SwissFEL RESONANT KICKER CONTROL SYSTEM

R. Krempaska, A. Alarcon, S. Dordevic, Ch. Gough, W. Portmann, M. Paraliev
Paul Scherrer Institute, Villigen PSI, Switzerland

Abstract

SwissFEL X-ray Free Electron Laser at the Paul Scherrer Institute is a user facility designed to run in two electron bunch mode in order to serve simultaneously two experimental beamline stations. 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 bunches and to send them to the respective beamlines. The resonant kickers control system consists of various hardware and software components whose tasks are the synchronization of the kickers with the electron beam, pulse-to-pulse amplitude and phase monitoring, generating pulsed RF power to excite a resonating deflection current, as well as movement of the mechanical tuning vanes of the resonant kickers. The feedback SW monitors and controls all the important parameters. We present the integration solutions of these components into EPICS.

INTRODUCTION

The Swiss X-ray Free Electron Laser [1] (SwissFEL) is a linear electron accelerator-based 4th generation light source capable of producing short, high brilliance x-ray photon pulses with duration of tens of femtoseconds down to hundreds of attoseconds for experimental research in material science, biochemistry, biophysics, and other fields [2]. SwissFEL has two undulator lines: a hard x-ray (Aramis) and soft x-ray (Athos) undulator line. To increase efficiency two closely spaced electron bunches are separated and sent to different undulator beamlines as schematically indicated in Fig. 1. This is done by a system of two high stability resonant kicker magnets followed by a septum magnet [3]. Both lines can operate simultaneously and independently up to the maximum machine repetition rate (100 Hz). In order to separate the two electron bunches both of them are deflected by a fast resonant kicker system: one up and the other 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 septum field sideways and is sent to the Athos beamline [3].

RESONANT KICKER CONTROL SYSTEM COMPONENTS

The Resonant Kicker control system was developed to meet high stability pulse-to-pulse beam position requirements necessary for the stable operation of the two FEL lines. Two identical kicker systems are used to reach the necessary beam deflection. The main components of each kicker magnet are: the timing and synchronisation system (TCS), the driver (DRV), the full range measurement (FRM), the precision amplitude measurement system (PMS) and finally the motion system used to remotely tune the resonant kicker (MOT).

Synchronisation and Timing System (TCS)

The goal of the TCS is to synchronize the kicker with the electron beam and to produce the so-called ‘pulse train’ in order to control the DRV. The TCS receives a start signal from an event receiver and resynchronizes it to a stable 142.8 MHz SwissFEL machine clock signal. The event receiver signal is provided by an EVR-300 card controlled by a VME IOC running on the IFC1210 module.

Driver (DRV)

A high amplitude stability and low phase-noise solid-state RF-driver developed at PSI provides up to ~7 kW RF power during the excitation period [3]. It is powered by a TDK-Lambda programmable DC power supply.

Full Range Measurement System (FRM)

The full range measurement system provides pulse-to-pulse amplitude and phase information about the oscillating current of the kickers. It is based on fast (250 MHz), high resolution (16-bit) ADCs interfaced by a field-programmable gate array logic (Virtex 6, Xilinx) [3]. Two ADCs are running in parallel to further reduce the measurement system jitter. The amplitude and phase information provided by the FRM is used for general resonant kicker monitoring and for a phase feedback [3].

Precision Measurement System (PMS)

The precision measurement system is a complementary offset-based system for higher performance amplitude measurements [3]. It provides higher (part-per-million) resolution measurement of the kicker’s sin-wave current amplitude using an offset or utilizing the so called balanced measurement method. However, this method has limited dynamic range (about 0.1% of the full range).

Motion System (MOT)

This module controls the stepper motors which move the mechanical tuning vanes of the resonant kickers and reads their position via incremental encoder attached to the motor. The motor control is used by the feedback SW for the resonant kickers’ tuning.

