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Timing requirements and proposal of a timing concept for the European XFEL

Elmar Vogel, Valeri Ayvazyan, Jan Becker, Wilhelm Kriens, Kay Rehlich, Stefan Simrock and Patrick Tege

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To fulfill these requirements the timing system has to organize and steer a time sliced operation. This can be realized by performing a cycle consisting of an rf pulse sequence which is accelerating subsequent the different types of beam.

In addition, the technical properties of various subsystems like for beam creation, high power rf and rf control, diagnostics, accelerator control and experimental setups using FEL light have to be taken into account for the design and construction of the timing system.

The paper presents the major accelerator subsystem requirements, the actual status of considerations on the timing system hardware and a concept for the organization of a time sliced operation. It has to be viewed as a proposal intend for circulating ideas as possible starting point to elaborate a conceptional design report.

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1 INTRODUCTION

In the initial development stage the future European XFEL (fig. 1) offers five beam lines to users performing experiments with FEL light in the x-ray range [1, page 27]. One requirement on the accelerator is to supply electron beams to the different user beam lines simultaneously.

A first operational scenario is to accelerate on each rf pulse the same beam. After the collimation system a fast switching device is sorting bunches by kicking them into the different beam lines and into a dump. In such a way a parallel operation of the beam lines is achieved [1, page 96].

In the second scenario, beam parameters like the energy or the bunch pattern should be adjustable completely independent for each user beam line from the other beam lines within limits given by the energy bandwidth of the beam delivery system and the locations of dumps [2, 3]. This can be achieved by switching the acceleration parameters from rf pulse to rf pulse and sent beam to the different beam lines pulse to pulse. It is reasonable to organize such an operation in a cycle consisting of an rf pulse sequence similar to the ‘super cycles’ of the CERN accelerator complex [4, 5].

For a timing[1] system able to steer and organize the time sliced operation required for the second scenario the organization of the first scenario is automatically guaranteed.

Experimentalists using the x-ray FEL light may demand new types of beam patterns and energy variations at least every eight hours when shifts change while other users perform long term studies. Hence, the timing system has to be able to change parts of the sequence at runtime without disturbing the rest.

In summary, the system and concept to be developed shall provide

1. an rf pulse cycle, beam pattern and beam energy management
2. a parameter and data separation for different rf pulse types on the hardware and control system level and an operation separation for different rf pulse types of components at the user interface level
3. all operational parameters to all subsystems well in advance of rf pulses inclusive subsystems confirmation
4. real time information (event triggers) indicating the start and type of the different rf pulses sufficiently early for steering all components together with a dedicated ‘beam on’ flag
5. that the event trigger indicating the rf pulse type and start is followed by local broadcast event triggers with adjustable delay starting the operation of different components separately for different rf pulse types
6. a start of the rf pulses synchronized to the mains frequency synchronous to the rf gun laser and the transverse deflecting rf
7. automatic, accelerator wide compensation of signal propagation delays for event triggers
8. accelerator wide synchronized time stamps
9. real time information on incidents changing the operation for subsequent rf pulses shall be provided via the telegram of the ‘read out’ event trigger marking the end of all actions within an rf pulse.

[1] definitions for the nomenclature used may be found in the appendix

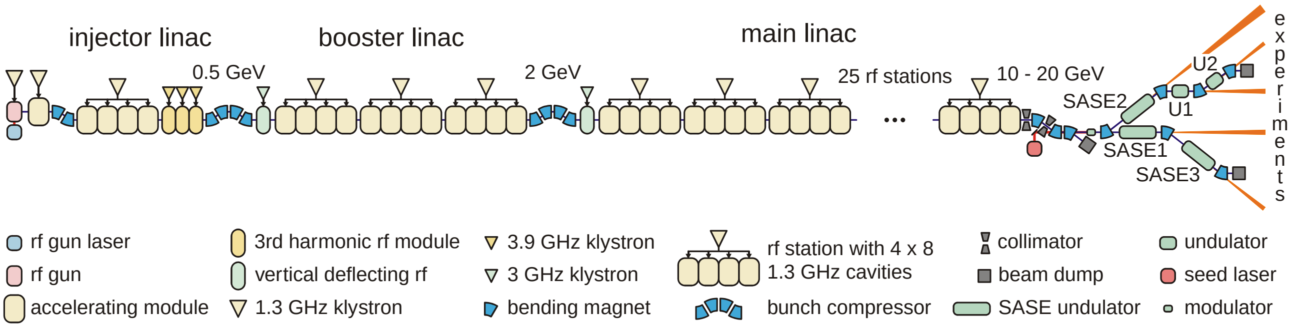

Figure 1: Sketch of the future European XFEL facility.

10. Real time information on incidents changing the operation within an rf pulse, e.g. beam inhibit required after beam loss will be distributed by the machine protection system (MPS). To keep the reaction time as short as possible the MPS is a distributed system operating independent [6, 7]. Nevertheless, MPS information shall also be broadcast postmortem by the timing system via the read out event trigger.

After presenting a collection of accelerator subsystem requirements in more detail a timing system organizing the operation of the different rf pulses will be discussed.

2 REQUIREMENTS FROM SUBSYSTEMS

2.1 RF control

For sufficient manageability the rf control electronics of the XFEL shall obtain for each rf pulse a complete set of event trigger signals: The first event trigger indicates the rf pulse type together with a time stamp information. The timing system shall sends this event trigger to the front end electronics accelerator wide at the same time with a resolution of one 1.3 GHz wave length (0.7 ns) and picosecond stability followed by a series of event triggers indicating the times to start various actions (fig. 2):

In a present scheme Lorentz force detuning is compensated using the piezo tuners for pre-excitation of the first longitudinal mechanical oscillation mode (284 Hz) of a cavity [8, 9]. The excitation is performed within four periods requiring 14 ms. Hence, before starting the rf pulse we have to wait at least 14 ms after an event trigger started the pre-excitation by the piezo tuners. The high voltage (hv) transformers have to build up and supply hv to the klystrons about 0.5 ms before the klystrons are able to drive the cavities. A drop of the hv can be prevented using bouncers or other hv cascade techniques. When the rf field in the cavities is build up beam can be accelerated.

