Research progress on coal mine laser methane sensor

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ABSTRACT

This paper discusses the research progress of low-power technology of laser methane sensors for coal mine. On the basis of environment of coal mines, such as ultra-long-distance transmission and high stability, a series of studies have been carried out. The preliminary results have been achieved in the research of low power consumption, temperature and pressure compensation and reliability design. The technology is applied to various products in coal mines, and achieves high stability and high reliability in products such as laser methane sensor, laser methane detection alarm device, wireless laser methane detection alarm device, and optic fiber multichannel laser methane sensor. Experimental testing and analysis of the characteristics of laser methane sensors, combined with the actual application.

Keywords: Laser methane sensor; temperature compensation; pressure compensation; self-diagnosis; stability; internet of things

1. INTRODUCTION

At the end of 2016, the State Administration of Coal Mine Safety Supervision issued document No. 5 of "Technical Plan for Upgrading and Renovating Safety Monitoring System". The document requires that the in-service safety monitoring system of large mines, coal and gas outburst mines be upgraded and renovated by the end of 2018.

At present, coal mine gas detection mainly includes carrier catalytic combustion, thermal conductivity, optical interference and infrared absorption, but these detection methods have different degrees of disadvantages, such as electro-chemical gas sensors are easy to drift, measurement range is small, long-term reliability Poor sex, low precision, easy to poison, etc.; infrared absorption sensor is prone to cross interference of different gases. Traditional methane sensors are difficult to measure in real time, online, and accurately in such harsh environments. With the development of optical fiber sensing technology, fiber-optic sensors based on laser spectral absorption have attracted more and more attention from researchers. The laser methane sensor has the characteristics of wide measuring range, low measuring error, fast response speed, long calibration period, long service life, high gas singleness and convenient maintenance in the later stage. By comparing the laser methane sensor with several other sensors, it has obvious advantages in terms of stability and reliability.

In the course of operation, faults, wrong alarms, and non-command control are inevitable. Sometimes the false alarm of the methane sensor will cause the monitoring substation to issue an incorrect command, or lead to power off, and then cause seriously affect to the normal production of the mine.

This paper introduces the research progress of laser methane sensors in coal mines, such as low-power technology, temperature and pressure compensation technology, self-diagnosis function model, data processing model, etc. in

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practical applications.

2. PRINCIPLE OF LASER METHANE SENSOR

Methane is detected by the principle of gas spectral absorption. According to Lambert-Beer's law, when a parallel light having a light intensity of $I_0(\lambda)$ passes through a gas chamber containing a gas to be tested, if the light source spectrum covers one or more absorption lines of the gas, the transmitted light intensity I The relationship between $I(\lambda)$and incident light intensity $I_0(\lambda)$and gas concentration C[2] is

$$I(\lambda) = I_0(\lambda)exp[-\alpha(\lambda)CL] = I_0(\lambda)\exp[-PS(T)\phi(\lambda)CL] \quad (1)$$

Where $\alpha(\lambda)$ is the absorption coefficient of the medium; L is the length of the light absorbing gas; P is the total pressure of the gas medium; $S(T)$ is the line intensity of the characteristic line of the gas, indicating the absorption intensity of the line, only Dependent on temperature; $\phi(\lambda)$ is a linear function that represents the shape of the measured absorption line and is related to temperature, total pressure, and the content of each component in the gas.In actual sensor design, it is generally assumed that the pressure and absorption line of the gas is a constant, and the concentration of the gas to be measured can be measured only by measuring the change of the light intensity before and after absorption. In order to improve the accuracy and reliability of the measurement, temperature and pressure compensation are required [8]. As shown by the change trend of methane absorption intensity with methane concentration, after the source and probe signals are normalized, the methane concentration absorption line can be obtained.

