# REFERENCE TEMPERATURE EXPERIMENTAL STUDY OF A RAMAN-SCATTERING BASED DTS SYSTEM

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**Abstract:** Principle of Raman-scattering based distributed optical fiber temperature sensor (DTS) system is introduced briefly in this paper. The reference temperature is an important factor to improve the measurement accuracy of the DTS system. An experimental method is presented to study the relationship between reference temperature and measurement accuracy. A temperature & humidity chamber is used to provide different reference temperatures. Experiment data show that the measurement deviation decreases when the reference temperature increases.

**Keywords:** DTS, reference temperature, measurement accuracy, temperature & humidity chamber

## 1. INTRODUCTION

Raman-scattering based DTS (distributed optical fiber temperature sensor) system has been widely used for real-time measurement of spatial temperature field. The optical fiber is a transmission medium as well as a sensor. Using optical time-domain reflectometry (OTDR) technology, the DTS system can locate precisely any measurement point along sensing optical fiber, as well as measuring the distributed temperature information. Being explosion-proof, corrosion resistant, insensitive to the electromagnetic interference, the DTS systems are of particular interest in the electrical applications, fire alarm systems, industrial processing monitoring, etc [6].

Many factors may affect the temperature measurement accuracy of the DTS system, for example, the signal to noise ratio, reference temperature, environmental temperature, losses of the optical fiber, etc. In this paper, we study the reference temperature and present an experimental method to analyze the relationship between the reference temperature and the measurement accuracy.

## 2. PRINCIPLES OF THE DTS SYSTEM

Configure of Raman scattering based DTS system is shown in figure 1. The pulse laser is generated by the pulse driver and coupled into sensing optical fiber through Bi-direction coupler. The excited photons transmit in optical fiber and activate to the molecules of optical fiber. During the excited photons come into collision with the molecules, anti-Stokes Raman scattering and Stokes Raman scattering photons are generated. An optical wavelength division multiplexing (OWDM) separates anti-Stokes Raman scattering light which carrying the temperature information and Stokes Raman scattering light which is used for reference. Then both anti-Stokes Raman scattering light and Stokes Raman scattering light signals are filtered by filters and converted to electrical signals by avalanche photo diode (APD). The two channel signals are processed by signal processor. Industrial personal computer (IPC) is used to calculate out the temperature distributed information along the sensing optical fiber by temperature demodulation software and display. The intensity of Raman backscattering (including anti-Stokes and Stokes Raman backscattering) in fiber is very weak. The intensity of Stokes Raman scattering is nearly insensitive to temperature, so temperature can be calculated by Stokes Raman OTDR curve demodulating anti-Stokes Raman OTDR curve[1,2,5].
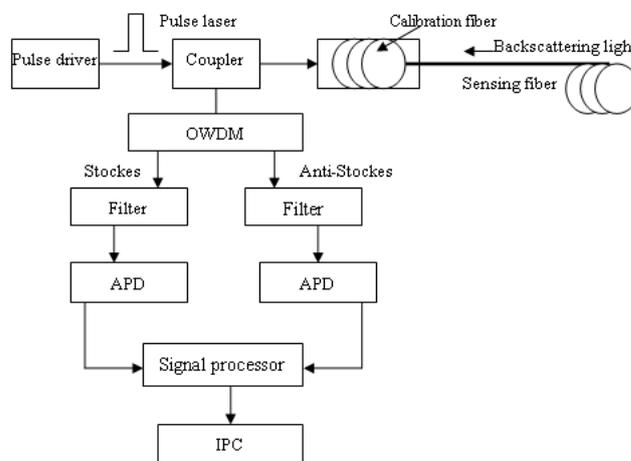


Figure 1. Configuration of Raman scattering based DTS system

Intensity of anti-Stokes Raman back-scattering:

$$P_{AS}(T) = \frac{v}{2} \bullet E_0 \bullet \frac{\exp(-h\Delta v / \kappa T)}{1 - \exp(-h\Delta v / \kappa T)} \bullet \Gamma_{AS} \bullet \exp[-(\alpha_0 + \alpha_{AS}) \bullet L]$$

(1)

Intensity of Stokes Raman back-scattering:

$$P_S(T) = \frac{v}{2} \bullet E_0 \bullet \frac{\exp(-h\Delta v / \kappa T)}{1 - \exp(-h\Delta v / \kappa T)} \bullet \Gamma_S \bullet \exp[-(\alpha_0 + \alpha_S) \bullet L]$$

(2)

Where, $P_{AS}, P_S$ are intensity of anti-Stokes and Stokes Raman backscattering respectively; v is the velocity of the light in fiber; $E_0$ is the power of the laser pulse; h is Planck constant; $\Delta v$ is molecular vibration frequency of Raman scattering, related to optical fiber material; k is Boltzmann constant; $\Gamma_{AS}, \Gamma_S$ are scattering factors of anti-Stokes and Stokes Raman scattering; $\alpha_0, \alpha_{AS}, \alpha_S$ are loss coefficients of optical fiber on the frequency of laser, anti-Stokes and Stokes Raman scattering respectively; L is the length of optical fiber.

