Simple-Structure LC-Type Multi-Core Fiber Connector with Low Insertion Loss

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Abstract: We demonstrated a single-fiber multi-core fiber (MCF) connector without additional or high-precision parts for rotational alignment. Fabricated MCF connectors achieved low insertion loss of 0.07 dB in average and passed Telcordia GR-326-CORE mechanical reliability test.

1. Introduction

The rapid growth of the optical network traffic has dramatically increased the demands for high bandwidth optical interconnects in large-scale data centers [1]. Today multi-fiber MPO connectors are widely deployed in data centers to splice multiple optical channels and create higher density. However, installation and reconnection of MPO connectors are troublesome due to the difficulty of end face cleaning due to debris created by the insertion of connector alignment guide pins and the high mating force for physical contact of all optical fiber channels. The single-fiber connector with a multi-core fiber (MCF) is a possible solution to realize high-density multi-channel splicing with easy end-face cleaning and low mating force similar to conventional today's single-fiber connectors [2]. However, since MCF has outer cores located in the non-center part of the cladding, precise rotational fiber alignment and ferrule floating from the connector housing needs to be implemented simultaneously in order to realize low insertion loss (IL) and a stable single-MCF connection. Figure 1 depicts how a typical floating ferrule design can rotate in a conventional single-fiber connector due to the clearance between the ferrule flange and the housing. To address these challenges various custom connectors with additional and/or higher-precision parts have been reported [3–5], as summarized in Table 1. However, such additional and/or high-precision parts would make the volume manufacturing of single-MCF connectors much more difficult compared to that of conventional single-fiber connectors with single-mode fibers (SMFs).

In this paper, we propose a simple-structure single-MCF connector that does not require any additional or higher-precision components and simultaneously realizes rotational fiber alignment and ferrule floating. We fabricated LC-interface MCF connectors with plastic injection molding housing and the other standard single-fiber connector components. Thus, every part of the proposed connector can be manufactured with the same volume-manufacturing facilities for conventional single-fiber connectors. The IL of the fabricated MCF connectors measured 0.07 dB in average and ≤0.21 dB at the probability of 97%, which is compatible to IEC 61753-1 Grade B for low-loss SMF connectors. We also performed Telcordia GR-326-CORE mechanical test to confirm the rotational alignment and ferrule floating are sufficient in the fabricated connectors, as well as confirmed that the IL and the return loss (RL) of the fabricated connectors were sufficiently suppressed under various mechanical stresses.

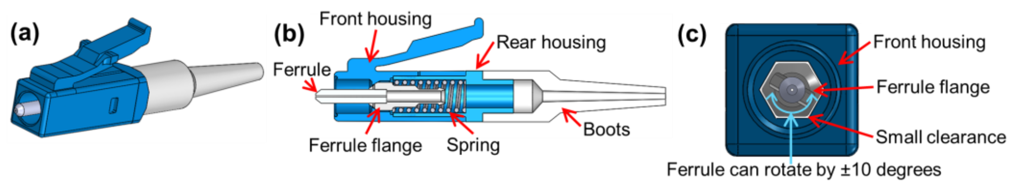

Fig. 1. (a) Appearance, (b) cross section, and (c) clearance between the ferrule flange and the housing of the conventional LC connector.

Table 1. Comparison of previously-reported and present single-MCF connectors

Ref.	Connector interface	Ferrule flange type	Number of additional parts	Estimated required precisions of parts
[3]	MU	Custom flange with Oldham coupling	2	High†
[4]	LC	Custom flange with Oldham coupling	2	High†
[4]	SC	Custom SC flange with tighter clearance	0	High†
[5]	SC	Standard flange with pressurizing spring	1	Standard‡
This work	LC	Standard MU flange	0	Standard‡

† High-precision machining may be required to suppress the clearance between Oldham coupling devices or between flange and housing.
‡ Standard-precision ferrule flange and housing can be used.

2. Structure and operating principle

To realize LC-interface MCF connector without increasing dimensional accuracies of components and without any additional parts for rotational alignment, we utilized the alignment–floating scheme whereby the MCF ferrule flange is rotationally aligned by contacting to the housing in the unmated state, and floated from the housing by being pushed back by the opposing connector in the mated state. Figure 2 shows the conceptual connector structure that we designed based on the described alignment–floating scheme. We utilized an MU ferrule flange (Fig .2b) instead of an LC ferrule flange (Fig. 2a) 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. 2c. The ferrule flange is floated from the housing when the ferrule is pushed by the opposing ferrule during connector mating, as shown in Fig. 2d. The only non-standard component of the proposed connector is the front housing with the tapered hole that does not require higher dimensional precision.

