# A Research Based on the Temperature Field of High Precision Temperature Measuring Method of ROTDR

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***Abstract*—According to the traditional measuring method of oil well temperature deficiency, the temperature measurement solutions based on Raman scattering principle is proposed, the oil wells temperature monitoring system based on the distributed optical fiber sensor is built, and analyzing and testing its feasibility. On the basis of promoting test system hardware index and improving demodulation algorithm,deeply studied the spatial resolution closely related to accuracy and temperature measuring accuracy, proposed a calibration method of improving the distributed optical fiber temperature sensor temperature measurement precision. The experiment showed that, this method can effectively achieve the temperature of the more distributed real-time fast measure on temperature field of the original distribution, good temperature measurement stability, high precision.**

***Keywords- distributed ROTDR temperature field measurement calibration spatial resolution***

## I. INTRODUCTION

The temperature is an important parameters in the process of heavy oil reservoirs dynamic monitoring development, accurate underground temperature measurement can analyze the oil producing extent, providing liquid ability, and other important information, and it is very important to improve the recovery. At present the conventional infrared measuring temperature infrared thermal imaging well temperature measurement method has obvious shortcomings: the temperature sensor of heat balance time is long; sensor moving will affect underground original temperature field distribution; can't make underground temperature field distribution of long-term reliable monitoring in the high temperature and high pressure environment. In view of the distribution of the optical fiber sensor unique、all optical transmission oneness、the adaptability of the bad environment、strong electromagnetic interference resistance、high insulation、light、flexibility、the convenience project installation etc advantages. This paper proposes an oil Wells temperature monitoring online scheme based on light time domain Raman scattering sensor (ROTDR) principle, effectively getting the temperature field of information of the entire optical fiber distribution area of the temperature field of information, compared with conventional sensor, Information acquisition cost within unit length greatly reduced, cost-effective, reliability.

## II. THE TIME DOMAIN RAMAN SCATTERING DISTRIBUTED OPTICAL FIBER TEMPERATURE SENSOR PRINCIPLE AND MAIN TECHNICAL PARAMETERS

### *A. The principle of distributed ROTDR temperature measuring*

According to the light's optical fiber timing reflecting (ROTDR) principle and the optical fiber Raman scattering back temperature effect. When the laser that frequency is V0 incident to optical fiber, it produces constantly afterward scattering light waves while it forward in the fiber transmission, among these backward scatter light waves, besides a center spectral lines the same as incident light frequency V0,in the both sides, still exist two $\Delta V$ spectral lines of ($V_0 - \Delta V_0$) and ($V_0 + \Delta V_0$).Center spectral lines is the Rayleigh scattering spectrum line, spectrum line that its frequency is ($V_0 - \Delta V$) and wave length is $\lambda_s$ at the low frequency side is Stokes line; spectrum line that its frequency is($V_0 + \Delta V$) and wave length is $\lambda_a$ at the high frequency side is Anti-Stokes line. Distributed optical fiber temperature sensor is using the principle that temperature is closely related to spontaneous Raman scattering Anti-Stokes light in the optical fiber, through testing the ratio of Anti-Stokes signal and Stokes scattering light signal when the laser pulse spread in the fiber is generated to get a piece of thousands of meters temperature information on optical fiber.

According to the Raman scattering theory, in natural Raman scattering conditions, the ratio R(T) of Anti-Stokes light intensity Ia and Stokes light intensity Is is:

$$R(T) = \frac{I_a}{I_s}(\frac{\lambda_s}{\lambda_a}) = \exp(-hc\Delta V / KT) \tag{1}$$

In the formula: h is a Planck constant; c is the speed of light in the vacuum; V is the offset of wave number; K is a Boltzmann constant; T is thermodynamics temperature.

From the formula, we can see, R(T) has something to do with the temperature T, however, has nothing to do with light intensity and incident condition, optical fiber, geometry size and fiber optic components. Accordingly, with the help of the ratio of Anti-Stokes and Stokes backward Raman scattering light intensity achieve measuring the temperature absolutely.

