

TIMING SYSTEM AT MAX IV - STATUS AND DEVELOPMENT

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Abstract

A MAX IV construction of two storage rings (SR1.5GeV and SR3GeV) and a short pulse facility (SPF) has been proceeding over last years and will be finished in the middle of 2016. In 2014, few timing procurements were successfully finalized according to the MAX IV requirements (see [1] for details) and the installation works are ongoing along with the TANGO control system integration. The design covers the timing synchronization (TIM) and acquisition, fast orbit feedback (FOFB), fast machine protection system (FMPS) and integration of MAX IV operation modes. The LINAC commissioning started in 2014 and was successful together with the first beam line (FEMTOMAX). The SR3GeV commissioning started in August 2015 and is ongoing. The SR1.5GeV is being installed and will be commissioned in 2016.

MAX IV OPERATION MODES

MAX IV will work in 4 different modes:

- LINAC 3GeV (LIN)
- LINAC 3GeV + Short Pulse Facility (SPF)
- LINAC 1.5GeV + Storage Ring 1.5GeV (SR1)
- LINAC 3GeV + Storage Ring 3GeV (SR3)

LIN and SPF are rated for 100Hz injection whereas SR1 and SR3 for 10Hz.

Each mode is synchronized to its own radio frequency (RF). LIN and SPF are driven by 39 harmonics of the LINAC master oscillator (MO) 3GHz ($2998500000/39=76884615.38\text{Hz}$ in reality, around 77MHz). The 39 harmonic is required for a synchronization of two laser systems, one at the beginning of the LINAC, other 400m away in the short pulse facility. This implementation also keeps the same constant phase for other frequencies: 100Hz LINAC injection trigger, 1kHz laser pumping frequency etc.

SR1 is locked to 100MHz (RF1) and SR3 is locked to 100MHz (RF3) but those frequencies are a bit different as the real value comes from the construction and temperature parameters of storage rings. Both rings work in the same way, each SR TIM generates a LINAC injection trigger which is locked to its RF and in constant phase to its machine clock (MC). The MC phase shift (10ns step) defines the SR bucket number. SR3 stores 176 electron buckets and its MC is equal to 568kHz, whereas SR1 stores 32 electron buckets and its MC is equal to 3.12MHz.

On top of that, the synchronization to mains electricity (ME) 50Hz will be implemented, so the injection will always be applied under constant parameters of high power devices.

In summary, 3 different LINAC triggers are delivered:

- LIN and SPF – TRIG0 (3GHz, 77MHz, 50Hz),
- SR1 – TRIG1 (100MHz, 3.12MHz, 50Hz),
- SR3 – TRIG3 (100MHz, 568kHz, 50Hz).

The brackets include a set of frequencies which are synchronized one other. The future timing improvement considers adding 3GHz master oscillator (MO) to TRIG1 and TRIG3 (see “MO 3GHz SYNCHRONIZATION” section for more information).

SWITCHING MODES

Switching over each operation mode has not been defined yet.

Main assumptions:

- The LINAC trigger runs 24/7 regardless other modes, so LINAC devices keep constant parameters (temperature etc.).
- Max LINAC death time (no trigger) around 5 second.
- To avoid an overcurrent injection to the nominal stored beam (500mA) in SR1 and SR3 without dumping the beam (BEAMDUMP).
- To avoid an overcurrent injection to a single storage ring bucket, so not to exceed the nominal 5nC/bucket.
- Full automatic operation, one instruction/button of the operator should be enough to run the machine.
- Once SR1 and SR3 are “full”, SPF/LIN mode should be activated (nominal conditions).
- Except TIM, other devices (which are much slower) will be a part of the switching mechanism (e.g. SR1 and SR3 LINAC bending magnets etc.).
- Each timing system (SPF, SR1, SR3) has to operate autonomously 24/7 regardless the actually selected mode, delivering acquisition triggers, beam pinging, MC, FMPS functionality etc.

CORE HARDWARE

Beam Position Monitors (BPM-s)

The BPM system is based on Libera Brilliance+ which is a uTCA 2U box containing:

- 1x timing module (EVRX) - connected to the timing system via an optical link,
- 3x or 4x BPM processor unit - connected to RF pick ups in the storage rings,
- 1x gigabit data exchange module (GDX) which exchanges the beam orbit data/calculations,
- 1x RS485 card controlling power supplies which are connected to ring corrector magnets,
- 1x CPU module running Linux and connected to Ethernet.

