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Design of Magnetostrictive Level Sensor Circuit Based on FPGA

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Abstract: With the development of the measurement technology, the magnetostrictive liquid level sensor has attracted more and more attention with its outstanding properties. This paper proposes a design plan for magnetostrictive liquid level sensor with the FPGA micro controller, bring a brief introduction of the advantages of the FPGA micro controller and the circuit design theory of the magnetostrictive liquid level sensor, which has great results in the experiments.

Keywords: Magnetostrictive liquid level sensor; FPGA; Circuit design

In recent years, the magnetostrictive liquid level sensor has been widely applied in various industrial measurements because of its good environment adaption, long measurement distance, easy maintenance, long service life, high stability and precision.

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1 Working Theory of the Magnetostrictive Liquid Level Sensor

The working theory of the magnetostrictive liquid level sensor is as shown in Figure 1. Put pulse current in the axial direction of the waveguide wire. Magnetic flow is generated by the pulse current in the area covered by the induction coil, which generates the induced voltage on the induction coil. According to the Maxwell's electromagnetic theory, the pulse current would generate a ring magnetic field on the axial section of the vertical waveguide wire, which flows through the waveguide wire along with the pulse current. When the pulse current is flowing through the area covered by the magnetic ring, the ring magnetic field perpendicular to the waveguide wire and the axial magnetic field parallel to the waveguide wire would generate a rotating magnetic field.[1] Because of the magnetostrictive effect caused by the waveguide wire, the rotated magnetic field rotates the waveguide wire, and then the torsional wave can be generated. The torsional wave spreads to the ends of the waveguide wire. When it runs through the area covered by the induction coil, the flux would be changed because of the magnetostrictive effect and the induced voltage would be generated on the induction coil. Finally, the torsional wave would be assimilated by the dampers on the ends of the waveguide wire. Since the speed of the pulse current is much higher than the torsional wave, the time difference between the two induced voltages on the induction coil times the speed of the torsional wave to obtain the distance between the magnetic ring and the induction coil.[2]

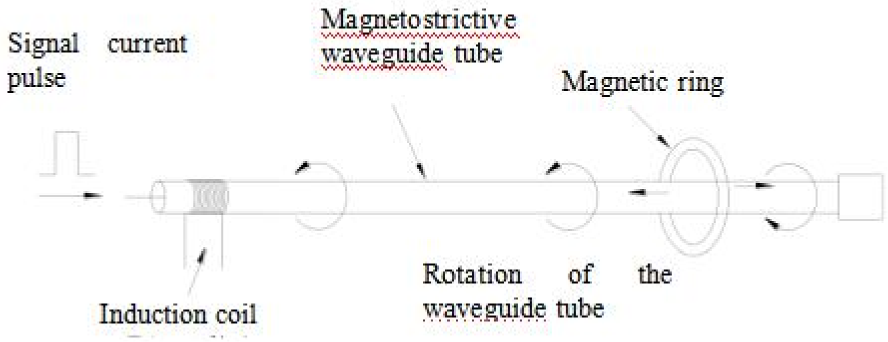

Figure 1 Working theory of the magnetostrictive liquid level sensor

Based on the working theory of the magnetostrictive liquid level sensor, the circuit structure of the magnetostrictive liquid level sensor should include: the micro controller, power amplifier, amplifying and waveshaping circuit, time measuring circuit and output circuit. The circuit structure of the magnetostrictive liquid level sensor is as shown in the Figure 2.[3]

