Second Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

SMAR 2013

Fiber Optical Scour Monitoring System for Subsea Oil Pipe Line

Xuefeng Zhao[1], Le Li[2], Yan Yu[3]

[1] School of Civil Engineering, Dalian University of Technology, Dalian, China
[2] TianJin Branch of China Construction Eight Engineering Division. Corp. LTD, Tianjin, China
[3] Faculty of Electronic Information and Electrical Engineering, Dalian university of Technology, Dalian, China

ABSTRACT: A scour monitoring system of subsea pipeline is proposed using distributed Brillouin optical sensors. The system consists in a thermal cable running parallel to the pipeline, which acquires frequency shift during heating and cooling, directly indicating temperature change. The free spans can be detected through the different behaviors of heat transfer between in-water and in-sediment scenarios. Firstly, temperature sensitivity test was conducted, and then scour monitoring test was conducted using the proposed system. Test results show that the proposed monitoring technique can monitor the sour suspension of subsea pipeline precisely.

Key words: Subsea pipeline, Scour, Monitoring, BOTDA

1 INTRODUCTION

Subsea pipeline is important structure of sea oil production. During the service period, the subsea pipeline will suffer the severe environmental loads. Not only subsea pipeline is affected by environmental loads, such as current load, but also inner corrosion, and Vortex-induced vibration induced by scour suspension, as well as inner pressure and impaction induced by falling items from ships [1]. The loads mentioned above will lead to structural failure of subsea pipeline, which will make bad effect on normal production directly. On the other hand, the oil leaking will make severe damage on ocean environment. Nowadays, there is some research works reported about safety monitoring of subsea pipeline structures[2-4]. Because of the distribution feature, it is very difficult to install sensors or monitoring equipment on the subsea pipeline surfaces, in some common ways which are applicable for other kinds of structures, such as welding, glue mounting.

Brillouin Optical Time Domain Analyzer (BOTDA) is a novel kind of optical sensing technique, which develops very quickly recent years [5,6]. BOTDA has many advantages over traditional sensors, such as good durability, electromagnetic interference immunity, long sensing distance, distributing sensing ability. Comparing to Fiber Bragg Grating (FBG) sensing technique, precision of BOTDA is relative low, but the sensor cost of BOTDA monitoring system is pretty lower than FBG monitoring system. Normal single mode optical fiber can be utilized as sensor. Strain and temperature at any point along more than 30km's sensing distance can be monitored by BOTDA analyzer. BOTDA has already attracted attention of some researchers, there are some application reported[7,8] .

There will be different requirement for the BOTDA optical sensor, according to different monitoring objects. Normally, BOTDA is used for strain and temperature monitoring over a long distance, such as distributing strain and temperature along a pipe line structure with length of several 10 kilometers. Strain and temperature monitored at some point are actually averaging value along certain amount of distance. In this paper, one novel kind of scour monitoring technique is proposed to detect the suspension length of subsea pipeline induced by scouring.

2 BASIC PRINCIPLE

The Brillouin optical time-domain analyzer is a distributed optical fiber sensing technique whose operation is based on the Stimulated Brillouin Scattering (SBS)[6]. SBS process arises from the interaction between the propagating light and thermally excited acoustic waves present in the fiber. This interaction generates backscattered waves that experience a Doppler frequency shift. The Doppler frequency shift, also called the Brillouin frequency shift is directly related to the velocity of the acoustic waves in the fiber and is given by:

$$f_B = 2nv_a / \lambda \qquad (1)$$

where n is the index of refraction of the fiber,   the acoustic velocity and   the wavelength.

Since the acoustic velocity depends primarily on the temperature and strain of the fiber, the Brillouin frequency shift is temperature and strain dependent. This dependence is linear and can be described as follows:

In the case of pure temperature variations, the relation can be expressed as

$$f_B = k_{ft}\Delta T + C \qquad (2)$$

where   is the temperature coefficient of Brillouin frequency shift, the temperature change and C a constant.

