

SDC
SOLENOIDAL DETECTOR NOTES

**DEVELOPMENT OF FIBER-TO-FIBER CONNECTORS FOR
TILE/FIBER CALORIMETERS**

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1. Introduction

Tile/fiber calorimeters require to bond waveshifting fibers and clear fibers with good optical coupling. Multi-channel fiber-to-fiber connectors are needed if we have to replace the calorimeter modules in the forward region. Optical connectors are helpful to route fibers for shower maximum detectors or "pizza pans" located at endcaps.

The methods of melting and fusing fibers in a glass tube have been investigated and showed optically satisfactory results. Light transmission of 90-95% with an rms variation of 2-5% has been achieved. For bonding thin quartz fibers the heat splicing method provides better light coupling than any type of connectors because of limited dimensional accuracy of connectors. We started R&D on fiber-to-fiber connectors, hoping that the tolerance of connector dimensions is insensitive for thick fibers (order of 1 mm) we are using. From the same reason, fiber-to-fiber connectors may provide as good optical coupling as fusion splicing.

We are developing a single-channel connector and an 8-channel connector. The connector R&D so far can be divided into two steps. At the first step, we machined ten of each of the following three types of connectors:

- (A) "Splicer": single fiber-to-fiber connector.
The fibers are set in a U-shaped straight groove and are held in tightly with two separate lids.
- (B) Single-channel disconnectable connector.
The fiber is held in a holder groove with a lid. Two of these fibers face at the middle of a connector housing.
- (C) Eight-channel connector: an eight-channel version of (B).

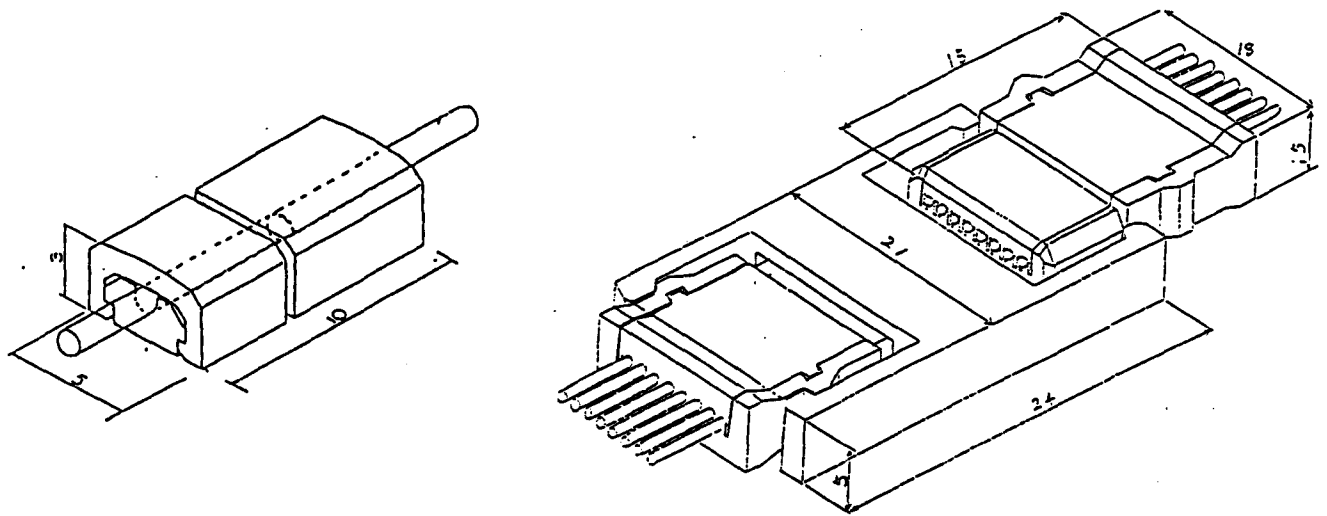


Fig. 1 Schematic diagrams of 1-ch splicer and 8-ch connector. The schematic diagrams of the 8-ch connectors (C) and (D) described in the text are almost identical, and the connector (B) corresponds to the case the number of channels is reduced to one.

