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FAST KICKER SYSTEM FOR EUROPEAN XFEL BEAM DISTRIBUTION

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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 600 µs long bunch trains with a repetition rate of 10 Hz and a maximum energy of 17.5 GeV. 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}) and a long flat-top (~300 µs) with relatively slow rise/fall times (~20 µs) and fast stripline kickers (KS) with moderate stability but very fast pulses (~5 0ns).

OVERVIEW

Figure 1 shows a schematic overview of the European XFEL fill pattern and beam distribution system. The six KL flat-top kickers are operated with a rectangular 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 KS stripline kickers is installed, with which it is possible to extract individual bunches into the dump beamline (TLD) with the maximum bunch frequency of 4.5 MHz. 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].

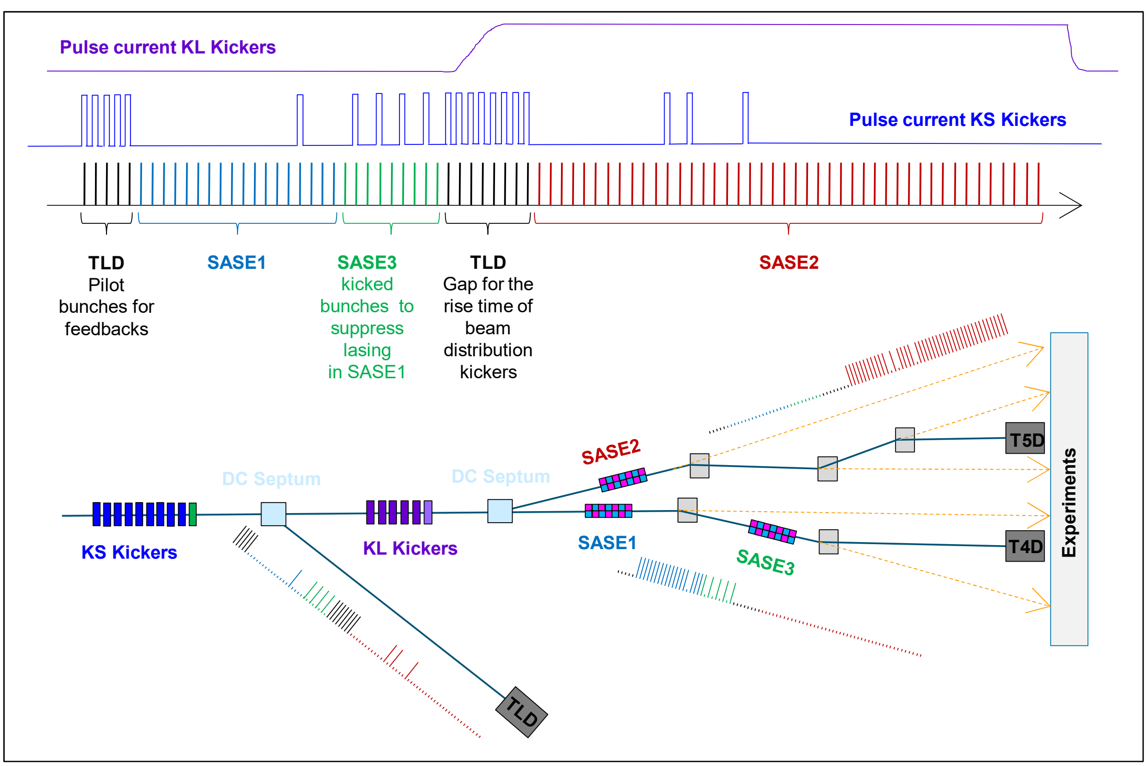

Figure 1: European XFEL fill pattern scheme: The flexible bunch pattern for the FEL lines is created by kicking all bunches that are not used for lasing into the main dump line (TLD) by means of the KS kickers. The bunch train parts for the FEL lines are distributed by the KL kickers. SASE2 bunches are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

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PARAMETERS

The kick angle $\Delta\theta$ [3] from a stripline kicker can be calculated with gap d and length L of the conductor:

$$\Delta\theta = 2g\frac{eV*L}{E*d}$$

E is the beam energy and V is the voltage between the two conductors. The geometry factor is $g \leq 1$ and a factor of 2 comes from the superposition of the magnetic and electric fields. The maximum operating voltage is ± 5 kV. The kicker has a length of 2 m and a gap of 30 mm. The maximum energy of the European XFEL is 17.5 GeV. The kick angle computes to 76 µrad for one kicker. 10 kickers are installed in the European XFEL accelerator, however, for the deflection angle of 0.5 mrad only 7 kickers are required, so there are 3 kickers as ready spares. Table 1 summarizes the KS kicker specification.

