Key Engineering Materials Vols 609-610 (2014) pp 1002-1007 *Online: 2014-04-09*
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.609-610.1002

Design And Experiment Of Ultrasonic Anemometer Using TDC-GP2 Time-to-Digital Converter

Du Hanyu, Qin Ming

(Southeast University, the Key Laboratory for MEMS of the Education Ministry of China, Nanjing, 210096)

Keywords: TDC-GP2, Ultrasonic anemometer, High accuracy

Abstract. An ultrasonic anemometer using TDC-GP2 high-accuracy time measuring chip is studied in this paper, the design of software and hardware parts and principle of flying time measurement using TDC-GP2 chip are also discussed in detail. Under this scheme, a prototype has been fabricated, with simpler circuit architecture. A wind tunnel experiment of the prototype was conducted, the test result shows that the ultrasonic anemometer can measure wind speed up to 39.9m/s, and the measurement error does not exceed 0.3m/s when wind speed is below 10m/s, or 3 percentage when it's above 10m/s. Wind directions vary from 0 to 359 degree can be detected with accuracy of 3 degree.

i. Introduction

Wind measurement system, also known as anemometer， have many application in many fields, such as weather, industry, agriculture, navigation, etc. The traditional mechanical anemometer is made in type of swevil or propeller, simple mechanism and low price are the biggest advantages, but also it has obvious drawbacks like easy to stain, mechanical wear, bulky and high maintenance costs etc [1]. Compared with the mechanical anemometer, ultrasonic anemometer has many advantages, such as high sensitivity and measurement accuracy, low maintenance cost, non-contact measurement, no freezing and mechanical wear problems and so on. For measuring wind velocity using an ultrasonic sensor, there are several methods: transit-time measurement, Doppler measurement, vortex measurement and correlation measurement. The method of transit-time measurement based on ultrasonic flight time difference in downwind and headwind condition is used to get the wind component, then calculate the final wind speed and direction via vector synthesis method. Transit-time ultrasonic anemometer has advantages of wide measuring range, good linearity etc. The ultrasonic flight time can be measured by Echo signal trigger MCU timer or designing timing circuit using FPGA matched with ADC module, but there are disadvantages such as accuracy is not high or circuit is too complexity. In this paper, circuit module built on TDC-GP2 is used to measure ultrasonic flight time, it has obvious advantages in the measurement accuracy, circuit design and power control [2].

ii. Wind measurement theory

In order to measure any changes of the two-dimensional wind vector, need to measure vector components of two mutually perpendicular dimensions represent as x-axis and y-axis.Thus, four ultrasonic transceiver integrated transducer should be fixed at the two axes symmetrically. When in the wind field, the two pair of the transducers measure x-axis wind component v_x and y-axis wind component v_y separately, then conduct vector synthesis method based on v_x and v_y to get the real wind vector, shows as Fig 1.

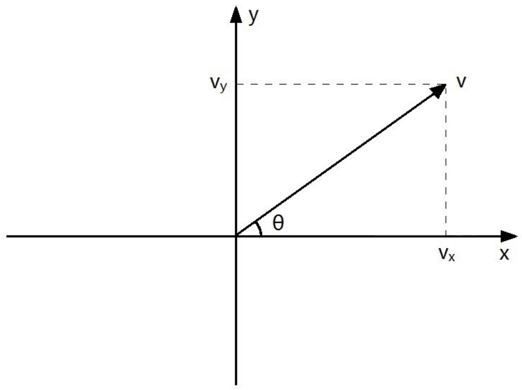

Fig. 1. Vector synthesis for wind vector

For calculating the wind vector v_x of the x-axis direction, ultrasonic flight time in downwind and headwind condition is needed, which can be measured by using a couple of transducers on the x-axis to conduct processes of emission and receiving. Here, *d* is the distance between the transducers on the x-axis, *c* is the ultrasonic flight time when there is no wind, t_1 is the ultrasonic flight time on the x-axis in downwind condition, t_2 is the ultrasonic flight time on the x-axis in headwind condition. Assuming that the wind direction is same as shown in Fig. 1. Using time-sharing method:

$$\begin{cases} \dfrac{d}{t_1} = c + v_x \\ \dfrac{d}{t_2} = c - v_x \end{cases} \tag{1}$$