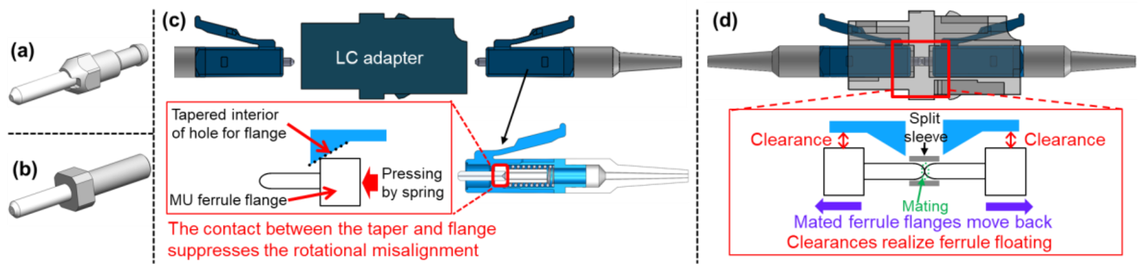

Fig. 2. Schematics of standard (a) LC and (b) MU ferrule flanges with the identical ferrule diameter, and (c) unmated and (d) mated LC-interface MCF connectors with the proposed housing a with tapered hole for a standard MU flange. When the connectors are unmated, ferrule flange is precisely rotationally aligned by the taper. When the connectors are connected, ferrule can be floating by the clearance.

3. Fabrication

We fabricated LC-interface MCF connectors with the alignment–floating scheme proposed above, using a 125-µm-cladding 8-core fiber where the cores are circularly located at the points distant from the cladding center by 40.5 µm and have the mode field diameter of 8.3 to 8.5 µm at the wavelength λ of 1310 nm [6]. The front housing with LC interface was modified to have a tapered hole for the flange–housing contact and floating feature, and fabricated using an ordinary injection molding method without any high-precision machining. A standard MU flange was utilized as mentioned above. The other components are standard LC connector parts. Thus, the present connector is compatible to the high-volume production processes for conventional single-fiber connectors and the external dimensions of the connectors are compliant with the IEC 61754-20 standard for LC connectors. We rotationally aligned an MCF to an MU ferrule with the misalignment less than 0.20 degrees by monitoring the MCF end face.

To confirm that the fabricated connectors have ferrule floating function and precise rotational alignment, we conducted Telcordia GR-326-CORE mechanical tests with one pair of the fabricated connectors. Figure 3a shows the jumper test apparatus to apply controlled bend θ, tension T, and twist φ. Table 2 summarizes the test results, and Figure 3b shows the IL variations during the durability test of 200 mating cycles. We confirmed the IL of less than 0.40 dB and the IL variation of less than 0.30 dB under all the mechanical tests. We also confirmed that the RLs were more than 40 dB for all the cores.

One interesting result in the mechanical tests is that the ILs were still suppressed after various stresses were applied, although the connector structure does not have ferrule rotation aligning mechanism *during the ferrule floating*. We believe the ferrule rotation due to the torque from external forces is suppressed by the pressing force of the connector end face and the friction between the split sleeve in the adapter and the ferrule. Our numerical simulation indicated that the torque to the ferrule more than 1 N·mm is necessary to rotate the ferrule in the split sleeve. Such a torque is unlikely to be applied to the ferrule, since the torque to the ferrule has to be transmitted through the spring from the rear housing, and the rear housing cannot rotate so much as it is fixed with the front housing.

We also conducted a random mating test to evaluate the IL characteristics of the fabricated MCF connectors. Figure 3c shows the IL histogram for 112 random connections with 3 mating cycles of the 8 cores of the MCFs, wherein 7 connectors were randomly selected from 20 connectors, and mated to each other and the unselected 13 connectors (${}_7C_2 + 7\times13 = 112$ connections). The IL was 0.07 dB in average, ≤ 0.21 dB for >97% of the samples, and 0.39 dB at maximum. The result is compatible to IEC 61753-1 Grade B for low-loss SMF connectors.

