BPM SELECTION FOR BEAM CURRENT MONITORING IN SSRF*

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

Abstract

Although New Parametric Current Transformers (NPCT), commonly called Direct Current Current Transformer (DCCT), is the general solution of beam current monitor, Beam Position Monitor (BPM) sum signals may still surpass it in some aspects such as the faster data rate and higher resolution in low current situations. Nevertheless, an additional monitor should be harmless. Meanwhile, the DCCTs in the storage ring of Shanghai Synchrotron Radiation Facility (SSRF) have been suffering from various noise and the signals from the BPMs could be an aid to provide the beam current more accurately. There're 140 BPMs in the storage ring in SSRF but not all of them are suitable for this particular usage. This article focuses on the methods used here to dynamicly choose the BPMs that meet the criteria.

INTRODUCTION

Beam current is one of the fundamental parameters to be measured in any particle accelerators and its direct current (DC) component is especially important in synchrotrons and storage rings. Thus, DCCT is almost the most widely used DC monitor in modern light sources around the world for its fine resolution less than 1 μA r.m.s. [1] and long-term stability.

An NPCT175 from Bergoz Instrumentation have been positioned on the storage ring as the beam current monitor and another one in addition as its backup since the beginning of the commisioning in SSRF [2, 3]. Both of them have been suffering from various noise from time to time [4]:

- power line noise,
- narrow band noise which is strongly related to the beam current,
- random square wave noise from nowhere.

Figure 1 shows a typical performance of the DCCT without any noise mentioned above and the BPM sum signal. The quasi-constant resolution of DCCT reading is less than 2 μA in all circumstances and that can be regarded as the limitation of the electronics. The situation of the BPM is a little more complex. The resolution of a single BPM is better than the DCCT's for a really low current (weaker than 10 mA) but gets worse as the beam current rises. Averaging the whole BPM system, on the other hand, can improve the performance significantly. The resolution of the BPM system is better than that of the DCCT when the current is weaker than 60 mA and it seems still under control even the current is stronger. It all seems that the BPM alternative is especially suitable for the low current mode. It is not unreasonable to assume that some BPM may act worse than the others and the new BPM set will work even better. The purpose of our beam experiment is to find an algorithm to dynamicly maintain such a list in which each BPM is relatively stable.

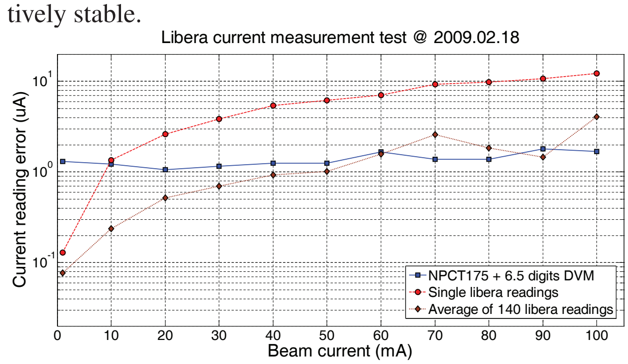

Figure 1: A performance evaluation of DCCT and BPM sum signal as the beam current monitor.

There're 140 BPMs on the storage ring [2] and some of the probes can be considered stable enough to accomplish the task of been current monitors. Using the BPM sum signal to relatively measure the DC beam current has already been a handful means during the commisioning of SSRF [2]. This idea is being urged by all the benefits it can offer: faster data rate, dead time free and sensitive even in low current situations. Hence, a performance evaluation is needed to pick out the qualified BPMs.

PRINCIPLES

The sum signal on the pick-ups of a BPM does not position insensitive. For such a resolution requirement, the nonlinearity problem must be taken into account. There're positions that the transverse motion of the beam is fierce and the BPMs at these locations are less desirable. Some BPMs might suffer from some kind of local noise like the DCCT does, or just encounter some machining, installation, even connection problems. So the algorithm we need will only choose good BPMs at good positions.

Some algorithms have been tried and compared, but it turns out that the one inspired by the theory of Principal Component Analysis (PCA) is better than others. One example is that we used to rate the BPMs by the r.m.s. of the difference the each BPM "waveform." The noisy or unstable BPMs could be picked out without problem. The one smooth but wrongly decayed or slowing drifting can get away. But PCA can be helpful to list all of them.

Overview of PCA

PCA is a useful mathematical technique for finding patterns in data of high dimension which has been introduced to the particle accelerator physics [5]. Only a statistical analysis of the BPM data matrix is needed to study the

* Work supported by National Natural Science Foundation of China (No. 11075198)
† chenzhichu@sinap.ac.cn
‡ Corresponding author, leng@sinap.ac.cn

ISBN 978-3-95450-119-9

beam dynamics by using PCA without the knowledge of the machine model. PCA uses singular value decomposition (SVD) to convert the P-by-M BPM data matrix B into a product of three matrices [5]:

$$B_{P\times M} = U_{P\times P} S_{P\times M} V^{\dagger}_{M\times M}, \tag{1}$$

where

$$S = \text{diag}(\lambda_1, \lambda_2, \ldots, \lambda_k) \tag{2}$$

is the singular matrix and λ_i the singular values.

