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LONG PULSE KICKER FOR EUROPEAN XFEL BEAM DISTRIBUTION

F. Obier, W. Decking, M. Hüning, J.Wortmann, DESY, Hamburg, Germany

Abstract

A special feature of the European XFEL [1] X-ray laser is the possibility to distribute the electron bunches of one RF pulse to different free-electron laser (FEL) beamlines. This is achieved through a combination of kickers and a Lambertson DC septum. The integration of a beam abort dump allows a flexible selection of the bunch pattern at the FEL experiment, while the superconducting linear accelerator operates with constant beam loading. The driver linac of the FEL can deliver up to 600µs long bunch trains with a repetition rate of 10Hz and a maximum energy of 17.5GeV. The FEL process poses very strict requirements on the stability of the beam position and hence on all upstream magnets. It was therefore decided to split the beam distribution system into two kicker systems, long pulse kickers (KL) with very stable amplitude (10^{-4}, flat-top) and relatively slow pulses (~300µs) and fast stripline kickers (KS) with moderate stability but very fast pulses (~50ns).

OVERVIEW

Figure 1 shows a schematic overview of the European XFEL fill pattern and beam distribution system. The six so-called KL flat-top kickers are operated with a rectangular current pulse with variable pulse length and switch the beam between the two main FEL beamlines. To create the flexible bunch pattern, a kicker-septum combination including ten so-called KS stripline kickers is installed, with which it is possible to extract individual bunches into the dump beamline (TLD) with the maximum bunch repetition frequency of 4.5MHz. Pilot bunches for the intra-bunch feedback that is needed to stabilise the beam, bunches during the still-needed gap for rise time of the KL beam distribution kickers and all bunches not needed for lasing are extracted to the dump. Bunches for the SASE3 undulator can be stimulated with a KS kicker so that they do not lase in the SASE1 undulator. All of this requires a sophisticated bunch pattern generator and timing system [2].

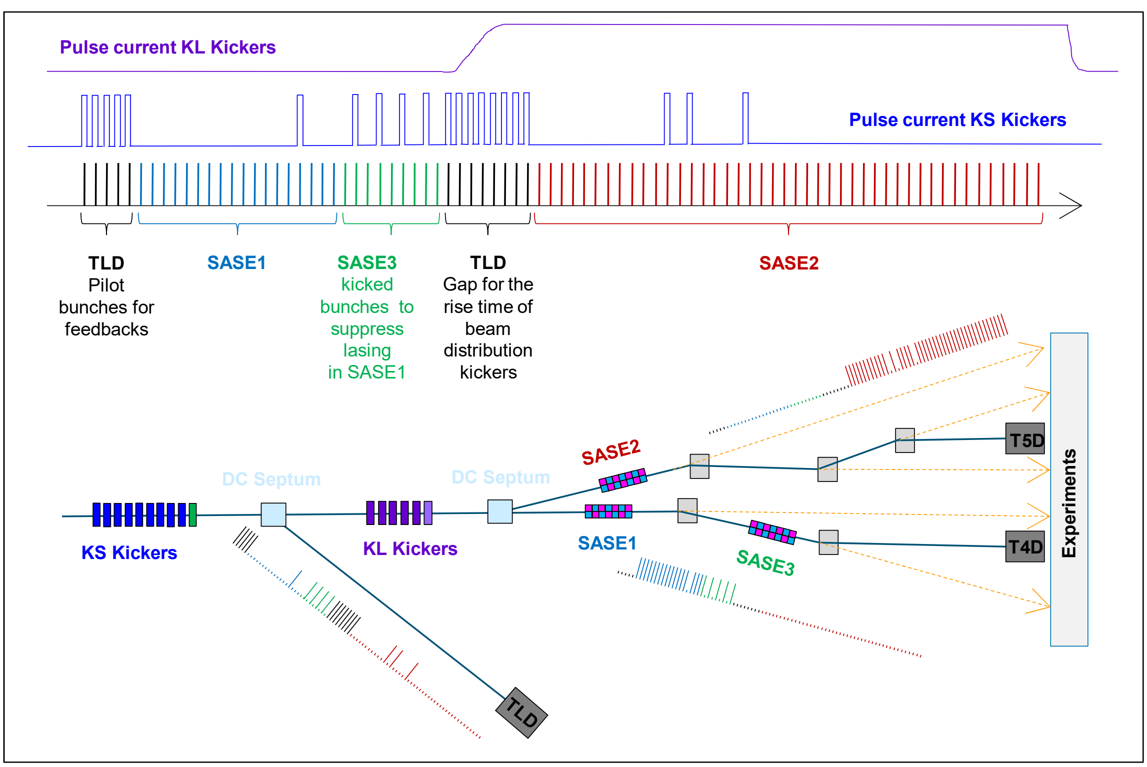

Figure 1: European XFEL fill pattern scheme: The flexible bunch pattern for the FEL lines is created by kicking all bunches that are not used for lasing into the main dump line (TLD) by means of the KS kickers. The bunch train parts for the FEL lines are distributed by the KL kickers. SASE2 bunches are kicked, SASE1/3 bunches are not.

