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A Methodological Approach to High Precision Measurement of Dynamic Torque of Engine

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Measurement of speed and torque fluctuations of Engine shaft power output is an important topic to improve the precision of test unit. In this paper we propose a non-contact torque measurement system based on multisensor information fusion technology. By making use of the photoelectric sensors installed on the two cross sections of the pivot, this equipment can save information of relative rotating angle of the axis between the two section. We can use this information to calculate the rotational speed and torque.

1. Introduction

The automotive engine is a device that converted chemical energy to power output by burning a liquid fuel inside the engine cylinder. When engine have been designed completely, we need to be sure engine combustion speed and the relationship between the engine export power, torque and rotational speed. In the engine development process, the need of dynamic torque and rotational speed measurement is increased.

2. Operating Principle and Structure Principle of the Equipment

The measurement of the rotating torque (Figure 1) is gained by measuring the twist angle of elastic axis transferring torque in the measuring device of transferring type. The relation between twist angle of elastic axis and transferring torque is shown as follows:

$$\theta = \frac{Ml}{GI_p} \cdot \frac{180}{\pi} = \frac{32Ml}{\pi d^4 G} \cdot \frac{180}{\pi} \quad (1)$$

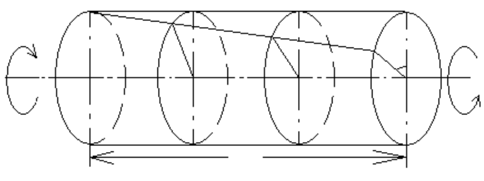

Figure 1: Abridged general view about angle of torsion

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In Eq.1, θ presents twist angle (°); G presents shearing modulus(GPa); I_p presents polar moment of inertia (mm^4); M presents torque (N.m); l presents the length of measured axis(mm); d presents the diameter of axis (mm).
According to Eq.1, if the diameter, the length and the materials are constant for the elastic axis, the twist angle corresponds to the torque. M is gained by calculating. The static characteristic of the axis is known by means of calibrating the axis. And the corresponding torque is gotten according to the twist angle.

3. The Whole Structure Project

A device is designed for measuring dynamic torque of medium speed diesel engine axis in the high duty diesel generator set system. Technical conditions are shown as follows:

- Measurement range of torque is: 0~100N.m;
- Measurement precision of torque is: ±0.2N.m;
- Rotating speed is: 0~2200rpm;
- Lasting work time is: 40min;

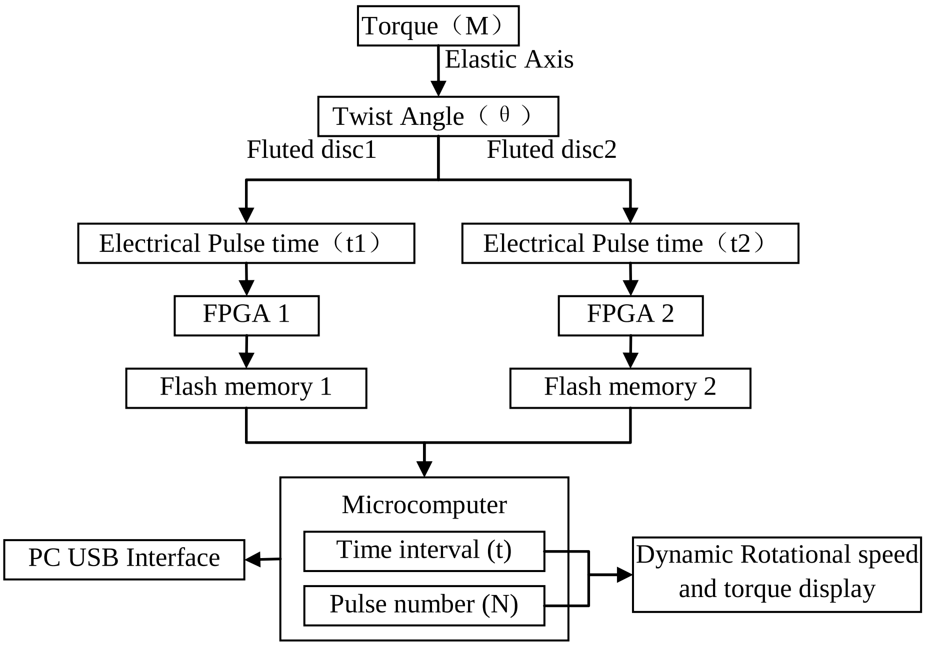

Figure 2: Flow chart of signals

According to technical conditions, the principle of fluted disc torque measurement is presented. Elastic axis transforms torque into angular, and fluted disc and photoelectric sensor transforms angular into impulse signal. Digital signal is written to flash memory and outputted after transforming and processing by single chip microcomputer system. Its flow chart of signal is shown as Figure 2 and the whole structure project as Figure 3.

