A Beam Diagnostic System for Accelerator Using Neural Networks

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Abstract

A diagnostic system is developed to detect large errors, such as a dipole field defect of a magnet and monitors to be adjusted in a particle accelerator. It makes use of the fitting method[1], based on an equation of ideal betatron oscillation, and makes an evaluation function with respect to orbit distortion. These errors are identified from the pattern of evaluation function, using neural networks and a rule system.

In a recognition test study, the correct answer was obtained in 95% of the cases having two errors or less.

1. INTRODUCTION

Recently accelerators are being constructed for industrial and medical applications, such as lithography, cancer therapy. For these various applications, easy commissioning and operation are required. We are developing a rapid commissioning and automatic operation system. As a first step, we constructed a system which give us useful information about large errors at commissioning time.

The fitting method is applied to find large errors, taken to be gross deviations in the magnet dipole field and beam monitor measurements. (Hereafter referred to as "errors" as distinguished from monitor "resolution" characterizing ultimate performance.) Value F_{in} is formed to estimate the deviation of the measured beam position from the fitted one.

$$F_{in} = \sqrt{\frac{1}{(n-1)} \frac{\sum_{j=i}^{i+n-1}(X_j - x_j)^2}{r}} \qquad (1)$$

where X_j is the calculated beam position in j-th monitor, x_j is the measured one, r is the monitor resolution and n is the number of measurement used in the fit. For a properly selected r, $F_{in} \sim 1$ when there are no large errors, and $F_{in} \gg 1$ when a large error occurs.

In the case of one large error, We find the following simple rules .

[1] The discontinuity of orbit occurring between monitor j and (j+1) leads $F_{in} \gg 1$, with index i which is within (n-1) upstream of j.

[2] The monitor error leads $F_{in} \gg 1$, with index i which is within n upstream of j.

Figure 1 and 2 show examples of such patterns.

In practice there are plural errors. It is very difficult to make rules for them, because the connection between errors and the pattern of evaluation function F_{in} is complex. We hence apply the pattern recognition technique and resort to the neural network method.

To test this system, we use the ring parameters and some measured C.O.D. data of the SR ring at SORTEC[2]. This SR ring is a 1GeV electron ring made of 8 FODO cells and equipped with 8 position monitors.
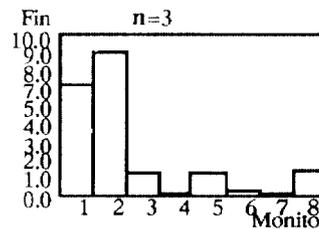
Figure 1. Example of F_{in} (in the case of dipole defect between monitor 2 and 3)
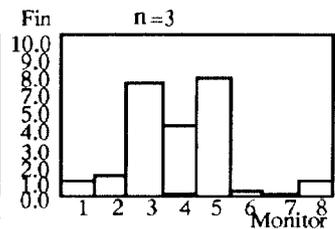
Figure 2. Example of F_{in} (in the case of error in monitor 5)

2. SYSTEM ARCHITECTURE

This system infers the monitor error or the section where the magnet errors occur, from the measured beam position, by using neural networks and a rule system. Figure 3 shows the system architecture which consists of independent units summarized below.

(1)Calculation by fitting method - calculate the evaluation function F_{in} from the measured data of beam position monitors.

(2)Neural networks - infer the location of the error from patterns of the evaluation function, learn patterns, and store many kinds of networks.

(3)Rule system - judge the output of networks and control the networks
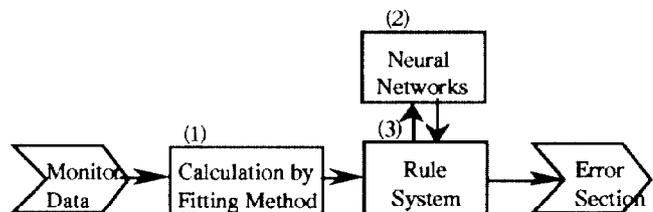
Figure 3. System architecture

3. NEURAL NETWORKS

3.1 Networks

The learning algorithm is back propagation illustrated in Figure 4. In this procedure, the strength of connection between 2 neurons are changed to reduce the difference between a desired pattern and the output data. A mean of the difference squared describes the progress of learning. Learning is completed if the mean is less than 0.08 and terminated if the number of learning exceeds 5000 times.

