Research and development of mine high precision wind speed sensor and temperature correction

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Abstract—According to the requirements of mine production for ventilation monitoring system, an ultrasonic wind speed sensor with high precision and low starting wind speed is developed. Based on the measurement principle of ultrasonic time difference method, an ultrasonic wind speed sensor is designed. The propagation speed of ultrasonic in the air is superimposed with the wind flow speed. The propagation speed is accelerated in the along wind flow direction and slowed down in the counter wind flow direction. Under certain detection conditions, it corresponds to the wind speed function, and the accurate wind speed can be calculated. Through the analysis of the relationship between ultrasonic speed and temperature, it is proposed to correct the ultrasonic propagation speed through temperature compensation. Through experimental research, it is found that eliminating the measured value of wind speed with the difference between ultrasonic temperature and air temperature greater than 1 ℃ can improve the measurement accuracy.

1. Introduction
With the development of our mining technology, the automation level of mining technology is higher and higher. With the increasing demand for coal, the requirements for coal mining rate are higher and higher. How to ensure the safety of mine production and underground production personnel while ensuring the improvement of coal mining rate is also a problem that needs to be paid attention to[1,2]. For a coal mine, the mine ventilation system is the respiratory system of coal mine underground operation. The ventilation quality is directly related to the air flow and air quality in each operation area, which is of great significance for coal mine production[3]. Among them, mine wind speed sensor is the "ear and eye" of coal mine ventilation system. It is used to monitor coal mine environmental parameters and production process parameters, and convert various physical quantities into electrical signals. It is an important guarantee for high-yield, efficient and safe production of coal[4,5].

2. Research status of wind speed sensor
The application and development of wind speed sensor in China are closely related to the development of coal mining enterprises. In the early stage of coal mining development, due to the underdevelopment of science and technology, the early monitoring of wind speed in China mainly used the tracer method[6], but due to the increasing requirements for wind speed measurement accuracy and stability, this method is no longer used. After that, with the further development of China's scientific research capacity, mechanical wind meter, thermal wind speed sensor, differential pressure wind speed sensor, ultrasonic vortex sensor, ultrasonic TDOA wind speed sensor and other wind speed sensors have been developed one after another, which provides a variety of options for wind speed measurement products, and the
stability and accuracy have been further improved\cite{7-12}.

At present, there are many kinds of wind speed sensors used frequently at home and abroad, mainly including the wind speed sensors of the following companies, as shown in the table 1 below:

| Model     | Measuring principle                                  | Measuring range (m/s) | Accuracy of measurement (m/s) |
|-----------|------------------------------------------------------|-----------------------|-----------------------------|
| GFW15     | Principle of ultrasonic vortex street measurement    | 0.4-15                | ≤±0.3m/s                    |
| GFY15     | Pitot tube differential pressure principle           | 0.3-15                | ≤±0.2m/s                    |
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| FC-CFJ-5  | Mechanical wind gauge                                | 0.3-5                 | ≤±0.1m/s                    |
| GYF15     | Pitot tube differential pressure principle           | 0.3-15                | ≤±0.2m/s                    |
| FWS200    | Ultrasonic time difference method                    | 0-60                  | 3%                          |
| GYF15     | Ultrasonic time difference method                    | ±0.1-15               | ±0.01m/s                    |
| WINDCAP®WMT700 | Ultrasonic time difference method                  | 0-75                  | ≤±0.1m/s & 2%               |

“Security Rules for Coal Mine” stipulates that the minimum allowable wind speed of conveyor roadway, air inlet and return roadway in mining area, coal face, coal roadway in excavation and semi coal rock roadway is 0.25 m/s; The minimum allowable wind speed of rock roadway and other ventilated pedestrian roadway in excavation is 0.15 m/s. The existing wind speed sensor can not meet the wind measurement requirements of the minimum allowable wind speed specified in the “Security Rules for Coal Mine”, and can not distinguish the wind direction. In order to achieve full coverage and accurate wind measurement in the mine, especially with the development of mine intelligent ventilation construction and ventilation monitoring technology, the demand for accurate wind measurement is increasing. The measuring wind speed range of an excellent mine wind speed sensor should meet the minimum wind speed of more than 0.1 m/s.

