FEASIBILITY STUDY OF THE PS INJECTION FOR 2 GeV LIU BEAMS WITH AN UPGRADED KFA-45 INJECTION KICKER SYSTEM OPERATING IN SHORT CIRCUIT MODE

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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 beams. This paper describes the evaluation of the proposed upgrade for the PS injection kicker. Different schemes of an injection for LIU beams into the PS have been outlined in the past already under the aspect of individual transfer kicker rise and fall time performances. Homogeneous rise and fall time requirements in the whole PSB to PS transfer chain have been established which allowed to consider an upgrade option of the present injection kicker system operated in short circuit mode. The challenging pulse quality constraints require an improvement of the flat top and post pulse ripples. Both operation modes, terminated and short circuit mode, are analysed and analogue circuit simulations for the present and upgraded system are outlined. Recent measurements on the installed kickers are presented and analysed together with the simulation data. First measurements verifying the performance of upgrade options have been taken during the last end of the year stop. The paper concludes with an upgrade plan and a brief overview of implementation risks.

INTRODUCTION

Within the framework of the LHC Injectors Upgrade (LIU) project [1] the injection of 2 GeV beams into the PS ring has been studied for implementation during the upcoming long shutdown 2 (LS2). Several options have been analysed [2] and together with the newly formulated homogenous kicker requirements [3] an upgrade of the existing injection kicker system became feasible. The performance improvement of the PS injection kicker system (KFA-45) in short circuited mode (SC-mode) has been preferred over the construction of an additional kicker system in straight section 53. The obvious challenges are the increased rise time in SC-mode as well as to mitigate the much higher ripple amplitude. In terminated mode the pulse is travelling from the Main Switch (MS) via the transmission cables (Tx-cables) into the magnet and is terminated at the matched termination resistor at the magnet output (Fig.1). In SC-mode the termination resistor is currently short circuited by a thyratron (SC-switch) such that the magnet output is pulled to ground hence reflecting the arriving pulse completely. This results in twice the magnet current but also in twice the magnet delay time (as the pulse travels two times through the magnet) and in significantly higher ripples. The higher ripple amplitude results from system mismatches which are due to the MS and SC-switch construction. The created ripples are then reflected several times between both line inhomogeneities. This paper focuses mainly on understanding the ripple source and mitigating its amplitude.

REQUIREMENTS

For all activities it needs to be noted that the PS injection kicker is a crucial system within the CERN accelerator chain hence it is an absolute requirement that no “risky” modifications are allowed for testing during operational periods and the proposed solution must be reliably delivering the required performance from the start. System specification parameters for the 2 GeV injection are outlined in Table 1. The system currently provides a nominal kick angle of 4.3 mrad when being pulsed at ~77 kV in terminated mode. This corresponds to a current of 1.47 kA. For 2.0 GeV injection a current of 1.91 kA is needed which exceeds the 1.5 kA limit of the terminated mode but can be provided in SC-mode pulsing at a PFL charging voltage of ~51 kV.

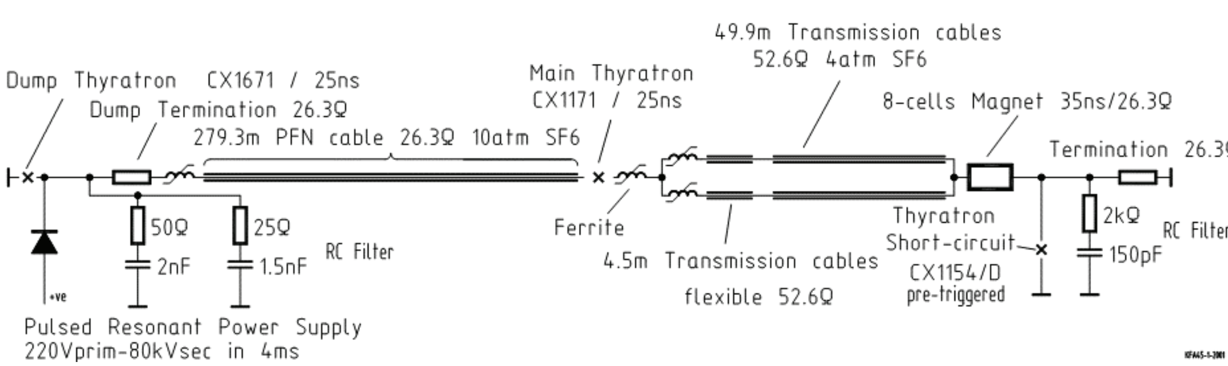

Figure 1: PS injection kicker system (KFA45) - schematic overview of one branch (out of four parallel) as installed.