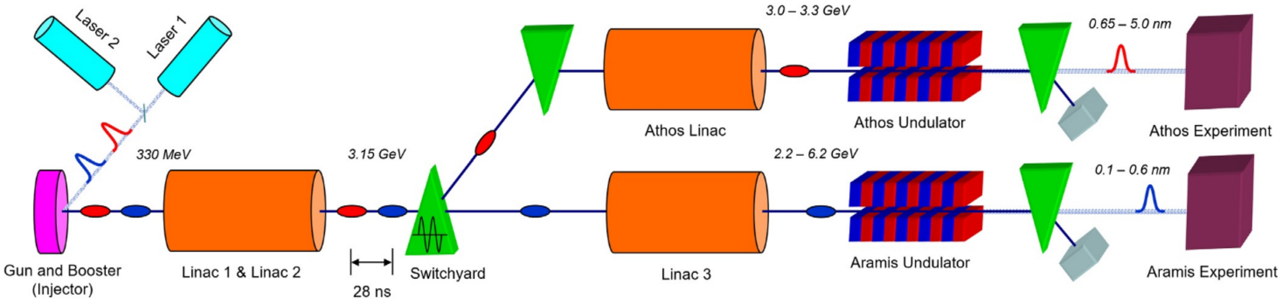


Figure 1: SwissFEL layout showing Athos and Aramis experiments and switchyard with resonant kickers.

EPICS Integration and User Interfaces

The resonant kicker magnets are integrated into the control system via EPICS [4] Input Output Controllers (IOCs) running on different platforms. On Fig. 2 there is an overview of electronic modules and control system hardware and software components. The IOCs for control and monitoring of all the required parameters of the timing, driver, full range and precision range measurement systems are running on the MOXA DA-662A-16-LX Linux servers [5] connected via serial RS422 interface with the respective electronic modules. To communicate with the electronic modules the EPICS stream device support [6] is used. The amplitude and phase readout of FRM and PMS systems is implemented in EPICS by using the RS422 interrupt (I/O Interrupt) with the full machine repetition frequency of 100 Hz. Each resonant kicker is controlled by IOCs running on dedicated MOXA servers.

The timing precision delay settings are implemented in EPICS IOCs, which communicate with the TCS electronics and the VME IOC using the event receiver card (EVR). In order to synchronize the kickers with the electron beam, we need to start the kickers' current excitation exactly in the moment when the current sin-wave has the correct phase. Because the granularity of the EVR is about 7 ns, (which in comparison with the kickers resonance frequency period of 56 ns is too coarse to make sufficiently small steps for the phase fine control) an additional fine delay concept is needed. The phase control with smaller steps, as well as the local delay control is done dynamically in EPICS IOCs as follows. When a specific delay is programmed to adjust the start of the pulse train (to ensure the proper resonant kicker current phase), the closest smaller delay with granularity ~7 ns is found and programmed to the EVR local delay. The rest of fine delay (smaller than the EVR step) is programmed to the TCS fine delay generator. On the operation side the time delay is set directly with higher resolution and is fully transparent for the user. Once a new delay value is programmed, the local EVR delay and the fine TCS delay settings are dynamically calculated in EPICS records and then they are programmed in the EVR and TCS systems respectively. In this way the EVR timing granularity of ~7 ns is improved with the resolution of the TCS fine delay (10 ps). Figure 3 shows the user interface to program the kickers timing parameters. There are delay settings fields for the pulse train and for the measurement window.

Each hardware component (TCS, DRV, FRM and PMS) has an integrated diagnostics capability that gives information about the internal states of the device (like PCB and chassis temperature, supply voltages alarm states etc.). To avoid developing specific IOCs for each device a standardized approach is used. An "intelligent" universal DIAG IOC is developed capable of serving all existing HW devices. After the DIAG IOC is started it acquires automatically information from the particular device it is connected to for all available process variables (PV) channels. This includes PV description, alarm levels, EGU etc. Such an automatized approach simplifies the IOC configuration with large amount of diagnostics data. DIAG interface and the rest of the other data interfaces are using separate physical channels and separate MOXA server to ensure seamless kickers' operation.

The motion control of the kickers' tuning vanes runs on the Power Brick Delta Tau Power PMAC system. As there are only two motor axis required the motor driver is shared with other systems.

For the temperature monitoring of kicker magnets (water and rack air temperature), a PSI in-house developed precise temperature measurement system is used which communicates with the sensors via EtherCAT using the EPICS ecat2 device driver [7].