After the rf pulse has been operated, an event trigger called ‘read out’ shall indicate the end of this operation distributing information on exceptional incidents potentially occurred and forcing front end electronics to provide data to the control system. Real time information on exceptional incidents like quenches, beam loss and single event upset caused breakdowns is required to prevent control loops using this exceptional rf pulse data spoiling corrections applied at subsequent rf pulses.

For rf calibration issues additional rf pulses without beam, lower duty cycle and gradient may be required. Inserting them, additional to the ‘normal’ rf pulse, may cause differences form the sequence of event triggers shown in figure 2. For such a scenario the timing system shall provide event triggers like the one for starting the klystron hv transformer two times before sending the (final) read out trigger.

Information for the front end electronics on how to react on the event triggers depending on the rf pulse type given has to be distributed in advance by the timing system via the local area network (LAN) requesting confirmation by the front end electronics. Such information are rf pulse type specific feed forward tables, gain factors, a definition of the algorithms to be applied, energy sweeps or chirps and so on.

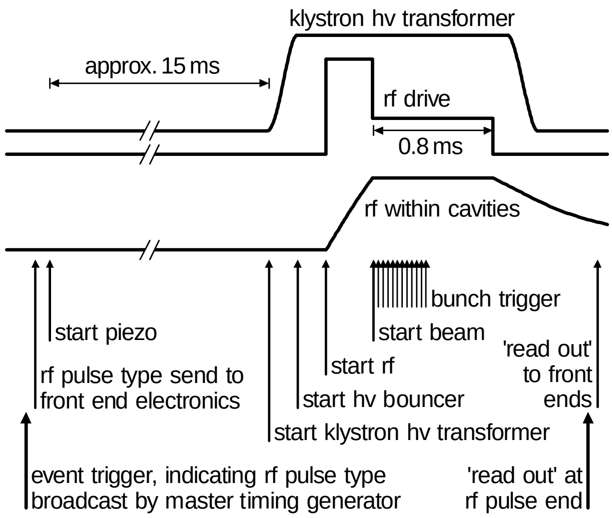

Figure 2: An event trigger send by the master timing generator (thick arrow) initiates event triggers adjustable per rf station (thin arrows) required to steer the time behavior of the front end electronics.

Table 1 (in the appendix) gives an overview on the timing signals required by the rf control systems. For completeness the rf reference and clock signals are also given.

2.2 *RF gun laser*

The electron bunches will be created via the photo effect by shooting short laser pulses on the cathode of a 1.3 GHz rf gun. To obtain the short laser pluses required (4.5 ps rms) a diode pumped neodymium-doped yttrium-lithium fluoride (Nd:YLF) laser oscillator with a round trip frequency of $f_{\text{round trip}} = 25\,\text{MHz}$ is operated in a harmonic mode locking scheme [10, 11]. The mode locker frequencies of 12.5 MHz, 100 MHz and 1.3 GHz obtained form the MO are determined by the round trip frequency of the laser oscillator which has to be an harmonic multiple of the maximum bunch spacing frequency of 5 MHz. In this way, a laser pulse train with a pulse repetition frequency of 25 MHz is generated from which a pulse picker lets pass only the pulses required for generating bunches, e.g. every 5th pulse for a 5 MHz bunch spacing. The laser pulses are amplified before being send to the rf gun cathode.

This scheme results in the following requirements on the timing and synchronization systems:

- Bunches can only be generated within a time grid of 25 MHz. Consequently the timing system shall only send event triggers starting rf pulses at times in correspondence to this grid.
- Changing phasings between the mode locker frequencies may cause shifts of the laser pulse train by multiples of 0.7 ns with respect to 25 MHz. Therefore, the phasings have to be controlled [11].
- The timing system has to provide triggers for the pulse picker to generate the bunch patterns requested.

2.3 *Transverse deflecting mode rf*

Measurements and diagnostics of the extremely short bunches are required for setting up FEL operation. One method foreseen for the XFEL is based on transverse deflecting rf cavities operating at 3 GHz, which is $\frac{30}{13}$ of the accelerating rf frequency (1.3 GHz). The high frequency time variation of the deflecting field is used to rotate the longitudinal beam profile into a transverse beam profile measured on an OTR screen [12, 13].

Bunches shall only be created at the correct 1.3 GHz to 3 GHz phasing, resulting in a time grid of 100 MHz. Hence, this phasing and the phasing of the mode locker frequencies discussed in the section above have to be adjusted and controlled appropriate.

2.4 *Accelerator operation*

The general requirements from accelerator operation on the timing system are already given by point 1 to 11 in the introduction. Concerning the points 1 and 2 the timing system to be developed should take into account the manageability by control room operators. In particular at the XFEL start up the system shall only provide an inevitable set of functionality to the operator which may be extended in case of missing features. The underlying hardware concept has to provide the flexibility for implementing missing features by reprogramming only.

A concrete requirement of accelerator operation on the timing system is a central management of the delay times and rf phases compensating the flight times of the beam. This will especially ease managing different path length through the accelerator, e.g. bypassing bunch compressors (rf phase changes required). Delays required by the front end electronics etc. will be added to this delays locally. These are rf pulse type specific parameters send via the LAN.

