ATLANTIS PRESS
Advances in Intelligent Systems Research, volume 165
International Conference on Modeling, Simulation, Optimization and Numerical Techniques (SMONT 2019)

Optic Grating Sensor Based High Precision Straight-line Displacement Measurement and Its Error Analysis

Songlin Wu, Lei Dang, Qian Yang, Bochen Bai and Longfei Gao
Faculty of Mechanical Engineering, Xijing University Xian China710123

***Abstract*—To accomplish precision straight-line and angular displacement measurement, the principle and realizing methods on the basis of optical grating are analyzed in detail. A new quadruple frequency circuit and its relative analogous circuit are designed, including scaling circuit of optical grating sensor and display module. For realizing displacement measurement in nanometer-size, corresponding software system of type-51 single chip microcomputer as a control core has designed accordingly. Output display and optic grating signal processing in real-time are achieved. Finally, the error source of system is discussed and error analysis is carried out in this paper. The experimental results show that system can realize high precision measurement and can be used in fine measuring instrument for high precision displacement measurement.**

Keywords*—optic grating; quadruple frequency circuit; displacement measurement

I. INTRODUCTION

Recent years, the amount of related instrument and equipment, to making use of high precision measurement of line and angular displacement, are required increasingly [1]. The instruments with high precision measurement provide the basis of quality assurance of mechanical products, through realizing fine measurements such as straight-line and angular displacement. At the same time, the progress of measuring technology promotes greatly the advance of mechanical manufacture. Measuring technique on the basis of optical grating sensor is widely used in the development of measurement instrument, coordinate measuring machine and high-precision machining. In nation, the study on displacement measurement making use of optical grating sensor makes great progress not only in measurement accuracy and resolution ratio as well, which has been the development tendency of precision measuring instrument and equipment [2]. Fine straight-line displacement based on optic grating sensor take an important role in high precision measuring technology and its application.

In practice, grating reader, as a core unit of optic grating sensing system, is easily affected by mechanical vibration. It induces a poor quality of output square wave in reading. In addition, even though the square wave pulse controlled by step motor is always constant, the running speed of the motor is of micro variety in different period. On the other hand, system are also influenced by temperature, humidity and micro deform in mechanical unit. All the factors together have an impact on the reader to produce an instable output of square wave, different spacing ratio and even missing pulse output [3]. In this way, displacement measurement precision is affected in a great extent. Generally, to increase the resolution and measurement accuracy a quadruple frequency circuit is usually applied in practice to stabilize the reading output and decrease the situation of missing pulse. In production, the quadruple frequency is usually achieved in software. Related hardware circuit in software way is simple respectively and easily accomplished. However, it is of inefficient, lower response and poor reliability. Even though a hardware quadruple frequency circuit is complicated, it is of high efficiency, stability and without taking up the time of MCU.

In this paper, an experimental device with high precision displacement measurement is designed on the basis of optic grating sensing system. A 51-type single chip microcomputer with advanced cost performance is used as a control core to achieve straight-line displacement measurement. It can be used as a feeding device in measuring instrument and related equipment, with higher practicability. To accomplish a high precision straight-line displacement measurement, an optimized quadruple frequency circuit is designed in a hardware way. Under keeping the principle function, new types of chips are used and the circuit is simplified. The amount of chips is decreased. Probability of the circuit is increased. High precision straight-line displacement measurement with nanometer scale has been achieved.

II. DESIGN OF QUADRUPLE FREQUENCY CIRCUIT

The type- GSI Mercury 5500 optic grating sensor is selected in system. Type-51 single chip microcomputer and hardware quadruple frequency circuit are used to collect and process the output signal of the grating sensor, in which STC89C52RC is chosen as CPU as a control chip. The application of hardware quadruple frequency circuit, shown as Fig 1, can efficiently decrease the situation of missing pulse in grating sensing unit, without changing hardware condition of sensing system. It is propitious to accomplish higher precision measurement and 4 times of resolution can be achieved without cost increasing. The signals through employing mono-stable processing keep the integrality of output square wave. First elected four data selector U3 is used to simplify the circuit and increase reliability. The AND or OR gates in traditional mono-stable quadruple frequency circuit are abandoned. The number of

Copyright © 2019, the Authors. Published by Atlantis Press.
This is an open access article under the CC BY-NC license (http://creativecommons.org/licenses/by-nc/4.0/).

chips in the circuit is decreased and the stability of output signal is increased.