In order to detect cooling-water failures, pressure gages are installed to monitor the input and output of the cooling circuit pressure [3]. This is done via IOC communicating with the WAGO I/O system using Modbus EPICS module [8].

To protect the driver module against overheating, there is an active protection via EPICS records which constantly monitor the driver's internal temperature. In case of overheating the module is switched off. In addition, there are so called soft IOCs running on Linux virtual machine providing information for the feedback program and for the SwissFEL Operation in the Control room.

Figure 4 shows the switchyard overview panel that includes the main parameters of all switchyard magnets. If more detailed information is necessary each of the submodules have dedicated expert panels. Figures 3 and 5 show the expert panels of the TCS and FRM components. The panels are running by using caQtDM Graphical User Interface [9], a standard tool developed and used at PSI.

ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUPDP106

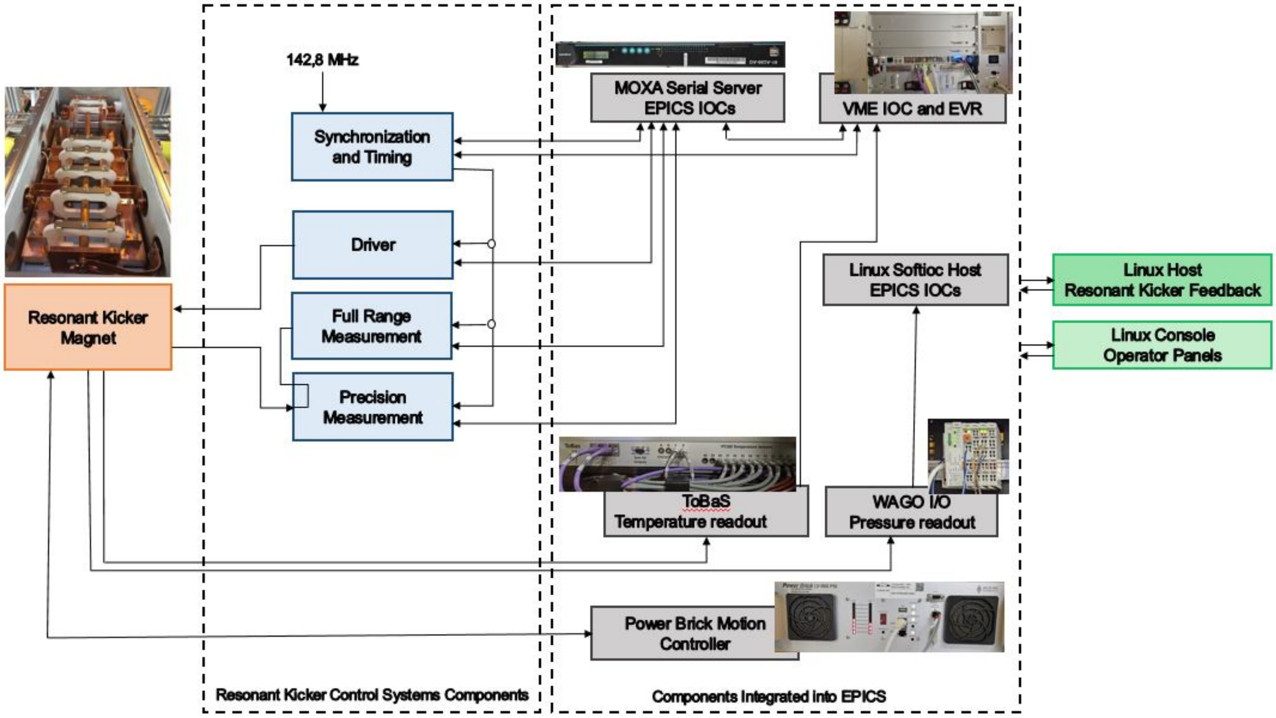
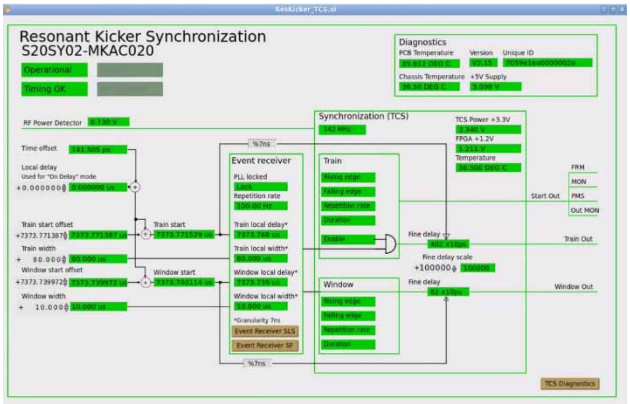
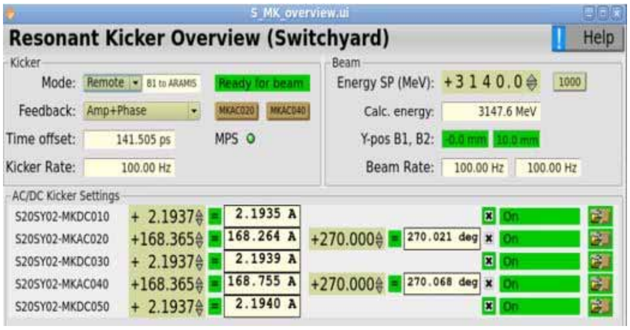


