Highly Reliable Optical Fiber Distribution Facilities in Central Office Employing Single-mode Hole-assisted Fiber Cord

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Abstract
We realized single-mode hole-assisted optical fiber (HAF) cord whose fiber has a superior bending loss characteristic that complies with ITU-T Recommendation G. 657 for use in highly reliable optical fiber distribution facilities in central offices. The cord has an excellent anti-shock characteristic, and can be detected with a conventional optical fiber cord identifier despite its very low bending loss. We also developed optical jumper units and indoor cables employing the cord for optical fiber distribution in integrated distribution modules (IDM) and central offices, respectively, which achieved almost the same characteristics as conventional facilities. These results show that the single-mode HAF cord we developed and its application to optical fiber distribution in central office can provide a highly reliable network service.

Keywords: Optical fiber; bending loss; optical fiber distribution; central office; FTTH.

1. Introduction
Recently, the optical access network has been growing rapidly, and this has led to a huge expansion of the optical fiber distribution facilities in central offices [1]. However, this has resulted in congested facilities. Therefore, during system installation and maintenance, technicians may accidentally bend the fiber cords being used for the communication service, and the service will stop if the bending radius becomes too small and a high bending loss is generated. Hole-assisted optical fiber (HAF) cord is a promising candidate solution since it hardly generates any bending loss when bent with a small radius. For example, ultra low bending loss HAF cord can realize a bending loss of less than 0.1 dB/turn at a bending radius of 2.5 mm and a wavelength of 1650 nm. HAF based free bending optical cord is a kind of ultra low bending loss HAF cord, and has already been installed in the optical fiber to the home network in Japan [2]. However, the application is limited because its superior bending loss characteristics may cause the confinement of the higher order mode. This may result in a cut-off wavelength that is long by comparison with the communication wavelength, which will degrade the quality of long-distance transmissions. Recently, NTT has realized a single-mode HAF with a low bending loss (<0.1 dB/turn at 1625 nm, bending radius of 5 mm), and a sufficiently short cutoff wavelength (<1260 nm), which satisfies the values specified in ITU-T Recommendation G. 657 [3].

2. Optical fiber distribution facilities in central office employing single-mode HAF cord
2.1 Highly reliable optical fiber wiring
Figure 1(a) shows an example of our highly reliable optical fiber distribution facilities employing single-mode HAF cord. Our optical fiber distribution frame is called an integrated distribution module (IDM) in Japan [1], and it consists of IDM-A and IDM-B. This configuration makes it possible to minimize the additional distribution of optical fiber cables even if an OLT or IDM-A or IDM-B is newly installed. Therefore, the configuration reduces the number of cable threads and relieves cable congestion. However, there is a possibility that the cord can be accidentally bent momentarily when a technician connects and disconnects it in an IDM, especially in IDM-A where this operation frequently occurs, because an IDM can house 4000 1.1 mm diameter optical fiber cords as shown in the photograph in Fig. 1(a) [6]. We realized a highly reliable optical fiber distribution facility by adopting single-mode HAF cord with a very low bending loss. We adopted an “optical jumper unit”, which we used for wiring, and connection and disconnection for cross connection with the single-mode HAF cord terminated optical connector in IDM-A, and that can house optical splitters and optical filters.
2.2 Optical fiber identification

Single-mode HAF cord can be easily identified during service demand, cable removal and maintenance work on the cord at IDM, in spite of its low bending loss characteristics. Below we describe two examples of single-mode HAF cord identification. In the first example, we launched a 1650 nm identification light, whose wavelength is in the maintenance band for our system, into the connection port of IDM-B. This light passes through the cable and cord in the central office and is checked at the cord in IDM-A by a conventional identifier as shown in figure 1(b). In the second example, an identification light is launched into the connection port of an OLT. We can identify the cord in IDM-B using a conventional identifier. These processes do not interfere with the communication light; so in-service testing can be undertaken without affecting data transmission.

The performance of the single-mode HAF cord is described in detail below.

3. Single-mode HAF cord

3.1 Single-mode HAF cord structure

We developed single-mode HAF cord that achieved a low bending loss of less than 0.10 dB/turn at 1650 nm with a 5 mm bending radius. Moreover, it can provide sufficient leaked optical power for identification with a conventional identifier. Figure 2 shows a cross-section of our single-mode HAF cord, which is composed of single-mode HAF, ultraviolet curable resin, high tensile strength fiber and a sheath. The diameters of the single-mode HAF, ultraviolet curable resin and sheath are 0.25, 0.5 and 1.1 mm, respectively. The number of air holes varies as reported in [3], and ten air holes are used as an example in Fig. 2. The cord can sustain a tensile stress of more than 30 N for 1 minute.

