Micro crack analysis of optical fiber by specialized TD-OCT

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Abstract: We have developed a method to evaluate absolute value of return loss from crack on optical fiber in an optical connector by using the specialized TD-OCT. The absolute measurement of the return loss could be accomplished with an error of ± 3 dB in the range from 10 to 100 dB. As a result, the micro crack of the optical fiber could be evaluated quantitatively. Furthermore, the state of the micro crack which could not be detected in the past could be analyzed without taking the product apart. If the value of the return loss and the elapsed time from its manufacturing are known, the angle of micro crack of the optical fiber and presence or absence of the gap between the fracture surfaces will be estimated.

Keywords: absolute measurement, reflection, OCT, micro crack, optical connector

1. Introduction

These days, the performance of the optical fibers has been improved therefore, it has been utilized in the various fields such as medical and sensing fields; however, the main materials of the optical fibers are glass, and the fear of micro crack still remains.

The product with the optical fiber often installs it into the main part of the system. Therefore, if there is a micro crack, the performance of the product would be deteriorated. Even the products need to be repaired, some products cannot be repaired by reinstalling the new fiber and it has a risk to cause serious accident such as communication disturbance. For these reasons, the manufacturers have to be careful for the quality of the optical fibers even more.

The detection of the micro crack has done mainly by measuring insertion loss and return loss. It is hard to detect the micro crack by this way because if there is a part which has the return loss away from the crack part in the measuring path, it is impossible to distinguish the crack part from the other reflections. Additionally, the position has been specified by checking a leaked red laser light with visual observation; however, it cannot be distinguished either the micro crack or a leaked light when a leaked light by bending is crossed to the crack part.

To detect the micro crack, it is necessary to measure the position and the return loss of the crack. OCT (Optical Coherence Tomography) can detect them, so it is suitable for micro crack detector.

However, in terms of detecting the micro crack, the return loss of the absolute measurement is needed for inferring the inside condition(1)(2)(3). The absolute measurement means recognizing the same return loss as the same value even if the measuring date, place and device are different.

As for the absolute measurement, TD (Time Domain)-OCT is superior to the other OCT method. In the cases of FD (Fourier Domain)-OCT or SS (Swift Source)-OCT, they have the nonlinear signal processing in viewpoint of interference intensity because of Fourier Transformation. On the other hand, when TD-OCT is used, it becomes linear because of its simple signal amplification, therefore, the linearity of the measurement value is high. Moreover, TD-OCT can carry out long-depth measurement, so it enables to check the inside of the optical connector, which depth is approximately 20mm.

We have developed the TD-OCT systems with the rotation mechanism for several years, and now it is possible to conduct absolute measurement within the error of ±3 dB and the return loss range of 10 to 100 dB. Therefore, this system is possible to detect the existence of the micro crack. The micro crack indicates the small crack which cannot be detected by the current return loss and insertion loss testing system. Optical fiber with initial stage of the micro crack can be used as usual; however, as the time elapses, the return loss and the insertion loss increase significantly, and the performance of the product declines remarkably. In this research, we utilized our developed system and analyzed the crack to predict the condition of the micro crack inside.

2. OCCR (Optical Component Coherence Reflectometer)

TD-OCT is a low coherent optical interferometer. Figure 1 depicts a principle of fundamental OCT using a Michelson interferometer. The beam from the low interference light source is divided into two
paths by an optical beam splitter, and their interference occurs only when each optical path length reflected from a sample and a reference mirror matches. This is because of a low coherent light source. The optical device of this system is configured by a optical fiber assembly.

Table 1 shows specification of this device based on our developed TD-OCT. SLD (Super Luminescent Diode) light source is $\lambda=1310$ nm and its power is 10mW to improve the sensitivity. To make the system stable in the temperature range of 10~40 °C, cooling device is attached.

The semi-diameter of rotation reflector ($^{(4)}$~$^{(8)}$) of the optical path length variable mechanism is 20mm ($^{(9)}$) to ensure the measurement length of 20mm. Additionally, considering the Doppler shift, Rotation speed is 1.1 sec/rotation to improve the strength of interference signal. As the only reference light gets the influence of Doppler shift, the interference intensity is weaken due to the rotation speed. The measurement light is taken inside the system though the optical fiber. Figure 2 shows the screen shot of measurement software when the system is connected to PC. The measurement result is shown in a graph, the horizontal axis is the distance from the fiber connecting point (0~20mm), and the vertical axis is the return loss (10~100dB). It is possible to set the threshold level of the return loss, and pass or fail judgement based on the threshold level is indicated. Maximum 6 points of detail information from the abnormal points are displayed. Figure 3 is the measurement result of the return loss obtained by this measurement system and an optical attenuator. It is possible to conduct absolute measurement of the return loss in the range of 10~100dB with less than ±3dB of error.

Figure 4 is the picture of the optical fiber micro crack part detected by the OCCR. The optical fiber micro crack parts seemed the mirror surface and had some degrees.

