High-Precision 32 Mechanically Transferable Ferrule for Single-Mode Fiber

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Optical interconnection has been increasingly required for data center applications and high performance computers. The standardization of the new multi-fiber connector for 40/100G Ethernet, 32 multi-fiber push on (MPO), is progressing to support high-speed, high-bandwidth applications. We have developed a 32 mechanically transferable ferrule for a single-mode fiber, which requires higher precision than a multi-mode fiber. Using the ferrule, the 32 MPO connector operated at an optical insertion loss of below 0.37 dB at random mating when applying 9.8 N compression springs.

Keywords: MT ferrules, MPO connectors, single-mode fiber

1. Introduction

In recent years, communication traffic volume has been rapidly increasing due to the popularization of cloud computing and mobile Internet, etc. Data centers (DCs) that process such information have been dramatically increasing in size. Optical interconnection has been increasingly employed because conventional metal interconnection poses difficulties in long-distance, high-speed, and high-capacity communication.

For optical interconnection between equipment in a DC, lucent connectors (LCs)*1 and multi-fiber push on (MPO) connectors*2 are mainly used for single-fiber and multi-fiber cables, respectively. The DC systems are expected to shift from 10 GbE*3 to 40/100 GbE in order to meet the growing bandwidth requirements. The standardization of next-generation 400 GbE is underway under the initiative of IEEE 802.3.*4 The standard is expected to be ratified by 2017. A 16-fiber MPO (32 MT, 16 MT) with an interface different from the current MPO has been proposed by TIA and IEC*5 as a 400 GbE multi-fiber optical connector.[1]

2. 32 MT Ferrule*6 Standards

In the standardized 40/100 GbE, the use of 12 MPO and 24 MPO is recommended. The 40 GbE specifications represent 12-fiber cable solutions in which 4-transmit fibers and 4-receive fibers are used (10 G × 4 ch). As a form of 100 GbE specifications, 10-fiber cables are used to transmit and receive respectively (10 G × 10 ch) in a 24-fiber system.

Figure 1 shows the interface of a 32 MT ferrule for 400 GbE currently proposed by TIA and IEC and a 24 MT ferrule in compliance with IEC. Sixteen fibers are used to transmit and receive, respectively (25 G × 16 ch). The 32 MT and current 24 MT ferrules have the same outside dimensions and fiber hole array pitch (X direction: 0.25 mm, Y direction: 0.5 mm). For the 32 MT ferrules, the guide hole pitch will be increased from conventional 4.6 mm to 5.3 mm (+ 0.7 mm) to secure the fiber array area for four additional fibers in the X direction. Meanwhile, the guide hole diameter will be reduced from conventional 0.7 mm to 0.55 mm.

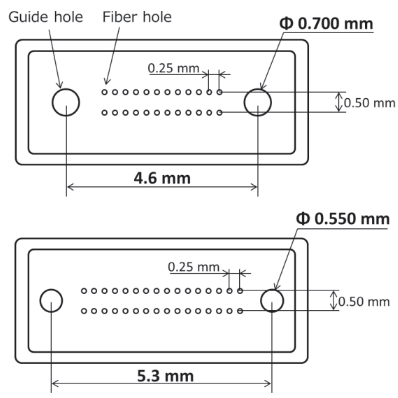

Fig. 1. Interface of 24 MT and 32 MT ferules

At present, discussions about standardization of 32 MT (MPO) focus on ferrules with a right-angled end face for multi-mode fiber (MMF). We have started the development of a 32 MT ferrule for single-mode fiber (SMF) that requires higher accuracy than MMF, with the future demand for long-distance communication in mind, and conducted an initial evaluation.

3. Design Review of 32 MT for SMF

Figure 2 shows the overview of an MPO connector using an MT ferrule as a key component. Fiber-mounted ferrules (with or without guide pins) are stored in the MPO housing, and are connected via an adaptor. A compression spring (9.8 or 22 N) is built into the housing to ensure mechanical connection (physical contact) of the fiber cores. Regarding MPO connectors for SMF, the connector end face is polished by 8° to reduce the return loss.

