Super Low-Loss, Super High-Density Multi-Fiber Optical Connectors

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ABSTRACT Optical connectors will be a key element in configuring large-scale optical networks of the future, and the authors have developed super low-loss, super high-density connectors. We have also developed assembly technology based on innovative high-precision molding technology, which eliminates fiber position error as a major factor in connector insertion loss. This has resulted in a striking reduction in insertion loss and remarkably high-density packaging compared with existing connectors. In terms of the reduction in loss, we obtained 0.15 dB (SMF) for an 8-fiber connector, and 0.30 dB (SMF) for a 24-fiber connector. And we were able to integrate 60 fibers within the same dimensions as existing connectors.

1. INTRODUCTION

With recent expansion of optical networks, the demand for high-speed, high-density transmission has been increasing. This requires low-loss, high-density optical connection technology in the transmission equipment, together with easy connecting and disconnecting functions. Thus, for the further development of optical networks, optical connectors must provide low loss, high density, and easy connection and disconnection. On the other hand, MPO connectors and MPX ™ connectors † are also in wide use in communications markets as connectors that can handle multi-fibers easily, with some variations in the number of fibers up to 24 in standard-size MTs. Against this background, we reported the development of an 8-fiber low-loss MT ferrule and 8-fiber low-loss MPO connector [4)]. In this work, we obtained lower loss and higher density for all of these optical connectors.

Photo 1 MPO connector.

Photo 2 MPX ™ connector.

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† LIGHTRAY MPX ™ is a registered trademark of Tyco Corporation.

2. STRUCTURE

2.1 Development Target

In this work, we have given prime consideration to compatibility with the existing family of MT connectors, and have developed 8-fiber, 24-fiber, 32-fiber, and 60-fiber connectors that offer lower insertion loss and higher fiber density within the standard MT ferrule size. We set our development target as follows.

Connector type	Max. Loss	Number of fibers
Super low-loss	≤ 0.15 dB	8-fiber
Low-loss high-density	≤ 0.35 dB	24-fiber
Super high-density	≤ 1.0 dB	32, 60-fiber

The end-face of the MT ferrules is shown in Figure 1. In order to utilize the standard connector housing for MT ferrules, the outer dimensions of each ferrule are the same as standard MT ferrules. The end-face is 2.5 mm in height and 6.4 mm in width. Fiber holes of all MT ferrules are located at a 0.25-mm pitch between columns. The holes of the MT24 are arranged in 2 rows of 12 columns, with 0.5-mm pitch between rows. The holes of the MT32 are

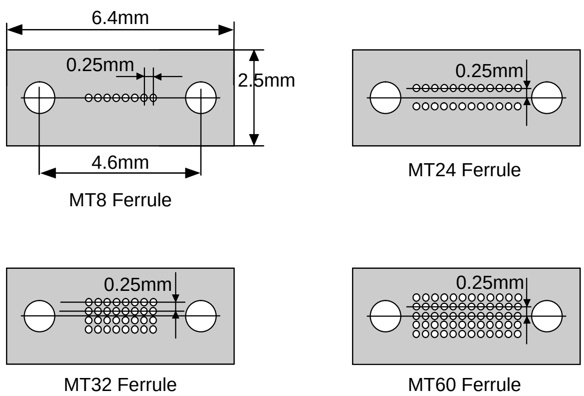

Figure 1 End-face of MT ferrules.

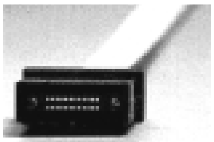

Photo 3 MT24 connector.

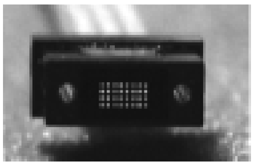

Photo 4 MT32 connector.

