A Fiber -optic Sensor for On-line Non-touch Monitoring Roll Shape

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ABSTRACT

Basing on the principle of reflective displacement fibre-optic sensor, a high accuracy non-touch on-line optical fibre sensor for detecting roll shape is presented. The principle and composition of the detection system and the operation process are expatiated also. By using a novel probe of three optical fibres in equal transverse space, the effects of fluctuations in the light source, reflective changing of target surface and the intensity losses in the fibre lines are automatically compensated. Meantime, an optical fibre sensor model of correcting static error based on BP artificial neural network (ANN) is set up. Also by using interpolation method and value filtering to process the signals, effectively reduce the influence of random noise and the vibration of the roll bearing. So the accuracy and resolution were enhanced remarkably. Experiment proves that the resolution is 1μm and the precision can reach to 0.1%. So the system reaches to the demand of practical production process.

Keywords fiber-optic sensor; monitoring; roll shape; ANN

1. INTRODUCTION

After long time working, the surface of a roll will be worn and the shape of rolls will be deformed. And the deforming of the roll will result in difficult controlling of the shape and the thickness of the steel boards. So it is very urgent to detect the roll deforming exactly and real time. At past time the roll shape had been detected periodically. Because of the intervals between two detecting period are too long, it is difficult to find the deforming of the roll real-time. So it can lead to the decline of the product quality of the rolling boards. In this paper a non-touch detective method has been produced by using a reflective displacement fiber-optic sensor[1]. It offers such advantages as non-touch, no electromagnetic interference, simple construction, stability and can been connected with computer easily to realize intelligent controlling.

2. MEASUREMENT PRINCIPLES

The principle of the detection system for monitoring roll shape is shown in Fig.1.

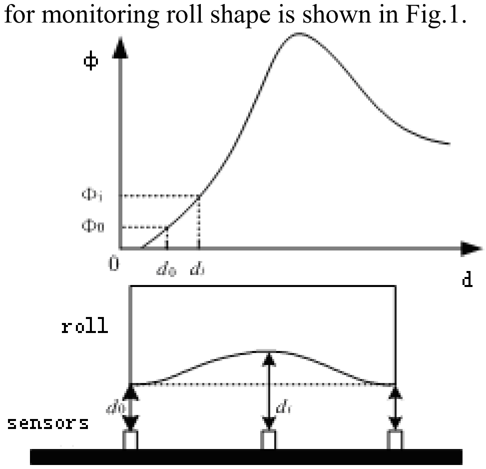

Fig.1 Principle of detecting roll shape

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The fundamental of this system is the deforming of the roll will make the displacement between the probe and the surface of the roll change. The system of our design is based on the technique of the fiber-optic reflective displacement sensor. In general it consists of a fiber as a light source (Transmitting fiber) and the other as a light receiver (Receiving fiber). The transmitting fiber illuminates the reflecting surface and the receiving fiber receives the reflected light. The light intensity of output of the receiving fiber is a function of the distance from the reflecting target to the receiving fiber probe. So by measuring the light intensity of the output of the receiving fiber, we can determine the displacement between the sensor probe and the reflecting target. When the distance is within some range, the light intensity and the distance have a good linear relationship. It can be seen in the curve of Fig.1. When the shape of the roll is deformed, the displacement between the probe and the surface of the roll will change. And the light intensity output of the receiving fiber is also changed. Then we can detect the roll shape by measuring the displacement accurately.

3. SYSTEM COMPOSITIONS AND OPERATION PROCESS

3.1 Composing of the detecting system

The schematic diagram of the system compositions is shown in Fig.2. There are three optical fiber sensors fixed along the axis of the roll a few centimeters above the roll surface. The first and the third senor fixed on each side of the roll cannot move. They were designed to detect the vibration of the ends of the axis. So the vibration yawp can be eliminated easily. The second sensor was driven by a stepping motor and mechanic gearing and scans the surface of the roll in constant speed along the axis. The second sensor scans the roll one time when it goes ahead 1.0 mm. And after we process the disperse data we can get the curve of the roll shape.

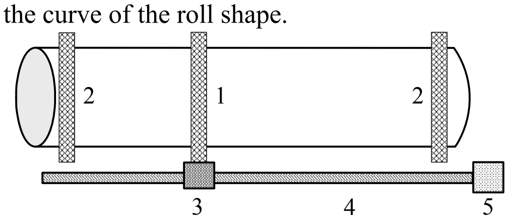

Fig.2 Schematic diagram of detective system composition

For the sake of getting those data, which can express the roll shape, we use the data of the two ends as benchmark. And then we can abstract the data of every other node in the roll. Because the data of the two ends are almost vibration of the roll and the data of other nodes in the middle have shape information as well as vibration information, it is easy to partition the two kind data. And also because the roll is a big solid cylinder, it can be regarded as rigidity. When there is no rolling burden, the center line of the roll can be regarded as a beeline. So we can use interpolation method to eliminate the vibration noise. Assume the detected values of the same time t are $d_1(t)$, $d_2(t)$, $d_3(t)$. And we can get the real displacement of roll surface $\triangle d(t)$:

$$\triangle d(t) = d_2(t) - [d_1(t) - (d_3(t) - d_1(t))vt/L] \tag{1}$$

Where v is the speed of the roll running, L is the length of the roll. Because v is a constant we make $x = vt$. Then the function of the roll surface displacement is

$$\Delta d(t) = f(t) \tag{2}$$

3.2 Disposals of the Signals

In this measurement system a novel fiber-optics probe is adopted. The structure of it is shown in Fig.3.