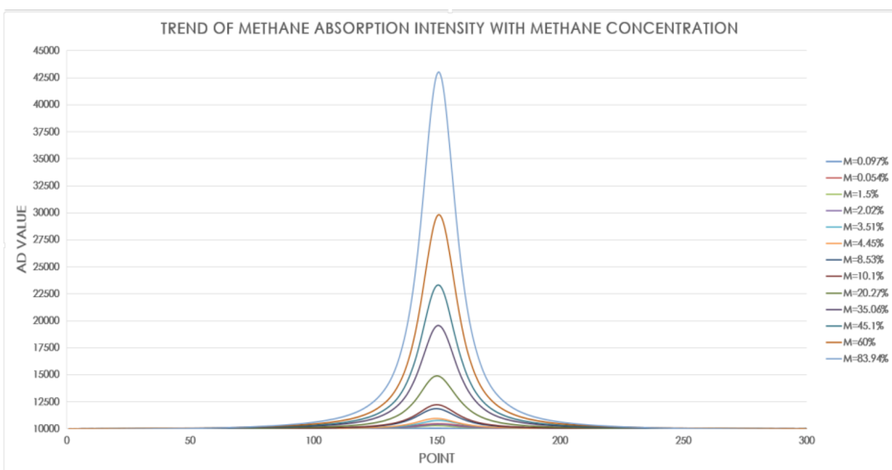

Figure1 Trend of Methane Absorption Intensity with Methane Concentration

The methane concentration actual value can be obtained by substituting the absorption intensity of the methane concentration $-\ln(I/I_0)$ from the absorption line into the above equation.

3. RESEARCH ON LOW-POWER TECHNOLOGY OF LASER METHANE SENSOR

By analyzing the actual application of coal mines, the laser methane sensor for coal mine has a transmission distance at least 3km or even 6km in applications such as methane measurement in coal mine working face. Conventional mining DFB laser methane sensors require the laser temperature to be adjusted to a fixed temperature, at which point the laser can output a laser beam of a specific wavelength containing methane gas to detect the methane gas concentration. Such laser temperature control is essential.

The VCSEL drive current is very small, the wavelength varies greatly with current. We design laser methane sensor based the VCSEL without the Thermo Electric Cooler（TEC）which the wavelength of the methane absorption peak locked by the laser wavelength. According to the data of the drive circuit I and the wavelength λ of the laser at 0℃/40℃. The equation of the drive circuit I and the wavelength λ at each temperature of -25℃～50℃ is derived.

As shown in the above figure, the operating temperature range of each absorption peak wavelength is inverted based on the spectral wavelength data of each absorption peak of methane gas. Thereby determining the operating temperature coincidence range of each absorption peak and determining the absorption peak wavelength switching point. The method can achieve the purpose of locking the peak wavelength of methane absorption according to the ambient temperature.

The laser methane sensor module was placed in a high and low temperature test chamber and the ambient temperature was cycled from 5℃～55℃. At this time, the peak wavelength of the methane absorption peak can be obtained following the temperature change trend curve. As shown below:

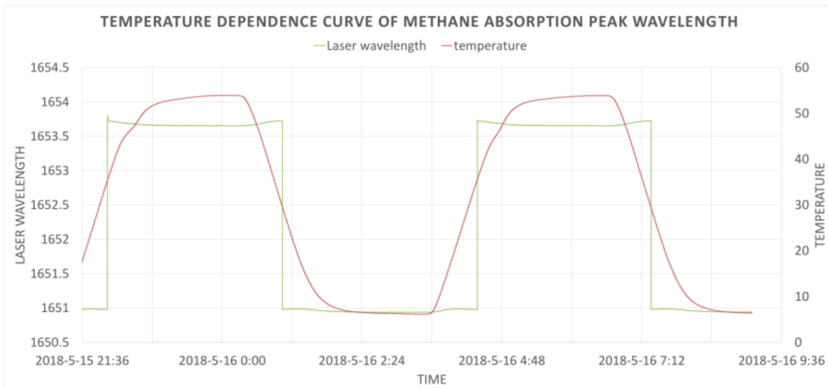

Figure2 Temperature dependence curve of methane absorption peak wavelength

The above test results show that in the implementation of low-power technology, even if the TEC control is removed, the locking effect of the absorption peak wavelength is very reliable.

