IOP Conf. Series: Materials Science and Engineering **382** (2018) 052006 doi:10.1088/1757-899X/382/5/052006

Study on Influence of Lighting in the Detection System of Inner Wall

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Abstract: This paper introduces a method for detecting the inner wall image of small-diameter workpiece based on composite reflector. Theoretical analysis of annular light source used in the system is conducted. The optical system is modeled and simulated based on TracePro. The influence of different types of light source on visual detection is analyzed by changing the condition and parameters.

1. Introduction

Small-diameter workpiece has been widely used in various fields of production and life [1]. But due to the small measuring space and poor illumination environment, the visual inspection of the inner wall has always been very difficult, implying a lot of key technologies. The measuring principle and method of the inner wall have become an important problem in this field.

The topic proposes a machine vision image detection method based on composite reflector. This method is non-contact and has simple structure and short response time with high resolution, which is very suitable for precision detection.

Lighting system is an important part of machine vision detection [2]. Reasonable lighting design can simplify many problems [3]. This paper simulates the annular light source in the detection system based on TracePro and focuses on the analysis of influence of different parameters and location of the light source. The optical system suitable for this topic is finally determined.

2. The inner wall image detecting system

The detection system schematic diagram is shown in Figure 1. The composite reflector is composed of two parts, one is a conical surface with an angle of 80°, used for diffuse reflection of light to improve the brightness, the second is a 45 ° section, namely reflecting surface [4]. The reflector is fixed, the light emitted from the light source fully illuminate the inner wall of the workpiece, then reflects upwards vertically through the 45 ° mirror and is captured by the CCD camera through telecentric lens. Using the stepping motor as a mechanical movement device, the workpiece is driven to rotate along the circumferential direction by a certain step, so the reflection image at a certain height of the entire circumference is obtained. After that, it is moved in the axial direction and the previous operation is repeated, so as to obtain the workpiece images with different height ranges. Finally, digital image technology is used to process and splice the images to get the complete inner wall image.

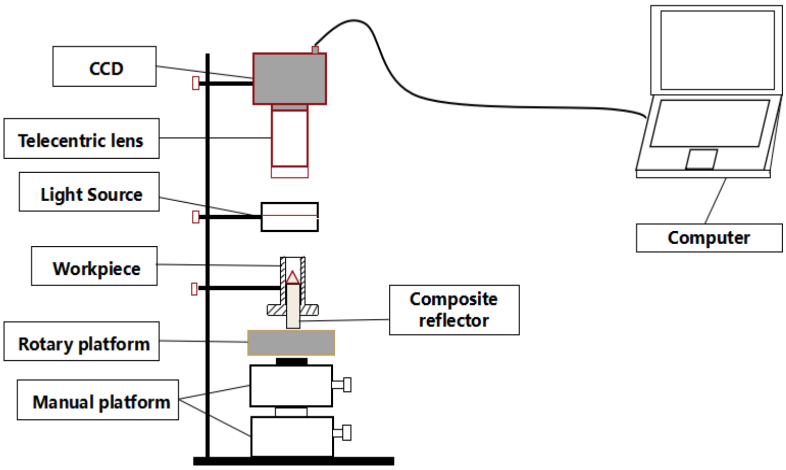

Figure 1 The detection system schematic diagram

The workpiece involved in this topic is made of beryllium copper alloy with small caliber and unpolished. The light that can enter the hole is very limited and is mainly diffuse reflection, and some will be absorbed. The annular light source has high density LED array with high brightness, concentrated beam and uniform illumination, which is suitable for the application.

3. Theoretical calculations about annular light source

There are many models of annular light sources. Its main parameters are outer diameter a, inner diameter b, and the illuminating angle α. Different types of light sources placed in different positions can have a great difference to the system [5].

To get the right light source and best working distance, this paper conducts some theoretical analysis. Referring to LED lighting characteristics, only take the main ray which is perpendicular to the luminous surface into consideration to simplify the analysis. The inner diameter of the workpiece is d; the depth that can be illuminated by the main ray is d x tanα. It is obvious that the larger the angle is, the deeper the inner wall can be irradiated.

Now consider two extremes.