Therefore, according to the wind speed measurement principle of ultrasonic time difference method, a low starting wind speed and high-precision mining ultrasonic wind speed sensor is designed, and the possible errors of the ultrasonic sensor in the measurement process are corrected through experiments.

3. Principle of Ultrasonic Wind Measurement

The propagation speed of ultrasonic wave in the air will be superimposed with the wind flow speed. It will accelerate in the direction along the wind flow and slow down in the direction against the wind. Under certain detection conditions, it corresponds to the wind speed function, and the accurate wind speed can be calculated. As shown in Fig.1, two ultrasonic probes are installed on the inner wall of the roadway so that the two ultrasonic probes are on a diagonal. In addition, there is air flow with wind speed of $V$ m/s in the tunnel, and the direction of ultrasonic wave is at an angle to the direction of air flow $\mu$. 

Here, \( s \): sound speed, m/s. \( L \): distance between sensors, m. The time of ultrasonic wave from sensor \( A \) (transmitter) to sensor \( B \) (receiver) is \( t_1 \), s. The time from sensor \( B \) (transmitter) to sensor \( A \) (receiver) is \( t_2 \), s, Establish the following relationship:

\[
\begin{align*}
  t_1 &= \frac{L}{s + V\cos\phi} \quad (1) \\
  t_2 &= \frac{L}{s - V\cos\phi} \quad (2) \\
  V &= \frac{L}{2\cos\phi} \left( \frac{1}{t_1} - \frac{1}{t_2} \right) \quad (3) \\
  L &= 2S \left( \frac{t_1}{t_1 + t_2} \right) \quad (4)
\end{align*}
\]

By measuring the propagation time of ultrasonic wave in downwind and upwind conditions, the average wind speed along the horizontal direction on the \( AB \) line can be obtained according to equation (3).

4. System design of anemometer

The sensor hardware is composed of single chip microcomputer, power supply, display, ultrasonic transceiver module and infrared locator. The single chip microcomputer integrates the functions of amplifier, filter, controller and signal processing unit to complete the measurement of wind speed by time difference method. Firstly, the power supply provides a voltage of 5V for the operation of the whole device; The single chip microcomputer calculates the wind speed and direction according to equation (3), and outputs the wind speed in real time to monitor the change of roadway wind speed; The key design of the device is the ultrasonic transceiver module (Fig.1, A and B). The ultrasonic transceiver module is used for ultrasonic transmission and reception. The two ultrasonic transceiver modules have four probes in total. The two ultrasonic transmitting probes and two ultrasonic receiving probes are staggered to form two ultrasonic transmission paths. The two modules work together, the propagation time of ultrasonic wave in specific wind speed field is measured. In addition, ultrasonic signal driving circuit and signal processing unit are the most important. The single chip microcomputer controls the ultrasonic driving circuit to drive the two ultrasonic transceiver modules to work, and excites the ultrasonic transmitting probe to emit the ultrasonic with the specified frequency; Two ultrasonic receiving probes receive ultrasonic signals and convert them into electrical signals. After amplification and filtering, the ultrasonic waves of the two channels are processed into rectangular waves by the signal processing unit. Compared with the transmitted ultrasonic waveform, the ultrasonic transmission time difference is obtained, and the wind speed and wind direction are calculated by equation (3).
5. Temperature correction of ultrasonic wind speed sensor
It can be seen from formulas (3) and (4) that the solution of wind speed is also related to the ultrasonic speed of sound. Therefore, this experiment studies how the probe uses temperature to improve the reliability of measurement.

Ultrasonic wave has the following relationship with air temperature:

\[ s = s_0 + 0.607 \times T {\degree C} \]  

(5)

Where: \( s_0 \) is the acoustic velocity at zero degree 331.5 m/s.

In the design, in order to correct the ultrasonic sound velocity, the semiconductor thermometer TMP36 is used for temperature measurement. The measured temperature is taken as the air temperature and recorded as \( T_0 \). Combined with formula (4), the distance \( L \) between ultrasonic probes is calculated to compensate the ultrasonic sound velocity and improve the measurement accuracy\(^{[13]}\).

