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Research on Distributed Optical Fiber in Oil Well Temperature Field Measurement System

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Abstract: Distributed optical fiber temperature measurement is an emerging technology. The technology has a good application prospects in oil well temperature field measurement. This article analyzes and studies Raman distributed fiber optic temperature measurement system principle from the aspects of distributed measuring principle, distributed temperature measurement principle and temperature algorithm. Then, its software and hardware design is introduced and an experimental system was developed. The experiments have verified that those conclusions are right.

Key words: Distributed optical fiber, Temperature field temperature measurement, Raman scattering

INTRODUCTION

In oil extraction process, the down-hole temperature measurement can be very important measurement parameters. Accurate down-hole temperature measurement has an important role for geological data interpretation and oil monitoring. Especially meet the need of monitoring the down-hole temperature changes in the heavy oil thermal recovery process (Smith *et al*., 2008). Because of the underground harsh environment, traditional test instruments though have significant impact and easily lead to testing errors. Modern distributed optical fiber temperature sensor has advantages of multiple measurement points and high precision and lightweight and can withstand harsh down-hole environment (Xiao *et al*., 1999). Currently, distributed optical fiber temperature sensor has been achieved parameters measurements such as down-hole temperature field (Xiao *et al*., 1999). In the heavy oil thermal recovery process, measurement of temperature field has broad application prospects (Bing *et al*., 2002).

DISTRIBUTED OPTICAL FIBER TEMPERATURE SENSOR PRINCIPLE

The principle of temperature measurement: Distributed temperature sensor is using ODTR to realize distributed measurement. Optical pulse injects fiber from the point O, it is scattered when light propagates in fiber (Belleville and Duplain, 1993). It takes some time, Back-scattering light returns to the point O (Valvano *et al*., 1999). Assume the time of optical pulse injects fiber is time origin, The relationship of the distance L of scattering point from the point O with the time T of scattering returns:

$$L = \frac{1}{2} * vt = \frac{1}{2} * ct / n \tag{1}$$

c is the speed of light in vacuum;n is the refractive index of optical fiber;t for the signal from transmit to receive the time spent (Finger *et al*., 2003).

We can see from the formula, echo at different times correspond to different distances generated by scattering (Finger *et al*., 2003). According to measurements at different times of the echoes, we can determine the location of the point by temperature measurement.

Temperature sensing and measurement is based on Raman scattering of fiber headed in opposite directions. From the experiment can be aware of Anti-Stokes Raman scattering is temperature-sensitive and strength was controlled by temperature, while the Stokes scattered light is nothing to do with temperature. The ratio between the light intensity is only related to temperature and scattering of light, As follows:

$$R(T) = \frac{Pa(T)}{Ps(T)} = (\frac{\lambda s}{\lambda a})^4 e^{-\frac{hc\Delta\gamma}{kT}} \tag{2}$$

h is Planck's constant; c is the speed of light in vacuum; k is Boltzmann's constant; T = absolute temperature; $\Delta\gamma$ is the number of off-set wave.

Therefore, anti-Stokes light as a signal channel, Stokes light as a reference channel, Can be demodulated

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temperature information of scattering zone by detection of the ratio between the light intensity (Corbett *et al*., 2003). The measurement of the Raman scattering headed in opposite directions signals combined with the OTDR technique, it can be achieved that system of measuring Temperature by distributed optical fiber based on Raman scattering headed in opposite directions.

Temperature algorithm: From the above formula 2, at the same time on both sides of it taking logarithmic functions are:

$$\ln R(T) = 4\ln\frac{\lambda s}{\lambda a} - \frac{hc\Delta\gamma}{kT} \quad (3)$$

Through the transformation, we can get:

$$T = \frac{hc\Delta\gamma}{4k\ln\frac{\lambda s}{\lambda a} - k\ln R(T)} \quad (4)$$

In the actual test process, the fiber optic sensor is placed on the temperature box of T0 to calibrate. Through the calibration, we can see that:

$$4k\ln\frac{\lambda s}{\lambda a} = \frac{hc\Delta\gamma}{T0} + k\ln R(T0) \quad (5)$$

Bring the Eq. 5 into 4 to can see that:

$$T = \frac{hc\Delta\gamma T0}{hc\Delta\gamma + kT0(\ln R(T0) - \ln R(T))} \quad (6)$$

From the above equation, after carrying out calibration, we can see distributed optical fiber temperature points by measuring the light intensity ratio of R (T).

TEMPERATURE FIELD MEASUREMENT SYSTEM DESIGN

Hardware design of measurement system: Distributed fiber optic temperature measurement system mainly consists of pulsed laser, fiber amplifier, optical fiber directional couplers, filters, photoelectric detectors, amplifiers, data acquisition and processing circuits, information processing and display (computer), sensitive optical fiber, incubators as so on (Ge *et al*., 2013). System structure diagram is shown in Figure 1.