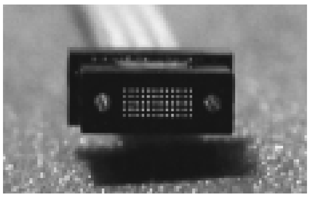

Photo 5 MT60 connector.

arranged in 4 rows of 8 columns, with 0.25-mm pitch between rows. Those of the MT60 are arranged in 5 rows of 12 columns, with 0.25-mm pitch between rows. One MT ferrule with optical fibers attached is accommodated in each MPO connector and/or MPX ™ connector.

It is difficult to achieve such high performance by ferrule design alone. We therefore used highly precise SM fibers at connector assembly and highly precise alignment pins when evaluating insertion loss.

2.2 MPO Connector Structure

The MPO connector, shown in Figure 2, is a connector for optical fiber ribbons conforming to JIS C 5982 F13 (IEC 1754-7). Each MPO connector accommodates one MT ferrule, which has two alignment holes and a specific number of fiber holes. The end-face of the ferrule is angle polished at 8 degrees with protrusion of fibers as in the case of SMF generally. Fiber protrusion enables physical contact between mated fibers, and it is therefore possible to get low insertion loss without the use of index matching gel. Angling the end-face of the optical fiber also prevents reflection of the light, thereby improving the return loss of the connector.

3. CAUSE OF INSERTION LOSS

In general, the main cause of connector insertion loss is position error of the fiber core. The following description uses the 8MT as an example. Insertion loss L caused by position error of the fiber core is defined by the equation

$$L = 4.34(R/w)^2\ [\text{dB}]$$ [5]

where:
R [μm] is position error between mated fiber cores, and
w [μm] is mode field radius.

This R is influenced by the following factors:
1) the clearance between the alignment pins and alignment holes of the MT ferrule (E1 in Figure 3);
2) the clearance between the fibers and the fiber holes of the MT ferrule (E2 in Figure 3);
3) fiber hole position error (E3 in Figure 3);
4) fiber hole tilt against alignment holes (E4 in Figure 4); and
5) bending caused by shrinking of the adhesive resin (E5 in Figure 5).

To achieve lower insertion loss, we improved the precision of mold pins and V-groove molds to reduce the value of E1, E2, and E3. We also reduced the size of the ferrule window, and thereby positioned it farther from the end-

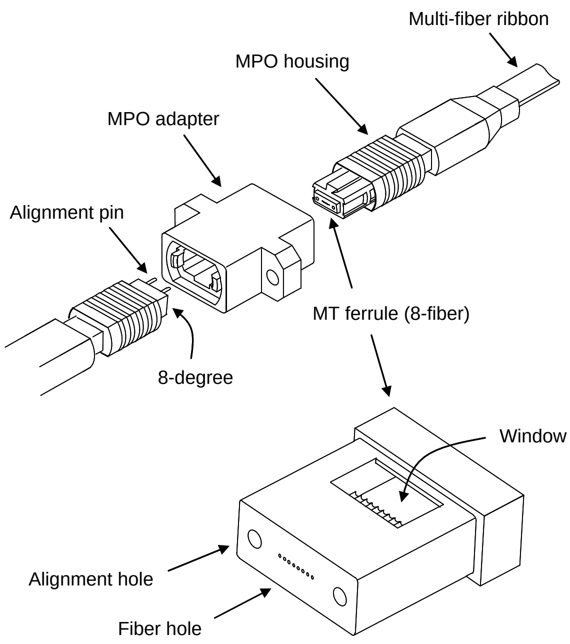

Figure 2 MPO connector structure.

