CORRELATION ANALYSIS OF BEAM DIAGNOSTIC MEASUREMENTS IN SSRF*

Zhichu Chen†, Yongbin Leng, Yingbing Yan, Baopeng Wang, SSRF, SINAP, Shanghai, China

Abstract

Signals from various probes of the beam diagnostic system in Shanghai Synchrotron Radiation Facility (SSRF) were processed with correlation analysis algorithms. The resulting data allowed us to sort the probes by confidence, which means the stable and accurate signals could be separated from the faulty or noisy ones. And the beam dynamics measurements became electronic instrument free at the same time. This makes it possible to eliminate bad sensors, such as noisy Beam Position Monitors (BPM), from critical uses, like the feedback system, to offer a more confident set of beam parameters and to estimate useful global information by extracting the relationship between some probes.

INTRODUCTION

There are more than 200 diagnostics devices, including 140 BPMs, two DC Current Transformers (DCCT), a filling pattern monitor, an X-ray pinhole monitor, an interferometer monitor, positioned around the storage ring of the SSRF[1]. Each one gives a specific signal which can be processed to indicate some properties of the beams at its position individually. Usually these monitors are used to inform the accelerator physicists and operators the local status of the beams. Comparing the measured and computed values of the beam dynamics at each position, one can tell how well the current setup fits the lattice model.

But these monitors were treated separately and locally. Beam parameters should be related in an accelerator, especially in a storage ring, so what if we see these signals as a whole and everyone is an aspect of the same beam with some individual features. Fortunately, a global data warehouse[2] with some modifications is already available for us to make the above attempt.

DATABASE DESIGN

MATLAB has been replaced by Java at the Experimental Physics and Industrial Control System (EPICS) channel access (CA) data acquisition and storage stage by using CAJ and JCA[3] for some reasons:

- MATLAB can hardly to do accurate timing jobs;
- labCA for MATLAB does not come with a CA monitor to a process variable (PV);
- although MATLAB is very efficient at matrix operations, we cannot actually benefit from that at this particular stage. Thounsands of loops are involved in this situation and the performance of MATLAB degrades like other interpreter languages;
- MATLAB behaves vulnerable on our servers for some reason;
- Java is flexible, powerful, robust, easy to code, and open source.

Every PV involved in the database, which is configurable through an XML file, will be created as a CA monitor. A global array is used to store the current PV values refreshed by the above monitors instantly and will be transfered into different objects by the PV names at a relatively fast rate. A slower data matrix will then be generated by averaging some periods of the fast data matrix and will be saved to the disk when reaching an appropriate size.

The fast data matrix serves as a buffer and will not be saved to the disk except for defined events, which are still configurable in the XML file mentioned above, like a sudden beam loss for at least 20 mA and the end of an injection. Not only can we find out the time of an emergency, but we can also trace the beam status from the fast data matrix and a warning signal would be provided if the same trend should occur in the future based on that phenomenon.

An application based on Java is running online in SSRF, exporting the continuous slow data and the event-based snapshots, including BPM fast acqusition (FA) turn-by-turn (TBT) data, BPM slow acqusition (SA) data, DCCT waveform data, raw image data from the X-ray pinhole camera, injection status and filling pattern from the beam current monitor.

FA DATA ANALYSIS

Lattice Monitoring

The BPM TBT data can be used to extract the β-functions (during injections or machine studies) and the dispersion functions by using singular value decomposition (SVD): $B = U \times S \times V^{\dagger}$.[4] Different measurements are presented to be compared with one another so that the minor changes in the quadrupoles are visible to the operators. Fig. 1 shows that quadrupoles' change has impacted the β-function at y-direction.

By keeping an eye on the lattice parameters, one can be aware of the variantion of the environment instantly. The percentage change chart can be an intuitive interpretation of the location of the origin.

Instrument Troubleshooting

In a harsh environment where high levels of radiation or other unexpected disturbance deteriorate instruments temporary or permanently all the time, troubleshooting is one

* Work supported by National Natural Science Foundation of China (No. 11075198)

† chenzhichu@sinap.ac.cn

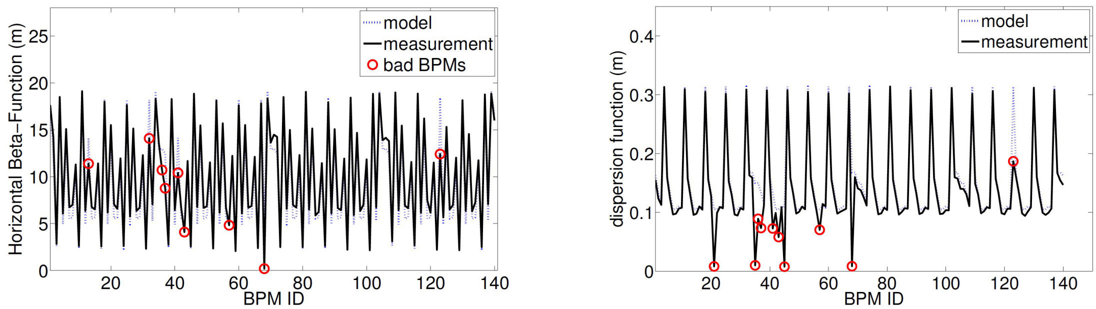

Figure 2: BPM troubleshooting results by comparing the theoretical values and the measured ones. Left: β-function at x-direction. Right: η-function.