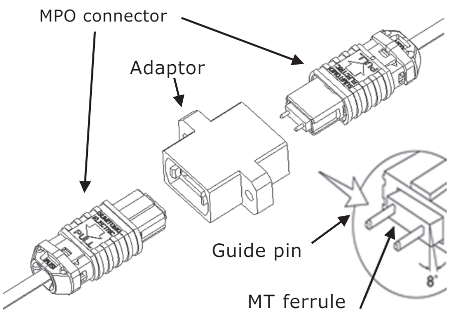

Fig. 2. Overview of MPO connector

SMF connectors require higher dimensional accuracy than MMF connectors (1/5 in terms of core diameter in simple calculation). In addition, the increase in the number of fibers affects the yield exponentially. In the manufacture of multi-fiber connectors, guaranteeing low connection loss is an important issue. We aimed to reduce the connection loss of a 32 MT (MPO) connector for SMF to ≤ 0.5 dB at random mating (maximum), which is generally referred to as the low loss grade.

To guarantee low connection loss, it is essential to 1) ensure the connector eccentricity design that guarantees the fiber position accuracy, 2) reduce the curvature of the fiber holes in ferrules, and 3) (for SMF) control the misalignment in the Y direction when engaging connectors (attributed to the slanted end face).

3-1 Eccentricity design for connectors

Axis misalignment of fiber cores is the dominant factor that contributes to the connection loss of MT (MPO) connectors. The theoretical calculation results (Fig. 3)(2) show that, to meet the target connection loss of ≤ 0.5 dB, the axis misalignment must be ≤ 1.6 µm, and the permissible misalignment for the connector is ≤ 0.8 µm (1/2 of the axis misalignment). The practical permissible axis misalignment that meets the target loss of ≤ 0.5 dB was set to ≤ 0.9 µm based on the tolerance analysis results.

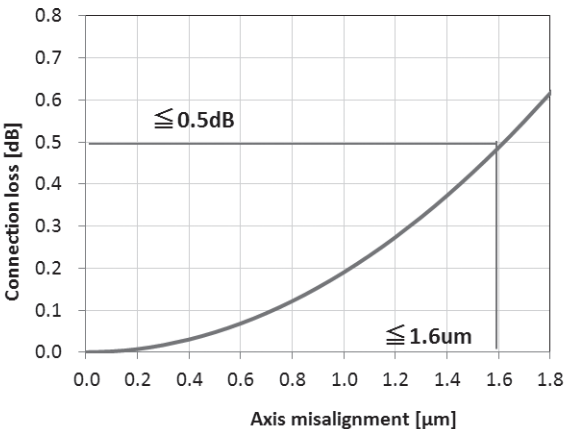

Fig. 3. Correlation between fiber axis misalignment and connection loss

The design values for ferrules, guide pins, and fibers, among others, were set based on the manufacturing results, specifications, etc. A tolerance analysis based on the Monte Carlo simulation was performed to verify the feasibility of the above targets (loss, axis misalignment).

Figure 4 shows an overview of the MT connector's end face. Three factors contribute to fiber axis misalignment: 1) eccentricity of a ferrule hole (r1), 2) clearance between a fiber hole and a fiber (r2), and 3) clearance between a guide hole and guide pin (r3). The synthesis of these factors was considered as the final eccentricity: R (= r1 + r2 + r3). Normal distribution was applied to the probability distribution of 1) and 2). For 3), probability distribution (contacting with directionality [< 90°]) was applied because the guide pin comes into contact with the guide hole in the case of SM connectors whose slanted end faces are compressed to each other.

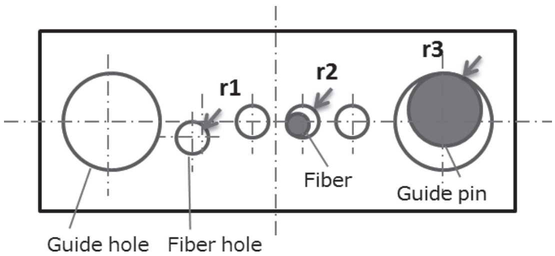

Fig. 4. End face of an MT connector, and definition of eccentricity

Figures 5 and 6 show the calculation results for fiber eccentricity and connection loss, respectively. It was confirmed that 97% of the fiber core axis misalignment (eccentricity) was within the target (≤ 0.9 µm) and the connection loss was almost entirely (99.7%) within the target (0.5 dB).