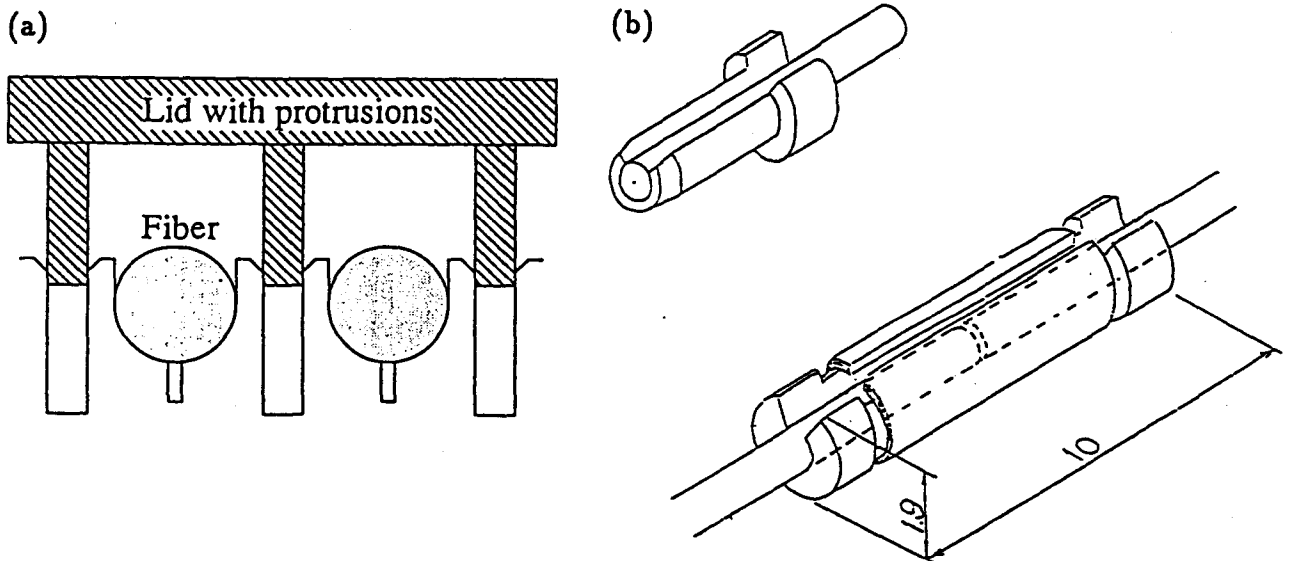


Fig. 2 (a) Detailed structure of fiber holding for the 8-ch connector. (b) Smaller 1-ch splicer. The top diagram shows the fiber holder, two of which are inserted into a metal sleeve as shown in the above diagram.

Construction of the connectors, made of ABS resin, is shown in Fig. 1. The fiber holding force was weak at some places in the 8-ch connector, and the material ABS resin was not strong against heat in this application. The splicer of $3 \times 5 \times 10$ mm would be useful, but substantially bigger than the joint of heat spliced fibers. Therefore, we changed the material to 66PA (15% glass added) and changed the fiber holding scheme for the 8-ch connector, and for a 1-ch connector splicer we employed a metal sleeve to keep hold the small holders into which fibers are embedded:

(D) Eight-channel connector: modified version of (C).

Fig. 2 shows the detailed structure of fiber holding. The fiber is placed in a U-shaped groove with a small slit at the bottom. Between the U-shaped grooves, there are square grooves, into which a lid with square protrusions is pressed to hold in the fibers. Previous 8-ch connector (C) employed V-shaped grooves. With this U-shaped groove, the fiber holding strength is improved. The diameter of the U groove is chosen to 0.80 mm so that 0.83 mm ϕ fibers (with an extreme deviation of 0.02 mm in diameter) can be held. The dimensions are 5 (H) \times 21 (W) \times 24 (L) mm.