The neuron is composed of an input layer, one hidden layer and an output layer. Input to the networks is the evaluation function value and the output indicates the probability of errors occurring. As the model accelerator of this test has 8 monitors, we set 8 neurons in input layer and 16 in output. Hidden layer is chosen to involve 24 or 32 neurons, in view of a speed of learning and recognition accuracy.
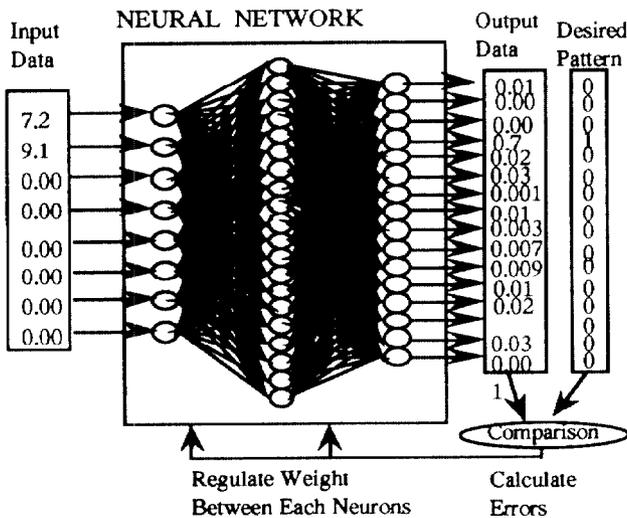
Figure 4. Structure of network

3.2 Pattern Learning

We made many networks for a recognition test. Pattern learning is set up on some combinations of magnet or monitor errors. It is assumed that the beam orbit is as large as the beam acceptance of the ring and monitor resolution is ignored. Many networks are completed in learning case of one error, two errors and additional learning, changing the neuron number of hidden layer and number of fitting. Some networks work well for monitor errors while others are suited to magnet errors. Table 1 shows the learning pattern of networks.

3.3 Recognition Test

The recognition test was performed using the simulator for COD analysis. The test conditions are the following.
(1) The errors are assumed to be similar types used in pattern learning. The monitor resolution is taken to be 0.5mm r.m.s..

(2) The error size is set to cause an orbit deviation of about 5 or 10 times.
(3) Test cases consist of the case of one error, two errors, and more than three errors. Each set of networks is tested in 24 cases for 1 error, 16 cases for 2 errors, and 6 cases for more than 3 errors.
(4) If the output value of network is exceeds 0.5, the output is considered to be the answer given by the network.
The result of the recognition test is shown in Table 2.

Table 1. Learning pattern

NO.	pattern	additional pattern	hidden
1	1-M or 1-BM or 1-CM	none	24
2	1-M or 1-BM or 1-CM	none	32
3	2-M or 2-BM or 2-CM	none	24
4	2-BM or 2-CM or 1-BM,CM	none	24
5	1-M or 1-BM or 1-CM	2-BM or 2-CM	24
6	1-M,BM or 1-M,CM or 2-BM	none	24
7	2-M or 2-BM or 2-CM	2-BM or 2-CM	24

n-A n: number of errors
A: error point (M:monitor, BM:bending magnet, CM:corrector magnet)

Table 2. Recognition test   (%)

N	kind of error		Network Number						
			1	2	3	4	5	6	7
1	M. field	correct	100	100	100	0	100	75	0
		misrecog	0	0	0	18	1	1	9
		correct	100	100	100	100	100	100	81
		misrecog	0	0	0	13	0	1	6
2	M. field	correct	33	33	67	0	17	0	0
		misrecog	0	0	5	0	0	2	0
		correct	50	60	50	100	90	70	70
		misrecog	1	1	1	9	6	6	7
3	M. field	correct	0	0	17	0	0	0	0
		misrecog	0	0	0	0	0	0	0
		correct	13	13	6	75	63	44	69
		misrecog	0	0	0	3	3	3	6

1) Network number indicates NO. in Table 1
2) 'correct' or 'misrecog' is the correct or incorrect answer of networks.
3) The figures indicate the rate of the correct or incorrect answer to situated errors.
4) N indicates number of errors.

The property of networks is following.
(1) In the case of 1 error, networks which learn 1 error recognize correctly, and give little misrecognition.
(2) In the case of 2 errors, the rate of correct answer is inferior to the case of one error. The networks which learn 2 errors work with high rate of correct answer.
(3) In the case of more than 3 errors,the rate of the correct answer is low. However, depending on the network used, it is possible to answer about 60% correctly.
The rate of correct answer depends on what the networks have learned. When plural errors exist concurrently, some networks identify many candidates which include misrecognition. It should be able to choose the correct answer out of them. The networks which have learned the case of only one error is effective in finding one big error, even when plural errors exist.