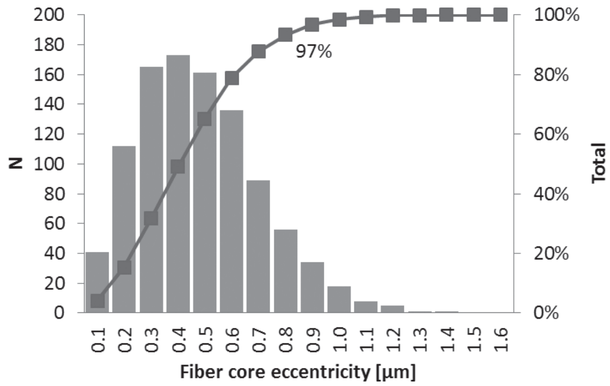

Fig. 5. Calculation results of fiber core eccentricity

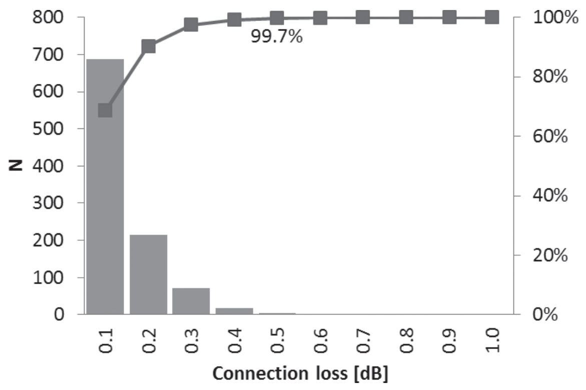

Fig. 6. Calculation results of connection loss

3-2 Curvature of fiber holes in ferrules

In general, MT ferrules are manufactured by molding resins. Due to the characteristics of the processing method (accompanied by the resin filling pressure and resin shrinkage after molding, etc.), fiber holes are slightly inclined from the guide holes (hole curvature). The end faces of MT connectors are polished after mounting fibers. As the polishing amount increases, the hole curvature causes the fiber hole position to change, as shown in Fig. 7. Notably, the polishing amount is different for the upper and lower tiers of SMF connectors, which have the two-dimensional array (8° end face). Thus, one of these tiers is affected significantly. To achieve a low loss, the fiber hole curvature must be reduced. We employed a unique parts structure for the mold used for manufacture, in order to reduce the hole curvature.

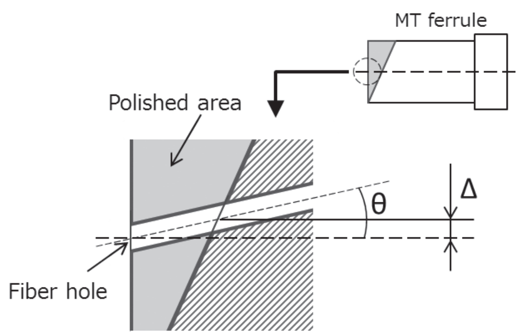

Fig. 7. Fiber hole curvature in an MT ferrule

The cavity support (CS) shown in Fig. 8 holds the core pins for forming fiber holes in the center of the mold. This helps reduce the core pin curvature caused by the resin pressure. Individual settings of the CS hole positions can control the hole curvature for each fiber. The use of this structure guarantees the fiber hole curvature of ≤ 0.2°.

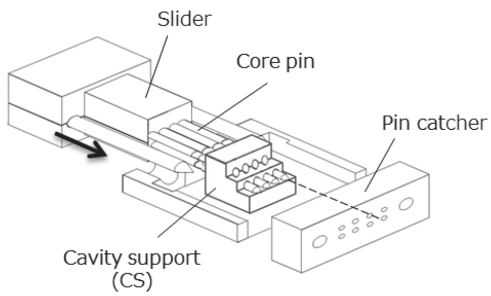

Fig. 8. Overview of mold parts for molding MT

3-3 Misalignment in the Y direction when engaging connectors (engagement misalignment)

MT connectors for SMF have a slanted connection end face, and a certain clearance between the guide hole and the guide pin. Thus, as shown in Fig. 9, when a compression force (F) is applied to engage connectors, the axis is misaligned in the Y direction (engagement misalignment [Δy]). In general, to compensate for the axis misalignment attributed to engagement, the fiber holes for ferrules are set at positions offset by the engagement misalignment from the reference position.