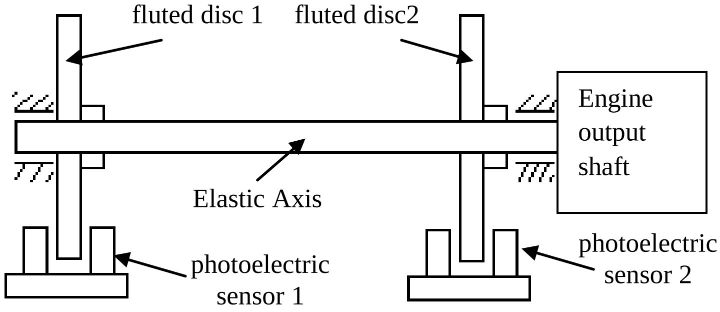

Figure 3: Schematic diagram for torque measurement system

The fluted disc divides into 720 teeth positions, then remove to the neighboring continual 2 teeth, the fluted disc altogether has 718 teeth. In the fluted disc one side installed light emitter diode, the other aspect of fluted disc installed the photosensitive triode. Elastic axis transforms torque into angular and fluted disc transforms angular into light impulse.

The fluted disc rotates every times, the photoelectric sensor will produce 718 pulse signals. The pulse width of lacks teeth position is widen than adjacent domain obviously. Transforms these pulses to the standard TTL level, then the monolithic integrated circuit may distinguish and FPGA calculated the impulse time and save time value to FLASH memory.

We select 40CrNiMoA as the elastic axis material. Its shearing modulus is 209GPa. Then preferred elastic axis length is 60mm, diameter is 10mm. The FLASH memory chooses the two 256 Mbytes capacity.

FPGA receives the sensor pulse signal rise edge and elimination signal vibration, then coded the pulse time into frame. The frame structure is shown in Table 1.

Engine outputted rotational speed between 0~2200 rpm. Pulse signal between 0~1579600 every minute. The system uses the same oscillator (60MHz) to carry on fixed time. Internal counter each microsecond carries on a counting, the counter uses 16bits lengths. When FPGA receives sensor pulse rising edge or trailing edge signal, then encode the current counting value into frame and save these byte message to FIFO, waiting for 718 pulse signal comes, FPGA begin to read FIFO data and save to FLASH memory.

The chip microcomputer read data from FLASH memory 1 and FLASH memory 2 then calculated the phase delay time and number of impulse, computation the elastic axis rotation speed and torque.

Table 1: Encode Frame Structure

0	*1*	*2*	*3*	···	*717*	*718*
time0	time1	time2	time3	···	time717	0xEB90

4. Data processing

1.1 4.1 Frame structure integrity analysis

Before the rotational speed and the torque computation, we need to guarantee the computer reads the data from FLASH memory is complete.

According the data frame structure to decompose frame structure integrity. If has the time value integer which some data contains to be short in 719, then carry on interpolation processing to this frame, causes it to turn a complete frame.

1.2 4.2 Rotational speed computation

Carries on the analysis to the data according to the frame structure, find the pulse time value of lacks the tooth place. All time value forms a new time series, such as t_1, t_2, t_3, ⋯, t_n, etc. can be calculated the rotational speed as shown in as Eq. 2.

$$
\begin{aligned}
\omega_1 &= \frac{2*\pi}{t_2 - t_1} \\
\omega_2 &= \frac{2*\pi}{t_3 - t_2} \\
&\cdots\cdots \\
\omega_{n-1} &= \frac{2*\pi}{t_n - t_{n-1}}
\end{aligned}
\tag{2}
$$

All data (ω_1, ω_2, ω_3⋯ ω_{n-1}) plan on a chart, is speed fluctuations graph.

