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Automatic Measurement and Control Method for the Code Edge of Stripe Rod

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Abstract: It is a tough question to measure the code edges of the stripe rod with high precision and high efficiency. An automatic measurement and control method for the code edges of the stripe rod is put forward in the paper. A laser interferometer is used not only as a means in distance measurement but also as a positioning sensor in closed-loop control. The acceleration-deceleration control of S curve is designed to ensure the system performance. An alignment area is set up to provide control redundancy and the alignment offset of measured edge can be obtained by image measurement. The measured code edge position is obtained by combining interferometer data with image data. The S curve control proves high efficiency and positioning precision of 0.03 mm. The repetition criterion deviation of edge measurement is less than 0.5 µm, which proves the data combination method is high precision. This is the first time that closed-loop control and control redundancy method is used to calibrate the stripe rod. *Copyright © 2013 IFSA.*

Keywords: Code edge, Automatic measurement, Motion control, S curve.

1. Introduction

Digital levels are being used more and more due to their accurate and automated height measurements. A digital level achieves height reading by virtue of a stripe rod [1]. The stripe rod as the carrier of the used scale is thereby of special interest, because precise height measurement only is possible with respect to its actual relation to the legal meter. The comparison of the rod scale with the international standards in terms of the ISO 9000 has to be accomplished by periodical calibration [2]. The rod scale is calculated according to the positions of the code edges on the rod.

A laser interferometer can be used as a superior measurement standard [3, 4]. An optical microscope can be used to align the code edges manually. Manual alignment has a low degree of precision and is time consuming.

An automatic measurement system for the stripe rod has been established in Taiwan [5]. They used a moving mechanism to move the code edges of the rod to the CCD image center, and then recorded the reading value of the laser interferometer. The method is effective compared with manual alignment. For a 3 m length, the uncertainty was 21.4 µm, which is worse than that in other countries. If the alignment offset is allowed to exist and can be calculated by image processing, the alignment difficulty can be reduced and the measurement precision can be improved [6].

A new CCD-based technique for the measurement of the stripe rod is developed in Germany [7]. The image and the interferometer data are obtained while

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the rod is moving. The efficiency is high, but the blurring effect of the image is unavoidable. The measurement precision can be improved by slowing down the speed of the rod motion, but the measurement time will subsequently increase [8]. How to ensure high precision and high efficiency at the same time is a tough question.

A new automatic measurement and control method for the code edge of stripe rod is put forward in this paper. The rod will move and stop by automatic control to ensure a high degree of efficiency. The image and the interferometer data were collected at a stop state to ensure a high degree of precision. The offset of the edge alignment is calculated by image processing to reduce control difficulty and ensure measurement accuracy. The image data is combined with its corresponding interferometer data to obtain the edge position, which then is the base for the derived rod scale.

2. Research Method

2.1. The System Configuration

The measurement and control system was designed by photoelectric measurement technique lab at Xi'an University of Technology in China. The basic setup of the measurement and control system is schematically shown in Fig. 1. It mainly consists of a rod carrier section, a motion control section, a length measuring section, an alignment section and a computer. The rod carrier section includes a base, a guide rail, a screw and a worktable. The motion control section includes a motor, a drive controller and a drive card. The length measuring section is a laser interferometer, including a reflector, a beam splitter, a laser head, an interferometer controller and an interferometer board. The alignment section includes a light source, a microscope and a CCD camera.

The screw and the guide rail are installed on the base. The motor drives the screw directly, driving the worktable to move along the guide rail. The rod is mounted on the worktable and smoothly moves along with the worktable in the horizontal direction. The computer controls the motion of the rod via the motion control section. The marble base is used to ensure the overall stability of the system. The rolling screw and the linear sliding rail have a low coefficient of friction and a high degree of precision to ensure the smooth motion of the rod. The closed-loop control is used to realize positioning requirement. The positioning sensor is the laser interferometer in the closed-loop control system.

