Economy Value of High Precision Ultrasound Flowmeter

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Abstract: In order to improve the measurement accuracy of intelligent water meter, a high precision ultrasonic flowmeter is designed. The device integrates the functions of CPU, DSP and FPGA on one chip to complete the timing function, which effectively improves the integration and stability of the system. The system uses time difference method to measure liquid velocity, and uses DSP Slices of Xilinx Corporation to complete smoothing filter function. The measurement accuracy is high and has a good application prospect.

1. Introduction

With the increasing shortage of water resources in the world, governments all over the world attach great importance to water quantity control. At the same time, because of the rapid development of electronic technology, it is possible to meet the needs of intelligent water meters with step pricing. Compared with traditional mechanical water meter, intelligent water meter has the advantages of high accuracy, wide range ratio, long life, good reliability, no moving parts and flexible replacement.

At present, the technology of ultrasonic flowmeter is widely used in intelligent water meters which can achieve high precision, and the principle of ultrasonic time difference measurement is generally used. Ultrasonic time difference measurement uses multiple pairs of ultrasonic transducers to receive ultrasound simultaneously or alternately[1]. The velocity of fluid is measured by detecting the time difference between the propagating of ultrasound in the medium in both the downstream and the countercurrent, and then the flow rate is calculated by integrating the velocity with time.

2. Principle of the Ultrasonic Flowmeter

In Figure 1, the ultrasonic transducers A and B are respectively placed in the direction of downstream and countercurrent of the flowing liquid[2].

![Figure 1 Schematic of the ultrasonic flowmeter](image)

In Figure 1, the time taken from transducer A to transducer B to receive ultrasound is

\[ t_1 = \frac{D}{\sin \theta (c + v \cos \theta)} + \tau \]  

(1)
where $c$ is the propagation speed of ultrasound in stationary liquid, $v$ is the flow velocity of liquid, $\theta$ is the angle between the direction of ultrasonic propagation and the flow direction of liquid, $L$ is the distance along the direction of pipeline between A and B transducers, $D$ is the diameter of pipeline, $\tau$ is the sum of the propagation time of ultrasound in the transducer and the wall and the delay of circuit[3].

The time taken from transducer B to transducer A to receive ultrasound is:

$$t_2 = \frac{D}{\sin \theta (c - \cos \theta)} + \tau$$  \hspace{1cm} (2)

Based on formula (1) and formula (2), it is found that the time difference in the direction of downstream and countercurrent propagation of ultrasound is as follows:

$$\Delta t = t_2 - t_1 = \frac{2D \cot \theta}{c^2 - v^2 \cos^2 \theta}$$  \hspace{1cm} (3)

So:

$$v = \frac{c^2 \Delta t \tan \theta}{2D}$$  \hspace{1cm} (4)

According to hydrodynamics, the average velocity of sound path is revised to the required average velocity of cross section:

$$v = \frac{c^2 \Delta t \tan \theta}{2DK}$$  \hspace{1cm} (5)

where $k$ is the correction coefficient of hydrokinetics. The coefficient is a function of the resistance coefficient of a circular pipe:

$$K = 1 + 1.25 \left( \frac{A}{8} \right)^{\frac{1}{2}}$$  \hspace{1cm} (6)

where $\lambda$ is a function of Reynolds number of fluids:

$$\lambda = 0.003 + 0.221 Re^{-0.237}$$  \hspace{1cm} (7)

So the velocity of liquid flow is as follows:

$$Q = \frac{\pi D^2 v}{4}$$  \hspace{1cm} (8)

The liquid flow rate is as follows:

$$\omega = \int_{t_1}^{t_2} Q dt$$  \hspace{1cm} (9)

3. Hardware Design

This design chooses FPGA designed by Xilinx corporation, which integrates Microblaze II processor and DSP Slices. It can realize the functions of FPGA, CPU and digital signal processor on a single chip. It effectively reduces the number of main control chips, and also reduces the number of connections between FPGA, CPU and DSP on board, because of which improves the stability of the system[4].

As shown in Figure 2, the hardwired logic of the FPGA controls the transmission and reception of ultrasonic by the ultrasonic module, and receives the signal from the ultrasonic module. After shaping and filtering, it is converted into digital signal which is transmitted to the DSP Slices of the FPGA through bus. The DSP Slices filters the input signal basing on smoothing filtering algorithm and sends the filtered signal to the Microblaze soft core, which displays the on LCD screen.
3.1. Microblaze module
MicroBlaze is Xilinx’s 32-bit RISC soft processor core, optimized for embedded applications on Xilinx devices. The MicroBlaze processor is easy to use and delivers the flexibility to select the combination of peripherals, memory, and interfaces as needed. The MicroBlaze processor is commonly used in one of three preset configurations: a simple microcontroller running bare-metal applications; a real-time processor featuring cache and a memory protection unit interfacing to tightly coupled on-chip memory running FreeRTOS; and finally, an application processor with a memory management unit running Linux. MicroBlaze can be used as a stand-alone processor in all Xilinx FPGAs or as a co-processor in a Zynq®-7000 SoC system. It can also be configured to add tamper protection and fault protection by configuring in lock-step mode as well as providing single-event upset mitigation with Triple Modular Redundancy. Designs with multiple processors can be debugged simultaneously using the Xilinx Software Development Kit (SDK).

