LINAC SUBSYSTEMS FOR BETTER BEAM CONTROL

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Abstract

Control of bunch arrival time, energy and trajectory of particle beams in linear accelerators is mandatory to reach performance goals and is carried out using different sub-systems. For optimal control and especially for accelerators aiming at the highest level of performance, for example FELs, these systems should be considered as a whole and work together. At Instrumentation Technologies such systems have been developed and tested on the field.

Precise control of amplitude and phase of the accelerating fields is performed with the Libera LLRF, a digital RF stabilization system that is coupled to Libera SYNC, a very low jitter master oscillator distribution system. The Libera Brilliance Single Pass system provides high resolution position information that allows accurate control of trajectories through critical machine sections such as bunch compression modules and FEL modulators and radiators.

These systems are described in detail in the paper with examples from field measurements.

MOTIVATION FOR DEVELOPMENT

Each of the instruments, Libera LLRF, Libera SYNC, Libera Brilliance Single Pass can contribute its part in providing stability and better beam control. However because they are based on a similar communication protocol, together they can do it more efficiently and less labouriously for the user integrating them in one control system.

RF STABILIZATION AND CHARACTERIZATION SYSTEM

For the stabilization of the RF field in the accelerating cavities the Libera LLRF – digital RF stabilization system – is used. Beside stabilization Libera LLRF has also functionality of characterizing the RF system which is a very useful part of diagnostics during installation, commissioning and maintenance.

The system

The Libera LLRF system was designed and developed to be modular and configurable, with the aim to fulfil various requirements from different accelerators. Fourth generation light sources have especially stringent requirements in terms of stability. A challenge of such systems can arise from the need to stabilise RF pulses of short duration.

Figure 1: front and side view of Libera LLRF

Modularity and configurability is possible by basing the system on µTCA standardized modules. However, to achieve better overall latency of approximately 270 ns, some unique solutions were introduced. In addition to conserve space, a special computer module and crate power supply has been provided.

The architecture

From the input RF signal(s), the Libera LLRF drives one klystron or IOT or some other high power RF source. By using also only one RF input the system is capable of controlling the RF field in the cavity.Up to 32 RF inputs can be used to control the drive signal of one klystron or IOT. The Libera LLRF system is based on the distributed FPGA processing of data. Virtex 5 FPGAs are used to process the partial and global vector sum and high level software is used for supported processing.

The input RF signals are sampled with 16 bit ADCs at approximately 100 MHz. In the unit there can be up to 4 modules called ADC9 that can sample 8 RF inputs each and each module has an FPGA for dedicated processing. That totals to 32 RF inputs per fully populated Libera LLRF unit.

After partial processing in the FPGA on the ADC9 the global FPGA processing is performed. To support this, low latency links are used to transport data from the ADC9's to a vector modulator module. After the global vector sum, control algorithm processing is employed. The entire stabilisation processis controlled by high level software.

An important operational aspect is the management and diagnostics of the system. This is achieved through IPMI (Intelligent Processing Management Interface) protocol. This allows complete control of the systems functionality from low level hardware access to the high level LLRF applications.

The capabilities

The system supports various RF systems including both normal conducting and superconducting systems, operating either in pulsed or continuous waves modes.

For easy operation various functionalities are included in the system:

- The generation of a model of the RF system for the calculation of control algorithm parameters
- Nyquist stablility analysis to help the operator to safely close the control loop
- RF system tuning for frequency and phase
- Interlock capability to ensure safety
- Arbitrary signal shaping to achieve less stressful cavity filling patterns and also the compensation of beam loading effects
- Feedback control algorithms to stabilize the RF field during the RF pulse
- A user friendly GUI (Graphical User Interface) for fast familiarization of the Libera LLRF system and intuitive setting of parameters as well as diagnostics tools

The software architecture also allows the user to modify control algorithms – e.g. experimenting with the LLRF system.

The dimensions of the compact Libera LLRF units are compact – 19 inch 2U form factor.

The tests

Testing of Libera LLRF systems was done on high power RF systems at FLASH Desy, Fermi@Elettra and at EMMA at Daresbury. FLASH and Fermi@Elettra are both FELs and EMMA a proof of concept accelerator for a non-scaling fixed field alternating gradient accelerator.

The tests demonstrated the high stability that can be achieved in the drive RF field with an amplitude and phase stability of 0.009 % RMS and 0.009 ° RMS at FLASH and EMMA respectively. Time saving installations was achieved using the associated RF system diagnostics that comes with the Libera LLRF system.

BEAM POSITION MONITORING

In LINACs beam position measurements are done on single pass bunches. In terms of signal processing this is a challenging endeavour. The transverse (and phase) position of the beam is determined from very short pulses or trains of pulses passing the beam position monitor (BPM).

