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Temperature detection circuit system research based on ultrasonic phase difference method

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Key words: Ultrasonic, Temperature Detection Circuit, Phase Difference Method

Abstract: A set of temperature measuring system hardware circuits is presented and investigated regarding to static errors. The measurement accuracy of the system can be up to 1%in the industrial applications. In addition, this paper proposes a recommending method to select hardware equipment and this approach plays an important role in temperature measurement in industrial applications.

Ultrasonic measuring method is used in non-intrusive measurement for temperature field with simple installation，non-contact measurement，low cost and high precision[1].At present, in boiler application, the temperature error is worse to 5% [2], which can be reduced to about 3% caused by the hardware configuration improved. This paper proposes an ultrasonic temperature measuring method of small error and low cost，which greatly reduces the cost and further improves accuracy.

The principle of measurement

In industrial measurement，temperature measurement mainly includes three methods: sound velocity measurement，frequency measurement method (Doppler effect) and phase difference measurement method (PDMM). In order to determine the distribution of temperature field in the space, the relationship between the propagation velocity c of sound waves in the flue gas and the flue gas temperature T needs to be deduced based on the thermodynamics of gas state equation and acoustic wave motion equation, such as Eq.1: [3,4]

$$c=\sqrt{\frac{R\gamma}{M}T}=Z\sqrt{T} \tag{1}$$

Where, R represents gas constant, γ stands for gas specific heat ratio, M is gas molecular weight, and Z means the constant for certain gas. Therefore, the accuracy of sound velocity is the key to measure temperature. The sound velocity is determined by acoustic travelling time. However, very high-precision requirements of hardware are necessary to get acoustic travelling time exactly. The PDMM is proposed to decrease errors and also the hardware requirement.

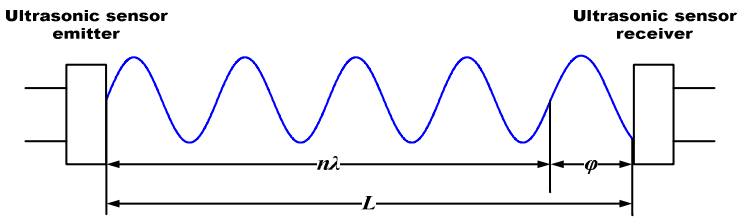

Fig. 1 The principle diagram of ultrasonic testing circuit

As shown in Fig.1，PDMM is a kind of ultrasonic propagation phase difference method to measure velocity without measuring time quantum. Supposing λ is ultrasonic wavelength, f is ultrasonic signal frequency, n is the whole number of wavelengths, φ is incomplete wavelength, the distance between ultrasonic sensor emitter and receiver L can be calculated by:

$$L=(n+\varphi)\,\lambda \tag{2}$$

Considering the relationship between sound velocity and wavelength frequency, Eq.2 can be changed as:

$$L=(n+\varphi)c/f \tag{3}$$

According to Eq.2 and Eq.3, selected two different frequencies $f_1$and f_2 adjusted phase difference within one cycle based on the ultrasonic senor optimal performance interval, which can be get:

$$L\Delta f=c\Delta\varphi \tag{4}$$

Δf is the difference between $f_1$and f_2.In order to get the average velocity of the ultrasonic, the phase difference should be accurately measured. The temperature distribution in the space can be restored based on the average temperature obtained from Eq.1.

Measuring circuitry system

The feasibility of ultrasonic phase difference method used to measure temperature is proved through the principle analysis. For further application in the industry, measuring circuit need to combine data acquisition, analysis and other modules to improve the entire system.