Table 1: Specification of the KS Kicker [4]

	Kicker (KS)
Pulse Form	Burst
Repetition Rate	4.5×10^{6}Hz
Max. Pulse Width	30×10^{-9}s
Rise/Fall Time	15×10^{-9}s
Rel. Amp. Stability	0.015
Rel. Residual Ripple	3×10^{-4}
Kick angle	0.5mrad
Int. Field at 20 GeV	33.4mTm
Kicker aperture	30mm
Kicker Type	Stripline
Kicker active length	2m
Number of kickers	10
Pulser Voltage	5kV
Pulse Current	100A

STRIPLINE KICKER MAGNET (KS)

The KS stripline kickers (Fig.2) are located inside the vacuum and act as a transmission line with an impedance of 50Ω. In order to obtain a small reflection factor, it is important to take into account the dimensions of the kickers on parallelism, separation and concentricity of the striplines to each other and the location of the striplines within the vessel. The striplines are mounted to half-shells with ceramic spacers. After assembling the striplines, the half-shells of the vacuum tank are welded together with a 2m weld. Ceramic spacers allow for mechanical expansion of the striplines relative to the vessel and vice versa, e.g. during vacuum bake-out. The centre spacer is fixed, whilst the end spacers allow for longitudinal movement (sliding). Bellows are installed for decoupling so that the forces of the length change (thermal expansion) of the conductor do not damage the insulating ceramics of the high-voltage feedthroughs. This is based on the design of the IBFB kicker developed by Paul-Scherrer-Institute (PSI) [5].

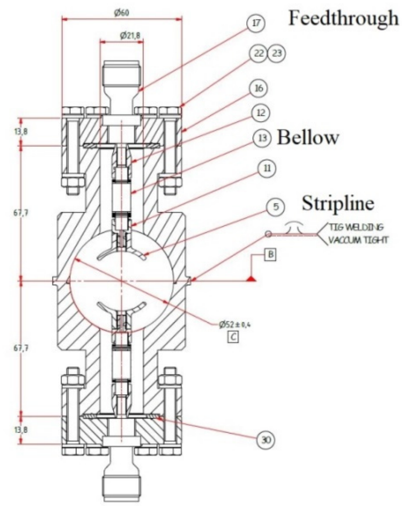

Figure 2: European XFEL KS dump kicker cross section.

PULSER (KS)

For the KS dump kickers, commercially available pulse generators from the company FID are used in push/pull configuration. Very important aspects for the pulse specification were the residual baseline ripple after 222 ns (4.5 MHz maximum pulse frequency) for those bunches that are passing into the undulator lines and to maintain a reasonable stability of the pulse amplitude for those bunches that are kicked into the dump line. The pulse rise and fall time is 14 ns. Statistical analysis of many kicker pulses shows very small variation of both the flat-top amplitude and the rising/falling edge shape (Fig. 3). The duration of the pulse flat top was fixed to 30 ns so pulse jitter will not influence the deflected bunch.

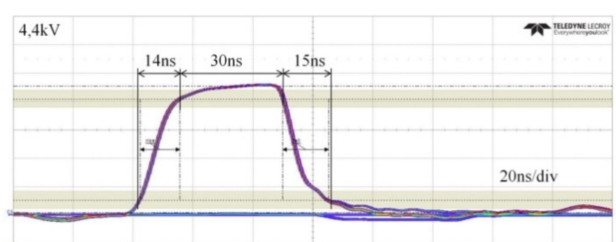

Figure 3: Scope screen showing overlaid pattern of pulses with stable flat top and non-ripple baseline.

A total of 20 pulsers are installed. During commissioning of the Linac, there were a significant number of failures of the pulsers, but these were quickly eliminated by partial redesign, more radiation shielding and improved operating procedures. In 2018, there were no more outages.

During the user runs, beam stability was further optimized and the number of bunches was continuously increased, so that the standard mode with 600 bunches at a repetition rate of 1.1MHz is possible. At present, the 600 bunches can be distributed to three user experiments.

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While reducing the bunch repetition rate in the SA1 beamline from 1.1 MHz to 584 kHz by kicking every second bunch into the dump beamline with the KS kickers, a rising displacement of the remaining bunch train in the SA1 beamline was observed (Fig.4). On the vertical axis is the displacement and on the horizontal axis is bunch position number. We see a displacement of 25 µm from the first to the last bunch of train.

