

Research of pipeline monitoring system based on fiber optic pressure sensor

Lv Jiabo, Xu Xiping, Cai Cunliang, Zhang Shaojun

(School of Electro-Optical Engineering, Changchun University of Science and Technology, Changchun 130022, China)

Abstract: For the problem that it is difficult to find and locate the leakage or the blockage of the pipelines buried in the soil, combined with fiber optic pressure sensor with high sensitivity, high anti-jamming feature, a pipeline monitoring system was designed based on fiber optic pressure sensor. It used polarimetric pressure sensor which consisted of single mode fiber optic coated with a suitable thermal expansion coefficient of the material to overcome ambient temperature perturbation well. The pressure sensitive probes with modular design were distributed in pipeline every 20 meters to form an array of source signal point. Combined with lattice array data reconstruction and "interpolation positioning algorithm" to determine the location of faults. The results indicate that the system of fiber optic pressure sensor can effectively overcome the adverse effects of temperature changes on the sensor measurement. Within the range of 5.5 km, the positioning accuracy of fault point is within ± 1 m.

Key words: fiber optic pressure sensor; modular; interpolation positioning algorithm

CLC number: TH741 **Document code:** A **Article ID:** 1007-2276(2015)11-3343-05

基于光纤压力传感器的管道监控系统研究

吕佳博,徐熙平,才存良,张少军

(长春理工大学 光电工程学院,吉林 长春 130022)

摘要: 针对运输管道埋设于土壤中面临的泄漏或堵塞点难发现、难定位的问题,结合光纤压力传感器高灵敏度、高抗干扰的特性,设计了一种基于光纤压力传感器的管道监控系统。系统采用包覆有合适热膨胀系数材料的单模光纤组成的偏振型压力传感器,能很好地克服外界环境温度扰动;采用模块化设计的压力敏感探头以 20 m 间距均布于管线上,形成信号点阵列源;结合点阵列数据重构与“插值定位算法”确定故障点的位置。结果表明:该系统的光纤压力传感器可有效克服温度变化对传感测量的不良影响,5.5 km 范围内对故障点的定位精度在 ± 1 m 内。

关键词: 光纤压力传感器; 模块化; 插值定位算法

收稿日期:2015-03-14; 修订日期:2015-04-16

作者简介:吕佳博(1989-),女,硕士生,主要从事大功率 LED 散热技术方面的研究。Email:992493483@qq.com

导师简介:徐熙平(1969-),男,教授,主要从事光电在线检测技术与仪器方面的教学与科研。Email:xsp@cust.edu.cn

0 Introduction

Fiber optic sensors are passive to avoid sparks and work in explosive environment. They are not afraid of hydraulic pressure or corrosion, and suitable for measuring in flammable, toxic environment and toxic liquid. Fiber optic sensors have some advantages as large capacity of information, easy to combine with optical remote sensing net and to achieve remote measurement and control. They have good prospect. Pipeline transportation has advantages like closed security, large capacity of transport and low price of transport cost and it is helpful to be controlled and managed. It has been widely applied as a safe, economical transportation method. Pipeline leak detection technology has gained increasing attention in IT work and become a top priority. Currently in domestic and international oil and gas pipeline real-time monitoring technology, fiber optic sensors use dual fiber as the signal arm and reference arm. Two light signals form an interference signal, after demodulation we can get fault point information. But the major drawback of interferometric fiber optic sensors is unavoidable disturbance of temperature to the fiber during measuring, so the great fault information interference brings about the failure of obtaining accurate location information. To solve the problem above, the system uses a polarization pressure sensor consist of single mode fiber which coated with suitable thermal expansion coefficient material to overcome the effect of ambient temperature effectively. Use modular sensor combined with three points mounting position and interpolation to pinpoint the location of the fault on the pipeline route.

1 Principle introduction

1.1 Single-fiber polarization interferometer pressure

Single fiber polarization interference-type pressure sensor is based on the high birefringence polarization to keep great propagation constant of the two

orthogonal polarization of single-mode fiber. At the same time the phase in external factor is different. Therefore, use the interference between these two modes to sense the pressure measured.

