# KICKER PULSER WITH HIGH STABILITY FOR THE BESSY FEL *

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## Abstract

In this paper the developement, design, and construction of a new semiconductor based very high stability kicker pulser is described. Measurements with a prototype pulser connected to a dummy coil show a relative field stability smaller than $\Delta x \leq 5 \mu$ m during 2 hours of operation. Further improvements are discussed.

## INTRODUCTION

The HGHG FEL [1] recently proposed at BESSY will operate with three independent FEL beam lines. The electron bunches from the source will be accelerated by the main LINAC and then distributed with a kicker with at a repetition rate of 1 kHz into the low energy and medium energy FEL beam lines at energies of 1.02 GeV and 2.3 GeV, respectively. To obtain maximum FEL gain it is crucial that the beam is well centred in the undulator sections. The limit for the relative stability of the extraction angle $\theta$ was found to be $\Delta\theta/\theta \leq 5 \cdot 10^{-5}$ . The BESSY II extraction and injection kickers achieve a relative shot-to-shot stability of around $7 \cdot 10^{-4}$ (excluding long term drifts) using established technology for the kicker pulser such as LC circuits with thyratron switches [3]. This seems to be the stability limit of a non-feedback design and is more than one order of magnitude away from the requirement for the BESSY FEL. Here we present the design and measurements a novel kicker pulser whose performance meets the requirements.

## DESIGN PARAMETERS

The FEL kicker system design result from performance requirements constrain due to the available space, the electron optics and the LINAC timing structure. Its parameters are independent of the specific design of the kicker magnets and are summarised in Table(1).

## SEMICONDUCTOR BASED PULSER

The performance of the extraction system is determined by the reproducibility and long term stability of the kicker pulser. There are two different causes of magnetic field variation: amplitude jitter and phase jitter. The phase jitter is generated by small temporal fluctuations of the pulse firing caused by thermal noise in the pulser electronics and by cross-talk. Amplitude noise is caused by fluctuations due to remaining ripples of the power supply and by temperature drift effects. A new kicker pulser was developed based on a power semiconductor switches (Insulated Gate

| Kick amplitude | 5 mrad |
|---|---|
| Deflecting field jitter | $5 \cdot 10^{-5}$ |
| Repetition rate | 1 kHz |
| Pulse form | sine half wave |
| Pulse duration | $< 2 \mu$s |
| Number of magnets | 5 |
| Number of windings | 1 |
| Total magnet length | 2.5 m |
| Kicker gap height | 12 mm |
| Max. pulse current | 120 A |
| Inductance incl. connectors | 1 $\mu$H |
| Circuit capacity | 200 nF |

Table 1: FEL kicker system parameters

Bipolar Transistor - IGBT), Fig 1. This prototype unit was built within the specification shown in Table (1) To optimize its stability during its development several measures where applied as

- optimized geometry of the power stack to minimize intrinsic inductivities

- careful design of the grounding geometry

- gate drive of the semiconductor switches hardened against cross-talk

- accurate pulse forming by electronic decoupling of stray capacitors, like cables, from power supplies.



Figure 1: Prototype Pulser unit with dummy coil (blue)

