ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPMF075

PERFORMANCE MEASUREMENTS AND ANALYSIS OF JITTER LIKE EVENTS FOR THE PS INJECTION KICKER SYSTEM

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Abstract

In the framework of the LIU project, several modifications have been made to the CERN PS injection kicker system during the winter stop 2016-2017 (EYETS). Current waveform and beam-based measurements were carried out in 2017 to validate the implemented design changes by observing the magnetic field impact on the beam. During these long-term measurements, increased values for the rise and fall times were observed when compared to single shot observations of the current waveform. An unknown source of "jitter-like pre-firing" in the main switch has been identified, creating an additional challenge to meet the already tight system rise and fall time specifications. This paper briefly describes the efforts made to fine tune the pulse generator after the EYETS, summarises the optimised configuration and analyses the observed jitter events. A new triggering system design is briefly outlined to address the issue.

INTRODUCTION

During 2017 the PS proton injection kicker system (KFA45) has been running permanently under an improved configuration in short circuit (SC) mode to comply with LIU 2 GeV kick strength specification [1]. The upgrade modifications reported in [2] were based on the conclusions of an intensive simulation work, all available in a feasibility study [3]. After modification deployment, preliminary performance measurements were taken during 2016/2017 annual shutdown and were evaluated in accordance with simulations results [2]. During machine operation in 2017, more measurements were carried out to precisely estimate the pulse generator performance. The obtained information, discussed here, has been used to better understand the impact of the modifications and to improve the kicker performance during 2018 operation.

PERFORMANCE MEASUREMENTS DURING 2017 RUN

The demanding LIU specifications requires a precise assessment of the KFA45 magnetic field rise and fall time. Since there is no magnetic probe in the magnet aperture, these values have been relied on the information provided by the current transformer (CT) installed at the magnet output. However, PSpice simulations indicate that the measured current at the CT position on the output of the magnet does not correspond to the magnetic field seen by the beam. This fact highlights the need for magnetic field measurements to accurately evaluate the system rise and fall time.

To do so, the insertion of a field probe in the magnet tank would be required. This is a major intervention since the

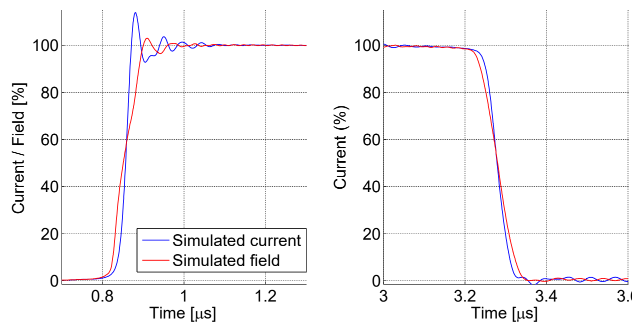

Figure 1: KFA45 simulated current and field.

kicker magnet is connected to rigid SF_6 gas filled cables and consequently the adjacent main bending unit of the PS ring would need to be moved. To overcome this difficulty, an alternative beam based method to measure the field waveform has been recently developed [4] and applied to the KFA45 [5].

In order to have a comparative set of information, current and field measurements were carried out with and without LC filter at the SC point of the magnet. Table 1 summarizes all the measured values. Due to the resolution limitations of the beam-based measurements, the rise and falls times of the magnetic field were only quoted with a $5-95\%$ and $95-5\%$ criteria. Note that the ringing observed in the current measurements at the rising edge enlarges some of the t_r values (Table 1 marked with an asterisk). These oscillations were well tracked by simulations (see Fig. 1) and tend to increase when the LC filter at the SC point is removed, however they are not representative of the magnetic field behaviour since the magnet partially filters out some frequency components.

KFA45 FINE TUNING

All the obtained data during the measurement campaign in 2017 shows a clear performance dependency relying on the SC filter configuration. Both current and beam based measurements strongly indicate that with the LC filter configuration the fall time is slightly over the targeted objective. Due to that, during the 2017/18 annual showdown, LC filters of all four KFA45 magnets were removed pushing the measured current fall time from 108 ns to 89 ns (17% reduction). As a side effect, current measurements show that without LC filter, flat top ripples increase [2]. Beam based measurement were not able to confirm this due to resolution limitations [6].

In order to test this new system setup and perform multiple sets of beam based measurements, the system will remain with no LC filters during 2018 operation. The upgraded configuration for this year is based on three elements. A

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Table 1: Measured Current and Field [5, 6] Rise/Fall Times

KFA45 termination	Current measurements				Beam based measurements	
	$t_r(2-98\%)$	$t_f(98-2\%)$	$t_r(5-95\%)$	$t_f(95-5\%)$	$t_r(5-95\%)$	$t_f(95-5\%)$
With LC filter	152 ns*	108 ns	75 ns	77 ns	(101 ± 5) ns	(111 ± 5) ns
Without LC filter	145 ns*	89 ns	118 ns*	60 ns	(78 ± 5) ns	(100 ± 5) ns

direct SC at the magnet end that allows current doubling, a ferrite loaded connection box at the magnet input and module dephasing, which together mitigate undesired ripples.