Figure 1 shows a single fiber-optic interferometer structure. The laser beam emitted from the He-Ne laser becomes circularly polarized light after through polarizer and a 1/4 wavelength plate to uniform excitation to the two orthogonal polarization mode of high birefringence single mode fiber. Single-mode fiber disturbed by external factors such as pressure, temperature, etc. makes the optical fiber produced phase shift in two different modes. The output light compounds rotary polarization state to get two beams of linearly polarized light through a Wollaston prism. One is 45° I_1 , another is 135° I_2 linearly polarized light. In order to counteract the effects of light intensity, two optical detectors receiving the two beams of linearly polarized. After treatment, we get the result:

$$\frac{I_1 - I_2}{I_1 + I_2} = \cos(\Delta\varphi) \quad (1)$$

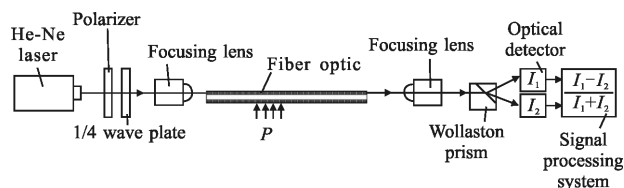


Fig.1 Single fiber interferometer

In the formula, $\Delta\varphi$ is "induced" phase shift caused by fiber optic mode in external pressure. Measurement and the phase shift is a function of the cosine. This will result in reducing sensitivity of the small signal region. To improve this situation, SHC compensator can be added in the optical path of the interferometer, the output light signal will be 1/2 wavelength phase shift. So the result will become sine function:

$$\frac{I_1 - I_2}{I_1 + I_2} = \cos\left(\frac{\pi}{2} + \Delta\varphi\right) = -\sin(\Delta\varphi) \quad (2)$$

Because the phase shift is formed by two orthogonal polarization modes:

$$\varphi=(\beta_x-\beta_y)l=\delta\beta l \tag{3}$$

where β_x, β_y are propagation constant of two orthogonal polarization modes respectively. l is fiber length. if

$$\delta\beta=k_0(n_1-n_y)=k_0\delta n \tag{4}$$

So,

$$\Delta\varphi=k_0\delta n dl+k_0 l d(\delta n) \tag{5}$$

or

$$\frac{\Delta\varphi}{l\Delta l}=\frac{\delta\beta}{l}+\frac{d(\delta\beta)}{dl} \tag{6}$$

According to the above equation, for high birefringence fiber, when only considering axial strain we get

$$\Delta l=-pl(1-2\mu)/E \tag{7}$$

Substituting into Eq.(6) we get

$$\frac{\Delta\varphi}{pl}=-\left(\frac{\delta\beta}{l}+\frac{d(\delta\beta)}{dl}\right)l(1-2\mu)/E \tag{8}$$

The relationship of phase shift in the two orthogonal modes between the measured pressure can be determined. Eq. (8) is the expression of single fiber interferometer type pressure sensor sensitivity.

To the birefringent fiber without cladding, The temperature sensitivity depends primarily on changes in residual stress in the fiber.

$$\Delta\varphi_i\Delta t=-\frac{2\pi}{\lambda}\left(\frac{Bl}{t_0-t_1}\right) \tag{9}$$

If you consider the fiber strain caused by tensile, the sensitivity is

$$\Delta\varphi/\Delta s_z \approx \frac{2\pi}{\lambda}RBl \tag{10}$$

Where R is a constant about fiber parameter and high birefringence fiber is generally about 20.

If the fiber optic elongation caused by thermal expansion of covering material on the fiber, we can counteract the effects of temperature changes on sensitivity.

The compensation condition is

$$a_i=\frac{1}{R(t_0-t_1)}+a_0 \tag{11}$$

To the covered with three polarization fiber optic, the coefficient of thermal expansion is

$$a_r=\sum A_i E_i a_i / \sum A_i E_i \tag{12}$$

1.2 Probe design principles

Sensor probe structure in the process take the following technical measures.

It has a function of sensor series, The sensors use the form of leading the fiber from the ends without pressure. There is no curvature to ensure the insertion loss and tandem. It can reduce long term drift in downhole environment. To reduce the creep, sensor uses temperature compensation, so that the stress on the fiber pressure sensor does not change with temperature change.

