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# PERFORMANCE VALIDATION OF THE EXISTING AND UPGRADED PS INJECTION KICKER

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*Abstract*

The CERN PS injection kicker KFA45 will be upgraded in the framework of the LHC Injector Upgrade (LIU) project to allow for injection of 2 GeV proton beams. This paper summarizes the recent efforts to validate beam based waveform measurements, Pspice simulations and current waveform measurements by direct magnetic field measurements in the aperture of the existing system. The magnetic probe, associated measurement hardware design and measurements results are discussed. The paper concludes with a performance comparison and an outlook to future waveform tuning possibilities.

## INTRODUCTION

In the recent years, a lot of effort has been made to make the CERN PS injection kicker (KFA45) ready for 2 GeV LIU beam injection. To assess and validate the required kick strength, rise and fall time and flat top performance [1, 2], a detailed feasibility study based on PSpice ® simulations was launched in 2015 [3]. The proposed modifications were implemented and preliminary tested during 2016 [4]. As a drawback of changes, undesired ripples in the pulse and enlarged rise and fall times were observed during the current measurement campaign in 2017 [5]. The demanding LIU specification requires a very precise assessment of the KFA45 performance which cannot only rely on the magnet current measurements and simulations. Thus, a non invasive technique to retrieve the magnetic kick waveform during kicker operations has been developed [6]. This indirect measurement technique was firstly tested on the KFA45 and results were recently published [7, 8]. In 2018, the fine tuning of the pulse generator was done [9] already based on the conclusions of [7]. In an effort to finally assess the pulse generator performance and to validate all the previous work, direct magnetic measurements on the magnet have been carried out during the early start of the Long Shutdown 2 (LS2). The chosen measurement methodology, the out coming results and plans for future measurements are discussed in this paper.

## METHODOLOGY

Since the KFA45 itself provides no means for direct field measurements, a measurement set up consisting of a magnetic field probe and an integrator was deployed in the Proton Syncroton (PS) ring in January 2019. The magnetic probe, inserted in the magnet aperture, allows to measure one out of four magnet modules. The design is based on previous stripline type models that have been used to assess the performance of several kicker magnets in the past. The estimated impedance for this design is 75 Ω, but it was decided to fully characterize it, both by simulations and measurements, obtaining 91.5 Ω. The near end of the probe is connected to a passive RC integrator via a short pigtail cable of 75 Ω (very close to the probe's nominal impedance). A 100 μs RC time constant was chosen to minimize the integrated flat top pulse decay whilst ensuring a good output signal level. The described measurement layout is shown in Fig. 1, and the deployed measurement set up in the PS ring is shown in Fig. 2.

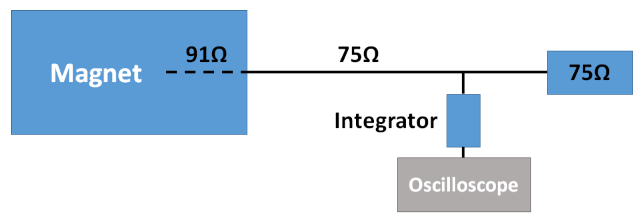


Figure 1: Schematic of layout.

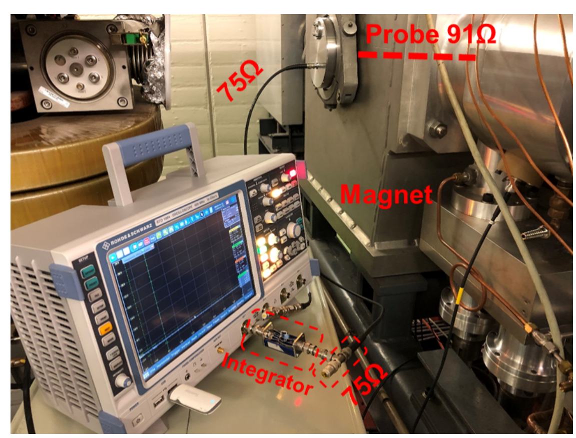


Figure 2: Measurement set up a the PS ring.

## MEASUREMENTS RESULTS

Two aspects of the pulse were of main interest: the precise assessment of the rise and fall time values and the quantification of the ripples with respect to the pulsed forming line (PFL) voltage. Both current and field were acquired simultaneously and statistics were performed in order to evaluate the measurement uncertainty.