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Table 1: Specifications for 2 GeV PS injection

Parameter	Unit	Value
Nominal kick	mrad	4.3
Max. kick	mrad	4.4
Beam Rigidity	T.m	9.28
∫B.dl	T.m	0.041
Rise & fall time (2-98%)	ns	105
Min. flat top length	ns	2105
Flat top ripple (peak)	%	±2

METHODOLOGY

As the KFA45 system is operational most of the time and measurements and test modifications to the system are only possible in a very limited way during technical stops, analogue simulation models were developed to analyse the system rise time, ripple structures and possible system improvements. In order to validate the simulation model pulse measurements at the magnet were performed during a technical stop in 2015. Consequently the development of system modifications was performed using the simulation model. To validate the individual proposals a measurement campaign was started during the yearly extended technical stop (YETS). Simulation and measurement results are outlined in [4] and summarized in this paper. As the magnet aperture is not accessible once the magnet is installed and removing it would be a major operation (breaking beam vacuum, disconnecting hydraulic circuits and sensitive SF6 gas filled cables) no direct field measurements were possible. Subsequently all quoted measurements are current measurements. It is expected that compared with the current waveform the field waveform will be smoother due to the integration effect of the magnet assembly. This effect can be simulated but not validated by direct field measurements. A tool for validation by beam based measurements is under development [5], first attempts in the past did not yield the required accuracy [6].

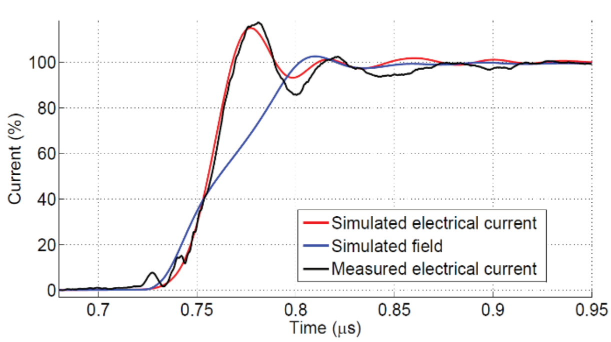

Figure 2: Comparison of measured current (black) with simulated field (blue) and current (red) for one module in SC-mode.

SIMULATIONS

A sophisticated analogue simulation model has been set up in the past and was further improved recently. The model comprises PFL cable losses, an approximation of the thyratron switches, filters, Tx-cables, connectors and the transmission line magnet itself. Figure 2 shows the simulated current and field waveform (rising edge) as well as the measured current which widely agrees with the simulation. It is important to note that compared to the magnetic field, current rise time values are substantially longer for the 2-98% definition as the overshoot and ringing at the rising edge significantly prolong the rise time.

The following improvements have been identified:

- LC-filter:

As the upgraded system would work in SC-mode only it was obvious to replace the SC-switch by a permanent short circuit. A parallel LC-filter was placed between the magnet and the short circuit in the model and results suggested a slower rising and falling edge but up to 25% less flat top ripple amplitude.

- Dephasing:

The KFA45 system consists of 4 independent modules. The concept of dephasing is based on the fact that with a well-defined difference in Tx-cable length for each model the ripples ideally cancel out. Simulations show that a reduction from 103.7% flat top ripple amplitude of a single module to 101.9% for four dephased modules is possible.

- LEMO ferrites:

Currently 5 cm long saturating ferrites are installed in the LEMO connection boxes. Reducing the ferrite length to 3 cm will reduce the flat top ripple by 18% (and partly improve the post pulse ripple whilst no effect on the rising edge was found.

- Post pulse ripples – magnet entry box ferrites:

Simulations and measurements indicated that significant post pulse ripples are present in terminated mode as well as in SC-mode. New saturating ferrites at the magnet entry box level are proposed to reduce the post pulse ripples. A 10% reduction of the flat top ripple amplitude is noted as well. On the other hand also the undershoot gets slightly bigger.

A simulation run with all modifications together indicates that the flat top ripple can be reduced to 101.2% and the post pulse ripple reduced from 2% to 0.8%.

MEASUREMENTS

Current waveform measurements on the operational system have been performed in 2001 and recently in September 2015 as well as during the YETS. All measurements agree on the flat top performance and do not show any substantial degradation. They also show a wide agreement with the simulated current for the installed system configuration. Dedicated measurements have been performed to validate the major proposed modifications:

- Dephasing

In order to validate the dephasing concept the 3.8 m short F&G Tx-cables have been replaced by the same type but different length. The length didn't correspond to the ideally calculated values but to available test cables. Results nicely show the phase shift which completely agrees with calculations. The black trace in Fig. 3 represents the nominal configuration (3.8m) whilst the red (4.5 m), blue (7.6 m) and magenta (15.8 m) curve corresponds to longer cables and hence provide the according delay.