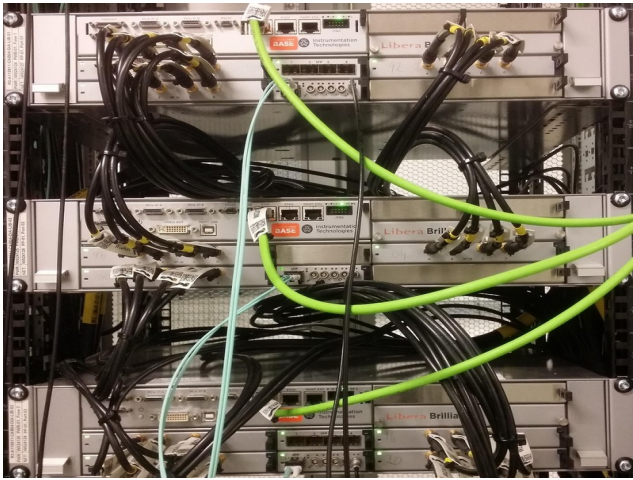


Figure 1: One generic BPM rack in SR3

The real example of one BPM set is presented in Figure: 1.

EVRX

The card processes acquisition triggers, machine clock, postmortem signals and generates interlocks (optical and electrical). Initially, the optical link compatibility was not supported and a dedicated firmware development has been requested to Instrumentation Technologies (I-Tech). It was finished successfully in June 2015 and it is during a validation process which will be finished at the end of 2016.

This improvement added new features to:

- FMPS: BPM interlock response time in microsecond range, propagation of the interlock signal over the whole machine in less than 1ms.
- TIM fast acquisition: possibility to implement higher amount of trigger signals (event codes) than 3 standard electrical inputs.
- TIM gets deterministic access to the BPM fast acquisition which is a base of a fast orbit feedback (FOFB).
- TIM gets access to control absolute time of BPM-s.
- TIM and FMPS can drive external devices in the deterministic way via EVRX electrical inputs/outputs.

BPM Processor

Standard features cover MAX IV needs. In total, 200 BPM-s were installed in SR3, driven by 117.53MHz sampling clock and performing 10.139ksp/s fast acquisition. In case of SR1, 36 BPM-s were installed, driven by 118.67MHz sampling clock and performing 10.074ksp/s fast acquisition.

The generated data is a base for the future FOFB implementation.

GDX

The GDX module is a core of FOFB system. It interconnects in series all the Libera boxes via an optical link, making a full data circle around SR1, SR3 and performs beam orbit correction calculations. Requirements

were defined in early 2014 and the optical installation was finished in March 2015. The I-Tech company delivered a MAX IV specific implementation which will be a base of a future FOFB integration. The development will be done at the end of 2016 (or in 2017). Except that, the module will deliver around 3.5 MB/s of global magnet data and 31 MB/s of global orbit data to the control system.

RS485 Module

The module has been developed upon request. The RS485 protocol is compatible to “Innovative Test Systems” (ITEST) corrector power supplies which will be driving corrector magnets with the 10kHz update rate of the FOFB set point.

CPU Module

A generic computer which contains: 2x CPU N270 @ 1.60GHz, 1GB RAM with Ubuntu 10.04.4 LTS operating system and provides the distributed control system – TANGO (see [2]).

TIM – Micro-Research Finland (MRF)

The timing procurement has been awarded to MRF company at the end of 2014. The hardware components were delivered in March 2015. Except that, two additional procurements were issued:

- “Fibre backbone for Timing system” - material and installation, covering TIM and FOFB requirements, awarded to COROMATIC and delivered in March 2015.
- “Compact PCI standard for MAX IV” awarded to “RECAP Embedded Computers” and delivered in April 2015.

In summary, the TIM implementation consists of MRF cPCI cards based on 8b/10b 2.5Gb/s optical link, OM4 fiber optic cables and generic cPCI components. A real installation example is presented in Figure: 2.

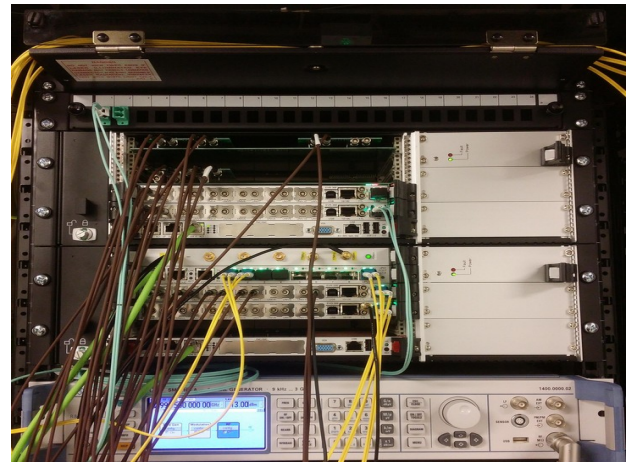


Figure 2: Main LINAC timing rack.