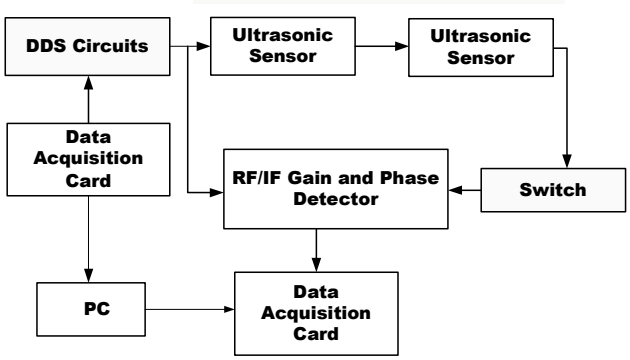

Fig. 2 Diagram of temperature measurement system based on ultrasonic phase difference Method

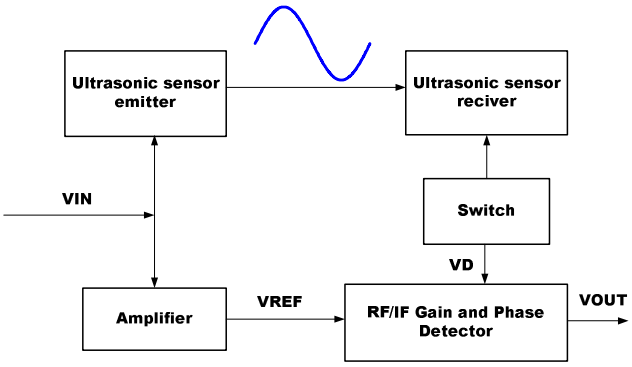

Fig.3 The diagram of Ultrasonic testing circuit hardware design

As shown in Fig 2, the system is designed as:

(1) First, data acquisition cards start to work under the control of the PC, which starts the DDS circuits and generate a sinusoidal excitation of fixed frequency40 KHz and 40.2 KHz, as the accuracy of ultrasonic sensors are the highest in40KHz and 40.2 KHz, which makes ultrasonic sensors emit ultrasonic waves.

(2) Sinusoidal excitation generated by DDS circuits is divided into two parts. One is transmitted to the transmitter as transmitting wave, and another to the chip (i.e.AD823).The signal will be reduced to a certain multiple as the reference wave.

(3) When the ultrasonic wave receiver receives the ultrasonic signal, the switch is turned on, the ultrasonic wave reception signal and the reference wave signal would be input into phase difference module (i.e.AD8302), and the accurate phase difference information is obtained.

(4) Phase difference information will go through analog to digital conversion before transmitted to the data acquisition card.

(5) All the phase difference information is transmitted to the PC by data acquisition card, and the average sound velocity data can be obtained by Eq.4 based on the phase difference information. The mean temperature information can be calculated by Eq.1during the operation of the ultrasonic.

The effect of ultrasonic sensors on the system error

400PT160 ultrasonic transducer is selected as ultrasonic transmitter and receiver in the system. As showed in Fig.3, when the transmitter receives a sinusoidal voltage signal VIN, it will emit ultrasonic wave of the same frequency which will zoomed by AD823, then the reference voltage V_{REF} is acquired. VD received by the ultrasonic sensor and VREF are both transferred to AD8302chip to measure phase difference. As the hardware itself has delayed and error, the system's accuracy can be acquired by a static error analysis.

