Improvement of absolute positioning of precision stage based on cooperation the zero position pulse signal and incremental displacement signal

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Abstract. In this paper, a scheme to measure the position of precision stages, with a high precision, is presented. The encoder is composed of a scale grating and a compact two-probe reading head, to read the zero position pulse signal and continuous incremental displacement signal. The scale grating contains different codes, multiple reference codes with different spacing superimposed onto the incremental grooves with an equal spacing structure. The codes of reference mask in the reading head is the same with the reference codes on the scale grating, and generate pulse signal to locate the reference position primarily when the reading head moves along the scale grating. After locating the reference position in a section by means of the pulse signal, the reference position can be located precisely with the amplitude of the incremental displacement signal. A kind of reference codes and scale grating were designed, and experimental results show that the primary precision of the design achieved is 1 μm. The period of the incremental signal is 1 μm, and 1000/N nm precision can be achieved by subdivide the incremental signal in N times.

1. Introduction.
Linear encoder is a kind of linear distance measuring instrument with nanometer resolution and micrometer precision [1-3], applied in various precision positioning fields [4], the range of which depends on the length of the scale grating (tens of centimeters). Linear encoder transfers light intensity of the moire fringe or interference fringe of the grating into electrical signal, and displacement of the encoder will be achieved after sampling and processing the electrical signal [5]. Among linear displacement transducer with nanometer precision are linear encoder, laser interferometer which achieves a resolution of 0.1-10nm over a range of 1m [6], atom force microscope (AFM) which achieves a resolution of 0.1nm over a range of 30-50μm and scanning electron microscope (SEM) which achieves a resolution of 1 nm over a range of 3-5mm [7]. Thus it can be seen that only linear encoder and laser interferometer provide a nanometer resolution and a relative large range at the same time. Compared with the laser interferometer, the linear encoder shows advantages in optical structure, circuit and data processing, which makes it more simple and compact. In addition, the linear encoder has prominent advantage over anti-jamming, cost and reliability, and is employed for various precision measurement and positioning applications such as closed loop CNC machine [8].

According the type of the encoder, there are incremental type and absolute type linear encoder. The incremental type linear encoder has to find a reference as zero before measurement while the absolute
type achieve the reading head position directly when star-up [9]. In the research, a two-probe optical encoder [10], consists of a zero position interpretation system and an incremental displacement system, is designed. The zero position interpretation system generates pulse signal to find reference positions while the incremental displacement system transfers interference intensity into elective signal to achieve the displacement. The positioning precision of the zero position interpretation is related to the width of pulse signal directly.

A pulse signal, in condition of a kind of reference codes, 150 bits, each width 10μ m, is simulated by using angular spectrum theory [11-13]. Figure 1(a) shows the simulation waveform of the zero position pulse signal, where the width at half-peak is 23μ m. Figure 1(b) the zero position pulse signal, achieved from experiment which performed with the designed codes as above, where the width at half-peak is 29μ m, is consistent with the simulated pulse signal in waveform. A flat region of 0.5μ m wide, caused by diffraction effect produced by the slit on mask and the installation error, appears at the bottom of the pulse signal when amplify it. It limits the positioning accuracy of reference zero to 0.5μ m, and thus constricts the measurement and positioning accuracy of the linear encoder.

![Figure 1. The simulate pulse signal (a) and the experimental pulse signal (b)](image-url)
The positioning accuracy needs to be further improved so that the linear encoder can apply in ultra-high precision measurement, such as lithography machine and closed loop CNC machine. In order to promote the positioning accuracy, in this study, a new method to find the reference positions, in aid of subdivision of the periodic incremental signal which is used to aligning reference zero, is proposed.