In the case of pure strain variations, the relation can be expressed as

$$f_B = k_{f\varepsilon}\Delta\varepsilon + C \qquad (3)$$

where is the strain coefficient of Brillouin frequency shift, the strain change and C a constant.

As a result, by measuring the Brillouin frequency shift we have access to the local temperature and strain conditions providing that the calibration coefficients,   and C are known for a given fiber.

3 TEST

3.1 Temperature sensitivity test

In order to test temperature coefficient and linear relationship at different fiber optic length. Five kinds of BOTDA temperature sensor with bare fiber optic length of 1m, 2m, 5m, 10m, 20m, are packaged and tested, respectively. Certain amount of fiber optic (1m, 2m, 5m,10m, 20m) is circled into circles with 10cm’s diameter, and then be placed into one plastic box. The optical circles are one point glued inside the box, which make the optical circle is only sensitive to temperature. The plastic box serves as one strain isolation shield and as packaging structure, as figure 1 show.

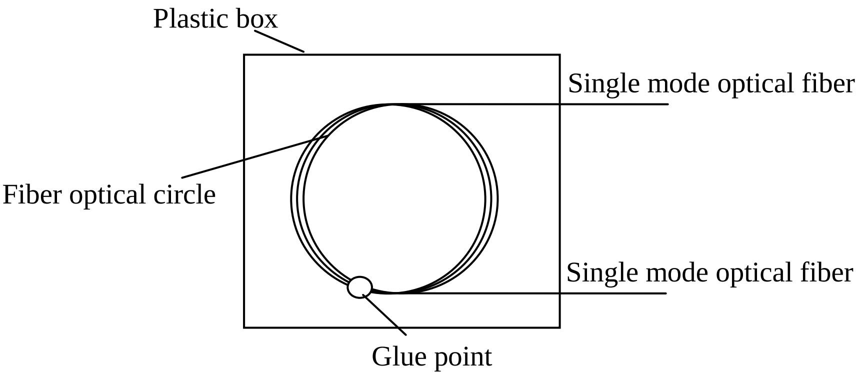

Figure 1. Package structure of BOTDA temperature sensor

Water bath machine is used to test the BOTDA temperature sensor, as figure 2 shows. Temperature resolution of the water bath machine is 0.1℃. Temperature is load and unload from 20℃-50℃ three times，with increment of 5℃ for every kind of BOTDA temperature sensor. BOTDA analyzer used is DiTest STA 200. Spatial resolution of 2m, and sampling interval of 1m is used for every test. Brillouin frequency is measured using BOTDR analyzer in every load step.

