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RESEARCH ON RESOLUTION EVALUATION OF STRIP-LINE BPM AT SXFEL-UF

B.Gao, J.Chen, Y.B.Leng*
Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai, China

Abstract

There are 49 strip-line BPMs installed in the injector section and linear accelerator section of Shanghai X-ray Free Electron Laser User Facility (SXFEL-UF) for electron beam position measurement. These two sections require resolution of 10 μm at 500 pC. Resolution evaluation is an important step in BPM installation and commission. This paper presents BPM resolution evaluation methods based on neural network. Experimental methods, data processing and result analysis will be discussed.

INTRODUCTION

Shanghai X-ray free electron laser user facility (SXFEL – UF) is a soft X-ray FEL, which is located at the SSRF campus. It is based on a 1.5 GeV normal conducting high gradient C-band (linear accelerator) LINAC and contains two FEL beamline, a seeded FEL beamline and a SASE beamline, and five experimental stations [1] as shown in Fig. 1.

In the injector and LINAC section, there are about 49 beam position monitors, the type is strip-line BPM (SBPM), 6 BPMs in injector, 46 BPMs in LINAC section. The resolution of BPMs at injector and LINAC of SXFEL-UF is better than 10 μm at 500 pC. The specific accelerator parameters and strip BPM parameters are shown in Table 1.

Table 1: Margin Specifications

Parameters	Value
Electron beam energy Gev	1.5)
Energy spread (RMS)%	<0.1
Normalized emittance (RMS)	<1.5
Bunch length (FWHM)/ps	<0.7
Bunch charge /nC	0.5
Peak current /A	>700
Repetition rate /Hz	50
Quantity of SBPMs	49
Electrode length of SBPM /m	0.15

Resolution evaluation is very important for the BPM system. It should be carried out during the project acceptance. The physicists need to know the resolution of each probe, because BPMs are prerequisites for accurate operation of orbit feedback system.

Cold test can provide the preliminary result of the resolution; however, it still has a gap with the real resolution. Beam based resolution evaluation has been introduced and employed in some facilities. Three BPMs in a drift section can be used to do the evaluation. Turn off the power of all magnets between the probes to construct a drift section to ensure that the beam propagates in a straight line between the probes [2]. Then, values from the first and the third BPM can be used to predict the beam position at the second BPM. Use this predicted value as the true value to evaluate the resolution with the measured value of the second BPM. However, we can not find drift section for every BPM.

A new method based on global correlation analysis was proposed. The neural network algorithm is used to establish the relationship model. The advantage of this method is that all probe data can be used to predict the probe data to be measured, and the resolution evaluation of all probes can be completed at one time.

Experimental methods, data processing and result analysis will be presented in this paper.

BEAM BASED EVALUTION METHOD IN DRIFT SECTIONS

When there is no accelerating structure between the probes, the power to the magnets between the probes can be turned off to keep the beam in a straight line as the Fig. 2.

Using the principle of two points to determine a line, the beam position read out from the first and the last probe can be used to predict the position of the beam in the middle probe in a drift section shown as Eq. (1).

$$POS2_{pred} = \frac{(POS3_m - POS1_m) * d1}{(d1 + d2)} + POS1_m, \quad (1)$$

where d1 is the distance between the BPM2 and BPM1, d2 is the distance between the BPM2 and BPM3. $POSi_m$ is measured position of the ith BPM, $POSi_{pred}$ is predicted position of the ith BPM.

Using the predicted value and the measured value can calculate the resolution of the BPM, formula is shown as Eq. (2).

$$resolution = \frac{std(POS2_m - POS2_{pred})}{\sqrt{2}}. \quad (2)$$

Figure 3 shows a typical drift section in SXFEL-UF: where SBPM8 is in the center of this drift section. Figure 4 shows a typical result of resolution measurement of the 8th SBPM at SXFEL-UF.