The prototype pulser unit was tested at rated currents of up to 200 A and with repetition rates from 10 Hz to 1 kHz. As a dummy for the kicker magnet coil a solenoid with five windings was used.
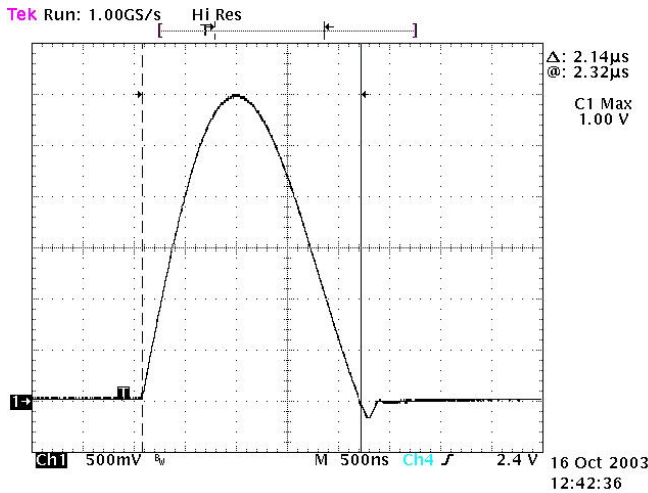
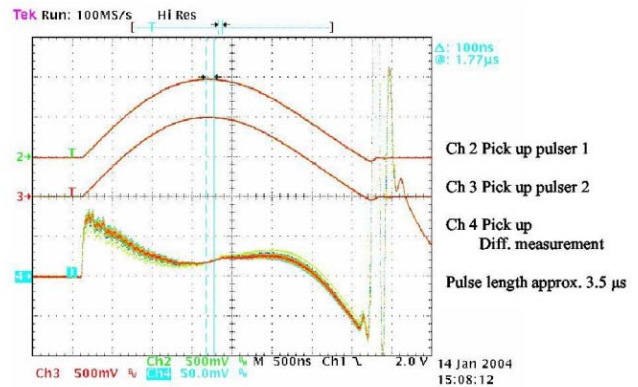Figure 2: Pulser current measured with the internal current transformer



Figure 3: Superposition of 100 consecutive kicker pulses generated by two identical kicker units and of the resulting difference signal. The amplitude of the difference signal (lower trace) is spread by a factor of 10 in comparison to the individual pulses (upper 2 traces)

## PULSE SHAPE MEASUREMENTS

The output current on a dummy coil measured with a low noise and EMI resistant Pearson current transformer is shown in Fig(2). The pulse length and width are in accordance with the theoretically expected values and no transient oscillations could be detected.

These measurements were carried out with a Tektronix oscilloscope at the resolution limit of the analyzer. As a trigger source and timing reference a very precise Stanford Research Systems Digital Pulse generator was used. The measured amplitude jitter limit is outside of the 8 bit resolution of the oscilloscope. Therefore from these direct measurements only an upper bound of $\Delta\theta/\theta \leq 3 \cdot 10^{-4}$ for the amplitude jitter can be given.

Hence a different method to prove a stability limit one order in magnitude smaller than this was developed. The current of two identically constructed pulser circuits pass the same current transformer but in reverse directions. The measured signal then is generated out of the substraction, of the two nearly identical pulse currents, leaving a signal with an amplitude attenuated by two orders of magnitude. Both pulsers were put front to front but rotated by $90^o$ such minimizing crosstalk via the magnetic field of both solenoid coils. As the output signal of the Pearson transformer is lowered the internal offset and the maximum resolution of the oscilloscope of 1mV could be used. The differentially measured voltage signal corresponds to the stability of two pulser systems. Presuming both pulser systems have the same stability, this value of stability can be divided by $\sqrt{2}$. The measured jitter amplitude of 3mV (see Fig.(4) and Fig(3) lower trace) corresponds to a peak to peak stability of $\Delta\theta/\theta \leq 5 \cdot 10^{-5}$ well within the given limits.
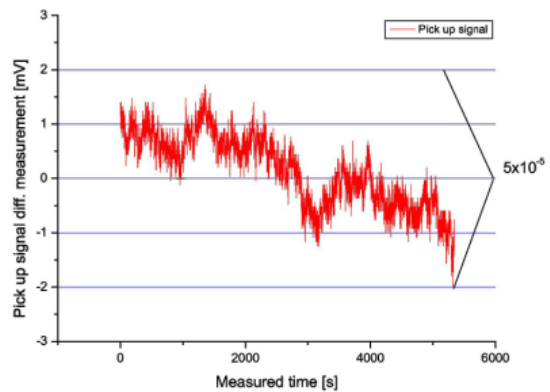


Figure 4: Test pulser; field amplitude at test coil vs. time in s

## ELECTRO-OPTICAL MAGNET PULSE MEASUREMENT

For calibration during FEL operation, an opto-electrical method is under development allowing online control of the magnetic pulse height.