We can get formula about *c* and v_x according to Eq. 1:

$$v_x = \frac{d}{2}\left(\frac{1}{t_1} - \frac{1}{t_2}\right) \tag{2}$$

$$c = \frac{d}{2}\left(\frac{1}{t_1} + \frac{1}{t_2}\right) \tag{3}$$

wind vector v_y on the y-axis can be represented in a similar way, t_3 is the ultrasonic flight time on the x-axis in downwind condition, t_4 is the ultrasonic flight time on the x-axis in headwind condition.

$$v_y = \frac{d}{2}\left(\frac{1}{t_3} - \frac{1}{t_4}\right) \tag{4}$$

Actual wind speed and wind direction can be calculated after synthesis based on v_x and v_y, which are shown in Eq. 5 and Eq. 6.

$$v = \sqrt{v_x^2 + v_y^2} = \frac{d}{2}\sqrt{\left(\frac{1}{t_1} - \frac{1}{t_2}\right)^2 + \left(\frac{1}{t_3} - \frac{1}{t_4}\right)^2} \tag{5}$$

$$\theta = \arccos\frac{v_y}{v} = \arccos\frac{\left(\frac{1}{t_1} - \frac{1}{t_2}\right)}{\sqrt{\left(\frac{1}{t_1} - \frac{1}{t_2}\right)^2 + \left(\frac{1}{t_3} - \frac{1}{t_4}\right)^2}} \tag{6}$$

Here, v represents the actual wind speed and θ represents the angle between wind direction and the x-axis. In practical situations, θ will Fall in different quadrants, angle correction is needed to express θ in 0 ° ~ 360 ° [3].

iii. The sensor system

A prototype of ultrasonic anemometer has been fabricated, appearance of the prototype is shown in Fig. 2. The system is mainly composed of ultrasonic transducers, emission circuit, receiving circuit, voltage booster module, TDC-GP2 time measurement module, SCM mudule, serial port communication module and PWW [4]. The overall system structure of ultrasonic anemometer is shown in Fig. 3.

Fig. 2. Prototype photo of anemometer

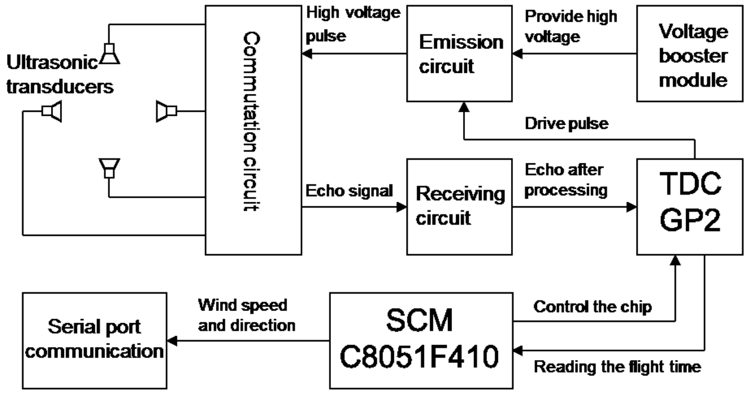

Fig. 3. Anemometer system

PWW mainly includes the power regulator converting external 12V DC voltage to required 5V and 2.5V DC voltage and power inverter inverting 5V DC voltage to -5V DC voltage. Four ultrasonic transducers placed perpendicular to each other, according to the wind measurement theory, wind component can be measured in both directions and actual wind speed and direction can be calculated by vector synthesis arithmetic. TDC-GP2 plays the role of providing drive pulse to emission circuit through internal fire-pulse generator and capturing echo signal after receiving circuit processing. When transmit ultrasonic, transducers require 150V ~ 200V high-voltage pulse excitation. Voltage booster module is able to promote external 12V DC voltage to 200V DC voltage and supply the emission circuit. When the transducer in the receiving state captures the ultrasonic wave, it will generate echo signal of millivolt level. The echo signal is able to generate 5V square signal after amplification, IF filter, voltage comparison of the receiving circuit, and it is this square signal captured by TDC-GP2. As the master control chip, C8051F410 SCM with good performance is chosen. The main tasks of SCM include: the cycle of the whole system working state, controlling the commutation circuit, configuring TDC-GP2 chip to control the time measurement process and get the ultrasonic flight time, Calculate values of wind speed and direction with algorithm optimization and sending them to the PC through serial port communication.

iv. Software control processes

System program design and development are finished on Silicon Laboratories IDE software, the overall running processes of program is shown in Fig. 4.

