ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRI078

FAST ORBIT FEEDBACK APPLICATION AT MAX IV AND SOLARIS STORAGE RINGS

P. Leban, E. Janezic Instrumentation Technologies, Solkan, Slovenia
M. Sjöström, MAX IV Laboratory, Lund, Sweden

Abstract

A common Fast Orbit Feedback (FOFB) application is planned for the new storage rings at MAX IV laboratory and SOLARIS. The application will run in the Beam Position Monitor (BPM) electronics (Libera Brilliance+). Global orbit data concentration will be conducted inside the gigabit data exchange (GDX) modules with a Virtex6 field programmable gate array, which will be daisy-chained around the storage ring. The feedback calculation algorithm is based on the Singular Value Decomposition (SVD) – the PI controller will be applied in the modal space for individual eigenmodes. The calculations will be distributed over all GDX modules to reduce overall latency. Each GDX module will calculate setpoints for four correctors, horizontal or vertical. The new setpoints will be sent directly to the magnet power supply controllers over a serial point-to-point link. This article presents details on FOFB implementation and control topology.

BACKGROUND

The MAX IV laboratory accelerators consists of a linear accelerator and two storage rings at 3 GeV and 1.5 GeV particle energies. SOLARIS light source in Krakow, Poland, is a copy of the 1.5 GeV storage ring. In order to stabilize the orbit of the storage rings a Fast Orbit Feedback (FOFB) system is required; this is particularly the case for the 3 GeV ring where the small vertical beam size of roughly 2 µm on the straight sections result in stability requirements on the 200 nm level [1].

TOPOLOGY

The planned topology for the FOFB system is a circular connection, linking all Libera Brilliance+ units in series. Fast power supplies for each achromat will be interfaced to the local cabinet station.

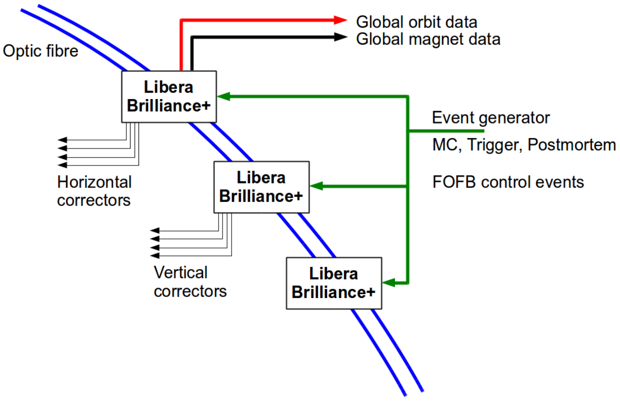

Figure 1: Topology overview.

Figure 1 shows an overview of data and trigger lines to FOFB system for 1 achromat in the 3 GeV storage ring. Green line carries the events important for BPM processing (revolution clock, asynchronous acquisition and synchronization trigger, postmortem trigger) and FOFB operation (e.g. ON, OFF). The blue lines are optic fibre cables that daisy-chain all Libera BPMs in the storage ring. The red and black lines are global data outputs; one carrying the magnet, the other carrying the orbit data. Global outputs are used for archiving purpose and are not actively included in the FOFB loop. The four black arrows are local magnet data. One Libera Brilliance+ platform calculates the data for 4 local magnets for the same plane (horizontal or vertical) [1].

PROCESSING

The FOFB application runs in the GDX module which is part of the Libera Brilliance+ platform. Prerequisite for correct (global) operation is the synchronization between all daisy-chained Libera Brilliance+ platforms. Synchronization assures all data (from turn-by-turn data on) is processed and output to the GDX module at the same time.

