CONSIDERATIONS ON THE FAST PULSED MAGNET SYSTEMS FOR THE 2 GEV BEAM TRANSFER FROM THE CERN PSB TO PS

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Abstract

Under the scope of the LIU project the CERN PS Booster to PS beam transfer will be modified to match the requirements for the future 2 GeV proton beam energy upgrade. This paper describes considerations on the PSB extraction and recombination kickers as well as on the injection kicker(s) into the PS. Different schemes of an injection into the PS have been outlined in the past and are reviewed under the aspect of individual transfer kicker rise and fall time performances. Recent measurements on the recombination kickers are presented and subsequently homogenous rise and fall time requirements in the whole PSB to PS transfer chain are discussed. New options for the PS injection kicker(s) are outlined and compared to the previously presented concepts.

INTRODUCTION

CERN's accelerator complex is undergoing a massive upgrade program in the framework of the LHC Injectors Upgrade (LIU) project [1]. In the CPS complex the Proton Synchrotron Booster (PSB) will see an energy upgrade to 2 GeV to enable the limitation in intensity due to the space-charge tune shift in the PS to be overcome [2]. The extraction systems of the PSB, the recombination beam lines and beam transfer elements, as well as the injection system of the PS will all need to function at the new higher beam energy. At the same time, the rise and fall times of the kickers must be compatible with the required bunch lengths and filling schemes for future HL-LHC beams, and with the specifications to reach the present performance for the existing 1.4 GeV beams for fixed-target users in the PS complex and the SPS. Table 1 gives an overview of the basic machine parameters.

Table 1: PSB and PS Main Beam Parameters

Parameter	Present	LIU upgrade
Beam energy [GeV]	1.4	2.0
Beam rigidity [T.m]	7.14	9.28
PSB t_{rev} [ns]	571	552
PS t_{rev} [ns]	2286	2210

Considerations on the Kicker Rise Times

The kicker rise/fall times (along with gap field) are key parameters, and affect strongly the technical choices, cost and performance of the planned upgrades, plus the overall feasibility and risk. The bunch lengths and gaps between bunches in the two machines are a function of the harmonic numbers, of the beam momentum and also of the beam type (intensity and longitudinal emittance/RF voltage). To alleviate the space charge limitations in the PS, the LHC type beams will be transferred at 2.0 GeV with the maximum possible bunch lengths and imposes together with the machine harmonic numbers the kicker rise and fall times. Table 2 shows an overview of the individual requirements for the involved kicker systems.

PSB EXTRACTION

The four BE.KFA14L1 kickers (one per ring) eject the beam from the PSB. The rise time must be short enough to fit into the shortest gap between the two longest bunches which is 105 ns for operation with PSB harmonic number 2 and PS harmonic numbers 7 or 8. Note that the PS harmonic number determines this shortest gap, and not the PSB one.

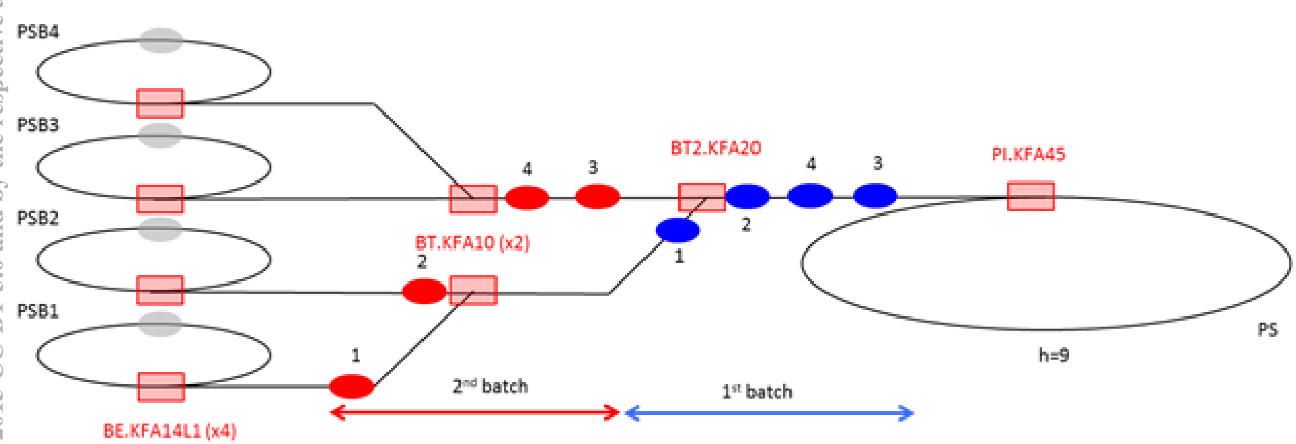

Figure 1: Schematic of beam transfer between PSB and PS, illustrated for the HL-LHC BCMS scheme [3].