The main problem is the large dynamic range required for the measurement of small fluctuations around a high amplitude signal. An electro-optical set up was realized to measure the magnetic field by means of the Faraday effect (see Fig.(5)). A crystal with a high Verdet constant (Terbium-Gallium-Garnet, TGG) is positioned inside the kicker coil. A polarized laser pulse from a He-Ne laser is sent through the crystal, passes a polarizer downstream and then hits a highly sensitive photo-diode. The TGG crystal turns the polarisation plane of the laser pulse according
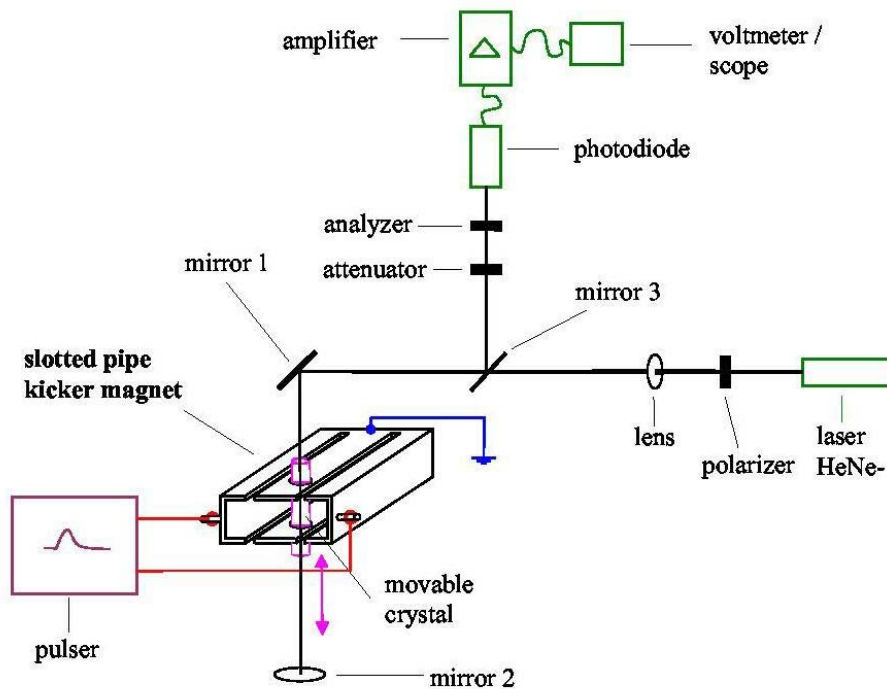
Figure 5: Scheme of an electro optical high resolution jitter measurement.

to the instantaneous magnetic flux delivered by the coil. The polarizer position is turned on maximum flux extinction with the magnetic field at its reference value. Small field fluctations around the reference field give rise to fluctations of the laser pulse flux after the polarizer measured by photo-diode.

The main advantage of this setup the ability to measure the fluctuations against a vanishing signal (black) instead small changes of the amplitude of a bright signal. A prototype setup was installed and it was demonstrated that its capable to directly map the kicker pulse. Such a system is planned to be used in a future amplitude feedback with the aim to actively stabilize long term amplitude drifts.

## FUTURE IMPROVEMENTS

The prototype pulser will being improved to even higher field stability . Important issues under investigation are:

- proper choice for the semiconductor parts

- influence of temperature changes during operation and effectiveness of measures against temperature drifts

- alternativ grounding concepts

- cross-talk behaviour for different realisations of the electronic boards

- different trigger concepts.

The stability of the power supply voltage is crucial for the magnitude of the amplitude jitter. The power supply unit used for our experimental setup so far was not optimized towards output stability. A more suited device should further improve the results.

## REFERENCES

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