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High-accuracy Wind Speed Measurement Based on Hall Sensor and FPGA

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Abstract: Anemometer is a typical wind speed measuring equipment, widely applied in new energy field and meteorological measurement. This paper analyzed the measuring principle of cup anemometer, and presented a high-accuracy wind speed measure based on orthogonal Hall sensors. The sensors were arranged appropriately to output orthogonal pulses, on this basis, signal filtering, subdivision unit, gated counter and interface were realized by FPGA。The precision analysis shows this method has much less relative error without too much cost and preserves the original dynamic characteristics. *Copyright © 2013 IFSA.*

Keywords: Wind speed measurement, Hall sensor, Orthogonal, Subdivision, FPGA.

1. Introduction

Wind energy has been well recognized as environmentally friendly, socially beneficial, and economically competitive for many applications [1, 2], and wind speed is one of the most basic meteorological parameters, in relevant research field of atmospheric dynamics, the measurement of it is significant, in addition, micrometeorology and control technology of wind power equipment needs higher measuring accuracy, and put forward more requirements. A cup anemometer is the most typical measurement device in all kinds of anemometers, widely used due to the specific characteristics (robustness, reliability and relative low cost) and despite well-known drawbacks (over-estimation of mean wind speed, inertial effects at higher frequencies) [3]. Based on this device, a high-accuracy measurement is presented in this paper.

2. Theoretical Background

Most cup anemometers have either three or four hemispherical cups mounted at the end of metal or plastic arms. Each cup is mounted at equal angles to each other; and its concave face turn in the same direction, all the arms and cups are fixed on a vertical central shaft. The shaft is supported by a base clamped or bolted immovably tight; a magnetic tooth ring is glued to the bottom end of it. When wind blows, a cup will 'capture' the wind and be pushed causing the next cup to be blown into its former position where that cup is now 'pushed' and so on and so forth, the result is spinning cups atop the shaft., meanwhile, the tooth ring spins with the shaft and cause periodical change of magnetic field, a magnetic sensitive sensor nearby the tooth ring will generate a series of electric pulses at a rate that is proportional to the wind speed. The structure of cup anemometer is shown in Fig. 1.

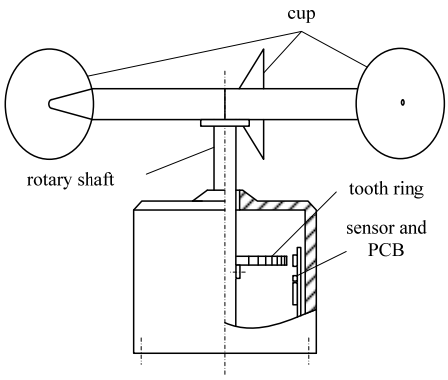

Fig. 1. The structure of cup anemometer.

Mathematically, the relationship between the rotary speed of cup, n, and the wind speed, v, can be expressed as shown in (1):

$$\begin{cases} 2Nv^2 - Dvn - B_1 n + B_0 = 0 \\ N = \dfrac{1}{2}\rho A r C_0 \\ D = 2\pi r^2 \rho A C_1 \end{cases}, \quad (1)$$

where ρ is the air density, A *i*s the cross-sectional area of cup, r is the turning radius of cup holder, C_0, C_1 is the structure constants of cup anemometer, B_0 is the static friction torque and B_1 is the kinetic friction torque.

If the friction damping torque can be ignored, the approximate mathematical model of wind speed measurement can be described as:

$$v = \frac{D}{2N} n \quad (2)$$

To improve the measurement resolution of cup anemometers, Hall sensor or photoelectric sensor are used to match a gear ring, the output pulses of sensor provide a frequency f_P that is proportional to the number of teeth n in (3):

$$f_P = kn, \quad (3)$$

The relation between wind speed v and output frequency f_P mentioned above is described as:

$$v = \frac{Dn}{2Nk} f_P, \quad (4)$$

And we can get the relative measurement error of wind speed as [4]:

$$\gamma_v = \frac{\Delta f_P}{f_P}, \quad (5)$$

Gathering terms, to improve the measurement accuracy of wind speed, we need to reduce the frequency measurement error and improve the frequency. On one hand, regarding to increase the frequency, we can directly increase the gear teeth number to implement, this way is simple theoretically and applied in certain areas, but it is limited by the volume of the system and machining processing technique, mostly in practice, the general ratio of gear teeth is between 48 and 60 [5]; On the other hand, to reduce the frequency measurement error, we can increase the counting gate time, but it will reduce the dynamic characteristics of the system. Aiming at the technical requirements of wind speed measurement mentioned above, a new measurement is proposed in this paper based on the orthogonal pulses, orthogonal signals can be subdivided and frequency multiplication can be realized, taking advantage of these characteristics and the programmable logic function of FPGA, we can improve the measuring accuracy without changing the mechanical structure of the system.