Figure 2: Resonant kicker control system overview. In the dashed rectangular on the left side the electronic kicker's control system components are shown, in the dashed rectangular on the right side the EPICS components are shown. The IOCs to control and monitoring the kicker electronic components run on the MOXA serial server. The synchronisation with the SwissFEL machine clock signal (142.8 MHz) is provided by the Synchronisation and Timing system, the trigger pulses are provided by the EVR-300 VME card. The cooling water temperature and pressure values are supplied by the WAGO and a PSI in-house developed precise temperature measurement system.



Time offset: 141.505 ps
Local delay: +0.000000 0.000000 us
Train start offset: +7373.771387 7373.771387 us
Train start: 7373.771529 us
Train width: + 80.000 80.000 us
Window start offset: +7373.739972 7373.739972 us
Window start: 7373.740114 us
Window width: + 10.000 10.000 us
Repetition rate: 100.00 Hz
Train local delay*: 7373.768 us
Train local width*: 80.000 us
Window local delay*: 7373.739 us
Window local width*: 10.000 us
TCS Power +3.3V: 3.340 V
FPGA +1.2V: 1.211 V
Temperature: 36.500 DEG C
Fine delay: 402 x10ps
Fine delay scale: +100000 100000
Fine delay: 82 x10ps
RF Power Detector: 0.730 V
PCB Temperature: 35.812 DEG C
Version: V2.15
Chassis Temperature: 36.50 DEG C
+5V Supply: 5.098 V

Figure 3: Timing and Synchronization expert panel to control the resonant kicker magnet (MKAC020).



Resonant Kicker Overview (Switchyard)

Kicker

Mode: Remote B1 to ARAMIS Ready for beam
Feedback: Amp+Phase
Time offset: 141.505 ps
Kicker Rate: 100.00 Hz

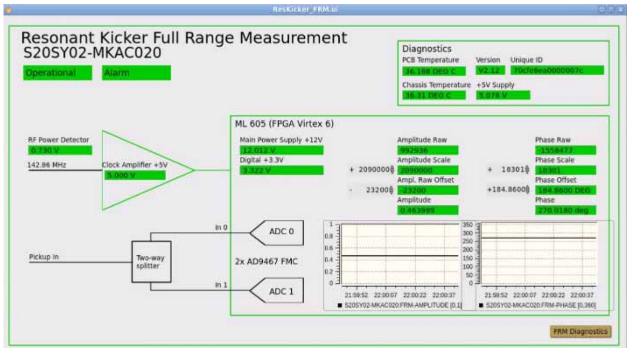
Beam

Energy SP (MeV): +3140.0 1000
Calc. energy: 3147.6 MeV
Y-pos B1, B2: -0.0 mm 10.0 mm
Beam Rate: 100.00 Hz 100.00 Hz

AC/DC Kicker Settings

S20SY02-MKDC010	+ 2.1937	2.1935 A			☒	On
S20SY02-MKAC020	+168.365	168.264 A	+270.000	270.021 deg	✕	On
S20SY02-MKDC030	+ 2.1937	2.1939 A			☒	On
S20SY02-MKAC040	+168.365	168.755 A	+270.000	270.068 deg	✕	On
S20SY02-MKDC050	+ 2.1937	2.1940 A			☒	On

Figure 4: Switchyard operation user interface.



