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High-performance bending insensitive fibre for hydrophone

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Abstract: Bending-resistant fibre is a waveguide-enhanced fibre, which is suitable for small bending radius application, such as fibre hydrophone. Based on the application requirements, the design concept, technical status and basic performance of bending-resistant fibre are described in this paper.

Keywords: Hydrophone, Bending insensitive fibre, Macro-bending, Mechanical strength

1 Introduction

The fibre hydrophone is a new type of optical fibre sensor, which is used to detect underwater acoustic signals. It is called as optical fibre sonar. It is an advanced means of establishing marine ecological environment and underwater observation network and can be used for the information collection in fishing, earthquake prediction and ocean current. The fibre hydrophone can be classified into intensity type, polarization type, phase interference type and so on. The phase interference fibre hydrophone has become the main object of current research and development because of its high accuracy, good stability, small volume, easy large-scale composition of the array and other advantages. The phase interference fibre hydrophone is based on Michelson and Mach-Zehnder interferometric principles and its interference structure has entered a mature stage of production. The basic principle of two methods is same. Firstly, the photodetector detects the change of interference fringes of wave in the sensing arm (the phase fluctuation of acoustic pressure signal accepted) and reference arm (the seal protection as reference base) and then extracts the acoustic pressure signal through the signal processor. The key component is the fibre loop which is wound by optical fibre. For the purpose of miniaturization, the size of the loop is usually small and the diameter can be 10mm at least. Therefore, the fibre hydrophone needs two special requirements for optical fibre: low bending loss and high mechanical reliability.

Based on above requirements, Yangtze Optical Fibre and Cable Joint Stock Limited Company (Stock Code of HK6869, hereinafter referred to as YOFC) develops the high-strength bending insensitive fibre for hydrophone application, which is used to wind the fibre loop of key component. The small bending diameter fibre loop wound with this fibre can still maintain low loss, providing a performance and reliability guarantee for large hydrophone array networking.

2 Technical principles

2.1 Macro-bending loss of bending insensitive fibre

The optical fibre waveguide consists of fibre core and cladding. The refractive index of fibre core is higher than that of cladding and its light guide principle is total internal reflection, that is, where the light shoots at the cladding from the fibre core, the light is completely reflected back to the fibre core when the incident angle is greater than the critical angle in the interface. When the fibre bends (it is indicated that the bending radius is much larger than the fibre diameter, i.e., macro-bending), the incident angle of a part of light ray changes in the interface and is smaller than the critical angle. This part of light rays penetrates the interface to form an evanescent field, causing loss (as shown in Figure 1). In addition, the change of refractive index caused by bending will also affect the loss of optical fibre.

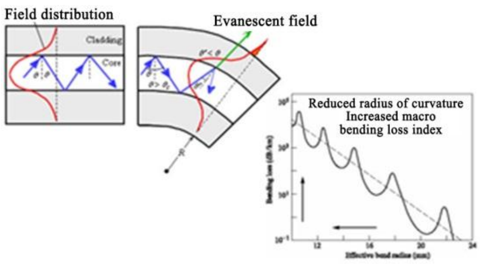


Figure 1 Schematic Diagram of Fibre Loss Caused by Bending

The method to improve the bending-resistant loss ability of optical fibre is to reduce the critical angle, specifically, to improve the refractive index difference on both sides of the core cladding boundary, that is, to increase the numerical aperture (NA) of optical fibre. At present, the domestic best level can achieve that the loss is below 0.02 dB when the bending radius of 25 turns is 5mm (BI1015 model of YOFC).

2.2 Mechanical reliability of bending insensitive fibre

Microcracks will be inevitably formed on the surface of glass cladding during the fabrication of fibre. Under external stress or active environment, microcracks will grow and eventually lead to fibre fracture. Under high tension, the cracks did not grow in time, with no obvious mirror surface, irregular cross-section shape and sharp angle. Fracture causes: a) fibre bending; b) too large stress on fibre side; c) bad cable, with crimping.

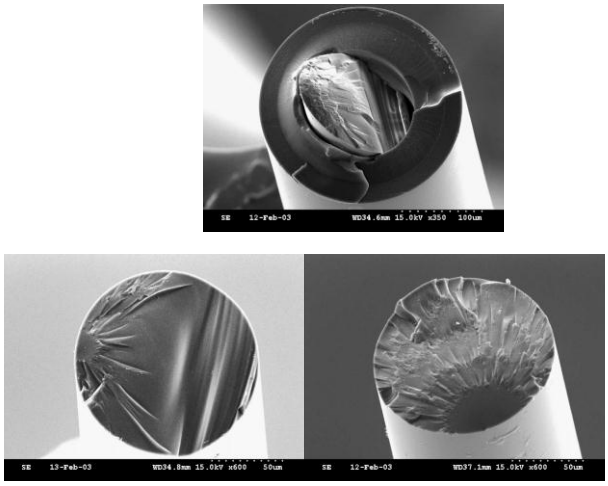


Figure 2 Diagram for Fracture End Face of Fibre under Different Stresses (Decreased from Left to Right)

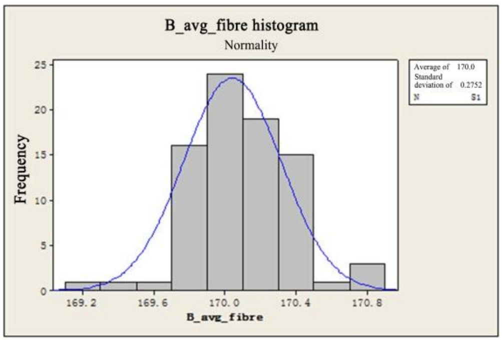
The fibre cracks due to fatigue under low stress. There are several stages, such as crack extension, acceleration and instability, with obvious mirror surface and obvious characteristics on it (mirror region, mist region and hackle region). Fracture causes: a) there are large external particles or stress catastrophe points on the surface of optical fibre; b) microcracks are formed on the surface due to the friction between preform or optical fibre and outside; c) the storage condition of optical fibre is improper and corrosive substances such as water molecules are entered. The Figure 2 shows the diagram for fracture end face of fibre under external stress.