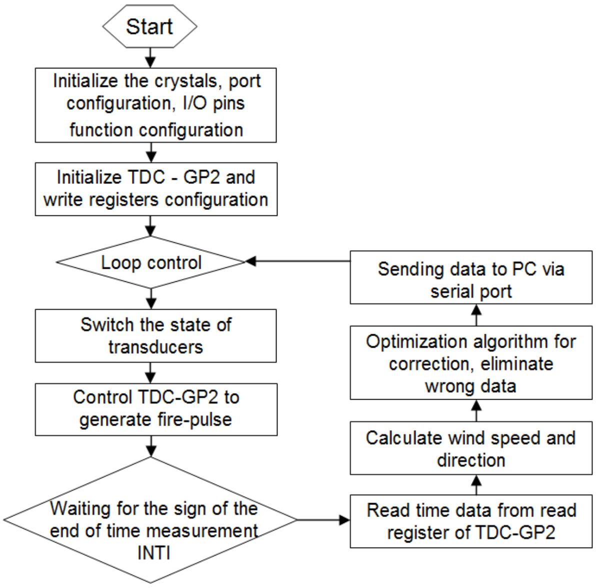

Fig. 4. Software running processes

TDC-GP2 chip generates fire-pulse and starts time measurement; the emission transducer will emit the ultrasonic wave almost at the same time. After hundreds of microseconds (the time need to measure), the receiving transducer will receive the signal and generate echo signal, then TDC-GP2 will receive square signal simultaneously and finish time measurement. The whole time measuring process is completed by TDC-GP2 under control of SCM, include: initialization, write registers configuration, fire-pulse generation and time measuring data reading. Other tasks of SCM should also be programmed, for example, switching the state of transducers, calculating wind speed and direction, Optimizing the algorithm, sending data to PC, etc.

v. TDC-GP2 module configuration and time measuring process

TDC-GP2 chip has 32 pins. SSN, SCK, SI and SO pins of TDC-GP2 is connected to the corresponding pins of SCM for SPI serial communication. Fire1 is the pin to export fire-pulse signal. En_Start, En_Stop (En_Stop1), Start, Stop (Stop1) are signal pins relevant with ultrasonic flight time measurement. By using SCM to do write operation to modify six write registers (Reg0-Reg5) of TDC-GP2, to complete the functional configuration of TDC-GP2. In order to ensure the TDC - GP2 meet the specific requirements of anemometer, There are some caveats: there are two kinds of chip optional measurement range, only choose the measurement range 2 of 500ns - 4ms can meet the requirements because the ultrasonic flight time is of microsecond level; pulse number and pulse frequency can be set by set the values of FIRE # and DIV_FIRE in write register Reg0; to shield the interference signal at Stop pin in short time after chip start time measuring, the value of DELVAL in Reg2 should be configured to set a certain delay before enable Stop pin. Configuration values of all write registers are given here: Reg0 = 3FB468, Reg1 = 214200, Reg2 = E03200, Reg3 = 083300, Reg4 = 203400, Reg5 = 080000.

The Fire1 signal generated by internal fire-pulse generator also import to Start pin as the square signal stimulus; Stop pin is triggered by a termination square signal, which is obtained through echo signal processed by receiving circuit. TDC-GP2 is able to measure time while En_Start and En_Stop are at high voltage, time measuring starts when rising edge of a high level pulse comes to Start pin, and it stops when rising edge of a high level pulse comes to Stop pin. As shown in Fig. 5. Ultrasonic flight time, t, is stored in Res0 read register, SCM can obtain the value of t through serial port.