Using semiconductor thermometer to measure temperature can not only improve the measurement accuracy, but also judge the measurement reliability. The ultrasonic wind speed sensor emits ultrasonic waves every 150 ms, and the ultrasonic wind speed sensor is corrected every 30 measurements. The first measured \( L \) is regarded as a fixed value, and the ultrasonic temperature \( T' \) after each measurement can be calculated by using formula (4) (5). The air temperature \( T_0 \) is used as the input temperature and the ultrasonic temperature \( T' \) is used as the feedback temperature. The measurement accuracy can be judged by comparing the two. If the measurement is normal, ultrasonic temperature \( T' \) and air temperature \( T_0 \) is basically the same, but if there is a problem with the ultrasonic measurement, the calculated ultrasonic temperature \( T' \) is incorrect, and the two temperatures will not be the same, that is, it can be judged that the measurement is wrong.

6. Experimental study
The above theoretical research shows that the measurement reliability can be judged by the difference between ultrasonic temperature and air temperature. However, due to the uncontrollable factors of measurement error in the instrument itself, there will be a threshold between ultrasonic temperature and air temperature. Within this threshold, the measurement reliability of ultrasonic wind speed sensor can also be judged.

Set the measurement distance of ultrasonic sensor \( L = 2 \) m and measure it under the condition of no wind. The measured wind speed results and temperature changes are shown in Fig.2 and Fig.3.

![Fig.2 Wind speed measurement results without wind](image)

![Fig.3 Temperature measurement results without wind](image)

It can be seen from Fig.2 that the fluctuation range of wind speed value is small, and the measurement result is reliable in the windless state. The fluctuation range of air temperature and ultrasonic temperature shown in Fig.3 is also small, and the difference between them is within 1 °C except for an abnormal value. The abnormal point of the temperature measurement result corresponds to the abnormal point of
the wind speed measurement, and the abnormal point corresponds to that when the ultrasonic temperature measurement is abnormal, the difference between the ultrasonic temperature and the air temperature is greater than 1 °C. Therefore, when the temperature difference between them is within 1 °C, it can be judged that the measurement of wind speed is reliable.

Set the same sensor distance and give a fixed wind speed for measurement. The measurement results are shown in Fig.4 and Fig.5.

![Fig.4 Time variation of wind speed under fixed wind speed](image)
![Fig.5 Time variation of ultrasonic air temperature and basic air temperature](image)

It can be seen from Fig.5 that when the difference between ultrasonic temperature and air temperature exceeds 1 °C, the wind speed in Fig.4 fluctuates greatly. Because the given wind speed is a fixed wind speed, the wind speed with large fluctuation is obviously abnormal. At this time, if the measuring point with the temperature difference of 1 °C is deleted, the abnormal data can be effectively removed. Fig.6 shows the change of wind speed value after removing abnormal points.

![Fig.6 Variation of wind speed after removing abnormal points](image)

Comparing Fig.6 with Fig.4, the wind speed becomes stable after removing the abnormal points. Therefore, the ultrasonic wind speed sensor can improve the reliability of measurement by eliminating the point where the difference between ultrasonic temperature and air temperature is greater than 1 °C.

7. Conclusion
Mine ventilation monitoring is of great significance to mine safety production. In this paper, an ultrasonic sensor based on the principle of measuring wind speed by time difference method is proposed. Compared with other ultrasonic wind speed sensors, it has the advantages of high measurement accuracy and low starting wind speed. The relationship between ultrasonic and temperature is used to reduce the impact of ambient temperature on the measured wind speed, and the ultrasonic temperature is compared
with the air temperature to eliminate the measured wind speed when the temperature difference is greater than 1 ℃ and improve the measurement accuracy. After improvement, it can adapt to various complex and changeable temperature environments. The ultrasonic wind speed sensor has high resolution and low starting wind speed, which can meet the requirements of accurate wind measurement in ultra-low wind speed roadway of mine. It will be further verified through practice in the future.

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