2. Overall Design of the System

The overall design scheme is shown in Fig. 2, two Hall sensors are designed and generate two sets of orthogonal pulses, the FPGA processes the two signatures and achieve the functionality of pre-filtering, subdivision, frequency multiplication, gating counting, data latching and output interface, etc; the gating signal and the data teletransmission are realized by the micro control unit MCU. The system is equipped with RS-485 serial interface to communicate with upper computer and make remote measuring, controlling.

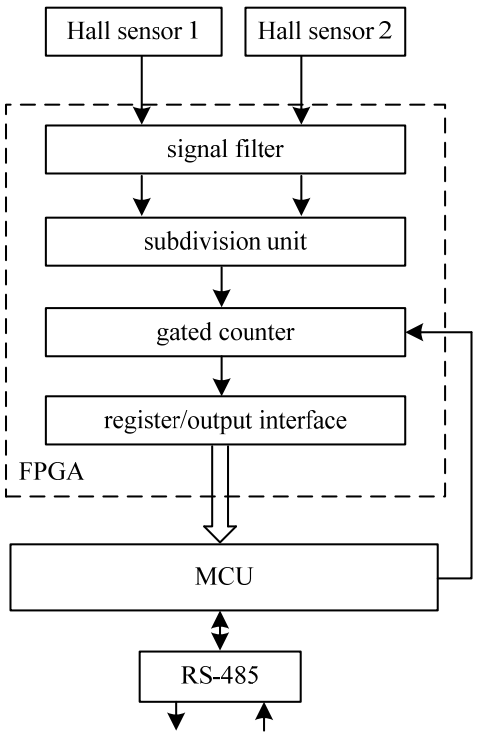

Fig. 2. The overall design of high-accuracy wind speed measuring system.

3. Acquisition of Orthogonal Pulses

If the teeth number of tooth ring is fixed, we can improve the output frequency f_p of wind speed measuring signal by subdivide the orthogonal pulses. A workable approach is to add a parallel set of Hall sensor and corresponding measurement circuit based on the primary structure of the anemometer, which transforms the wind speed pulses from single-channel signals to orthogonal double-channel ones, the structural layout is shown in Fig. 3.

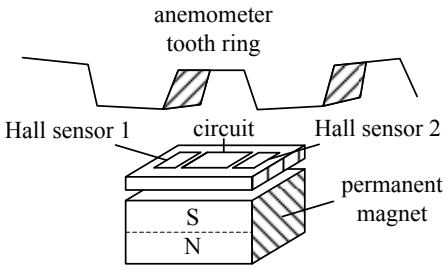

Fig. 3. The arrangement of Hall sensors.

The Hall sensors are pumped by the permanent magnet as shown; the anemometer gear ring is made of conducted magnetic materials. When the gear ring rotates under the action of wind, the distance between the ring and sensors changes alternatively and leads to periodic change of magnetic field distribution which through the sensors, then the sensor output goes through the pre-circuit and pulses are obtained. Adjust the relative position of two sets of sensors, and the orthogonal signals needed are obtained. The pulses are shown in Fig. 4.

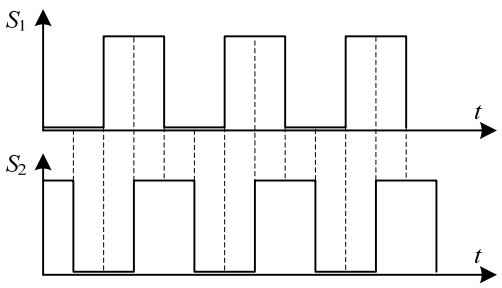

Fig. 4. Output pulses of Hall sensors.

4. Signal Filtering

The pre-circuits transform the received analog signals from Hall sensors into square-wave ones, in this process, high-frequency noise signals usually appear nearby the triggering marginal value and affect subsequent subdivision and counting. The noise signals width is mostly between several dozens or hundreds of nanoseconds, in order to avoid the influence to the following process, we must apply the noise filter after shaping circuit of square-wave signals firstly. The width of noise pulse is much smaller than the normal square-wave pulse's, according to this characteristic, a time-delay processing to the input signal is carried on, therefore, whether the current pulse is the noise jamming or not can be determined. This paper carries on the noise judgment and filtration through taking 4 clock widths as the threshold value, which means when a pulse width is smaller than the width of 4 clocks, the pulse is considered as a noise signal, and can be ignored. The principle of noise filter based on FPGA is shown in Fig. 5, A presents the output signal of Hall Sensor 1, CLK_0 is the clock signal from dividing the system clock and the filtering result is marked as QA_F.

