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A double-ended Raman temperature measurement method for hazardous chemicals warehouse

Xue-jun Liu[a], Hao Lu[a,b,*], Bi-xian Yuan[a,b], Yu-chen Wei[a], Yong Yan[a]

[a] *Beijing Institute of Petrochemical Technology, School of Information Engineering, Beijing, 102617, China*
[b] *Beijing University of Chemical Technology, School of Information Science and Technology, Beijing, 100029, China*

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ABSTRACT

An adaptive calibration method for distributed temperature sensor is proposed to eliminate the influence of fiber attenuation and APD dark current fluctuation. The two ends of one fiber are connected to the different measuring channels of the system. In a measurement period, two measuring channel alternately inject pulse signal into optical fiber. With the help of the measured data obtained from the two channels, the attenuation function part in demodulation formula which is a function related to the distance is converted to a constant. The mean filtering method is used to restrain the influence of APD output fluctuation on the measurement results. The experiment shows that compared with the traditional adaptive demodulation method, the temperature measurement curve is smoother and the error is reduced from about 1 °C to less than 0.5 °C.

1. Introduction

At present, the three-dimensional warehouse is a major trend in the development of logistics and storage. During the operation of dangerous chemicals storehouse, due to the inflammable, explosive and toxic characteristics of dangerous chemicals, it is necessary to strictly monitor the parameters in the storage environment of goods in order to prevent the occurrence of safety accidents.

The temperature monitoring methods of stereoscopic warehouse include sensor network temperature monitoring scheme based on point sensor, video monitoring scheme based on flame recognition and temperature monitoring scheme based on optical fiber temperature measurement.

The optical fiber distributed temperature sensor (DTS) based on Raman scattering has been widely studied and developed in recent years. Due to its excellent electromagnetic interference resistance and its wide range of detection features, DTS has been successful applied in various fields, such as fire alarm, electric cable monitoring and leakage detection of oil pipeline [1,2]. For hazardous chemical warehouse, the warehouse temperature monitoring need to measure the temperature value of each location. The temperature monitoring of each position on the shelf can be realized by winding the temperature measuring optical fiber on the shelf of the warehouse.

When a certain frequency of laser is injected into the optical fiber, a collision and energy transfer between the photon and the optical fiber are produced; a Stokes light with higher wavelength than the original incident light and an anti-Stokes light with lower wavelength is produced. Fig. 1 shows the scattered light spectrum for a single wavelength signal, compared with other inelastic scattering, the scattering light produced by Raman scattering is larger and easier to separate. Besides, the Raman scattering signals contain temperature related information, thus, the Raman scattering signal can be used to obtain the temperature information of

* Corresponding author at: Beijing Institute of Petrochemical Technology, School of Information Engineering, Beijing, 102617, China.
E-mail address: 5320150415@bipt.edu.cn (H. Lu).

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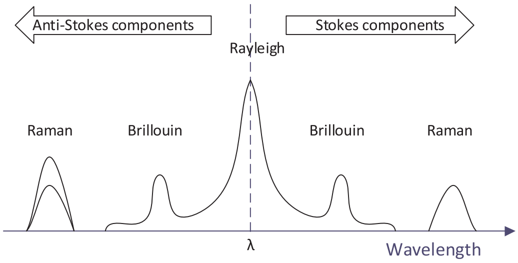

Fig. 1. Scattered light spectrum diagram.

scattering point in optical fiber.

At present, The DTS based on Raman scattering have demodulation methods based on Stokes lights and Anti-Stokes lights. This scheme can reduce the effect of laser output fluctuation on the measurement results [3]. The values of Stokes and Anti-stokes light signals obtained by system collection meet the following formula [4]:

$$I_{as}(l,\ T) = P_0\Gamma_{as}\frac{1}{\exp(\frac{h\Delta_v}{kT(l)})-1}\exp\left(-\int_0^l \alpha_p(l)dl-\int_0^l \alpha_{as}(l)dl\right) + N_{as} \tag{1}$$

$$I_s(l,\ T) = P_0\Gamma_s\frac{1}{1-\exp(-\frac{h\Delta_v}{kT(l)})}\exp\left(-\int_0^l \alpha_p(l)dl-\int_0^l \alpha_s(l)dl\right) + N_s \tag{2}$$

Where $I_{as}(l, T)$ and $I_s(l, T)$ are the values of Anti-stokes and Stokes signal respectively, P_0 is the intensity of the incident pump light. $\alpha_p(l)$, $\alpha_{as}(l)$, $\alpha_s(l)$ are the attenuation coefficients of the incident light, the Anti-stokes light and the Stokes light respectively. The N_{as} and N_s are the dark current noise of the Anti-stokes optical path and the Stokes optical path, respectively. Γ_{as} and Γ_s are the scattering coefficients of Anti-stokes and Stokes light, respectively.

Typically, the ratio between anti-stokes light and stokes light can be expressed as a function related to the location of the measurement points and its temperature. The R(l) is given by [5]:

$$R(l) = \frac{I_{as}-N_{as}}{I_s-N_s} = \exp\left(\int_0^l \alpha_s(l)dl-\int_0^l \alpha_{as}(l)dl\right) * \Gamma e^{-\frac{h\Delta_v}{kT(l)}} \tag{3}$$

By formula (3), the R(l) is the function related to $\alpha_{as}(l)$, $\alpha_p(l)$, Γ and T(l). In the long range temperature detection, the optical fiber attenuation will have influence on the demodulation results. When demodulation, it can be considered that the attenuation of optical fiber is only related to distance, which also means that $\alpha_s(l)$ and $\alpha_{as}(l)$ are constant value [6]. The optical fiber is placed in the same temperature environment, the data of backward scattering light are collected, and those data are fitted by exponential function fitting to get the value of $\alpha_s(l)$ and $\alpha_{as}(l)$.

The R (l) could be used to calculate the absolute temperature. A section of reference fiber is set in DTS, this reference coil is maintained at a known temperature, the temperature values of each point on the fiber can be obtained by the following formula as

$$T(l) = (\frac{k}{h\Delta_v}\ln(\frac{R(l_0)}{R(l)} + \frac{1}{T(l_0)})^{-1} \tag{4}$$

At present, there are a lot of studies on improving the temperature measurement accuracy of DTS system. In Ref. [7] B.N. Sun analyses the effect of Rayleigh scattering light noise contained in the acquisition signal and eliminates it in order to improve the temperature measurement accuracy. Liu Lei using the wavelet de-noising method to improve the measurement precision of the system in [8]. In addition, there are some schemes for high resolution and high precision measurement by changing the optical path or changing the internal structure of the equipment [9–11].

2. Theory of improving the accuracy of measurement

2.1. Analysis of the cause of error

The typical DTS system uses Eqs. (3) and (4) to calculate the temperature. However, the dark current noise in APD circuit and optical fiber attenuation coefficient need to be measured. Considering the N_{as}, N_s as a constant will affect the measurement accuracy of the system, and the fiber attenuation coefficient may be different at different points due to different fiber wiring schemes.

Generally, the DTS acquisition data is affected by optical fiber insertion loss, fiber attenuation loss and APD dark current noise, as is shown in Fig. 2. From Fig. 2, the intensity of Stokes and Anti-stokes light decreases with the increase of measurement distance, and there is fiber insertion loss in some areas at DTS. The length of the optical fiber is about 1700 m, and the signal value beyond the length of the measured fiber is produced by the APD circuit in the case of non-optical input.

Since the data of the original optical fiber measurement contains the output of the APD circuit without the input of the optical signal. The values of these parts in each measurement can be selected as the dark current noise values in the APD circuit. Fig. 3 shows