3.2 Bending loss characteristics

Figure 3 shows the measured bending losses of single-mode HAF cord, ultra low bending loss HAF cord and conventional single-mode fiber (SMF) cord at 1650 nm, whose fiber parameters are shown in Table 1. The SMF is conventional single-mode fiber. The diameters of all the cords were 1.1 mm. The bending loss of the single-mode HAF cord is higher than that of the ultra low bending loss HAF cord. However, the single-mode HAF cord achieved a sufficiently low bending loss of less than 0.10 dB/turn at 1650 nm with a bending radius of 5 mm. The bending loss of the communication band at wavelengths shorter than 1650 nm is lower than that at 1650 nm, which provides ease of handling and safety during maintenance work.
3.3 Anti-shock characteristics

We measured the transmission performance and time-dependent change in the transmission loss when the cords in Table 1 received a strong momentary shock caused by dropping a weight on the cord to simulate an accidental bend caused by hanging a tool on the cord when working on the system. Figure 4 shows our experimental setup. A cord was wound around two horizontally aligned bobbins, and looped between them to obtain the desired slack length. Finally, the cord was fixed to the bobbins. A metal mandrel at the top of the weight was hooked over the slack point of the cord.

A signal from an OLT at 1550 nm, 10 Gbit/s and 64 bytes per frame was transmitted through the cord, and the frame loss was monitored. We also monitored the bending loss by measuring the output signal power from the optical fiber cord with an O/E converter and a digital oscilloscope. As the cord remains attached to the metal mandrel with the weight, they both fall downwards halfway between the tops of the two bobbins as shown in Fig. 4. As a result, the weight imparts a strong shock to the cord. The diameter of the bobbins and the space between them were 100 and 280 mm, respectively. The metal mandrel had a diameter D of 10 mm and weighed 364 g. The frame loss increased as the mandrel diameter decreased owing to the increased bending loss. We used a diameter of 10 mm to represent that of a pen as an example tool. We performed 30 measurements under each condition. The bending angle when the weight shocks the cord is defined as $\alpha$. In this experiment, we set $\alpha$ at 90°.

Figure 5 shows the time-dependent changes in the transmission loss fluctuation when the weight fell onto the single-mode HAF cord and the SMF cord. The SMF cord generated a loss fluctuation of more than 5 dB, while the single-mode HAF cord hardly generated any fluctuation. The fluctuation of the SMF cord converged to 2.5 dB, which means an excess loss of around 3 dB was induced by the shock. Because there was hardly any frame loss at less than around 3.5 dB, the first strong shock at around 0.5 s on the SMF cord was dominant as regards the frame loss. In all cases, the first shock was dominant as regards the frame loss, namely, the occurrence of frame loss depends on the first shock, which generates the maximum loss fluctuation.

Figure 6 shows the frame loss dependence of the maximum loss fluctuation. Some frame losses of less than 140 occurred only for the SMF cord at maximum loss fluctuations of around 5 dB. Considering all the results, the frame loss is proportional to the maximum loss fluctuation in the region, which is more than 4 dB. We expect the dominant causes of this fluctuation to be the bending loss caused by the cord lengthening and $\alpha$ decreasing momentarily.

Consequently, we used our proposed shock test to demonstrate that our developed single-mode HAF cord has superior anti-shock characteristics, which enables us to realize a highly reliable access network service.

3.4 Identification characteristics

We compared the optical fiber cords in Table 1 in terms of identification characteristics using a conventional identifier and a non-destructive macro-bending method [4][5]. Figure 7 shows our experimental setup. We used 1650 nm LDs modulated at 270 Hz as identification light sources. We measured the leaked light power at the identifier. We defined the difference between the input power into the cord and the power monitored by the identifier as the coupling loss. A reduction in coupling loss means an increase in the monitored identification light power, and this makes it easy to identify the cord. We performed 50 coupling loss measurements with each cord. The average coupling losses of single-mode HAF cord, ultra low bending loss HAF cord and SMF cord were 49.6, 79.1, and 38.9 dB, respectively. In general, there is a trade-off between coupling loss and bending loss. However, the bending radius of 5 mm is different from that of the bender in the identifier [4][5]. We plotted the coupling loss against the bending loss per turn at the identification wavelength of 1650 nm and with a bending radius of 5 mm for each optical fiber cord as shown in Fig. 8. The
coupling loss is almost inversely proportional to the bending loss. In our network service, the maximum specified limit for the coupling loss is around 70 dB. This limit is decided by the minimum inputted identification light power and the limit of the identification power needed for the identifier. The coupling loss of the ultra low bending loss HAF cord is too high to allow us to identify the cord in our network service. On the other hand, the coupling loss of the single-mode HAF cord is sufficiently low to satisfy the specified value for our network service.