(E) Splicer: single channel connector with a metal sleeve.

The fiber holder made of 66PA is a tube with a quarter section cut out to allow the fiber to be pressed in. The metal sleeve with a slit works as a spring and keeps hold the fiber holders. By using metal, it was possible to reduce the diameter to 1.9 mm. The connector is 10 mm long. The fiber holder and the connector as a whole are sketched in Fig. 2.

In this note we report the performance measurements for these connectors mainly on (D) and (E). In the following figures, the data may be expressed in terms of variation of light power (dB). The value x (dB) can be translated into the percentage y (%) by $y = [10^{x/10} - 1]/100$. For small x , this equation can be approximated by $y(\%) \sim 2.5 x(\text{dB})$.

2. Performance Tests

The following tests were performed: (1) light transmission with and without matching grease, (2) change in light transmission after up to 20 times of re-connections, (3) light transmission as a function of temperature, (4) change in light transmission after heat cycles, (5) change in light transmission after vibration, and (6) change in light transmission after keeping at 40°C for 24 hrs. We measured the fiber holding strength, which is defined as a weight when the light loss increases by 0.2 dB (4.7%). Signal cross talk is also measured for the 8-ch connector.

2.1 Light transmission

Fig. 3 shows the initial light losses for the 8-ch connectors. The data with and without silicon matching grease are shown. Throughout the measurement, 1 m long, 0.83 mm ϕ Kuraray clear fibers were used. The fibers were coupled to the LED or the photodiode by means of commercially available connectors, DDK 905D. The initial light yield through the fiber was measured by injecting red LED lights from one end. The same fiber was cut halfway to

furnish the connector and the light yield was measured in a similar way. The light transmission is defined as the ratio of these two readings.

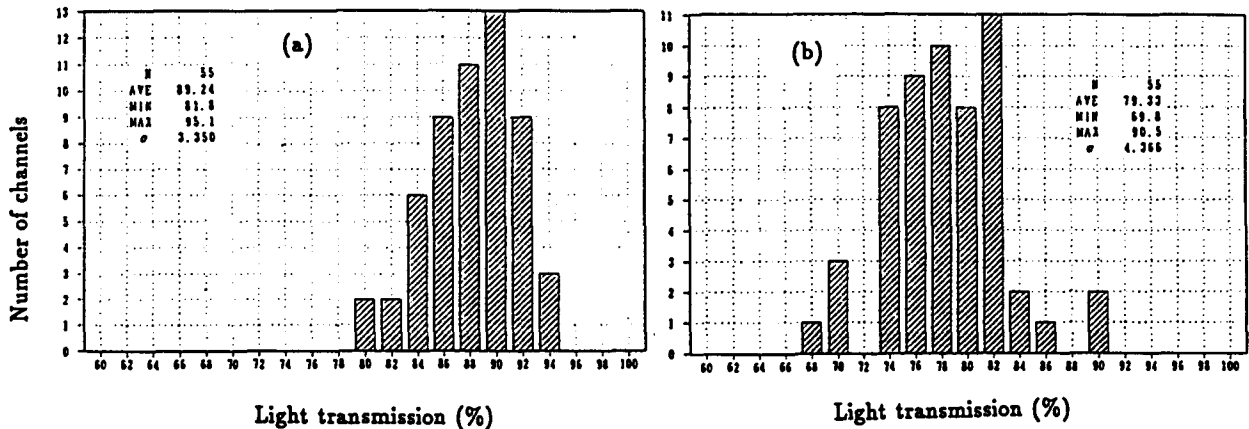


Fig. 3 Light transmission of the 8-ch connector (a) with and (b) without matching grease. The rms spread is wide as described in the text.

