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Simple-Structure Low-Loss Multi-Core Fiber LC Connector

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The rapid growth of optical network traffic has dramatically increased the demands for high-density optical interconnects in data centers. To realize high-density multi-channel optical connections with easy handling, single-fiber connectors with multi-core fibers (MCFs) are expected. In this paper, we present a new type of LC-interface MCF connector. The connector has passed the Telcordia GR-326-CORE reliability test and achieved low insertion loss compatible with IEC 61753-1 Grade B for low-loss SMF connectors.

Keywords: multi-core fiber, LC connector, single-fiber connector, low loss

1. Introduction

In recent years, network services typified by video delivery have come into widespread use. Along with this trend, network traffic has been growing exponentially. The rapid growth of the optical network traffic has dramatically increased the demands for high bandwidth optical interconnects in large-scale data centers (DCs).(1)

Today multi-fiber push-on (MPO) connectors*1 are widely deployed in data centers to splice multiple optical channels and create higher density. In line with the future trend toward transmissions with an even higher capacity, the number of fibers contained in an MPO connector is expected to increase. In this regard, two issues are foreseen.

1) While at the connecting end of the connector, each core is connected to another core with no gap between them so as to eliminate optical reflection, this physical contact (PC) connection (Fig. 1)(2) is not readily achievable.
2) The connector becomes more vulnerable to dust and/or soiling.

Regarding 1), PC connections are achieved by deforming fiber end faces by way of spring force exerted when mating connectors. The amount of fiber deformation increases with an increasing number of fibers. Hence, it is necessary to control the shapes of fiber end faces more strictly at connector ends. Alternatively, a higher mating force may be used. However, this raises concern about less ease of handling for connector installation and reconnection.

Regarding 2), dust and/or soiling at the end face of an optical fiber causes optical loss. Therefore, the end face must be cleaned in a dependable manner. The area to be cleaned becomes larger with an increasing number of fibers. Then, a solution to this challenge needs to be devised.

To issues arising from an increasing number of fibers, as described above, a single-fiber connector such as the Lucent (LC) connector*2 with multi-core fiber (MCF), known as a single MCF connector, is a promising solution.(3) The single MCF connector can realize high-density multi-channel splicing with easy end-face cleaning and low mating force similar to conventional today's single-fiber connectors (Fig. 2). This report describes the challenges to be addressed in realizing a single MCF connector and the single MCF connector developed by Sumitomo Electric Industries, Ltd.(4),(5)

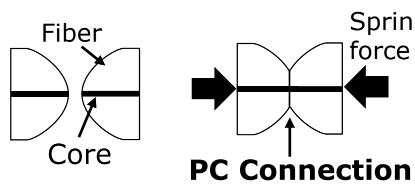

Fig. 1. PC Connection

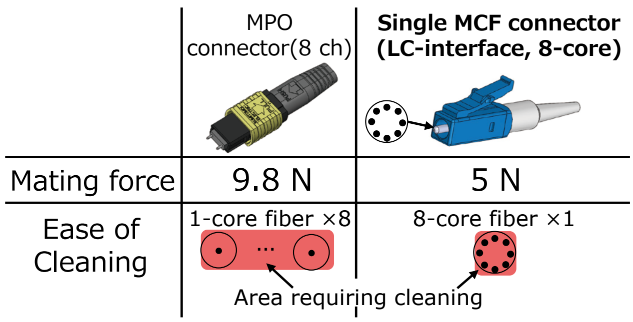

Fig. 2. Advantages of a single MCF connector

2. Challenges for Single MCF Connector

The requirements for single-fiber connectors for single-core fibers (single SCF connectors) used with existing optical transmission systems are: an insertion loss (IL) of less than 0.5 dB, a Return Loss (RL) of more than 40 dB, and ensuring these characteristics are maintained for optical connection even under the application of an external force to the connector with light being passed through. To fulfill these requirements, single SCF connectors incorporate the techniques outlined in Table 1.

Table 1. Techniques used in Single SCF Connectors

Items	Technique
Low IL	High-precision XY alignment of cores by means of a zirconia ferrule and split sleeve
Isolation from external forces	Ferrule floating structure inside the connector
Suppression of RL	PC connection

Single MCF connectors should have similar characteristics to those of single SCF connectors. However, direct use of the techniques outlined in Table 1 is not useful for the connector to demonstrate satisfactory characteristics. This is because MCF has outer cores located in the non-center part of the cladding. Hence, the following two additional challenges need to be addressed and are detailed in the following sections.