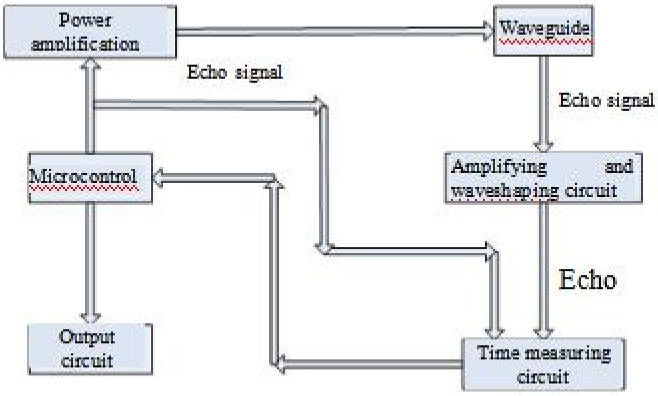

Figure 2 The circuit structure of the magnetostrictive liquid level sensor

2 Microcontroller and Time Measuring Circuit

In the design, as the core controlling unit, FPGA not only has the advantages of high speed and parallel processing, but also can provide multiple internal phase-locked loops, each of which can generate many clock signals of different frequency and phase. Therefore, FPGA has great advantage in frequency and phase compared with DSP and ARM. FPGA allows parallel processing, so different clocks can be used to record the time while each of them would not be affected by others. So FPGA can be applied in the measurement of time and frequency. According to the features of the phase-locked loops inside FPGA, with a high-accuracy time measurement method, the phase-locked loops of FPGA can carry out multiple frequency phase shift on the external clock. And then measure the input signals with the generated clocks. This method is easy to be realized, which highly improve the time measurement accuracy of the signals without increasing the cost of the external clock.

The magnetostrictive liquid level sensor confirms the displacement by measuring the time internal T between the pulse and the echo pulse. The width of it is the running time of the torsional wave in the waveguide wire (i.e. the time interval between control pulse and inductive pulse), which would vary along with the location of the magnetic float. The time-measuring theory is as shown in Figure 3.[4]

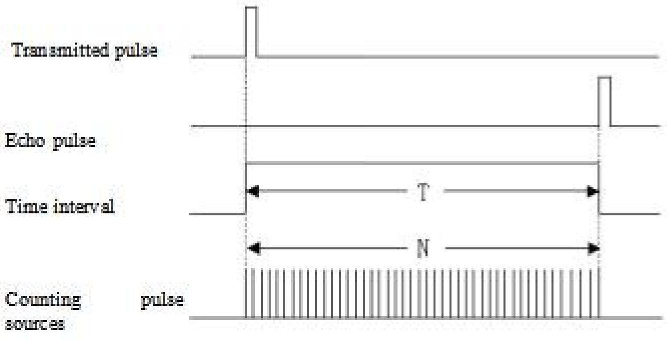

Figure 3 Diagram of time-measuring Theory

The frequency of the clock signal decides the resolution of the time measurement. The speed of the torsional wave on the waveguide wire is constant, which is about 2,600 m / s, i.e. 2.60 mm / μs. The range of the sensor is 1.0 m. In this design we use the Cyclone III series EP3C25Q240C8N chip from Altera companyand its working frequency is set as 50 MHZ. After setting 5-time frequency with the phase-locked loop, the phase shift of 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° is respectively made as the counting pulses. Then the measurement resolution within the measuring range of 1 m is:

$$\Delta = \frac{V}{f} = \frac{2640}{250 \times 8 \times 10^{6}} = 1.32 \mu m \tag{1}$$

3 Power Amplification Circuit

According to the working theory of the magnetostrictive liquid level sensor, the waveguide wire is rotated under the spiral magnetic field, which generates the torsional mechanical wave. For the same waveguide wire materials, the rotation degree of the waveguide wire is determined by the current on the waveguide wire. For larger current, the ring magnetic field would be larger, so are the torsional deformation and the detected SNR of torsional signal.[5] However, since the pulse signal cannot provide drive current that is large enough, the power amplifier circuit is needed to amplify the pulse signals to improve the driving ability of the pulse current signal.

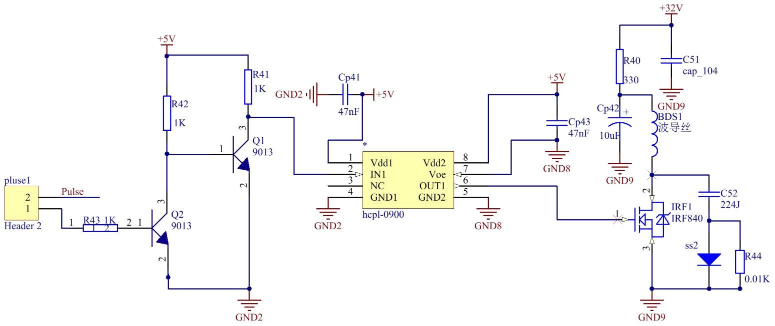

Figure 4 Principle Diagram of the Power Amplifier Circuit

4 Amplifying and Waveshaping Circuit

The torsional wave on the waveguide wire is transferred into the voltage pulse signals proportional to the torsion angle by the coil. But the amplitude of the voltage pulse is only about ten more millivolt with strong signal interference. So it should be filtered and amplified with enough times and strong noise suppression ability is needed.[6] The signal filtering amplifying circuit can be divided into two stages. The first stage is the differential amplifying circuit that provides enough magnification times with high common-mode rejection ratio and the ability to effectively restrain the zero drift with the AD620 instrument amplifier. The amplifying circuit on the second stage is the secondary amplification of the amplified signals from the first stage to acquire large and stage output signals with the AD8421 chip.