PCB Temperature: 36.188 DEG C
Version: V2.12
Unique ID: 70cfe6ea0000007c
Chassis Temperature: 36.31 DEG C
+5V Supply: 5.078 V
RF Power Detector: 0.730 V
Clock Amplifier +5V: 5.000 V
Main Power Supply +12V: 12.012 V
Digital +3.3V: 3.322 V
Amplitude Raw: 992936
Amplitude Scale: + 2090000 2090000
Ampl. Raw Offset: - 23200 -23200
Amplitude: 0.463989
Phase Raw: -1558477
Phase Scale: + 18301 18301
Phase Offset: +184.8600 184.8600 DEG
Phase: 270.0180 deg

Figure 5: Full range measurement expert panel to monitor important parameters, like amplitude and phase information about the oscillating current of the kicker.

FEEDBACK SOFTWARE

The goal of the feedback software is to monitor and control kickers' parameters by using more than 80 EPICS PVs. There are three main feedbacks implemented, each using a different algorithm. The amplitude control of the kickers' deflecting current is done using a proportional integral (PI) type controller, the phase control of the kickers' deflecting current uses an integral (I) type controller; and the kickers' frequency tuning is done by an iterative algorithm similar to the I-type controller. To avoid interference effects between coupled feedbacks, the software implements the different controllers with different time response. This makes sure that, the faster feedback finishes before the next controller will start to react. The program runs in a loop measuring the kicker parameters, calculating the regulation outputs, such as charging voltage, timing delay and motor's movement, which are then finally set to the respective kicker's control system components. The feedback SW writes periodically the most important parameters of the system in a log file. The time interval between two entries depends on the dynamics of the regulation. When the system does not require large corrections the entries are made on larger intervals in order to reduce log file size.

The software is able to detect fault conditions like connectivity disruption or potential overloads. In such a situation it puts the system in a safe state and records the kickers' settings and system status for later analysis. In addition, a watchdog functionality runs on an IOC to indicate the feedback software is working properly. The program runs on a dedicated Linux virtual machine.

CONCLUSION

The SwissFEL machine operates routinely in the double bunch mode which allows simultaneous operation of two undulator beamlines Aramis and Athos. The separation of the two closely spaced (28 ns) electron bunches does not degrade the machine performance [3]. The two resonant kicker magnet systems developed at PSI provide stable separation between the two bunches. Finally, various electronic components are integrated into EPICS to provide a comfortable interface for the SwissFEL Operation and hides the complexity of the systems. We note the occasional communication interruptions of the IOCs running on MOXA DA-662A-16-LX serial servers which is due to high CPU load from IO traffic with kicker's electronic components. In order to avoid these issues, we plan to use more modern MOXA NPort serial servers and migrate the EPICS control on more efficient computers in near future.

ACKNOWLEDGEMENTS

The authors would like to thank the PSI expert groups for their professional contributions and help.

REFERENCES

[1] SwissFEL, `http://www.psi.ch/swissfel`

[2] SwissFEL Conceptual Design Report, PSI Bericht Nr.10-04, April 2012.

[3] M. Paraliev, "SwissFEL double bunch operation," *Phys. Rev. Accel. Beams*, vol. 25, p. 120701, Dec. 2022. `doi:10.1103/PhysRevAccelBeams.25.120701`

[4] Experimental Physics and Industrial Control System, `http://www.aps.anl.gov/epics`

[5] Moxa, `https://moxa.com/`

[6] EPICS StreamDevice. `https://paulscherrerinstitute.github.io/StreamDevice/`

[7] ecmaster, `https://github.com/paulscherrerinstitute/ecmaster`

[8] modbus, `https://epics-modules.github.io/modbus/`

[9] caQtDM, `http://epics.web.psi.ch/software/caqtdm/`