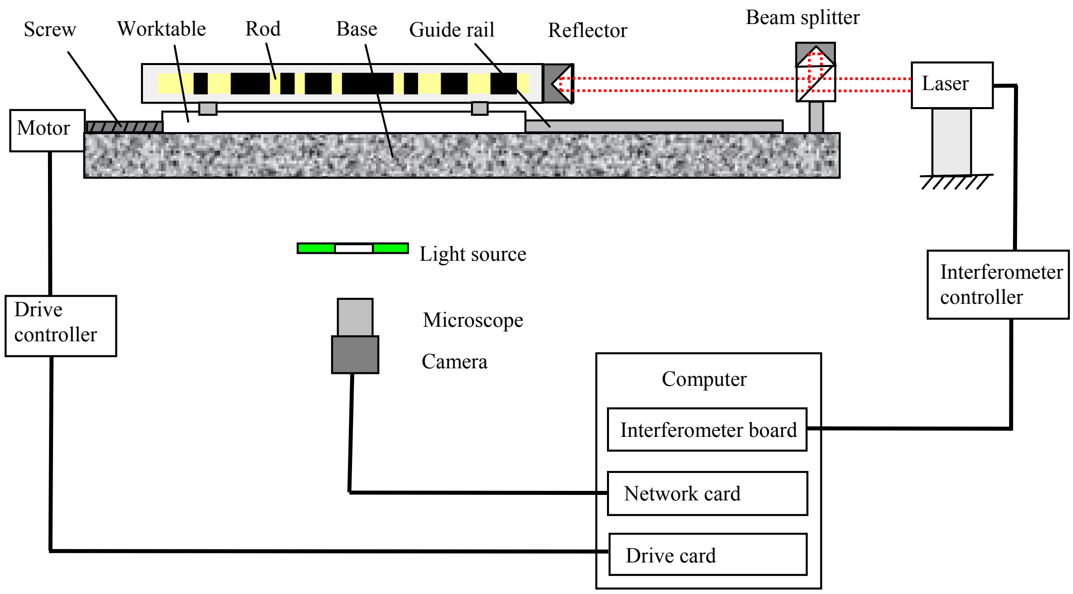

Fig. 1. Schematic of the automatic measurement system.

A laser interferometer was used as a means to measurement the rod. According to the Abbe principle, the reflector was fixed on the rod and its optical axis coincides with the rod axis. Thus the mobile distance of the rod can be obtained precisely [9]. The laser interferometer responds quickly, it not only can meet the needs of real-time measurement but it can also be utilized in rapid positioning control.

The illumination of the measured code edges is realized by an LED light source. Green light was chosen due to it having the highest contrast and best responses characteristics with the CCD camera. The microscope magnification is approximately 1x. In the CCD camera, the pixel size is 4.65 μm. Thus the actual size projected onto each pixel is approximately 4.65 μm. The image localization accuracy is 1/10 of a pixel, which corresponds to less than 0.5 μm.

The measurement system is controlled by an industrial computer with Windows XP as the operating system.

2.2. The Automation Measurement Method

A reference code edge is chosen to define the zero position of the rod and the reference position (close to image center) in the image taken by the CCD camera. The measure task is to measure the distance between the reference code edge and any code edge of interest, called a measured edge, which appears in the image after moving the rod to the measurement position, as shown in Fig. 2. The laser interferometer measures the movement distance. The CCD camera not only serves to indicate the measured edge, but also to determine its distance from the reference position to actual position of the measured edge in the image. Final measurement result is a combination of the movement distance and the position offset in the image.

The pixel distance of the measured edge towards the reference position in the image is designated as *D*. The movement distance measured by the interferometer is designated as *L*. The measured edge position on the rod is *x*.

$$x = L + D \times k \,, \tag{1}$$

where *L* is the interferometer value in [*mm*]; *D* is the offset of measured edge in [*pixel*]; *k* is the actual size projected onto each pixel in [*mm/pixel*]. *k* can be obtained by calibration before measurement [10].

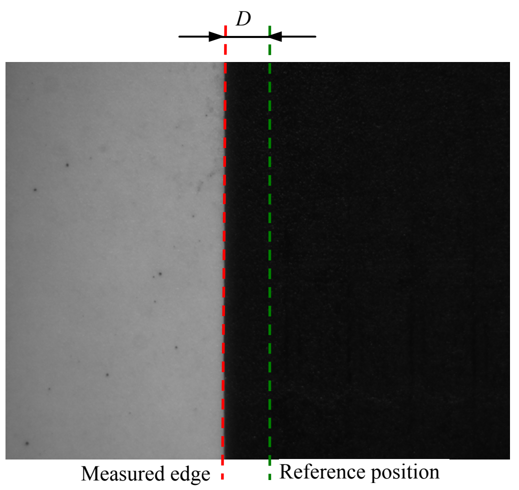

Fig. 2. Image measurement schematic.