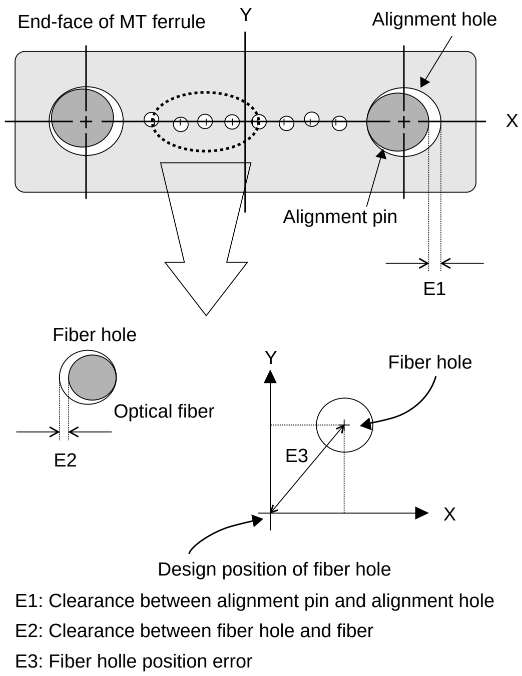

Figure 3 Causes of position error of fiber core.

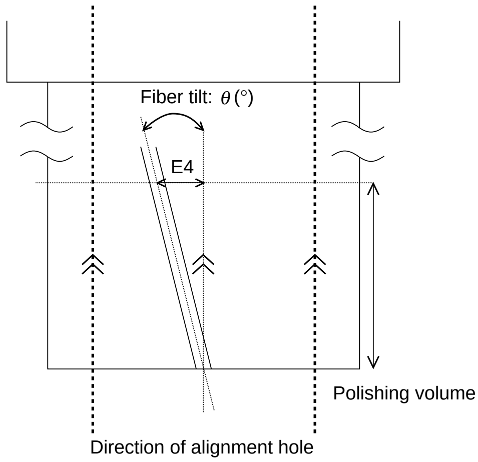

Figure 4 Fiber hole tilt.

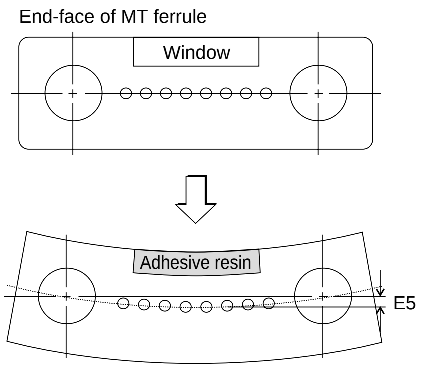

Figure 5 Bend by shrinking of adhesive resin.

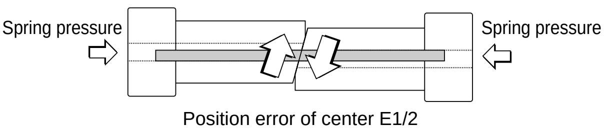

Figure 6 Position error by slipping.

face in order to reduce the influence of adhesive shrinkage, reducing the value of E5.

Because of the clearance between the alignment pins and alignment holes of the MT ferrule, two angled MT ferrules slip when they are mated to each other. This causes position error for the center of the mated MT ferrules, as shown in Figure 6. It is therefore important to optimize the position of the fiber holes in investigating these causes in relation to Y_{offset}

$$Y_{offset} = E1/2 + E4 + E5$$

We investigated these values minutely in determining the Y_{offset} value.

Next we will explain in greater detail about fiber hole tilt, with the example of a multi-row ferrule (24-fiber). Figure 4 shows the tilt in the ferrule width direction. The ferrule also has a tilt in the ferrule height direction as shown in Figure 7. It is necessary, however, to make each fiber hole and each alignment hole parallel as shown in Figure 8, in

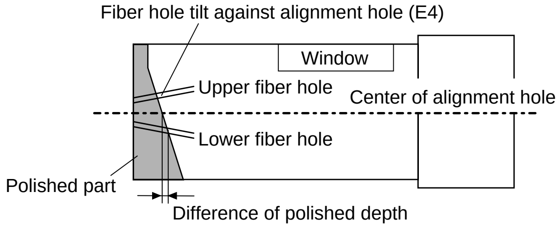

Figure 7 Fiber hole tilt of 2D-MT ferrule.