The average transmission is 89.2% (3.4% rms spread) with grease and 79.3% (4.4% rms spread) without grease for the 8-ch connectors. The matching grease increases the light transmission by nearly 10% and reduces its rms spread. peak-to-peak deviation with grease is +5.9% and -7.5%. The lids of the new connectors using 66PA were too tight to be pressed into so that each one of the two protrusions were trimmed. This repair caused the fiber axis to shift, and the rms spread of the light transmission increased. The rms deviation of the connector (C) was 2.6%. By using injection molding, the uniformity is expected to be about 2.6% or smaller.

Since the cross talk measured for the connector (C) was small, we have not repeated measurement for the new connectors (D). For the connector (C) the cross talk defined as the light yield when the light is input to the adjacent fiber is less than 0.11% and typically 0.06%, which is consistent with the background in the measurement.

The transmission for splicers is 94.5% in the average and 1.9% in the rms spread, as shown in Fig. 4. Here matching grease is used. The splicers may be used at the place where the fiber is bent at a certain curvature. We measured the effect of fiber bending. The fiber with a splicer (A), while one fiber end was kept fixed, was turned by 90° with a curvature of 30 mm. The light transmission was measured with changing the position of the splicer from the fixed end. Although the transmission increases gradually with increasing the splicer position from 15 mm to 45 mm, it agrees to within 1% for the four samples we measured.

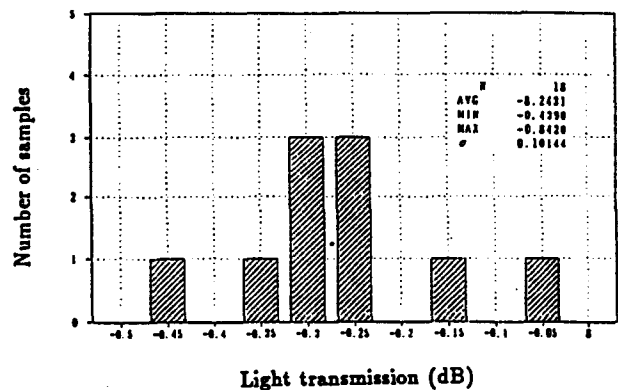


Fig. 4 Light transmission of the 1-ch splicers.

2.2 Durability

In the durability test we measured the light loss by repeating disconnection and connection up to 20 times. Fig. 5a shows the results for the 8-ch connector with and without matching grease and for the splicer with grease. The figure shows the variation of the light yield with respect to the first data point. The positive data mean that the light transmission increased. Both the edge channel (ch1) and the center channel (ch4) of the 8-ch connector (D) show a similar variation of less than $\sim 2\%$ (0.1 dB). The variation seems to be smaller (less than $\sim 0.5\%$) with matching grease except for one data point. This bad data point is suspected to be due to air that went into the grease. Similar behavior is seen for the splicer as shown in Fig. 5c.

2.3 Transmission dependence on temperature

Fig. 6 shows the variation of light yield of the splicers and 8-ch connectors as a function of temperature from 80°C to -10°C . The pattern of temperature variation is also shown in the figure. In the sample one control fiber (without a connector) is included to see any change in the fiber itself. The 8-ch connector shows a small variation of less than 2% throughout the measurement and the light yield comes back after the temperature is set to room tempera-