The simulation of signal filtering based on QUARTUS II is shown as in Fig. 6, from which we can see that, the narrow noise pulses appears in the normal level have been filtered.

5. Signal Quadruple Subdivision and Frequency Multiplication

In order to improve measurement resolution of wind speed, a logical processing is carried on after filtering the noise of two orthogonal square-wave signals to realize subdivision [6]. We designed quadruple subdivision circuit and Fig. 7 shows the schematic diagram realized by FPGA. The input signals QA_F and QB_F are filtered wind speed pulses, the exclusive-or gate is to latch the edge and finally go through nor gate to get a quadruple frequency output COUNT_P. The subdivision simulation result is shown in Fig. 8 and Fig. 9. Fig. 8 simulates the high wind-speed situation, the frequency of the signal is 20 kHz; Fig. 9 simulates the low wind-speed condition, the frequency of the signal is 200 Hz.

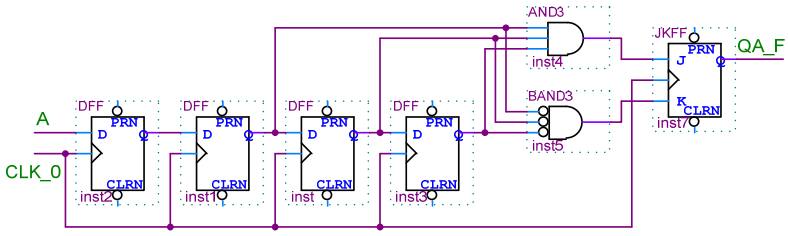

Fig. 5. Schematic diagram of signal filtering.

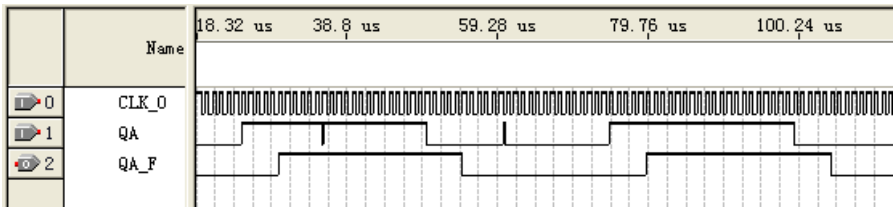

Fig. 6. Signal filtering simulation.

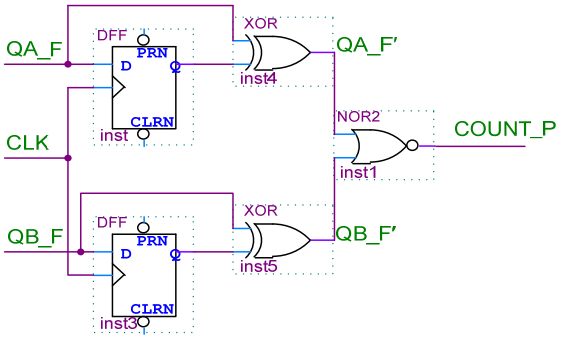

Fig. 7. The schematic diagram of quadruple subdivision circuit.

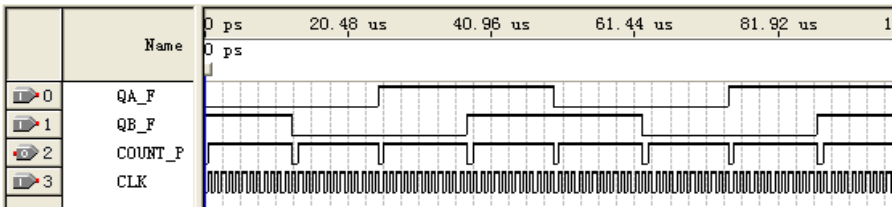

Fig. 8. The high wind speed simulation of subdivision and frequency multiplication.