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PARAMETERS

The kick angle $\Delta\theta$ from a kicker can calculated with Energy E and magnetic field B

$$\Delta\theta = \frac{e_0 c}{E}\int Bdl = \frac{e_0 c}{E}\cdot\frac{I * N * \mu_0 * l_{eff}}{l_{gap}},$$

with I the current, l_{eff} the length of the kicker, l_{gap} the gap width and N the number of windings.

The maximum energy of European XFEL is 17.5GeV. The kick angle is calculated about 104µrad for one kicker. We need 5 kickers for a kick angle of 0,5mrad, one kicker is a spare. Table 1 summarizes the KL kicker specification.

Table 1: Specification of the KL Kicker [3]

	Kicker (KL)
Pulse Form	Flat top
Repetition Rate	10 Hz
Max. Pulse Width	300×10^{-6}s
Rise/Fall Time	$\approx20\times10^{-6}$s
Rel. Amp. Stability	3×10^{-4}
Rel. Residual Ripple	3×10^{-4}
Kick angle	0.5 mrad
Int. Field at 20 GeV	33.4 mTm
Kicker aperture	50 mm
Kicker Type	Strip Line
Kicker active length	936 mm
Number of kickers	6
Pulser Voltage	100 V
Pulse Current	600 A

KICKER MAGNET (KL)

The KL kicker magnets are realised as air coils outside the beam vacuum system (Fig. 2). They use striplines that form a single vertical conductor loop around a ceramic beam chamber, which is sputtered (metal-coated) on the inside. The conductor consists of high-frequency litz wires to reduce eddy current effect, skin effect and proximity effect. The mounting structure of the kickers needs to be non-metallic, as otherwise eddy currents are induced which strongly distort the magnetic field of the current pulses. The thermoplastic PEI was chosen for radiation, heat resistance and mechanical properties.

The design of the kickers requires a metal-coated ceramic chamber. The following aspects of sputtered ceramic chambers are important: Sputtering is necessary in order to transport the mirror current of the beam and to contain the radio frequency (RF) fields from the beam inside the chamber while the magnetic field of the kickers (at lower frequency) penetrates the chamber's wall. The coating material is stainless steel 4.4541 (titanium-stabilised). The thickness of the coating is determined by a compromise between reduction of the magnetic field and heat dissipation due to the mirror current.

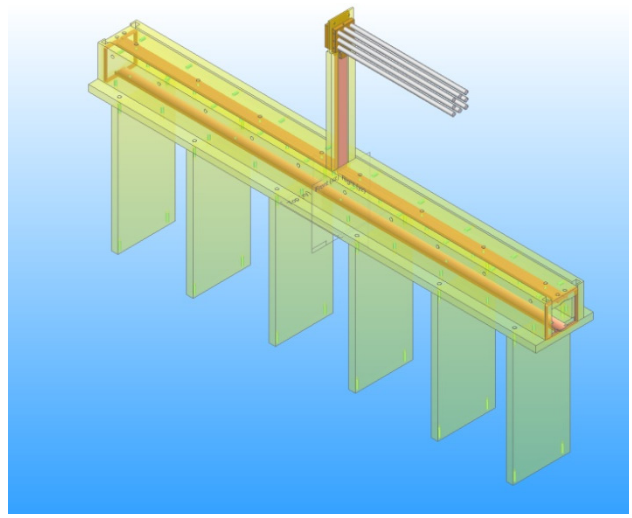

Figure 2: Sketch of the KL beam distribution kicker without ceramic chamber.

PULSER (KL)

For the KL beam distribution kickers, a nearly rectangular current pulse is required, so short rise and fall times of less than 20µs and a very stable flat top of the pulse are important. Therefore, a pulse-regulated current source with MOSFET technology is used. The main MOSFET is switched by a push–pull driver providing a fast rise time. While turned on, the current through the kicker magnet is sensed and fed back to the main MOSFET through a high precision controller (operational amplifier circuit), providing a very stable flat top (Fig. 3).

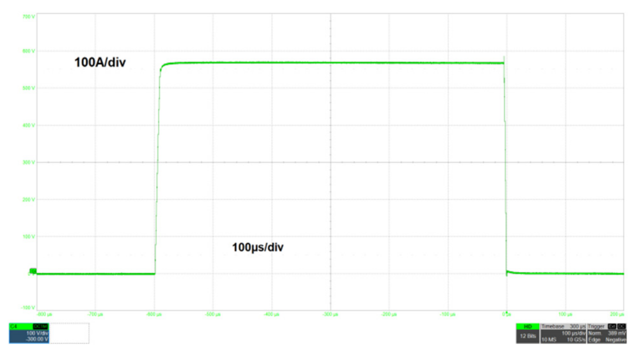

Figure 3: Example of current pulse.