JITTER MEASUREMENTS

To properly kick the beam, all four magnet modules need to be precisely aligned in time to synchronously deliver the required pulse. Any deviation from this scheme will distort the magnetic field and therefore lead to higher rise and fall times.

During the beam based measurement campaign in 2(large shot to shot instabilities in the rising edge shape w reported for the first time [5]. After a preliminary analy main switch (MS) thyratron desynchronization was poir as source of the issue. In order to confirm the hypothe and quantify the phenomenon, an intensive jitter meası ment campaign was launched. The measurement set up designed such it could independently disentangle the con and the thyratron jitter of each module.

Figure 2 shows a multiple shot acquisition of some of used signals. The blue curve shows an overlay of the module one thyratron trigger signal, and the red trace represents the magnet CT signal. By analysing both curves' rising edge time position respect to the machine timing reference,

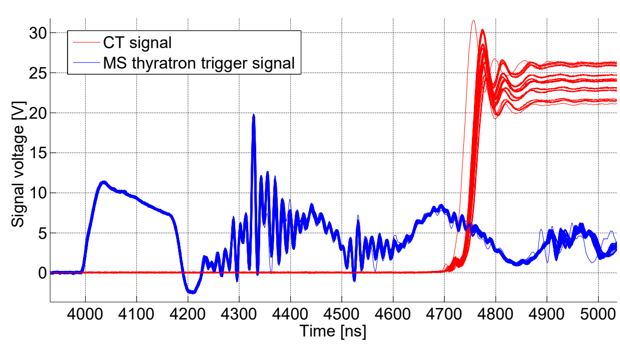

Figure 2: Acquisitions of a thyratron trigger (blue) and CT signal (red) on KFA45 module 1.

Control Jitter

The measurements were carried out during several weeks for every KFA45 MS and dump switch (DS) control module. Measurement results, summarized in Table 2, are well below 5 ns which is the maximum jitter value commonly accepted for this control system.

In addition to the jitter values, scatter charts were used to spot any possible outlier value (glitch) during the test.

Table 2: Measured MS and DS Controls Jitter (2σ)

	Module 1	Module 2	Module 3	Module 4
MS	2.93 ns	4.22 ns	1 ns	0.75 ns
DS	1.57 ns	1.73 ns	3.23 ns	2 ns

Figure 3 shows the scatter chart of module 1 MS control. The compact cloud of points indicates a stable control system performance. This behaviour was observed in all four measured modules.

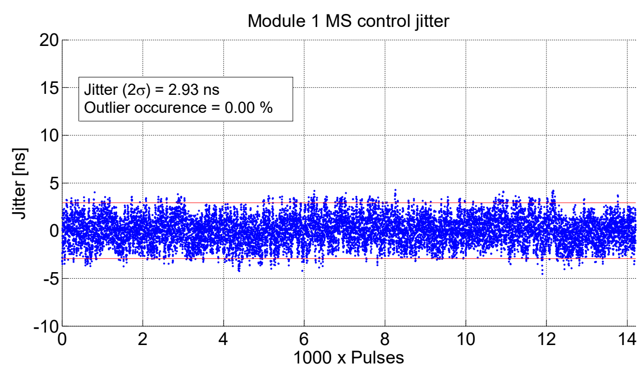

Figure 3: KFA45 module 1 MS control jitter.

Thyratron Jitter

In a similar way the thyratron jitter was evaluated and Table 3 summarizes all the measured values. Different kick strength settings applied during machine operation increased the measurement uncertainty by ~3 ns. Figure 2 CT signal, shows the mentioned differences in kick settings. Taking this into account, measured values for MS thyratron jitter are within manufacturer specifications [7].

Table 3: Measured MS and DS Thyratron Jitter (2σ)

	Module 1	Module 2	Module 3	Module 4
MS	7.84 ns	6.85 ns	6.6 ns	6.62 ns
DS	4.48 ns	3.32 ns	3.34 ns	3.03 ns

Unlike the controls, the scatter chart of the MS thyratrons (Fig. 4), clearly confirms the presence of outliers. These events indicate a pre-firing of the MS up to 30 ns , which was observed recurrently on modules 3 and 4. Such an event is visible in Fig. 2 where one of the current rising edges (red traces) is advanced with respect to the others. Table 4 shows the outlier occurrence per switch. No outliers were reported in the DS thyratrons.