4. RESEARCH ON LASER METHANE SENSOR TEMPERATURE COMPENSATION TECHNOLOGY

According to “AQ6211-2008 non-dispersive infrared methane sensor” for coal mine industry standard, the operating temperature range of methane sensors is 0～40℃. In applications such as wellheads or ground gas drainage monitoring systems in coal mine application, there are higher requirements for methane sensor’s operating temperature range.

The laser methane sensor of the conventional DFB laser requires a temperature control, and the controllable temperature range is not very large, and it is difficult to further increase the operating temperature range. Laser methane sensors based on low-power technology have higher ambient temperature adaptability due to temperature-free control units. Using low-power technology to compensate the temperature in a wide temperature range, the measurement results are corrected and compensated by the least squares method, and the error caused by the temperature of the laser methane sensor in the gas concentration measurement process is eliminated to the greatest extent, and the stability of the sensor is improved.

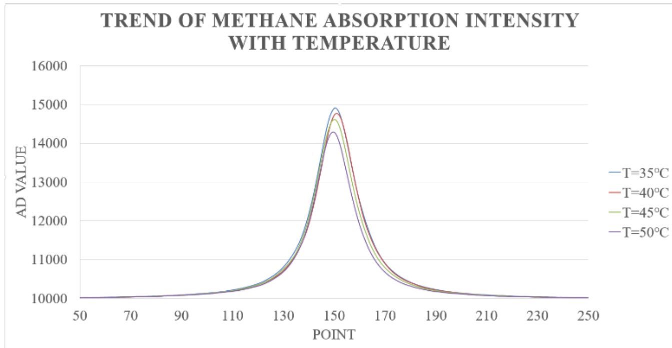

Figure3 Trend of Methane Absorption Intensity with Temperature

The relationship between the absorption intensity of methane and the temperature change trend is that the relationship between the temperature and the absorption intensity of the methane concentration is that the lower the temperature, the greater the intensity of the absorption spectrum. According to this phenomenon, the measurement results are corrected and compensated by the least squares method. The compensation coefficient curve is shown in the figure below.

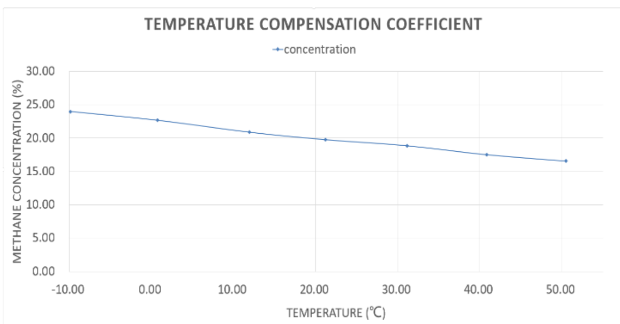

Figure4 Temperature Compensation Coefficient

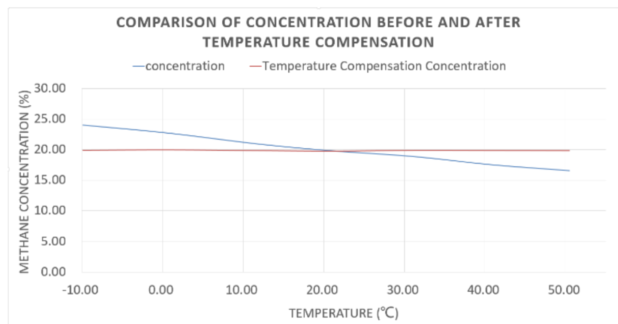

Figure5 Comparison of Concentration

The temperature compensation coefficient curve shows that the methane concentration is linear with temperature. The temperature compensation coefficient is added to the system for real-time compensation. The current compensation temperature is -10℃～50℃. The compensation completion effect is as follows:

The data shows that the compensation method is very effective. When the temperature range is -10℃～50℃, the basic error is less than 1% of the true value. The accuracy of temperature compensation monitoring has been significantly improved.

