High Accuracy Speed-fed Grating Angular Acceleration Measurement System Based on FPGA

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Abstract

Shaft angular acceleration is one of the most important parameter of rotary machines, the error of angular acceleration increased when the shaft speed up. For this problem, a new high accuracy angular acceleration measurement system is presented, the principle of measurement is self-regulating the period of speed sampling signal according to the proportion of the shaft speed up. This measurement system combined FPGA and SCM, the speed of shaft is received by the timer of SCM responding the interrupts of FPGA, and then set the parameter of frequency divider in FPGA, so as to make the period of speed sampling consistent with the proportion of the speed up. This measurement system could overcome the error when system speed up according to the experiment.

Keywords: *Grating, Angular Acceleration, FPGA, Speed-feed*

1. Introduction

Angular acceleration can be divided into the acceleration of inclined angle and rotation angle, the former is used in controlling and testing the state of the object motion mainly. The latter can reflect the vibration state of the rotating shaft, the response of the various incentive to axis can be analyzed through the measurement of the angular acceleration, especially various dynamic interference of rotation system, will be reflected in form of angular acceleration. The method of angular acceleration measurements can be divided into direct measurement and indirect measurement at present, and the traditional method of angular acceleration measurement include accelerometer, flow potential, piezoelectric crystal and the strain gauge method [1].

In recent years, some experts implement lots of research on angular acceleration measurement and obtained a series of achievements. A virtual instrument for measuring angular acceleration based on LabVIEW was introduced by Li Bo [2]. A novel measurement method for the torsional vibration of high-speed rotary machine is proposed by Huang Zhen[3], which based on laser Doppler technique and the principle of optical heterodyne, the angular acceleration is measured directly. A Newton predictor (NP)is incorporated into the Kalman filter(KF)for online angular acceleration estimation, and the acceleration feedback control is applied to design an acceleration close-loop in terms of stability and robustness[4]. Wu Xiao-sheng combined the analysis of developing trend and characteristics of other angular accelerometers, a novel micro-machined angular accelerometer with fluid inertial mass was proposed [5]. Li Jian-li presented a kind of pendulous micro-mechanical silicon angular accelerometer with force feedback [6]. Yang Wen shuo gives the ideas and method of creating the analysis model of ensemble structure for the angular accelerative sensor, which has been established by using combination of the finite elements[7]. A new method to measure the mechanical angular acceleration of rotating system is established by changing the exciting mode of AC asynchronous tacho-generator, and form a angular acceleration tacho-generator to measure the mechanical angular acceleration directly [8].

An angular acceleration measurement system is designed in reference [9], the speed signal is acquired through grating and infrared photocell, theninterpolation speed signal with high-frequency pulses, the shaft angular acceleration is received by processing pulses. But the measurement error increased when the shaft speed up. For this problem, a new high accuracy angular acceleration measurement system is presented, the principle of measurement is self-regulating the period of speed sampling signal according to the proportion of the shaft speed up.

2. Measuring Principle of System

Grating pieces with even grid are fixed on the shaft through the grating components, the infrared radiations are installed on the electricity of grating pieces. The speed signal can be collected by using the photoelectric tube when the axis rotating, and the signal shaped like sine. The signal is processed by filtering、amplification and plastic, such as S in figure 1. Put the speed signal into FPGA, the speed value can be received by the timer of SCM responding the interrupt of FPGA. Set the low speed of shaft is n_L, and the high speed is n_H. n_L is saved in the SCM memory, the ratio $k = n_H / n_L$ is received when get the value of n_H, frequency division ratio of FPGA divider is K ,which is set by SCM, and K is a even which more than and nearest k . The speed signal changed as FP after frequency division, the signal FP and high-frequency pulses signal CLOCK implement and logic, then received signal GPCZ.

