Experimental Research of Displacement Sensor Based on Virtual Instrument Technology

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Abstract. In order to create a kind of wide-ranged and nanoscale accurate displacement measurement which requires low manufacturing costs and has strong anti-interference capabilities and stable performance, the nanometer time-grating sensor based on AC electric field coupling has been researched. Functions like the settings of the frequency, amplitude and phase of standard waveform can be achieved by combining the LabVIEW software of virtual instrument development platform with the hardware of the PXI-5422 arbitrary waveform generator from NI company. The experiment concludes that phase adjustment can improve the accuracy through adjusting the amplitude of excitation signal which can avoid the effect that the different installation sites have on nanometer time-grating. The virtual instrument technology applying in the experiment of nanometer time-grating gives technological support to the improvement and progress of the function of excitation signal, which provide convenience to the research on the sensor.

1. Introduction
Nanometer displacement measurement technology is the core technology of nanometer CNC machine tools, special equipment of VLSI and special require- ments of the defense industry ultra-precision high-end nd manufacturing equipment, which directly determines the performance of the host [1], and is the guarantee to achieve high-end manufacturing, national defence industry, aerotechnics field of macro-structure of nanometer precision manufacturing [2-4]. At present, on large range, high-resolution, high-precision displacement measurement occasions, only the grating and laser interferometer are the nanometer resolution displacement measurement tools to achieve millimeter range. Therefo- re, there is an urgent need for a new measurement method to solve the problem of a large number of processing nanometer scale displacement measurement.

Nanometer time-grating displacement sensor (ref- erred to as nanometer time-grating) is on the basis of the principle of the time-gate. Which a time-gate meas- rement method based on alternating electric field coupling. The basic principle is time-space coordinate transformation. That is the amount of time constitutes space measuring reference [5-7], the time scale to impr- ove the resolution and accuracy of the measurement of the spatial scale, in order to avoid the impact of the wavelength of light and optical diffraction limit to na- nometer displacement measurement.

2. Working principle
Nanometer time-grating model is shown in Figure 1 (a), including a moving ruler and a fixed rule. Used semiconductor technology plated on a layer of low resistivity thin metal layer on the moving
ruler matrix and the fixed ruler matrix. The shapes corresponded are: the moving ruler of electrode is as a sinusoidal shape and divided into two symmetrically placed with a wire to lead the sensor signal. The fixed rule of electrode is rectangular and arranged in two rows, but the starting position has 1/2 electrode width W of the up row electrode and the down row electrode, and there is certain gap between each electrode sheet. As shown in Figure 1 (b).

(a) Measurement model of the nanometer time-grating.

(b) Connection diagram of fixed ruler pole.

Figure 1. Sensor principle of work.

The odd-numbered electrodes of the up row fixed ruler connected to a group, and the even-numbered electrodes are connected to a group. The two electrode group are connected to excitation signal A; the odd-numbered electrodes of the down row fixed ruler are connected to a group, the even-numbered electrodes connected to a group, the two electrode group are connected to excitation signal B. The moving ruler and fixed ruler are placed parallel face to face with a distance of delta. The down row electrode of moving ruler and fixed ruler is placed face to face to form two sets of differential capacitance between the upper and lower.

Using the transformer to transform the excitation signal A and B into four excitation signal, as shown in Figure 2, excitation signal A and B phase expression as follows.

\[
U_A = U_m \sin(\omega t) \tag{1}
\]

\[
U_B = U_m \sin(\omega t + \pi / 2) = U_m \cos(\omega t) \tag{2}
\]

**Formula.** \(U_m\) is the amplitude of the excitation signal, \(\omega\) is the frequency of the excitation signal, \(t\) is the amount of time.

Figure 2. A excitation differential capacitance model.

When the moving ruler and fixed ruler are relatively moved, the voltage value of moving ruler which is faced with covering area shows periodical change two sets of sinusoidal moving ruler electrode coupled signals are \(U_a\), \(U_b\), and the formation of two road of standing wave, which is expressed as:
\[ U_a = KeU_\omega \sin \omega t \cos \frac{\pi x}{W} \]  
\[ U_b = KeU_\omega \cos \omega t \sin \frac{\pi x}{W} \]  

**Formula.** \( Ke \) is the electric field coupling coefficient, \( x \) is relative displacement between the moving ruler and the fixed ruler, \( W \) is the width of the electrode.

Two electric field coupling output signal \( U_a \) and \( U_b \) adder synthesis output as one of traveling wave signal \( U_x \), which expressed as:

\[ U_x = U_a + U_b 
= KeU_\omega \sin \omega t \cos \frac{\pi x}{W} + KeU_\omega \cos \omega t \sin \frac{\pi x}{W} 
= KeU_\omega \sin(\omega t + \frac{\pi x}{W}) \]  

The line of synthesized sinusoidal traveling wave signal \( U_x \) and one of phase fixed frequency reference sinusoidal signal \( U_r \) which access the shaping circuit processing, are converted to two square-wave signal of the same frequency into the phase comparison circuit for processing. The use of high-frequency clock Interpolation technology is the phase difference between the two signals. The amount of linear displacement between nanometer time-gate sensor moving ruler and fixed ruler can be obtained after being processed by the microcomputer system.