2. Principle and Experiments.

The reference positions of the linear encoder are spread on grooves of scale grating in a mode of different spacing. For example, there are 13 reference positions on the scale grating, the distances between adjacent reference codes are: 10.02mm, 9.98mm, 10.04mm, 9.96mm, 10.06mm, 9.94mm, 10.08mm, 9.92mm, 10.10mm, 9.90mm, 10.12mm, and 9.88mm. The distances between each reference codes are unique, and so are the positions in incremental signal within a period, where each peak of zero position pulse corresponding.

When linear encoder moves along X-axis, the phase of the incremental signal has a relationship with the displacement of the encoder as following.

\[ \Omega_x = \Omega_{x0} + \frac{2\pi \cdot \Delta X}{g} \]  

Where \( \Omega_x \) is the phase of the incremental signal, \( \Omega_{x0} \) is the initial phase of the incremental signal, \( \Delta X \) is displacement of the encoder, \( g \) is grating constant.

The phase of the incremental signal corresponds to the displacement of encoder, as show in Figure 2, and the reference positions can be marked on the incremental signal within a period. When located in a period on the incremental signal with the zero position pulse, the reference positions can be found precisely, which will improve the positioning accuracy of the zero position pulse signal significantly and make the positioning accuracy of linear encoder related to degree of subdivision of the incremental signal directly.

![Figure 2](image.png)

**Figure 2.** The relationship of incremental signal and zero position pulse signal

Steps of positioning the reference position based on cooperation the zero position pulse and incremental displacement signal are as follows.

First, we locate the zero position pulse signal in a period of the incremental signal by set a threshold.

\[ I_{th} = I_{Max} \cdot k \]  

(2)
\[ I_{x_1} = I_{x_2} = I_{th} \quad \text{(3)} \]
\[ |x_2 - x_1| \leq P_y \quad \text{(4)} \]

Where \( I_{th} \) is the threshold of zero position pulse signal, \( I_{Max} \) is the maximum amplitude of zero position pulse signal, \( x_1 \) and \( x_2 \) is corresponding position when the amplitude of zero position pulse signal achieve the threshold (suppose \( x_1 < x_2 \)); \( P_y \) is periodic constant of the increment signal.

According (2)-(4), pulse interval \([x_1, x_2]\) is achieved when the width of pulse signal equal to periodic constant of the incremental signal by adjust \( K \) to set a proper threshold, where the reference position stay. In this step primary positioning is realized as the reference position is located in incremental signal within a period.

Second, searching the reference position marked with phase previously in \([x_1, x_2]\) to complete the precisely positioning.

In order to verify the process, experiments were done to prove the position the peak of the zero position pulse signal corresponding to in the incremental displacement signal is unique. We did two group of experiments, stop the linear encoder at several different positions during measurement, and achieved the incremental displacement signal waveform as below.

![Waveform of Incremental Displacement Signal](image)

**Figure 3.** The waveform of incremental displacement signal

Two channels interference signal is extract from encoder in each group show in Figure 3, we can see that the two channels incremental displacement signal have different light intensity when laser beam from reading head shoot at different position of the scale grating, which proves the incremental displacement signal is unique at different positions. Therefore the position in the incremental displacement signal the peak of the zero position pulse signal corresponding to is unique too, which can be used to locate the reference positions.

To confirm the result proved above even further, we did another 4 groups of experiments, moving reading head from position 1 to position 2 along the scale grating, passing the same reference position every time. The positions in the incremental displacement signal, which the zero position pulse corresponding to, are show in Figure 5.
3. Conclusion.
A new scheme is proposed in this paper to align the reference positions from zero position interpretation system, cooperating with the incremental sinusoidal periodic signal. The experiments results show the positions in incremental sinusoidal signal the peaks of the zero position pulse signal corresponding to
are unique. Because of the distances between each adjacent reference positions on the scale grating are different and determined by range coding, the positions in incremental sinusoidal signal the peaks of the zero position pulse signal corresponding to are different. Therefore subdivision of the incremental displacement signal [14-16] within a period is a powerful aid in location of the reference positions, which further improves the positioning accuracy.

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