Data Concentration

Each Libera Brilliance+ platform contains 3 or 4 BPM modules. The data from these internal BPM modules is streamed via LVDS links to the GDX module. The Libera Grouping+ processing block uses 2 SFP slots in the GDX module to exchange the BPM data with other GDX modules. Redundancy is ensured with 2 optic fibre / copper links from/to each GDX module. The bitrate of the 2 SFP slots is 6.5 Gbit/s to ensure low latency. Once the data from all BPM IDs is received, the data is packed to a global orbit data packet (called “P”) [2]. For 3 GeV storage ring, the P matrix holds 200 BPM IDs, for the 1.5 GeV storage rings the length of the P matrix is 36 BPM IDs. The high bitrate minimizes the time needed to concentrate all BPM data. Estimated delay contribution of a single Libera Brilliance+ (3 or 4 BPM modules) is about 250-300 nanoseconds [2]. The overall delay depends also on the link lengths.

Global Orbit Data Output

The P matrix consists of the position data (horizontal, vertical), the SUM (average amplitude) and several status bits. The status bits transfer the information of the PLL status, the Interlock, the ID of the BPM and the validity of data. Data length from one BPM ID is 16 bytes (4x 4 bytes). Figure 2 shows the content of the global orbit data packet in details. The total payload depends on the number of BPM IDs. For 3 GeV, the 200 BPM IDs result in 3200 bytes packet size, for 1.5 GeV the packet size is 576 bytes.

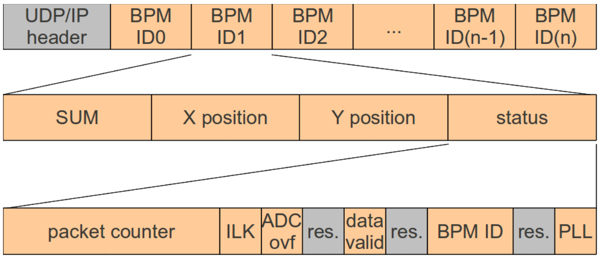

Figure 2: Global orbit data output through SFP2.

Matrix Calculations

The global orbit data packet holds the Interlock status information from all BPM IDs. Prerequisite for any further calculation is cleared Interlock status. If any of the BPM IDs is in Interlock, the calculation cycle will not start. An Interlock status masking has been introduced in order to exclude one or more BPMs disabled in the feedback loop from Interlock check.

Depending on the software configuration, the FOFB algorithm will extract either horizontal or vertical position data from the P matrix and use it for calculations. The current orbit is compared to the target (golden, G) orbit. The delta (G-P) is an orbit error which is then multiplied with the $S^{-1}U^{T}$ matrix which converts the orbit error into modal space. Multiplications are done in parallel for all eigenmodes at once. For the 3 GeV storage ring, matrix dimensions are 80 x 200, for the 1.5 GeV storage rings, matrix dimensions are 24 x 36. Multiplications with PI controller's coefficients are done in parallel for all eigenmodes at once. The PI controller includes anti wind-up protection. If the saturation is detected, it will indicate the saturation status and stop further accumulation of the I-term. As soon as conditions change in reverse direction, it will react immediately.

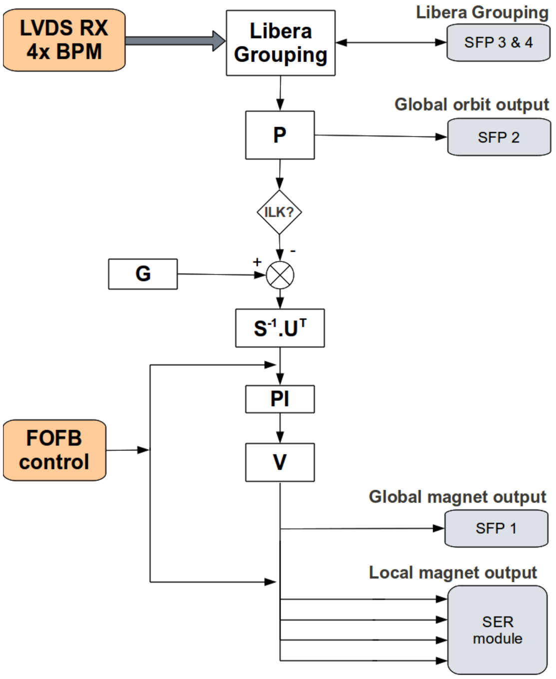

Figure 3: Processing stages.