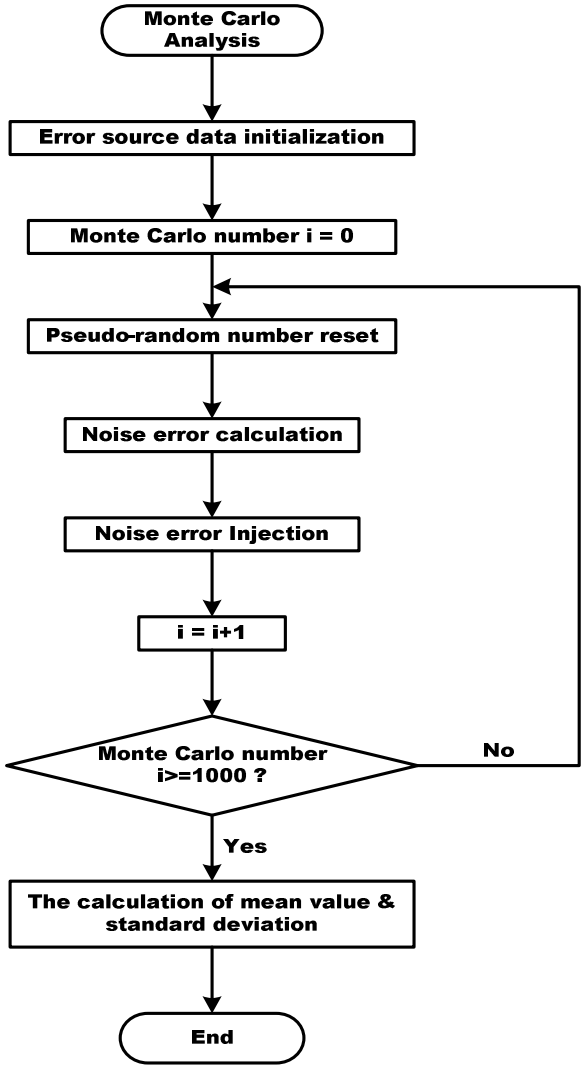

Fig.4 MONTE CARLO simulation flowchart of ultrasonic velocity measuring system error

MONTE CARLO method is used to simulate. The key step of MONTE CARLO approach is in the random number generation, sometimes the factors which affect the event is unpredictable. A group of pseudo-random number is generated by the computer in accordance with an event occurrence probability, which can be approximated as a true random number. Based on Gaussian distribution function which generates pseudo-random number, the approximate simulation of error probability of the chips is accord with the laws of mathematical statistics in practical application of the chip. Simulation flow chart is shown in Fig.4.

Large coal-fired boiler furnace size is generally10 ~ 20min industrial applications, and the flue gas temperature range is about800 ~ 1800℃. Z is approximately equal to19.08 when the flue gas as a medium. Ultrasonic velocity is about625 ~ 869 m/s by Eq.1[2] When the distance selecting is 10m and temperature is 800 ℃, this paper simulates the actual boiler environment in the temperature measurement. See Figure 5.