3.2. DSP Slices
FPGAs are efficient for digital signal processing (DSP) applications because they can implement custom, fully parallel algorithms. DSP applications use many binary multipliers and accumulators that are best implemented in dedicated DSP slices. All 7 series FPGAs have many dedicated, full-custom, low-power DSP slices, combining high speed with small size while retaining system design flexibility. The DSP slices enhance the speed and efficiency of many applications beyond digital signal processing, such as wide dynamic bus shifters, memory address generators, wide bus multiplexers, and memory-mapped I/O registers.

3.3. Ultrasound transducer
Ultrasound transducer is an energy converter which converts alternating electrical signals into acoustic signals or external acoustic signals into electrical signals in the range of ultrasonic frequency. It is a key device in ultrasonic technology. Its performance directly affects the effect and application scope of ultrasonic application technology.

4. Software Design

4.1. MicroBlaze and DSP Builder Programming
After detecting the echo signal from hardwired logic, DSP Slices read the time measurement result and stores it., including the output results in both downstream and countercurrent state several times. Because the ultrasonic flowmeter is affected by various interference factors in its work, thus affecting the accuracy of measurement results, smoothing filter algorithm is used to process each measurement result in DSP Slices. The final result after processing is sent to MicroBlaze for displaying on LCD screen.

4.2. Hardwired Logic
Hardwired includes phase-locked loop circuit, first pulse acquisition circuit, second pulse acquisition circuit, synchronization circuit, counter and interruption circuit.
The PLL circuit is used to input 80MHz clock and output 160MHz four-way clocks with 90-degree difference. The output four-way clocks provide clock signal for the second pulse acquisition circuit, and the output first clock serves as clock signal for other circuits.

The first pulse acquisition circuit is used to collect the rising edge of synchronous pulse of Nios II soft core input hardware logic, and send the excitation signal to the counter. The first pulse acquisition circuit eliminates the metastable interference of asynchronous signals by two-stage D flip-flops. When the output of the third D flip-flop is low and the output of the second D flip-flop is high, the rising edge of the collected pulse is determined, and the control counter starts to count.

The second pulse acquisition circuit is used to synchronize the rising edge of the feedback signal of the ultrasonic module and notify the synchronization circuit after the rising edge of the feedback signal is collected[5]. The second pulse acquisition circuit uses four clock signals for external acquisition. The clock signal frequency is 160 MHz and the phase difference is 90 degree, which can effectively reduce the measurement error.

The synchronous circuit is used to eliminate the metastable effect of the second pulse acquisition circuit caused by the asynchronous clock after receiving the notification signal from the second pulse acquisition circuit, and then send the notification signal to the counter and the interruption circuit. The synchronous circuit uses internal FIFO to eliminate the metastable effect of the second pulse acquisition circuit caused by the asynchronous clock, which completes the signal transmission across the clock domain[6].

The counter starts timing after receiving the excitation signal from the first pulse acquisition circuit and stops timing after receiving the notification signal from the synchronous circuit. The counter is implemented with an IP core inside the FPGA, and is configured with bit width of 24 bits, a synchronous zero-clearing pin and a threshold output pin[7-8].

The interrupt generating circuit is used to send the interrupt signal to the Nios II soft core after receiving the notification signal of the synchronous circuit, and to notify the Nios II soft core to start the inversion of the ultrasonic transceiver and start a new ultrasonic transceiver process.

5. Conclusions
Aimed at the shortcomings of traditional ultrasonic flowmeter, a high precision ultrasonic flowmeter is designed. The device uses high precision time digital conversion chip TDC-GP22, and applies Nios II, DSP Builder and FPGA logic circuit to the measurement system. The functions of CPU, DSP and hardware circuit are realized on one chip, which effectively enhances the integration of the system and improves the stability of the system. The equipment uses time difference method to measure liquid velocity and Kalman filter to reduce the interference of noise to the measurement results, which ensures the measurement accuracy and has good application prospects.

In addition to measuring water resources, ultrasonic flowmeter has been rapidly popularized in the field of oil and gas and even almost all the growth of the ultrasonic flowmeter market in recent years has been attributed to the increased sales of this product in the oil and gas fields. Sales of ultrasonic flowmeters in this field have nearly doubled compared with before.

In a word, ultrasound flowmeter is a new flow measurement technology and the market demand potential of ultrasonic flowmeter in China is huge. The investment income of the industry will gradually increase.

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