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COMMISSIONING AND STABILITY STUDIES OF THE SwissFEL BUNCH-SEPARATION SYSTEM

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Abstract

SwissFEL is a linear electron accelerator based, X-ray Free Electron Laser at the Paul Scherrer Institute, Switzerland. It is a user oriented facility capable of producing short, high brightness X-ray pulses covering the spectral range from 1 to 50 Å. SwissFEL is designed to run in two electron bunch mode in order to serve simultaneously two experimental beamline stations (hard and soft X-ray one) at its full repetition rate. Two closely spaced (28 ns) electron bunches are accelerated in one RF macro pulse up to 3 GeV. A high stability resonant kicker system and a Lambertson septum magnet are used to separate the bunches and to send them to their respective beamlines. With the advancement of the construction of the second beamline (Athos) the bunch-separation system was successfully commissioned. In order to confirm that the beam separation process is fully transparent a stability study of the electron beam and the free electron laser in the main beamline (Aramis) was done.

INTRODUCTION

The first undulator line of Swiss X-ray Free Electron Laser (SwissFEL) [1], Aramis, was inaugurated in 2016 and the first pilot experiment was conducted in 2017. In 2018 the nominal electron beam energy was achieved and the free electron laser reached its shortest designed X-ray wavelength of 1 Å. The two experimental stations of Aramis (Alvira and Bernina) were commissioned and in the beginning of 2019 Aramis SwissFEL line started regular user operation. In parallel, the second undulator line (Athos) is being constructed [2]. First electron beam to Athos was sent in September 2018 and in December the bunch-separation system was commissioned and the separation of the two bunches was successfully demonstrated. Starting two bunch operation in the early stages of Athos commissioning is very beneficial because it can be done in parallel with regular Aramis user operation.

In order to separate the two electron bunches they both are deflected by a fast resonant kicker system [3] – one up and one down. Compensating dipoles counteract the deflection of the down-kicked bunch and send it straight through the zero-field region of the Lambertson septum to the Aramis beamline. The up-kicked bunch is deflected by the Lambertson field sideways and it is sent to Athos beamline. Since the two bunches are deflected the stability of the kicker system is crucial for the proper operation of both beamlines. To confirm that the bunch-separation is fully transparent and does not affect operation of Aramis beamline several tests were conducted. The results of these tests are discussed below.

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RESONANT KICKER COMMISSIONING

The two Resonant Kicker (RK) magnets are a key component of SwissFEL electron bunch-separation system. They deflect the two consecutive electron bunches in opposing directions vertically before they are finally separated by a Lambertson septum about 8 m downstream. To work properly RKs need adequate electrical excitation and tight synchronization to the electron beam. To ensure that the deflection amplitude stability down to the ppm level is not dominated by the phase error the RK should be synchronised to a 10s of ps level. A dedicated synchronization module was developed to combine the trigger from the generic accelerator timing system (providing 7 ns resolution) and high stability RF clock in order to generate proper timing with 10 ps programmable delay resolution. High stability RF driver (17.8 MHz) excites the resonant structure to reach the required current, respectively the deflecting magnetic field.

Envelope Synchronization

The RKs were first commissioned in the straight accelerator beamline (Aramis). Using a small deflection amplitude (within the machine acceptance) and detecting the kick with beam position monitors (BPMs) downstream the resonance envelope was located. Figure 1 shows an envelope scan of the RKs excitation. The excitation curve appears backwards because the RKs' delay with respect to the beam arrival time in the scan is increased.

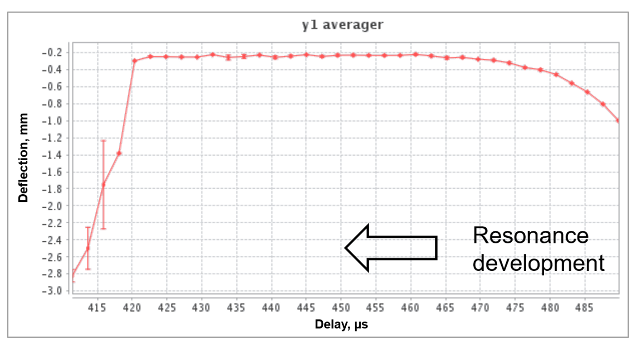

Figure 1: RKs' excitation envelope scan of vertical deflection downstream the kickers.