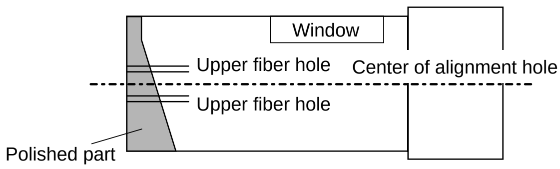

Figure 8 Parallel arrangement of holes.

order to obtain accurate fiber position after the ferrule is polished. Since a ferrule is given an end-face angle of 8 degrees at assembly, it is necessary for alignment holes and fiber holes to be parallel in the ferrule length direction over the polished part. Moreover as can be seen in Figure 7, the polished part of the lower fiber row is larger in case of multi-row ferrules, so it is necessary to guarantee parallel accuracy over a longer length in the direction of depth from the end-face.

4. STRUCTURE OF METAL MOLD

4.1 Improvement in Parallel Accuracy of Each Hole

Based on the above analysis, we improved metal mold to thoroughly eliminate the factor of fiber core gap, focusing especially on decreasing fiber hole tilt of the metal mold. Figure 9 shows the structure of the metal mold of a MT24 (2-row) ferrule. In the conventional metal mold, accurate

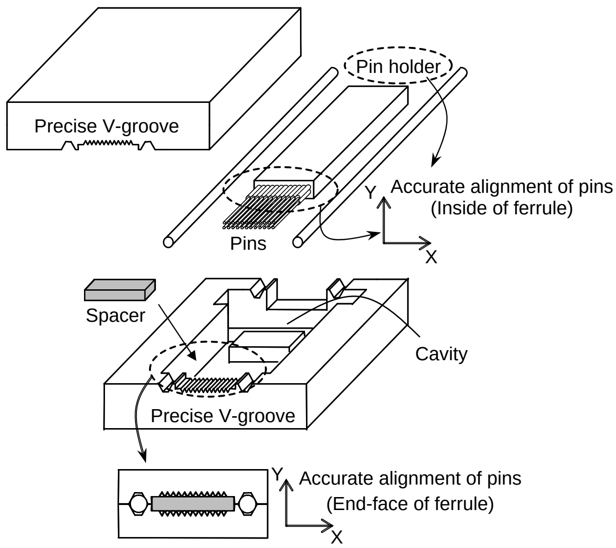

Figure 9 Structure of precise metal mold.

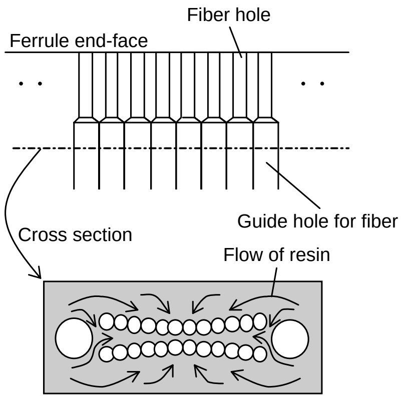

Figure 10 Structure of conventional pins.

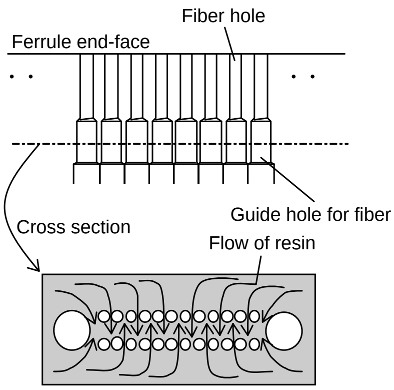

Figure 11 Structure of improved pins.

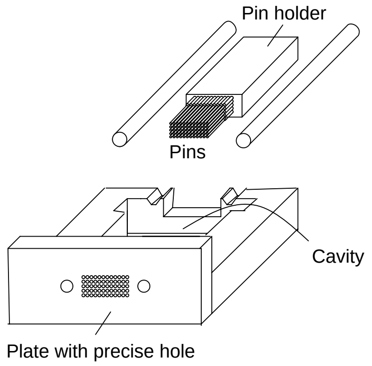

Figure 12 Super high-density ferrule metal mold.

