. Fig. 6 shows the integration of two refurbished PSB to PS under vacuum septum magnets (5 mm septum thickness) accommodated in a newly designed tank located in front of the internal dump TIDVG.

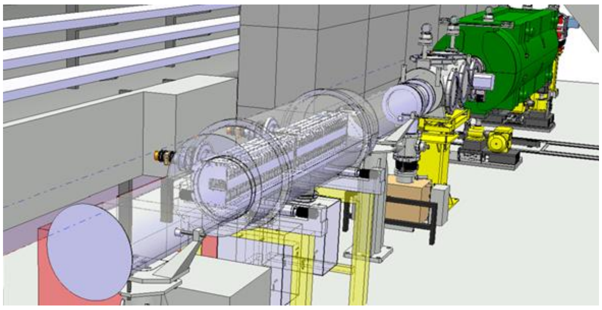

Figure 6: Integration view of the new MSI-V septa.

The MSI-V will provide a 13 mrad deflection, be powered by MegaDiscap generators and operated in pulsed mode. Integration and the radiation hardness of the components will be the main challenges.

Transverse Damper

The SPS transverse damper system will be required to damp injection oscillations thus keeping the emittance blow up small. Preliminary studies showed that for a 2% amplitude mismatch efficient damping could be provided but requires an ion-specific upgrade of the low level electronics.

FAILURE ANALYSIS

Four different failure scenarios have been analysed: MKPS kicker not firing; main magnet failures in the transfer line; MSI-V failures and MSI failures. In case of MKPS failures, p^+ beams are still safely dumped on the TBSJ; however a new absorber block to dump non-kicked ion beams is required.

Due to its low stored energy (0.06 MJ), the ion beam does not represent a threat to the injection elements. Proton beam however might seriously damage the MSI-V in case of MSI failures. MSI currents between 75 and 95% of the nominal value may lead to a direct impact of the FT-beam onto the MSI-V. Hence, a failsafe interlocking of the MSI current is mandatory.

CONCLUSION

Detailed studies have been performed to evaluate the feasibility of a 50 ns injection kicker system for Pb-ions in the SPS. The developed solutions could just satisfy the 50 ns (10-90%) requirement, however it would result in a significant emittance blow up during injection. Feasibility studies for an even faster system avoiding this disadvantage would need major R&D efforts. An alternative is outlined to upgrade the pulse generators for the existing MKPS kickers to reach 100 ns. This solution requires an additional MSI-V septum and ion inj. dump and the development of an impedance preserving switch between the pulse generators.

REFERENCES

[1] D. Manglunki et al., “Plans for the Upgrade of CERN’s Heavy Ion Complex”, Proc. IPAC13, Shanghai, May 2013, p.2645 ff.

[2] B. Goddard et al., ”A new Lead Ion Injection System for the CERN SPS with 50 ns Rise Time”, Proc. IPAC13, Shanghai, May 2013, p.398 ff.

[3] J. Uythoven, “The New SPS Injection Channel”, proc. Chamonix Workshop IX, Chamonix, 1999.

[4] T. Kramer et al., “MKP-I Kicker System: Design and Feasibility”, LIU-SPS 50ns Injection System for Pb Ions Review, CERN, October 2013.

[5] T. Kramer et al., “New ion injection system in the SPS”, LIU-day 2014, CERN, April 2014.