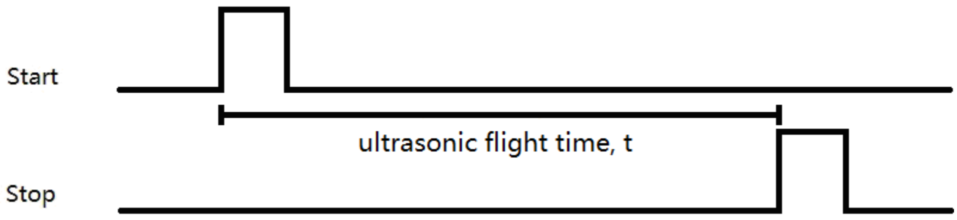

Fig.5 TDC - GP2 measuring ultrasonic flight time

vi. Experiment Results

As described above, the measured value of ultrasonic flight time is entirely decided by square signals at Start and Stop pins. It is very necessary to ensure the quality of the signals, especially the quality of Stop pin signals. Waveform oscilloscope is applied to observe the signals. The prerequisite, clear original echo signal should be observed, the observation result is show in Fig. 6, the oscillation wave on green is echo. In Fig. 7, the yellow line represents the signal at Start pin, three very narrow square waves on the line are fire-pulses, there is a interference square wave in the corresponding position on green line, because signal of receiving transducer shakes at this time. This is a normal phenomenon, but should be shielded by set the value of DELVAL as described above. The square wave on the right is the needed stop signal, it has extreme short rising time and there is no other interference before it. By analyzing the waveform, the obtained ultrasonic flight time is considered to be reliable and accurate, which ensures the reliability of the anemometer.

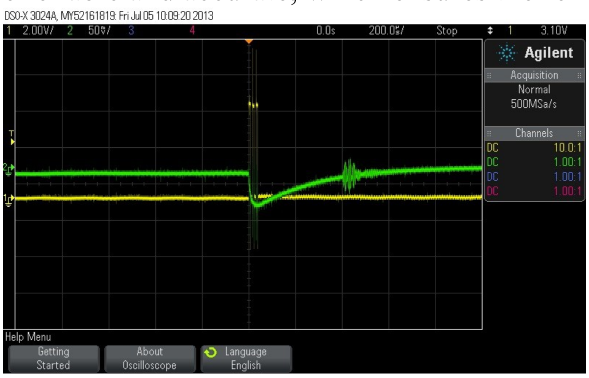

Fig.6 Echo generated by receiving transducer

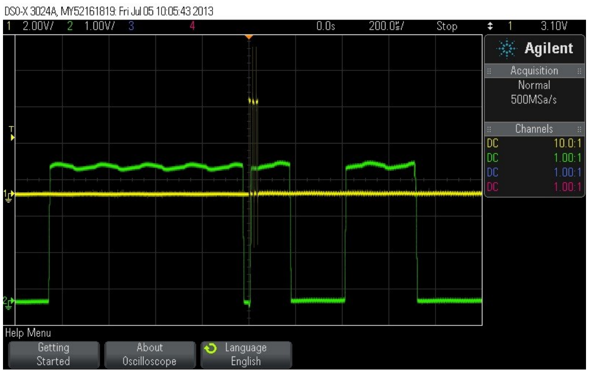

Fig.7 Signal at the Stop pin

The prototype has been characterized in the wind tunnel.

First, wind direction is fixed, and wind speed measurement accuracy is investigated, the test result is shown in Fig. 8. The output power of wind tunnel is adjusted by AC Driver from 0-50 Hz, compare to wind speed calibration table, the corresponding Wind speed range is 0-39.9m/s. As can be seen from the curve, the experimental data is identical to the calibration value, with an error no more than 0.3m/s when wind speed is below 10m/s, or 3 percentage when it's above 10m/s

To investigate the wind direction measurement accuracy, we fixed the output power at 15Hz, the corresponding wind speed is 11.2m/s, wind direction is changed by rotate the base plate. The test result is shown in Fig. 9, the abscissa is actual wind direction, the vertical is measured wind direction, and the data of measured wind direction is read for every 45° . The ideal curve should be slope of 1 as a straight line, can be seen from the figure, the plotted curve is close to the ideal one. This indicates that the measured direction is close to the actual direction and the accuracy can reach 3 degree.

During the wind direction measurement test, the data of wind speed is also recorded. The test result is shown in Fig. 10, The actual wind speed is 11.2m/s, as described above. As the wind direction changes, the measured wind speed is floating around the true value. The floating of the measured wind speed can be attributed to several possibilities. Error of transducers mounting position or the position deviation caused by mold processing is considered to be the main reason, also does not exclude the quality diference of transducers or other reasons. Speculations need further testing and validation to verify.