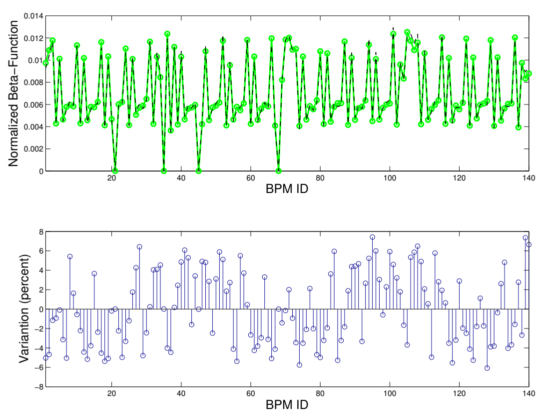

Figure 1: β-function varies with the quadrupoles' values. Top: β-function extracted from the TBT data at two different tunes. Bottom: percentage change of the β-function from one status to another.

necessary process. The lattice extraction method mentioned above is also good at this. The calculated values are used to be references and those who deviate too much from the model are considered malfunctional. A BPM filtering result from checking the consistency of model β-functions or the dispersion function and the measured ones is shown in Fig. 2.

Another useful application of the TBT data is to eliminate the above physics modes from the data matrix by setting the first several singular values to zeros: $S \to S' = \mathrm{diag}(0, 0, \ldots, 0, \lambda_k, \lambda_{k+1}, \ldots)$. A physics-free data matrix is obtained with a simple multiplication $B' = U \times S' \times V^\dagger$ and only local noises are left. The BPMs' resolutions can be got from this error-matrix, a normalization through the right singular vectors is needed, and the best ones can be the candidates for critical uses, e.g., the feedback system. Fig. 3 shows a typical result of the beam based BPM resolution measurement in SSRF. Some BPMs have relatively small standard deviations and it turns out that they are the ones that have migrated to the new Libera Brilliance electronics during the previous upgrades. Several BPMs have one or more extremely noisy channels so the readings are unreliable. The thresholds of these BPMs in the interlock system should be a little looser if we want to avoid rapid false alarms.

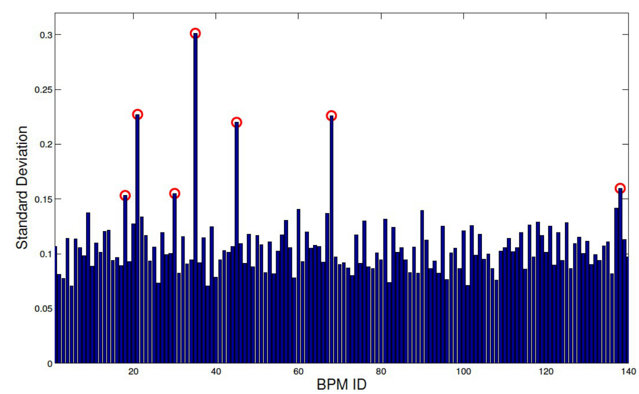

Figure 3: A beam based BPM resolution result.

SA DATA ANALYSIS

BPM, DCCT and Filling Pattern SA Data

The BPM SA data matrix is not only a beam position recorder. The sum of the fourth probes of a BPM is proportional to the charge of the beam and we do find a strong positive linear correlation between the DCCT outputs and the BPM sum signals. An SVD of the matrix consists of the BPM sum signals and the DCCT values can extract the principal temporal pattern—a mode that is shared by all beam-current related variables. Using the first singular value will give us the pure beam current decay curve and the factors which can be used to calibrate the BPMs for absolute current measurement. And just like the TBT data, one can still omit the principal component and get the BPM resolution array as well as the DCCT resolutions. Fig. 4 shows the resolutions of the BPMs and one DCCT. Dozens of BPMs even have better performances than the DCCT. This result may be due to the fact that the DCCT has been suffered from the burst noises from nowhere since a couple of years ago.[2] The BPM sum signals seem to be adequate as a complement of the beam current and life monitor.