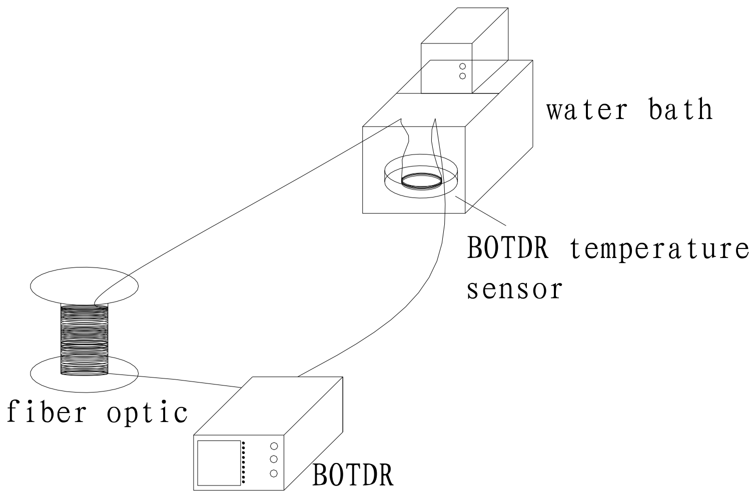

Figure 2. Temperature sensitivity test set up

3.2 Subsea pipeline scour monitoring test

3.2.1 Sensing cable Packaging

Figure 3 shows the packaging of scour sensing cable. Heating belt was used to generate heat along the cable using 220v current. Fiber optic with protection layer was placed along the heating belt, and one layer of protection tube was used to package the fiber optic and heating belt together and make the sensing elements stay in one waterproof environment. In the scour monitoring test, sensing cable was placed along the subsea pipeline model, as shown in figure 4. During the monitoring process, linear heat can be generated using heating belt in sensing cable. When certain length of subsea pipeline was scoured and then exposed to water, the sensing cable was also exposed to water. According to the thermodynamics theory, heat conduction ability are quite different between sensing cable in sand and in water, which will make the temperature distribution difference along the sensing cable. As mentioned above, suspension length of subsea pipeline can be detected according to the temperature distribution along the pipeline.

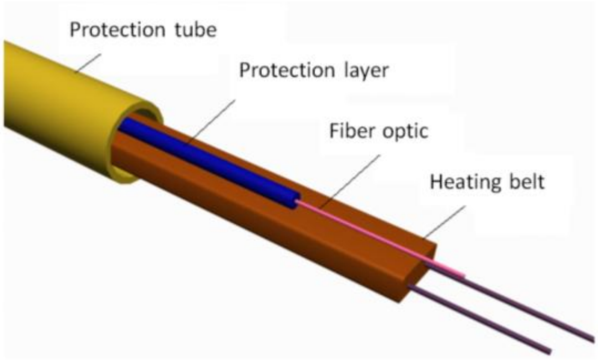

Figure 3. Packaging structure of the scour sensing cable

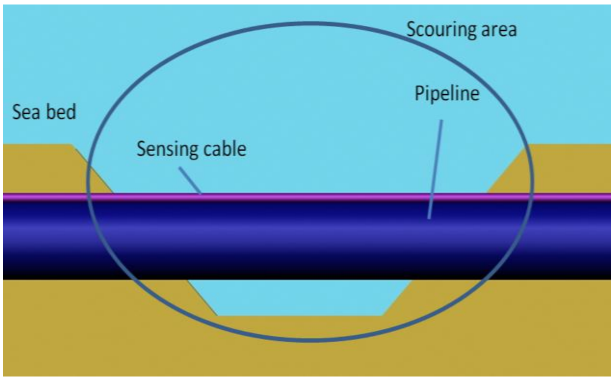

Figure 4. Illustration of scour monitoring using sensing cable

3.2.2 Scour monitoring test

Scour monitoring test was conducted using water tank with dimension of 48m*1m*1.5m. Galvanized iron pipes were welded together as subsea pipeline model, with diameter of 100mm, and with total length of 21m. Pipeline model was placed in the water tank as shown in figure 5. In the middle part of pipeline model, pipeline with length of 6m was isolated with the sand cover using two brick wall, where serves as suspension area. The other part of pipleline was covered with sand, cover depth is about 500mm. During the test, water flow from left side to another side with speed of 0.1m/s. Fiber optic was led out of the sensing cable and connected with BOTDA analyzer. Temperature along the sensing cable was interrogated every 6 minute during the test. When the scour monitoring test was finished, sand was used to make fully cover in the middle suspension part for further comparasion test.

