Optical cable fault locating using Brillouin optical time domain reflectometer and cable localized heating method

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Abstract. A novel optical cable fault location method, which is based on Brillouin optical time domain reflectometer (BOTDR) and cable localized heating, is proposed and demonstrated. In the method, a BOTDR apparatus is used to measure the optical loss and strain distribution along the fiber in an optical cable, and a heating device is used to heat the cable at its certain local site. Actual experimental results make it clear that the proposed method works effectively without complicated calculation. By means of the new method, we have successfully located the optical cable fault in the 60 km optical fiber composite power cable from Shanghai to Shengshi, Zhejiang. A fault location accuracy of 1 meter was achieved. The fault location uncertainty of the new optical cable fault location method is at least one order of magnitude smaller than that of the traditional OTDR method.

Keywords: fault location, Brillouin optical time domain reflectometer, optical time domain reflectometer, localized heating, optical cable, optical fiber

1. Introduction

Optical cable, which is the channel to be used to transmit information in the form of optical pulses of a specific wavelength, is the basic component of the optical communication networks. Unfortunately, optical cables laid on the sea floor and under the earth are vulnerable to all kinds of threats. For
instance, under-earth optical cables are often damaged because of natural disasters and human interventions. Similarly, man-made attacks, such as ship’s anchoring and fishing activities, are the major cause of submarine cable faults. If a cable line fault occurs, the huge amount of information will be lost, which makes optical cable fault location as well as optical cable maintenance a crucial problem to solve.

Generally, Optical Time Domain Reflectometer (OTDR) is used to identify optical cable fault[1-3]. By means of OTDR, one can get the distance from the fault site to the measurement site along the optical fiber housed in the optical cable. In most kind of optical cables, optical fibers are usually housed in a tube, and are laid with an excess length of fiber compared to the length of the tube in order to protect the sensitive optical fibers against external mechanical and chemical factors. Therefore, in such optical cables the length of the optical fiber is not equal to that of the cable. Thus one cannot directly obtain the spatial location of the optical cable fault by using the OTDR equipment. In order to locate the spatial site of optical cable fault, related project documentation, such as the cable line’s property sheet and the map of cable connection, and complicated calculating based on the scale on each map of cable routes are need. In general, in this method the fault location accuracy of under-earth optical cable and that of submarine optical cable is respectively about 40–50 meters and hundreds of meters, though the OTDR can provide sub-meter or even mm-order spatial resolution[4]. In order to improve the accuracy and efficiency of the fault location, a simple and direct optical cable fault location method is proposed in this paper. The new optical cable fault location method is based on BOTDR and cable localized heating. Experimental results verify the effectiveness of the new method.

2. Principle

The Brillouin optical time domain reflectometer (BOTDR) is a fiber optic strain and temperature distributed sensing system, which can measure strain and temperature along arbitrary regions of an optical fiber. If the optical cable is heated in certain part of the cable, and the temperature distribution curves along the fiber before and after the heating process are measured by the BOTDR, the corresponding heated point in the temperature distribution curves along the fiber can be identified by comparing the difference between the two curves. Since the location of the optical fiber fault also can be obtained by using the BOTDR, the distance between the faulty site and the heated site along the cable can be determined by reading the distance between the faulty site and heated site along the fiber. Therefore, the optical cable fault location can be determined without related project documentation and complicated calculating. The accuracy of the fault location depends on the spatial resolution of the BOTDR and the distance between the heated site and the faulty site. The less distance there is, the more accurate the fault locating result is. We can increase the times of the heating process to decrease
the distance between the heated site and the faulty one, and thereby obtain higher fault location accuracy. The schematic of the proposed optical cable fault location method is shown in figure 1.

Figure 1. Schematic of the proposed optical cable fault location method.

The process of optical cable fault location is as following:

1. Firstly a BOTDR is connected to certain optical fiber in the optical cable and the optical loss distribution or distributed strain along the optical fiber is measured. The faulty site in the fiber is determined by observing the distribution curve of the optical loss or strain along the fiber.

2. Estimate the approximate spatial site of optical cable fault according to the faulty site in the fiber and then heat 1 meter length of optical cable at the estimated cable fault site with an automatic temperature-control heating device. The distance between the estimated faulty site and the measurement site along the cable depends on the excess length of the fiber in the optical cable. In general, the distance is chosen as about 0.85 ~ 0.95 of the distance between the faulty site and the measurement site along the fiber.

3. After the temperature of the local optical cable increase to a certain value, the BOTDR is used to measure the distribution of the strain along the fiber once more. Because the variation of temperature and strain both can cause a frequency shift of spontaneous Brillouin scattered light, there will be a sharp increase corresponding to the heated location in the strain curve map, provided that there is no other frequency shift factor except the temperature increase in the heated site. Thus we can obtain the heated site in the strain curve map and accurately determine the distance between the heated site and the faulty one along the fiber.

4. Move forward the above determinate distance along the cable route and observe the optical cable at the new location. If there is evident cable damage at this location, then the position is just the location of the optical cable fault. Otherwise, heat the optical cable at the new location.

5. Repeat step 3 and 4 until finding the evident damage existing on the cable or until the heated site and the faulty site in the fiber are the same point in the strain curve map.
Generally two or three repeated processes are enough to determine the location of the optical cable fault. Depending on the spatial resolution of the BOTDR and the repeated times of heating process, the optical cable fault location accuracy is good to 1 meter. In next section, the actual application results will make it clear that the proposed method works effectively. The fault location result by use of the new method also will be compared with that by use of the traditional OTDR method.