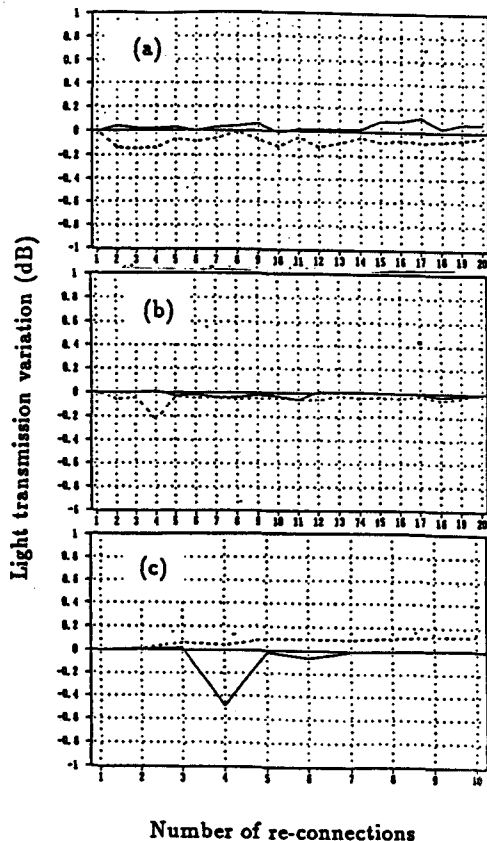


Fig. 5 Light transmission variation of the 8-ch connectors (a) without and (b) with matching grease, and of (c) splicers with grease as a function of number of re-connections. Two channels are measured for each.

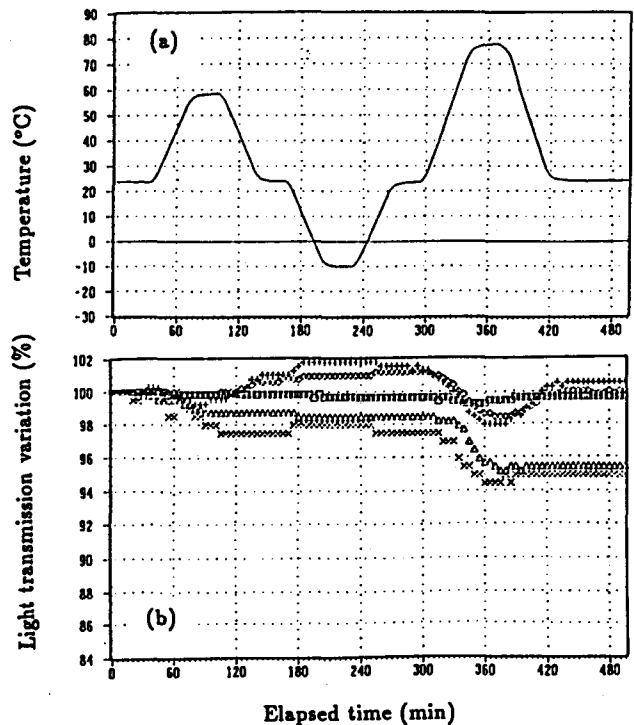


Fig. 6 Light transmission variation as a function of temperature. (a) Temperature pattern and (b) data for bare fiber (square), 8-ch connector ch-1 (plus) and ch-4 (diamond) and splicers (triangle and cross).

ture. The previous version of the 8-ch connector (C) showed a large variation of $\sim -15\%$ at 85°C . By changing the material from ABS to 66PA, the heat resistance has clearly improved.

On the other hand, the splicer showed 2% loss at 60°C and 5% loss at 80°C . The light loss does not seem to decrease after the temperature is set back to room temperature. Deformation in the fiber shape was recognized. The metal sleeve was in fact too tight and it was hard to press the fiber holders into the sleeve. We need to optimize the diameter of the sleeve.

2.4 Variation of light loss due to heat and vibration

1) Heat cycles

In order to simulate aging effect of the connectors, the light yield was measured with cycling through the temperature. The temperature was changed from -10°C to 60°C , and this cycle was repeated 10 times. Fig. 7 shows the variation of the light transmission for the 8-ch connector with and without matching grease. The light transmission varies periodically according to the heat cycle. The data for the case grease is used are similar except for one channel. This bad channel showed a variation of up to 10%. We suspect that the amount of grease was not adequate, or the gap between the fibers was critical so that the grease did not work properly at the lowest temperature. This bad behavior became less obvious when the heat cycle period was set longer, and disappeared after some moment.