The last in a row of multiplications is the V matrix which converts from modal space to magnet space. The matrix dimensions are 80 x 80 (3 GeV) or 24 x 24 (1.5 GeV). Multiplications are done in parallel for all magnets at once. The result is a vector that holds the DAC value for all magnet IDs. Complete processing scheme is shown in Figure 3 and is done for a single plane only. 2 GDX modules are needed for calculation of both planes.

MAGNET DATA OUTPUT

The magnet data is output through:

- SFP slot
- RS-485 outputs in SER module

The result of matrix multiplications is a global magnet vector "M". The DAC values are given in 20 bits (±19 bit). The data packet for a single magnet contains also information about the magnet ID and direction (horizontal or vertical). Altogether, the single magnet data is packed to 4 bytes (Figure 4). The global packet contains a header with a packet number which is same as for global orbit data packet. This way, both global outputs are aligned. Additional header bit indicates whether the magnet values have been applied to magnets or not (ON or STANDBY mode of operation; this is described later).

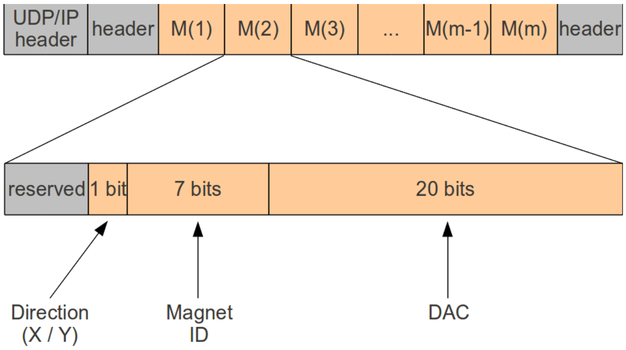

Figure 4: Global magnet data output through SFP1.

The global magnet data output is used for archiving purpose. Same data is sent to the SER module over Libera Brilliance+ backplane (LVDS links). The SER module features 4x RS-485 interfaces that connect directly to (local) 4 different magnet power supplies. Each of the four outputs is controlled independently and can be set to output any magnet ID. The DAC value in the SER module is cut by 4 LSBs to fit into 2 bytes. The link's baud rate is 1.25 Mbit/s which results in about 16.8 µs transmission time (including start, stop and parity bits).

FOFB CONTROL

Operational States

The FOFB application can be set to 3 modes of operation:

- OFF (default)
- ON (normal operation with SER magnet data output)
- STANDBY (normal operation without SER magnet data output)

Each of the states defines the values of various parameters or link statuses. Each transition between any of the three states triggers specific actions. The full FOFB states' scheme is shown in Figure 5.

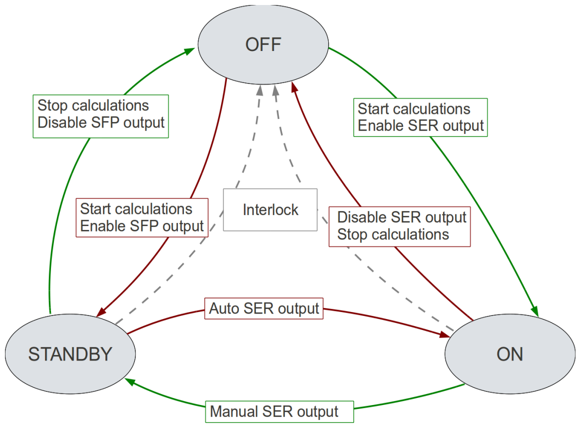

Figure 5: Simplified FOFB state diagram.