**Table 1. Specification of OCCR**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>$\lambda=1310$ nm $\Delta\lambda=40$nm</td>
</tr>
<tr>
<td>Fiber</td>
<td>SM (10/125)</td>
</tr>
<tr>
<td>Scanning Range</td>
<td>20mm</td>
</tr>
<tr>
<td>Resolution</td>
<td>1.25µm</td>
</tr>
<tr>
<td>Return Loss</td>
<td>10~100dB</td>
</tr>
<tr>
<td>Return Loss Accuracy</td>
<td>+/-3dB</td>
</tr>
<tr>
<td>Measurement Time</td>
<td>3 seconds</td>
</tr>
<tr>
<td>Size</td>
<td>431×89×350mm</td>
</tr>
</tbody>
</table>
Additionally, we have done temperature character test with the optical connector sample which is detected the optical fiber micro crack by the OCCR measurement in the range of -40~85℃. The wavelength is λ=1.31μm. As a result, after 27 temperature cycles, Insertion Loss increased greatly, approximately 10dB. After that, insertion loss was around 10~20dB, and it did not return normal value. Figure 5 shows that state. The adhesive is used between a ferrule and a fiber; therefore, the gap between micro crack surface would become bigger as the time passes, because the temperature cycle appeared in the measurement values.

3. Micro crack of optical fiber

The formula of the return loss RL (1)\(^{(10)}\), when depends on the degree of the surface of the fiber micro crack, is below.

\[
RL(1) = RL_0 \exp \left( -\frac{2\theta_b}{\theta_c} \right)^2
\]

\[RL_0 = \frac{(n-1)^2}{(n+1)^2} \quad \theta_c = \frac{\lambda_0 n}{\pi \omega_0}
\]

here, RL\(_{0}\): return loss of vertical incidence, \(\lambda_0\): wavelength in a vacuum, n: Refractive index, \(\omega_0\): semi diameter of mode field.

In addition, in the case that the surfaces of a fiber micro crack confront with a gap between them, the formula of the return loss RL (2) is represented by multiple interference as below.

\[
RL(2) = \frac{4R_{gap} \sin^2(\delta/2)}{(1 - R_{gap})^2 + 4R_{gap} \sin^2(\delta/2)}
\]

\[R_{gap} = \frac{(1 - n)^2}{(1 + n)^2} \quad \delta = \frac{4ng \cos \theta_b}{\lambda \cos^{-1}(n \sin \theta_b)}
\]

here, g: gap length between micro crack.

The actual return loss is represented by the combination of RL (1) and RL (2). We simulated the conditions of optical fiber micro crack using the FC/APC connectors with different polish degrees, (Figure 6). Furthermore, the gap caused by the time elapse was simulated that surfaces of two connecters contacted physically at first (RL (1) + RL (2)), and that the infinite gap is represented by single surface of a connector (RL (1)).

Figure 7 shows the results of the simulation and the experiment. The results are as follows.

1) The experimental results matched with the theoretical formula (1) and (2) until the degree of the surface angle of \(\theta_b \leq 8^\circ\).

2) When \(\theta_b\) is over \(8^\circ\), the measured value and the theoretical value did not match. The experiment results were stable in the range of 90~100dB.

3) The return loss difference between the physical contact results RL (1) + RL (2) and non-physical contact RL (1) was correlated with the surface angle as follows.
When the degree of the micro crack $\theta_b$ is small, the surface’s gap is big because of large return loss. When $\theta_b$ is large, the gap is small. When $\theta_b$ is larger than 8°, the difference is almost none.

Figure 6. FC/APC Connector with different polishing angle $\theta_b$

Table 2. Specification of FC/APC sample simulating micro crack.

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector Type</td>
<td>FC/APC Connector</td>
</tr>
<tr>
<td>End Face Angle: $\theta_b$</td>
<td>0~15°</td>
</tr>
<tr>
<td>Fiber</td>
<td>SM (10/125)</td>
</tr>
</tbody>
</table>

4. Consideration

As the result of analyzing the optical fiber micro crack using the developed TD-OCT system which can conduct absolute measurement of its return loss, it is found that it is possible to predict the condition of the optical fiber micro crack without dismantling. If the micro crack angle is within 8 degrees, the micro crack angle can be predicted.

The return loss follows the theoretical formula $RL (1) + RL (2)$ when the time elapse is short after the fiber micro crack occurs. It also follows theoretical formula $RL (1)$ when the time elapse is long. In addition, when it is hard to predict the length of time elapse, by remeasuring it after running in temperature cycle -40~85°C, it would be more similar to the theoretical formula $RL (1)$. In brief, the return loss of the fiber micro crack is different depending on the time elapse.

This phenomenon can be explained as follows. The epoxy-based adhesive is used for fixing of optical connector; therefore, the adhesive repeats expansion and contraction as the time passes, and the gap would become bigger. The biggest return loss in the condition of physical contact and the surface angle of micro crack $\theta_b = 0$ was -60dB. It is lower than the return loss of the usual fiber connection point. It is exceedingly hard to detect in the general RL testing. By getting the position information of the micro crack, this system can detect the fiber micro crack accurately.

5. References