Combining the alignment offset with the interferometer data needs only the measured edge existing in the view field. The method does not require precise optical alignment for the measured edge, so the measurement is rapid and high effective.

The measurement process is as follows. The motor causes the rod to move. The laser interferometer is used as the feedback sensor. The rod moves given distances and then stops. When the rod has stopped, the laser interferometer measures the distance of the movement. At the same time, the code image is taken with the CCD camera and is processed to obtain the code edge. The edge is correlated with its reference position to obtain the offset of the measured edge in the image. According to equation (1), the offset is combined with its corresponding interferometer data to obtain measured edge position.

Controlling the rod movement automatically requires no manual participation and ensures the measurement efficiency. The code edge images and the interferometer data is collected when the movement has stopped, guarantying correspondence between the collected images and data, avoiding the motion blur of the detected edge and ensuring the measurement accuracy.

2.3. The Motion Control Method

The motion control is aimed at automatic measurement of code edge with high efficiency and high accuracy. The difficulty is that the movement distance may be different, sometimes hundreds of *mm* and sometimes only 1-2 mm. In any circumstances, the distance error and cumulative error does not allow bigger. Therefore, two measures are used to ensure high efficiency and high accuracy of the motion control. (1) To set up alignment area to provide control redundancy. (2) To design reasonable motion control algorithm.

If only the detected edge exists in the alignment area, the position of the detected edge can be obtained by combining image data with interferometer data. So the measurement is rapid and high effective. The bigger the alignment area is, the lower the measurement accuracy is; the smaller the alignment area is, the more difficult the motion control is. Reasonable alignment area not only ensures measurement accuracy but also facilitates motion control. Through a lot of experiments, the alignment area is set to ±0.2 mm.

The motion control method is as follows. The computer gives control signal to the drive controller through the driver card which resides in computer, as shown in Fig. 1. The driver card sends pulse to the drive controller by pulse unit. The speed and the motion distance of the servo motor are controlled by the frequency and the quantity of the pulse.

The schematic of motion control loop is shown in Fig. 3. The laser interferometer is used as the feedback sensor. The motion distance is obtained by the laser interferometer in real time. The motion control is determined by the difference between given distance and motion distance. Flexible curve of speed control is adopted to reduce shock and realize accurate positioning [11].

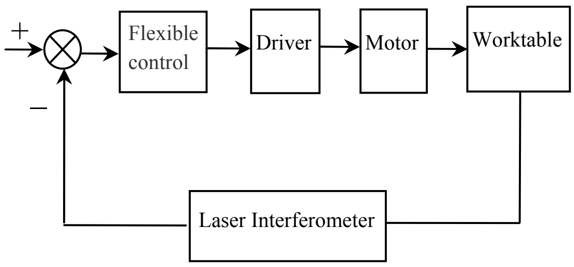

Fig. 3. Schematic of motion control loop.

By means of attenuation of acceleration stage and deceleration stage, the acceleration-deceleration control of S curve is used to ensure the motor performance and reduce the shock [12]. An acceleration-deceleration process of S curve can be divided into 7 stages: fast acceleration, uniform acceleration, slow acceleration, uniform velocity, slow deceleration, uniform deceleration, fast deceleration, as shown in Fig. 4. In this figure, *T* stands for time; *S* stands for distance; *V* stands for velocity; *A* stands for acceleration; *J* stands for jerk. The detail instruction of the S curve is shown in Table 1.