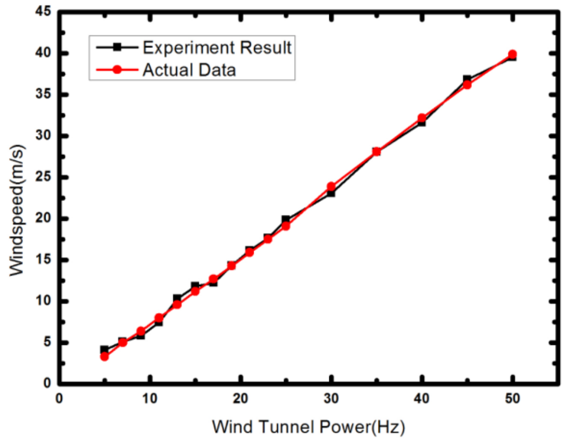

Fig.8 Wind speed curve

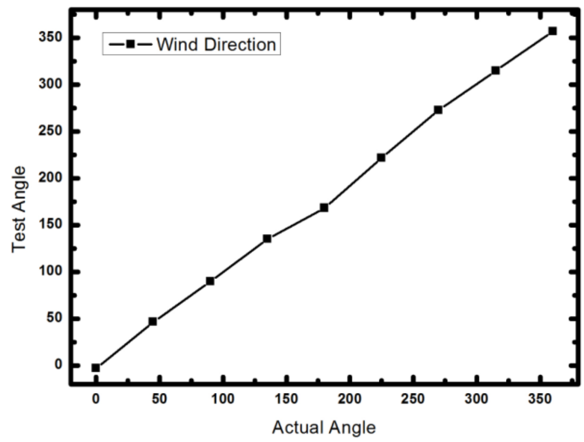

Fig.9 Wind direction curve

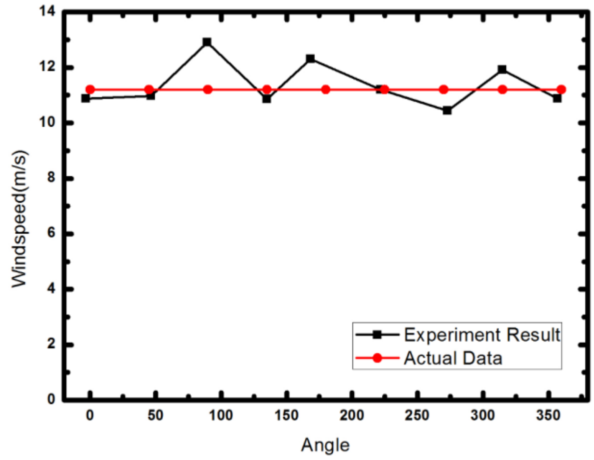

Fig.10 Floating of measured wind speed as wind direction changes

vii. Conclusions

A new ultrasonic anemometer is designed, TDC-GP2 high-accuracy time measuring chip is used to simplify the ultrasonic flight time measurement. Using SCM C8051F410 as main control chip, complete system structure is designed, The theory and experiments show that the designed anemometer has high accuracy in the range of 0-40m/s in the wind speed measurement and an error smaller than 3 degree in wind direction measurement.

Acknowledgement

This work was supported by the the National Nature Science Foundation of China under Grant No. 61076071 and the High-Tech Research and Development Program under Grant No. 2013AA041106.

References

[1] DING Xianghui, LI Ping, MENG Xiaohui. Design and Implementation of High Accuracy Ultrasonic Anemometer [J]. Instrument Technique and Sensor, 2011, (2): 41-44.

[2] BIAN Qiyong, HAN Qingbang, SHAN Minglei, ZHU Chang-ping. A Research of Improved Time-difference Ultrasonic Flow Measurement [J]. Technique Acoustics, 2010, 29(4): 391-393.

[3] GAN Jiangying, GONG Zhaogang, ZHANG Xiaohua, SHAO Lihua, FU Huihui. Ultrasonic Wind Velocity and Direction Detection Detecting System Based on SOPC [J]. Journal of Shanghai Maritime University, 2009, 30(4): 75-79.

[4] CUI Guoheng, CAO Kejing, ZHU Yinbing. Design of Ultrasonic Anemometer Measurement System with High Sensitivity based on C8051F020 [J]. Computer Measurement & Control, 2009, 17(11):2158-2160

Micro-Nano Technology XV

10.4028/www.scientific.net/KEM.609-610

Design and Experiment of Ultrasonic Anemometer Using TDC-GP2 Time-to-Digital Converter

10.4028/www.scientific.net/KEM.609-610.1002