5. RESEARCH ON LASER METHANE SENSOR PRESSURE COMPENSATION TECHNOLOGY

According to “AQ6211-2008 non-dispersive infrared methane sensor for coal mine” industry standard, the working pressure range of methane sensors for pipeline is 50-130kpa. In applications such as gas drainage monitoring systems in coal mine applications, there are higher requirements for the operating temperature range of methane sensors.

In order to adapt to the application of various occasions, it is necessary to study the wide pressure compensation method. In this paper, the high-precision pressure compensation technology is studied to achieve accurate measurement within the pressure range of 30 to 200 kPa. As shown in the figure below, the methane absorption intensity shows the trend of pressure change. The relationship between methane concentration and pressure are positive proportional.

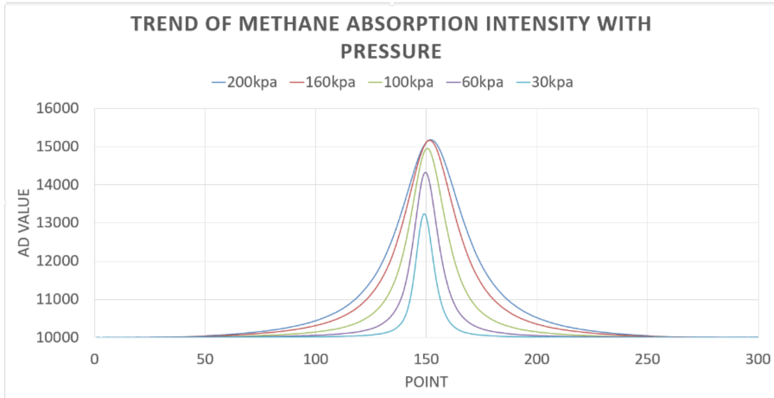

Figure6 Trend of methane absorption intensity with pressure

According to this phenomenon, a least squares curve fitting pressure compensation algorithm model is established to correct and compensate the measurement results. The error of the laser methane sensor in the gas concentration measurement process is eliminated to the greatest extent, and the stability of the sensor is improved. The pressure compensation coefficient curve is shown below:

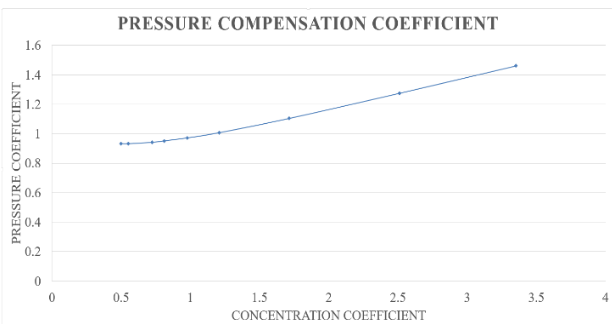

Figure7 Pressure Compensation Coefficient

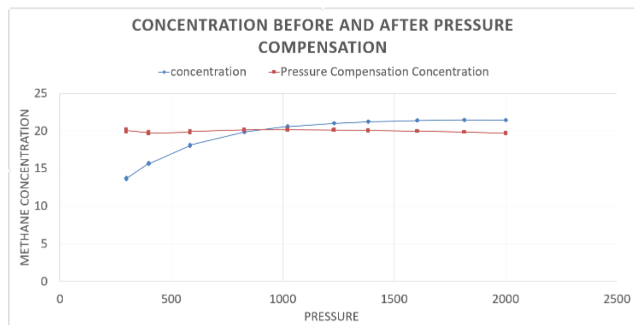

Figure8 Comparison of Concentration

The pressure compensation coefficient indicates that the relationship between methane concentration and pressure is a quadratic linear relationship. The pressure compensation coefficient is added to the system for real-time compensation, and the current compensation temperature is 30 ~200 kPa. The compensation completion effect is shown in the following table and curve.

