Study on precise detecting and controlling technology of lag angle based on image processing

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Abstract. A precise method of detecting and controlling of lag angle during the optical fiber winding procedure is described in this paper. The system is composed of three modules, image collection, image processing and PC controller. Images of lag angle are collected by an industrial high-speed camera. Binary treatment on lag angle images of the motive optical fiber is done by global threshold method. Image identification of lag angle of the motive optical fiber is realized by Hough transform, thus the digital values of lag angel are obtained. PC outputs controlled variables to modify the winding motion based on detecting results so as to limit the lag angle in a precise range. The research result indicates that application of image collection and identification technology to optical fiber winding can avoid winding flaw effectively such as gap and lamination thus to improve the quality and efficiency of optical fiber winding.

1. Introduction
Optical fiber technology originated in the 1970s [1]. Fiber optic guidance has a broad application prospect, precise fiber winding technology is an important technology of fiber optic guidance. The precise winding of optical fiber is to tightly wind the optical fiber to a spool with a certain tension and specified winding pattern, turn by turn, layer by layer, without defect, and finally form a fiber bundle [2]. The optical fiber is arranged orderly and evenly on the line axis, the upper optical fiber is embedded in the groove formed by the lower optical fiber, and the turns are in close contact with each other, no winding defects such as gap and overlap. Otherwise, it will cause the attenuation and loss of the optical transmission signal, and it will easily lead to the failure of the fiber optic cable package setting out, which will eventually affect the guidance precision.

2. Fiber lag angle and parameter control
There are many factors that affect the quality of optical fiber cable arrangement, the lag angle is the key [3]. In order to ensure the close contact between turns, a certain lag angle should be maintained. At present, high-precision servo system and high-precision actuator are widely used in domestic optical fiber winding machine, which can meet the requirements of optical fiber precise wire arrangement in theory. However, due to the uneven change of the actual diameter of optical fiber, the lag angle will still change in the process of optical fiber wire arrangement. When the lag angle changes beyond a certain range, winding defects will appear. If the lag angle is too small, the turn gap will increase, as shown in figure 1, if the lag angle is too large, it is easy to cause stacking defects, that is, the follow-up optical fiber will be pressed on the front optical fiber, as shown in figure 2. Therefore, in
order to meet the requirements of defect free line arrangement, the lag angle should be controlled in a more accurate range.

![Figure 1. Gap defects.](image1)

![Figure 2. Overlap defects.](image2)

The lag angle is a small angle between the fiber and the direction perpendicular to the fiber axis, as shown in figure 3.

![Figure 3. Schematic diagram of lag angle θ.](image3)

According to the geometric relationship, the lag angle θ is:

\[ \theta = \arctan \frac{s}{l} \]  

(1)

Where, \( l \) is the distance from the feeder point to the plane where the winding axis and the fiber line point are located, which is a fixed value; \( s \) is the distance from the feeder point to the plane passing through the line point and perpendicular to the winding axis, which is a dynamic variable. In the process of winding, with the widening of winding, the axis winding system needs to offset the change of \( s \) by axial displacement compensation to keep the lag angle \( \theta \) within the control range.

In an ideal state, when the lag angle \( \theta \) remains unchanged, the winding widening amount should be the same as the axial displacement compensation amount, the rotation around the shaft and the linear composite motion should meet the following relationship:

\[ n_1 \cdot d = n_2 \cdot t \]  

(2)

\( n_1 \) - rotation speed of spindle motor (R / min)
\( n_2 \) - rotation speed of the line motor (R / min)
\( d \) - diameter of optical fiber (mm)
\( t \) - screw pitch of the line lead screw (mm)

The speed ratio of the spindle motor and the cable arranging motor is as follows:

\[ i = \frac{n_1}{n_2} = \frac{t}{d} \]  

(3)

If the change of fiber diameter \( d \) is ignored, the speed ratio \( i \) is a fixed value. In an ideal state, the lag angle will remain unchanged when the cable is arranged according to the above-mentioned fixed speed ratio relationship; however, in the actual cable arrangement process, because the fiber diameter...
changes unevenly, the actual cable pitch will change, resulting in the change of the lag angle, so it is necessary to adjust the size of s to keep the lag angle within the control range. The control of s is realized by adjusting the speed n2 on the premise of keeping the speed n1 constant.

3. Lagging angle detection and control system
The detection and control system of lag angle consists of image acquisition, image processing and upper computer control, as shown in figure 4. The image acquisition system collects and transmits the lag angle image online and real-time to the computer; the image processing system processes and analyzes the collected image in real time and obtains the actual value of the lag angle; the upper computer control system corrects the line movement in real time according to the actual value of the lag angle and precisely controls the lag angle within the given range to realize the fiber defect free and precise line arrangement.

Figure 4. The system of detecting and controlling on lag angle.

3.1. Image acquisition system
The quality of image acquisition directly affects the accuracy of image recognition. The quality of image acquisition mainly depends on the following factors: the selection of image sensor; the configuration of lens and light source; the selection of lens and camera parameters and the design of acquisition environment [4-6].

According to the requirements of optical fiber winding process, the measurement accuracy of the lag angle is set to 0.1° based on the control requirements of the lag angle without winding defects. In order to avoid the damage to the optical fiber surface during the detection process, the non-contact high-precision image sensor - industrial CCD camera is used to continuously shoot the optical fiber moving at high speed frame by frame, to realize the image of the lag angle of the moving optical fiber collection.