3. **Design of Excitation Signal System**

LabVIEW software is a graphical programming language to create applications with icons instead of text, with intuitive, simple, fast, and ease of development [8]. NI PXI-5422 is designed for time domain and frequency domain measurement applications bandwidth, which provides 80MH bandwidth, low pulse offset, low cross-interference modulation distortion. It also includes many of the following characteristics: Analog Waveform Editor is used to quickly create test waveforms, using SMC technology to achieve synchronization with other PXI modules nanosecond, up to 512MB shared waveform Sequence of storage, 84MB/s waveform data download rate [9-10].

Nanometer time-gating course of the experiment, a set of flexibly adjusted excitation signal experimental system been needed. Therefore, by means of a virtual instrument development platform, an excitation signal experimental system is designed, cosine and square wave signals are generated by three PXI-5422 boards, and the three-way signal must achieve synchronization.

The front panel of LabVIEW software been used to provide users with an arbitrary waveform generator interface, which generates a user-friendly interface. On one hand, users can display and process results; On the other hand, users can also simulate the traditional instrument operation through the switches and buttons on the control panel. Excitation signal according to nanometer time-gating experimental requirements, the design of the front panel includes: waveform parameters, hardware board selection, sampling rate, stop button, amplitude and gain waveform DC offsets settings. Shown in Fig 3, the front panel controls are divided into two parts, the right part of the waveform diagram shows the controls. From the top to the bottom are as follows: sine, cosine, and square wave. The left part is parameters of the input control. The upper left is the channel selection section, corresponding to a total of three channels nanometer time-gating two signals with square wave. The lower part is the set of three signals parameter settings you can set the cor relative parameters of the amplitude, phase, gain and offset.

The generation of three signals uses the NI-FGEN modular instrumentation signal generator that can generate arbitrary waveform and sync output signal. Signal generating flowchart is shown in Fig
4. The block diagram of the design is shown in Fig5. For the convenience of description, the key part of the program is worked in digital serial number; Regional channel selection signal generator; Region 3 is the creation of the waveform; Region 4 is the waveform parameter settings and sample rate settings, Region 5 is signal synchronization settings; Regional 6 and 7 are the stop and error prompt of the program. The For loop is used in program, while loop and Case conditions determine the structure of the system application framework.

4. Experimental research and analysis

4.1 Excitation signal design of the front panel
According to the requirements of the nanometer time-gating sensor experiment, experimental platform structures are shown in Fig6. By means of the NI corporation's virtual instrument as the excitation signal system, the United States corporation Aerotech's precision linear flotation working platform is regarded as the driving moving ruler movement (stroke 1200 mm, accuracy 0.75μm). The nanometer time-gating sensor signal processing system draws displacement values while processing the induction signal. The British RENISHAW corporation's ML10 laser interferometer (accuracy of ± 0.7ppm) is used for the nanometer time-gating error calibration as a reference value.
4.2 Experimental analysis

The nanometer time-gating original signal excitation system is used to produce sine, cosine, and square wave signal on a pole (2*W width that is 0.44mm) which is measured and obtains the original error, as shown in Fig 7. The original excitation signal error curve is shown in that. The error is 1.6 μm. Remove the original excitation signal in the signal processing system, and use the Virtual Instrument PXI-5422 board directly to the two signals input fixed ruler. Then the square-wave signal is connected to the signal processing system in the same measured over the range of pole obtaining the original error, as shown in Fig 7. Virtual instrument excitation signal error curve shows the error of 1.4μm. By the error curve in Fig 6. It can be concluded that the stability of the signals generated by the excitation system in the virtual instrument technology is superior to the original signal excitation system, and it improved it accuracy.

During the course of the experiment. Due to the mechanical mounting position of the moving ruler and the fixed ruler it is difficult to keep the same. Which guarantee the moving ruler and the fixed ruler equally spaced and parallel. Through the oscilloscope, it is observed that the two induction signals of moving ruler is not equal to the amplitude, under which case a extremely original error is obtained, as shown in Fig 8. The pre-adjustment error curve shows, an error of 1.5μm. By adjusting the gain control of the virtual instrument front panel, the amplitude of the two sensor signals are made to be equal. The error curve measured in the same pole position, as shown in Fig 8. After adjusting the amplitude of the error curve, the error 1.4μm, as shown in Fig 8. Error curve indicated by the experimental data shows that Virtual Instrument excitation signal error curve (Fig 6) and the amplitude of the error curve adjusted (Fig 8) is almost the same. It is shows that in certain mechanical position deviation range, the nanometer time-gating by through adjusting the gain of the excitation signal, ensure that each experimental condition is the same. under the premise that the two induction signals amplitude is equal, and then adjust the phase of the excitation signal original error. The adjusted phase
error is shown in Fig7, the error as 800 nm, It comes to the conclusion that adjusting the phase of the excitation signal within a certain range can improve the accuracy of nanometer time-gating.

![Adjusted error curve](image)

5.Conclusions
The combination of the virtual instrument technology and the experiment research, an experimental excitation signal system of nanometer time-gating is designed. Take the advantage of the Virtual instrument platform to make the research convenient, more flexible and reduce the impact on the testing precision of mechanical installation. It also provides the basis for the research and improvement of nanometer time-gating excitation signal system, and lies the foundation for the design and further accuracy improvement of the next nanometer time-gating system.

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