Phase Synchronization

Once the rough position of the resonance envelope is located the correct phase has to be found. A much finer scan (Fig. 2) was used to probe RKs' deflection and later was used to position the electron bunch at the sine wave crest, where the deflection is maximum and is least sensitive to phase error.

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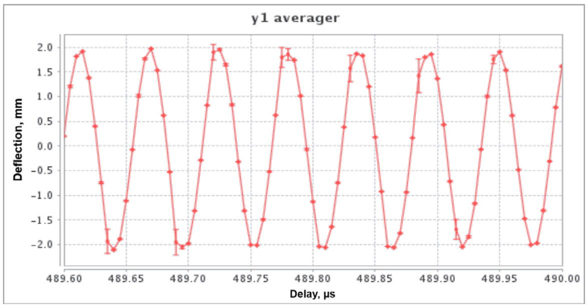

Figure 2: RK phase scan of vertical deflection downstream the kickers.

BUNCH SEPARATION

After the timing setup, the system was tested for phase inversion. It was confirmed that a single bunch can be sent to either Aramis or Athos depending on RKs' phase (180º RKs phase inversion). The proper beam position at the septum location (bunches separation of 10 mm, Fig. 3) depends on all five deflecting elements: two RKs and three compensating dipoles. Since the two bunches are aligned with the positive and negative crest of the RKs' sine deflecting field they experience a deflection and thus a vertical separation. The compensating dipoles act on the two bunches equally, deflecting them up-wards. The amplitude of the RKs and the compensating dipoles is automatically set to provide trajectory compensation for the down-kicked bunch and the required deflection for the up-kicked bunch according to the beam energy.

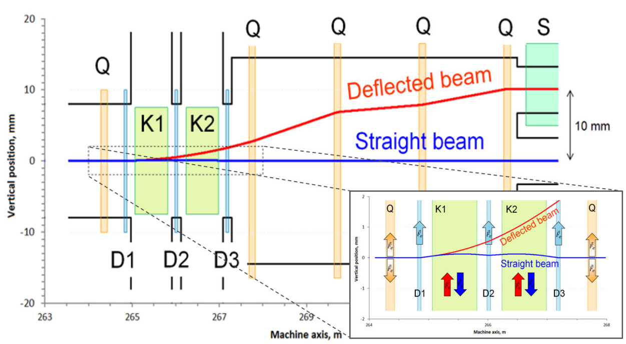

Figure 3: Bunch trajectory in the switchyard region and a zoom into the RKs' region with their corresponding deflecting field regions: Q – quadrupole magnet, K1, K2 – resonant kickers, D1, D2 and D3 – compensating dipoles and S – septum.

SwissFEL BPMs are specially designed to distinguish position and charge of the two 28 ns spaced electron bunches [4] allowing us to track both bunches separately even when they still share the same beam pipe. Figure 4 shows vertical beam position in the two beamlines for the first beam separation test. The RKs-Septum range is indicated. The apparent difference in position is due to the fact that first graph plots the vertical position against machine "Z" axis and the second against BPM number. Bunch two makes large excursion from the beam pipe axis on its way to field gap of the septum 10 mm upwards. Please note the different vertical scale of the two graphs.

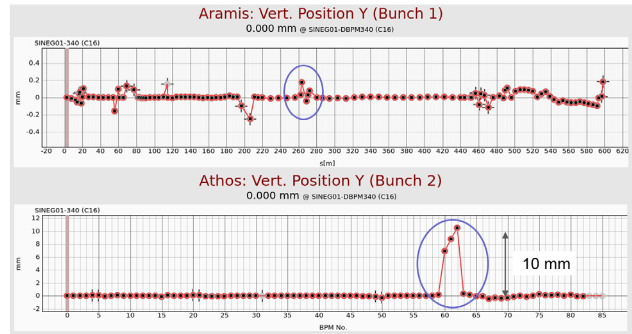

Figure 4: Vertical position of the two bunches during bunch-separation: upper graph – "Bunch 1" through Aramis beamline and lower graph – "Bunch 2" through Athos.