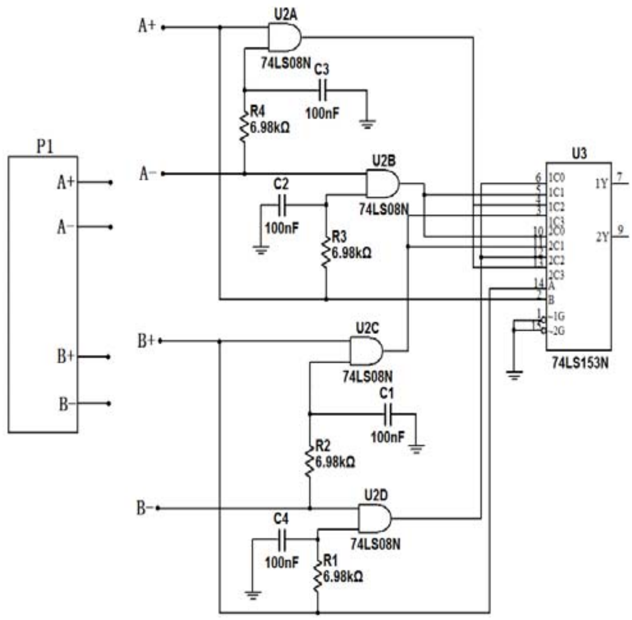
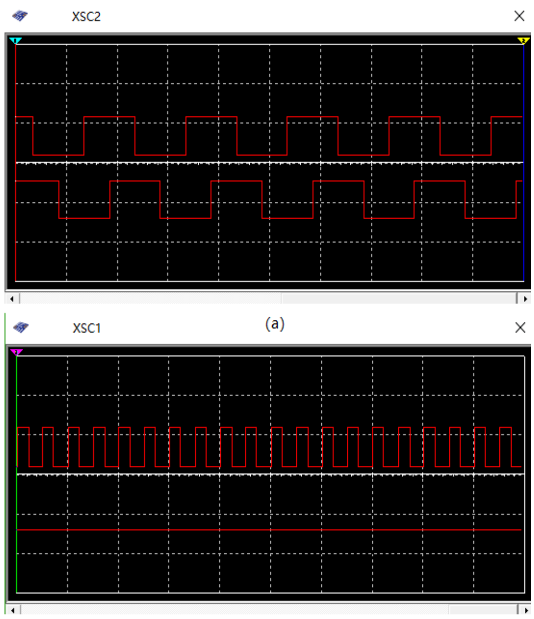


FIGURE I. OPTIMIZED QUADRUPLE FREQUENCY CIRCUIT



(b)

FIGURE II. ORIGINAL AND SIMULATED OUTPUT SQUARE WAVE

The phase of four-channel square wave signal A+, A-, B+, B- from signal B+ is just of π/2 difference. Differential signals are A- between B- and A+ between B+. Four-channel signals from the optic grating sensor are input to the quadruple frequency circuit with direction identifying. The signals through processing by the quadruple frequency circuit are then changed as two channel signals. One is the quadruple square wave pulses and the other is direction signals. The two channel output signals are corresponding to 1Y of pin 7 and 2Y of pin 9 in the double first elected four data selectors U3, in which 2Y is the output signal with high voltage and 1Y is the output of quadruple frequency square wave. When the optic grating sensor moves to right, 2Y is the signal with high voltage and 1Y is then the output of quadruple frequency square wave. When the optic grating sensor moves to left, the result is just opposite. After then, the two channel output signals are sent to the single chip microcomputer and countered out of the respective data values.

The operation of the designed quadruple frequency circuit is simulated as shown as in Fig 2. The simulation results before and after treatment by the circuit show as (a) and (b) in Fig 2, in which they are the waveforms of two phases signals A+ and B+ and the pulses and direction signals after processing by the quadruple frequency circuit respectively.

Graphic lattice liquid crystal display, LCD12864 and LCD1602, are selected in system display module. It is composed of line driver, row driver and lattice liquid crystal display. Direct access and indirect control in the interface method between system display module and the single chip computer, shown as Fig 3.

