



# An artificial neural network based method for beam position calculation in electron storage ring

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## ABSTRACT

We propose a novel method based on artificial neural network (ANN) for beam position calculation and fault diagnosis of beam position monitors (BPM) in electron storage rings. BPM are diagnostic devices used to determine position of stored electron beam in storage rings. BPM commonly uses four button type electrodes as sensors to sense the electric field of electron beam circulating in storage ring. A mathematical polynomial of suitable degree is generally used to compute beam position from the button electrode signals of the BPM when beam excursions are large from the design orbit. The coefficients of the polynomial are derived from the bench calibration data of BPM. In the proposed new method, a neural network predicts the position of electron beam using four electrode signals of a BPM. A feed-forward network with three hidden layers using backpropagation training algorithm has been designed and trained with the bench calibration data of each BPM. The beam position predicted by the network was compared with conventional polynomial method. Neural network based method was tested on the BPM of 2.5 GeV electron synchrotron radiation source named Indus-2 at Raja Ramanna Centre for Advanced Technology, Indore, India. The root mean square (rms) error in neural network predicted beam position in horizontal plane and vertical plane was 24 and 26 microns respectively as compared with 100 and 101 microns with first polynomial and 61 and 66 microns with second polynomial in the central region of  $\pm 5$  mm on bench calibration data. The reliability of beam position measurement was assured by another neural network by doing self consistency check. In this paper we present architecture, training of neural network and improvement in beam position measurement in comparison with polynomial method.

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## Introduction

BPM [1] [2] are non-interceptive devices used in electron storage rings for beam position measurement and closed orbit correction. BPM usually consists of four button type electrodes which sense the electric field of electron beam. The button type electrodes used in Indus-2 [3] BPM are not placed on the symmetry axis of vacuum chamber of BPM but are placed on diagonal directions to avoid hitting by synchrotron radiation. Another reason for doing this is due to mechanical constraint of race track geometry adopted for vacuum chamber housing of BPM in Indus-2. This placement of buttons in non-symmetric axis results in non linear response of BPM. The conventional method used to find the position assumes that combinations of the four button signals are proportional to the beam position and is termed as difference over sum method. The difference over sum method [4] for converting BPM signals to beam position works well for beams in the center of the beam pipe, but the linear relationship breaks down at large displacements. In this case a polynomial of suitable degree is used to compute the beam position from four button signals of BPM [5] [6]. The coefficients of the polynomial are computed from bench calibration data of each BPM. The beam position measurement accuracy depends upon the nature of mathematical polynomial used to find the beam position. Moreover it is also important that all the four button electrode signals should be correct and if any BPM is malfunctioning it should be identified. Hence the

consistency of these signals should also be checked to avoid any wrong beam position calculation. Finding proper polynomial requires extensive simulation which is tedious and time consuming due to complicated geometry of BPM. In this paper, a new method based on ANN for beam position calculation and for checking consistency of BPM has been described.

### Artificial neural network architecture

ANN can be described as parallel computational models which have tightly interconnected adaptive processing units [7]. Adaptive characteristic of ANN makes them suitable to train them by example. Multi-layered feed-forward backpropagation neural network architecture has been adopted for this system due to its simplicity and speed. Two networks are designed, one for beam position computation and another for detecting malfunctioning of BPM by doing consistency check. The difference between these two networks is in their training data. Both of these networks are made up of one input layer, three hidden layers, and one output layer. Input and output layer each has two neurons (corresponding to two inputs and two outputs) while each hidden layer has 5 neurons. The learning rule is back propagation. The dot-product is used as input function while tan-sigmoid function that maps the input to the output in the interval (-1, 1) is used as transfer function in each layer. The performance function is mean squared error. Levenberg-Marquardt algorithm has been used as back propagation training algorithm.

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**Training of Ann**

Training of an ANN is a procedure whereby a network is adjusted to do a particular job. During training, a set of inputs and desired outputs are presented to the network until the mean square error given in (1) is reduced to desired level.

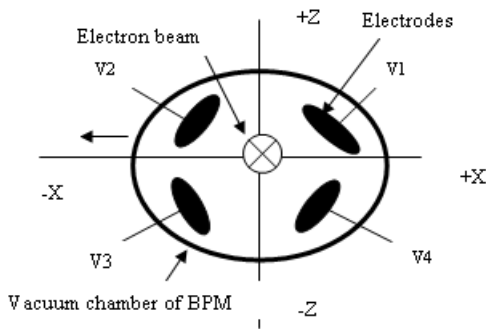
$$E_{mse} = \frac{1}{2N} \sum_{i=1}^n \sum_{k=1}^m (t_k - y_k)^2 \tag{1}$$

$t_k$  is the target or desired output,  $y_k$  is the network output,  $m$  and  $n$  are rows and column of the training data. The neural network designed for this system is a supervised network trained by bench calibration data of BPM. The BPM of Indus-2 were calibrated on a bench [8] [9]. In this calibration procedure, an antenna was used to simulate the electric field of the electron beam. The antenna was moved in a step of 1 mm in a grid of 5 mm x 5 mm and signal induced on all four button electrodes along with antenna position was recorded. To make position measurement independent of beam current and beam shape, we define two dimensional less quantities  $\delta H$  and  $\delta V$  as in (2) and (3). Fig. 1 shows the schematic diagram of a BPM.

$$\delta H = \frac{V1 - V3}{V1 + V3} + \frac{V4 - V2}{V4 + V2} \tag{2}$$

$$\delta V = \frac{V1 - V3}{V1 + V3} + \frac{V2 - V4}{V4 + V2} \tag{3}$$

$V1, V2, V3, V4$  are signals induced on four buttons of BPM.