ELECTRICAL STABILITY

The RK system was specially developed to meet high stability pulse-to-pulse beam position requirements necessary for proper Free Electron Laser (FEL) operation. Dedicated RF drivers were designed to excite the resonance with 1 ppm amplitude resolution. To monitor and stabilize the RKs' amplitude two dedicated measurement systems were developed: a Full Range Measurement (FRM) system and Precision Measurement System (PMS). The FRM system measures the overall amplitude of the RKs with measurement noise floor of ~5 ppm rms and the phase with ~1 millidegree rms. The PMS has much smaller measurement window (~1 ppt) but measures with sub ppm resolution level[3]. The pulse-to-pulse amplitude jitter of the RKs during routine operation is 2 to 3 ppm rms and the phase stability is 2 to 3 millidegree averaged over the macro pulse (the phase noise contribution to the amplitude is negligible). An amplitude feedback (using PMS) and a phase feedback (using FRM system) are controlling the magnets in order to ensure high precision deflection. Motorized mechanical tuner, driven by an iterative algorithm is used to tune RKs' resonator frequency in order to operate at the top of the resonance curve where deflecting current amplitude is maximum and the magnet is least sensitive to mechanical vibrations.

ELECTRON BEAM STABILITY

The bunch-separation system (mainly due to its RKs) is expected to be the most critical element concerning electron beam stability. Since the two bunches are deflected it is possible to check stability using the bunch going straight through Aramis beamline (in single bunch mode). A direct comparison between the bunch going directly through (all deflecting elements off) and when it is deflected (down) and back compensated is done for electron beam trajectory, electron beam shot-to-shot position stability, FEL photon beam shot-to-shot pulse energy and pointing stability. No significant change in horizontal and vertical beam trajectory was found. This indicates proper strength of the RKs and compensating dipoles.

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Figure 5 shows shot-to-short horizontal and vertical electron beam position running standard deviation of 100 consecutive pulses measured by a BPM (SARUN02-DBPM070) right before the FEL undulator section. Note that bunch-separation system is On when the "Kicker mode" shows zero (bottom curve in all following figures). The large jump in vertical standard deviation is due to the turn-Off transient of the deflecting elements. The reprogramming of the RKs and the compensating dipoles is not beam synchronous and up to a couple of bunches could be disturbed during the transient. No notable change in electron beam stability can be seen.

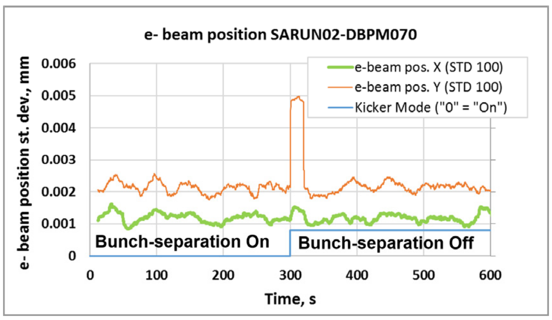

Figure 5: Electron beam position standard deviation of 100 consecutive pulses right before the FEL undulator section with bunch-separation system On and Off.

PHOTON BEAM STABILITY

The effect of bunch-separation system on FEL photon beam pulse-to-pulse stability was checked as well. Measuring the FEL pulse stability should be an even more sensitive way to detect electron beam disturbance and furthermore it serves as ultimate test to determine if the system stability is sufficient.

Amplitude Stability

For FEL photon pulse energy pulse-to-pulse stability two measurement methods were used. The first one was based on the non-destructive gas monitor (SARFE10-PBPG050) and the second (destructive) was based on an integration of photon beam camera image (SARFE10-PPRM064).