2.5 *Experiments with x-ray laser light*

Experiments using x-ray laser light require event triggers, indicating the rf pulse type and the rf pulse end. The signal propagation time of these event triggers has to be compensated in the same way as it is the case for electronics used for the accelerator subsystems. In addition, experiments require rf reference signals with different frequencies and the rf pulse type specific parameters send via the LAN. Using these signals and information they are able to set up electronics consisting of counters, programmable logic devices (like PFGAs) accessible from the control system to generate all trigger and clock signals fitting their needs [14], see table 2 in the appendix.

3 TIMING AND SYNCHRONIZATION

In addition to the timing system two synchronization systems are foreseen for the XFEL. One is based on distributing low noise rf clock signals [1, page 73] and the second one supplying drift free clock signals with femto second stability using laser light [1, page 126]. Figure 3 shows how all three systems may work together and Figure 4 shows a sketch of a potential physical topology.

A master timing generator (MTG) sends event triggers and telegrams synchronized to the mains frequency together with time stamps generated by counting a 1.3 GHz clock signal received from one of the master oscillators (MO or LMO) in correspondence to time information supplied by an external time normal like the computer time or a GPS receiver. These signals are processed locally by clock and timing relays (CTRs) before being sent to the front end electronics like beam diagnostics electronics or electronics for rf control. Timing decoders (TDs) within the front end electronics interpret the signals in real time and trigger the algorithms intended.

At a rough guess the XFEL requires about 500 crates for the front end electronics. Each of these crates contain one CTR. Common technology used in optical data transfer may be well suited for transporting the trigger and telegram signals from the MTG to the CTRs [16]. In case

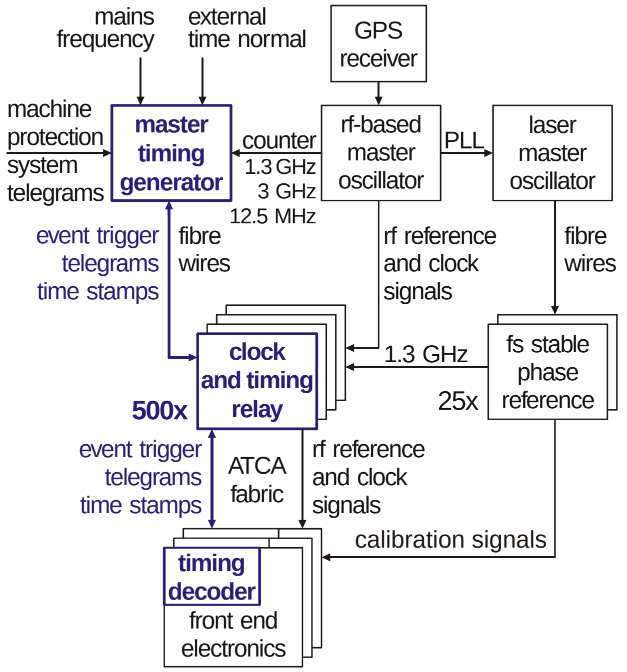

Figure 3: Sketch of the interrelations between the timing system and the synchronization systems.

of Advanced Telecom Compute Architecture (ATCA) [17] or μTCA crates the timing signals can be transmitted from the CTRs to the front end electronic using the gigabit link technology of the fabric. Data rates of 1.3 Gbit/s or 2.6 Gbit/s could be a natural choice for operating synchronous to clock and rf signals otherwise used at the accelerator.

Changes in the event trigger signal propagation times due to temperature effects may cause the arrival time of event triggers corresponding from time to time with synchronization system clock flanks. This may cause unwanted hopping effects within the event trigger arrival times. Possible cures have to be examined. Using the setup of a common time base for all CTRs, described below, the problem occurs at restarts of the timing system only.

4 MASTER TIMING GENERATOR

The MTG (fig. 5) obtains clock signals from the MO and information on the 'absolute time' from an external reference, reasonably from the computer network or a GPS receiver. In addition the MTG obtains real time information on exceptions form the MPS to be remastered and broadcast.

All together it generates, processes and distributes the following signals:

- event triggers indicating the start and the type of the rf pulses synchronized to the mains frequency from the electricity supplier in steps of 40 ns ($= 1/25$ MHz) for being synchronous to the rf gun laser and the transverse deflecting rf

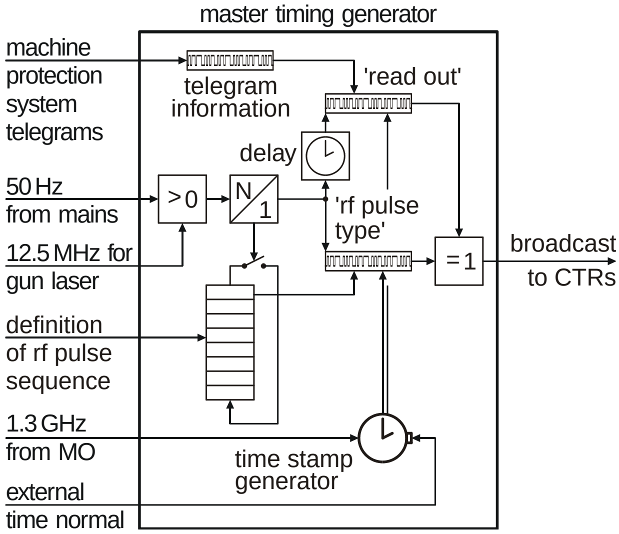

Figure 5: Sketch of the basic functionality of the master timing generator.

- after operating rf pulses, event triggers called 'read out', carrying information obtained from the MPS, indicate special events and exceptions like beam loss and cavity quenches
- time stamps shall be attached to both types of event triggers.