A diagram of the sensor structure is shown in Fig.2. The stress sensitization tube uses stainless steel whose expansion coefficient is $17 \times 10^{-6}/^{\circ}\text{C}$. The protective coat is made of carbon steel whose expansion coefficient is $11.5 \times 10^{-6}/^{\circ}\text{C}$. Thermal expansion coefficients of the two materials are similar but subtle differences. When the temperature rises, the two kinds of materials expand by heat differently to generate additional pressure to the pressure sensitive fiber optic. Resist the pressure sensitive fiber expansion caused by temperature increasing, So that the pressure sensitive fiber optic substantially independent of temperature changes.

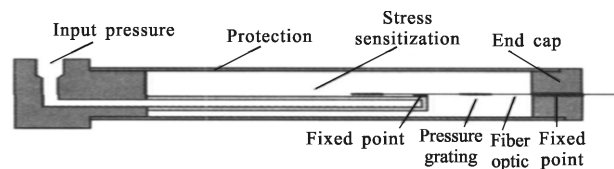


Fig.2 Schematic diagram of the structure of sensor

1.3 Three-point positioning principle

Pipeline monitoring system based on a modular fiber optic pressure sensor uses three-point positioning model. The basic idea is selecting three detection points from the probe points covered on the pipeline. When a fault signal occurs, three detection points will detect the corresponding signal respectively. Using the interpolation algorithm to calculate the signal intensity respectively to obtain value of the corresponding distance. The solve each of the three circles to find

the center of gravity in public areas in order to determine the physical location of the fault signal. If we assume that each node is in the same plane and is able to receive signals, the physical location of each node can be pinpoint.

2 Algorithm description

2.1 Fault signal sorting algorithm

System select fault signal algorithms correctly from the passive radar signal sorting mechanism. Passive radar does not radiate electromagnetic waves, but with the help of external non-cooperative radiation source to detect and locate, it provides location information of the target and the nature of the target. So passive radar has advantages of hiding and not easy to be found to against anti-radiation missiles, low-altitude aircraft, cruise missiles and other attacks. Radar pulse signal sorting technique is based on the direction of the radar pulse DOA, and the characteristics of the pulse width PW, pulsed carrier RF, etc. Pulse repetition interval de-interlace achieves a precise split and reconstruction of different target signal.

2.2 Interpolation positioning algorithm

At a distance along the three detector to detect a series of points of the signal strength and write in the configuration file respectively. When detecting the signal intensity, make a interpolation of signal strength in the configuration file respectively to find out the appropriate distance and solve the circle with the three distance radius to get the center of gravity.

If we set point coordinate on both ends of the line: $a(x_1, y_1)$, $b(x_2, y_2)$ $x_1 \leq x \leq x_2$, the actual slope of the line interpolation process can not be infinite. So only consider the general situation:

$$y_0 = \frac{(y_2 - y_1)(x_0 - x_1)}{x_2 - x_1} \quad (13)$$

In the positioning process, the detector A intercepted invasion signal intensity is p . If the signal strength of the samples p is between the twp sampling points in the probe A. We can solve for the invasion

signal at a distance L after linear interpolation is

$$L = \frac{(L_{x+1} - L_x)}{p_{x+1} - p_x} + L_x \quad (14)$$

3 Experiment and data processing

3.1 Diagram of system

Fiber optic pressure sensor working diagram is shown in Fig.3.

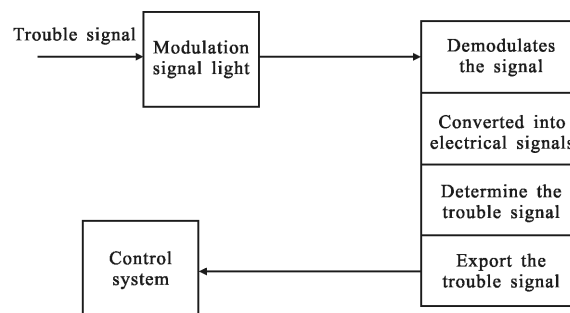


Fig.3 Fiber optic pressure sensor working diagram

Modular fiber optic pressure sensors are distributed in the pipeline uniformly. Fault signal modulate light through the sensitive fiber optic. From optical output different polarization states of modulated light, then demodulate and convert the collected signal. When determining fault signal, transmit the signal to the host machine and control system through radio repeater station. When some sensors answer the fault signal, PC makes analysis and scream out warning. Working diagram of modular fiber optic pressure sensor security system is shown in Fig.4.