1) A connector structure that completely fulfills rotational alignment of MCF, floating structure, and productivity requirements
2) Connector end face suitable for PC connection of cores located in the outer portions of the fiber

2-1 Challenge 1: connector structure

MCF has outer cores located in the non-center part of the cladding, as shown in Fig. 3. To achieve a low insertion loss, these cores must be aligned between connectors not only in the x and y directions, but also in the rotational direction. Take, for example, the eight-core MCF 125 µm in cladding diameter developed by Sumitomo Electric (with the cores 40.5 µm away from the fiber center arranged in a ring form).[6] To realize an IL less than 0.5 dB, the rotational misalignment between connectors has to be less than ±0.5°.

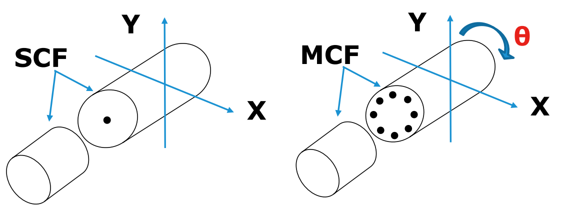

Fig. 3. Core alignment in SCF and MCF

In addition to a structure designed to suppress rotation, the single MCF connector should have ferrule floating structure which isolates fiber from external force. Figure 4 shows a conventional LC connector structure. The clearance between the LC front housing and ferrule flange allows ferrule floating which isolates fiber from external force, but induces 10-degree ferrule rotation at maximum. Thus, the structures of the front housing and the ferrule flange need to be optimized to realize a single-MCF connector with small rotational misalignment. By higher–precision parts, it becomes possible to meet both rotation

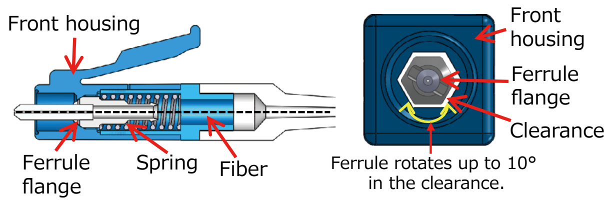

Fig. 4. Single SCF connector structure

suppression and ferrule floating. However, this make the volume manufacturing of single MCF connectors much more difficult compared to that of conventional single-SCF connectors. For this reason, a suitable structure for MCF that fulfills both rotation suppression and ferrule floating without higher-precision parts.

2-2 Challenge 2: PC connection

To suppress RL, PC connection has to be achieved between each mated pair of the MCF cores. However, it becomes difficult for the non-center cores of the MCF to achieve PC connection under the standard requirements for the connector end face dimensions.[7],[8] Figure 5 shows PC connections at connector end faces. The end face dimensions are specified by curvature radius R, apex offset d of MCF end faces between the fiber apex and ferrule apex after polishing; and fiber withdrawal (or protrusion), U. To achieve all cores of PC connection, it is necessary to fabricate an end face shape suitable for MCF, such that PC radius, a, is greater than the area in which the cores are existed.

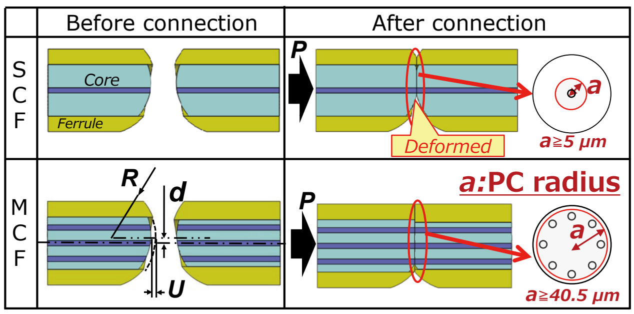

Fig. 5. Requirement of PC radius

3. Structure of the proposed Connector

3-1 Structure for low IL and ferrule floating

To realize single MCF connector without increasing dimensional accuracies of components for rotational alignment, we proposed a connector structure suitable for MCF. Figure 6 shows the structures of a single SCF connector and the proposed MCF connector. We utilized an MU ferrule flange instead of an LC ferrule flange because a longer straight edge of the rectangular MU flange is suitable to suppress the ferrule rotation, compared to the LC flange with conical and hexagonal portions.

We modified the interior of the LC front housing such that the hole for the flange has a tapered interface for the

MU flange. The straight edge of the MU flange can contact to the tapered interior of the hole, and thus the ferrule rotation angle is fixed in the unmated state, as shown in Fig. 7. The ferrule flange is floated from the housing when the ferrule is pushed by the opposing ferrule during connector mating, as shown in Fig. 8.

The only non-standard component of the proposed connector is the front housing with the tapered hole that does not require higher dimensional precision. Consequently, the proposed structure is excellent in terms of productivity.