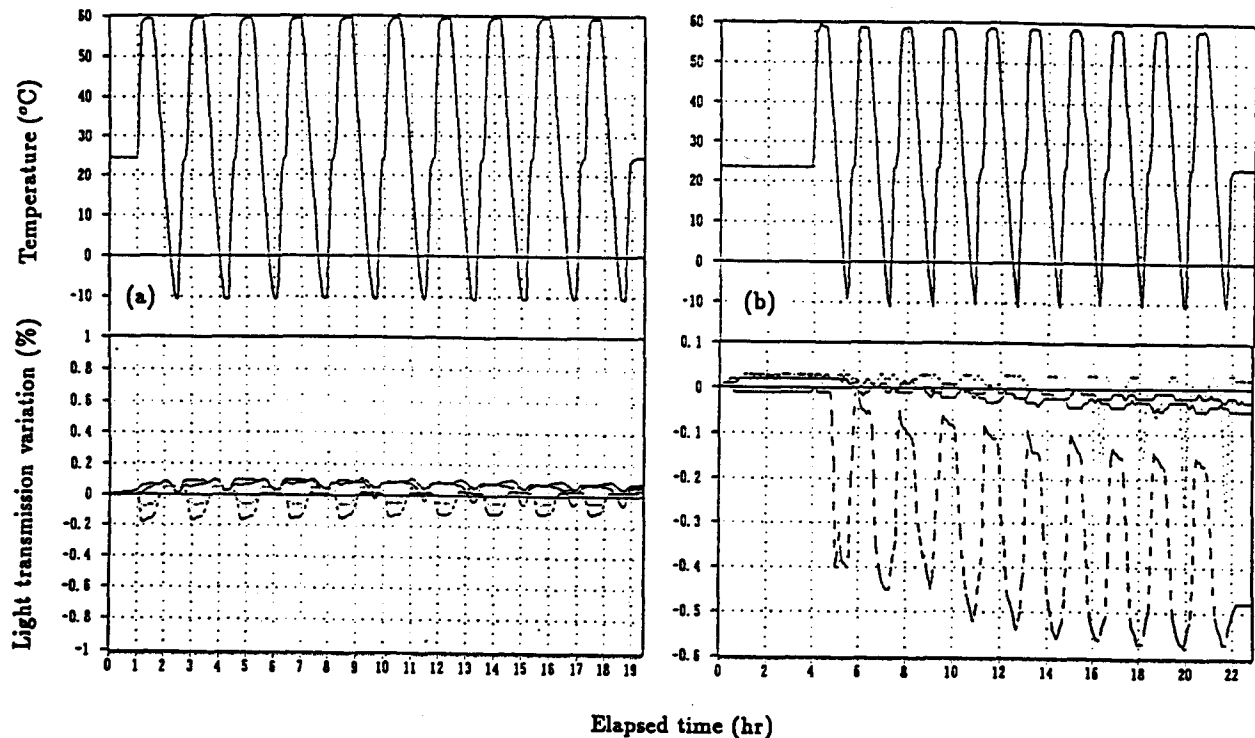


Fig. 7 Heat cycle test of the 8-ch connectors (a) without and (b) with matching grease. The temperature patterns are shown above the each plot. In each plot four channels are measured. The bad channel in (b) depends on the time scale of the heat cycle and disappeared after some time.

observation, the matching grease may be critical for the present application. We planed to do measurements with silicon rubber sheets instead of matching grease.

2) Light loss at -40°C for 24 hrs

If the fibers furnished with connectors are transported by aircraft, the connectors have to experience a temperature as low as -40°C . A test was performed to measure the light loss variation while keeping the connectors at -40°C for 12 hrs. The test was repeated twice. In Fig. 8 the temperature pattern and the light transmission variation are shown for the 8-ch connector. No matching grease was used. While the light transmission decreases by 7-8% at -40°C , the transmission recovers to a 1-2% level after the temperature is set to room temperature. The light transmission for the splicers decreases by less than 3% after a similar test. It was observed that the transmission of fibers only seems to decrease by about 1% after the test, which is added in the above values.