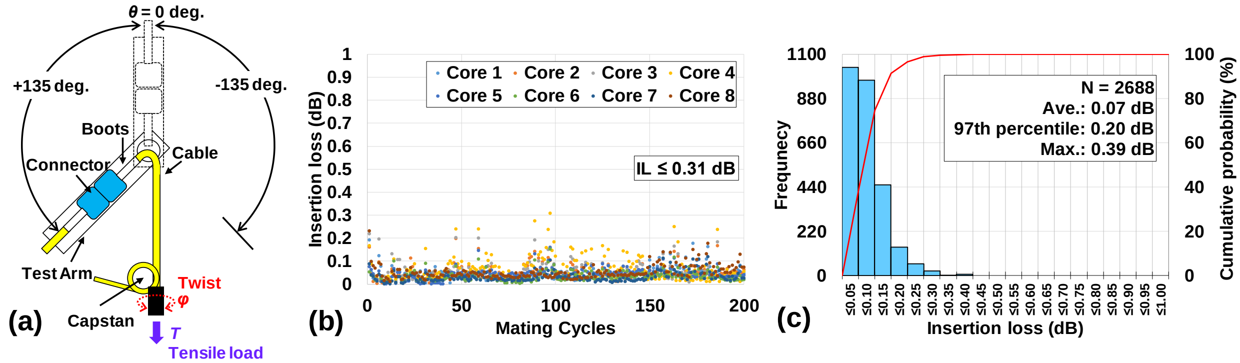

Fig. 3. (a) Jumper test facility for the mechanical tests, (b) the IL variation during the durability test for 1 pair of the fabricated connectors, and (c) the IL histogram for the random mating test (Sample size 2688 = 112 random connection pairs × 3 mating cycle × 8 cores).

Table 2. Results of the mechanical tests of the fabricated LC-interface MCF connectors at λ of 1310 nm

<table>
<tr><th rowspan="2">Items</th><th rowspan="2">Conditions</th><th colspan="2">Requirements</th><th colspan="2">Measurements</th></tr>
<tr><th>Max. IL</th><th>Min. RL</th><th>Max. IL</th><th>Min. RL</th></tr>
<tr><td>Vibration test</td><td>2-hr vibration with peak-to-peak amplitude of 1.5 mm and frequency sweeping continuously between 10 and 55 Hz at a rate of 45 Hz per minute, for each of x, y, z axes</td><td rowspan="7">0.50 dB</td><td rowspan="7">40 dB</td><td>0.24 dB</td><td>47.0 dB</td></tr>
<tr><td>Flex test</td><td>100 cycles of θ = (0°, 90°, 0°, −90°, 0°) at T = 0.6 kgf</td><td>0.20 dB</td><td>50.1 dB</td></tr>
<tr><td>Twist test</td><td>9 cycles of φ = ±900° at T = 1.35 kgf</td><td>0.17 dB</td><td>49.3 dB</td></tr>
<tr><td>Proof test</td><td>Straight pull: T = 4.5 kgf, 6.8 kgf at θ = 0°
90° side pull: T = 1.5 kgf, 3.4 kgf at θ = ±90°</td><td>0.36 dB</td><td>48.4 dB</td></tr>
<tr><td>Transmission with applied tensile load</td><td>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°</td><td>0.34 dB</td><td>47.9 dB</td></tr>
<tr><td>Impact test</td><td>8-times 90° swing impacts from 1.5-m height against concreate block</td><td>0.09 dB</td><td>50.1 dB</td></tr>
<tr><td>Durability</td><td>Connect and disconnect: 200 cycles</td><td>0.31 dB</td><td>47.1 dB</td></tr>
</table>

5. Conclusion

We proposed and demonstrated a simple-structure LC-interface single-MCF connector without any additional or higher-precision components. Rotational fiber alignment and ferrule floating are realized by employing a standard MU ferrule with a straight flange edge and the modified LC housing with a tapered hole that can contact to the ferrule flange. Every component of the proposed MCF connector is compatible to the volume-manufacturing using conventional manufacturing facilities for single-fiber connectors. In the experimental validation, the IL of the fabricated MCF connectors achieved 0.07 dB in average and ≤0.21 dB at the probability of 97%, which is compatible to IEC 61753-1 Grade B for low-loss SMF connectors. The IL of the fabricated connectors were sufficiently suppressed during Telcordia GR-326-CORE mechanical tests, which assures that the rotational alignment and ferrule floating functions properly work in the fabricated connectors. The proposed MCF connector will be able to become a volume-manufacturable and economically-viable solution to realize low-loss and high-density multi-channel optical connections with easy handling.

Acknowledgments

This research is supported in part by the National Institute of Information and Communications Technology (NICT), Japan.

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