(1) The light source moves in the direction of the workpiece. When the light from the inner circle can just irradiate the hole, as shown in Figure 2, the main ray will not be able to irradiate the upper part of inner wall if the source continues to move down. According to the trigonometric function, the distance from the workpiece at this point is

$$L_1 = \frac{b+d}{2} \times \tan\alpha - \frac{a-b}{2\tan\alpha} \quad (1)$$

(2)The light source moves away from the workpiece. When the light from the outer circle can just irradiate the bottom through the hole, as shown in figure 3, the main ray will not illuminate the bottom of the inner wall if the source continues to move up. The distance from the workpiece at this point is

$$L_2 = \frac{a+d}{2} \times \tan\alpha - d \times \tan\alpha \quad (2)$$

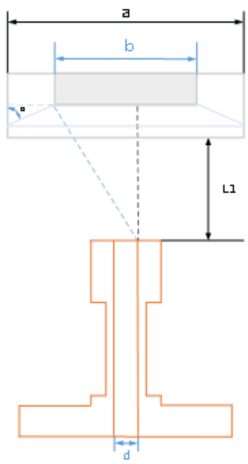

Figure 2 One extreme

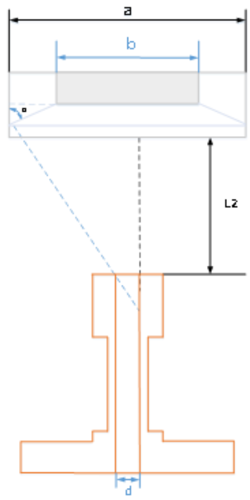

Figure 3 The other extreme

According to the simplified model analysis and calculation, the ideal working distance between the light source and the workpiece should be between L1 and L2. In this range, the light source can be most effectively utilized.

$$\Delta L = L_2 - L_1 = \frac{a-b}{2} \times (\tan\alpha + \frac{1}{\tan\alpha}) - d \times \tan\alpha \qquad (3)$$

ΔL is a monotonic function about a, b, α. The larger a is, the smaller b is and the larger α is, the larger the value of ΔL will be. And the light source will have a better working condition.

In this topic, the inner diameter of the workpiece is 2.4mm and the length is 10mm. According to theoretical analysis and practical production, to ensure that the light will return to the CCD, annular light source with inner diameter of 14 mm, outside diameter of 28 mm and irradiation angle of 75 ° can have a good effect. The ideal working position should be between 28.7 ~ 47.8mm from the workpiece.

4. Simulation analysis and experimental verification

In order to verify the lighting conditions and theoretical calculation under different light sources, we use TracePro to model and simulate the optical system.

The simulation steps are as follows [6]:

(1) Build a solid model. The optical system consists of an annular light source, workpiece and the composite reflector. The shape and internal structure of the LED's impact on the experiment is negligible, so the annular light can be seen as a collection of point lights. The simplified model is shown as Figure 4.

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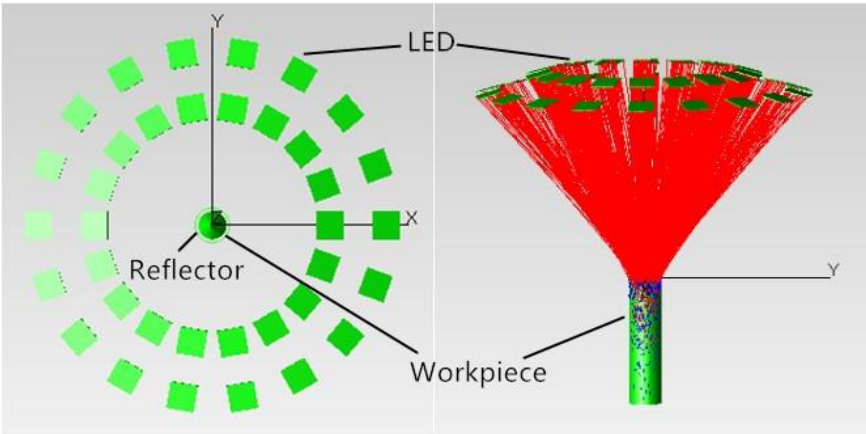

Figure 4 The simulation model

Considering that the workpiece is of very small diameter, too many LEDs don’t increase the brightness a lot. So we use two laps of LEDs in the simulation and the inner and outer diameter can be combined into one parameter. The reflector is placed at the bottom of the workpiece to enhance the illumination and observe the light at the bottom.