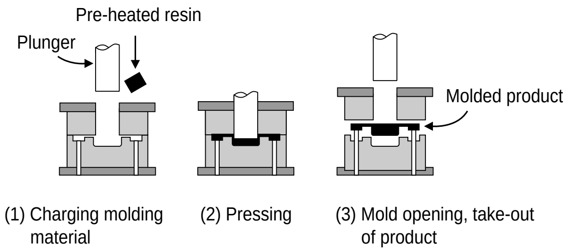

Figure 13 Transfer molding process.

alignment of the pins was done only at the end-face of the ferrule. Here, however, in order to make each hole more accurately parallel, the forming pins were aligned with the pin holder, which in turn was aligned with the cavity parts. In this way it was possible to make hole alignment highly precise not only at the ferrule end-face but also inside the ferrule.

4.2 Measures for Preventing Fiber Hole Bending

Multi-row ferrules of the conventional structure had another problem in terms of hole accuracy. As shown in Figure 10, the pitch between the upper and lower fiber holes becomes narrower at the center of the row inside the ferrule. We attribute this to resin flows. In general, as shown in Figure 10, MT ferrules have fiber guide holes linking with the fiber holes. In the conventional ferrules, the diameter of the fiber guide hole is the same as the fiber pitch, so resin cannot easily flow into the space between the upper and lower pins during the molding process. The pins are therefore pressed by the resin from the outside and bent. In order to solve this problem, we designed new fiber guide holes and pins as shown in Figure 11. The diameter of the fiber guide holes was reduced to less than the fiber hole pitch, so that the resin flows easily in the space between the upper and lower pins through the gap between the pins in each row.

4.3 Metal Mold for Super High-Density Ferrule

From the standpoint of reducing insertion loss with highest priority, the V-groove type metal mold mentioned above is more suitable for getting higher precision and alignment of holes, since it is the structure in which the pins are aligned at three points. However, in making a two-dimensional arrangement for a ferrule of three or more rows, the metal mold structure that sandwiches the spacers between V-grooves becomes very complicated, and productivity of such a metal mold could deteriorate. Thus, as shown in Figure 12, we adopted a metal mold structure in which the pins are held by a plate with high precision supporting holes. Although the arrangement of pins is not as accurate as with the V-groove type, we developed a metal mold processing technology that can reduce supporting hole misalignment to less than ±1 μm. In this way, we have realized ferrules for super high-density connectors that have 32 fiber holes (4 rows of 8 columns) and 60 fiber holes (5 rows of 12 columns)

5. MOLDING

In order to achieve super low loss and super high density, we have adopted a transfer molding process using a thermosetting epoxy with a high filler content and low shrinkage. Figure 13 shows the process. The mold is first clamped tightly in the clamping device of the molding machine, and, molding resin in tablet form is pre-heated by a microwave heater and introduced into the pot, as shown in Figure 13 (1). The plunger is then inserted into the pot and presses the resin so that it fills the cavity section, as shown in Figure 13 (2). After being pressed and heated for a certain time, the mold is opened, and the molded product is ejected from the cavity, as shown in Figure 13 (3). In transfer molding, the temperature, heating time and molding pressure of the resin are very important factors affecting the characteristics of the molded product, and these molding conditions were therefore optimized.

6. RESULTS

6.1 Super Low-loss MPO8 Connector

By means of the described above improvements, we were able to obtain ferrules in witch the position accuracy of the holes is strikingly improved inside the ferrule in particular. In the case of the MT8, a hole position accuracy of ±0.4 μm was realized. Figure 14 shows the insertion loss of MPO8 connectors using the improved MT8 ferrules. Since it is difficult to realize a super low-loss type connector merely by improving the ferrule, we also used precise fibers and polished the end-face very precisely at assembly. As compared with the conventional low-loss type (max 0.35 dB), this super low-loss type achieved the striking loss reduction to not more than 0.15 dB, a result which is equivalent to a ceramic-type single-fiber connector.