ISBN 978-3-95450-115-1

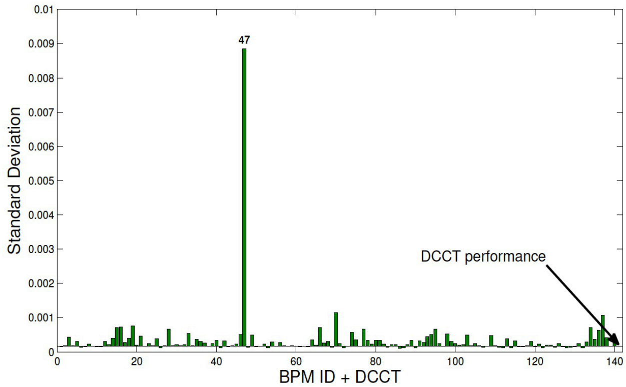

Figure 4: A comparison of BPM and DCCT as the direct current monitors. The base line is the resolution of the DCCT.

X-ray Pinhole Image

The image from the X-ray pinhole camera could be considered as rows of horizontal image lines or columns of vertical image lines. The left and right singular vectors are the vertical and horizontal basic vectors respectively. These vectors represent the probability density functions (p.d.f.) of the vertical and horizontal photon distributions. The principal mode does not contain the quantization noises of the CCD pixals or the random background, so it's able to provide a more reliable standard deviation on the horizontal or the vertical direction. Fig. 5 shows the resulting transverse distributions by applying the SVD decomposition or by averaging part of the image slices for a low beam current of 0.5 mA. The second and third modes in our case represent the amount of rotation which might be the contributed by the misalignment of the camera or pinhole.

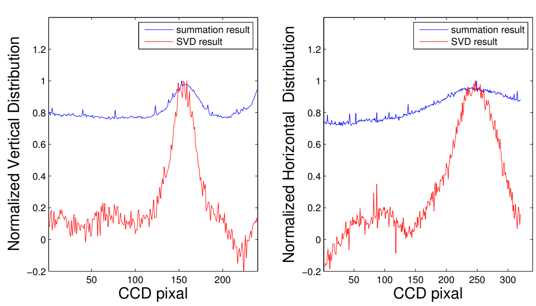

Figure 5: SVD decomposition can "successfully" separate the signal from the background even for low beam current. Red ones are background-free distribution results.

We also find that the image size decreases with the decay of the beam current and the correlation coefficient between them is larger than 0.97. Fig. 6 shows how the image sizes and the DCCT readings are related.

The slope and intercept of the fitted line will change sometime after an injection and then might change back slowly. This may be because the bunch charge distribution

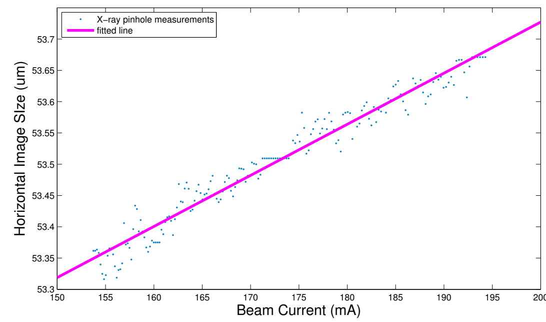

Figure 6: The X-ray image size on the camera is strongly linear correlated with the beam current.

failed to preserve. A correlation analysis between the image size and filling pattern is needed in furture work.

CONCLUSION

A new storage engine has been designed to save the slow data continuously and catch the events as we wanted. The slow data are used to indicate the beam dynamics and the event-based data are used to study the machine without consuming beam experiment time.

Correlation analysis has been proved to be useful in many aspects in SSRF. Since we have so many devices that are related, the noise reduction is obvious. We can also estimate the resolution of each BPM by neglecting the relevent components, making it possible to sort the BPMs by confidence to highlight the best ones for critical uses such as feedback system. The two DCCT monitors can be benefit from the approach as well by using the BPM sum signals as a complement.

REFERENCES

[1] Y.B. Leng, K.R. Ye, and W.M. Zhou, etc., "SSRF Beam Diagnostics System Commissioning," DIPAC2009, Basel, Switzerland, 2009: 24–26.

[2] Y.B. Leng, Y.B. Yan, Z.C. Chen, and R.X. Yuan, "Beam Diagnostics Global Data Warehouse Implementation and Application at SSRF," Proceedings of IPAC2011, San Sebastián, Spain, 2011: 1287–1289.

[3] M. Sekoranja, "Native Java Implementation of Channel Access for EPICS," Proceedings of ICALEPCS2005, Geneva, Switzerland, 2005, PO2.089-5.

[4] Chun-xi Wang, Vadim Sajaev, and Chih-Yuan Yao, "Phase Advance and Beta Function Measurements Using Model-Independent Analysis," Phys. Rev. ST Accel. Beams 6, 104001 (2003).