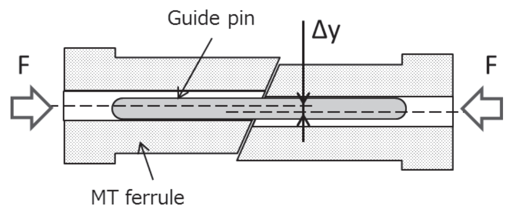

Fig. 9. Misalignment in the Y direction when the connector is engaged

The engagement misalignment depends on (i) the clearance between the guide hole and the guide pin and (ii) the compression spring force. When (i) is constant, it is necessary to determine the offset depending on the compression force.

The standard for the 32 MT ferrules for SMF is yet to be established, so is the compression force. Thus, the compression force was evaluated using samples incorporating two types of springs (9.8 and 22 N), while referring to the existing MPO and 32 MPO for MMF (whose standard is yet to be established). The offset values for fiber holes in ferrules were set for each spring.

4. Prototype Production Method

Injection molding technology was used for prototype production of 32 MT ferrules for SMF. In injection molding, one of the plastic processing methods, heated and molten material is injected into a mold and cooled for solidification to create molded articles.

Figure 8 shows the mold structure. For the mold parts that determine the hole position accuracy of the ferrule end face, a round-hole pin catcher mechanism (machined with submicron accuracy) was employed. The PPS*7 resin characterized by excellent dimensional stability was used as the molding resin.

A two-dimensional image measurement apparatus was used to measure the dimensions of the ferrules. Various evaluations were made on the optical characteristics by building a 32 MT ferrule into a standard MPO housing.

5. Results of Prototype Production

Figure 10 shows the R eccentricity measurement results for fiber holes of 32 MT ferrule prototypes that were designed for the compression force of 9.8 N. The R eccentricity was 0.22 µm on average and 0.67 µm at the maximum. Figure 11 shows the loss at random mating of 32 MPO connectors using the ferrules (measured wavelength: 1.31 µm). The connection loss was 0.08 dB on average, and 0.37 dB at the maximum, successfully

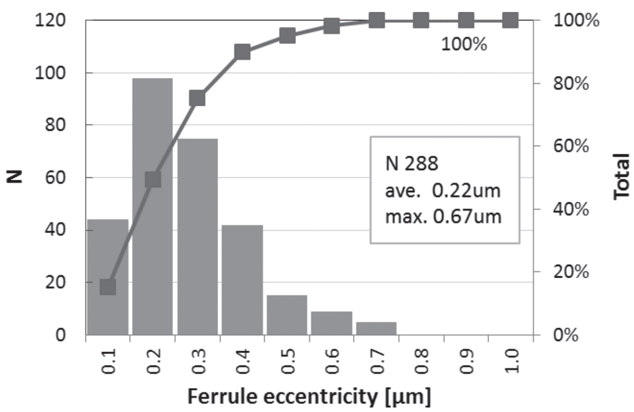

Fig. 10. Eccentricity of the ferrule hole (compression force: 9.8 N)

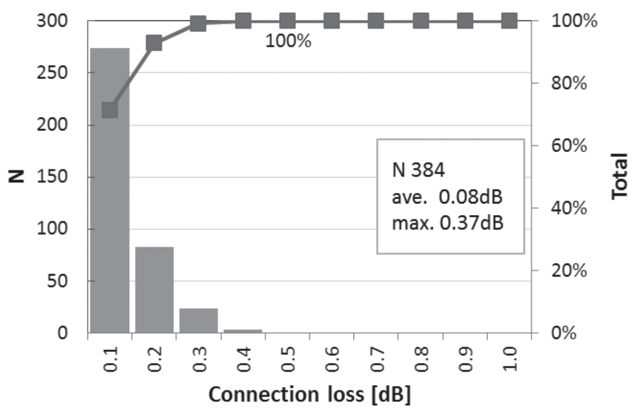

Fig. 11. 32 MPO connection loss (compression force: 9.8 N)

meeting the target connection loss of ≤ 0.5 dB. The results are almost congruent with the results of the theoretical review. Thus, we could confirm the validity of calculation.