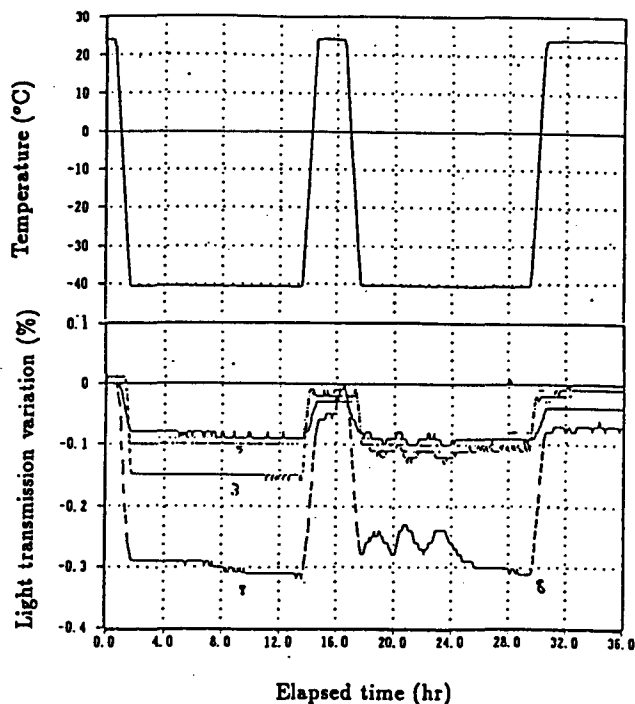


Fig. 8 Low temperature (40°) test for the 8-ch connector. Matching grease is not used. The test was repeated twice in total 24 hrs.

3) Light loss after vibration

The connectors (A)-(C) were tested for stability against vibration. They were placed on a stage that vibrated with an amplitude of 0.75 mm at 10-55 Hz. The test continued for 24 hrs. The light transmission of all the samples was stable within 4% and typically 2%. The worse data were obtained for the sample which showed a relatively large change in the low temperature test; This test was performed right after the test at -40°C using the same sample. Probably deformation of these channels recovered by vibration, and actual transmission variation due to vibration may be smaller.

2.5 Fiber holding strength and unplugging force

The fiber holding strength for the splicers is 1.6-1.7 kg. This value was found not to change after the heat cycle and low temperature tests described previously.

Fig. 9 shows the holding strengths measured for the 8-ch connectors. We aim for the holding strength to be more than 1 kg so that the fibers will not slip out the connector due to usual handling. We designed the fiber holding scheme to achieve this value, based on a bench test. But, as mentioned previously, the half of the protrusions were trimmed off. This has apparently decreased the holding strength to 0.6-0.7 kg. The holding strength does not change after the heat cycle test and the low temperature test. Although the fiber holding strength is expected to be made more than 1 kg if the connectors are injection molded with proper dimensions, we plan to use glue in addition to provide enough holding strength.

The force needed to unplug the 8-ch connectors was measured. This unplugging force has to be reasonably high (more than 1 kg) to prevent the connector from being unplugged accidentally and has to be less than 2 kg to allow for the connectors to be unplugged when necessary. Since the previous connector (C) was unplugged easily at 0.5 kg, the wall thickness of the hooks was increased to 1.0 mm (it was 0.8 mm) in addition to change of material to harder 66PA with 15% glass. This modification was apparently too much: the connector needs a force of more than 2.5 kg to unplug. The present material 66PA with 15% glass added is very hard and it took time to polish the fiber end to length. Therefore we plan to change the material to a softer one in injection molding while keeping the nice properties against heat. To avoid optimization of the hook thickness, we plan to use screws to prevent from being unplugged.