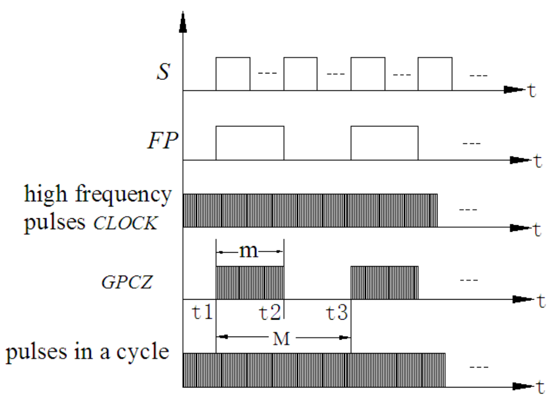

Fig.1 Timing diagram of principle

The grid number is z , the grid and the bar distributed evenly. The angle is $\theta = 2\pi/z$ responding a cycle of signal S . Frequency of pulses *CLOCK* is f , the number of pulses in a width of signal *GPCZ* is m , the number of pulses in a cycle of signal *GPCZ* is M . There are $K/2$ cycles of signal S in periods of $t1 \sim t2$, the average velocity is $\omega 1 = \dfrac{\pi \cdot f \cdot K}{m \cdot z}$; there are $K/2$ cycles of signal S in periods of $t3 \sim t4$ too, the average velocity is $\omega 2 = \dfrac{\pi \cdot f \cdot K}{(M - m) \cdot z}$, so the average angular acceleration in periods of $t1 \sim t2$ is:

$$\gamma = \frac{\omega 2 - \omega 1}{0.5(t3 - t1)} = \frac{2\pi \cdot f^2 \cdot (2m - M) \cdot K}{Mm \cdot (M - m) \cdot z} \quad (1)$$

The frequency f and grid number z are known, the K is received when SCM has measured the speed, according to formula (1), angular acceleration γ is obtained as long as the pulse number m and M are informed of.

3. System structure

Figure 2 is block diagram of measurement system. The system includes four parts, there are photoelectric sensor and gratings, signal processing circuit, data processing circuit and LCD display. Speed signal produced from photoelectric sensor are put into FPGA after filter, amplification, and plastic. Starting and stopping of SCM timer are controlled by FPGA, the timing time is t , which is a cycle time of shaft turn, then n_H is received, last is K . The frequency divider parameters of FPGA is set by SCM, then divided signal S . The signal FP and CLOCK carried on and logic, the number m and M are counted at the same time, the SCM counting out the result. The micro-controller processing the data from FPGA, and control the LCD display the angular acceleration.

4. System realization

In order to obtain n_H、 m and M , the circuit diagram of measurement system is as shown in figure 3 according to the principle of measurement system.

In figure 3: speed signal is S ; the timer of SCM starting signal is TS ; the timer of SCM ending signal is TE ; Counters reset, frequency divider, time control circuit and gate control circuit initialization signal is $RESET$; SCM sets frequency coefficients signal is SET ; Opening the and logic signal is G ; The speed signal S changed as *FP* after frequency division; Signal *FP* and signal *CLOCK* implement and logic, then received signal *GPCZ*; Counters begin to count signal is *START* ; Counters end to count signal, Latches latch count value, opening eight choose one data selector and informing SCM count over signal is *DONE* . The working processes of the system are presented as follows.

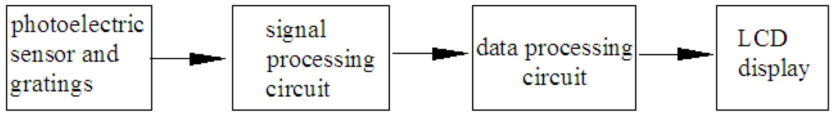

Fig.2 Block diagram of measurement system

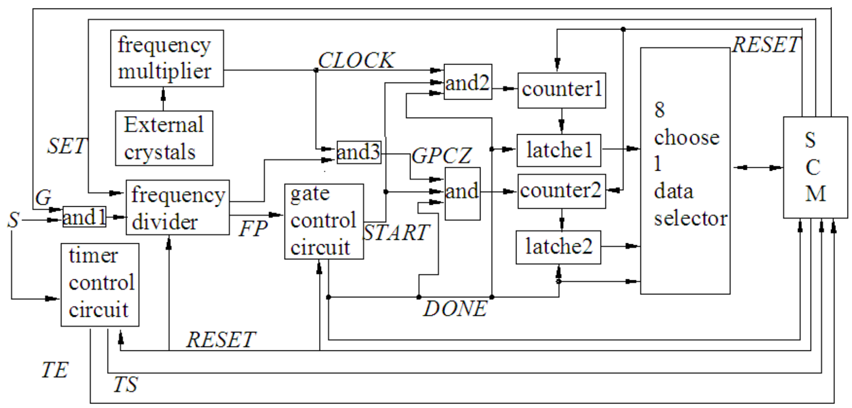

Fig.3 Circuit diagram of measurement system

(1) SCM initialization and timer reset firstly, then signal *RESET* is logic '1', internal counter of FPGA reset, divider, time control circuit and gate control circuit initialization; Last setting G signal is logic '0' and closing and1 logic gate before the frequency divider.