6.2 Low-loss High-density MPO24 Connector

We also examined the effect of improving the metal mold on the fiber position error of 24-fiber connectors. Figure 15 shows fiber position error (E3, E4) at the end-face and the inside of the ferrule, which means the tilt between the alignment holes and fiber holes. The position error inside the ferrule was measured at a depth of 400 μm which is the expected value during the polishing process. We obtained good results for hole position, less than 1 μm error at the end-face and less than 1.3 μm inside the ferrule. Figure 16 shows the insertion loss of MPO24 connectors using the improved low-loss type MT24 ferrules, representing a striking reduction to not more than 0.30 dB. It is particularly noteworthy that low insertion loss was obtained not only at the usual polishing value of 150 μm but also at 400 μm, demonstrating that the hole tilt inside the ferrule is greatly reduced.

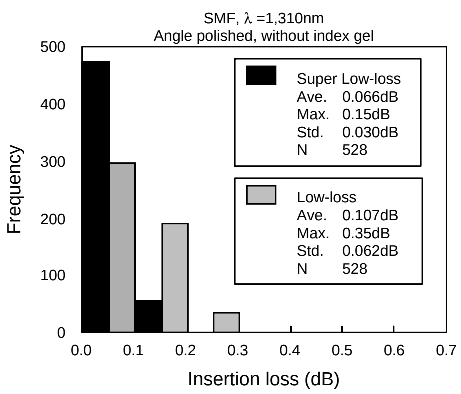

Figure 14 Insertion loss of super low-loss MPO8 connector.

6.3 Super High-density 32- and 60-Fiber Connectors

We were also able to produce ferrules for 32-fiber connectors and 60-fiber connectors. Figure 17 shows the insertion loss for a 32-fiber connector, evaluated using a connector with an end-face polished to flat shape, a SMF and index matching gel. We obtained good values for insertion loss of not more than 0.8 dB, sufficient performance for practical use with SMF.

Figure 18 shows the insertion loss of a 60-fiber connector, evaluated using a connector with an end-face polished to flat shape, a MMF and index matching gel. We obtained good values for insertion loss of not more than 0.1 dB with MMF.

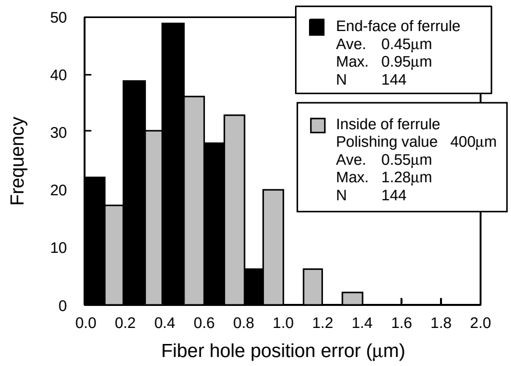

Figure 15 Fiber hole position error of low-loss MT24 ferrule.

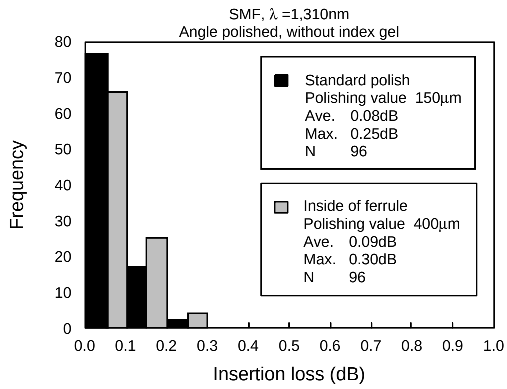

Figure 16 Insertion loss of low-loss MPO24 connector.