The spatial temperature distributed curve is made by demodulation. Anti-Stokes Raman backscattering OTDR curve is demodulated by Stokes Raman backscattering OTDR curve. The ratio of the intensity of anti-Stokes and Stokes Raman backscattering has a simple exponential relation with the temperature:

$$R(T) = \frac{P_{AS}(T)}{P_S(T)} = \exp(-h\Delta v / \kappa T) \bullet \frac{\Gamma_{AS}}{\Gamma_S} \bullet \exp[(\alpha_S - \alpha_{AS}) \bullet L]$$

(3)

During $T = T_0$,

$$R(T_0) = \frac{P_{AS}(T_0)}{P_S(T_0)} = \exp(-h\Delta v / \kappa T_0) \bullet \frac{\Gamma_{AS}}{\Gamma_S} \bullet \exp[(\alpha_S - \alpha_{AS}) \bullet L]$$

(4)

The ratio of these two curves is given as following:

$$\frac{P_{AS}(T)}{P_S(T)} \bigg/ \frac{P_{AS}(T_0)}{P_S(T_0)} = \frac{\exp(-h\Delta v / \kappa T)}{\exp(-h\Delta v / \kappa T_0)}$$

(5)

Where, $T_0$ is the reference temperature, which is known. $P_{AS}(T)/P_S(T)$, $P_{AS}(T_0)/P_S(T_0)$ can be measured[3]. Therefore,

$$T = \frac{h\Delta v \bullet T_0}{h\Delta v - \kappa T_0 \bullet \ln[\frac{P_{AS}(T)/P_S(T)}{P_{AS}(T_0)/P_S(T_0)}]}$$

(6)

The distributed temperature on the optical fiber is calculated from formula (6). It can be seen from formula (6) that the temperature T is decided by the reference temperature $T_0$ and the ratio of the intensity of anti-Stokes and Stokes Raman backscattering. Reducing the impact of the reference temperature to DTS system is important to improve the performance of the DTS system.

## 3. EXPERIMENTAL SCHEME AND METHOD

In order to analyze the impact of reference temperature to the measurement accuracy of a DTS system, we proposed an experimental method.

The whole DTS system is placed into a temperature & humidity chamber, which is used to set different initial temperatures and provide different reference temperatures of the DTS system. A calibration bath is used for measurement. A optical fiber coil of 10 meters long and a

standard second-class platinum resistance are put into the calibration bath to measure the water temperature simultaneously. High sensitivity standard second-class platinum resistance is used to measure temperatures for comparison. The temperatures of the standard second-class platinum resistance are obtained as standard temperatures.

When the initial temperature parameter of the temperature & humidity chamber is setting, and DTS system is stable for a while, measurement begins. The reference temperature of the DTS system can be observed from the system. Then, the calibration bath is heating to 10℃, 20℃, 30℃, 40℃, 50℃, 60℃, 70℃, 80℃ gradually, and the experiment is repeated. After measuring, the measurement data is sending to the IPC to be processed by the demodulation software and LabVIEW. Then comparison is taken out for each measurement.

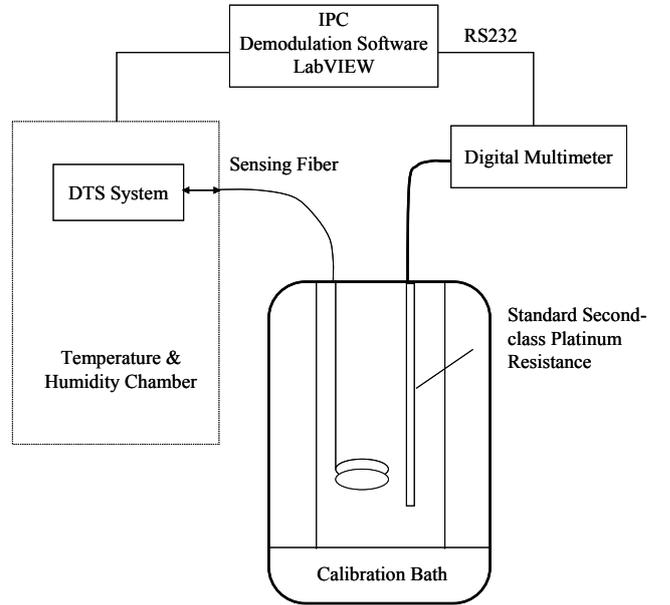The configuration of the experimental system is shown in figure 2.