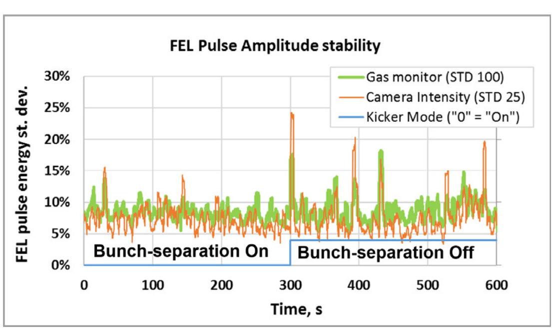

Figure 6: FEL photon beam pulse energy standard deviation of 100 consecutive pulses measured with gas monitor and photon beam image camera with bunch-separation system On and Off.

Since the camera pixels' intensity is proportional to the number of absorbed photons (with FEL wavelength 1.5 Å, within the linearity of the screen conversion) the image intensity integral is proportional to the total absorbed photon pulse energy (not to electromagnetic field intensity). Figure 6 shows standard deviation of the two measurements. Camera image acquisition was about 4 times slower (roughly giving information for each fourth FEL pulse). To match the two results' time structure the running standard deviation calculation for the camera measurement takes 4 times less data points

Pointing Stability

Bunch-separation system effect on the FEL photon beam pointing position was also investigated using the same beam image camera described above. Figure 7 shows horizontal and vertical position running standard deviation of the beams' centre of mass for 100 consecutive pulses. Apparently horizontal stability is much worse than the vertical. This is attributed to the mechanical stability of the screen-camera system (removable screen). The standard deviation peaks around seconds 390 and 580 are due to missing data points and could be associated to the limited bandwidth of the camera server. Thus the peak around turning Off the bunch-separation system might be real. Nonetheless there is no visible change in the FEL pointing position due to the bunch-separation system.

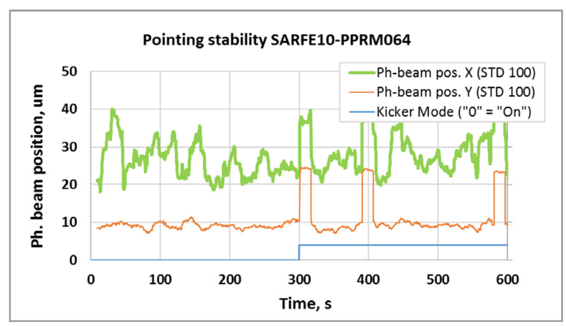

Figure 7: FEL photon beam horizontal and vertical position standard deviation of 100 consecutive pulses with bunch-separation system On and Off.

CONCLUSION

Aramis beamline of SwissFEL is in regular user operation. Commissioning of the second beamline (Athos) is on its way. A fully transparent operation of the bunch-separation system is crucial to the efficient operation of SwissFEL. Number of tests were conducted to check its effect on the electron beam and FEL. It was confirmed that for the level of stability of the Aramis FEL beam present for our measurements, the bunch-separation system did not add any additional jitter to the FEL pointing and pulse energy.

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REFERENCES

[1] SwissFEL, https://www.psi.ch/en/swissfel

[2] T. Schietinger, "Towards Full Performance Operation of SwissFEL", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 24-28. doi:10.18429/JACoW-IPAC2018-MOZGBD1

[3] M. Paraliev, C. Gough, "Resonant Kicker System with Sub-Part-per-Million Amplitude Stability", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3174-3177. doi:10.18429/JACoW-IPAC2017-WEPIK098

[4] B. Keil, R. Baldinger, R. Ditter, W. Koprek, R. Kramert, F. Marcellini, G. Marinkovic, M. Roggli, M. Rohrer, M. Stadler and D. Treyer, "Design of the SwissFEL BPM System", in *Proc. IBIC'13*, Oxford, UK, Sep. 2013, paper TUPC25, pp. 427-430.