3. Experimental results

In the actual experiment, a 60 km optical fiber composite power cable that contains 5 optical fibers, which was laid on the shallow sea floor from Shanghai to Shengshi island, Zhejiang, China, was damaged by ship anchor and needed to fault location before repairing. The BOTDR system commercialized by Ando Electric Corporation, AQ8603, was used in this experiment. The BOTDR was placed at the end of the cable on the shore and connected to certain optical fiber in the cable. A special cable localized heating box manufactured for the experiment also used in the actual optical cable fault location process. In the fault location process, the heating box was placed in the sea to heat certain part of the cable. In order to compare the performance of the proposed method and the traditional OTDR method, an OTDR was used to measure the optical loss distribution curves to get the location of the optical fiber fault.

First, the optical loss distribution curves along each of the five optical fibers were measured by the AQ8603. We observed two fibers, Fiber 1 and Fiber 4, were broken at the location that is 2660m from the measurement site. The measurement site is the location where the BOTDR was placed. On the contrary, the other three fibers, Fiber 2, 3 and 5, were undamaged at this location but broken at the location that is 54068m from the measurement site. The optical loss distribution curve of Fiber 1 is shown in figure 2. Therefore, the faulty site in fiber was 2660m down the fiber.

![Figure 2. The optical loss distribution curve of Fiber 1 before the cable was repaired.](image-url)
As it was expected, we obtained the same results of the optical loss distribution curves by using the OTDR. According to the traditional OTDR cable fault location method, we calculated the spatial site of optical cable fault by use of the original design and construction documentation, such as cable line’s property sheet and the map of cable connection.

Then, the repair ship arrived at a certain location along the cable route. The location was about 100m near the estimated cable faulty site and was between the estimated cable faulty site and the measurement site. After part of cable was dug from the sea floor at the location, a 1-meter length of optical cable was put into the heating box. A detector placed in the box measured the water temperature in the box. Then we used the BOTDR to measure the distribution of the strain along the fiber. The water temperature before and after heating was 28°C and 35°C, respectively. The corresponding partial distribution curves of the strain along the Fiber 2 before and after heating are shown in figure 3. It was proved that the distance between the heating site and the measurement site is longer than that between the fiber faulty location and the measurement site, which is the reason for choosing Fiber 2, not Fiber 1, as the measurement fiber.

![Figure 3. Partial distribution curves of the strain along the Fiber 2 before and after heating.](image)

As it can be seen in figure 3, since the AQ8603 does not allow direct temperature measurement, the temperature variation for a 500m length surrounding the faulty site in fiber are displayed as the difference of the two strain traces. There are two peaks in the train traces when the temperature is 35°C. The magnification of the strain traces that contains the two peaks is shown in figure 4. The left...
one is located at 2660m down the fiber, where is just the location of the optical fiber fault. The right
one is located at 2706m down the fiber, where the strain difference corresponding to the two different
temperatures is 0.0178%. Because coefficients of 1.22 MHz/°C and 500MHz/% have been used
for Brillouin frequency shift–temperature conversion and Brillouin frequency shift–strain conversion
respectively[5-6], the strain difference of 0.0178% is corresponding to the temperature difference of
7.3°C. Since the real temperature difference is 7°C, we can determine that the heated site is located
at 2706m down the fiber. Therefore, the faulty site in the cable should be 46m near the heated site and
located between the heated site and the measurement site. Based on this estimation, the repair ship
returned back 46m. At the new location, part of cable was salvaged from sea floor and an evident
damage was found on the surface of the cable. After engineers repaired the cable by replacing the
damaged section with a 20-meter length of new cable, the optical loss distribution curve along Fiber 1
were measured by the BOTDR, which is shown in figure 5. As it is shown in this figure, the cable
fault that is located at 2660m down the fiber has been repaired successfully.

![Figure 4. The magnification of the strain traces that contains the two peaks.](image-url)
Figure 5. The optical loss distribution curve along Fiber 1 after the cable was repaired.

The actual optical cable location experiment verified that the accuracy of the proposed method was high to 1 meter. On the contrary, the accuracy of the OTDR method is about 146m in this experiment.

4. Conclusion
In conclusion, a new optical cable fault location method based on BOTDR and cable localized heating has been proposed and validated with actual experiment. In the method, a BOTDR system is used to measure the optical loss distribution and strain distribution along the fiber with a high accuracy. And an automatic temperature-control heating device is used to heat the cable in its local section without damaging the cable. Actual experimental results verified that the proposed method works effectively without related project documentation and complicated calculation. The new method can locate the cable fault with a high accuracy. The fault location uncertainty of the new optical cable fault location method is at least one order of magnitude smaller than that of the traditional OTDR method.

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References
[1] Sankawa I, Furukawa S, Koyamada Y and Izumita H 1990 Fault location technique for in-service branched optical fiber networks IEEE Photon. Technol. Lett. 2 766-68
[2] Otani T, Horiuchi Y, Kawazawa T, Goto K and Akiba S 1998 Fault localization of optical WDM submarine cable networks using coherent-optical time-domain reflectometry IEEE
Photon. Technol. Lett. 10 1000-1002

[3] Hara T, Terashima K, Takashima H, Suzuki H, Nakura Y, Makino Y, Yamamoto S and Nakamura Y 1999 Development of long range optical fiber sensors for compositesubmarine power cable maintenance IEEE Trans.Power Delivery, 14 23-30

[4] Lee B 2003 Review of the present status of optical fiber sensors Opt. Fiber Technol. 9 57–79

[5] Kurashima T, Horiguchi T and Tateda M 1990 Thermal effects on Brillouin frequency shift in jacketed optical silica fibers Appl. Opt. 29 2219-22

[6] Shimizu K, Horiguchi T and Koyamada Y 1995 Measurement of distributed strain and temperature in a branched optical fiber network by use of Brillouin optical time-domain reflectmetry Opt. Lett. 20 507–509