3.5 Connection characteristics

MU connectors, which are used as standard optical connectors in IDMs, were mounted at both ends of single-mode HAF cord for measuring connection characteristics. The ends of the connectors were terminated by fusion splicing them to SMF to prevent dust entering the HAF air holes as shown in Fig. 9. Figure 9 also shows our experimental setup for measuring insertion loss. First, we inputted a light into two cascaded SMF cords terminated with MU connectors, and measured the output light power $P_{o1}$ with an optical power meter (Fig. 9(a)). Then, we inserted a 5 m single-mode HAF cord between the two SMF cords, and measured the output light power $P_{o2}$ again (Fig. 9(b)). We defined the insertion loss as the difference between $P_{o1}$ and $P_{o2}$. Figure 10 shows histograms of the insertion and return losses of 25 single-mode HAF cords at 1310 nm and 1550 nm. The insertion losses at 1310 and 1550 nm were less than 0.60 and 0.70 dB, respectively, which is sufficiently low for use in our network service. On the other hand, the return losses at 1310 and 1550 nm were more than 48.1 and 47.9 dB, respectively, which were almost same as that of the SMF cord and exceeded our system requirements.
4. Characteristics of optical jumper unit

Figure 11 shows a photograph of the prototype of an optical jumper unit employing single-mode HAF cord. The jumper unit in IDM-A as shown in Fig. 1 can house a maximum of 64 optical fiber cords, an optical splitter and an optical filter [6]. The optical jumper unit is connected to indoor cable from IDM-B at connector adaptors of optical jumper unit. During service demand and removal work, an optical fiber cord terminated with an MU connector from an optical jumper unit is connected and disconnected to the connector panel for cross connection in IDM-A [6].

Figure 11 Photograph of optical jumper unit employing single-mode HAF

Figure 13 Photograph of indoor cable employing single-mode HAF

Figure 14 Structure of 64-fiber count indoor cable employing single-mode HAF cord

(a) Insertion loss

(b) Return loss

Figure 12 Histograms of insertion and return losses of optical jumper unit

Figure 15 Histograms of insertion and return losses of indoor cable
Figure 12 shows histograms of the insertion and return losses of an optical jumper unit that has 32 single-mode HAF cords without an optical splitter. The maximum insertion loss and the minimum return loss at 1310 nm were 1.19 and 36.5 dB, respectively. These values are almost the same as those of a conventional optical jumper unit and satisfy our system requirements.

5. Characteristics of indoor cable
Figure 13 shows a photograph of the prototype of an indoor cable, which contains 64 single-mode HAF cords. The cable structure is shown in Fig. 14. The cable is composed of three layers that accommodate cords. The 1st, 2nd and 3rd layers house 16, 21 and 27 cords, respectively. A strength member made of aramid FRP is located at the center of the cable. The cords are covered with an FRPE cable sheath. The cable diameter is 13.8 mm.

Figure 15 shows histograms of the insertion and return losses of a 200 m long indoor cable with 64 single-mode HAF cords. We randomly chose 22 single-mode HAF cords from 64 single-mode HAF cords in the cable for their measurements. The maximum insertion loss and minimum return loss at 1310 nm were 0.66 and 44.1 dB, respectively. Their characteristics were almost same as those of conventional indoor cable, and exceeded our system requirements.

6. Conclusion
We proposed a highly reliable optical fiber distribution facility that employs single-mode HAF cord for use in a central office. The single-mode HAF cord realized a very low bending loss of less than 0.10 dB / turn at 1650 nm with a bending radius of 5 mm, and satisfied the values specified by ITU-T Recommendation G. 657. We measured the transmission performance when the cord was bent momentarily and confirmed that there was no transmission error. In general, it is difficult to obtain the desired coupling loss and bending loss simultaneously because of their trade-off relationship; however, the single-mode HAF cord we developed achieved our system requirements for both characteristics simultaneously. The end of the HAF cord was terminated by fusion splicing it to an SMF, and its connection loss with an MU connector was sufficiently low. An optical jumper unit and indoor cable employing the HAF cord achieved almost the same connection characteristics as conventional facilities. As a result, we showed that our developed fiber distribution facility provides highly reliable service and maintenance work in a central office.

7. References

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