These signals and information may be distributed in a common way in accordance with the concept of sending triggers followed by serial data for encoding events and timing markers [18]. Figure 6 shows a possible signal composition: A trigger signal is followed by a telegram consisting of 16 bits at least. The subsequent time stamp consists of a larger number of bits to overcome overflow problems and to obtain an appropriate time resolution (0.7 ns).

In the example, the first part of the telegram indicates the begin of an rf pulse where the second part defines the rf pulse type.

Information describing an rf pulse type in detail requires

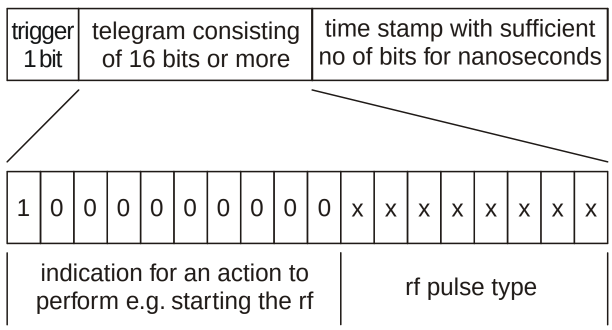

Figure 6: Example for a serial arrangement of a trigger, telegram and a time stamp.

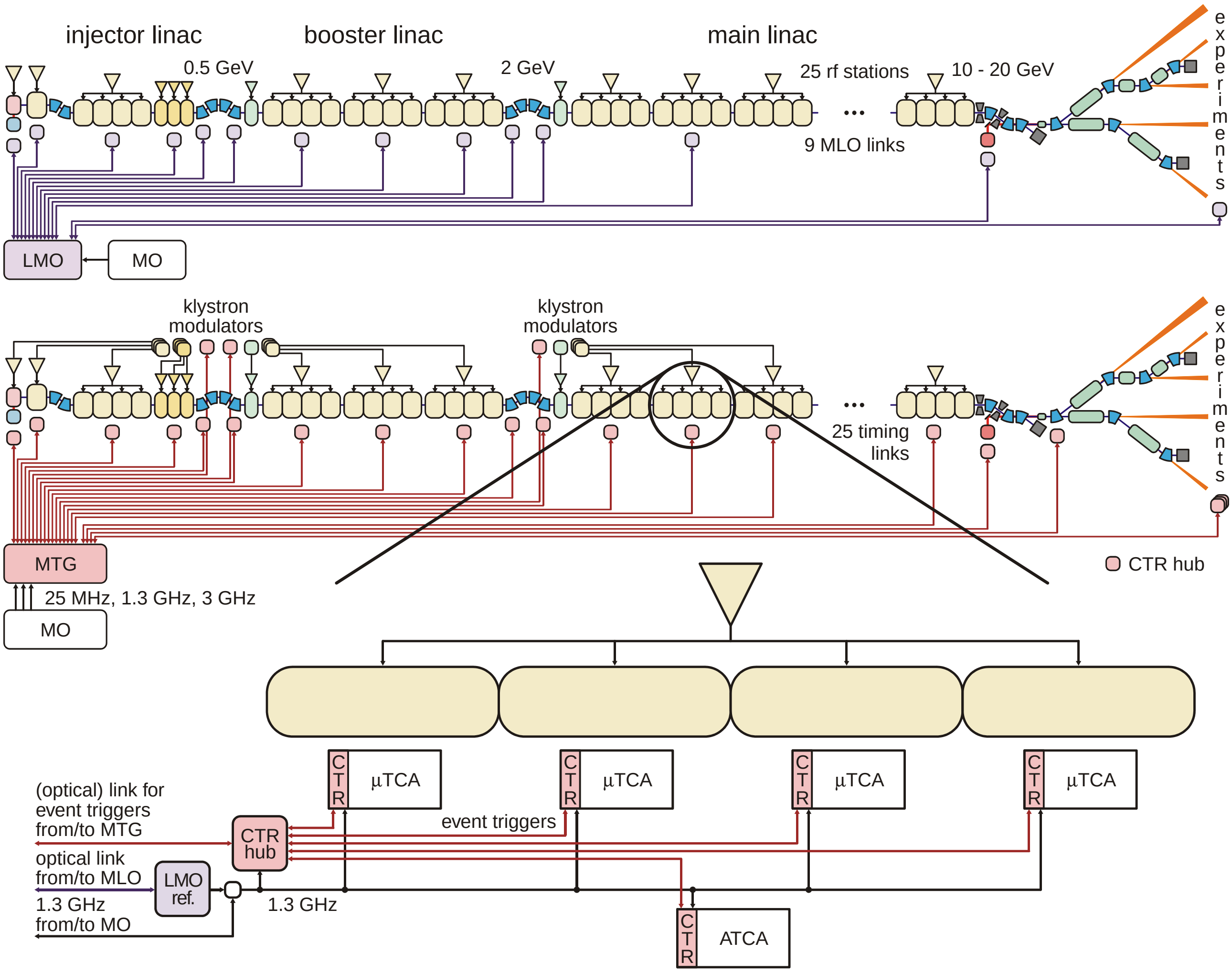

Figure 4: Sketch of the fs stable clock (MLO) distribution system [15] and a possible star like event trigger (MTG) distribution of the timing system using the synchronization systems as time base for the local re-synchronization of the event triggers.

not be sent by the MTG in real time. Instead, this information should first be sent by the MTG control system software via the LAN to all accelerator components which have to deal with the rf pulse type. The components confirm via the LAN that they are able to accept the rf pulse type. Afterwards the MTG control system software first forces the MTG to send triggers with this rf pulse type number. In such a way parameters and tables to be down loaded into front end electronics do not need to stick to a custom designed data protocol of a timing system.

