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APPLICATION OF CLUSTERING BY FAST SEARCH AND FIND OF DENSITY PEAKS TO BEAM DIAGNOSTICS AT SSRF*

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Abstract

With the increased technological complexity of accelerators, meeting the demand of beam diagnostics and operation need more powerful and faster methods. And detecting the accuracy and stability of beam position monitors(BPMs) are important for all kinds of measurement systems and feedback systems in particle accelerator field. As an effective tool for data analysis and automation, the machine learning methods had been used in accelerator physics field, recently. Among machine learning methods, the clustering by fast search and find of density peaks as a typical unsupervised learning algorithms could be performed directly without training in arbitrary accelerator systems and could discover unknown patterns in the data. This paper used clustering by fast search and find of density peaks to detect faulty beam position monitor or monitoring beam orbit stability by analysis five typical parameters, that is beta oscillation of X and Y direction (BetaX and BetaY), transverse oscillation of X and Y direction(AmpX and AmpY) and energy oscillation(AmpE). The results showed that clustering by fast search and find of density peaks could classify beam data into different clusters on the basis of their similarity. And that, aberrant run data points could be detected by decision graph. Morever, analysis results demonstrate the characteristic parameters AmpE, AmpX and BetaX amplitude have the same effect to distinguish the faulty BPMs and the AmpY and the BetaY amplitude are also.

INTRODUCTION

The storage ring in SSRF is equipped with 140 BPMs located at 20 cells of the storage ring to monitor the beam dynamics [1]. The BPMs at the beam lines after the insertion devices (ID) or the bending magnets are of great importance, because they also serve as the orbit feedback system to ensure stability of the electron Beams [2]. Meanwhile, the BPM confidence levels included in the feedback system can be used to estimate stability of the beam dynamics. Some BPMs can be also used to do measurements other than the beam position, such as the (relative) beam current or life time. Therefore, an abnormal BPM should be found and treated and a beam position monitor (BPM) system is an essential diagnostic tool in storage ring of a light source.

A typical BPM system consists of the probe (button-type or stripline-type), electronics (Libra Electronics/ Brilliance in SSRF) and transferring component (cables and such). Ever since the SSRF commissioning in 2009, the BPM have occurred all kinds of malfunction. They were permanently damage of individual probe or corresponding cable, misaligned (position/angle) probes, high-frequency vibrations, electronics noise, and others. These faults mean totally useless of the signals from the BPM, which should be ignored until its replacement or repair. Hence, it is essential to find an effective method to detect the faulty BPM for operation of the storage ring.

With development in machine learning methods, a series of powerful analysis approaches make it possible for detecting beam position monitor's stability. Cluster analysis is one of machine learning methods. It is aimed at classifying elements into categories on the basis of their similarity [3]. Its applications range from astronomy to bioinformatics, bibliometric, and pattern recognition. Clustering by fast search and find of density peaks is an approach based on the idea that cluster centres are characterized by a higher density than their neighbours and by a relatively large distance from points with higher densities [4]. This idea forms the basis of a clustering procedure in which the number of clusters arises intuitively, outliers are automatically spotted and excluded from the analysis, and clusters are recognized regardless of their shape and of the dimensionality of the space in which they are embedded. In addition to, it is able to detect nonspherical clusters and to automatically find the correct number of clusters.

Based on the advantage of clustering by fast search and find of density peaks, this study researches the stability of beam position monitors to locate the BPM malfunctions at SSRF.

EXPERIMENTAL DATA AND ANALYSIS METHOD

In this study, the experimental data were collected from the beam running data including beta oscillation of X and Y direction, the amplitude of X and Y direction and the amplitude of energy oscillation. In general, the malfunctions could be judged by the abnormal fluctuations of above parameters. The parameters also have an important problem that is to detect the performance differences of different BPMs. Therefore, this study research the accuracy and stability of beam position monitors based on the data of above five parameters. Theoretically, the BPM could be considered as malfunction when its fluctuation ranges beyond the range of horizontal β-function which is reference value. On the other hand, the performance differences of different BPMs were be expect to distinguish by different cluster centres based on cluster analysis.