If need more precise rotational speed fluctuations graph, does not want to carry on the data choice. To all lacks the tooth place time series, carries on interpolation processing. Added two pulse becomes at lack tooth position. All time value forms a new time series, such as T_1,T_2,T_3⋯,T_n, etc. carries on the computation according to the Eq.3. We can obtain the extremely precise rotational speed.

$$
\begin{aligned}
\omega_1 &= \frac{2*\pi}{T_2 - T_1} \\
\omega_2 &= \frac{2*\pi}{T_3 - T_2} \\
&\cdots\cdots \\
\omega_{n-1} &= \frac{2*\pi}{T_n - T_{n-1}}
\end{aligned}
\tag{3}
$$

1.3 4.3 Torque computation

Using generate time series (T_1,T_2,T_3 ⋯ ,T_n) method. We carry on the computation separately to the signal 1 and the signal 2. Obtains two group of time series, T_1,T_2,T_3⋯ ,T_n, and T'_1, T'_2, T'_3⋯, T'_n. The neighboring time-gap correspondence corner is 0.5 degree. We can obtain the revolution axis phase difference change sequence using Eq.4.

$$\theta = \frac{T_2' - T_1}{T_2' - T_1'} \tag{4}$$

We can obtain the revolution axis torque change sequence using Eq. 1. Thus, we have obtained the precise torque fluctuations chart.

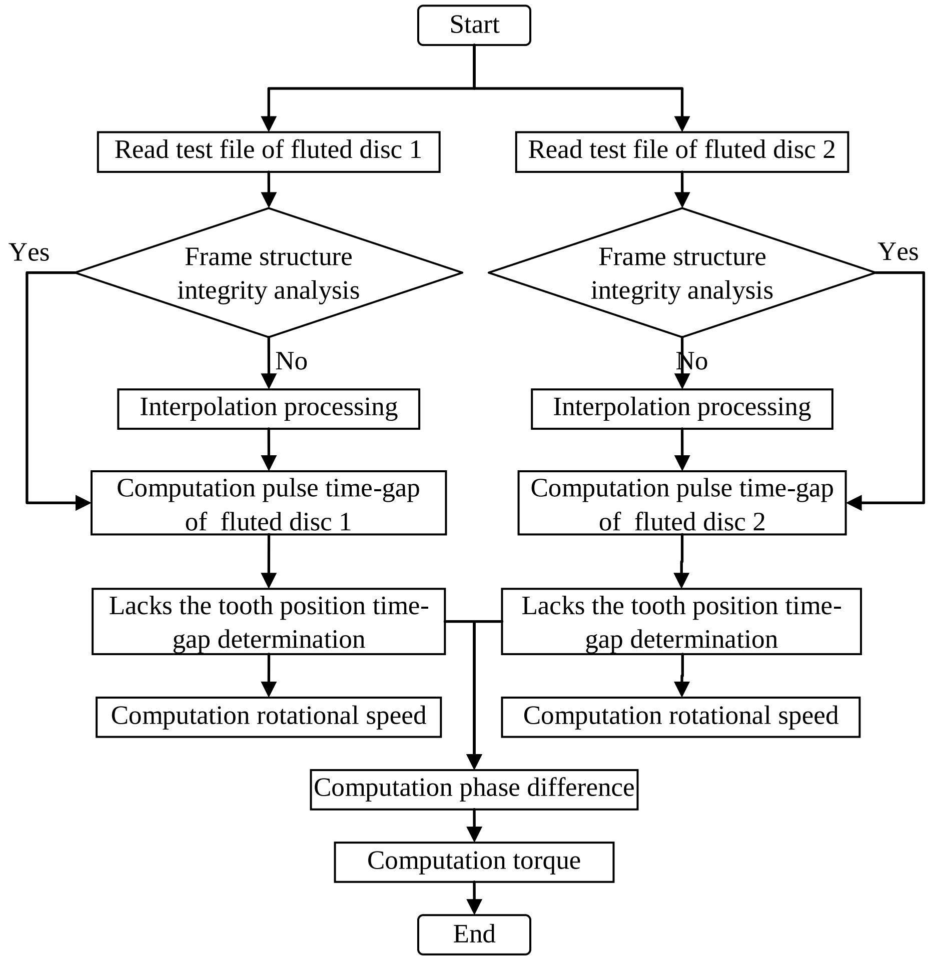

Figure 5: Diagram of calculation rotational speed and torque

5. Conclusion

This article designs engine speed, torque measurement system. This system selected the non-contact survey method to carry on the test. The monolithic integrated circuit system measure revolution axis rotation through recording fluted disc and photoelectric sensor generated pulses rising edge, Carries on the analysis to obtain the engine speed fluctuations, the torque fluctuations using PC machine after the test over.

This test recording system structure is simple, and the function is reliable, has realized the precision measuring, to the sensor precision request is not too high. This measurement system can use for the existing engine laboratory function expansion and laboratory transformation plan. It will avoid spending the massive time, the manpower and the physical resource. This test plan convenient, nimble, the precision is high. Also may take in the vehicles travel process as the test recording system.

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