PERFORMANCE AND FUTURE DEVELOPMENT OF THE DIAMOND FAST ORBIT FEEDBACK SYSTEM

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Abstract

The electron beam in the Diamond Synchrotron Light Source is stabilised in two planes using the Fast Orbit Feedback system. This feedback system takes the beam position from 168 Libera electron beam position monitors, for both planes, and calculates offsets to 336 corrector power supplies at a rate of ~10 kHz. The design and implementation will be summarised, and system performance and first operational experience presented. Current and potential future developments of the system will be considered.

INTRODUCTION

The Fast Orbit Feedback (FOFB) system on the Diamond Light Source storage ring began routine operation in July 2007. It achieves integrated beam stability, up to 100 Hz, of X < 1.0 μm and Y < 0.4 μm, at primary eBPMs, which are well within the required 10% RMS beam dimensions. The FOFB implementation has been refined during this operational period to improve stability and to cope with anomalous behaviour in eBPMs and the communications network.

While the FOFB meets the current requirements it is recognised that the system needs to be further developed to meet increasing demands on beam stability, arising from smaller vertical beam sizes, higher sensitivity beamlines and additional sources of beam motion.

CONTROLLER

The FOFB system performs a global orbit correction using the position from 168 horizontal and 168 vertical eBPMs to 168 horizontal and 168 vertical corrector magnets [1,2]. The correction system is distributed around the 24 cells of the storage ring, with one computation node per cell.

Singular Value Decomposition (SVD) is used to break down the response matrix into its Input Modes (U), Output Modes (V Transposed) and a diagonal matrix (Σ) of the singular values (σ). A pseudo inverse response matrix can be produced from the transposed Input Modes, Output Modes and inverted non zero singular values in (Σ). However, the singular values are ill-conditioned covering three decades, so would make the system sensitive to small changes in the sensors. To address this Tikhonov regularisation [3] is applied to scale the singular values thereby retaining information for all modes. Using the scaled singular values a pseudo inverse response matrix is created. This is then partitioned into 24 sub matrices, with dimension 7x168 for each of the computation nodes, with each giving the output for 7 PSUs.

The transfer function of the process system is determined by first order lag in the power supply and magnet and by latency from the filters in the Libera eBPMs and the data transfer, hence approximates to a low pass filter plus a delay of 3.3 sample periods. An Internal Model Controller (IMC) is used to realise the controller. This uses a model of the process p(z) in the feedback part of the loop, together with compensation for the process in the forward loop, and provides for a single tuning parameter controlling the bandwidth of the loop, Fig 1. IMCs with the same dynamics operate on each output of the pseudo inverse response matrix [4]. This minimises the computation required, as the controller only has to be applied for the outputs required by that computation node ie the PSUs in that cell, so lends itself to being distributed.

A secondary loop performs correction of the residual horizontal orbit by adjusting the RF frequency.

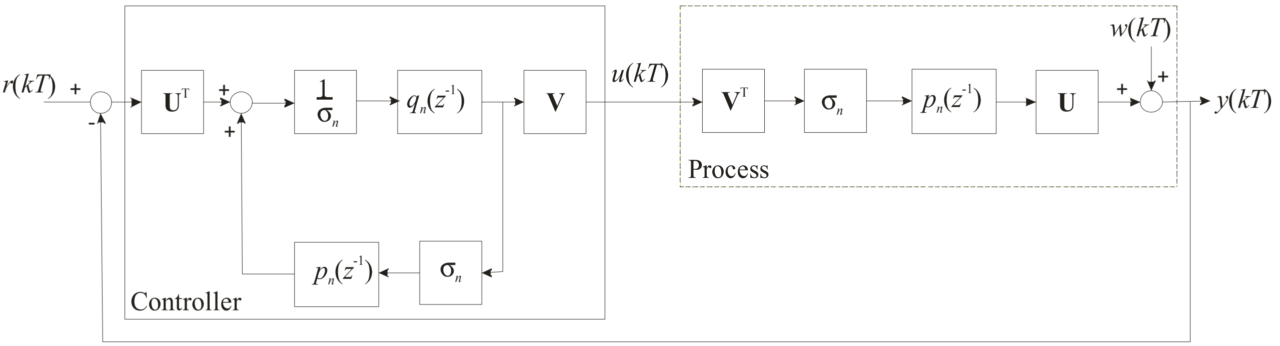

Figure 1: Feedback controller structure, r demanded orbit, u correctors, y measure orbit, p plant, q compensator for plant, σ singular values