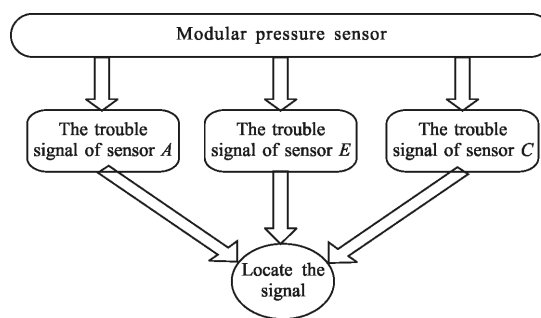


Fig.4 Modular light pressure sensor security system working schematic diagram

3.2 Experiment and data processing

For a single optical fiber pressure sensor test

device is shown in Fig.5.

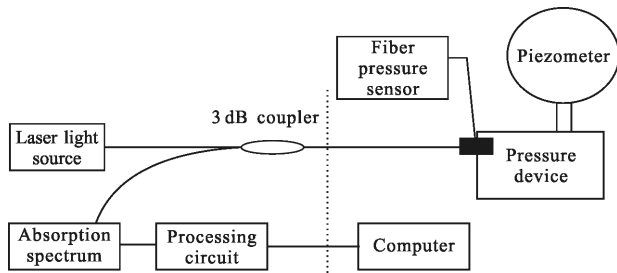


Fig.5 Laboratory testing schematic

Under normal temperature conditions, the modular fiber optic pressure sensors were distributed in the pipeline every 20 m, for 60 fault simulations, anchor point and the actual measurement point interpolating data simulated by Labview as shown in Fig.6.

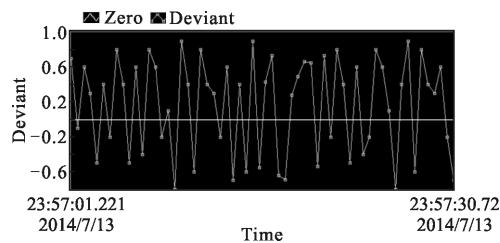


Fig.6 Laboratory testing schematic

4 Conclusion

Polarization type modular fiber optic pressure sensor uses shrouded birefringent fiber to avoid disturbance of the temperature effectively. Using the three-point interpolation positioning algorithm to locate the fault signal. Practice has proved that the

system has high sensitivity and reliability for long hours of work. Combined with waterproof housing and floating beacon, the system can also be applied to subsea pipeline security.

References:

- [1] Liu Wu, Li Min, Liu Yi, et al. Decision of optical scheduling scheme for gas field pipeline network based on hybrid genetic algorithm[J]. *ACM*, 2009: 369–374.
- [2] Zhao Tianfeng, Duan Menglan, Pan Xiaodong, et al. Lateral buckling of non-trenched high temperature pipelines with pipelay imperfections [J]. *China University of Petroleum*, 2010, 7(1): 123–131.
- [3] Wang Xuan, Duan Changgui, Yu Biyong. Layout optimization of branched gas network by genetic algorithm [J]. *Gas & Heat*, 2005, 25(4): 1–4.
- [4] Wei Yufeng, Hu Yunjian, Xie Xin. Application of an improved genetic algorithm for the layout of natural gas networks [J]. *Journal of Beijing University of Chemical Technology Natural Science Edition*, 2007, 36(6): 666–660
- [5] Anatoli A Chtcherbakov, Pieter L Sawart, Polarzation effects in the Sagnac-Michelson distributed disturbance location sensor [J]. *Journal of Lightwave Technology*, 1998, 16(8): 1404–1412.
- [6] Martinelli M, Russell A C. Endless polarization control algorithm using adjustable liner retarders with fixed axes[J]. *Journal of Lightwave Technology*, 2003, 21(9): 2089–2096.
- [7] Youssef M A, Agrawala A, Shankar A U, et al. A probabilistic clustering based indoor location determination system [R/OL]. [2002 –03 –22]. <http://hdl.handle.net/1903/1192>.
- [8] Xu Lanfang, et al. Survey of context aware mobile computing research [J]. *Computer Science Engineering*, 2007, 29(4): 132–134.