For the fibre hydrophone, the very small bending radius is the main cause of fibre fracture. For example, the tensile stress on the outer surface of 125 μm fibre is about 585 MPa (about 85 kpsi) under the bending radius of R=7. 5 mm. Under the same conditions, the tensile stress of 80 μm fibre is about 374 MPa, which is 64% of that of 125 μm fibre. Therefore, the smaller the outer diameter of the fibre, the more obvious the advantage.

The main method to improve the bending fracture resistance of optical fibre is to reduce the surface defects of the fibre cladding. The specific measures include the use of high-purity synthetic quartz raw materials, large preform and high-cleanliness production workshop. In addition, the compressive stress formed on the surface of optical fibre by special process can also improve its bending fracture resistance (the principle is similar to tempered glass). At that same time, in storage and use, the avoidance measures of fibre coating damage, active environment, fibre crimping during winding and so on are important methods.

3 Technical status

YOFC is one of the earliest manufacturers with the development of bending insensitive optical fibres in China. The screening strength varies from 100 kpsi to 150 kpsi and then to 200 kpsi. At present, the designed minimum bending diameter is 10mm, covering ordinary 125/250 optical fibres and thin-diameter 80/165 optical fibres. Geometrically, the out diameter tolerance of coating layer can be controlled within ± 2µm, while the cladding tolerance is within ± 1.5 µm (as shown in Figure 3), which is critical for accurate cabling and reduction of splicing loss.



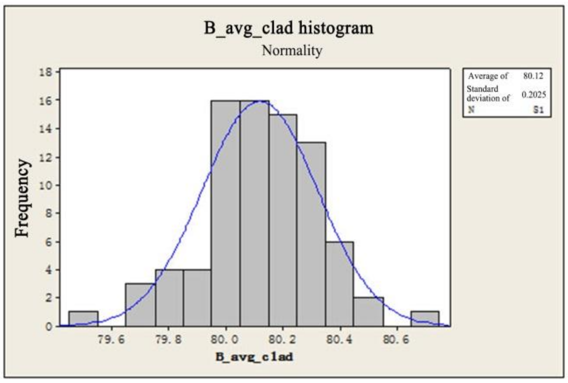


Figure 3 Statistics of YOFC's BI1015-B Series Fibre Coating and Cladding

In addition to conformance to 200 kpsi screening in strength, it also performed well in tensile and aging resistance (as shown in Figure 4). We also have compared and verified the service life under the bending radius interested by customers (as shown in Figure 5) and results of the obtained data on the service life derived from the industry default formula have far exceeded the customers' requirements.

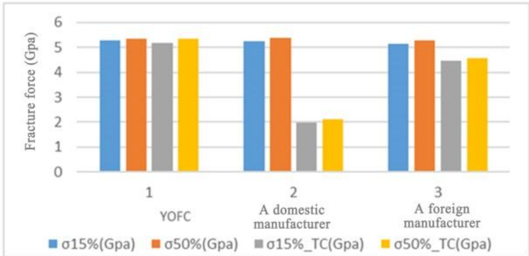


Figure 4 Test Data of the Bending Insensitive Fibre on Fracture Force before and after Aging (TC Represents Aging)

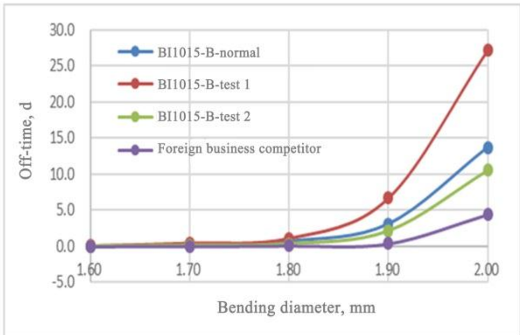


Figure 5 Comparison of Bending Insensitive Fibres on Fracture Time at Home and Abroad under Minimal Bending Radius

Besides the advantages of low macro-bending loss and high mechanical strength, the bending insensitive fibre manufactured by YOFC also has good tapering and polishing properties and provides supporting hydrophone devices, such as fibre coupler, isolator, DWDM, circulator and Faraday rotating mirror. In the aspect of new technology, YOFC has successfully developed and industrialized the high-strength bending insensitive optical fibre with compressive stress and special coating on its surface. Besides, the fibre is easy to be cabled, which provides a powerful guarantee for the overall reliability of the fibre hydrophone system and makes a new contribution to the marine industry of China.

4 Summary

With the demand of ocean information network becoming more and more obvious, the market prospect of bending-resistant optical fibre is broad. At present, domestic bending-resistant optical fibre can meet the corresponding requirements, but in the long run, smaller size and higher reliability are the general trends, which pose new challenges to the design and process of bending-resistant optical fibre. As the demand for marine information network becomes more and more obvious, the market for bending-resistant fibres has broad prospects. At present, domestic bend-resistant fibres can meet the corresponding requirements, but in the long run, it is the overall trend for the smaller size and higher reliability. This presents new challenges to the design and process of bending-resistant fibre.

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