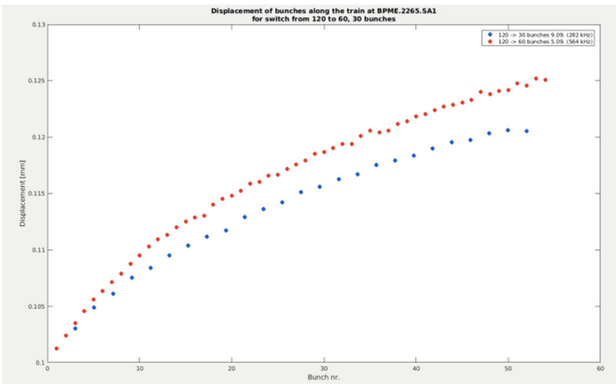

Figure 4: Displacement of bunches along the train at BPME.2265.SA1 for switch from 120 to 60 bunches.

This effect was later re-examined during a 4.5 MHz study period. In the accelerator 500 bunches were generated with a bunch repetition rate of 4.5 MHz. The experiment was started with 100 pre-bunches and 400 bunches in beamline SA1. The offset was measured with a downstream high precision cavity beam position monitor (Fig. 5).

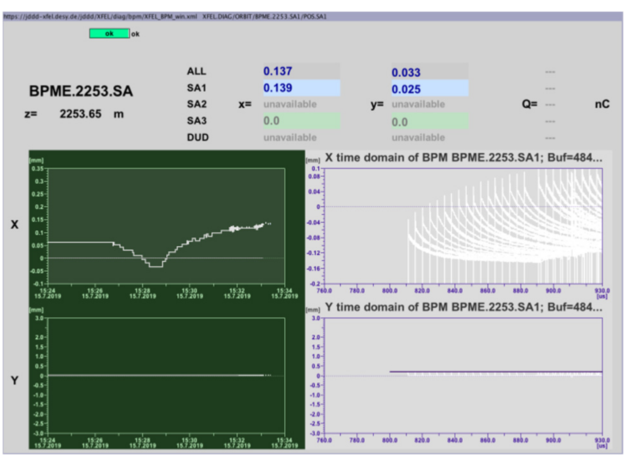

Figure 5: Displacement of bunches along the train at BPM_2253.SA1 with operation of 4.5 MHz.

Then step-by-step the number of pre-bunches was increased by 20 and the number of SA1 bunches was reduced by 20, so that the maximum allowed number of bunches remained the same. An increasing offset with an initial amplitude of up to 200 µm and an exponential decay clearly can be seen. We attribute this effect to eddy currents in the kicker chamber. The eddy currents induced by each kicker pulse (while kicking the pre-bunches into the dump beamline) have not decayed yet when the next pulse occurs, this leads to accumulation of the residual field up to a saturation level. As the bunches in the SA1 bunch train are not kicked, the residual field induced into the kicker chamber decays.

Figure 6 shows a fit of the rising x-offset with rising number of pre-bunches (blue line) and the decreasing x-offset over the SA1 bunch train (red line). The eddy currents lead to about 2 µm relative kick after 200 ns with a damping time of approximately 20 µs. The nominal kick of the KS kickers is about 18 mm at this position, thus the effect is of the order of 1e-4.

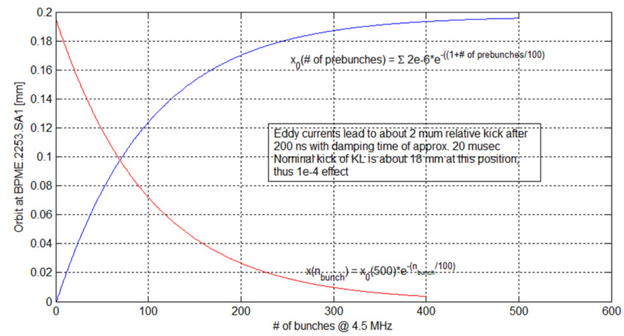

Figure 6: coarse fit of x-offset rising with rising number of pre-bunches (blue) and decreasing over SA1 bunch train (red).

The time constant of the eddy current can be influenced by the choice of chamber material, by its conductivity, or by the pulse shape (rise and fall time). The lower the conductivity of the material, the faster the eddy currents will decay, and the slower the rising and falling edges, the lower the eddy currents will be. This will be studied in the future to reduce the effect.

SUMMARY

The Beam Switchyard of the European XFEL allows fast switching between the various SASE beamlines, which was made possible by the development of a fast kicker system. The residual orbit changes caused by the fast switching should be eliminated by the feedforward capabilities of the intra bunch train feedback.

As the offset due to the eddy currents exceeds the specifications for the existing intra bunch feedback system, a new feedforward system has to be implemented. Most probably one of the KL kickers [6] will be modulated with a correctional signal.

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