Figure 2. Configuration of the experiment system

A commercial Raman-scattering based DTS system FGC-MR-I is used for measurement. The main specifications of the DTS system are listed as below:

Temperature Range: 0-100℃
Measurement accuracy: ±1℃
Spatial resolution: 3 m
Measurement range: 2 km
Minimum measurement time: 5s

Other experiment equipment: temperature & humidity chamber (Espec SETH-Z-042R), calibration bath (Fluck 7321 High Precision Bath), digital multimeter (Agilent 34401A 6 1/2 Digital Multimeter).

## 4. EXPERIMENTAL RESULTS

In each measurement experiment, the humidity of the temperature & humidity chamber is 50%RH, and the initial temperature is 10℃, 20℃, 30℃, 35℃ respectively. The reference temperature is around 10℃ higher than the initial

temperature. Deviation is calculated by subtracting standard temperature from measurement temperature.

Experiment data for initial temperature 10℃ ($T_0$ =20.4℃) is shown in table 1:

Table 1.   Experiment data sheet for $T_0$ =20.4℃

| No. | Standard Temperature (℃) | Measurement Temperature (℃) | Deviation (℃) |
|---|---|---|---|
| 1 | 9.7 | 9.1 | -0.6 |
| 2 | 19.7 | 19.4 | -0.3 |
| 3 | 29.7 | 29.1 | -0.6 |
| 4 | 39.7 | 39.2 | -0.5 |
| 5 | 49.7 | 49.2 | -0.5 |
| 6 | 59.7 | 59.1 | -0.6 |
| 7 | 69.6 | 68.9 | -0.3 |
| 8 | 79.5 | 79.3 | -0.2 |

Experiment data for initial temperature 20℃ ($T_0$ =30.6℃) is shown in table 2:

Table 2. Experiment data for $T_0$ =30.6℃

| No. | Standard Temperature (℃) | Measurement Temperature (℃) | Deviation (℃) |
|---|---|---|---|
| 1 | 9.7 | 9.0 | -0.7 |
| 2 | 19.9 | 19.2 | -0.7 |
| 3 | 29.7 | 29.2 | -0.5 |
| 4 | 39.8 | 39.3 | -0.5 |
| 5 | 49.8 | 49.3 | -0.5 |
| 6 | 59.7 | 59.2 | -0.5 |
| 7 | 69.6 | 69.2 | -0.4 |
| 8 | 79.5 | 79.0 | -0.5 |

Experiment data for initial temperature 30℃ ($T_0$ =40.3℃) is shown in table 3:

Table 3. Experiment data for $T_0$ =40.3℃

| No. | Standard Temperature (℃) | Measurement Temperature (℃) | Deviation (℃) |
|---|---|---|---|
| 1 | 9.7 | 9.3 | -0.4 |
| 2 | 19.7 | 19.5 | -0.2 |
| 3 | 29.7 | 29.5 | -0.2 |
| 4 | 39.7 | 39.7 | 0.0 |
| 5 | 49.7 | 49.6 | -0.1 |
| 6 | 59.7 | 59.7 | -0.0 |
| 7 | 69.6 | 69.6 | -0.0 |
| 8 | 79.5 | 79.2 | -0.3 |

Experiment data for initial temperature 35℃ ($T_0$ =45.1℃) is shown in table 4:

Table 4. Experiment data for $T_0$ =45.1℃

| No. | Standard Temperature (℃) | Measurement Temperature (℃) | Deviation (℃) |
|---|---|---|---|
| 1 | 9.7 | 9.3 | -0.4 |
| 2 | 19.7 | 19.4 | -0.3 |
| 3 | 29.7 | 29.5 | -0.2 |
| 4 | 39.7 | 39.6 | -0.1 |
| 5 | 49.7 | 49.6 | -0.1 |
| 6 | 59.6 | 59.7 | 0.1 |
| 7 | 69.6 | 69.6 | 0.0 |
| 8 | 79.6 | 79.5 | -0.1 |

## 5.  CONCLUSION

It can be seen from the above tables that the measurement deviation of the Raman scattering based DTS system decreases when the reference temperature increases. It is reasonable to choose a relative higher reference temperature to obtain better measurement results.

The impact of the reference temperature is important to design and calibrate the DTS system. Further experiment and analysis should be done to improve the measurement accuracy of the DTS system.

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