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The clustering by fast search and find of density peaks has its basis in the assumptions that cluster centres are surrounded by neighbours with lower local density and that they are at a relatively large distance from any points with a higher local density. For each data point i, we compute two quantities: its local density ρi and its distance δi from points of higher density. Both these quantities depend only on the distances d_{ij} between data points, which are assumed to satisfy the triangular inequality. The local density ρi of data point i is defined as

$$\rho_i = \sum_j \chi(d_{ij} - d_c) \tag{1}$$

where χ (x) =1 if x < 0 and χ (x)=0 otherwise, and d_c is a cutoff distance. Basically, ρ_i is equal to the number of points that are closer than d_c to point i. The algorithm is sensitive only to the relative magnitude of ρ_i in different points, implying that, for large data sets, the results of the analysis are robust with respect to the choice of d_c. In this paper, the d_c is 0.02. On the other hand, δ_i is measured by computing the minimum distance between the point i and any other point with higher density:

$$\delta_i = \min_{j:\rho_j > \rho_i} (d_{ij}) \tag{2}$$

For the point with highest density, we conventionally take $\delta_i = \max_j (d_{ij})$. Note that δ_i is much larger than the typical nearest neighbour distance only for points that are local or global maxima in the density. Thus, cluster centres are recognized as points for which the value of δi is anomalously large. Generally, the value of δi and ρi represent whether the point is cluster centre, the typical characteristic of cluster centre is the value of δi and ρi are larger. Decision graph could depict the value of δ_i and ρi and show which points are cluster centre.

RESULTS AND DISCUSSION

Generally, the BPM malfunctions could be detected by the compare of actual oscillation and the theoretical β-function. In the data processing, the BPM signals are 140 ID* 2048 turns [5]. If the maximum amplitude of each BPM signal in 2048 turns exceeds the range of β-function, the BPM must be fault. Figure 1 showed that the maximum amplitude (normalized) of each BPM signal is normal, thus it is ineffective method to detect BPM. But the spectrum information can reflect the malfunction of BPMs.

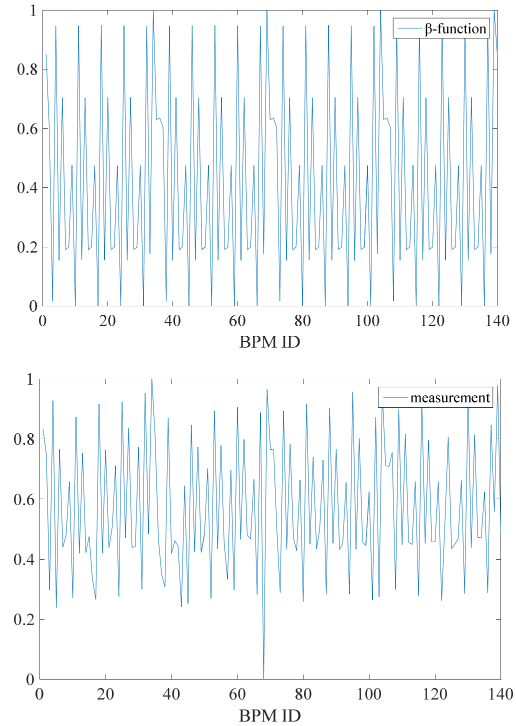
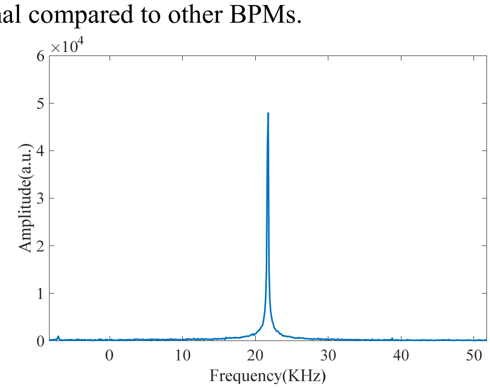
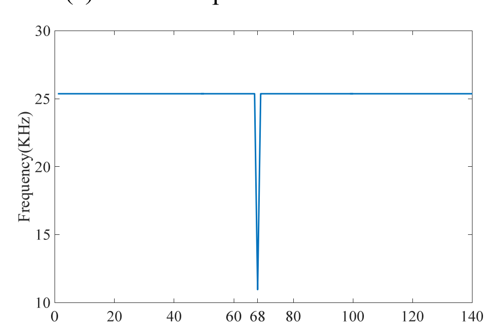


Figure 1: Transverse oscillation of Y direction.

The spectrum information with respect to the 1# BPM is shown in Fig. 2(a) and the spectrum information of all BPM is showed in the Fig. 2(b). From the spectrum information of Fig. 2(b), it could be concluded that the 68# BPM is malfunction. Because its centre frequency is abnormal compared to other BPMs.