5 RELAYS AND DECODERS

The European XFEL is a linear facility with a length of about 3.4 km. Taking into account additional distances for the passage of shafts and tunnels optical fibres between the MTG and the CTRs will be up to 6 km long. Hence, a trigger signal broadcast by the MTG will last up to 30 μs before arriving at a CTR input. A common accelerator wide system providing ‘absolute time’ information should correct these delays.

To establish a common time base each CTR contains a local time stamp generator which is clocked by synchronization system (MO) signals. The local generator can be synchronized to the time stamp generator of the MTG in the following way (fig. 7):

First, the MTG sends a trigger to the CTR with a telegram indicating that this trigger and time stamp has to be sent back instantaneous. Subtracting the returned time stamp from the actual time stamp gives two times the signal propagation time. Afterwards, the MTG sends a second trigger with a time stamp corrected by the signal propagation time so that the CTR receives the exact time and loads it into the local time stamp generator.

In case of a star like topology each CTR may repeat this procedure with subordinate CTRs.

As long as the MTG time stamp generator and the CTR time stamp generator run synchronized to the drift free MO signals both time stamp generators remain locked to each

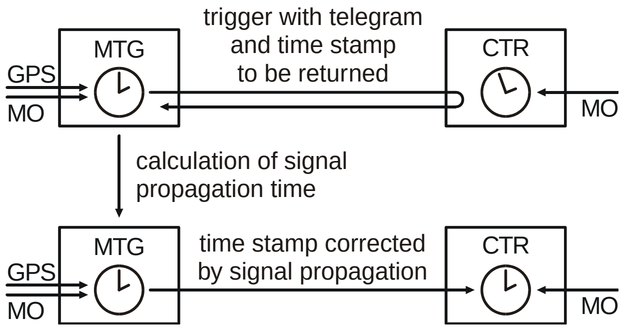

Figure 7: Concept for synchronizing local time stamp generators taking signal propagation times into account. The term 'GPS' is used synonymous for any external time reference.

other. In case the external time reference (LAN or GPS time) requires a correction of the MTG time stamp generator also the CTRs need to be re-synchronized.

Event triggers indicating the start of rf pulses should be send from the CTRs to the TDs everywhere at the same time. This can be achieved by defining a fixed delay which is longer than the signal propagation time from the MTG to the most distant CTR ($\geq 50\,\mu$s). A CTR adds to the MTG time stamp the predefined delay and transmits the event triggers to the TDs when the result agrees with the local time stamp. In this way event triggers broadcast by the MTG are transmitted from the CTRs to the TDs accelerator wide at the same time and remain locked to the mains frequency.

In addition to the trigger indicating the start and type of an rf pulse, the CTRs shall create locally additional triggers starting different subsystems as shown in figure 2. Transmitting the rf start and type event trigger to the TDs a CTR starts to count MO clock signals. Reaching programmed numbers of counter readings it transmits additional event triggers and telegrams to the TDs, e.g. for starting piezo actuators, rf control, rf drive and so on. Delays taking into account the beam flight time should be applied by adjusting the programmed delay numbers appropriate. The CTR created event triggers shall be programmable for each CTR and rf pulse type independently.

The TDs in the front end electronics interpret the signals in real time and trigger the algorithms intended. If required the TDs may receive at a regular basis additional time stamp information provided from the next CTR locally.

After an rf pulse operation the MTG sends a 'read out' trigger indicating the end of operations within rf pulses. It also forces algorithms working on an rf pulse to pulse basis starting their operation. Such algorithms shall be prevented from using data taken while exceptions like beam loss or quenches occurred. Therefore, exception information obtained from the MPS is broadcast by the MTG via the telegram of the 'read out' trigger.

A dedicated printed circuits board (PCB) with an FPGA hosting a TD, delay circuits and TTL drivers supplying 5 V at 50 Ω to several output channels in combination with a CTR may satisfy the requirements from the experiments (section 2.5). We may name this PCB 'timing receiver' (TR).

6 TIME SLICED OPERATION

Time has to be divided in periods for supplying electron beams individually from rf pulse to rf pulse to different user beam lines. Presently no rapid changes in the operation of the high voltage modulators for the klystrons are foreseen. Their design rely on a periodic operation. Consequently, the length of the time periods should always be equal, defining a basic rf pulse repetition rate. The basic rf pulse repetition rate will range from 2 Hz to 30 Hz corresponding to time slices lasting 500 ms down to 33.3 ms.

For this operation the MTG sends an event trigger containing an rf pulse encoding number in the telegram at the begin of each time slice. Each hardware and software component of the accelerator performs the operation predefined for this individual encoding number. For instance, a first encoding number may define an rf pulse operation resulting in a beam energy chirp within a bunch train and the encoding number for the subsequent rf pulse will lead to constant beam energy.

For the first development stage eight different encoding numbers may be treatable and ready on call within each hardware component. This has to be doubled when additional user beam lines are added to the XFEL in a later development stage.

The subsequent chapters describe how such an operation may be organized by an operator within the XFEL control room.

7 SEQUENCE BUILDING

Figure 8 shows the potential layout of the main XFEL timing panel for organizing the time sliced operation. Timing signals generated and broadcast by the MTG are organized by an operator in the following way:

First, an operator has to choose the basic rf pulse repetition rate. In the example (fig. 8) this is 10 Hz defining that each time slice has a length of 100 ms.

Only minor beam energy variations of $\pm 1.5\%$ are accepted by the optics of the beam delivery system [1, page 38]. Hence, the operator may adjust the mean beam energy by choosing magnets settings via an 'optics file system'. After that, the timing system obtains beam energy information form the optics file system.