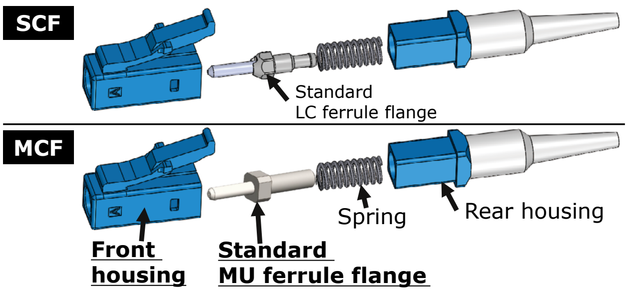

Fig. 6. Structure of standard LC connector and the proposed MCF connector

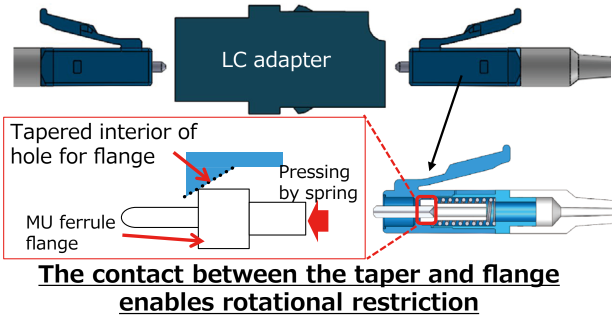

Fig. 7. Unmated state

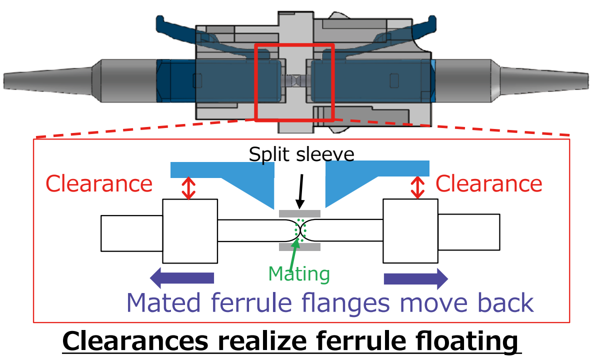

Fig. 8. Mated state

3-2 PC connection

By using a finite element method, we studied the PC condition of an 8-core fiber with a 125-µm cladding at a mating force of 5 to 6 N which is the International Electrotechnical Commission (IEC)*3 standard mating force. Analysis-related parameters were as given in Fig. 5 presented above. The connector pressing force, *P*, and fiber withdrawal *U*, were set to typical values used with single SCF connectors of 5 N and 50 nm, respectively. The calculation results are shown in Fig. 9. The results show that a small apex offset enables PC connection. Based on the results, we fabricated the proposed connector with a small apex offset by optimizing ferrule polishing conditions.

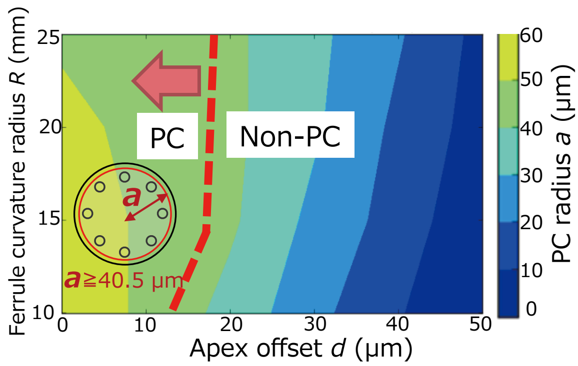

Fig. 9. Calculated PC radius of 125um-8core fiber

4. Evaluation of Single MCF Connector

4-1 IL characteristics

To evaluate the IL characteristics of the fabricated MCF connectors, we conducted a random mating test. Figure 10 shows the IL histogram for 112 random connections with 3 mating cycles of the 8 cores of the MCFs. Insertion losses of a total of 2,688 cores were evaluated. The average IL was 0.07 dB, the 97th percentile was 0.20 dB, and the maximum value was 0.39 dB. The result is compatible to IEC 61753-1 Grade B for low-loss SMF connectors.