The data shows that the compensation method is very effective. When the pressure range is 30～200kPa, the basic error is less than 0.5% of the true value. The least squares curve fitting pressure compensation algorithm model can solve the problem that the measurement accuracy of the laser methane sensor is affected by the pressure error in the complex environment of the coal mine, and the maximum elimination of the pressure on the laser methane sensor in the gas concentration measurement process The resulting error significantly increases the stability of the sensor.

6. RESEARCH ON RELIABILITY DESIGN OF LASER METHANE SENSOR

The theoretical life of the laser methane sensor is more than 5 years. Following the laser methane sensor standard for new coal mines, the calibration period will be extended from the theoretical calibration of the catalytic/infrared methane sensor to 15d. The theoretical lifetime of the laser methane sensor is very reliable, but the stability of the laser methane sensor exists in terms of factors such as device stability used by the sensor. Due to the failure of some devices, the laser methane sensor fails during the operation of the working surface and the calibration period has not yet been reached. A long-term unsupervised state of 180d will occur, which seriously jeopardizes the personal safety of the mine staff. Therefore, the addition of a self-diagnostic function to the laser methane sensor is essential. Real-time monitoring of the working status of the laser methane sensor in real time, even if the safety personnel of the laser methane sensor are notified, will ensure the safety of workers in hazardous areas such as the working face.

By analyzing the principle of laser detection and the practical application of coal mine, a self-diagnosis function model is realized inside the laser methane sensor. The self-diagnosis function can effectively analyze the working status of the laser methane sensor in real time.

The laser methane sensor for coal mine consists of main components such as laser, photodetector, detection chamber, reference chamber, laser current drive circuit, operational amplifier circuit, signal acquisition circuit, temperature and pressure detection circuit, MCU and other functional units. Among them, the laser is the most important functional device, and the key monitoring object is the laser. Secondly, the possibility of contamination of the gas chamber for long-term contact with the outside world is detected, so it is also the key monitoring object. Therefore, the self-diagnostic fault function listed in the table below is proposed.

Table 1 Self-diagnostic function code

Status code							
High 8 bit							
B7	B6	B5	B4	B3	B2	B1	B0
1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0
The first time Power sign	Reserve	Reserve	User parameters	T-P Module failure	Pressure Out of range	Temperature Out of range	LD signal
Low 8 bit							
B7	B6	B5	B4	B3	B2	B1	B0
1/0	1/0	1/0	1/0	1/0	1/0	1/0	1/0
Reserve	Reserve	Reserve	Power supply voltage	Reference signal	LD voltage	Reference voltage	Probe voltage

Among them, the light source voltage is the monitoring laser power, the probe voltage is to monitor whether the detection chamber is unobstructed, the reference voltage and the reference signal monitor whether the laser methane sensor reference is invalid, and the signal of the supply voltage, temperature, pressure is abnormal, and the like.

In coal mine applications, the self-diagnostic function model accurately reports the working state of the laser methane sensor. Safeguard the safety of coal mine workers.

The failure, false alarm, and non-command control caused by the actual operation of the coal mine are inevitable. Frequent occurrence of methane sensor false alarms on the working surface has an impact on the leadership decision-making, causing tension to the staff; sometimes the methane sensor false alarm causes the sub-station to issue an error command to the methane breaker to cause the working face to be powered off, seriously affecting the normal production of the mine.

Through the experimental test and the actual situation of the coal mine, an effective data processing model was established to judge the false positives and other information more effectively.

During the operation of the laser methane sensor in coal mines, the trend of concentration data is judged in real time. The trend of concentration data is divided into data rising phase, data falling phase, and data stabilization phase. In the data rising phase, the data falling phase is a monotonic curve, and the data falling phase is not processed.