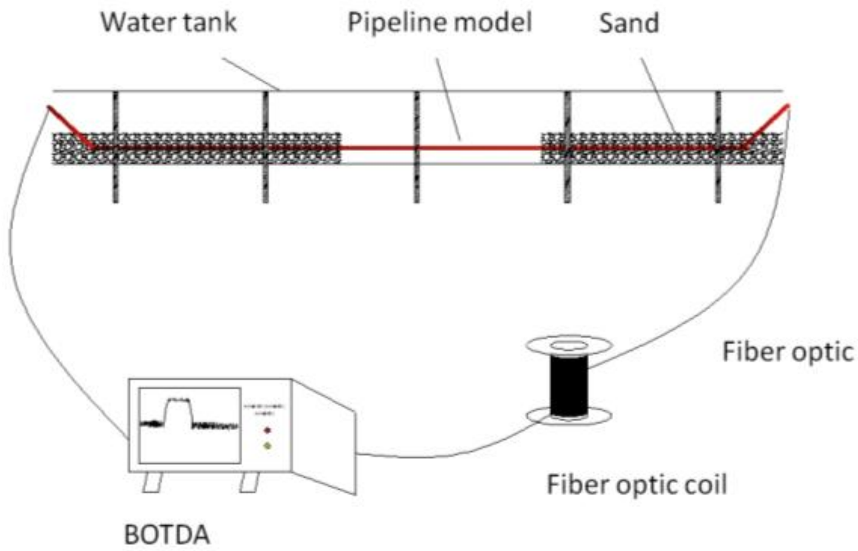

Figure 5. Setup of scour monitoring test

4 RESULT ANALYSIS

4.1 Semperature sensitivity test

Figure 5 shows the test result of BOTDA sensor with length of 5m. There are good relationship between temperature and Brillouin frequency of three load cycles. The reproducibility is improved comparing to former two kinds of sensor. Averaging temperature coefficient of 0.942GHz/℃ is obtained. Figure 6 shows the result of the sensor with length of 20m. There are good relationship between temperature and Brillouin frequency of three load cycles. The reproducibility is good. Averaging temperature coefficient of 1.027GHz/℃ is obtained.

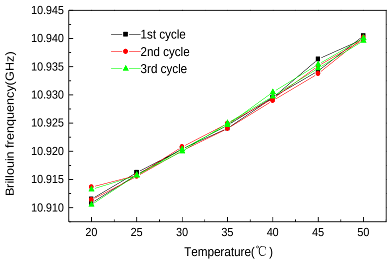

Figure 6. temperature test result of BOTDA sensor with length of 5m

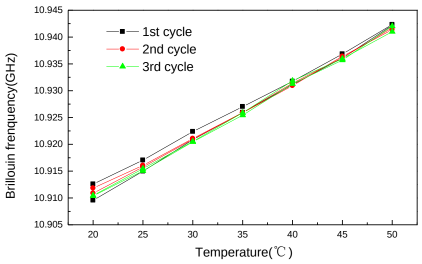

Figure 7. temperature test result of BOTDA sensor with length of 20m

Results mentioned above show that there is good linear relationship between tempearture change and Brillouin frequency, and also good reproducibility.

4.2 Subsea pipeline scour monitoring test

Figure 8 show the Brillouin frequency variation and temperature distribution results at the moment heating was stopped. Brillouin frequency shift was monitored along the fiber optic in the area from 10m-40m of optical loop, where the sensing cable located. There is obvious Brillouin frequency shift change in the area from 14-35m, where the heat belt is placed. Furthermore, in the area from 21m-28m, there is about 0.035GHz increment of Brillouin frequency shift. In the area from 13m-20m, and 28m-34m, the Brillouin increment shift is beyond 0.05GHz, and even 0.06GHz maximum. Temperature in the middle part is obviously smaller than other part of pipeline model, which means the temperature in the water is lower than in the sand, because of different heat conductivity ability.

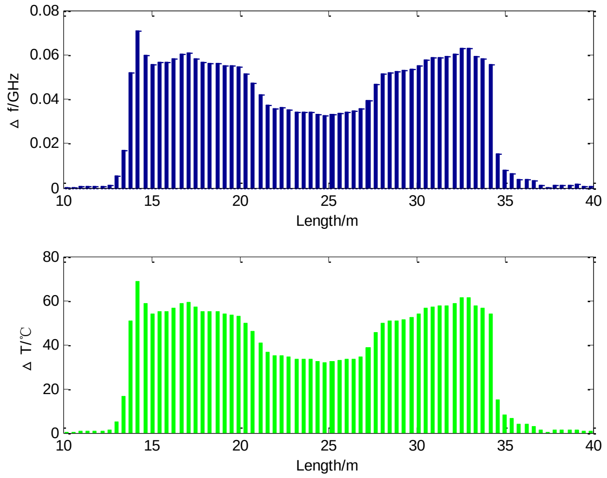

Figure 8. The variation of frequency and temperature at the end of heating between the distance of 10th m and 40th m

