Optical Fiber Technology 18 (2012) 470–479

Contents lists available at SciVerse ScienceDirect

Optical Fiber Technology

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Tool for inspecting faults from incorrectly cleaved fiber ends and contaminated optical fiber connector end surfaces

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ARTICLE INFO

Article history:
Received 9 April 2012
Revised 20 June 2012
Available online 13 August 2012

Keywords:
Optical connector
Physical contact
Insertion loss
Return loss
Fiber cleaver

ABSTRACT

We investigated and analyzed faults in field installable connection due to incorrectly cleaved fiber ends and manufactured physical contact (PC)-type connectors with contaminated end surfaces in optical access fiber networks. The insertion and return losses of fiber connections using incorrectly cleaved fiber ends might be at worst more than 40 dB and less than 30 dB, respectively. With PC-type connectors whose end surfaces are contaminated, the insertion and return losses might be at worst 8.7 and 27 dB, respectively. We developed an inspection tool for cleaved fiber ends and connector end surfaces as a countermeasure. The proposed tool has a simple structure and does not require focal adjustment. It can be used to inspect and clearly determine whether a fiber has been cleaved correctly and whether there is contamination or scratches on the connector end surfaces. The tool requires a slight increase of 11% in operation time compared to conventional fiber end preparation and assembly procedures. The proposed tool provides a simple and cost-effective way to inspect cleaved fiber ends and connector end surfaces and is suitable for field use.

1. Introduction

The number of subscribers of broadband services in Japan now exceeds 34 million, and that of fiber-to-the-home (FTTH) services reached about 20 million in 2011 [1]. The amount of optical fiber cables continues to increase as the number of FTTH subscribers increases; however, unexpected faults have occurred along with this increase. One such fault is damage caused by wildlife such as rodents, insects, and birds [2], and another is caused by defective optical fiber connectors [3]. It is very important to detect and investigate the causes of these faults and to supply the appropriate countermeasures.

The Technical Assistance and Support Center (TASC) is engaged in technical consulting and fault analysis on optical fiber networks of the NTT group in Japan and contributes to finding the cause of various faults and reducing the number of faults of optical fiber facilities in FTTH networks. We have investigated faults of various fiber connections and reported faults of fiber connections using refractive-index matching material with large gap width [4] and faults of fiber connectors with imperfect physical contact [5].

For this study, we report on faults of field installable connection using incorrectly cleaved fiber ends and those of manufactured connectors with ends contaminated with oil or dust. These faults lead to optical performance deterioration of the connections. A countermeasure against these faults is inspection before assembling or connecting. Therefore, we developed an inspection tool for optical fiber ends. The main components of this tool are a microscope, cell phone, and special holders for the fiber or connector being inspected. The tool can be used to determine whether a fiber end was cleaved correctly and whether there is contamination or scratches on the connector end surface. This inspection tool is also simple and cost-effective.

2. Faults and analysis

2.1. Field installable connectors and manufactured connectors in FTTH facilities

Fig. 1 is a configuration of a typical FTTH facility in Japan, which is mainly composed of an optical line terminal (OLT) in the central office, underground and aerial optical fiber cables, and an optical network unit (ONU) inside a customer's home. The facility requires various fiber connections at the central office, outdoors, and home sites. With the fiber connections at aerial and home sites, in particular, field installable connectors or mechanical splices are used to fit the best wiring depending on the aerial condition and room arrangement. Field assembly (FA) termination connectors and field assembly small (FAS) connectors are types of field installable connectors [6,7]. In contrast, manufactured connectors, such as miniature-unit coupling optical fiber (MU) and single fiber coupling optical fiber (SC) connectors [8,9], are used in the central office

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http://dx.doi.org/10.1016/j.yofte.2012.07.004

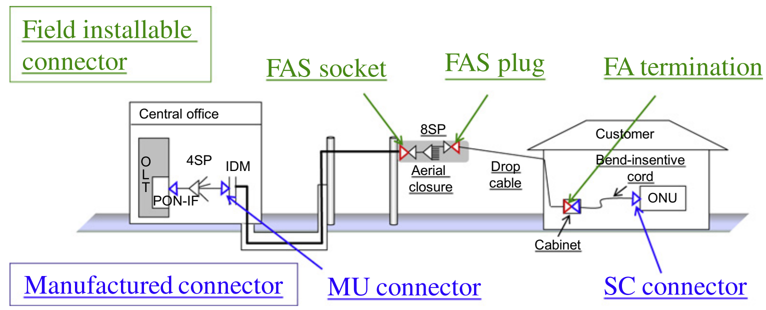

Fig. 1. Optical fiber access network and connectors.

and home. These connectors require more frequent reconnections than field installable connectors.