There are several different kinds of BPMs that are used: button pick-ups, striplines or cavity BPMs. Each of these BPMs involve different kinds of signal typologies. Libera Brilliance Single Pass is able to process the signals produced by the first two of the above mentioned BPMs since there is bandwidth matching between processing unit and the signal frequencies.

Libera Single Pass H is a new generation of single pass monitor that is designed for proton or heavy ion LINACs. Beside the position of the beam it also measures the phase of the particles.

Figure 2: Libera Single Pass H

Data Processing and Performances

The all-in-one Libera Brilliance Single Pass instrument has a 19 inch 1 U form factor that provides analog and real-time digital signal processing. The high-level software, that is common to the complete the set of Libera instruments, enables easy integration into the control system.

The goal of the Libera Brilliance Single Pass instrument is to achieve good position resolution at operational bunch charges and maintain good position results at very low bunch charges in ranges of 10 pC, see Figure 3. The capability of processing extremely low signals make this instrument an ideal tool during machine commissioning and machine studies, as well as during normal operation.

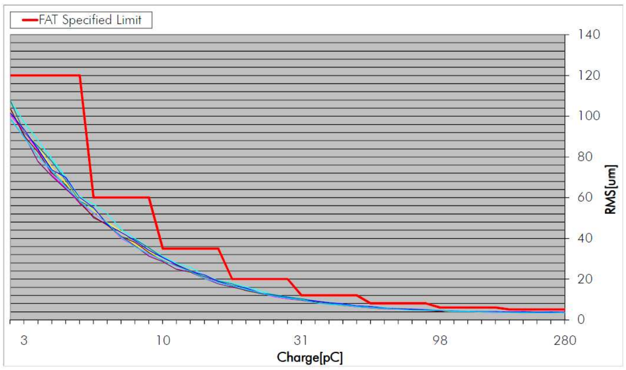

Figure 3: Some typical RMS of measured position in Libera Brilliance Single Pass units – red line user specifications, other colours measured positions

Normally the operationally accelerated bunches have charges in the nC range which contributes to higher signal level, better measured position and also stability of RMS values. The expected position RMS values for higher charges are in range of 2 um. The confrontation of signal levels for lower charges is shown in Table 1.

Table 1: Confrontation of Signal Levels for Libera Brilliance Single Pass

Estim.Charge [pC]	Measured Peak[mV]	Libera Level Setting	ADC Counts (± 1000)	Required RMS
280	4400	-10	15000	**5**
98	1560	-19	15000	**6**
31	500	-29	15000	**12**
10	160	-31	7000	**35**

The Libera Brilliance Single Pass instrument is optimized for electron linacs and was first tested with the team at Sincrotrone Trieste. Fermi@Elettra is the first completely equipped Free Electron Laser with Libera Brilliance Single Pass.

Other units are deployed at the IHEP BEPCII Linac, the SSRF Linac, Spring 8 etc.

Additionally, the ESRF team successfully operated the Libera Brilliance Single Pass unit for injection efficiency measurements.

The instrument has proved the capability of precise bunch position/charge measurements at several machines. The instrument benefits from a high degree of accuracy, resolution and temperature stability. Together with implemented fast communication protocols (e.g. Gb Ethernet), it represents a reliable and deterministic building block for fast feedback systems or feed forward loops and thus enables higher beam stability.

SYNCHRONIZATION

In order to achieve strict stability requirements that are needed for FELs, a low added jitter distribution system of RF master oscillator must be used to allow remote RF stations to receive an RF signal with deterministic phase and frequency.

With this goal in mind the Libera SYNC system was developed.

Figure 4: Libera SYNC

The principle

Libera SYNC uses optical fibers to distribute the RF signal from one point to another. The system consists of a transmitter and receiver which are connected with a pair of commercial telecom grade optical single-mode fibers.

The operation

Output from the RF master oscillator is connected to the transmitter input. Optical output of transmitter is connected to receiver optical input with one optical fiber and vice versa. Output of receiver has 2 phase aligned RF outputs delivering stabilized 15 dBm RF signal.

The performance

Performance of the Libera SYNC system was evaluated at Fermi@Elettra, which also contributed to the development of the system and at PSI's 250 Mev test stand Injector LINAC.

The added jitter of Libera SYNC stabilized link is 5.5 fs RMS in the frequency range of 100 Hz to 10 MHz. At an RF of 3 GHz this contribution is equivalent to 0.006 ° of phase instability contribution from this system.

At Fermi@Elettra long term (24h) drift measurement of system was found to be in the range of 16 fs RMS.

CONCLUSION

All the above mentioned systems can be individually employed in a LINAC's diagnostics and control system and contribute to stable beam control. Libera Brilliance Single Pass and Libera Single Pass H provide accurate beam position information for feedback or feedforward systems, Libera SYNC by assuring stable clock distribution and better synchronization of several RF stations along the LINAC and Libera LLRF provides stable RF drive signals. Together they can be combined to give the operator extensive control of FEL stability or delivery of exotic heavy particle beams.

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