Table 2: Kicker Requirements [3]

Parameter	KFA14	KFA10	KFA20	KFA45
1.4 GeV t_r/t_f (2-98%) [ns]	104	104	104	104/ 116
2.0 GeV t_r/t_f (2-98%) [ns]	105	105	105	105/ 105
Flat top length 1.4/ 2 GeV [ns]	456/ 447	456/ 447	1120/ 1078	1120/ 1078
Max. ripple [%]	±2	±2	±2	±2
Max. B.dl [T.m]	0.073	0.082	0.052	0.041
Magnetic length [m]	1.76	1.548	1.548	0.884

The extraction kicker fall time is not constrained. The installed KFA14L1 system basically provides the required rise time and can be run at 2 GeV which will require an increase in voltage from 42.5 kV to 55 kV. However, the subsequent increase in the magnetic field raises the question if saturation effects might become visible. Dedicated measurements have therefore been executed in the lab (Fig. 2) which do not show any evidence of saturation.

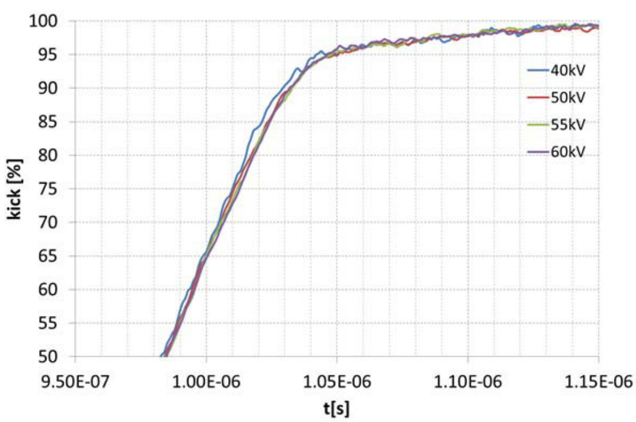

Figure 2: Measured BE.KFA14 L1 pulses: the curves show the normalized kick strength for voltages up to 60 kV. No saturation effects are visible.

PSB TO PS TRANSFER

The BT2.KFA20 and BT.KFA10 kickers recombine the four PSB rings into a single beam line (Fig.1). For the present operation scheme fall times are not critical but might be important for operation schemes where double pulsing is required. The KFA10 system consists of two 12.5 Ω delay line magnet modules (23 cells) pulsed in parallel with each pair of served booster rings. As for the KFA14L1, the operational voltage will be increased from 42.5 kV to 55 kV for 2GeV operations. The KFA10 2-98% kick rise time has been measured as 121 ns (Fig. 3) and exceeds the specified time of 105 ns. Studies will be required to optimize or possibly modify the existing system rise time. The KFA20 magnets are very similar to the KFA10 but part of a longer PFL.

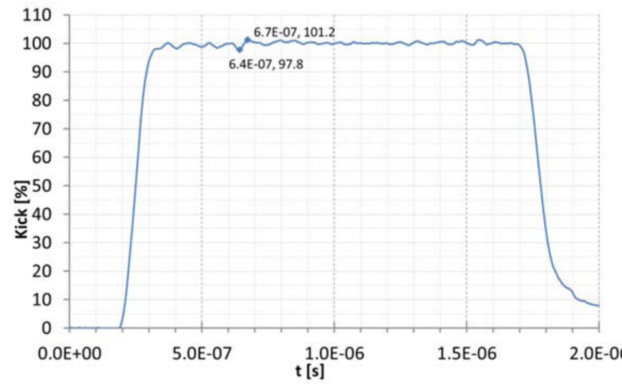

Figure 3: Measured BT1.KFA10 pulse: Blue curve shows normalized kick strength; Kick rise time: 5-95%:98 ns; 2-98%: 121 ns; 1-99%: 156 ns.

PS INJECTION

The existing PI.KFA45 system injects the beam into the PS and can be operated in terminated or short circuited (SC) mode. Whilst the terminated mode provides an ultrafast rise time of <50 ns, the SC mode doubles the kick strength but can only provide a rise time of around <100 ns. The rise time must be short enough to fit between the two longest bunches on the highest PS operational harmonic (h=9) whilst the fall time is similar to the rise time (constrained by the h=8 bunch spacing and length as in this case there is no missing bunch in the PS bunch train). New rise time requirements have been elaborated and are shown in Table 2.