For the formula (1), taking logarithm function to the both sides, get:

$$LnR(T) = 4\ln\frac{\lambda_s}{\lambda_a} \quad (2)$$

Through the transform , get:

$$T = \frac{hc\Delta r}{4k\ln\frac{\lambda_s}{\lambda_a} - k\ln R(T)} \quad (3)$$

In the curse of the actual testing, the fiber optical sensors are placed in the constant temperature box that its temperature is T to calibrated, when distributed optical fiber temperature sensor calibrated, sensor data is measured in a certain temperature, while measuring the corresponding values of standard thermometer. Before the measurement, optical fiber is placed in the constant temperature box for 2 hours, in order to ensure the balance between the optical fiber inside and outside and the temperature of the constant temperature box. Through the calibration, we can know:

$$4k\ln\frac{\lambda_s}{\lambda_a} = \frac{hc\Delta r}{T_0} + k\ln R(T_0) \quad (4)$$

Substitute formula 4 into formula 3, get:

$$T = \frac{hc\Delta r T_0}{hc\Delta r + kT_0[\ln R(T_0) - \ln R(T)]} \quad (5)$$

From the above formula, we can know, after calibrating, by measuring the ratio of the light intensity, it can deduce distributed optical fiber temperature value on different points. Therefore, regarding Anti-Stokes light as a signal channel, stokes light as the reference channel, detecting the ratio of the two light intensity, it can demodulate temperature information in the scattering area, while it also can effectively eliminate the instability of light source and coupling wastage in the process of optical fiber transmission, optical fiber connectors loss, optical fiber bending loss and optical fiber transmission loss and etc influence.

### B THE MAIN TECHNICAL PARAMETERS OF DISTRIBUTED ROTDR

#### 1) The spatial resolution

Refers to the minimum space distance when the distributed optical fiber sensor measured the measurement along the distribution of the fiber length. Light spreads in fiber optic, it need three processes to turn the light signal into the electrical signals that a computer can receive: laser source is poured into the laser pulse photoelectric detector response and processor conversion. Because the speed that light propagated in the optical fiber caused is much faster than that of the hardware circuit response signal. As shown in figure1, when the signal of point A in the optical fiber is detected circuit

response, corresponding to the original light signal in the position of point A l has spread to point B, therefore, need certain optical fiber length to achieve measuring accurately a temperature points. In the optical field, this optical fiber length L (which is the distance from A to B,) is defined as the spatial resolution. It is thus clear that, backward Raman scattering information that measurement system every moment gets from measuring terminal is a certain period on the signal accumulation of optical fiber sensor and is not an infinitesimal segment information on the optical fiber sensor. Backward Raman scattering signal of all points in the optical fiber sensor that is less than the spatial resolution when it arrives at terminal of the system is overlapped each other in time, obviously, the spatial resolution is the smaller, the better. The production process of the optical fiber's spatial resolution as shown in figure 1 below.

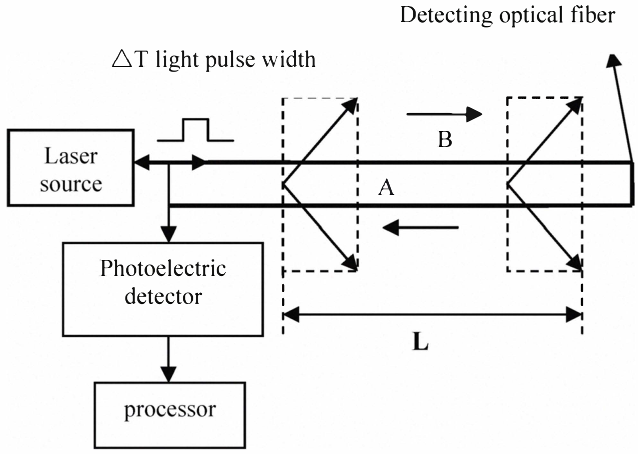



Figure 1. The generation processof optical fiber spatial resolution process

#### 2) Temperature resolution

Temperature resolution refers to the corresponding temperature variation when the signal-to-noise ratio is 1. It reflects a sensor system realize the extent of the accurate measurement, and it is concerned with signal-to-noise ratio of the system、 the fiber optical pulse energy、 backward Raman scattering coefficient of optical fiber and other factors etc. In order to increase the temperature resolution, measuring terminal must use the technology which can improve the signal-to-noise ratio, we should try to narrow amplifier band width to minimize noise in the premise of meeting spatial resolution of the system..