Functions of each part are as follows: Pulsed laser's primary role is to provide light pulses for the system (Naylor, 1998). Fiber amplifier amplify low-light signal and increase the signal strength. Optical fiber coupler coupled into the fiber in accordance with design requirements of the optical signal and the scattered light signal of return coupled into the light processing pathway by a predetermined ratio. Filters isolated Stokes light and anti-Stokes light and filtered Rayleigh backscattering light. Photoelectric detector will convert the receiving optical signals into corresponding electrical signals to provide inputs for information processing circuits. Amplifier amplifies the weak electronic signal for A/D conversion. Data acquisition and processing circuitry mainly complete optical signal A/D conversion and signal correlation processing. Data analysis and display processing by computer communicates with the data

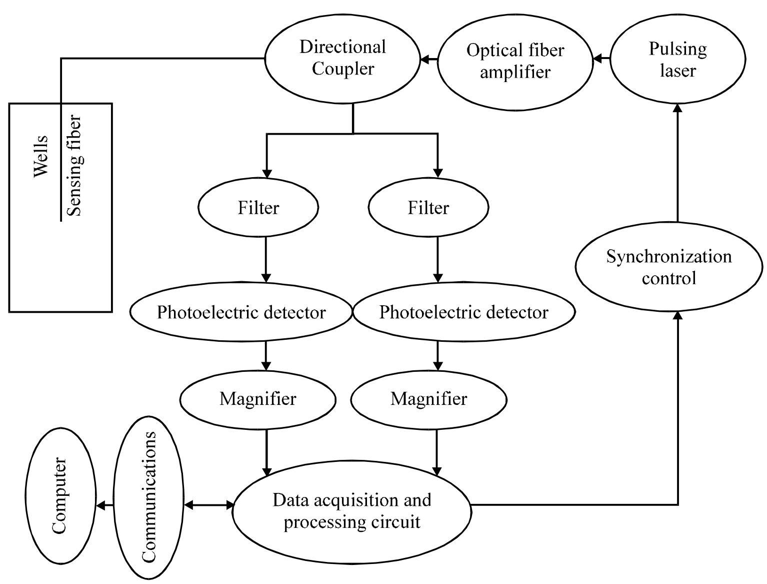

Fig. 1: Block diagram of temperature field measurement system

acquisition circuit. Optical fiber couplers, filters and photoelectric detector and other key components are placed in the thermostat (The constant temperature is 200°C)

The working process of temperature field measurement system is stated as follows: under the control of the computer and data acquisition circuits, pulsed laser sent light pulses signals (Yang, 2005). After Optical pulse signal has been amplified, directional coupler coupled Optical pulse signal to the sensing fiber. Optical fiber sensor is put in heavy oil temperature field. Light pulses transmission in the sensing fiber will trigger scattered light (the Stokes and anti-Stokes in Raman scattered light) in the position of each point. Part of backscattering in scattered light entered the directional coupler through the optical fiber transmission channels. The directional coupler coupled into the receiving channel. After the optical filter, filter out Rayleigh backscattering of the relative strength energy and isolate the anti-Stokes light and Stokes light of containing the temperature information. Respectively, achieve conversion of optical signals in photoelectric detector. After amplification, sent to the data acquisition and processing circuit to achieve A/D conversion and signal correlation processing. Processed information is sent to the computer. Computer can complete analysis and processing and display.

Software of measurement system design: System software includes data collection and processing terminal software and computer terminal software. Among them, data collection and processing terminal software are mainly responsible for signal collection. At present, this technology is already very mature. Computer terminal software of the system uses LabVIEW which is from NI Company. It is mainly to achieve control of temperature field testing system, system settings and temperature distribution graph shows etc. Software interface shown in Fig. 2.