Below the selection box for the repetition rate the panel (fig. 8) shows the pulse sequence. With a basic pulse repetition rate of 10 Hz all boxes represent 100 ms each. The MTG sends every 100 ms a trigger with empty rf pulse encoding number (zero) because the sequence has not yet been defined.

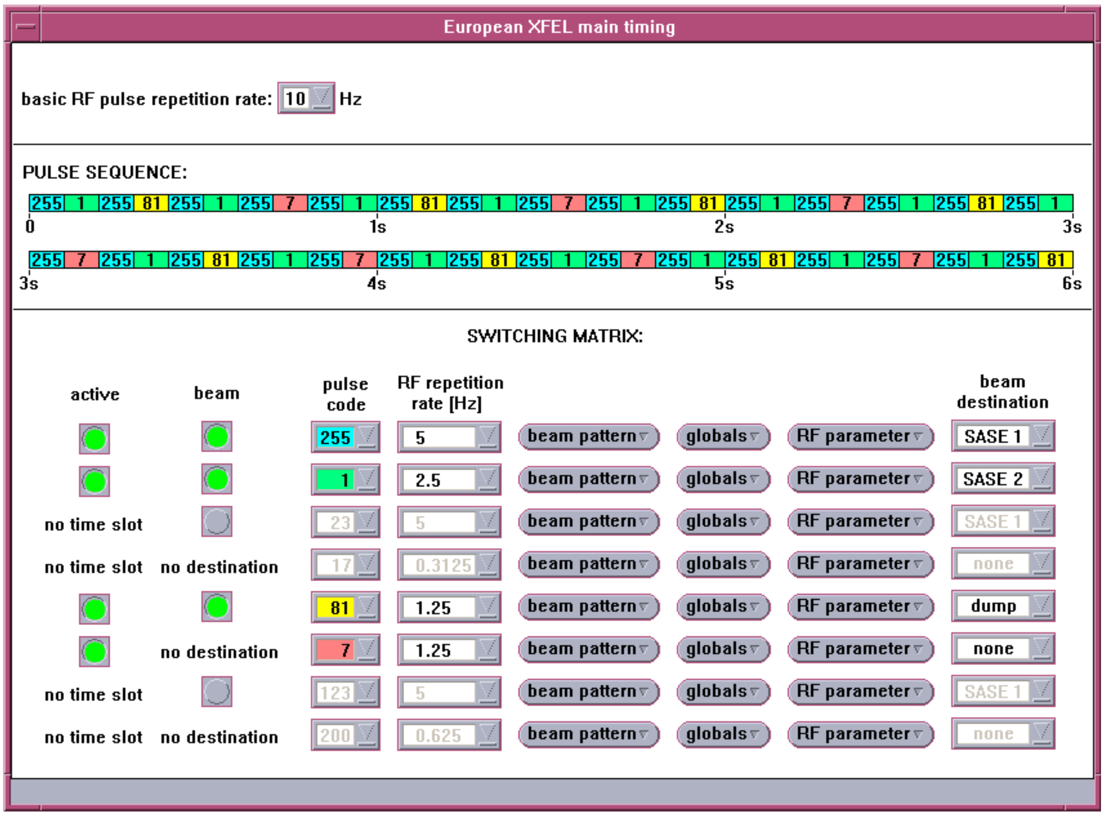

Figure 8: First sketch of a main XFEL timing panel for organizing the time sliced operation.

The operator may define via the 'switching matrix' the first pulse code to be '255' with a repetition rate of 5 Hz. As a result the pulse sequence shows the pulse code number in every second box in the pulse sequence.

Then the operator chooses the beam pattern, global parameters like small energy variations, the rf pulse length and also sending the beam to the SASE 1 beam line. Switching the pulse code active the operator forces all components to load parameters necessary for providing the operation requested into the hardware. The electronics of the rf gun laser prepares itself to create the bunch pattern specified in case the encoding number '255' together with a beam enable signal[2] triggers it. The rf control electronics loads all parameters into the FPGAs or DSPs of the rf controllers necessary to execute the operation triggered by the encoding number '255'. The same is valid for beam feedback systems, beam diagnostics and so on. Finally the electronics of the kicker magnets in the beam distribution also prepare them selves for kicking beam into the SASE 1 beam line.

Each component reports back when it is prepared to execute its task when encoding number '255' appears. The green dot arises in the main timing panel only when all components responded being on stand-by. Afterwards, the MTG sends triggers with encoding number '255' according to the pulse sequence. In case of a missing positive response, an error message is created and the encoding number '255' is not sent out. This mechanism prevents switching on the beam when not all components are prepared for this operation.

How restrictive this handshake mechanism should be implemented requires additional consideration. Exceptions may be necessary for debugging purposes, low intense beam operation or operation with single bunches.

A second pulse code must have 5 Hz or less. The operator chooses pulse code '1' appearing with a frequency of 2.5 Hz. Every fourth box in the pulse sequence is filled with '1' and the procedure with defining beam pattern, rf parameters and the beam destination is repeated. All components have to prepare themselves to be able to treat pulse code '1' in addition to the already defined pulse code '255' and send the confirmation. The preparation for the pulse code '1' is performed in parallel to an operation of pulse code '255' without interruption or influence of the on going operation.

The third and fourth pulse code may have a repetition rate of 1.25 Hz each. In general, for selecting the frequencies the operator has to start with the pulse code with the highest repetition rate and choose afterwards the pulses codes with lower frequencies. The switching matrix shall only display frequencies which are still available. In the example, the operator shall no longer be able to choose a repetition rate of 5 Hz for the third pulse code because there are not enough time slots left.

[2] Beam may be enabled by a separate bit in the event trigger telegram.