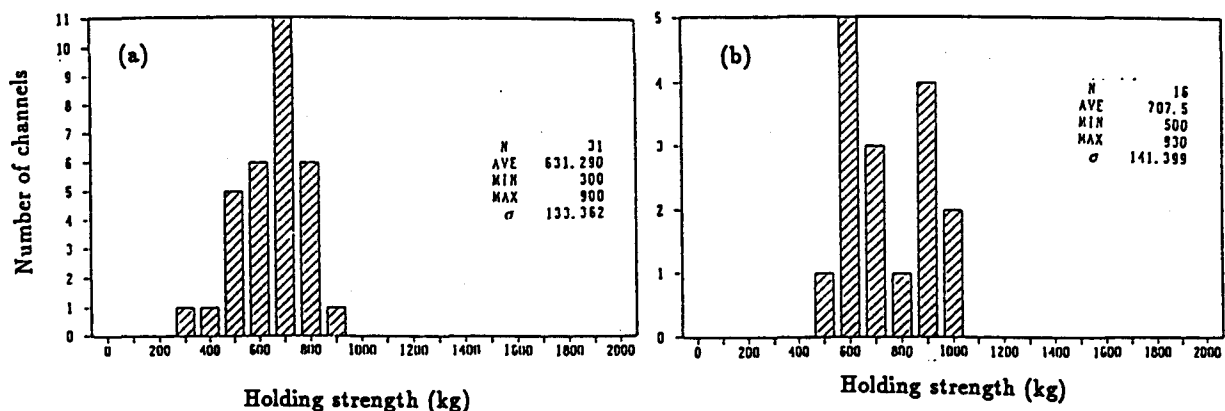


Fig. 9 Fiber holding strength for the 8-ch connector (a) before and (b) after heat cycle test.

3. Summary

We have started R&D on fiber-to-fiber connectors. We have machined single and eight channel connectors and measured the optical and mechanical properties.

An average transmission 89.1% and an rms spread of 3.7% are obtained for the 8-ch connector if matching grease is used. The rms spread was worse than the previous 8-ch connector (2.6%) because of temporary repairs made for the new ones. This nonuniformity is expected to become smaller when the connectors are injection molded. The 1-ch splicers show an average of 94.5% transmission and 1.9% in the rms spread, performances comparable to those spliced by the fusing method. By using matching grease the light transmission increases by nearly 10%, and also the rms spread becomes smaller. The transmission agrees to within 2%, or 0.5% if matching grease is used in repeating disconnection and connection up to 20 times.

The 8-ch connectors made of 66PA show good properties against heat. The light transmission can vary by 2–3% at 80°C, but returns to the initial value at room temperature. Instead, the silicon matching grease seems to induce occasionally strange behavior in the heat cycle test. We started tests on silicon rubber sheets to replace the grease.

The 1-ch splicers are 1.9 mm in diameter and 10 mm long by use of a metal sleeve. The diameters of the sleeve and the fiber holder have to be adjusted, since it was hard to insert the holders and the fiber deformed due to heat.

The fiber holding strength measured for the 8-ch connectors are 0.6–0.7 kg and stable after the heat cycle and low temperature tests. It should be about 1 kg if the connector has been machined as designed. We plan to add glue to enhance the fiber holding strength. The holding strength for the 1-ch splicers is more than 1.5 kg before and after the heat tests.

The fiber ends are polished using sand paper (#1500) and wrapping film (1.5 μm). It was found that the fiber clad (Kuraray clear fibers) tended to be scratched off at a rotation speed (the film is 80 mm in radius) above 100 rpm. So we kept the speed below this limit. By using glue around the fiber, the speed can be set high.

We have started design of 10-ch connectors which are to be injection molded. There are some more modifications. The connector is designed such that 0.83 mm ϕ fibers, 1.0 mm ϕ fibers, or 0.83 mm ϕ fiber and 1.0 mm ϕ fiber (asymmetric) can be connected by choosing suitable fiber holders. The transmission variation should become small by stepping up at the connector. According to a bench test measurement, 2% transmission decrease is caused by 20 μm axis shift for 0.83 mm ϕ fibers, whereas it is caused by 100 μm axis shift if the 0.83 mm ϕ fiber is stepped up to 1.0 mm ϕ fiber. Although the connector should be able to hold the fibers up to about 1 kg as described before, we have not succeeded. We have decided to use glue to secure good fiber holding strength.