Table 3: Main Magnet Parameters for Present KFA 45 and Planned KFA53

Parameter	KFA45	KFA45	KFA53
Mode	Term.	SC	SC
Z [Ω]	26.3	26.3	15
t_r/ t_f (2-98%) [ns]	<50/<100	<100/<100	<50/<100
$U_{PFL(max)}$ [kV]	80	80	40
$B.dl_{(max)}$ [T.m]	0.0314	0.0601	0.0187
Ripple(flat top/ post kick) [%]	±2/ ±1.25	±3/ ±1.5	±3/ ±1.5
Mod./ length [m]	4/ 250	4/ 250	4/ 165
Cells/ length [m]	8/0.025	8/0.025	-

KFA 53 Option

The initial LIU upgrade plan was to maintain KFA45 in terminated mode and to provide the missing kick strength for the injection of 2 GeV beams by a new kicker in straight section 53 [4]. SS53 is however partly occupied

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and hence only allows a kicker of 730 mm length (flange to flange). The limited space imposes a short circuited system with relatively low impedance to deliver the required kick strength nevertheless which would be in contradiction with the fast 50 ns rise time and therefore being considered to be a major development project. Table 3 shows key parameters of the existing KFA45 system and the KFA53 design parameters.

New KFA 45 Option

As an alternative to the KFA53 magnet different options of newly designed kicker systems in SS45 were studied (Table 4). The first approach was to reuse the existing 26.3 Ω generator and to only shorten the magnets and cells of the existing system such, that the SC mode would comply with the at that time discussed 50 ns rise time. It would hence require 8 very short 122 mm long magnets consisting of only 7 short 17 mm cells each. Production of such a magnet is considered to be challenging. The 2nd approach was to boost the kick strength of the terminated mode by lowering the system impedance to 16.6 Ω and compensating the increased rise time by again shortening the magnets. Six 163 mm long magnets with either eight 20 mm or nine 18 mm long cells would be required. Whilst the cell cut off frequency is beneficial for shorter cells and also more cells will mitigate the system ripples [5], production and conditioning is much easier for the longer cells. Electrical stress between cell parts can be limited as the nominal voltage in terminated mode can be lowered to 60 kV.

Table 4: KFA 45 Design Parameters

Parameter	26.3 Ω		16.6 Ω	
Mode	Term.	SC	Term.	SC
Modules/cells	8/7	8/7	6/9	6/9
Length (mod./ cell) [mm]	122.5/ 17.5	122.5/ 17.5	163/ 18	163/18
U_{nom}/U_{max}[kV]	80/80	46/80	60/60	30/60
$B.dl_{nom}$ [T.m]	0.035	0.041	0.042	0.042
I_{nom}/ I_{max}[kA]	1.5/1.5	1.75/3	1.8/1.8	1.8/3.6
$t_{transition}$[ns]	16.5	33	35	70

Existing KFA 45 in Short Circuit Mode

The reviewed kicker rise time of 105 ns allows reconsidering the operation of the presently installed KFA45 system in permanent SC mode. A system consolidation would comprise the suppression of the SC thyratrons in the tunnel to improve reliability, as well as a redesign of the filter circuits and pulse steepening ferrites. Both will be necessary to reduce the ripples in SC mode from presently ~±3% to the required ±2% level. Especially the mitigation of a reflection after the first third of the flat top duration will be in the main focus. Measurements made in 2010 [6] suggest an additional 10% emittance growth with the present system without any modifications. Since those measurements were performed a new transverse damper system has been installed in the PS and will also be available in the future for damping of injection oscillations [7].

Finally the replacement of the almost 40-year-old SF6 gas filled PFL cables is planned, as well as the consolidation of the RCPS, electronics and controls.

CONCLUSION

The PSB to PS beam transfer has been reviewed in view of the planned LIU 2 GeV upgrade. Important rise and fall time parameters have been redefined and allow now for decisions on the upgrade projects: The PSB extraction kicker can be operated without major upgrade; the recombination kickers basically also support 2 GeV operations but will have to be reviewed concerning the new rise time requirements, which will possibly result in the modification of the present system. With regard to the PS injection, the KFA53 project will be deferred in favour of an optimization of the existing KFA45 system. For all systems, the increased performance parameters will require more maintenance effort and will result in a decreased thyratron lifetime.

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