According to the accuracy requirements of lag angle detection, the minimum resolution of image detection elements should be calculated, and the corresponding lens and light source should be selected.

1. The camera field of view monitoring range is about 100mm × 100mm.
2. The resolution is 2048 × 2048 pixels.
(3) The image processing speed is 10 frames / s.
(4) When processing this image, the next image can be read normally, and the actual lag time is 100ms.

In the process of image processing, the processing of straight line is full edge fitting, it is easy to ensure the accuracy. The algorithm is:

Normally, the resolution of a point is 100000 μm / 2048 = 48.828 μm

The maximum sum of the errors at both ends of the optical fiber in the field of view is 48.828 μm × 2 = 97.656 μm

Then the maximum angle error is tanθ = 97.656 / 100000 = 0.00097656

Then the lag angle detection error is 0.056 ° < 0.1 °, which can meet the precision of lag angle detection.

According to the above analysis and calculation, the German Basler industrial high-speed camera is selected for lag angle image acquisition, as shown in figure 5, its basic performance parameters are shown in table 1. The lens adopts computer universal telecentre lens, as shown in figure 6. According to the environment requirements of the lag angle image acquisition, the optical fiber is auxiliary illuminated by the highlighted strip white light source, as shown in figure 7.

![Figure 5. Industrial high speed camera ACA2000-50gm.](image1)

![Figure 6. The lens M1214-MP2.](image2)

![Figure 7. The light source BR314-30-W.](image3)

| Basler  | resolution /H×V | sensitive chip | scanning mode | target size /” | pixel size /μm | frame rate /fps |
|---------|-----------------|----------------|---------------|-----------------|----------------|----------------|
| ACA2000-50gm | 2048×2048      | Sony ICX274    | progressive scan | 2/3             | 5.5×5.5       | 50             |

### 3.2. Image processing system

In the image processing system, the special software of lag angle image recognition based on Visual C + + 6.0 is used. Firstly, the global thresholding method is used to binarize the lag angle image of moving optical fiber and separate it from the background. Then, the single pixel straight line is obtained by thinning, and the lag angle actual value is obtained by Hough transform. The image processing flow is as follows: read in the picture -- > shrink -- > graying -- > threshold segmentation -- > anti color -- > thinning -- > set extraction line area -- > extract the straight line -- > Hough transform -- > calculate the lag angle. Because the original image has a large resolution, in order to improve the speed of image recognition, zoom the picture before processing, half the length and width of the
picture, the speed of image recognition reaches 10 frames / minute, which can meet the precision and real-time requirements of lag angle detection. The lag angle image processing process is shown in figure 8.

![Image Processing for Lag Angle](image)

**Figure 8.** Image processing for lag angle.

3.3. *Upper computer control system*

The industrial control computer is used as the main control unit, the executive components are digital servo system and image processing system. The upper computer is equipped with Windows 7 operating system to complete parameter input, display, operation mode selection, etc., and to provide dynamic information of winding and wire arranging servo system. The upper computer control system is shown in figure 9. The actual value of the lag angle obtained from image recognition is written into the address designated by PLC and compared with the set value. Then the upper computer outputs the control quantity to adjust the rotation speed of the line laying motor and control the lag angle within the given range. The human-computer interface system is shown in figure 10.
4. Flawless precision wire arrangement test

4.1. Test device and parameters
Using the above system, the experiment of optical fiber automatic wire arrangement is carried out on the optical fiber winding machine. The experimental parameters are shown in table 2.

| Fiber type      | Fiber diameter d/ mm | Winding tension N/ cN | Spindle speed n/ r/min | Lag angle θ/° | Upper speed ratio i₁ | Lower speed ratio i₂ |
|-----------------|----------------------|-----------------------|------------------------|---------------|----------------------|---------------------|
| weaving cable   | 0.40±0.02            | 235±5                 | 220                    | 0.8～1.2      | 20                   | 10                  |
4.2. Speed ratio regulation method
According to the empirical value of no winding defects, the control range of lag angle is 0.8 ° to 1.2 °. The lead screw pitch of the winding mechanism is t = 5mm, the rotation speed ratio of the spindle motor and the winding motor in the ideal state is

\[ i = \frac{n_1}{n_2} = \frac{L}{d} = \frac{5}{0.4} = 12.5 \]

Adjusting the axial compensation s by adjusting the speed ratio. When the lag angle is reduced, the axial compensation amount s is reduced by reducing the speed n2 of the winding motor, otherwise, when the lag angle is increased, the axial compensation amount s is increased by increasing the speed n2 of the winding motor. The specific control method is as follows:
1. When the lag angle is reduced to the lower limit value of 0.8 °, the upper limit speed ratio i1 = 100:5 = 20 is taken for wire arrangement.
2. When the lag angle is increased to the upper limit value of 1.2 °, take the lower limit speed ratio i1 = 100:10 = 10 for wire arrangement.

4.3. Test results
The results of defect free wire arrangement test are shown in figure 11. The optical fiber surface is arranged orderly, compact and even, turns and turns are parallel to each other. There is no gap, overlap or other winding defects. The quality of wire arrangement is good.

![Figure 11](image_url)

Figure 11. Result of precision winding without defects.

5. Conclusion
The image acquisition and processing technology is applied to the optical fiber precise winding process, which realizes the dynamic detection and precise control of the lag angle of the moving optical fiber, effectively reduces winding defects, improves the precision and quality of the optical fiber winding. It lays a technical foundation for the realization of fiber automatic precision winding.

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