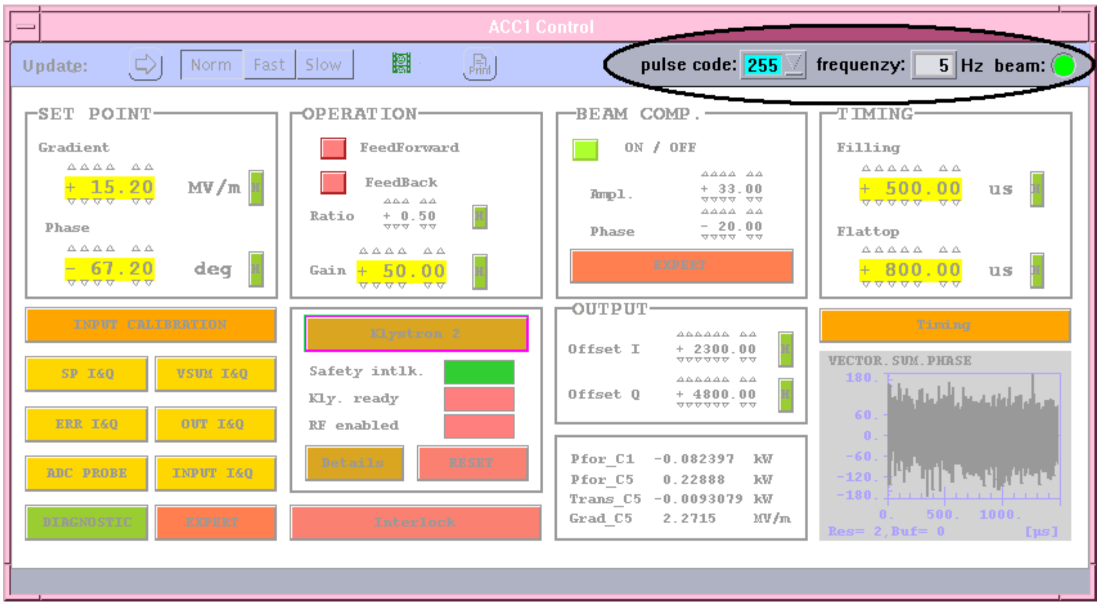

Figure 9: A panel for a component displays only data and settings for the pulse code specified in the upper right corner. Changes of parameters affect only the operation of the pulse code specified.

Exchanging a running pulse code by an other one has to be possible by deactivating the old code and activating the new one. Deactivating two pulse codes with lower repetition rate shall enable activating a single pulse code with higher repetition rate using the time slots opened. The MTG has to accept all these rearrangement at run time without interrupting or disturbing still running pulse codes.

An automatic scheme may have to be applied preventing empty time slots in the sequence while sequence changes. Hence, the timing system may not be allowed to simply switch off rf pulse types within the running sequence and switch on the next one first after some time even when the operator is doing so. This would change the cryogenic heat load and may affect the operational stability. For all cases an operator switches off an rf pulse the timing system may run automatically a ‘dummy’ rf pulse type without beam in the meantime keeping the heat load constant.

8 COMPONENTS OPERATION

Panels for the components within the control room should look equal for all pulse codes. In the upper right corner each panel shall show the pulse code of the data displayed in a selection box (fig. 9). In case an operator would like to observe the behaviour of the component during operation of pulse code ‘255’, he selects from the selection box ‘255’ and the data taken within the time slots for pulse code ‘255’ is presented. By opening a second panel and selecting a second pulse code he is able to observe the data for this pulse code in parallel. Additional to the pulse code number, the repetition rate and a beam indication may be displayed (fig. 9).

An rf pulse code separation at the user interface level requires that hardware components mark all data with the rf code number and time stamps while providing it to the control system. The same is valid for parameters which are set or changed within the hardware. This includes algorithms written in VHDL or running on DSPs. Furthermore, each control system ‘property’ depends on the rf code number. Hence, the timing concept becomes an integral part of the control system.

As a result, changes of parameters within a components panel shall only affect the operation for the pulse code specified. For example, pressing buttons for switching on and off a control loop within an rf control panel switches the loop only on and off for the pulse code specified. Pulse codes executed in parallel are not affected in any way.

9 ENERGY CHIRPS AND SWEEPS

According to the user requirements [2, 3] the beam energy chirps and sweeps shall be provided by the XFEL within the energy acceptance of $\pm 1.5\%$ of the beam distribution system. We define an energy chirp is a continuous change of the beam energy within an rf pulse resulting in a constant energy change from bunch to bunch. In contrast, a sweep is a continuous change of the beam energy from rf pulse to rf pulse of the same pulse code. As a result the FEL laser light will be chirped and swept required by experiments examining sharp spectroscopic edges or resonances.

Chirping and sweeping the beam energy for an rf pulse with a certain pulse code shall not influence the beam energy of rf pulses with other pulse codes operating at the same time. The chirping and sweeping parameters like the energy range to be covered, the gradient and the speed of the energy variation may be chosen from the ‘globals’ dialogue box obtained by pressing the button ‘globals’ within the main timing panel (fig. 8).

Chirps require the modification of set point tables within the rf control loops in the main linac. Slow sweeps may be realized by slow changes of the mean set points of the rf controls via LAN broadcasting techniques from the control system. Fast and with experiments synchronized sweeps may be realized by using the time stamps within the rf control loops executing predefined energy variations from rf pulse to rf pulse.

10 ACCELERATOR PROTECTION

The MPS has to be integrated into the timing scheme described. As an example, beam should only be inhibited for an rf pulse with a certain pulse code in case of beam loss only taking place when the rf pulse with this code number is executed. Other rf pulses operated at the same time and not leading to beam loss shall not be affected.

