Optical Fiber On-Line Detection System for Non-Touch Monitoring Roller Shape

Y Guo\textsuperscript{1,2} and Y T Wang\textsuperscript{1}

\textsuperscript{1}College of Electric Engineering, Yan Shan University, He Bei Qin Huangdao, 066004, China
\textsuperscript{2}College of Information Engineering, Qi Qihaer University, Hei Longjiang Qi Qihaer 161006, China

E-mail: guoyuan1974@yahoo.com.cn

Abstract. Basing on the principle of reflective displacement fiber-optic sensor, a high accuracy non-touch on-line optical fiber measurement system for roller 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 fibers in equal transverse space, the effects of fluctuations in the light source, reflective changing of target surface and the intensity losses in the fiber lines are automatically compensated. Meantime, an optical fiber 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 roller bearing. So enhance the accuracy and resolution remarkably. Experiment proves that the accuracy of the system reach to the demand of practical production process, it provides a new method for the high speed, accurate and automatic on line detection of the mill roller shape.

1. Introduction

After long time working, the surface of a roller will wear and the shape of rollers will deform. And the roller deform will result in the difficult controlling of the shape and the thickness of the steel boards. So it is very urgent to detect the roller deform exactly and real time. At past time the roller 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 roller real-time. So it can lead to the decline of the product quality of the rolling boards. In this paper using a reflective displacement fiber-optic sensor has produced a non-touch detective method. 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. Principle of detection

The principle of the detection system for monitoring roller shape is shown in Figure1. The fundamental of this system is deform of the roller will make the displacement between the probe and the surface of the roller 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 Figure 1. When the shape of the roller is deformed after wearing, the displacement between the probe and the surface of the roller will change. And the light intensity output of the receiving fiber is also changed. Then we can detect the roller shape by measuring the distance.

![Figure 1. Principle of detecting roller shape.](image1)

3. System Compositions and Operation Process

The schematic diagram of the system compositions is shown in Figure 2. There are three optical fiber sensor fixed along the axis of the roller a few centimeters above the roller surface. The first and the third sensor fixed on each side of the roller cannot move. They were designed to detect the deliberate of the ends of the axis. So the deliberate yawp can be eliminated easily. The second sensor was driven by a stepping motor and mechanic gearing and scans the surface of the roller in constant speed along the axis. The system uses near infrared LED as its light resource whose wavelength is 850nm, half-band width is 45nm and least output power is 80mw. The second sensor scans the roller one time when it goes ahead 1.0 mm. And after we process the disperse data we can get the curve of the roller shape.

![Figure 2. Schematic diagram of detective system composition.](image2)

For the sake of getting those data, which can express the roller shape, we use the data of points a, b as benchmark. And then we can abstract the data of every other node in the roller. Because the data of points a, b are almost liberation of the roller and the data of other nodes in the middle have shape information as well as liberation information, it is easy to partition the two kind data. And also because roller is a big solid cylinder, it can be regarded as rigidity. When there is no rolling burden the center line of the roller 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 roller surface $\Delta d(t)$:

$$\Delta d(t) = d_2(t) - [d_1(t) - (d_1(t) - d_1(t)) \times v / L]$$ (1)

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

$$\Delta d(t) = f(t)$$ (2)

4. Disposals of the signals

In this measurement system a novel fiber-optics probe is adopted. The structure of it is shown in Figure 3. The author have given the principle of how optical fiber sensor got signals [3]. So we did not deduce it any more here. So the amount of reflected light received by receiving fiber1 and 2 can be illuminated as following equations.

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

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

When we use the ratio of $\Phi_2$ and $\Phi_1$ as a modulating function of the optical fiber sensor, we can get

$$M(z) = \frac{\Phi_2}{\Phi_1} = \exp\left[-\frac{3d^2}{\left[a_0 + k \cdot \tan \theta_2 (2z)^{3/2}\right]^2}\right]$$ (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 the using of 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. Principle of it is just as shown in Figure 4.