Figure 9 shows the Brillouin frequency shift and temperature shift results monitored when suspension area was filled with san. At this time, whole subsea pipeline model was embedded in sands. Comparing with figure 8, there are not obvious deduction of Brillouin frequency in the middle suspension part of subsea pipleline model. When there is suspension in the middle part, the temperature difference between suspension part and two side part without suspension is about 20℃. On the other hand, when there is no suspension, in all part of the model, the temperature is all about 50℃, the difference is only several degree, and is almost the same. Therefore, scour suspension can be detected at the moment the electrical heat is stopped after certain heating period.

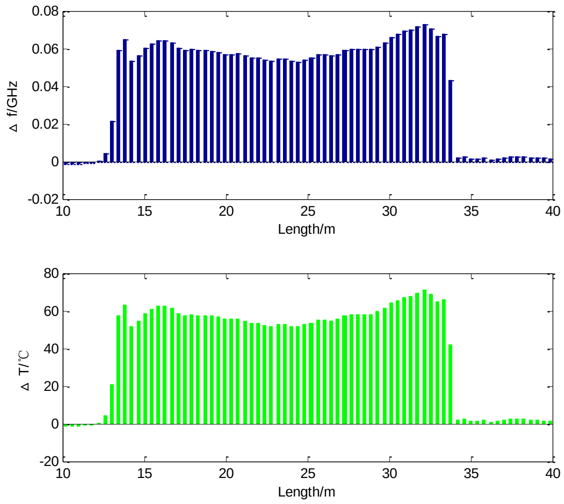

Figure 9. The variation of Brillouin frequency and temperature at the end of heating after putting sand into the suspended part.

5 CONCLUSIION

A scour monitoring technique of subsea pipeline is proposed using distributed Brillouin optical sensors. The system consists in a thermal cable running parallel to the pipeline, which acquires frequency shift during heating and cooling, directly indicating temperature change. The free spans can be detected through the different behaviors of heat transfer between in-water and in-sediment scenarios. Temperature sensitivity test result show that there are good relationship between temperature and Brillouin frequency of three load cycles. The reproducibility is good. Scouring monitoring test results show that the proposed monitoring technique can monitor the sour length of subsea pipeline precisely, in the moment when the heating is stopped.

6 REFERENCE

[1] J.B. HERBICH, Offshore pipeline design elements, Marcel Dekker Inc., New York, 1981.

[2] W. Jin, J. Shao and E. Zhang, Basic Strategy of Health Monitoring on Submarine Pipeline by Distributed Optical Fiber Sensor, ASME Conference Proceedings 36827 (2003) 531-536.

[3] W. Jin and J. Shao, A Practical Algorithms on Health Monitoring of Submarine Pipeline and Its Application, ASME Conference Proceedings 47497 (2006) 309-313.

[4] A.A. Elshafey, M.R. Haddara and H. Marzouk, Free spans monitoring of subsea pipelines, Ocean Systems Engineering 1 (2011) 59-72.

[5] T. Horiguchi,T. Kurashima, M. Tateda, M.. “Tensile strain dependence of Brillouin frequency shift in silica optical fibers.” IEEE Photonics Technology Letters, (1989) 1(5), 107-108.

[6] K. Shimizu, T. Horiguchi, Y. Koyarnada, T. Kurashima. “Coherent seif-heterodyne Brillouin OTDR for measurement of Brillouin frequency shift distribution in optical fibers.” Lightwave Technol., (1994)12(5), 730-736.

[7] H. Murayama, K. Kageyama, I. Kimpara.. “Structural health monitoring of IACC yachts using fiber optic distributed strain sensors: A technical challenge for America's Cup 2000.” SPIE, (2000)3986, 312-323.

[8] T. Shimizu, T. Yari., K. Nagai. “Strain Measurement Using a Brillouin Optical Time Domain Reflectometer for Development of Aircraft Structure Health Monitoring System.”SPIE, (2001)4335, 312-322.