The result shows that the resolution at horizontal direction of the 8th SBPM reach 3.7 μm at 500 pC and the vertical position resolution reach 1.6 μm. This method is able used to evaluate the resolution of SBPM, however, disadvantage

* lengyongbin@zjlab.org.cn

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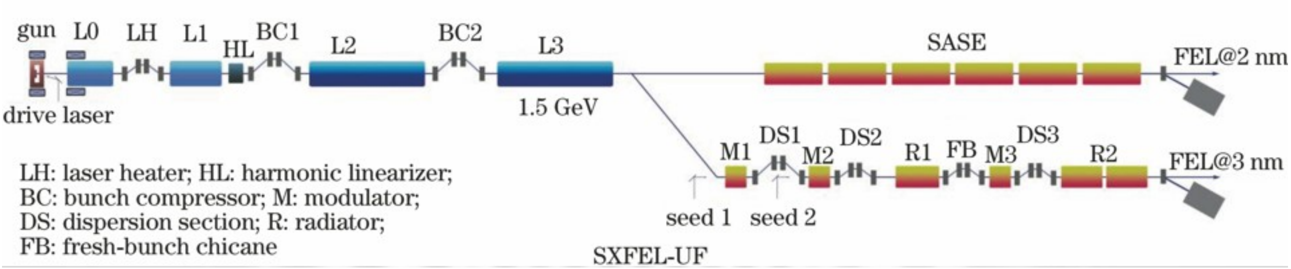

Figure 1: Schematic diagram of SXFEL-UF.

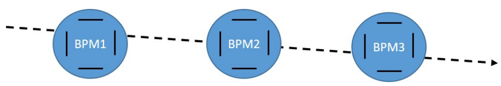

Figure 2: Schematic diagram of drift section.

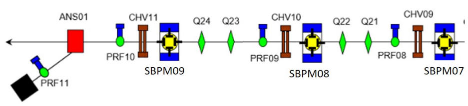

Figure 3: A typical drift section in SXFEL-UF.

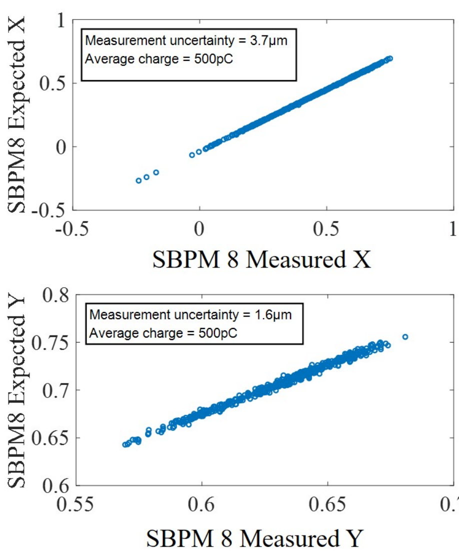

Figure 4: Resolution measurement of the 8th SBPM at SXFEL. (upper) measurement of the horizontal direction; (bottom) measurement of the vertical direction.

of this method is that we cannot find drift section for every BPM.

NEURAL NETWORK BASED METHOD TO EVALUTE RESOLUTION

Basic Principle

When the beam optical parameters and acceleration phase are fixed in the electron linear accelerator, the electron beam will move along a fixed orbit. Figure 5 shows the beam trajectory in SXFEL-UF for a period of time. The position of the electron beam is basically stable regardless of whether it is in the horizontal or vertical direction.

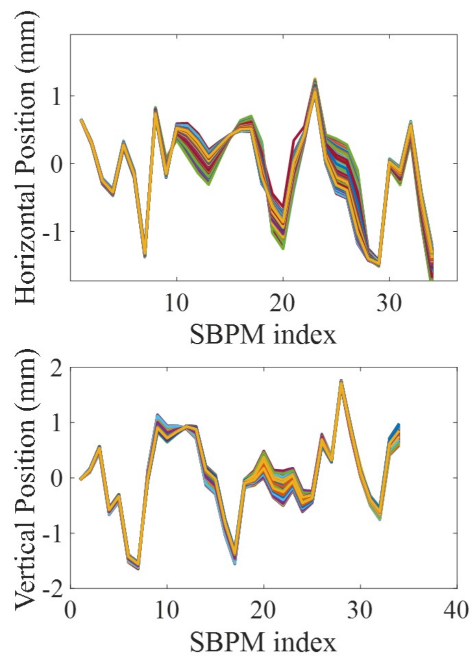

Figure 5: Beam transverse position orbit data in a period of time in SXFEL-UF. (upper) orbit data in the horizontal direction; (bottom) orbit data in the vertical direction.

For a point on a fixed curve, the value of other points can be used to predict one of the points on the curve. This method can be called global data association analysis. Global correlation analysis can make use of all probe parameters, which can make predictions more accurate.