In addition, the MPS has to inform components like beam diagnostics, beam feedback systems and the rf control systems via the MTG. This is necessary to prevent feedback loops using the data and error signals, obtained within an rf pulse when the beam was switched off, for error corrections at subsequent rf pulses.

Only a MPS which is sensitive to the different pulse codes may enable the debugging of certain operational states parallel to user operation.

11 FIRST TESTS AT FLASH

FLASH [1, page 11] is operated at 5 Hz repetition rate. During the accelerator studies in August 2006 the possibility to operate the last accelerating modules (ACC4/5) with 10 Hz and alternating rf pulses has been established [19]. The rf pulses synchronous to the 5 Hz rf pulses are used for FEL and SASE operation whereas the gradient of the remaining rf pulse can be chosen independently and is used for long term high gradient studies.

The gradient of the 5 Hz synchronous rf pulse is between 5MV/m and 20 MV/m according to the SASE wavelength. At present the second rf pulse operates always at 20 MV/m.

In addition, an operation of two different gradient levels within a single rf pulse has also been set up.

The control performance shows no degradation as compared to the simple 5 Hz operation. Long term experience from operating these schemes in parallel to FEL user operation since August 2006 confirms such a time sliced operation does not affected the SASE process and the experimental program.

12 SUMMARY AND OUTLOOK

In this paper ideas for a possible timing system concept and its integration with the two synchronization systems at the future European XFEL has been discussed: A master timing generator broadcast event triggers carrying telegrams and time stamps synchronized to the mains frequency. Clock and timing relays process and purify the event triggers. They are delayed appropriately for being transmitted to the front end electronics accelerator wide at the same time. Distributed time stamp generators can be synchronized sending time stamps corrected by signal propgation times measured.

The operational concept discussed in the second part of the paper allows the operational flexibility required by organizing a time sliced operation of the facility. This is achieved by performing a cycle consisting of an rf pulse sequence which is accelerating subsequent the different types of beam. This cycle can be managed and rearranged form an operator via a main timing panel. A handshake mechanism enables cycle changes at run time. For diagnostics purposes and for synchronized energy sweeps absolute time stamps are an integral part of the concept.

First long term tests of such accelerator operation schemes at FLASH, operating alternating rf gradients parallel to FEL user operation, look quite promising.

Before being able to write a conceptional design, we have to collect all information on additional requirements from other subsystems. Fixing a protocol for event triggers including a definition of message encoding numbers should be one of the next steps. In parallel we may perform first tests concerning the synchronization of distributed time stamp generators (clock counters).

13 APPENDIX

13.1 Nomenclature

Collaboration work may become complicated in case the collaborators use different words describing the same object. Therefore, we agreed on using the following nomenclature:

The word **timing** is commonly defined as the regulation of occurrence, pace, or coordination to achieve a desired effect [20]. Here, we use the word timing for the accumulation of software and hardware components starting and controlling the sequences of actions required for accelerator operation. Real time information and signals distributed by the timing system are triggers, telegrams and time stamps. Asynchronous information distributed by the timing system are instructions on actions to be taken, triggered by the real time signals.

Synchronization means the process of maintaining one operation in step with another. The usual definition of timing includes the regulation of pace and therefore timing includes synchronization as a subset. In contrast, naming different fields of work with separate names we agree to use the word synchronization for all technical installations dealing with the generation and distribution of stable clock and rf reference signals.

A **clock** is a source of regularly occurring pulses used to measure the passage of time.

We use the electronic engineering definition of **trigger** as a pulse that initiates the action of a component. Except for defining the time to start an action it contains no information on which action to perform.

Table 1: List of synchronization and timing information required by the rf control systems.

rf refrences	clock signals	event triggers	telegram data	rf pulse type data
$f_{\mathrm{RF}} = 1300\,\mathrm{MHz}$ $f_{\mathrm{LO}} = 1350\,\mathrm{MHz}$ $f_{\mathrm{cal}} = 1299\,\mathrm{MHz}$ $f_{\mathrm{IF}} = 50\,\mathrm{MHz}$	$f_{\mathrm{ADC}} = 75\,\mathrm{MHz}$ $f_{\mathrm{bunch}} = 5\,\mathrm{MHz}$ $f_{\mathrm{MLO}} = 50\,\mathrm{MHz}$	rf pulse type piezo hv transformer hv bouncer open rf gate start rf start beam bunch # close rf gate read out cavity simulator	rf pulse type action to start exceptions time stamp	ff tables gain tables loop parameter chirp tables sweep tables trigger delays

Table 2: List of synchronization and timing information required by x-ray laser light experimentalists.

rf refrences	clock signals	event triggers	telegram data	rf pulse type data
$f_{\mathrm{RF1}} = 100\,\mathrm{MHz}$ $f_{\mathrm{RF2}} = 200\,\mathrm{MHz}$ and others?	$f_{\mathrm{MLO}} = 50\,\mathrm{MHz}$ $f_{\mathrm{MLO}} = 100\,\mathrm{MHz}$ and others?	rf pulse type trigger 1 to trigger 10 start beam bunch # rf pulse multiple rf pulse fraction read out?	rf pulse type trigger no. exceptions time stamp	chirp tables sweep tables

In contrast an **event trigger** is the combination of a trigger and a telegram. A **telegram** is a message using coded signals. Hence, an event trigger defines the start of an action together with the information on the particular action to start.

Finally, a **time stamp** is the number of seconds or in our case of $\frac{1}{1.3} \times 10^{-9}$ seconds after a given time (e.g. January 1, 1970 in case of UNIX time stamps).

We define an **energy chirp** is a continuous change of the beam energy within an rf pulse resulting in a constant energy change from bunch to bunch. In contrast, an **energy sweep** is a continuous change of the beam energy from rf pulse to rf pulse of the same rf pulse type.

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