2.2. Incorrectly cleaved fiber ends

We have investigated faults with field installable connectors. In 2009, we collected defective connectors in a certain region of Japan and investigated these connectors in terms of outward appearance, optical characteristics, and dismantled tests [3]. As a result, we specified the causes of such faults. The direct causes of the faults are summarized in Fig. 2. The causes of connector faults are, in order of occurrence frequency, scratched fibers, fractures of the mechanical splice part, incorrect fiber lengths, incorrect cleaving, and incorrect joining. These faults result from incorrect fiber end preparation and assembly procedures or use of an inappropriate tool. If there are problems with the fiber cleaver in particular, the fiber end would not be cleaved correctly, that is, it would not have an ideal flat and smooth end perpendicular to the fiber axis. An incorrectly cleaved fiber end leads to abnormal joining between fiber ends and may result in an increase in insertion loss [10]. Fig. 3 shows photos of incorrectly cleaved fiber ends. These fiber ends are not flat but uneven. We explain the experimental results from investigating the optical performance of field installable connectors using incorrectly cleaved fiber ends.

Fig. 4a shows the structure of a field installable connector, which is composed of three main parts, the ferrule, mechanical splice, and clamp. The basic fiber end preparation and assembly procedure for a field installable connector is comprised of six steps.

1. Strip the fiber coating.
2. Clean the stripped fiber (bare fiber) with alcohol.
3. Cut the bare optical fiber using a fiber cleaver.
4. Insert the properly prepared bare optical fiber into the mechanical splice part.
5. Join it to the built-in optical fiber.
6. Fix the position of the bare optical fiber.

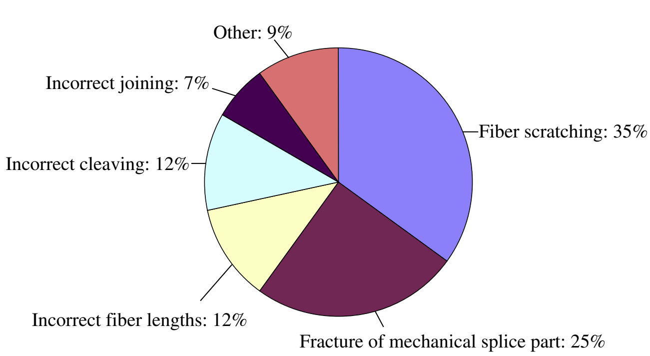

Fig. 2. Summary of direct causes of faults in field installable connectors.

If there are no problems with the fiber cleaver in step 3, the fiber will be cleaved correctly and have a correct, flat, and smooth end perpendicular to the fiber axis. However, if there are problems, the fiber will have an incorrect and uneven end [11,12]. Fig. 4 also shows two connection states using correctly and incorrectly cleaved fiber ends. Fig. 4b shows the normal connection state using a correctly cleaved fiber end, and Fig. 4c shows abnormal states using an incorrectly cleaved fiber end. In state (b), the normal connection state has a very narrow gap between the correctly cleaved fiber ends, and the gap is filled with refractive index matching material (matching material). In state (c), the abnormal connection state has a wide gap between correctly and incorrectly cleaved fiber ends. However, the gap between the fiber ends is filled with matching material.

We experimentally investigated the optical performances of fiber connections using an incorrectly cleaved fiber end. Twenty-five field installable connectors using incorrectly cleaved fiber ends were fabricated as samples. These incorrectly cleaved fiber ends were intentionally made by adjusting the fiber cleaver so that the bend radius would be too small. The cracks of these incorrectly cleaved fiber ends were from 30 to 200 μm in the axial direction. Five connectors using correctly cleaved flat fiber ends were also fabricated for comparison. All 30 connectors were subjected to a heat-cycle test in accordance with IEC 61300-2-22 (−40 to 70 °C, 10 cycles, 6 h/cycle) to simulate conditions in the field. We measured the insertion and return losses at a 1.55-μm wavelength. There are two types of optical performance changes for analyzing all experimental results. Two typical sample results are described below.

The results of two samples fabricated using incorrectly cleaved fiber ends varied greatly (Figs. 5 and 6). The insertion loss of sample 1 (Fig. 5) varied from 0.4 to 0.9 dB. This variance is thought to have been caused by a tiny offset or tilt between the fiber ends. The return loss was always over 40 dB. The maximum insertion and minimum return losses with field installable connectors using correctly cleaved fiber ends during the heat-cycle test were less than 0.8 dB and more than 40 dB, respectively. Consequently, the insertion and return losses with sample 1 were very stable and almost the same as that of correctly cleaved fiber ends.

The initial insertion loss of sample 2 (Fig. 6) was 1.0 dB but increased to more than 40 dB according to the change in temperature. The return loss was temporally less than 30 dB. These results are very unstable. The change in the insertion and return losses is attributed to a partially air-filled gap. The gap was not completely filled with matching material; it was partially filled with air because of the incorrectly cleaved fiber end. The smaller return loss in sample 2 than in sample 1 is thought to be due to this air gap. These results suggest that the insertion and return losses of fiber connections using incorrectly cleaved fiber ends might be at worst more than 40 dB and less than 30 dB, respectively. Such a substantial increase in insertion loss can affect the quality of an