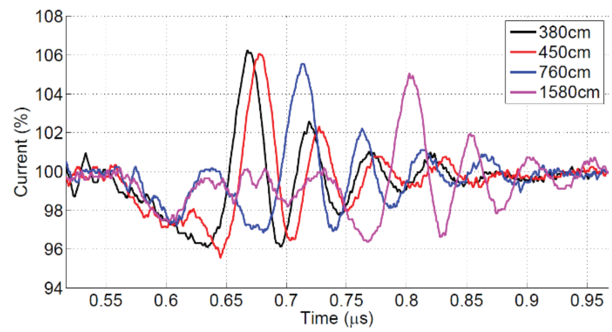

Figure 3: SC-mode dephasing measurements: Shift in flat top ripple corresponds to different Tx-cable length.

- LC-filter

The SC-switch was removed and a permanent short circuit with integrated LC-filter was installed. The inductivity was varied by using different coils up to 4 turns.

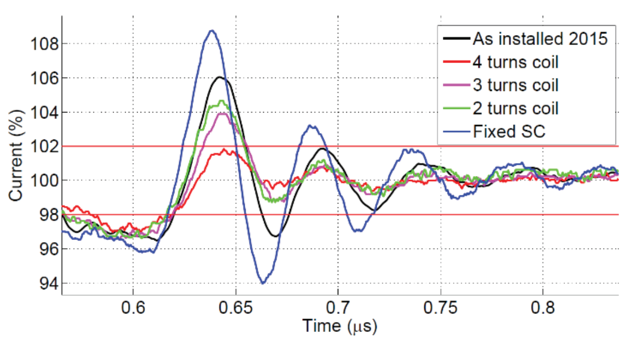

Figure 4: Measurement results for SC-mode (black), permanent SC-mode (blue) and additional LC-filters.

Figure 4 shows the results for the nominal system using the SC-switch (black), the system with permanent short circuit (blue) and for the different LC-filters added.

It can be seen that the replacement of the thyratron by a permanent short circuit increases the ripple which already indicates that the thyratron inductance and parasitic capacitance are relevant. Measurements with the different LC-filters clearly show that the higher the inductance is the smaller the ripple gets. Unfortunately also the overshoot on the rising edge decreases in the same manner.

- Other measurements performed:

Tests with saturating ferrites have not been conducted to minimize the risk to the magnet during the short YETS. Additional measurements on the MS thyratron cathode heaters and reservoir circuits have been performed mainly outlining the effect of common mode ferrites being added. A significant influence has been identified suggesting that the MS assembly could be improved to reduce the mismatch and hence the source of ripples. Further studies are needed to understand this behaviour in more detail.

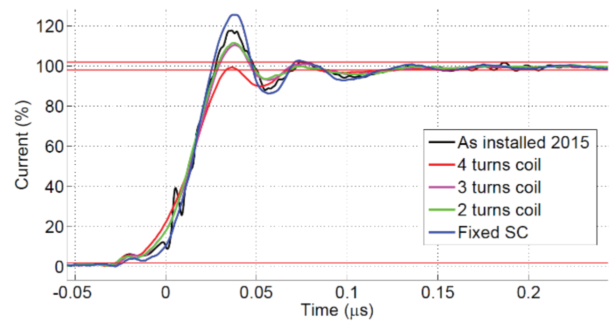

Figure 5: Rising edge measured for different SC-mode configurations.

OPERATIONAL ASPECTS, RISKS AND SCHEDULE

The max. demanded deflection of 4.4 mrad requires a current of ~2 kA with 4 modules or 2.6 kA with 3 modules (~69 kV, SC-mode) which indicates already that operation with one faulty module is possible. Operation with 2 modules only will not provide the required deflection as it is currently the case. Any module missing will also result in a "degraded" mode, as the dephasing does not work with full yield. Simulations suggest that the ripple will be worse but still within specification for the worst case of module 4 missing.

Project risks have already be mitigated by first test measurements outlined in this paper. The implementation risks will mainly be on the modification of the magnet entry box as the sensitive SF6 gas filled cables have to be removed. In order to mitigate availability risks new spare cables for the 52.6 Ω F&G and SF6 filled cables have to be ordered.

Implementation of the proposed improvements is foreseen for the next (extended) YETS however termination resistors and SC-switch infrastructure would be kept until LS2 such that a roll-back is quickly possible during this period.

CONCLUSIONS

An upgrade of the KFA45 system has been proposed to improve the SC-mode performance for future LIU beams. Simulations have been performed to outline improvements and measurements have been taken to validate the simulations. The obtained data is widely coherent and in good agreement. However due to the unavailability of direct field measurements only current measurements could be compared. To mitigate the remaining uncertainty and risks, further simulations will be conducted to better understand the current to field relation and beam based measurements are planned.

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