In addition, increase the protection mechanism of the output data. When the above conditions are met, the output data will be updated. Otherwise, it will not be updated. If the output density data is >0.8%, the output data will be modified to 0.11%. The purpose is to abnormal data. The concentration data exceeds the alarm threshold and reduces the alarm time.

Based on the above-mentioned real-time processing data trend, the anti-jump large number processing is added. The anti-jump large number processing principle is to always output the previous value. Three sets of data are always cached in the data queue to determine whether there are large numbers in real time. The judgment is based on setting the relative error threshold. When the absolute difference between the two sets of data comparison exceeds the relative error threshold of the average value, the current measured methane concentration is changed to delay the change of the methane concentration, and the method delays the response time to some extent. However, the measurement interval of the laser methane sensor is 0.3s, and the response time still meets the requirement of ≤15s.

In addition to the data processing model, measures such as the protection level and EMC rating of the laser methane sensor are improved. Through laboratory simulation and coal mine field application, the above-mentioned reliability measures have basically avoided the occurrence of coal mine face power failure caused by false alarms and improved coal mine production efficiency.

7. APPLICATION OF LASER METHANE IN COAL MINE

The laser methane detection technology based on the low power consumption principle has been widely used in laser methane sensors for coal mines, laser methane detection alarms, wireless laser methane sensors for coal mines, and intrinsically safe fiber multi-channel laser methane sensors. The two main applications below are examples.

The wireless pipeline laser methane sensor for coal mines is a fusion of low-power technology and wireless technology, which is more reliable than the traditional catalytic/infrared methane sensor. Catalytic methane sensors have high concentrations of poisoning, and infrared methane sensors have water vapor interference, so there are always inevitable defects in pipeline applications. As shown in the figure below, the wireless pipeline laser methane sensor for coal mines has been operating reliably for one and a half years in the mine drainage monitoring system.

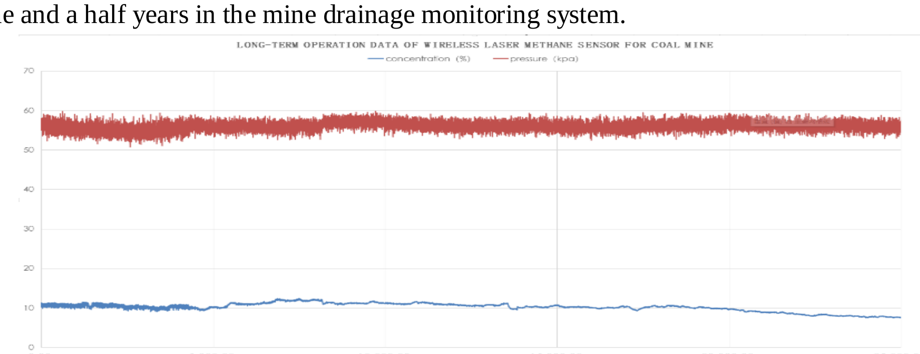

Figure9 Field Application of Wireless Pipeline Laser Methane Sensor in Coal Mine

The above cases were applied in the most severe gas drainage pipelines in the coal mine environment, and verified the practicality of low-power technology, temperature compensation technology, pressure compensation technology and reliability design.

8. CONCLUSION

This article describes the application and progress of laser methane sensors for coal mines. By analyzing the principle of laser detection and the practical application in coal mine, the research on low-power technology, wide temperature and wide pressure compensation technology has realized in the laser methane sensor which is more suitable for the practical application of coal mine. At the same time, in order to avoid the occurrence of coal mine face power failure caused by false alarms and improve coal mine production efficiency, the reliability design of self-diagnosis function model, new data processing model and anti-jump large number processing model was realized. A series of designs validated their reliability through applications in two gas drainage monitoring systems.

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