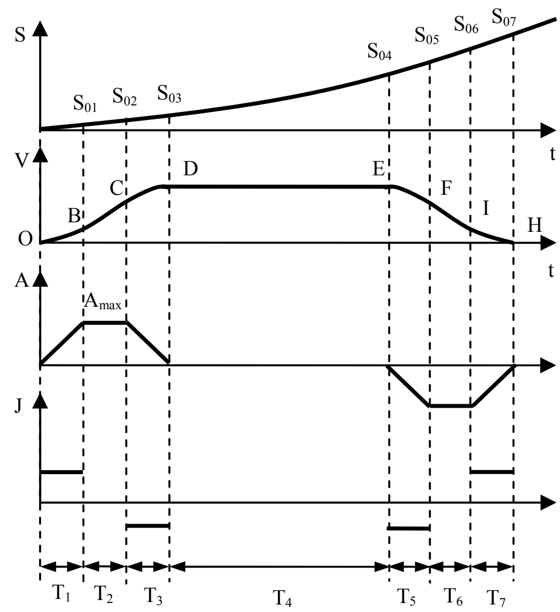

Fig. 4. S curve acceleration and deceleration

The acceleration and deceleration of the S curve is the changing process of parabola – straight – parabola actually. The maximum acceleration $A_{\max}$, the jerk J and the maximum frequency $f_{\max}$ must be known to compute the velocity of acceleration and deceleration.

Table 1. The detail instruction of the S curve.

Section	Stage	Terminal Velocity	Terminal Acceleration	Jerk	Run Time
OB	Fast acceleration	V_{01}	A_{max}	J	T_1
BC	Uniform acceleration	V_{02}	A_{max}	0	T_2
CD	Slow acceleration	V_{03}	0	–J	T_3
DE	Uniform velocity	V_{04}	0	0	T_4
EF	Slow deceleration	V_{05}	$-A_{max}$	–J	T_5
FI	Uniform deceleration	V_{06}	$-A_{max}$	0	T_6
IH	Fast deceleration	0	0	J	T_7

It takes 10 minutes for the worktable to move 3 meters continuously. So the linear velocity of the worktable is:

$$F = 0.3\, m/\min = 5\, mm/s\,, \tag{2}$$

And the Pulse equivalent is:

$$\delta = \frac{C}{4A} \times \frac{M}{N} = 1\, \mu m/p\,, \tag{3}$$

where C is the screw pitch; A is the encoder resolution and M/N is the gear ratio.

The motion velocity in pulse quantity is:

$$F_p = F/\delta = 5000\ p/\mathrm{s}\,, \tag{4}$$

So the maximum frequency of the motor is

$$f_{\max} = 5000\, Hz\,, \tag{5}$$

It is assumed that the maximum acceleration and the jerk are $A_{\max} = 25000\ p/s^2$ and $J = 250000\ p/s^3$. Then,

$$\begin{cases} T_1 = T_3 = T_5 = T_7 = \dfrac{A_{\max}}{J} = 0.1 \\ T_2 = T_4 = \dfrac{f_{\max}}{A_{\max}} - \dfrac{A_{\max}}{J} = 0.1s \end{cases}, \tag{6}$$

The velocity of every stage is

$$\begin{cases} V_{01} = V_{06} = \dfrac{1}{2} J T_1^2 = 1250 p/s \\ V_{02} = V_{05} = V_{01} + J T_1 T_2 = 3750 p/s \end{cases}, \tag{7}$$

The displacement of every stage is

$$\begin{cases} S_{01} = \dfrac{1}{6} J T_1^3 \approx 42p \\ S_{02} = S_{01} + V_{01} T_2 + \dfrac{1}{2} J T_1 T_2^2 = 292p \text{,} \\ S_{03} = S_{02} + V_{02} T_1 + \dfrac{1}{3} J T_1^2 = 675p \end{cases} \quad (8)$$

So the minimum acceleration-deceleration distance of complete S curve is obtained.

$$S_{\min} = 2S_{03} = 1350\,P = 1.35\,mm, \quad (9)$$

And the deceleration zone of S curve is 0.675 *mm*.

The acceleration-deceleration control of S curve is adopted to ensure the system performance and high efficiency. The motion distance is obtained by the laser interferometer in real time. The interferometer data is used for feedback control. The deceleration control is determined by the difference between given distance and motion distance. When the difference is less than deceleration zone, the deceleration control begins. According to the servo motor frequency table of the S curve, the motor decelerates flexibility. And finally the detected edge locates accurately in the alignment area.

3. Experimental Results and Discussion

3.1. The Positioning Control Experiment

In different positions of the guide rail, a lot of positioning experiments of given distance is done. The positioning experimental data of 10 mm distance are shown in Fig. 5. The positioning experimental data of 100 mm distance are shown in Fig. 6.