PROTECTION/SAFETY SYSTEMS

General Implementation

A machine protection system (MPS) and personal safety system (PSS) are based on programmable logic controllers (PLC-s) whereas the fast machine protection system (FMPS) uses timing cards based on field-programmable gate arrays (FPGA-s).

MPS monitors conditions of: cooling water, chamber and magnet temperatures, power supplies, vacuum and system interlocks, protecting locally devices/systems and globally the machine. PSS manages conditions related to a human protection and blocks user actions if safety requirements are not resolved.

MAX IV had two main protection challenges: LINAC and storage rings.

LINAC

The LINAC MPS is simpler than storage rings as except the general conditions, the LINAC beam is not stored. The LINAC MPS response time constrain is in range of 100ms and the standard PLC-s cover all the requirements. In addition, the main LINAC trigger can be only one and has to be selected for a particular operation mode, the trigger integration is presented in Figure 3.

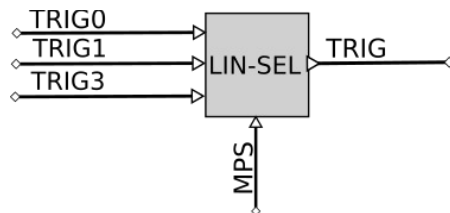


Figure 3: LINAC trigger selector with the MPS functionality

The selector is controlled by MPS which monitors the current conditions of each storage ring, blocking the TRIG, or changing the operation mode, if the stored current for the particular mode reached the set limit (nominal value), or in case if the operation mode was not applied properly (e.g. some devices could not be enabled because of a failure).

Storage Rings

FMPS is mainly important for the storage rings as 3GeV 500mA beam outside its orbit can damage the chamber in few milliseconds, moreover if a vacuum pollution appears in any beam line, a protecting fast closing valve can be melted in 3ms by the photon beam produced by an insertion device. The main FMPS requirement is to dump the beam in less than 3ms. The storage ring MPS implementation is presented in Figure: 4. The green line presents a monitoring bus by TANGO. The orange line shows the LINAC trigger disable capability. The red line is the most critical because triggers the BEAMDUMP. The MPS BEAMDUMP acts directly on RF transmitters via slow but reliable PLC contacts whereas FMPS acts on low level RF system (LLRF) which is instant but without

switching off the plant which is powered off 100ms later by MPS-PLC as the same alarm signal is exchanged between these two systems. The red signal is also a source for the postmortem (PM) acquisition (blue line) which can be triggered by FMPS, MPS-PLC and TANGO.

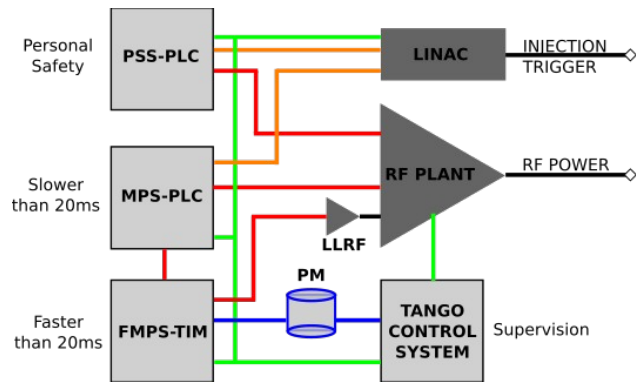


Figure 4: MPS flow of storage rings - general block diagram.

TANGO INTEGRATION

One global timing graphical user interface (GUI) is under definition and will be implemented in 2016. Nevertheless, all the timing components/nodes have been included in TANGO and the commissioning is proceeding by utilizing standard TANGO tools (see [2] for more information).

General

The timing components are presented in Figure: 5.