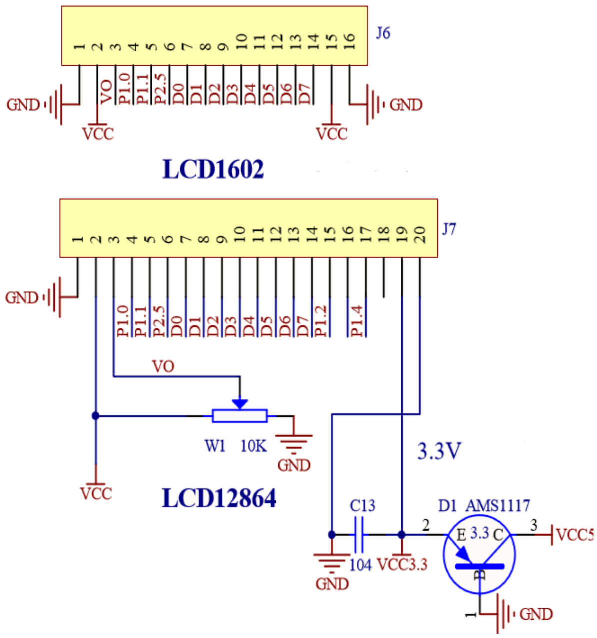


FIGURE III. CONNECTION BETWEEN DISPLAY MODULE AND MCU

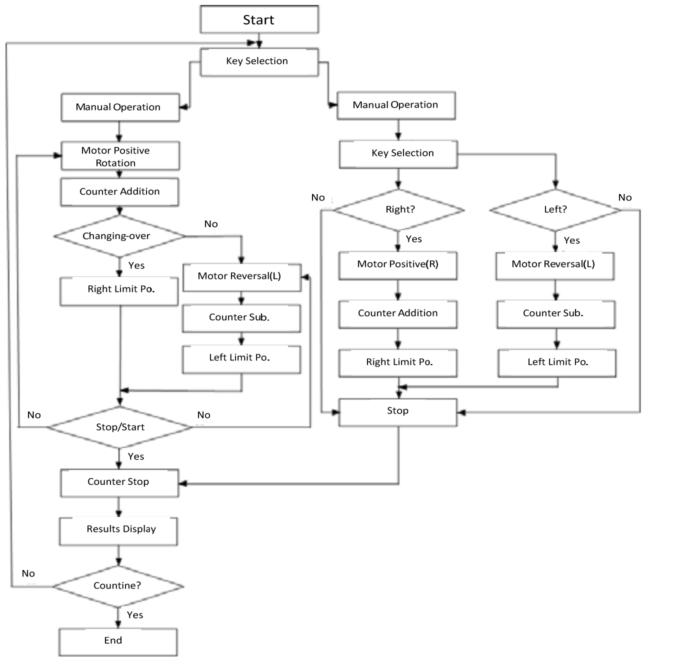


FIGURE IV. PROGRAM PROCESS OF THE MEASUREMENT

III. DESIGN OF SOFTWARE AND PROGRAMMING

The control programing in the single chip computer is designed as Fig 4. Two computer developing boards STC89C2RC are used as control unit and to control motor and optic grating reader. One is to display the running condition of step motor through LCD12864 (Liquid Crystal Display) installed. When the slider powered by the motor touches the limit switch at the two ends, the motor will run at an opposite direction as an automatic model and stop in manual way. The LCD1602 installed on the other board is to show the displacement the slider moves. As the default condition, the positive direction is right.

The electrical part includes type-42HS02 step motor, the motor driver DM320C, Switching Mode Power Supply HT20-D3, limit switches, the quadruple frequency circuit and GSI Mercury 5500 optic grating sensing system.

The signals of A and B phases from step motor are connected with output end of the motor driver. The MCU IO is connected with the input end. The optic grating sensor output square wave pulses under the motor running. The four subdivision pulse and direction signals processed by the digital quadruple frequency circuit are transferred into the interrupt port of the MCU. The moving of the slider powered by step motor produces the straight-line displacement and square wave pulses exported by the reader in optic grating sensor then. The square waves are two types, direction and zero position signals. There are 4 channels of direction signals, A+, A-, B+ and B- respectively. The phase of signal A from B is just of π/2 different period. There are two channels of zero position signals, Z+ and Z- correspondingly. The direction signals through processing of the quadruple frequency circuit are countered in pulses shown as Fig 5.

Output waveforms and signals processed practically through the sensor are shown in Fig 6. Original signals from the optic grating sensor are square wave pules, A and B. They are used in directions following in terms of order. After processing of the quadruple frequency circuit, there are two channels of signals, square wave pulses subdivided in quadruple frequency and voltage level signal. Two channels of signals then are used to complete direction following through exchanging output. It can be seen that technique of the quadruple frequency makes a 4 times of increasing in the resolution and stable signal output.