(2) Single-chip microcomputer control signal *RESET* changed as logic '0', then signal TS flips as logic '0' when the first speed signal pulse rising edge arriving, and external interruption 0 of SCM responding this signal and starts timing.

(3) The grid number is 200, so there will generate 200 speed signal pulses when the rotor have been turning a round. The signal TE flips as logic '0' when the 201th speed signal pulse rise edge arriving, external interruption 1 of SCM responding and timing is over.

(4) n_H is received through the timing time, the frequency coefficients K is obtained, the signal SET controlled by SCM sets the divider parameter. Set signal G as logic '1', open the 1 logic gate before the frequency divider.

(5) The speed signal changed as *FP* after frequency division, the signal *FP* and high-frequency pulses signal *CLOCK* implement and logic, then received signal *GPCZ*.

(6) The signal *START* flips as logic '1' when the rising edge of first *FP* signal coming, internal counters FPGA start to count the number of pulses in a width of signal *GPCZ* and the number of pulses in a cycle. The signal *DONE* flips as logic '0' when the rising edge of second *FP* signal coming, internal counters of FPGA end count and the count value exists in latches, the data selector is opened and informing the SCM read the count results.

(7) The I/O mouth of SCM is 8 bits, the internal two counters of FPGA are 24 bits, the count value is read into memory of SCM through eight choose one data selector, single chip microcomputer carries on the data processing according to formula(1).

Simulation for the circuit of the system, assuming that frequency coefficient i 4, the simulation results are as shown in figure 4. Predictably, the designation of circuit is able to perform complete required functions of measurement system.

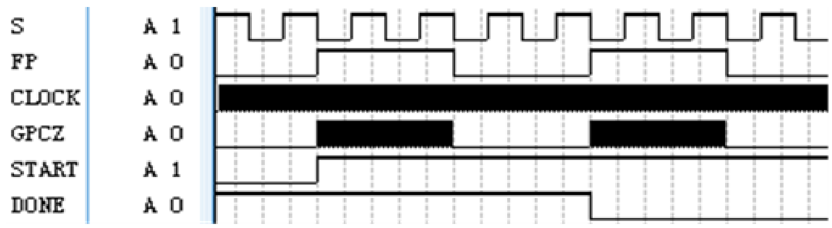

Fig.4 Function simulation of system circuit

5. System realization

Experiment is tested in order to verify the feasibility of the measurement system. The type of FGPA is EP2C8Q208; the high frequency pulse is 400MHz; the model of infrared photoelectric emit tube is $IR333C-A$; infrared photoelectric receiver tube is $PT334-6B$; the grid number is 200; the type of SCM is AT89S52, and its clock frequency is 12MHz.

Experiment 1: The speed signal S is generated from another FPGA (model is EP2C5T144) and active crystals, the signal S is square wave, the frequency of square wave signal is about 500Hz, and duty ratio is 50%, so the theoretical value of angular acceleration is zero. At this time the SCM sets frequency coefficients K as 1, the signal is put into measuring system, and the experimental results is shown in table 1.

Table.1 Experiment 1 results

m	M	$\gamma\ (rad/s^2)$
399994	799987	0.03
399993	799987	-0.03
399994	799988	0
399995	799989	0.03

From the result of experiment 1, we know that:

(1)The accuracy of speed signal which is generated by high FPGA and high-frequency crystals is very high. The count errors of pulses in a *GPCZ* width and a cycle are produced in the period of counter counts start and end.

(2)Angular acceleration measurement can reach higher precision.

(3)The grid number is 200, namely there will generate 200 pulse when the shaft have been turning a round. The frequency of speed wave signal is about $500\,Hz$, and converted it into speed of $150\,r/\min$.

Experiment 2: Set $n_L = 150$ in the SCM, frequency coefficients K initialized to zero, adjust the frequency square wave signal is about $5KHz$, the rest of the conditions unchanged. Put the signal into measuring system, and the experimental results as shown in table 2. Predictably, the system can automatically adjust the period of sampling signal according to the rotor speed, which overcome the influence of the measurement precision of the system when the speed change.

Table.2 Experiment 2 results

m	M	$\gamma\ (rad/s^2)$
399995	799989	0.03
399993	799987	-0.03
399994	799988	0
399993	799986	0

6. Conclusion

This paper proposes a high precision speed feedback type angular acceleration measurement system based on FPGA and SCM, the measuring principle and method of system are introduced in detail. According to the experiments results, the system could overcome the error when system speed up. The measurement system has short responding time and high precision, we expect it will be used widely.

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