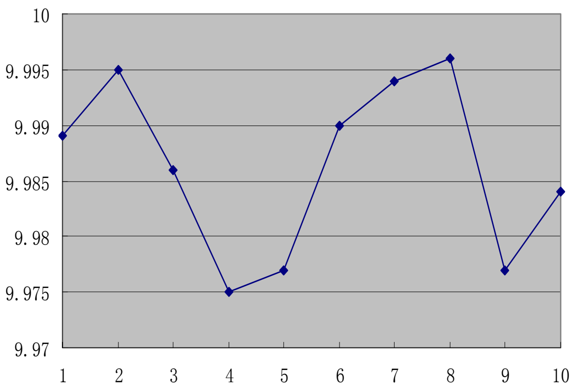

Fig. 5. The positioning data of 10 mm distance.

The experiment data shows that the positioning error of the motion control system is irrelevant to motion distance and the positioning error is less than 0.03 mm. Considering the timer interval, the deceleration control begins a bit earlier. Even so, the positioning error is far below the system requirements, which is 0.2 mm.

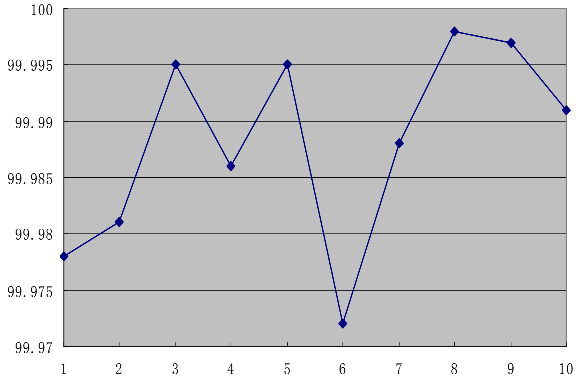

Fig. 6. The positioning data of 100 mm distance

In the experiment, the start and the stop of the motor are smooth and quick. The experiment proves the motion control algorithm is effective and accurate.

Considering the timer interval, the deceleration control begins a bit earlier. If the deceleration control begins at right time, the positioning error can be less than 15 μm. So the motion control method can be used to precise positioning under more occasions.

3.2. Measurement Accuracy Experiment

The motion control system controls the rod, moving it back and forth. The same edge was measured several times at different alignment locations. The edge position was obtained by combining the alignment offset with the interferometer data. Data from the repetitions measurements of a left edge (bright – dark transition) position and a right edge (dark – bright transition) position is shown in Table 2.

The repetition standard deviation $\sigma_{\bar{x}}$ can be obtained by equation (10):

$$\sigma_{\bar{x}} = \sqrt{\frac{\sum_{i=1}^{n} (x - \bar{x})^2}{n(n-1)}}, \quad (10)$$

The repetition standard deviation are $\sigma_{\bar{x}_r} = 0.38\,um$ and $\sigma_{\bar{x}_r} = 0.29\,um$ respectively, while the standard requirement is less than 2 μm. The accuracy of the measurement system is very high.

The experiment shows that the data consistency is good when measuring the same edge in different alignment locations and proves the combination of the image data with the interferometer data ensures measurement accuracy.

The experiment proves that the data combination method is reliable if only the detected edge is exiting in the alignment area, so the control redundancy method is effective. The automatic measurement and control method for the code edge is effective and accurate.

Table 2. Repetition measurement data of detected edge position.

No.	**Right edge, (mm)**	**Left edge, (mm)**
1	-0.4019	-0.4237
2	-0.403	-0.424
3	-0.4025	-0.4234
4	-0.4022	-0.4234
5	-0.4028	-0.4239
6	-0.4029	-0.4237
7	-0.4025	-0.4238
8	-0.4029	-0.4231
9	-0.4024	-0.4237
10	-0.403	-0.4233
11	-0.4031	-0.4233
$\sigma_{\bar{x}}$	0.00038	0.00029

4. Conclusions

To determine the rod scale of a stripe rod, a new automatic measurement and control method for the code edge was designed and described in this paper. The system configuration is presented in detail. The rod is driven by closed-loop control and the data are collected at stop state. A laser interferometer is used in not only determining length but also as a positioning sensor. The edge position was obtained by combining the alignment offset with the interferometer data.

The data combination method reduces control difficulty and ensures measurement accuracy. The closed-loop control method improves efficiency and guaranties data correspondence. The acceleration-deceleration control of S curve ensures the system performance and high efficiency. The measurement and control method has been used to calibration stripe rod with high efficiency and high precision.

Acknowledgements

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