In OFF state, none of the magnet outputs is active. Data concentration runs independent from the FOFB state. When going to ON state, the FOFB calculations start and both magnet outputs are activated. If going to STANDBY state, the global magnet output remains active (for archiving purpose) but the output values in the SER module are under user's control (initial value is the last value calculated by the FOFB). If an Interlock is detected in any of the (non-masked) BPM IDs, the FOFB state changes to OFF automatically. User may change the state to OFF with an OFF or "Beam dump" events.

Event-based Control

The FOFB states are controlled by events exclusively. The FOFB-related events arrive through the event receiver module where they are filtered out from all other events.

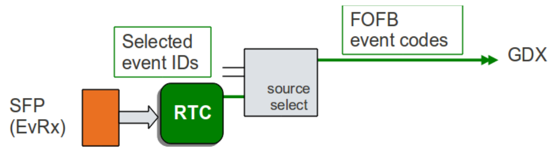

Figure 6: Event decoding.

Figure 6 shows a simplified path of events that control the FOFB states. The event stream is provided to the SFP slot in the EvRx module. From a large pool of various events only the relevant ones are filtered out by the Relevant Trigger Coding (RTC) table. The RTC equips the selected event IDs with internal (Libera) codes and distributes them to the GDX module. The FOFB application receives the events through internal event stream and reacts properly to them.

Double Buffering

The main accelerator control system will periodically update the FOFB reference orbit as it adjusts stronger but slower correctors to offload the FOFB correctors. As software commands may arrive to different Libera Brilliance+ platforms at different times, such an update would not necessarily be synchronous on a live system. In order to ensure a synchronous update double buffering of some parameters, including the reference orbit, has been introduced. The FPGA contains two locations (buffers) for double buffered parameters. The read-only buffer contains the values that are currently used by matrix multiplications, the write-only buffer can be changed by the control system. The transition from buffered to active values is controlled by the dedicated optic event ID.

Processing Performance

The FOFB cycle lasts about 100 µs. Figure 7 shows the simplified sequence of different processing stages or data transmissions.

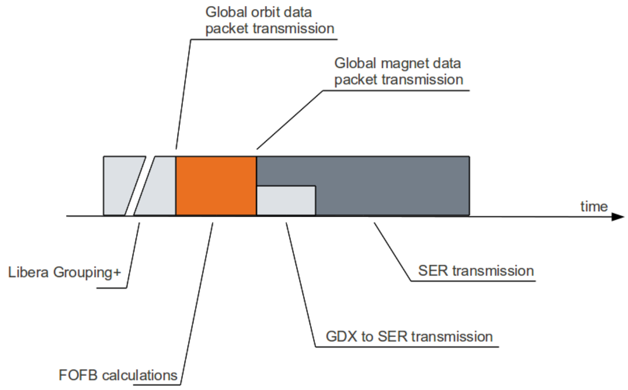

Figure 7: Time portions in the FOFB cycle.

Estimated times are gathered in Table 1. The time needed to group all orbit data depends on the group size. The estimated contribution of a single BPM ID is < 0.1 µs.

Table 1: Time Portions of Various Processing Stages

Processing stage	Time [µs]
Libera Grouping+	< 20*
FOFB calculations	< 2
GDX to SER transmission	~ 0.5
SER transmission	~ 16.8

* Depends on the group size.

CONCLUSION

The application has been implemented and was confirmed in laboratory environment so far. Due to its flexibility, it can be used with various BPM ID number or magnet IDs. Two magnet data outputs (GbE and RS-485) provide a good test environment that confirm correctness of data synchronism. However, the link to the actual power supplies has not been tested yet. The field test with 200 daisy-chained BPM IDs and full TANGO Control System-based FOFB control is still down the road.

REFERENCES

[1] M. Sjöström et al, "Technical Specification: Fast Orbit Feedback for the MAX IV Storage Rings", internal project documentation.

[2] P. Leban et al., "Fast Orbit Feedback Calculation Implementation for TPS", TUPA33, IBIC'12, Tsukuba, Japan (2012).