Figures 12 and 13 show the R eccentricity and connection loss, respectively, of fiber holes of ferrules designed for compression force of 22 N. The R eccentricity was 0.33 µm on average and 0.93 µm at the maximum. The connection loss was 0.13 dB on average and 0.63 dB at the maximum, failing to meet the target by a small margin. This was because the ferrule hole offset value was slightly off the design value. Fine adjustments in the ferrule hole position are expected to achieve characteristics equivalent to those of ferrules for 9.8 N.

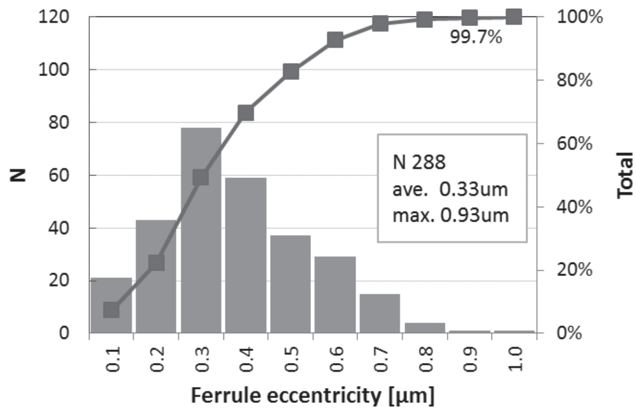

Fig. 12. Eccentricity of the ferrule hole (compression force: 22 N)

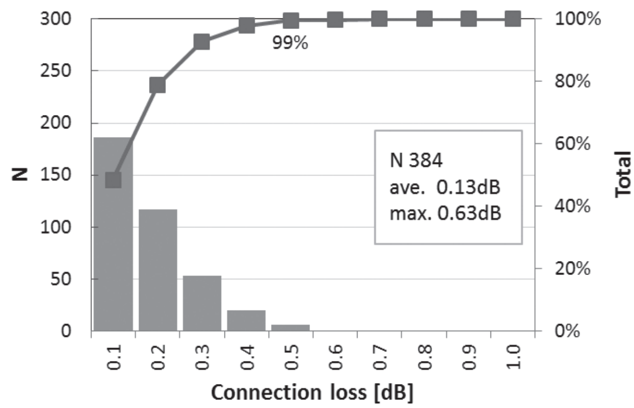

Fig. 13. 32 MPO connection loss (compression force: 22 N)

6. Conclusion

We evaluated the initial characteristics of 32 MT ferrules for the single mode for 400 GbE. The connection loss was highly congruent with the results of the theoretical review. The maximum loss at random mating of 0.37 dB was achieved in the design for the 9.8 N spring. We will verify the mechanical and environmental characteristics toward commercialization.

Technical Terms

∗1 LC connectors: Optical connectors for single-fiber connection using zirconia ferrules (1.25 mm in diameter) developed by Lucent.

∗2 MPO connectors: An abbreviation for multi-fiber push on connectors. Multi-fiber optical fiber connectors for connecting optical fibers by means of the physical contact (PC) connection technology.

∗3 GbE: An abbreviation for Gigabit Ethernet. Ethernet standard for the communication speed of 1 Gbps. 1 GBps represents the data transfer speed of one billion bits per second.

∗4 IEEE: An abbreviation for the Institute of Electrical and Electronics Engineers, Inc., a standardization organization in the U.S. IEEE 802.3 is a working group on the Ethernet standards.

∗5 TIA, IEC: TIA is an abbreviation for the Telecommunications Industry Association organized by industry organizations in the U.S. to standardize communication equipment. IEC is an abbreviation for the International Electrotechnical Commission, an international standardization organization specializing in the fields of electrical engineering and electronics.

∗6 MT: ferrules An abbreviation for mechanically transferable ferrules. A main component of multi-fiber optical fiber connectors (e.g. MPO connectors).

∗7 PPS: An abbreviation for Poly Phenylene Sulfide. PPS is one of crystalline thermoplastic engineering plastics, and is characterized by excellent dimensional accuracy, mechanical strength, and chemical resistance.

References

(1) http://www.ieee802.org/3/400GSG/

(2) D. Marcuse, "Loss analysis of single-mode fiber splice," Bell Syst. Tech. J. vol.56, pp. 703-718 (1977)

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