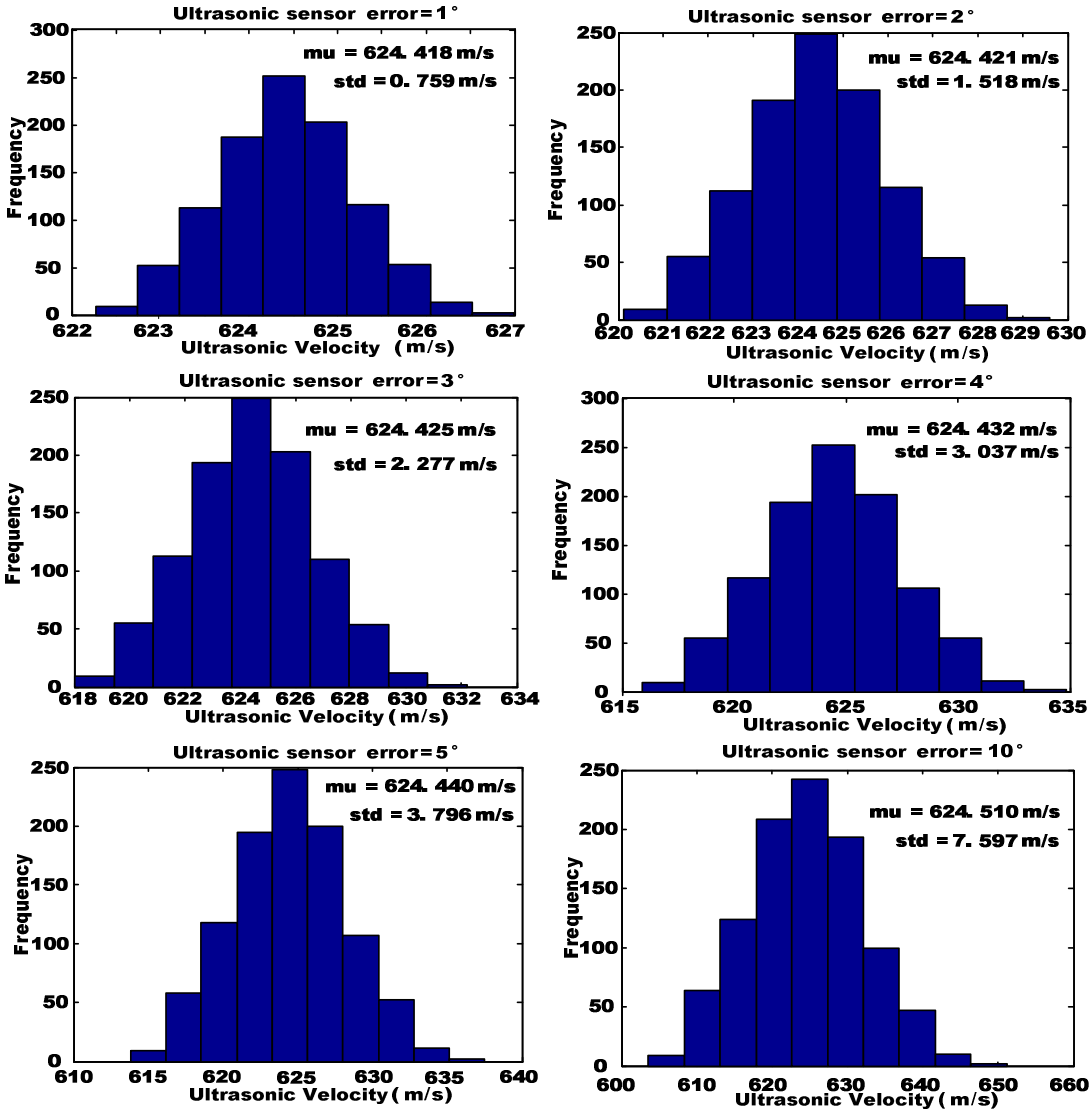

Fig.5 10 m distance ultrasonic velocity MONTE CARLO error analysis diagram

From Fig.5, the ultrasonic frequency is 40KHz according to the industrial boiler environment. Velocity error simulation results can be obtained which are shown in Table 1 when changing the distance and temperature. Several conclusions can be obtained from Table 1:

Table 1 Errors analysis table of ultrasonic sensor and system velocity measurement

T(℃)	Distance（m）	Ultrasonic sensor error（°）	std error
800	10	1	1.2‰
800	10	2	2.4‰
800	10	5	6.1‰
800	10	10	1.2%
800	10	20	1.8%
800	10	30	2.3%

(1) Ultrasonic sensor error is at 30° or less, and the error of ultrasonic velocity measuring system is less than 1%.Currently, available ultrasonic sensor accuracy can be achieved at least a millimeter. And ultrasonic frequency is 40 KHz in the boiler. the wavelength is 15.625mm to 21.725mm, using a precision of 1mm (0.046 to 0.064 times the wavelength equivalents that phase difference is 16.57 ° to 23.04 °) of the ultrasonic sensor, the actual measurement error caused by the hardware is only 1.35% to 1.8%.The current hardware manufacturing fully

meets the measurement system, so the ultrasonic sensor hardware requirements is reduced greatly when the measurement accuracy remains unchanged in an industrial measurement environment.

(2) When the ultrasonic sensor error within the range of 10°, the system measurement accuracy can reach about 1%.

Simulation and analysis of ultrasonic temperature measurement

We can get the corresponding theoretical phase different for different distance values, according to the relationship between distance and wave length the system can be measured a set of phase difference information by the phase difference output of the chip. Velocity is determined by the phase difference derived from theory and measurement phase difference according to Eq.4. The temperature is obtained by Eq.1.The relationship between the temperatures that are in the ideal case and measured in non-ideal case is shown in Fig.6.