(a) Fourier Spectrum of 1#BPM



(b) Frequency of all BPMs

Figure 2: Spectrum of BPMS.

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But the data of beta oscillation of X direction(BetaX), transverse oscillation of X direction(AmpX) and energy oscillation(AmpE) indicate that the broken-down BPMs are 68# BPM and 75# BPM. It shows in Fig. 3.

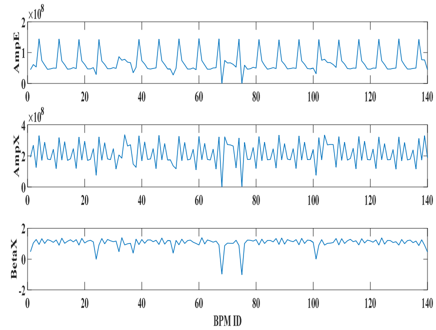

Figure 3: Abnormal BPMS.

Now the key problem is to detect the performance differences of different BPMs for locating abnormal BPMs. The research used the amplitude value of five character parameters of each BPM by cluster analysis. The idea comes from the basic assumption: if the data belongs to the same cluster, the feature of data should be same.

Based on the clustering by fast search and find of density peaks, the decision graph is showed in Fig. 4.

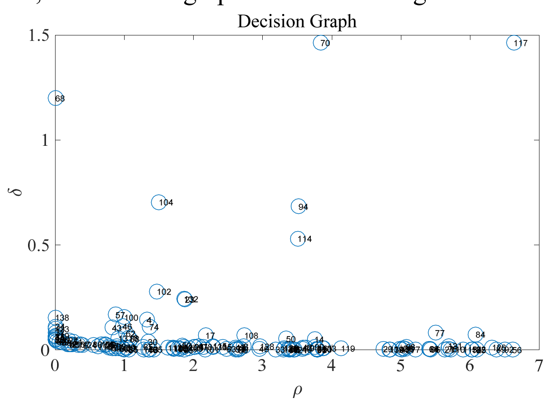

Figure 4: Decision graph for Transverse Oscillation of Y direction.

As anticipated, the only points of high δ and relatively high ρ are the cluster centres. 70 and 117 are two cluster cores in Fig. 4. Points 68 has a relatively high δ and relatively low ρ because it is isolated, it can be considered as cluster composed of a single point, namely, meaning a faulty BPM.

By cluster analysis of five character parameters of each BPM, respectively. It can draw a conclusion that the characteristic parameters AmpE, AmpX and BetaX amplitude can be seen as the same effect to distinguish the faulty BPMs. The AmpY and the BetaY amplitude could be seen as the same effect to distinguish the faulty BPMs. The all BPMs' cluster is shown in Fig. 5 by different parameter cluster analysis.

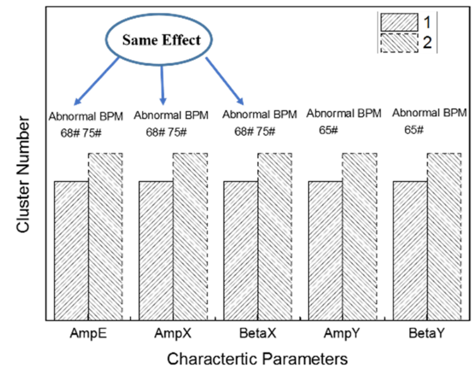

Figure 5: Different Parameters cluster.

The BPMs which are marked number belong to the first core, the other BPMs belong to another core. The performance differences of different BPMs stability of beam position monitors could be judged by clustering distribution. Therefore, the result demonstrates the characteristic parameters AmpE, AmpX and BetaX amplitude have the same effect to distinguish the faulty BPMs and the AmpY and the BetaY amplitude are also.

CONCLUSION

As the key beam diagnostics tool, BPM systems are widely equipped in all kinds of accelerators and are being used in daily operation and machine study. To better ensure the operation of the light source, a proper method detecting faulty beam position monitor or monitoring their stability is essential. This study proposed a cluster analysis method based on clustering by fast search and find of density peaks to search faulty BPMs.

The experimental results demonstrate that the proposed cluster analysis method could capture the accuracy and stability of beam position monitors. Especially, the decision graph could be find more key information about BPMs. Meanwhile, the analysis results demonstrate the characteristic parameters AmpE, AmpX and BetaX amplitude have the same effect to distinguish the faulty BPMs and the AmpY and the BetaY amplitude are also. But the validity needs more numbers to back it up.

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