**Figure1. Schematic diagram of BPM**

The training of neural network for beam position calculation was carried out by presenting the  $\delta H$  and  $\delta V$  as input to the network and output was antenna position normalized by dividing it by 5. The purpose of normalization is to limit output in range of [-1, 1]. The consistency of BPM button electrodes data was tested with three electrode method. In this case the position was computed from three button electrodes data of BPM. For calculation of beam position using three electrodes, we combine three electrodes signals to form  $H11, H22, V11,$  and  $V22$  as given in (4-7). By combining  $H11, H22, V11, V22$  as given in (8-15), we can find horizontal and vertical position of beam.

$$H11 = \frac{V1 - V2}{V1 + V2} \tag{4}$$

$$H22 = \frac{V4 - V3}{V4 + V3} \tag{5}$$

$$V11 = \frac{V2 - V3}{V2 + V3} \tag{6}$$

$$V22 = \frac{V1 - V4}{V1 + V4} \tag{7}$$

$$X1 = f_x(H11, V11) \tag{8}$$

$$X2 = f_x(H22, V11) \tag{9}$$

$$X3 = f_x(H22, V22) \tag{10}$$

$$X4 = f_x(H11, V22) \tag{11}$$

$$Z1 = f_y(H11, V11) \tag{12}$$

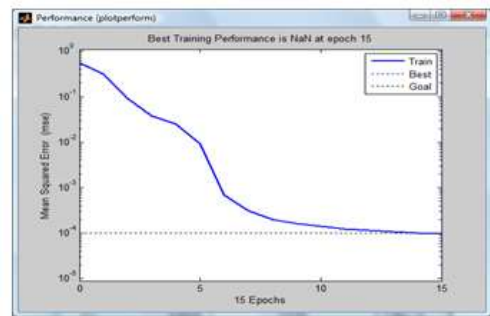
$$Z2 = f_y(H22, V11) \tag{13}$$

$$Z3 = f_y(H22, V22) \tag{14}$$

$$Z4 = f_y(H11, V22) \tag{15}$$

If all button electrode signals coming from BPM are correct, the results from combinations of ( $V1 V2 V3$ ), ( $V2 V3 V4$ ), ( $V3 V4 V1$ ), ( $V4 V1 V2$ ) (by using  $H11 V11$  etc) should coincide with each other within a given band. The consistency for horizontal position is defined as standard deviation of  $X1, X2, X3$  and  $X4$  and standard deviation  $Z1, Z2, Z3$  and  $Z4$  for vertical position. The neural network for this was trained with  $H11, V11$  etc as input while  $X1, X2$  etc as output for horizontal position and  $H11, V11$  etc are used as input and  $Z1, Z2$  etc are used for output for vertical position.

Performance of both networks was evaluated on different data sets to ensure proper training for each BPM. Fig. 2 shows the training of neural network for beam position calculation. The neural network was trained in typically 15 epochs with mean square error reduced to 10 microns.



**Figure 2. Training of network for beam position calculation**

Neural network toolbox in Matlab (R2009) was used to design and train the network.

**Result**

The neural network predicted beam position was compared with the position computed from two different polynomials. The following two polynomials were used to compare the beam position result with neural network method.

Polynomial - I:

$$X = a1*\delta H + b1*\delta H^2 + c1*\delta H^3 + d1*\delta V^2 + e1*\delta H^4 + f1*\delta H^2 * \delta V^2$$

$$Z = a2*\delta V + b2*\delta V^2 + c2*\delta V^3 + d2*\delta H^2 + e2*\delta V^4 + f2*\delta H^2 * \delta V^2$$

Polynomial - II:

$$X = a1*\delta H + b1*\delta H * \delta H * \delta H + c1*\delta H * \delta V * \delta V$$

$$Z = a2*\delta V + b2*\delta V * \delta V * \delta V + c2*\delta V * \delta H * \delta H$$

$a1, a2, b1, b2, c1, c2, d1, e1, f1, a2, b2, c2, d2, e2, f2$  are coefficients of polynomial which were computed by least square fitting procedure from calibration data of each BPM.  $X$  and  $Z$  is the position of the beam. Table I shows the rms error in beam position measurement on standard bench calibration data set. As can be seen from table I, neural network based method gives much better accuracy in beam position measurement than the polynomial based method. The neural network based method

was also used for testing consistency of BPM on actual data obtained from Indus-2 BPM. More than 90 % of the BPM installed in Indus-2 ring was found be consistent within a given band. Based on this technique, software named Neural Beam Orbit Measurement System (NEBOMS) has been developed. Software computes beam position by both methods viz. using polynomial and neural network method and display beam position graphically as well in table format. The beam position data can be saved in excel format or simple text file for further offline analysis.

**Table I. Comparison of ANN method with polynomial method**

Method	RMS error	
	Horizontal rms error	Vertical rms error
Polynomial - I	100 microns	101 microns
Polynomial - II	61 microns	66 Microns
ANN	24 microns	26 microns

### Conclusions

Traditional method of finding beam position using BPM requires a polynomial to compute beam position from button electrode signals when beam excursions are large from the design orbit. Detailed simulation of BPM is required to work out a suitable polynomial which is complicated and time consuming. An alternate simple and better method using neural network is described in this paper which not only improves the accuracy in beam position measurement but also can detect faulty beam position monitors. In future we plan to integrate the NEBOMS software with control software of Indus-2 to provide online beam position measurement.

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