As show in Fig. 3 ripples in the flat top and in the post pulse are clearly visible in both magnetic and current mea-

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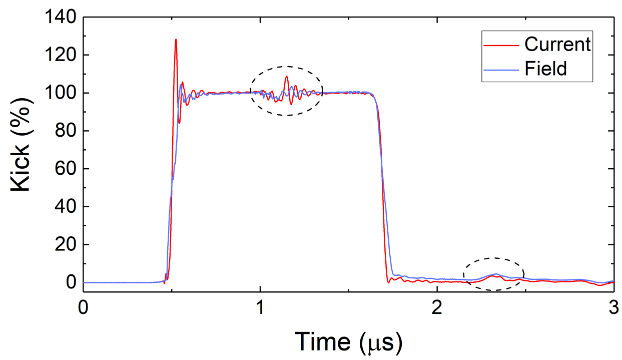


Figure 3: Current (red) and magnetic field (blue) pulses measured at 55 kV.

surements, whilst flat top ripples are lower in the magnetic field with respect to the current.

The achieved measurement accuracy is a major step forward, since the last beam based measurements could not confirm the presence of flat top ripples due to resolution limitations [7, 8]. Some disagreement is observed between current and field after the falling edge leading to an increased field fall time. Therefore, in Table 1 the fall time values were taken from 98% to 5%. It is believed that a bad ground reference is behind this measurement error, currently under more detailed investigations.

Table 1: Measured Pulse Parameters at 50 kV

| $t_{rise}$ (2 – 98 %) | $t_{fall}$ (98 – 5 %) | Ripple | |
|---|---|---|---|
| | | Flat-top* | Post-pulse |
| 74 ns | 107 ns | 6.6 % | 5.0 % |

*Amplitude peak-to-peak

Because the magnetic measurements were carried out in only one module, the dephasing effect between modules is not visible. This leads to the increased flat-top ripple values for single module measurements compared to the values from simulations and measurements for the complete system. In addition to that, the measurement analysis methodology used this time is peak-to-peak rather than the previously used peak definition [5]. It is important to highlight that since 2018 the LC termination is removed in favour of faster rise and fall edges, and is as a consequence not mitigating the flat-top ripple [9].

It is interesting to note the evolution of the rise time with respect to the PFL voltage. In Fig. 4, which shows a clear dependency of the rise time on the PFL voltage, highlighting the need of a proper tube gas pressure adjustment according to the operational voltage. Therefore briefly usage of injection kicker modules for tune kicker purposes at very low voltage is not recommended.

To validate the previous beam based measurements, a comparison with direct field measurement is provided in Fig. 5 for the rising and falling edge and for the post pulse in Fig. 6. Both methods show an excellent agreement on the ris-

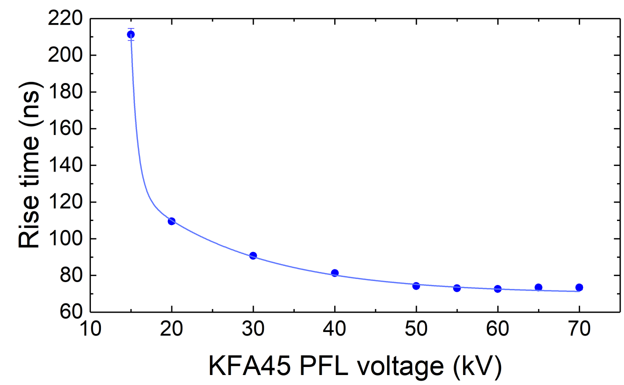


Figure 4: Rise time evolution with respect to PFL voltage.

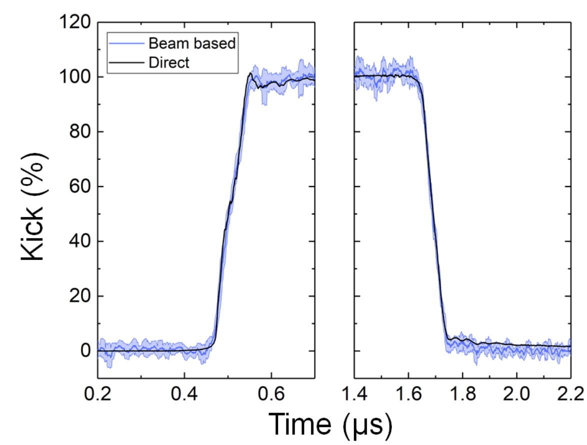


Figure 5: Rise and fall times comparison of beam based (BB) measurement (blue) and direct measurements (black).

ing and the falling edge. The post pulse ripple bump, placed 600 ns after the falling edge is observed by both methods, however, as previously mentioned, the direct field measurement seems to have an offset error that is slowly decaying along the post pulse.