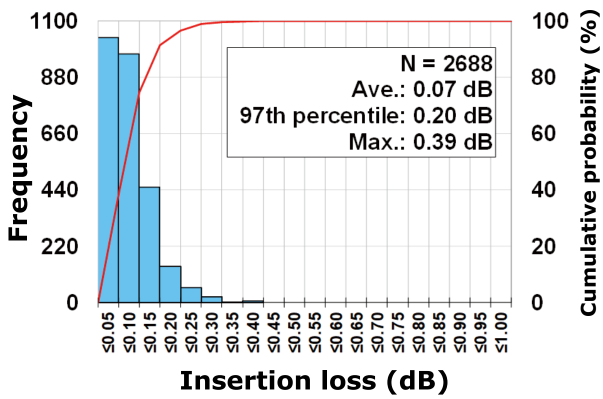

Fig. 10. IL histogram for the random mating test

4-2 Reliability testing

To confirm that the proposed connectors simultaneously have a ferrule floating function and precise rotational alignment, we conducted Telcordia GR-326-CORE mechanical tests with two pair of the fabricated connectors.

Photo 1 shows the appearance of the fabricated connector and axis definition, and Fig. 11 shows the jumper test apparatus to apply controlled bend θ, tension T, and twist φ. Table 2 summarizes the test results. Figures 12 and 13 show the IL and RL variations during the durability test of 200 mating cycles. The criteria of IL was less than 0.5 dB (Max. IL in Table 2).The criteria of RL was more than 40dB (Min. RL in Table 2). We confirmed that the IL and the RL were suppressed under the criteria in all the tests.

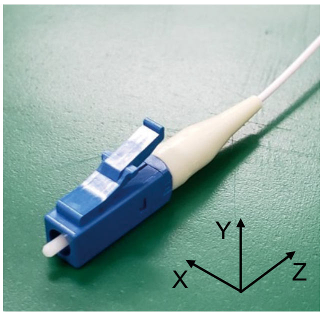

Photo 1. The appearance of the fabricated MCF-LC connector

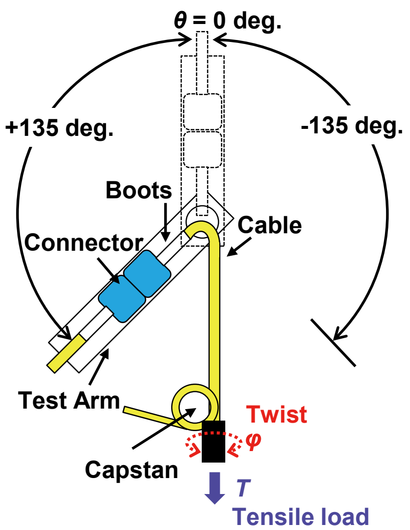

Fig. 11. Jumper test facility for the mechanical tests

Table 2. Results of the mechanical tests

Items	Conditions	Max. IL	Min. RL
Vibration test	XYZ, 2 h each, 1.5 mm (p-p), 10-55 Hz	0.24 dB	47.0 dB
Flex test	100 cycles of θ=(0°, 90°, -90°, 0°) at T=0.6 kgf	0.20 dB	50.1 dB
Twist test	9 cycles of φ=±900° at T=1.35 kgf	0.17 dB	49.3 dB
Proof test	T=4.5, 6.8 kgf at θ=0° T = 1.5, 3.4 kgf at θ=±90°	0.36 dB	48.4 dB
Transmission with applied tensile load	T=0.25 to 2.0 kgf at θ=0°, T=0.17 to 1.3 kgf at θ=±90°, T=0.17 kgf at θ=±135°	0.34 dB	47.9 dB
Impact test	8-times 90° swing impacts from 1.5-m height against concrete block	0.09 dB	50.1 dB
Durability	Connect and disconnect 200 cycles	0.31 dB	43.0 dB

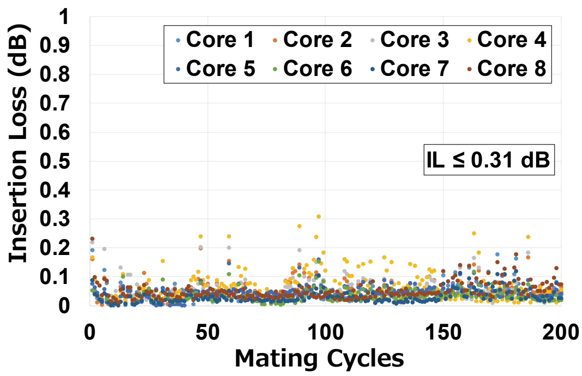

Fig. 12. IL variation of the durability test

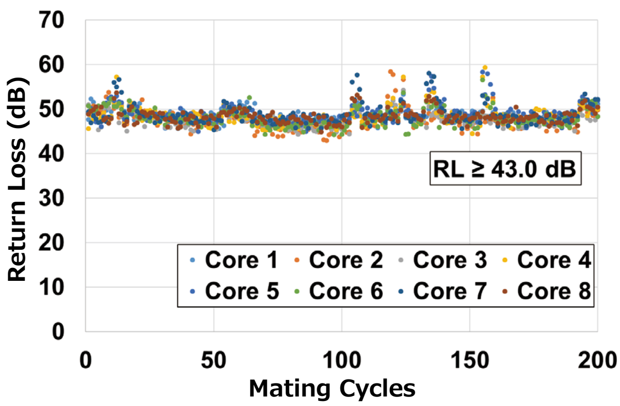

Fig. 13. RL variation of the durability test

These results assured that the proposed design has precise rotational fiber alignment and a structure that allows ferrule floating.