Each singular value has its mode. A global mode, which is usually related to an aspect of the beam dynamics physics, tends to correspond to a significantly large singular value and should be shared by all BPMs. The thermal noise modes could be divided and mixed in an unpredictable combination of almost negligible singular values. A local mode will only imply the malfunction of a specific BPM. Thus, only the thermal noise modes and the local modes are needed to evaluate the performance of BPMs.

Selection Algorithm

Normally, PCA extracts the beam transverse motion modes along with the longitudinal ones. In our case, the BPM sum signal matrix would be decomposited to get the spacial vectors as well as the temporal ones. The principal component will be the decay mode with little doubt. There might also be some singular values much greater than the noise floor in practical cases. They may due to the nonlinearity of the BPM probes or something alike, but what should be concerned is always the principal decay mode. The other modes should be considered as some kind of noise in spite of their internal physical mechanics because we only use the sum signal to monitor the beam current without optimization.

Once the SVD is done, the deviation matrix can be easily derived by setting the first element of the singular value matrix, say λ_1, to zero without touch the others and multiplying them back:

$$B'_{P\times M} = U_{P\times P} S'_{P\times M} V^{\dagger}_{M\times M}, \tag{3}$$

where

$$S' = \text{diag}(0, \lambda_2, \ldots, \lambda_k). \tag{4}$$

The r.m.s. value of each column denotes for the standard deviation of each BPM.

BEAM EXPERIMENTS

The data of the BPMs and the DCCT are being fetched during the daily operation and machine study time is not really required. The normal operation mode in SSRF is to inject beam into the storage ring with the energy of 3.5 GeV until the current reaches 210 mA or so every 12 hours before it starts to decay for the rest of the time. The time series data from 10:20 a.m. to 4:20 p.m. on May 2, 2012 were used here as a demonstration. Figure 2 shows a typical BPM sum signal (BPM 1) and a noisy one (BPM 47) which this algorithm aims to highlight.

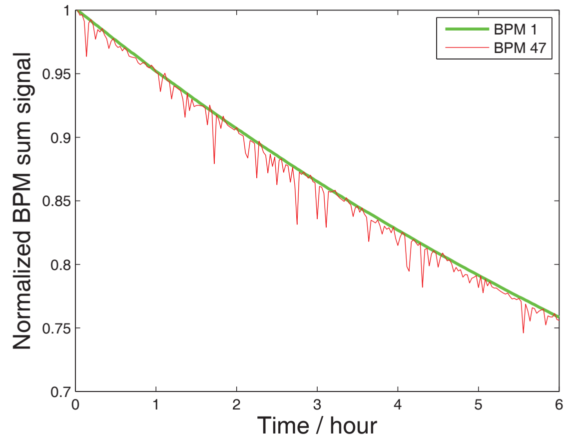

Figure 2: Typical BPM sum signals.

The Result of PCA

After a simple SVD of the BPM data, unrelated modes are separated:

$$B = (u_1, u_2, \ldots) \times S \times (v_1, v_2, \ldots)^{\dagger}. \tag{5}$$

The principal mode u_1 is the decay mode which matches the DCCT readings (see in Fig. 3) as expected. The slight difference between them implies the nonlinearity of the ADCs.

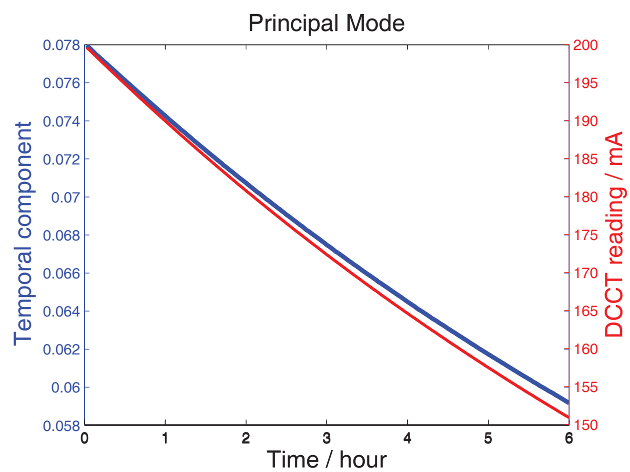

Figure 3: The principal mode of the BPM data (blue) along with the DCCT data (red).

The peak in the spacial component v_2 of the secondary mode u_2 (see in Fig. 4) indicates this mode is a local mode that concerns just one single BPM. The mode appeared at the 47th component exclusively which is why the waveform is so messy in Fig. 2.

To obtain the performance of the overall system, the estimating process as mentioned in Eq. (3) is made. Figure 5 shows that some BPMs may behave poorly but we can still get a couple of BPMs that are both steady and correlated to the beam current.