![Figure 3. Structure diagram of the fiber-optic fiber-optics probe with equal space.](image)

![Figure 4. Principle of correcting static error based on BP artificial neural network.](image)
It has been proved that an artificial neural network of three layers can approach any continuous nonlinear function. 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 \( t = (t_1, t_2, ..., t_k) \) are \( k \) parameters, which can influence the measured parameter. So we can get \( x = f'(z^*, t) \) \( x = f^{-1}(z^*, t) \). And the model of correcting static error is \( z = \varphi(z^*, t) \). Making \( z = \varphi(z^*, t) = f'(z^*, t) \), we can get

\[
z' = \varphi(z^*, t) = f^{-1}(z^*, t) = x
\]

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 get:

\[
\{ (x_i, t_i, z_i^*) \in R^{k+2} : i = 0,1,...,n \}, t_i = (t_{i1}, t_{i2}, ..., t_{ik})
\]

(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 \( z^* = f(z^*, t) \) 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 \( = \)

\[
D' = \frac{0.9(D_0 - D_{0\min})}{(D_{0\max} - D_{0\min}) + 0.05}
\]

(8)

\[
D' = \frac{D - D_{min}}{D_{max} - D_{min}}
\]

(9)

Where \( D_0, D_0 \) are the original input samples and output samples in neural network training. When the objective function---error sum of squares

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

(10)

drive to zero we can get the model of the sensor.

5. Experiments and result discussion

We used single chip to control those three sensors in order to ensure they work synchronization in the experiment. And the detecting system was fixed to ensure that the rail of the system is parallel with the axis of the roller. The detection must start at no rolling time. When new roller is fixed to the roll mining we regard it has not be frayed. So we scan the shape of the new roller and input the standard shape \( f_0(t) \) to the computer. Because the ferric oxide will adhere to the roller surface during the rolling time and this will shell of some surface layer of the roller making the state of roller surface change, we must grind the roller and wipe off the ferric oxide before detecting. After rolling for a period of time we compare the detecting displacement function \( f(t) \) with standard shape function \( f_0(t) \). And the margin of the two functions \( \Delta f(t) \) is the real curve of the roller shape.

In the experiment we choose the roller of \( \frac{1}{3} 410 \times 1400 \) to start detecting. During the scan the second sensor goes ahead every 1.0 mm the system detecting one time. And after processing the disperse data \( \Delta f(t) \) and correcting static error by BP, we can get the roller shape curve shown in Figure5. 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. The curve above is the one, which did not be processed, and the one below is processed by BP artificial neutral network (moving down for 105mm). At the same time we extract 6 detective points value \( \Delta \bar{W} \) to have a compare with the value \( \Delta W_1 \),
which measured by micrometer. The detective error was $\delta_{\Delta W} = |\Delta W - \Delta W_s|$. All these data were shown in Table 1.

![Figure 5. Detective curves of roller shape.](image)

**Table 1. 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 $\Delta W$ (μm) | 5.5   | 9.7   | 10.1  | 17.2  | 10.5   | 5.1    |
| Result measured by micrometer $\Delta W_s$ (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    |

### 6. Conclusion

Basing on the principle of reflective displacement fiber-optic sensor a non-touch on-line optical fiber measurement system for roller shape is presented. Also a novel fiber-optics probe of three optical fibers in equal transverse space is used to compensate the effects of fluctuations in the light source, reflective changing of target surface and the intensity losses in the fiber lines are automatically. Meantime, an optical fiber sensor model of correcting static error based on BP artificial neural network (ANN) is set up. So the intrinsic errors such as effects of fluctuations in the light, circuit excursion, the intensity losses in the fiber lines and the additional losses in the receiving fiber caused by bends are eliminated. Also by using interpolation method and value filtering to process the signals, effectively reduce the influence of random noise and the vibration of the roller bearing. So enhance the accuracy and resolution remarkably. 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 non-touch detecting roller 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 and Multi-wavelength 2002 Optical fiber liquid refractometry based on intensity modulation *Sensor and Actuators A* **100** 160-164

[2] H.Colnabi 2002 Design of an optical fiber sensor for linear thermal expansion measurement *Optics & Laser Technology* **34** 389-394

[3] Libo Yuan 1998 Automatic Compensated Two-Dimensional Fiber-Optic Sensor *Optical Fiber Technology* **4** 490-498