## III. THE DESIGN OF ROTDR TEMPERATURE MONITORING SYSTEM UNDER THE WELL

The structure of Raman scattering temperature sensing system as figure 2 shows, including sensing optical fiber, terminal system (DTS) and computer three parts.

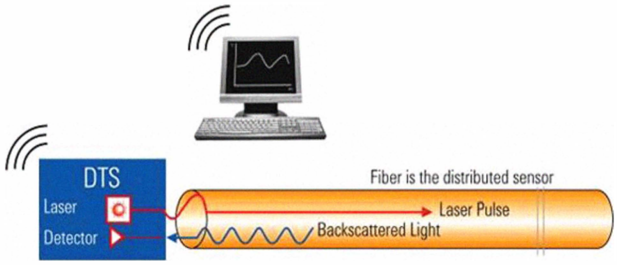



Figure 2. Raman scattering temperature sensing system structure

The front detection optical fiber is not only transmission media, but also sensing media, DTS is the core component of the sensor system, including light source, couplers, Wavelength Division Multiplexer and photoelectric detector, its main function is to realize the signal transmitting and receiving 、 filtering. Amplification and data analysis and output. Computer realizes the system control , signal processing, display storage and external other function expansion. Structure diagram of the system as shown in figure 3 below.

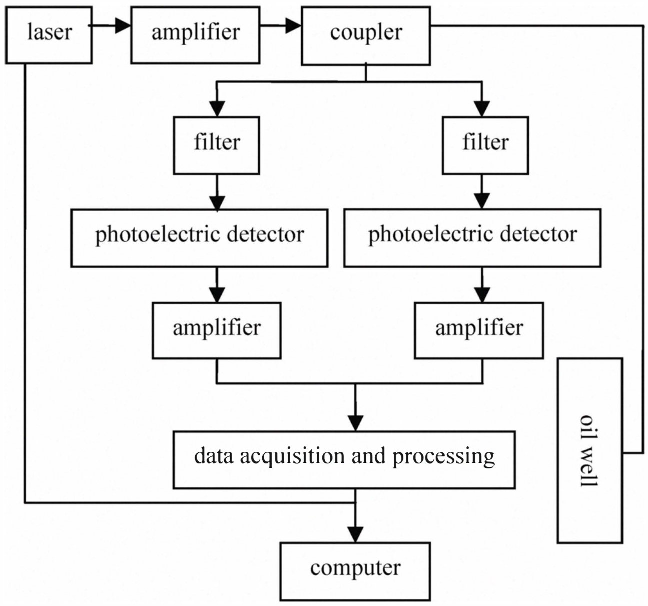



Figure 3. The structure diagram of temperature measurement system

Figure3 distributed ROTDR work process: semiconductor asers produce a very narrow pump modulation pulse, the light pulse from laser tail fiber output after fiber amplifiers power ascension through the coupling device goes into the sensing optical fiber. After laser happened scattering in the fiber, Rayleigh backward scattering light and Raman backward scattering light with a temperature information return to the light path coupling device, light path coupling device will directly couple launch light to optical fiber sensor, coupling scattering light to the filter, they respectively filter out Stokes light and Anti-Stokes light, the two way of optical signal through receiver were engaged in photoelectric conversion and amplification, so it is to finish photoelectric detection work on the signal. Now signal has converted light signals into electrical signals, again entering into the amplifier to amplify electrical signals respectively, and then respectively converting two pieces of A/D card through modulus to digital into digital signal, send the computer to carry on the signal processing、analysis and calculation，finally obtained the temperature field information of the corresponding points. Therefore, after a light pulse, sampling backward Raman scattering signal at a high speed more times, we can get along the temperature field distribution of the fiber axis, to realize temperature detection.

## IV. ROTDR CALIBRATION TEST

At present, ROTDR doesn’t have unified calibration specifications and standards in measuring. In order to ensure the precision of temperature measurement, try on the original ROTDR basis to calibration experiment design and temperature calibration test analysis for the actual temperature measurement error.

The objective: to determine the relationship of the temperature measurement error and fiber optic ring spatial resolution; ensure the influence of optical fiber ring length and position for the temperature measurement precision.