(2) Set elements material. The inner diameter of the workpiece is 2.4mm and the length is 10mm; Set the reflectivity of the inner wall at 0.2, diffuse reflectance at 0.3 and the absorption rate of light at 0.5. The reflectivity of the composite mirror is set at 0.9 and the absorptivity and diffuse reflectance are both 0.05.

(3) Define light source. Set the wavelength of the LED at 0.5641μm [7]. Because the amount of light determines the accuracy of the simulation, the tracing light of each LED is set at 100,000 to reduce the error.

(4) Trace the light. The results are analyzed using irradiance maps. Irradiance is the radiative energy projected to the unit area per unit time and it’s can be used to indicate the intensity of light and the degree of illumination of the object's surface.

Experiment 1: To verify the influence of the diameters of the annular light source on the illumination system, keep the angle of the light source at 75 ° and the working distance at 30mm referring to theoretical analysis. Then Change the inner diameter and analyze the influence. Figure 5 shows the irradiance map of the inner wall when the inner diameter of the light source is respectively set at 14, 22 and 30mm.

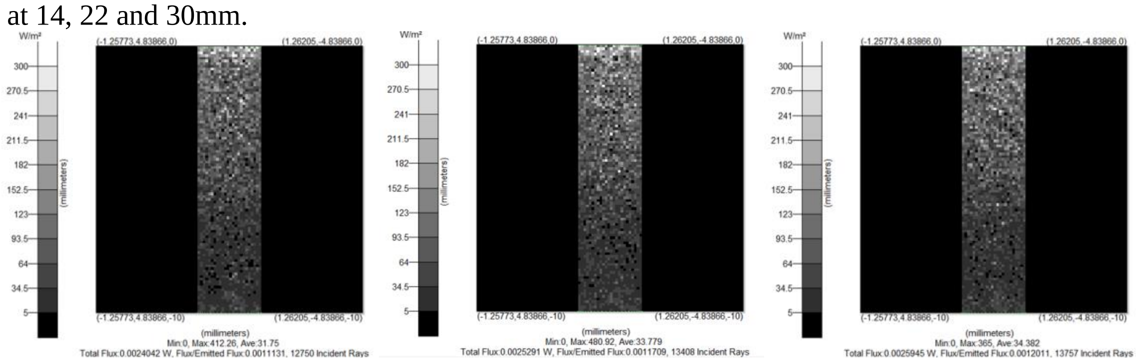

Figure 5 Comparison of irradiance of different inner diameters

The pictures above show the frontal irradiance of the inner wall. The vertical axis is the irradiance value corresponding to different luminance the larger the irradiance value is, the brighter the image will be. When the irradiance value is less than 5, it will be set to black. By comparison, it can be found that and the decrease of the brightness is very obvious with the increase of the inner diameter.

Experiment 2: In order to verify the impact of irradiation angle on the system, keep the inner diameter of the light source at 14mm and working distance at 30mm. Set the irradiation angle to 45 °, 60 ° and 75° respectively to get the corresponding irradiance map shown in figure 6. It can be seen from the comparison that the definition of the inner wall is very similar at different angles. The results are entirely reasonable because for a light source, the emitted light has a certain angle range. So the difference in irradiation angle has little effect under the same condition.