Using these connectors, we also conducted Telcordia GR-326-CORE environmental tests. Table 3 summarizes the test results. Figure 14 and 15 the IL and RL variations during Humidity Condensation Tests. The criteria of IL and RL were the same as those for the mechanical test. We confirmed the fabricated connectors passed under all the tests.

Table 3. Results of the environmental tests

Items	Conditions	Max. IL	Min. RL
Thermal Age test	85°C,168 h	0.44 dB	46.4 dB
Thermal Cycle test	-40 to 75°C, 8 hrs/cycle,168 h	0.37 dB	44.2 dB
Humidity Age test	75°C, 95%, 168 h	0.37 dB	44.3 dB
Humidity Condensation Cycle test	-10 to 65°C, 90~100% 12 hrs/cycle, 168 h	0.36 dB	44.0 dB

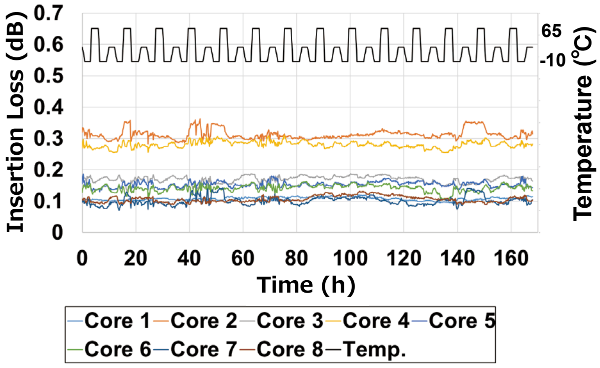

Fig. 14. IL variation of Humidity condensation cycle test

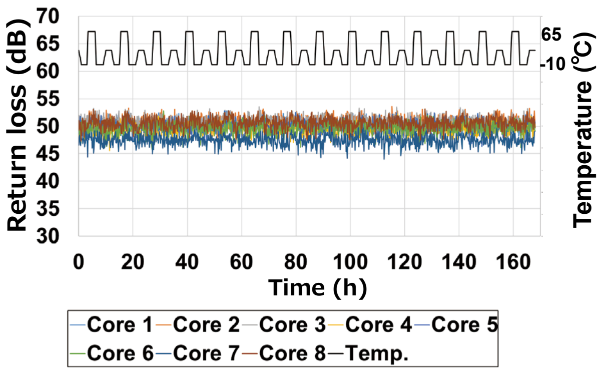

Fig. 15. RL variation of Humidity condensation cycle test

5. Conclusion

We proposed and demonstrated a novel simple-structure single-MCF connector. The present connector has a standard LC-interface and does not require any additional or higher-precision components and simultaneously realizes low insertion loss and reflection. Rotational fiber alignment and ferrule floating are realized by employing a standard MU ferrule with a straight flange edge and a modified LC housing with a tapered hole that can contact the ferrule flange. Every component of the present MCF connector is compatible to volume-manufacturing using conventional manufacturing facilities for single-fiber connectors. We conducted Telcordia GR-326-CORE mechanical and environmental tests. We confirmed that the IL and the RL were suppressed under the criteria of GR-326-CORE in all the tests. We also conducted a random connection test and confirmed that the IL distribution of the present connector is compatible to IEC 61753-1 Grade B for low-loss SMF connectors. These results assured that the proposed design has precise rotational fiber alignment and a structure that allows ferrule floating. Future tasks include improving the manufacturing technologies used for, and the performance of, the newly developed connector and other MCF-related components, and fulfilling demand for high-density connections for optical cabling.

6. Acknowledgments

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Technical Terms

∗1 Multi-fiber push-on (MPO) connector: A multi-fiber connector that mates optical fibers by the PC connection technique.

∗2 Lucent (LC) connector: The optical connector developed by Lucent Technologies, Inc. for single-fiber connections, which uses a zirconia ferrule 1.25 mm in diameter.

∗3 International Electrotechnical Commission (IEC): An international standardization organization specializing in the fields of electrical and electronic engineering.

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