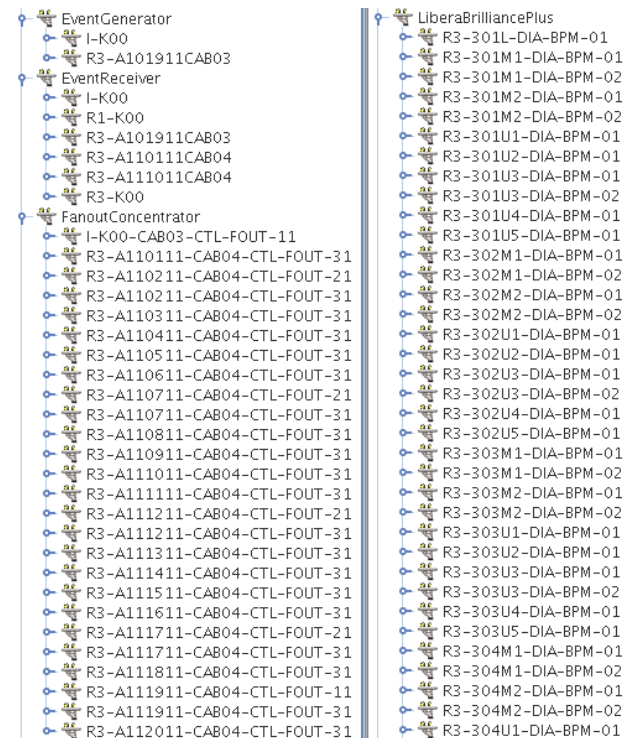


Figure 5: A JIVE (a TANGO database browser) representation of the timing system: MRF TIM (SR3, 20 sectors) on the left, Libera BPM (SR3, 4 sectors) on the right.

State Grid

All the timing components have been included to be monitored in a state grid for a future system reliability estimation. The implementation is presented in Figure 6. The state grid is a GUI application intended to give the operator an overview of the current condition of the control system. It presents the TANGO states of a set of devices, e.g. "ON", "OFF", "ALARM", "FAULT", etc. The state grid relies on a specialized TANGO device that runs in the control system, listening to changes in state for a configured set of devices. The grid application receives updates from this device whenever a state changes.

Pre-Press Release 23-Oct-2015 11:00

3 GeV ring					
	VAC	VAC/Valves	TIM	DIA	
301	5/6 ON	4/4 OPEN	2/2 ON	26/26	ON
302	5/7 ON	1/4 MOVING	2/2 ON	31/33	ON
303	5/6 ON	2/2 OPEN	ON	30/30	ON
304	5/6 ON	2/2 OPEN	ON	29/29	ON
305	5/5 ON	2/2 OPEN	ON	30/30	ON
306	5/6 ON	2/2 OPEN	ON	30/30	ON
307	5/6 ON	2/2 OPEN	2/2 ON	30/30	ON
308	5/5 ON	2/2 OPEN	ON	30/30	ON
309	5/6 ON	2/2 OPEN	ON	30/30	ON
310	5/6 ON	2/2 OPEN	2/2 ON	32/32	ON
311	5/6 ON	4/4 OPEN	ON	30/30	ON
312	5/6 ON	2/2 OPEN	2/2 ON	30/30	ON
313	5/6 ON	4/4 OPEN	UNKNOWN	30/30	ON
314	5/6 ON	4/4 OPEN	ON	30/30	ON
315	5/7 ON	4/4 OPEN	ON	30/30	ON
316	5/6 ON	4/4 OPEN	ON	30/30	ON
317	5/6 ON	4/4 OPEN	2/2 ON	30/30	ON
318	5/6 ON	4/4 OPEN	ON	30/30	ON
319	5/6 ON	4/4 OPEN	3/3 ON	30/30	ON
320	7/8 ON	4/7 OPEN	ON	32/32	ON
PLC	20/20 RUNNING				
Alarm					
Global			3/3 ON		

Figure 6: A segment of the SR3 state grid.

MO 3GHZ SYNCHRONIZATION OF THE LINAC TRIGGER FOR STORAGE RING INJECTIONS

The future improvement of the MAX IV timing is related to the LINAC trigger (TRIG1 and TRIG3) which is not synchronized to the LINAC 3GHz MO which is used to produce electron bunches in the thermionic gun. Around three (from 2 up to 3.5) electron bunches (330ps period) are chopped by the LINAC chopper synchronized to RF1 or RF3 and construct a charge for one SR bucket (see [3] for details). This solution has a drawback as each LINAC shoot has a different charge per bucket.

The potential solution is presented by the formula:

- $MO+TRIG(RF,MC,ME)=TRIG(MO,RF,MC,ME)$.
- The idea is to design a device with “two inputs” (for MO and TRIG) which synchronizes the TRIG phase to MO. The MO signal is a 3GHz sinus and the TRIG signal is a TTL pulse (width adjustable).

If someone has an idea how to solve this issue, please email the paper author.

REFERENCES

[1] J. Jamroz et al., “TIMING SYSTEM AT MAX IV”, THPPC103, Proceedings of ICALEPCS2013, San Francisco, CA, USA, (2013)

[2] TANGO control system, <http://www.tango-controls.org/>

[3] D. Olsson et al., “A chopper system for the MAX IV thermionic pre-injector” <http://dx.doi.org/10.1016/j.nima.2014.05.052>