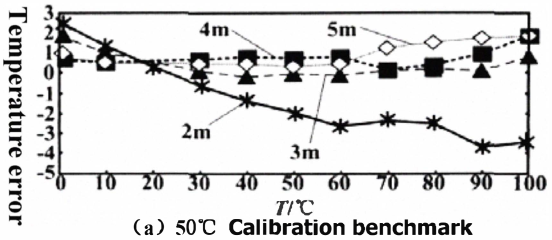
Test conditions: selected temperature range: 0～100℃; fiber optic ring spatial resolution: 2m、3m、4m、5m；Temperature measurement precision: ± 1K

Test equipment: Constant temperature cistern, standard platinum resistance thermometers, digital multimeter, ROTDR

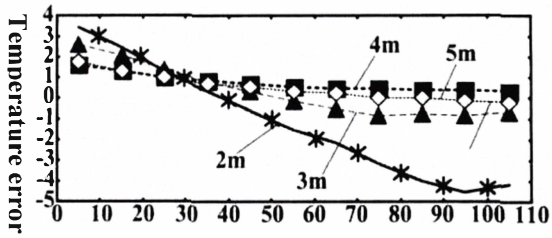
In the calibration experiment, the fiber optic ring and the standard that the length are required placed in the same environment ,ROTDR and standard platinum resistance thermometers synchronous large sample data collection, considering the random error factors, regarding the mean value of the error as a test data result.

### *A. Calibration test and analysis of different spatial resolution fiber optic ring*

Open constant temperature sink to control temperature, selecting 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 (unit:℃) as an experiment temperature points and then put respectively 2, 3, 4, 5 (unit: m) fiber optic ring in constant temperature sink. When 5 m fiber optic ring is calibrating test, 50, 80 were selected (unit:℃) as benchmark to test the two groups, each group of test through calibrating a temperature points as the benchmark, realize the temperature measurement error research for the test temperature points. According to the data of fiber optic ring calibration test, computing the mean temperature mean error as shown in figure 4.




(a) 50℃ **Calibration benchmark**




(b) 80℃ **Calibration benchmark**

Figure 4. Temperature error chart

Calibration experiment test results show that distributed optical fiber temperature sensor in each temperature point error is different, the distance between temperature measuring point and calibration benchmark is more far, the error is the greater. Choosing different calibration benchmark for 3m fiber optic ring can achieve satisfying the requirement of accuracy in the small scope, however, for 5 m fiber optic ring, selecting two calibration benchmark can make temperature measurement error meets the demand of precision, among them, the 50℃ calibration benchmark can ensure that the absolute error in the low temperature period is within 1K, satisfying the requirement of accuracy; 80℃ calibration point can ensure that absolute error in the high temperature period is within 1K, satisfying the requirement of accuracy; when selecting a calibration benchmark, calibrating 5m fiber optic ring effect was significantly better than calibrating 3m fiber optic ring, thus greatly improving temperature range the requirement of accuracy which meets the system; the mean error of 2m fiber optic ring is obviously without ±1K, verifying that when the length of fiber optic ring is less 3m than spatial resolution, temperature measurement error can not reach the temperature measurement precision of the distributed optical fiber temperature sensor; 3, 4, and 5(unit: m) fiber optic ring (detection fiber optic ring quartile length ≥spatial resolution) the results of the mean error show, the distribution trend of temperature error is consistent. When actually measuring the bigger range's temperature, according to the specific temperature measuring point , selecting appropriately several or more calibration benchmark to realize the calibration process.

### *B. The influence test of the optical fiber position for the detection accuracy and analysis*

Table 1 shows the corresponding error mean list of different fiber position measurement error test results.

TABLE I. TEMPERATURE ABSOLUTE ERROR DATA

| Fiber position/m | optical fiber length/m | | |
|---|---|---|---|
| | 3 | 4 | 5 |
| 96 | 0.25 | 0.21 | 0.05 |
| 521 | 049 | 043 | 051 |
| 901 | 1.82 | 1.80 | 1.20 |
| 1101 | 2.21 | 2.03 | 1.36 |
| 1210 | 2.79 | 2.14 | 1.07 |

From the table, we know that, the fiber optic ring which has the same length and different locations, the distance between light source and fiber position is further, absolute error of ROTDO is bigger. The same position and the different length of fiber optic rings, have different errors, and 5m optical fiber annulus comparing with 3m, 4m fiber optic rings, temperature measurement error is smaller.

Research shows that, the factors of influencing distributed optical fiber temperature sensor temperature measurement precision include calibration benchmark, fiber optic ring length and fiber position selection. Considering the three factors, through the above calibration method it can improve the measurement accuracy of distributed optical fiber temperature sensor temperature.