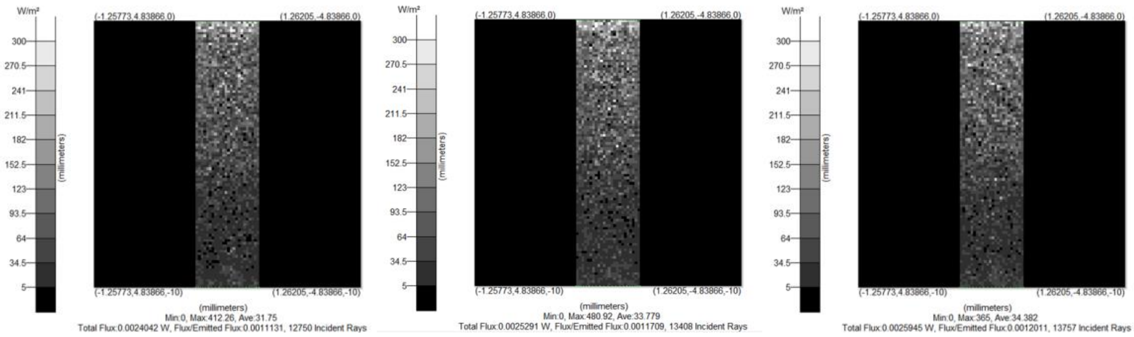

Figure 6 Comparison of irradiance at different irradiation angles

Experiment 3: In the system design, it is necessary to determine the distance between the light source and the workpiece to ensure that the entire inner wall can be illuminated. In order to determine the ideal working position for a given light source, set the inner diameter at 14 mm, irradiation angle at 75 ° referring to the previous experiment. Collect the average values of the irradiance of all pixels at the bottom of the workpiece separately when the working distance varies from 20 mm to 50 mm. And make the data into a graph shown in Figure 7. The horizontal axis represents different working distance; the corresponding vertical axis represents the average irradiance value.

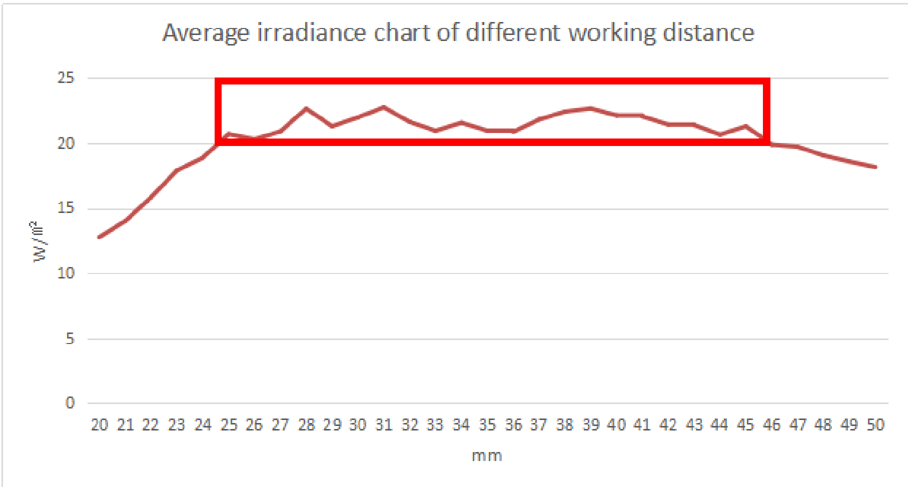

Figure 7 Average irradiance chart of different working distance

It can be found that when the light source is close to the workpiece, the bottom's average irradiance of the workpiece is relatively low. As the distance gradually increases, the average value starts to increase and tends to be stable within a certain range. When the distance continues to increase, the average value starts decreasing gradually. It's because with the increase of distance and deviation of irradiation angle, the irradiation intensity will be smaller [8]. According to the line graph, the ideal working distance is shown in the red flag area. This result is similar to the theoretical calculation.

In this topic, the light finally need to return to the CCD camera through the middle of the light source, so the actual inner diameter cannot be too small, otherwise the CCD's view will be affected. On the basis of theory, experiments and actual production, we finally choose white LED annular sources with an inner diameter of 14mm, an outer diameter of 28mm, the illuminating angle of 75°. A diffuse plane is added to improve illumination uniformity. The working distance is between 30 and 35mm.

5. Conclusion

The type and the position of the light source have a direct effect on the acquisition of image, thus affecting the subsequent image processing. The choice of light source and position is the easiest way to enhance the visual effect.

In this paper, a detailed analysis of the optical system in the visual inspection of the inner wall is carried out. The influence of the inner diameter, angle and working position of the annular light source is analyzed based on TracePro and the parameters are optimized. The results show that a suitable type of annular light source with suitable working distance can be used to effectively measure the inner wall of the small-diameter workpiece in this system.

Acknowledgment

This study was supported by the National Key Scientific Instrument and Equipment Development Projects of China (No. 2014YQ090709).

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