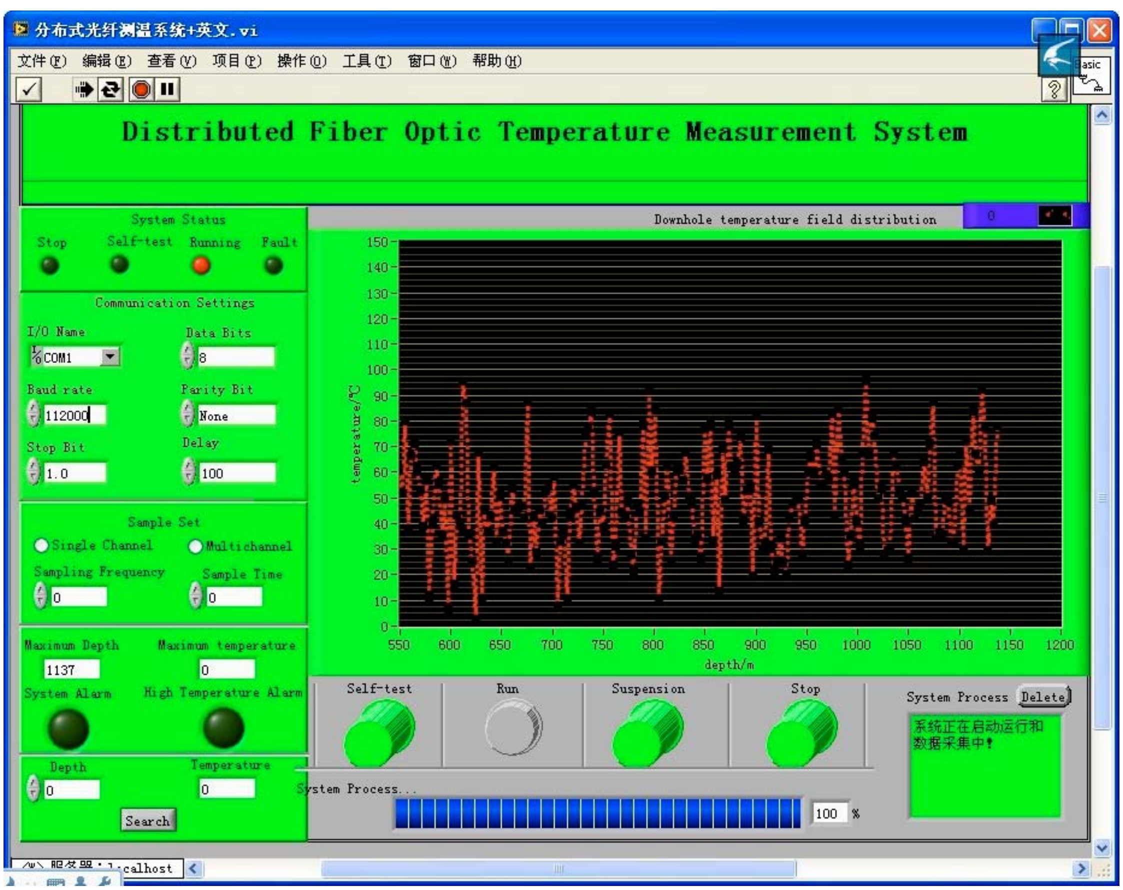

Fig. 2: Temperature field display interface

EXPERIMENTAL DESIGN OF TEMPERATURE FIELD MEASUREMENT SYSTEM

According to the diagram 1, construct measurement system. Pulse illuminant chooses home-made big high-power semiconductor lasers. The peak power of fiber is 110 w. Pulse width is 50 ns. Center wavelength is 1550 nm. Offset is less than 2 nm. Coupling ratio is 50:38:12. The purpose is to reduce the optical loss. Filters use coated optical filter chip. And use multi-chip stack in order to reduce the interference of pump light. Wavelength offset of filter is less than 5nm. Photoelectric detector required 80 MHz bandwidth and selected C30902E/C30724E. Amplifier must be high-gain, broadband, low-noise amplifier and use rail-to-rail Operational Amplifier AD8552. Optical fiber sensor is made of linear distributed optical fiber temperature sensor and distributed optical fiber point windings temperature sensor. A/D converter of data acquisition circuit uses A/D converter AD9048 of high-speed 8-bit to achieve and the maximum sampling rate is 35 MSPS.

After calibrated self-designed temperature field measurement system, when measuring heavy oil High-temperature mining in temperature field, fiber are distributed in the insulating tube and temperature field measurement can be realized approximately to 1400 m. Proven discovery, the temperature field measurement system design method is unique. The spatial resolution of the system reaches 1m. Temperature measurement accuracy achieved 0.5. Satisfy temperature field measurement requirements of heavy oil High-temperature mining.

CONCLUSION

Distributed optical fiber temperature measurement system as a temperature measurement is currently emerging new technologies in temperature measurement areas (Song *et al*., 2004). Its advantages are clear. Not only can apply in high-end areas, but also have been rapidly expanded in traditional industrial areas. The system is particularly suitable for large area, multi-point continuous real-time temperature field measurement requirements. Entirely by virtue of its unique material and merits on the shape replace most of the traditional temperature measurement system. At present, the use and development of distributed fiber optic temperature measurement system are at an early stage in China's oil industry. But can be predictable, with the growing maturity of the production technology and continuous improvement of device performance, distributed fiber optic temperature measurement system will be more widely used in the oil exploration areas.

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