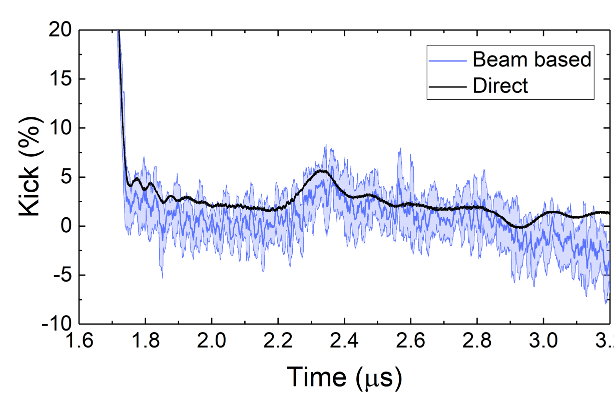


Figure 6: Post-pulse comparison of beam based (BB) measurements and direct measurements (back).

It was observed in current measurements that the post pulse ripple is strongly dependent on PFL voltage, largely

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decreasing when higher voltages are applied. The observation was finally confirmed by direct field measurements, showing again a strongly correlated behaviour (see Fig. 7).

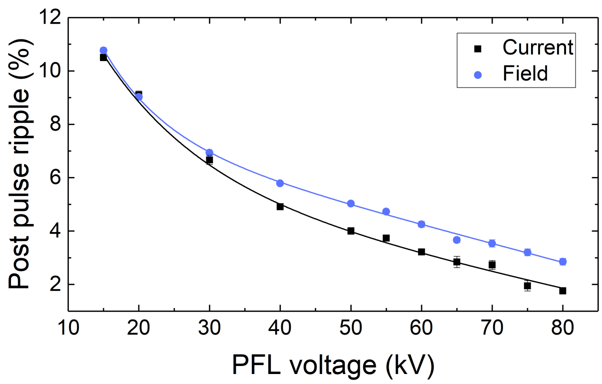

Figure 7: Post-pulse ripple amplitude evolution with respect to PFL voltage for current (black) and magnetic field (blue).

Table 2: Measured Main Pulse Parameters at 40 kV

| **Measurement technique** | $t_{rise}$ (2 – 98 %) | $t_{fall}$ (98 – 5 %) | **Post-pulse ripple** |
|---|---|---|---|
| Beam based | 93 ns | 104 ns | 4.6 % |
| Direct | 81 ns | 106 ns | 5.6 % |

Profiting of the measurement campaign in January 2019, the saturation effect of the present magnet was measured too. Figure 8 clearly shows the lack of linearity in the field for voltages above 55 kV, confirming previous observations [10].

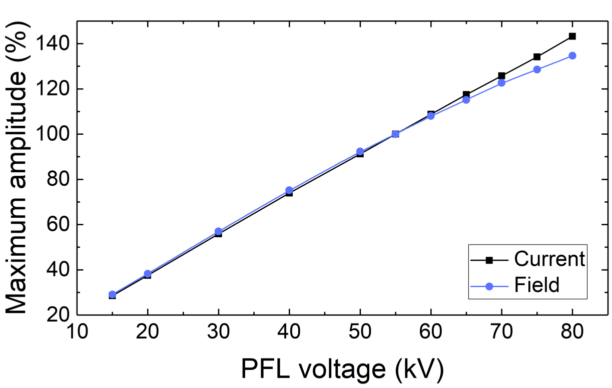

Figure 8: Flap-top kick amplitude with respect to the PFL voltage for current (black) and magnetic field (blue).

## KFA45 TEST GENERATOR

As already discussed in [9], a new magnet module type with enlarged cross-sectional ferrites to avoid saturation has been designed. Together with the magnet a new tank featuring a new SF6 free connection box is going to be installed during LS2.

The new connection box will allow to install two independent sets of RC filter and several ferrite rings providing new pulse tuning capabilities. Preliminary simulations done in Pspice showed promising filter configurations that might improve the pulse shape, pushing down especially the post pulse ripple. In order to test these recently proposed configurations and to condition the new magnet, a new KFA45 test generator has been built. This test platform is an exact copy of the actual KFA45 pulse generator and will provide freedom and flexibility for deploying and testing of more complex modifications and measurements. It is planned to perform the magnetic measurement of the new magnet in this set up with an improved probe version. The measurements will be used to validate the new magnet and connection box performance.

## CONCLUSIONS

Direct magnetic field measurements have been carried out in January 2019, providing very valuable information on the system performance. A magnetic probe and a RC integrator circuit have been designed, constructed and deployed, yielding important experience for future magnetic measurements. Rise and fall times have been precisely assessed, and ripples amplitude have been carefully studied and quantified. In addition, the direct measurements have been compared with previous beam based measurements showing an excellent agreement. This result represents a successful validation of the beam based method which provides a reliable tool for future non invasive measurements during operation.

In a parallel way, a new magnet, tank and magnet connection box are being constructed. These new elements will be tested in the recently build KFA45 test generator. New magnetic measurements are planned on this platform together with the final filter tuning to improve the system performance after LS2.

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