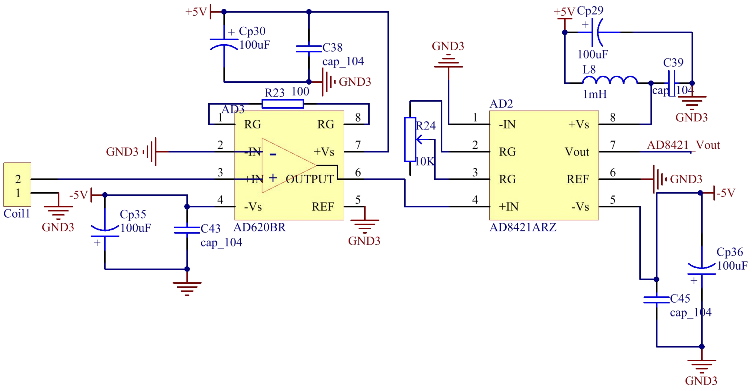

Figure 5 Differential amplification circuit

Since the induction signals have larger amplitude and the wider pulse width than the induction echo signals, comparator reshaping should be carried out on the signals from differential amplification to adjust the induction signals and induction echo signals into two pulse signals with identical amplitude and pulse width for the calculation of the time difference in FPGA.[7]

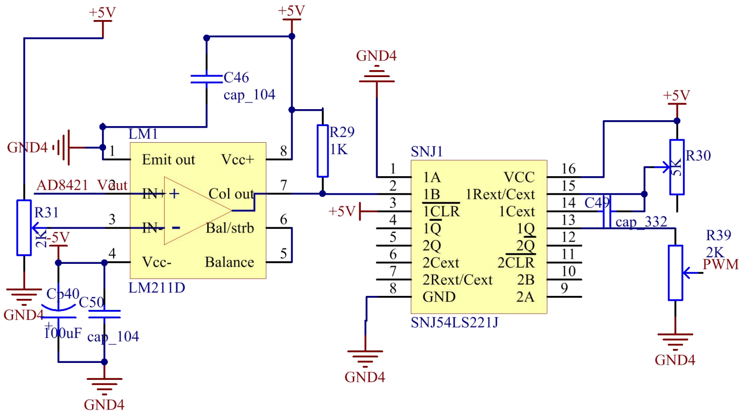

Figure 6 Shaping and filtering circuit

5 Measurement Results

According to the experiment data in Table 1, the difference on the sensor is very small, so the accuracy of sensor can be guaranteed. And the measurement data is acquired directly by the ruler, which is not enough for the calibration of the sensor. Measurement by ruler can easily be affected by the location of the magnetic ring and the error of the Human eye. The measuring error of the ruler is 1mm and according to the measuring data, all the measurement errors are within 0.5 mm. During the measurement of the moving magnetic float, the absolutely error and the relative error are both within the required range, presenting good experiment results.[8-11]

Table 1 Measurement results

Relative displacement L (mm)	Positive stroke			Reversal stroke		
	Measurement time T(ns)	Calculated value L (mm)	Absolute error |ΔL| (mm)	Measurement time T(ns)	Calculated value L (mm)	Absolute error |ΔL| (mm)
100.0	39094	99.980	0.020	39084	99.953	0.047
150.0	58595	149.851	0.149	58639	149.964	0.036
200.0	78127	199.803	0.197	78193	199.970	0.030
250.0	977446	249.972	0.028	97681	249.809	0.191
300.0	117179	299.673	0.327	117270	299.906	0.084
350.0	136799	349.851	0.149	136808	349.874	0.126
400.0	156376	399.916	0.084	156401	399.981	0.019
450.0	175885	449.808	0.192	175907	449.864	0.136
500.0	195431	499.796	0.204	195483	499.927	0.073
550.0	215003	549.849	0.151	215010	549.867	0.133
600.0	234590	599.941	0.059	234532	599.792	0.208
650.0	254095	649.823	0.177	254123	649.894	0.106
700.0	273706	699.976	0.024	273678	699.905	0.095
750.0	293209	749.852	0.148	293244	749.942	0.058
800.0	312783	799.912	0.088	312737	799.795	0.305

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