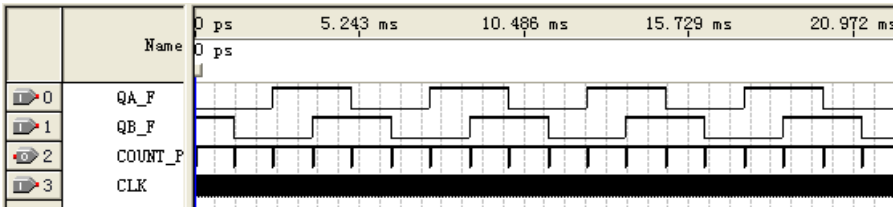

Fig. 9. The low wind speed simulation of subdivision and frequency multiplication.

6. Counter and Interface

The frequency of subdivision circuit's output signal COUNT_P can be implemented by gating counting, and then the wind speed measurement is realized. Therefore the gating counter needs to be configured. The counting results are 16 bits, and we need to convert them to 2 bytes to be compatible with the conventional data interface and finally realize teletransmission. Thus, we designed a multiplex programmable counter and the schematic diagram is shown in Fig. 10. In this diagram, the counting depth of counter is devised as 16bits to make certain wind speed measurement range; a 2 × 8 multiplexer is designed to transmit the 16-bits counting results byte separately; 74273 is a data latch to access MCU.

7. Precision Analysis and Conclusion

We take a certain Hall type cup anemometer for example, the intrinsic mechanical system of it has a 60-teeth measuring gear, when the wind speed is 22.8 m/s, the frequency of measuring output pulse is 1.8 kHz, we also can estimate that if the wind speed is 0.2 m/s to 50 m/s, the output frequency is between 78 Hz and 4 kHz; adopt the technique this paper introduced above, the speed measuring frequency will quadruple the former one, and if set 0.5 s as the gate time (T), according to (5) and measurement error (6), the relative errors under different wind speed conditions can be obtained, the results is shown in Table 1.

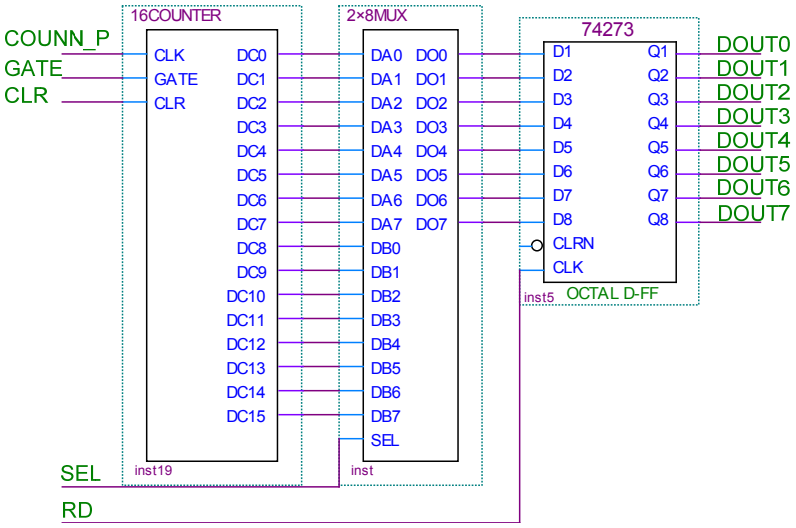

Fig. 10. Schematic diagram of multiplex programmable counter.

$$\frac{\Delta f_P}{f_P} = \frac{1}{Tf_P} + \frac{\Delta f_0}{f_0}, \quad (6)$$

where $\frac{\Delta f_0}{f_0}$ is the relative error of crystal oscillator for MCU, it can be ignored.

Table 1. The relative errors under different wind speeds (The wind speed pulses error is only considered).

Wind speed (m/s)	Before subdivision		After subdivision	
	Relative measurement error	Count value	Relative measurement error	Count value
1	2.56%	39	0.64%	156
25	0.10%	975	0.03%	3900
50	0.05%	1950	0.01%	7800

From Table 1, we can see that if the wind speed is 50 m/s, the maxim counting value is about 7800, much smaller than the ultimate value 65535 of 16-bits counter, and shows the design mentioned in Part 6 can satisfy the practical requirements completely.

From this comparison, we can see that the wind speed measurement based on FPGA and Hall sensors has higher accuracy and better dynamic characteristics, and improve the measuring effect significantly, in the meanwhile, doesn't have to change the mechanical structure of cup anemometer. But from an overall perspective, the main error factor of this equipment is mechanical damping of the supporting structure, the wind cup usually has large turning radius to acquire nice aerodynamic performance, hence has larger inertia which affects the dynamic performance mostly [5]. Further studies will be taken aiming at these factors to improve the precision more, such as designing an advanced structure of cup or other ways.

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