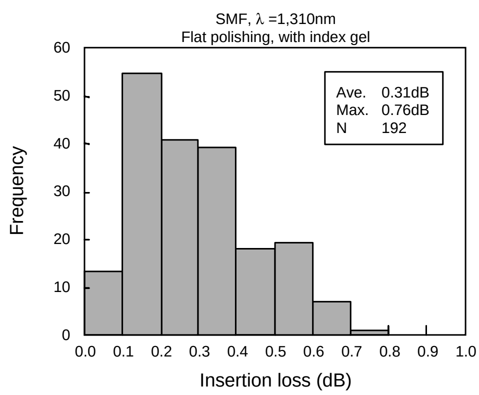

Figure 17 Insertion loss of super high-density 32-fiber connector.

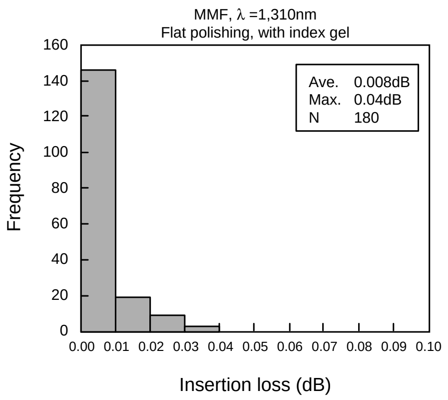

Figure 18 Insertion loss of super high-density 60-fiber connector.

Table 1 Result of reliability tests on MPO8 and MPO24 connectors.

Test	Duration	Test Parameter	Insertion loss variation
Thermal Aging	14 days	85°C	< 0.1 dB
Humidity	14 days	95 % at 60°C	< 0.3 dB
Temperature Cycling	42 cycles (14 days)	-40 °C to 75°C	< 0.3 dB
Vibration	2 hours/axis for 3 axes	10 to 55 Hz	< 0.2 dB
Twist		2.2 N	< 0.1 dB
Straight Pull		2.2 N	< 0.1 dB
Side Pull		2.2 N	< 0.2 dB
Impact	8 cycles	1.5 m drop	< 0.1 dB
Durability	200 cycles	Connect and disconnect	< 0.3 dB

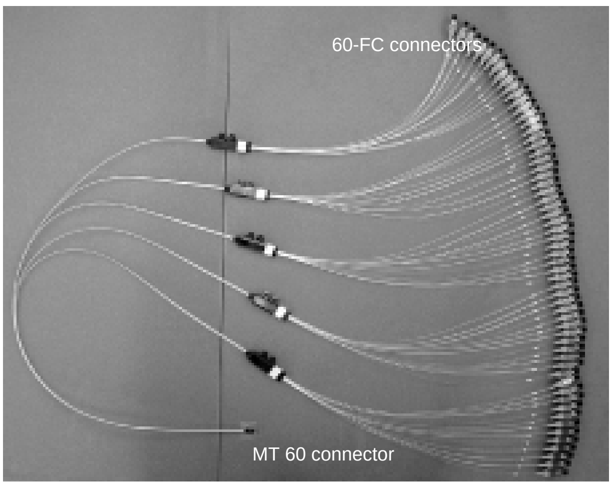

Photo 6 MT60 fan-out.

6.4 Reliability

Environmental and mechanical performance were evaluated, and Table 1 shows the result of tests on super low-loss MPO8 connectors and low-loss high-density MPO24 connectors with an end-face polished to angle. Test conditions are based on Telcordia GR-1435-CORE. Good results were obtained for each test item.

7. CONCLUSION

We have succeeded in developing super low-loss, super high-density connectors. In the 8-fiber and 24-fiber connectors, optical characteristics not inferior to the existing single-fiber connectors were obtained. The use of this connector can be expected to effect a significant reduction of space and simplification of operation in the wiring of optical telecommunication systems.

Good optical characteristics were also obtained for 32-fiber and 60-fiber connectors. These super high-density connectors have the possibility of being used in other applications, such as super high-density multi-fiber arrays for large-scale optical switches. Photo 6 shows a typical fan-out application. We intend to make further improvements, to facilitate application not only in optical connectors but in other various optical components,

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