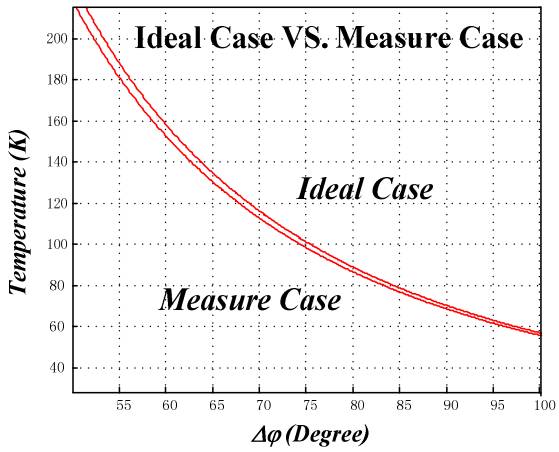

Fig.6 Analysis of the temperature measurement results in ideal case and measure case

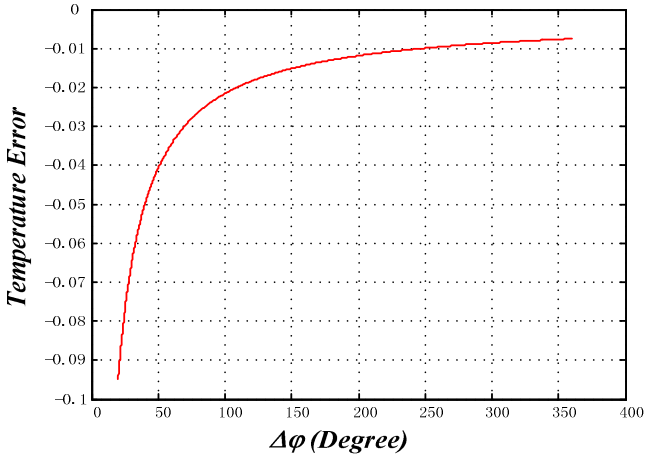

Fig.7 The temperature error analysis diagram in ideal case and measure case

The detailed measuring error values between ideal case and measure case have been displayed in Fig.6 and Fig.7 can be drawn:

(1) The phase difference is between200 °to 360 °, when measuring a distance of 10m and the ultrasonic sensor error is 10 °.The measuring error for temperature measurement is 1%.

(2) When the phase difference is close to0°, the error is large. The system temperature measuring error is about 10% in the vicinity of phase difference 20 °. In order to reduce the systematic error and obtain more accurate measurement which will help to restore a more accurate spatial temperature distribution, the system can be improved by adding the reference wave. The reference wave and the emission waveare90° phase difference through the signal generator, when the reference wave is used in the large error interval by the software to be selected.

Conclusions

Ultrasonic measurement has many advantages that compared with traditional measurement methods. Due to well realizing of the non-intrusive measurement, ultrasonic measurement is expected to be applied to real-time monitoring of power plant boiler temperature field. The accuracy of some measurements remains to be improved. This paper designs a circuit system of ultrasonic temperature measurement and analyzes the static error of system core part. Here are the following conclusions.

(1) This temperature measurement error for ultrasonic phase difference method is only 1% in the phase difference between 200° to 360°, which will help to restore a more accurate temperature distribution.

(2) This system is designed for industrial environment temperature measurement with very small error through static error analysis. The choice of the ultrasonic sensor is very important in selecting hardware; furthermore, the recommendation is that the error is between 1 ° to10 ° or at least in the millimeter accuracy of ultrasonic sensor.

(3) Because there is a big error in the system when the phase difference is from 0 ° to 100°, the measurement process should avoid the phase area. In order to solve the problem of this big error when the measurement is in the same frequency, another different phase reference wave should be added by using two wave switches.

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