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Table 4: KFA45 MS and DS Thyratron Outlier Occurrence

	Module 1	Module 2	Module 3	Module 4
MS	0.29 %	0.007 %	0.9 %	1 %
DS	0 %	0%	0 %	0 %

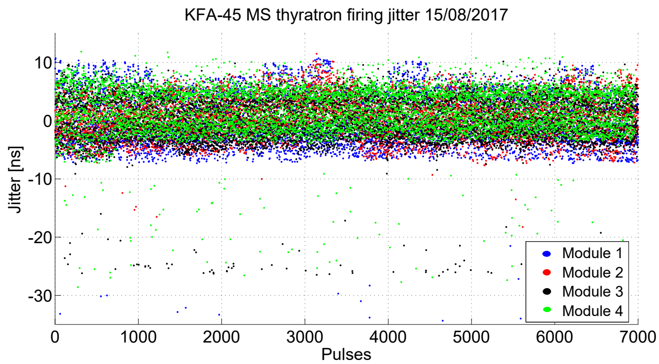

Figure 4: KFA45 all modules MS thyratron jitter.

The MS thyratron pre-fire like events are the suspected cause of the distorted rising edge seen in earlier multi module beam based measurements [5]. This phenomenon is only present at the MS (CX1171A thyratron), and none of them were observed at the DS (CX1671 thyratron). To fully understand this, more tests are foreseen with redundant current pulse measurements. A plug-in CT measurement box has been developed for this purpose. In addition, an improved version of the thyratron trigger system is under consideration as an overall jitter mitigation technique.

KFA45 Trigger Upgrade

As a strategy to mitigate the thyratron jitter, an improved version of the present trigger system is under study. The current configuration uses thyratron grid one (G1) as a priming electrode with a positive DC bias voltage and grid 2 (G2) as a triggering electrode. This configuration, although simple, is less immune to jitter and erratics during operation. The new proposed system pulses both electrodes (G1 and G2) in such a way that G1 is pre-pulsed 550 ns before G2. This technique requires extra complexity to generate two non simultaneous triggering signals from a single one. However, it offers extra protection against erratics and a reduced jitter value of 2 ns [8]. The upgraded triggering system will improve the module synchronization and therefore gain an important margin for the system rise time.

KFA45 UPGRADING PLANS FOR THE LONG SHUTDOWN 2 (LS2)

The currently installed magnet was designed for beam energies below the present 1.4 GeV injection kinetic energy. For future 2 GeV operation the required magnet current for standard operation with all four modules will start to reach the non-linear magnetic field region in the ferrites. In case of degraded operation with only three modules, the higher required current will saturate the magnet cells ferrites. Under these circumstances, magnetic kick strength is not linearly related to the pulse flat top current. To overcome this, a new magnet module with increased ferrite cross-sectional area has been designed and it will be installed during LS2, together with a new magnet tank.

In addition, the replacement of the old SF_6 gas filled transmission cables by a new RG220-like cables (CLP52) with high-density polyethylene (HDPE) insulation is foreseen. SF_6 gas is a safety and environmental concern at CERN and its handling is complex and costly, making these cables a very delicate element. The main issue when replacing gas filled cables is the impact of increased cable losses on the pulse rise and fall time. Gas filled cables tend to perform better in terms of losses compared to polyethylene insulated ones [9]. To evaluate the replacement impact, cable losses have been measured with a recently developed technique [9]. With the obtained information a PSpice model has been developed and simulations have been carried out to comparatively observe the rise and fall performance under both cable configurations. Figure 5 shows that almost no performance degradation is expected.

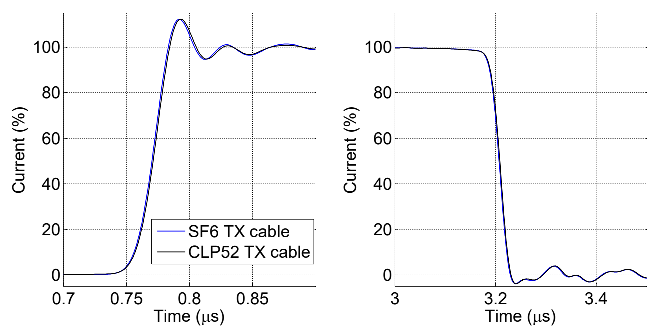

Figure 5: KFA45 simulated pulse with SF6 gas filled and CLP52 transmission cables.

CONCLUSION

Efforts have been made to precisely evaluate the KFA45 performance during 2017 operation. Current and beam based measurements have been used to assess the system rise and fall time. The conclusions made from these observations have been used to tune the pulse generator performance by removing the LC filter at the SC point of the magnet. During beam based measurement campaign, increased rise time values pointed to module desynchronizing events. Long term jitter measurements in the system control and thyratrons were carried out and an unexpected pre-firing of the MS thyratrons was discovered. More studies are ongoing to fully understand this phenomenon. As a parallel mitigation effort, an improved version of the MS trigger system is under study. Finally, the present kicker configuration for 2018 has been presented and the upgrading plans for LS2 have been outlined.

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