REALISATION

To realise the required 10 kHz update rate, a custom communication controller, implemented in VHDL, is used to move X and Y positional and control data from the 168 Libera eBPMs to each of 24 computation nodes [5]. This network uses the multigigabit serial transceivers on the FPGAs in the Libera eBPMs and PMC interface cards on the 24 computation nodes. The network topology is structured as a 2D torus, with one computation node per cell, and gives a degree of independence from failure of single or combinations of eBPMs or links, as shown in Fig 2. The communication controller is realised as a data forwarding protocol whereby each node forwards its data plus each piece of incoming data once. The data is encapsulated in a low overhead packet including CRC. Each of the computation nodes receives data from all eBPMs, and uses a dedicated MVME5500 VME processor board to calculate the outputs for a sub pseudo inverse response matrix i.e. corresponding to the seven correctors for that cell. The IMCs are then implemented as fifth order IIR filters on the outputs of the sub pseudo inverse response matrix followed by a series of boundary checks to trap for erroneous conditions and to shutdown the system in a graceful way in the event of unrealistic corrector demands. The new PSU demand values are written over dedicated 1Mbps point to point links from each computation node to the PSU controllers for that cell.

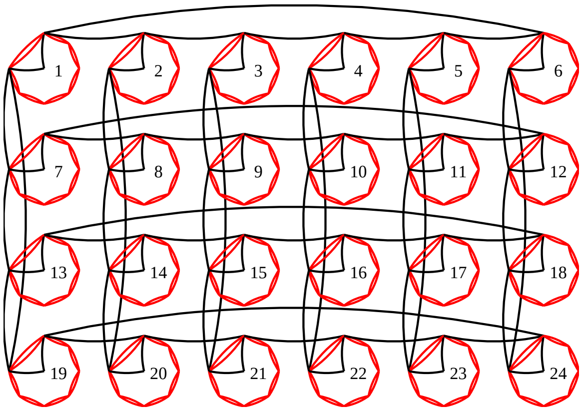

Figure 2: FOFB communication network topology, with each circle being one cell consisting of 7 eBPMs, and a computation node in the centre. The interconnection is as a 2D torus.

PERFORMANCE

The FOFB provides around 20 dB of suppression at 16 and 24 Hz where most ground noise is coupled to the girders, with a crossover point at 80 Hz. This is in good agreement with the model, Fig 3, and meets performance targets. The FOFB is unable to correct beam motion near 300 Hz caused by the girder cooling water flow and mechanical resonances, Fig 4.

The FOFB also prevents insertion device movements from affecting other beam users by compensating for the beam motion remaining despite the use of feed-forward tables.

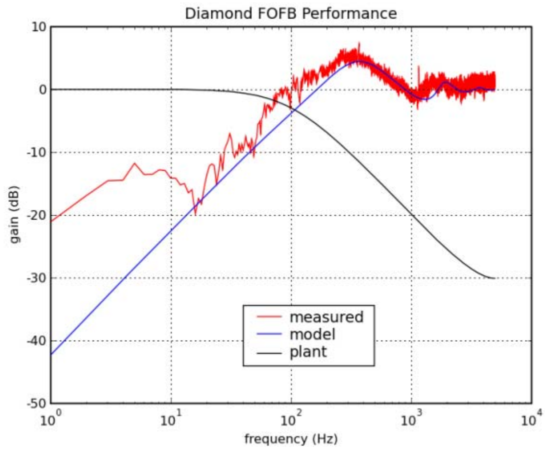

Figure 3: Theoretical and measured suppression in the vertical plane. Below 10 Hz is noise dominated in the measured data.

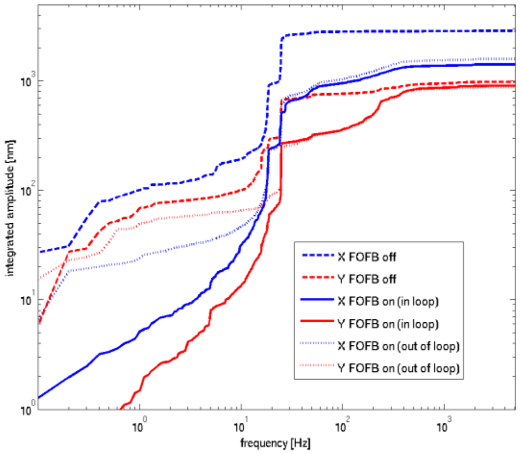

Figure 4: Integrated amplitude of positional noise for Feedback Off, Feedback On, in loop, and Feedback On, out of loop.