4. Rule System

4.1 Outline of rule system

The rule system is applied in order to judge the correct answer from many candidates. The function of the rule system is the following.
- Rules choose the networks to use.
- Rules decide the correct answer from the network outputs.
- If the rules cannot decide them, the rules call upon different networks.
- Rules give some preferential ranking to these results.
The rule system procedure is as follows.
(1) input the fitting evaluation value, and load 3 kinds of basic networks.
(2) distinguish the candidates which give more than 0.5.
(3) determine the candidate selected by every network to be the result.
(4) save the other candidates for next network analysis.
(5) choose the appropriate networks from the characteristic of next candidate.

Above procedure is repeated until the following conditions are met.
- There are no more candidates left to be tested
- There are no more networks left to test
The result which the system determines the first cycle is rank A. Ranks B,C and D are determined on the second,third and fourth or later cycles respectively.

4.2 Result

The total system performance is examined using measured data and C.O.D data simulated from ring parameters at the SR ring of SORTEC. We consider the following errors which cause the horizontal deviation on simulation.
(1) Bending magnet alignment error position ΔX_B ΔZ_B
rotation θ $_{By}$
dipole field defect $\Delta B/B$
(2) Quadrupole magnet alignment error position ΔX_Q
rotation θ_{Qy}
(3) Corrector magnet kick angle θ_{Cx}
(4) Monitor wrong measurement ΔX_M
The test is carried out some combination of errors mentioned above.
In addition to these, it is examined by measured data when the dipole field defect $\Delta B/B$ of BM is given. Figure 5 shows the measured C.O.D. data of SORTEC in the case of no defect, and figure 6 shows the case of dipole field defect

$\Delta B/B=0.002$ in BM2. From figure 6 we set random error equal 0.5mm r.m.s..
Test pattern and result are shown in table 3. From these results we find some consideration.
In the case with two or fewer errors in the ring with 8 position monitors,
(1) The result given rank A is correct in more than 95%. The system detect wrong monitors or the section where errors occur in more than 60% of situated errors.
(2) The result given rank B is correct in more than 70%.
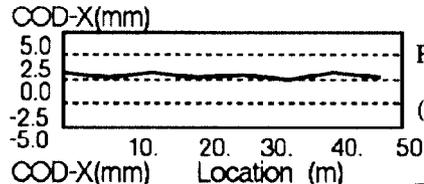
Figure 5 C.O.D data at SORTEC (in the case of no defect)
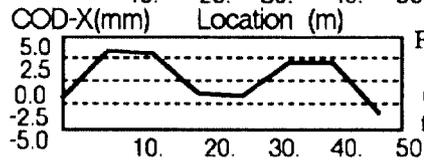
Figure 6 C.O.D data at SORTEC (in the case of dipole field defect in BM2)

5. Conclusion

It becomes clear that the developed system is effective for the following.
(1) It can detect large errors with significant probability.
(2) Even if there are plural errors, the most probable candidate is selected by using neural networks and a rule system.

The results depend on the learning patterns of neural networks. We should improve the learning method and the patterns used to increase the rate of recognition.

The present system assumes that beam is circulating and C.O.D data is available. In the future, this should be extended to earlier commissioning stages and include survey data as well as the magnet factory data.

6. References

1. D.Brandt and A.Verdier, Exhaustive Search of Field Defect Compensation and Reading Errors in A.G. Machines , 1st EPAC (Rome,June 1988)
2. Y.Yamamoto et al. ,Performance of the 1GeV Electron Storage Ring for the Synchrotron Radiation Source at SORTEC , 2nd EPAC (Nice,June 1990)

Table 3. Result of rule system (error size ΔX : mm , ΔZ : mm , θ : mrad , Underline indicate correct results)

| error section | Simulated data | | | | | | | | | | Measured data | | |
	QD4	BM4	BM1	3M	2M 5M	BM3 BM8	4M BM2	BM3 CM8	3M,BM4 CM7	2M,BM4 BM7,CM1	BM2	BM2 BM4	BM2 BM5
error size	$\Delta X_Q=1$ $\theta_{Qy}=2$	$\Delta X_Q=1$ $\Delta Z_Q=1$	$\Delta B/B$ =0.005	ΔX_M =3	$\Delta B/B=0.005$		ΔX_M =5	θ_{Cx} =3			$\Delta B/B=0.002$		
rank A	4M-5M	4M-5M	1M-2M	4M-5M		3M-4M 8M-1M	2M-3M	3M-4M 8M-1M			2M-3M		
rank B			2M-3M	3M	2M 5M	2M	4M 4M-5M 3M	1M	4M-5M 6M-7M 6M	1M-2M 1M 8M		2M-3M 4M-5M 4M	2M-3M 5M-6M