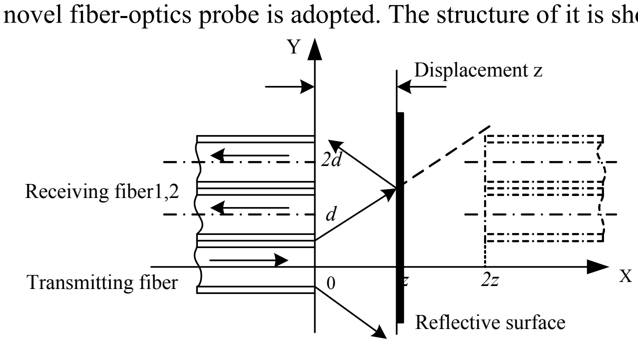

Fig.3 Structure diagram of the fibre-optic fibre-optics probe with equal space

The author have given the principle of how optical fiber sensor got signals[2,3]in some papers before. So we did not deduce it any more here. And the amount of reflected light received by receiving fiber1 and 2 can be illuminated as following equations.

$$\Phi_1 = \rho_1 \frac{K_0 K_1 S_1 \Phi_0}{\pi R^2(2z)} \exp(-\sum_i \eta_i r_i) \exp[-d^2 / R^2(2z)] \tag{3}$$

$$\Phi_2 = \rho_2 \frac{K_0 K_2 S_2 \Phi_0}{\pi R^2(2z)} \exp(-\sum_j \eta_j r_j) \exp[-(2d)^2 / R^2(2z)] \tag{4}$$

When we use the ratio of Φ_1 and Φ_2 as a modulating function of the optical fiber sensor, we can get

$$M(z) = \frac{\Phi_2}{\Phi_1} = \exp\left|\frac{-3d^2}{[a_0 + k \cdot \tan\theta_c (2z)^{3/2}]^2}\right| \tag{5}$$

It can be noticed that the ratio output $M=\Phi_2 / \Phi_1$ is independent of other factors and is a function only of the distance z. So by using this kind of fiber-optics probe, the testing system can compensate the fluctuations in the light source, losses in the optical fiber system and variations in the reflectivity of the reflecting device. Then the good accuracy and stability of this system can be ensured.

Although using the probe of three optical fibers in equal transverse space can eliminate some error of the interfere factors, there are other factors such as circuit excursion and light source excursion. So an optical fiber sensor model of correcting static error based on BP artificial neural network (ANN) is set up in this paper. The principle is just as shown in Fig.4.

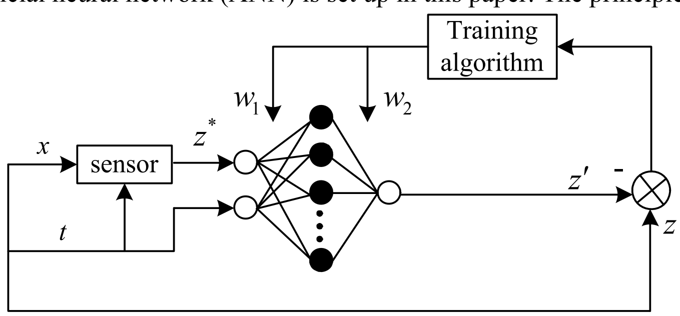

Fig.4 Principle of correcting static error based on BP artificial neural network

It has been proved that an artificial neural network of three layers can approach any continuous nonlinear function[4]. So we chose a BP network of two input points, six implication points and one output point to establish an ANN back run model of the optical fiber sensor and use error back propagation to train it. The model of the sensor is $z^*=f(x,t)$. And x is the parameter, which can be measured. And $t = (t_1, t_2, ..., t_k)^T$ are k parameters, which can influence the measured parameter. So we can get $x = f^{-1}(z^*, t)$. And the model of correcting static error is $z = \varphi(z^*, t)$. Making $\varphi(z^*, t) = f^{-1}(z^*, t)$ we can get

$$z' = \varphi(z^*, t) = f^{-1}(z^*, t) = x \tag{6}$$

It shows that the output z has a linear relationship with the measured parameter x, and has nothing with t. So we can realize the correcting of static error. The two functions $f(x, t)$ and $f^{-1}(z^*, t)$ are both nonlinear and they are unable to be expressed as mathematic formulae. But by experiments the data can be gotten:

$$\{(x_i, t_i, z_i^*) \in R^{k+2} : i = 0,1...,n\}, t_i = (t_{1i}, t_{2i}, ..., t_{ki}) \tag{7}$$