Eight MOSFETs are operated in parallel, generating a pulse current of up to 600 A. Data communications, internal timings, power-up and power-down sequences and some service modes are realised with an FPGA board (Fig. 4). The pulser is triggered with a 5V TTL signal from the MTCA-based main timing system, with the pulse length and trigger start time being controlled by the bunch pattern [2].

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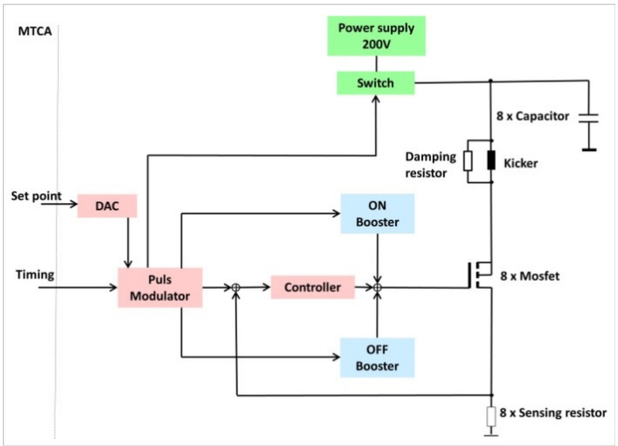

Figure 4: Block diagram of the KL beam distribution pulser.

During commissioning, the pulse flatness (Fig. 5) was also examined with 200 bunches at 1.1 MHz and measuring the SASE intensity in the SASE2 beamline. The beam distribution pulser was set to maximum pulse length of 600 µs. Then the timing was adjusted so that the 200 bunches were at the beginning of the current pulse flat top. Then the delay was changed in 50us steps until the end of flat top. The shape of the SASE intensity signal did not change over the pulse flat top.

Figure 5: Measurement of KL kicker current pulse amplitude stability. Bottom plot shows kicker pulses (600µs) and bunch train (200 bunches). Top plots show SASE2 intensity over bunch train, at beginning (left) and end (right) of pulser flat top (pulser trigger timing was shifted).

The bunches can be distributed into the SASE2 beamline at the beginning or end of the bunch train and so either the falling edge or the rising edge of the KL pulser must be fast, so both were examined. At the falling edge a too long influence on the non-kicked SASE1 bunches (about 50 µs) was observed. This can be avoided by a modification of the pulser's power circuit. Tests are ongoing and the modification can be installed at the next shutdown in August 2019.

Furthermore, one of the 8 Mosfet stages in one of the pulsers was modified, so it is now possible to generate a variable pulse shape of 80 A, needed to build a feed forward system. A first test (Fig. 6) was carried out at the FLASH accelerator. A bunch train of 95 bunches was taken to the FLASH 2 beamline. For an energy of 600 MeV two kicker magnets with a current of 245 A are used. In the study, the orbit placement of the bunch train was measured at a BPM and averaged over several iterations. These data were processed using a MATLab algorithm and passed to the pulser stage via a DAC.

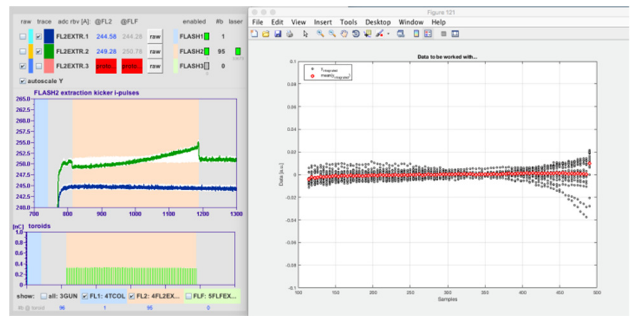

Figure 6: Measurement at FLASH with a modified KL pulser. Left plot shows zoomed current pulses (blue: standard pulser; green: modified pulser with modulated pulse) and bunch train (95 bunches). Right plot shows BPM offset over the pulse train (red: corrected with modulated pulse; dark: history while correction is computed).

SUMMARY

The Beam Switchyard of the European XFEL allows fast switching between the various SASE beamlines.

The pulse flat top stability of the KL kicker system meets the demands for stable SASE operation.

Tests are ongoing to further improve the pulse edges in rise/fall times and ripple.

The orbit changes caused by the offset due to the eddy currents of the fast kickers (KS) [4] exceed the specifications of the existing intra bunch feedback system. A new feedforward system has to be implemented. One of the KL kickers will be prepared to receive a modulated correctional signal.

REFERENCES

[1] M. Altarelli *et al.*, "The Technical Design Report of the European XFEL", DESY 2006-097.

[2] L. Fröhlich *et al.*, "Multi-Beamline operation at the European XFEL", presented at the FEL'19, Hamburg, Germany, Aug. 2019, paper WEP008, this conference.

[3] W. Decking, "Layout of the Beam Switchyard at the European XFEL", in *Proc. EPAC'08*, Genoa, Italy, Jun. 2008, paper WEPC073, pp. 2163-2165.

[4] F. Obier *et al.*, "Long pulse kicker for European XFEL beam distribu-tion", presented at the FEL'19, Hamburg, Germany, Aug. 2019, paper WEP014, this conference.