OPERATIONAL EXPERIENCE

To maintain loop stability the FOFB is only operated in the linear region of the eBPMs, up to 100 um. Inputs outside this limit stop the system. Large glitches driven by the eBPM analogue front-ends were regularly stopping the system, the worst few eBPMs were replaced, reducing the frequency of glitches across the whole system to once per week. The system has been recently been altered to saturate and ignore any one out-of-limits input, the MVME5500 PowerPC vector unit was needed for this calculation to meet timing constraints. The automatically archived post-mortem facility was essential to diagnosing these rare glitches, saving the last 1s of internal state from all feedback processors through the EPICS based control system whenever the FOFB stops.

The instantaneous demand current during feedback will produce a poor steady-state orbit as the controller proportional gain is greater than one. To compensate for this, at the time of stopping, the feedback writes a suitably filtered steady-state value, this greatly reduces the disruption caused by any unexpected stops.

During long runs corrector strengths were increasing near disabled eBPMs due to the growth of unobservable modes. These were damped by moving the integrator pole in the controller slightly toward the origin.

The FOFB will stop whenever the number of nodes on the feedback network changes. One particular eBPM failure mode prevented the FOFB system from starting. If the eBPM processor crashes the feedback communications controller can become desynchronized and the number of nodes on the feedback network will oscillate. This has been fixed by communicating the identities of each node as well as the total number so that unresponsive eBPMs can be ignored. This fault has occurred roughly every two weeks and was disruptive because the eBPMs form part of the machine protection system and cannot be rebooted without dropping the beam.

FUTURE REQUIREMENTS

While the FOFB system meets the original targets of beam stabilization and provides ~3dB of suppression, in both planes, up to 100Hz, this does not necessarily meet the needs of all the users. Future developments will take into account the detailed requirements of each beamline. In 2009, the first IR beamline on Diamond will come on line. By the nature of the experiment they will potentially be sensitive to beam disturbances up to 1 kHz. A future beamline to produce fast changing polarisation in the photon beam will use two undulators and a series of magnets to move the electron beam between them with a repetition rate of 10 Hz is a potential new source of beam disturbance. The Diamond storage ring currently operates with 1% coupling which determines the vertical beam size, but this is likely to be reduced in the future. Incorporation of pBPMs in the feedback system, in addition to the electron beam position monitors, is also under consideration.

FUTURE DEVELOPMENTS

Improvement in performance will require the suppression of high frequencies to reduce their contribution to the integrated amplitude. In the current design the same controller dynamics are applied to all modes, so all modes have the same bandwidth. It should be advantageous for each mode to have its own dynamic response. The difficulty with this approach is that the calculation of the control error in mode space requires a multiplication of the eBPM values by the transposed Input Modes (U^T), and scaled singular values (σ). The IMC controller dynamics would then be applied to these values and the result is then multiplied by the Output Modes (V) to convert from mode space to corrector space. Given that U^T and V matrices have dimensions of 168x168, the two matrix multiplications require a significant amount of computation.

The latencies in the system come from three areas, the group delays in the eBPM filters, data moves to the computation nodes and PSU bandwidth. In each of these areas there are possibilities to reduce the contribution to the overall latency.

To incorporate the pBPMs the analogue position information from the pBPMs need to be integrated in to the communication network. To realise this an acquisition module using an FPGA with multigigabit serial transceivers will be developed. The pBPM positional information can then be reflected back into electron space and incorporated into the global correction scheme. However, pBPMs will have different dynamics compared to the eBPMs hence one controller dynamics for all modes may no-longer be valid. In addition correction of pBPM contamination from upstream dipole photon flux is likely to be required.

A programme of work to investigate and develop of these areas is now planned. There is also an ongoing programme of work to identify, understand and reduce sources of the beam motion. Some of these are known to relate to water flow, cooling pumps and resonance in mechanical structures.

CONCLUSION

The Diamond FOFB system has been implemented and is operating successfully. While the system meets current stability criterion it is recognized that these will become more demanding in the future, hence work is planned to improve the performance of the feedback system and hence orbit stability.

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