Sorting the standard deviations should offer the confidence list. There is no human intervention needed, so the

ISBN 978-3-95450-119-9

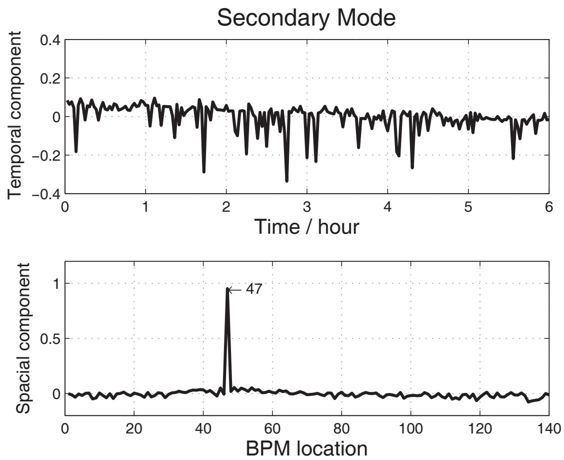

Figure 4: The secondary mode of the BPM data (upper) and its corresponding spacial component (down).

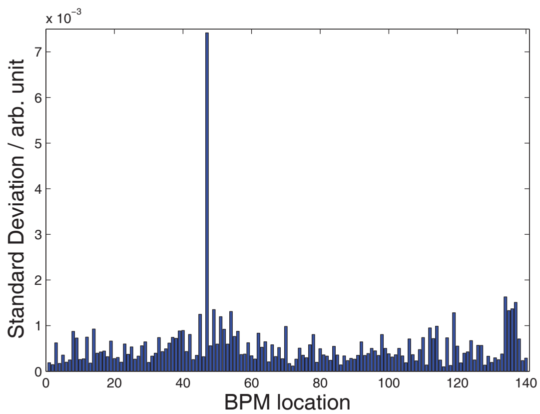

Figure 5: The performance of the overall BPM system in the PCA process. The BPM sum signals are normalized before the process and the absolute value of the standard deviation of each BPM is irrelevant so that an arbitrary unit is adopted here.

list could use the live BPM data and refresh itself automatically.

The Result of Difference Method

As a comparison, the difference method we've talked about is also applied and the result is show in Fig. 6. BPM 47 is quite distinguishable while other BPMs behave just alike. It is hard to tell whether one BPM is more suitable for the current measurement than another since the result suggests many of them have reached the electronic noise limits. It'll be very difficult to decide the threshold to filter the "improper BPMs." Thus, it is not safe to run this method without the manual monitoring.

This method seems to be qualified to filter those obviously noisy BPMs. The stable BPMs can also be entangled among low frequency fluctuations, which means they are not totally usable, or they can have unfortunately intolerable nonlinear problems, which means each BPM should be calibrated separatedly. So even if a threshold is chosen, the selected BPMs still need a careful check individually.

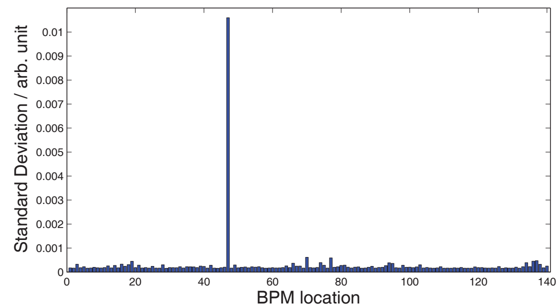

Figure 6: Result of the performance of the overall BPM system by using the difference method.

CONCLUSIONS

The BPM sum signal has been used as an alternative to the DCCT in SSRF. The BPM probes still have readings even there's no beam in the ring, so the zero drift is not neglectable. The ADCs at the electronics front-end do not have perfect linear responses. Therefore, a careful calibration is needed when the sum signal method becomes a practical application.

In spite of the above problems, the BPM has a better performance than DCCT sometimes, e.g., under the condition of low current. BPMs with fine resolutions, little noise and luck locations that the transverse movement of the beam is of small amplitude are needed to be picked out to aid the DCCT. A new BPM selection algorithm based on PCA was then proposed to choose such a set of BPMs.

The new algorithm for the beam current measurement has several advantages over other ones tried in SSRF. The main reason why it's chosen is that PCA can extract the correlationship between BPMs. This feature assures that the selected BPMs have the max likelihood of the beam current. Besides, the PCA idea is user friendly. The total process is neat and obvious. That makes the algorithm easy to be implemented and work online.

REFERENCES

[1] D.J. Martin, S. Allison, and B. Scott, et al., "Evaluation of Bergoz Instrumentation NPCT," Proceedings of PAC09, Vancouver, BC, Canada, 2009: 4021–4023.

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

[3] Y.B. Leng, Y.B. Yan, and W.M. Zhou, et al., "Precise Beam Current Measurement for Storage Ring Using Beam Position Monitor," High Power Laser and Particle Beams, 2012, **22**(12): 2973–2978.

[4] Z.C. Chen, Y.B. Leng, and Y. Xiong, et al., "Modelling and Performance Evaluation of DCCTs in SSRF," these proceedings.

[5] C.X. Wang, "Measurement and Application of Betatron Modes with MIA," Proceedings of PAC03, Portland, Oregon, U.S.A., 2003, **5**: 3407–3409.

ISBN 978-3-95450-119-9