Because a neural network of three layers can approach any continuous nonlinear function, using the experiment data z_i^* and t_i as input samples and x_i as output samples to train neural network it can adjust every value to realize $f^{-1}(z^*, t)$ automatically. Because too many data of input in neural network training will make the cells of neural network saturate fast, the original data must be changed before training. In order to get better accuracy, we may alternate the original data as following

$$D'_0 = \frac{0.9(D_0 - D_{0\min})}{(D_{0\max} - D_{0\min}) + 0.05} \tag{8}$$

$$D'_i = \frac{D_i - D_{\min}}{D_{i\max} - D_{i\min}} \tag{9}$$

Where D_i, D_0 are the original input samples and output samples in neural network training. When the objective function——error sum of squares F_{obj} driving to zero we get the model of the sensor.

$$F_{obj} = \sum_{i=1}^{m} [z(i) - z'(i)]^2 \tag{10}$$

4. EXPERIMENTS AND RESULT DISCUSSION

In the experiment we choose the roll of ∮410×1400 to start detecting. When the second sensor goes ahead every 1.0mm, the system scans one time. And after processing the disperse data $\Delta f(t)$ and correcting static error by BP, we can get the roll shape curve shown in Fig.5.

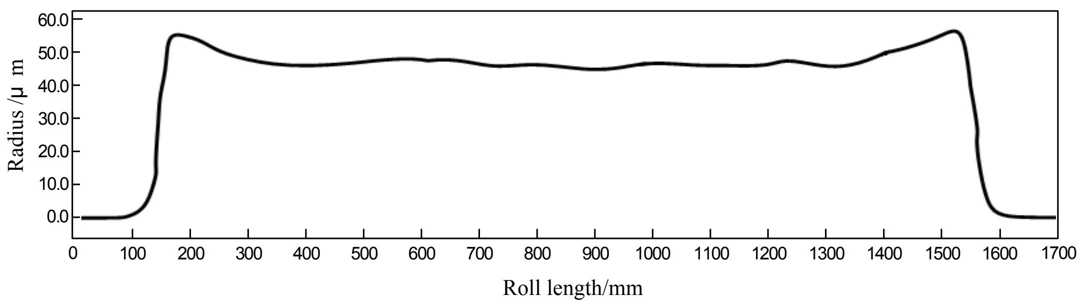

Fig.5 Detective curves of roll shape

We adopt BP artificial neutral network of 2 input points, 30 covert points and 1 output point. After studying 10*105 times, the error sum of squares almost drive to zero. At the same time we extract the six detective points value $\Delta\overline{W}$ to have a compare with the value ΔW_s, which measured by micrometer. The detective error was $\delta_{\Delta W} = \left|\Delta\overline{W} - \Delta W_s\right|$. All these data were shown in Table1.

Table1 Results of detective points value

Position of detective points L(*mm*)	200.0	400.0	600.0	800.0	1000.0	1200.0
Detective result in experiment $\Delta\overline{W}$ (μm)	5.5	9.7	10.1	17.2	10.5	5.1
Result measured by micrometer ΔW_s (μm)	5.3	10.6	8.7	15.1	9.7	5.3
Detective error $\delta_{\Delta W}$ (μm)	0.2	0.9	1.3	2.1	0.8	0.2

5. CONCLUSIONS

Theoretical analysis and experimental result show that this measurement system is feasible. By discussing in theory and experiment, the measuring range is 0 to 2.0mm, the resolution is 1μm and the precision can reach to 0.1%. This system offers such advantages as non-touch, no electromagnetic interference, simple construction and stability. It is suitable for no-touch detecting roll shape on-line. And improved a little it can also be used to monitor other tiny displacement on real time. So it has some applied foreground.

REFERENCES

[1] A. L. Chaudhari, A. D. Shaligram, "Multi-wavelength optical fiber liquid refractometry based on intensity modulation," Sensor and Actuators A 100,160-164(2002)

[2] Guo Yuan, Wang Yutian, "Design of a Reflective Optical Fiber Displacement Sensor for Testing Roll Wear," Journal of Transduction Technology, 2004, 2, 255-257

[3] Guo Yuan, Dai Xuefeng, Wang Yutian, "A Novel Optical Fiber Displacement Sensor of Wider Measurement Range Based on Neural Network," PROCEEDINGS OF SPIE6150,1o1-1o5(2006)

[4] Lars Nolle,, "Optimum work roll profile selection in the hot rolling of wide steel using computational intelligence," Knowledge-Based Systems,20:203-208(2007)