The method based on the relation matrix has been used to evaluate the resolution of BPM, and the method has been proved to be effective [3]. However, the limitation of this type of method is that the solution of matrix coefficients is often limited to the restriction of solving the inverse matrix, requiring the matrix of measured to be a square matrix and the determinant is not 0. The limitation of the square matrix has restricted the efficiency of the solution and the number of measurement points involved in the calculation.

Neural Network Model

The neural network model provides a powerful tool for the establishment of this global nonlinear relation-ship model.

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Hence, neural network based Global correlation analysis method was proposed to evaluate the resolution online.

Under the condition of fixed beam optics, read all the probe position data at the same time, construct and train the neural network, obtain the correlation of the beam position between the probes, and use all other probe data to predict the position of the beam at each probe, and use the measured position and the predicted position to calculate the position resolution. The evaluation formula is as Eq. (3).

$$resolution = \sqrt{\frac{1}{p}(\sum_{i=1}^{p}(xi_m - xi_{pred})^2)}, \quad (3)$$

where, resolution is the calculated resolution, p is number of measurement, xi_m is the measured position of the ith measurement, while $xi_(pred)$ is the predicted position.

We built a 4-layer neural network model as shown in Fig. 6.

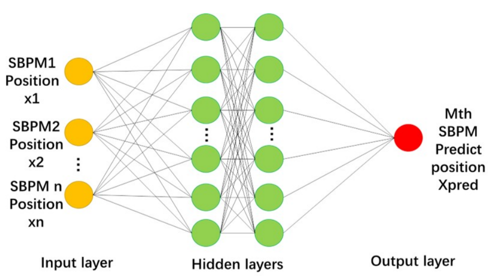

Figure 6: Schematic diagram of neural network model built for resolution evaluation of SBPMs.

This is a four-layer neural network: input the position data (single direction) read by all probes in the input layer; the hidden layer is 2 layers, each layer has 10 neurons, after training the two layers will be able to resolve the relationship The black box; the output layer is the position data we predicted. Activation function selection Sigmoid function. The training algorithm is an adaptive gradient descent algorithm.

Here we also selected the resolution evaluation result of the 8th SBPM as a display, which can also be com-pared with the previous method. The results are shown as Fig. 7

The result shows that the resolution at vertical direction of the 8th SBPM at SXFEL-UF can reach 1.1 μm at 500 pC. This result is consist with the result of the beam based evaluation method in drift sections.

The most critical advantage of the neural network-based evaluation method is that it can evaluate the resolution of all probes at one time. The results are shown in Fig. 8.

The results show that the resolution of all probes tested is better than 3 μm at 500 pC, which is better than expected technical indicators.

CONCLUSION

A new method based on neural network has been employed to evaluate all SBPMs at SXFEL-UF and the Result is close to the method based on drift section.

The neural network-based evaluation method can evaluate the resolution of all probes at one time. The batch results of resolution evaluation is better than 3 μm at 500 pC.

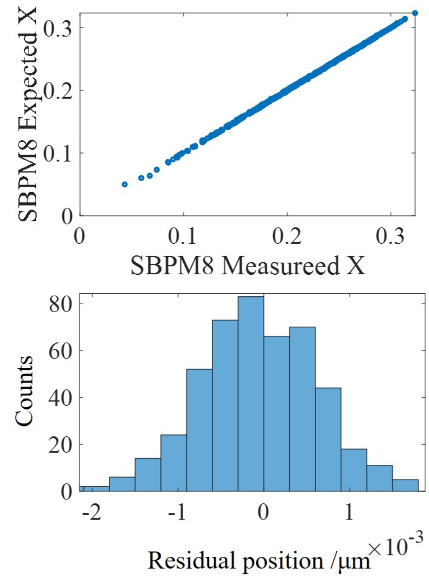

Figure 7: The results of resolution evaluation of the 8th SBPM by neural network.

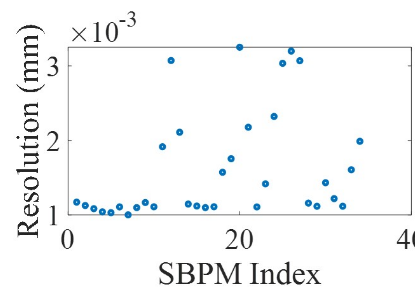

Figure 8: The batch results of resolution evaluation of SBPMs by neural network.

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