## V. THE EXPERIMENT DESIGN OF OIL WELL'S TEMPERATURE FIELD MEASUREMENT SYSTEM

Take an oil field observation wellas the test well, and use optical fiber temperature sensor to test its underground temperature.

According to the figure3, building systems, optical fiber sensor selection will multimode fiber encapsulation into temperature measuring optical cable, mainly is in order to avoid damage in the practical applications, the overall length of test cable is 1.3km. Take this way that optical fiber sensor with the oil tube bound together into the well to measure temperature. Pulse light source use domestic big light cavity high power laser diode, the peak power of the optical fiber reached 1.0W, pulse width is 50 ns, center wavelength is 1550nm, the offset is less than 2 nm; the division ratio that the coupler used is 50:38:12, the goal is to reduce the loss of light; filter adopting the coating of optical filter, and overlying use three slices to reduce the interference of pump, the wavelength offset of the filter is less than 5nm, Photoelectric detector bandwidth requirements for 80 Mhz, choosing C30902; the A/D converter Data of acquisition circuit adopts high speed A/D converter 8 bits to realize.Through testing experiment for test well we can see, along with the increase of depth, temperature gradually reduced, when it reduced to about 350 m, the temperature begin to rise, so we can judge it is close to mining face. As the temperature increases, when you get to the 800 m depth, temperature rises sharply, high temperature range covering about 200 m, it can judge that the interval is oil layer.Through the experiments, it prove that the temperature measurement precision and the spatial resolution of distributed optical fiber temperature measurement system can completely meet the needs of the temperature logging, and work in high temperature, high pressure, strong magnetic such complex conditions.

## VI. CONCLUSION

Distributed optical fiber temperature sensor as a new rising modern measuring temperature technology at present, has obvious advantages. This paper is based on the high precision temperature measuring method of ROTDR temperature field, overcoming the limitation of the sensor volume, electromagnetic interference which traditional electronic measurement equipments are in the complex environment under the wells, and also solve the problem of long distance signal transmission at the same time. The paper proposed the calibration method which select the suitable temperature calibration benchmark, fiber optic ring optical fiber length and position and effectively improve the accuracy of the ROTDR temperature measurement according to distributed ROTDR temperature measurement range, thus greatly reducing the distributed optical fiber temperature sensor measurement error, and laid a foundation for other calibration researches which has more big temperature range.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## REFERENCES


[1] Zhen'an Jia and Xiaobo Zhou, " The development status and trends of distributed optical fiber temperature sensor. " Optical Communication Technology.2008(11) .

[2] Huijuan Dong,,KanYang,and Guangyu Zhang."Comparative Experiment Study of Distributed Optical Fiber Temperature Monitoring Methods." IEEE International Conference on Information and Automation,2010

[3] KERSEYAD. " Optical fiber sensors for permanent down well monitoring applications in the oil and gas industry.. " IEICE Transelectron, 2000,E83-c(3),pp.400-404.

[4] John S.Selke, Luc The'venaz. " Distributed fiber-optic temperature sensing for hydrologic systems." Water Resources Research. 2006, 42,pp.1-3.

[5] P.Y.Zhu, Luc Thévenaz, " Seepage and settlement monitoring for earth embankment dams using fully distributed sensing along optical fibers." Proc.SPIE. 2008, 7160,pp.1117-1119..

[6] Zhiquan Li, Zhihua Bai and Huibo Wang." The research of multipoint temperature measurement of the distributed optical fiber temperature sensor." Optical Instruments, 2007, 29( 6),pp.: 8 - 11.

[7] Nath D K, Finley D B and Kaura J D. " Real-time fiber-optic distributed temperature sensing (DTS)--new applications in the oil field." SPE103069.2006.

[8] Goiffon J and Gualtieri D. " Applications of fiber-optic real-time distributed temperature sensing in a heavy-oil product on environment." SPE99449. 2006.

[9] Zhi Zhou, Chunguang Lan and Jinping Ou."New kind of FBG-based crack (large strain) sensor." SPIE,2006,(616714),pp.1-5.

[10] Suman,George O. Jr. "Casing bucking in producing interbals." Petroleum Engineer International.2005,(6),pp.:138-141.