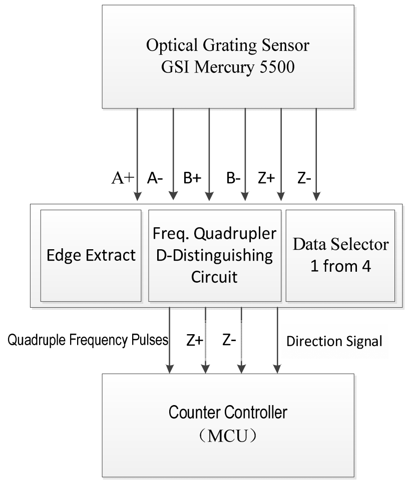


FIGURE V. FLOW-PROCESS DIAGRAM OF SIGNALS PROCESSING

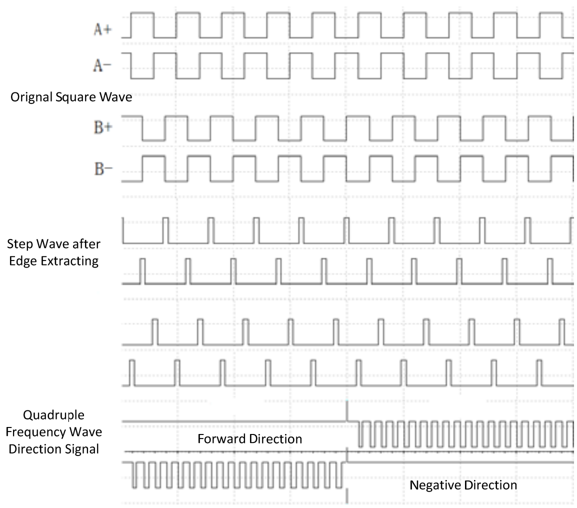


FIGURE VI. VARIATION OF THE WAVEFORM

The error in straight-line displacement measurement comes from 4 aspects, sensing system, mechanical system, signal processing, and environment error, as shown in Fig 7.

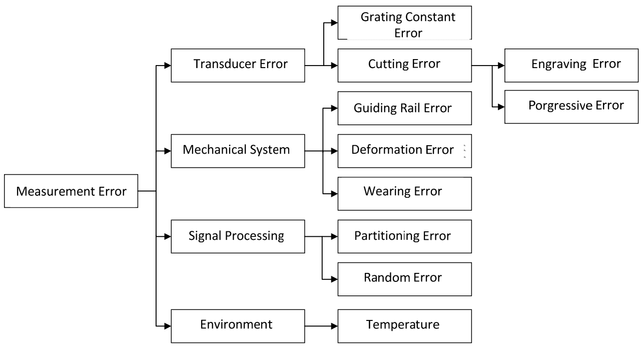


FIGURE VII. SOURCES OF ERROR

The errors in sensing system include grid error and grid line engraving error. The line engraving error is composed of single line engraving error and accumulative error. Generally, the average function of Morie fringe makes this kind of error negligible. In mechanical system, movement and deform of platform and leading rail are the factors to influence displacement measurement. Long period of wear action is another impact factor. The error produced by signal processing consists of random error and subdivided error, which can be separated and decreased by spectrum analysis and filter technology. In addition, temperature alternation in environment is an important factor to influence grid pitch, which should be corrected in high precision measurement.

Practical testing experiment shows that moving space of the slider on leading rail is about 60mm. The full range of output is of 120000±3000 pulses at all. It respect to 59.85mm~60.15mm of the slider moving space. Absolute error in full range is 150um. The practical resolution of the optic grating sensor is 50nm in experiment. After processing of the quadruple frequency circuit optimally designed, The full range of output is of 480000±3500 pulses practically. It respect to 59.96mm~60.04mm and the error is 43.75um. Actual resolution is 12.5nm, about the 4 times increase.

IV. SUMMARY

The priciple and accomplish method of high precision dispalcement measurement are analzed detailly in this paper. An optimal design of quadruple frequency circuit is developed, including the reading and results display module. High precision straight-lin displacement measurement in nano-meter scale has been achieved. Finally, the sources of measurement and its influences to displacement measurement have been discussed accordingly. The experiment show a promise results. The developed system can realiaze the high precision diaplacement measurement and the device can be used in precision measuring instrument with line displacement measurement.

ACKNOWLEDGEMENT

This research was financially supported by the Shanxi Province Innovation Training Plan Project for University Student, Design of Express Automatic Access Device (No.127152017015) and the National Innovation Training Plan Project for University Student, Design of Straight-line Displacement Measurement Device with High Precision (No.201812715005).

REFERENCES

[1] Hu Guo Liang, Study on the Key Technique of Absolute Optic grating Sensing [D]. JiLin University 2017.

[2] Qiao Dong, Technical Study on Absolute Optic Grating Ruler with High Precision [D], Graduate School of Chinese Academy of Sciences, 2015.

[3] Li Suyun, Theory research on metrological grating sensor in Nano-meter scale [D]. AnHui University, 2006.

[4] Liu HongYan, Development of Optical Grating Sensor Interface Card based on USB [D]. Herbin Industry University.

[5] Tang Pan, Zhang HouWu, Design of Displacement Measurement System on the baisis of FPGA optic grating Sensing System [J]. Electronical and Software Engineering, 2017,(09):93-94.

[6] J Zhu, X Cai, Y Chen et al.. Theoretical model for angular grating-based integrated optical vortex beam emitters. [J]. Optics letters, 2013, 38(8).

[7] Guo XiaoChong, Optimal Structure Design of High Precision Optical Grating Sensor for Displacement Measurement [D]. ZhongYuan Scientific Technology University, 2015.