Termination of Plastic-Clad Fiber

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ABSTRACT

Optical waveguides are ideal in a nuclear weapon environment because of their resistance to electromagnetic interference. Of the fibers on today's market, plastic-clad silica (PCS) is the most radiation resistant and therefore the best choice. Because terminating PCS is complex, this paper attempts to address the major problems associated with these terminations including selecting the proper connector and optimizing the terminating procedures. The sources of losses in the connectors are summarized and typical loss values are given for four connectors which were tested.
Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction</td>
<td>7</td>
</tr>
<tr>
<td>II. Connector Selection Criteria</td>
<td>7</td>
</tr>
<tr>
<td>III. Problems Associated With Terminating PCS Fiber</td>
<td>8</td>
</tr>
<tr>
<td>IV. Termination Procedures</td>
<td>13</td>
</tr>
<tr>
<td>V. Testing Procedures</td>
<td>19</td>
</tr>
<tr>
<td>VI. Mode Stripping of PCS Fiber</td>
<td>19</td>
</tr>
<tr>
<td>VII. Test Results</td>
<td>23</td>
</tr>
<tr>
<td>A. ITT Cannon FON and FOT Connectors</td>
<td>23</td>
</tr>
<tr>
<td>B. Deutsch-Lensed Connectors</td>
<td>23</td>
</tr>
<tr>
<td>C. AMP Optimate Connectors</td>
<td>26</td>
</tr>
<tr>
<td>VIII. Summary and Conclusions</td>
<td>26</td>
</tr>
<tr>
<td>IX. References</td>
<td>26</td>
</tr>
</tbody>
</table>
TERMINATION OF PLASTIC-CLAD FIBER

Section I. Introduction

The optical connectors evaluated were the ITT Cannon FON and FOT, the Deutsch-Lensed, and the Amp Optimate. Termination of optical fibers with an optical connector would seem to be a simple, straightforward task if the commercial specification sheets are taken at face value. However, such is not the case for PCS fibers. Some connectors present problems such as: (1) end separation, (2) axial misalignment, and (3) angular misalignment, all of which adversely affect junction performance. Section II discusses the criteria that must be met in connector selection. Besides these specific problems, discussed in Section III, the complexity of terminating PCS greatly increases the possibility of high connector losses. In addition, manufacturers have not really designed connectors for PCS fibers. Certain epoxies and polymeric recladding materials have been developed recently which improve the situation, and the use of these is discussed in Section IV. Also discussed are ways to optimize the standard terminating procedures for PCS.

Section II. Connector Selection Criteria

There are several manufacturers who claim to have optical fiber connectors with excellent coupling efficiencies, but, in fact, at this time there are none that can meet their published specifications when used with PCS fibers. Therefore, the selection of the best connector for a particular application is essential. Several criteria must be met: 1

A. Optimum alignment and spacing must be maintained after repeatedly mating and unmating.

B. Alignment must be maintained regardless of the hostile environment.

C. Cumulative degradation of mechanical characteristics of fiber or optical quality of the finish on the end face should be minimized.
Fig. 1. Photomicrograph of a Polished Fiber That Is Non-concentric to the Ferrule
Fig. 2. Reduced Core Overlap Region Due to Axial Offset
Fig. 3. The Effects of Axial Misalignment of the Fiber Core (Dc) on Connector Insertion Loss
Section IV. Termination Procedures

Although this section gives pertinent information related to terminating ITT Cannon PCS fibers with jeweled optical connectors, these procedures are applicable to many other types of connectors that use an epoxy bond. The procedure for terminating the Amp Optimate connector was the same as for the ITT Cannon connectors except that the curing of the epoxy was done at room temperature. The Deutsch termination is different and was performed according to Deutsch's Assembly instructions (see Deutsch Optical Waveguide System, Bulletin 131).

Jacket Removal
Strip away approximately one-half inch of jacket (color-coded and hytrel) with .010 inch CLAUSS' No-Nik strippers (Figure 4).

Cladding Removal
Expose a one-half inch section of fiber by removing the silicone cladding. If any residue remains, it can be removed by dipping the exposed end in undiluted H₂SO₄ for 1 minute. Remove the acid with a DI-H₂O rinse. Then remove the water using alcohol and blow dry with air or N₂. Do not touch exposed portion of fiber with fingers because the contamination will degrade the fiber. Reclad immediately because exposure to air for a long time will also cause degradation.

Recladding of Exposed Fiber
Dip the exposed portion of the fiber into Optelecom Type 139 or Epoxy Technology's Epo-Tek 394 cladding solution. (Refer to Optelecom and Epoxy Technology application notes.) After withdrawing the fiber from the solution, let dry at room temperature for 1 minute. Then blow dry with a heat gun until coating becomes transparent. Do not expose recladding solution to temperatures above the manufacturer's recommendations.
Fig. 4. Exposed Core of ITT T-1011 PCS Fiber
Epoxy Preparation

The epoxies used are Epoxy Technology's Epo-Tek 391 and 353ND which are mixed 10:1 by weight (+ 5 to 10 percent tolerance) with the hardener. The cure cycle time at 70-90°C is approximately 5 hours. Do not use a heat gun to shorten the curing time; this will degrade the cladding material.

Fiber Termination

Before proceeding with the actual termination, be sure to degrease the connectors and blow dry with Freon. Then install the knurled nut and spring onto fiber (only for Cannon's FOT connectors). Install the jeweled ferrule in the groove of the curing fixture and finger-tighten the ferrule hold-down screw (Figure 5). Slip the plastic tubing attached to the vacuum syringe over the ferrule end and apply suction while slowly filling the back of the ferrule with epoxy to prevent air bubbles from being trapped in the ferrule while slowly filling with epoxy. When a small bead of epoxy appears on the face of the jewel, the suction can be discontinued. Wipe away excess epoxy with a Q-tip.

Then insert the fibers to be terminated into the ferrules until the jacket prevents further penetration. The epoxy will wick around the fiber at the end-face of the jewel (Figure 6a). Secure the fiber to the fixture to eliminate any movement before curing is complete. Let the epoxy cure for 30 minutes, cleave the fiber, and cap it with epoxy (Figure 6b). After the epoxy has completely cured, remove the ferrules from the fixture. (A complete curing cycle is marked by the change of the epoxy from amber to deep red.)

Lapping of Ferrule-Fiber End-Face

The connector with the terminated fiber is placed in the polishing fixture (Figure 7) and secured to keep the ferrule from moving within the fixture. The polishing tool is then placed on a 6 μm diamond-bonded grinding disc and worked in the motion of a figure eight with moderate pressure. Rotate the polishing fixture approximately 90° every 10 strokes. Inspect the lapped surface of the ferrule frequently because the only purpose of the lapping process is to remove the epoxy from the end-face of the ferrule.
Fig. 5. V-Grooved Epoxy Curing Fixture
STAINLESS STEEL FERRULE

CLEAVE AT THIS POINT WITH DIAMOND TOOL

FIBER

WATCH JEWEL

EPOXY

PLASTIC CLADDING

EPOXY CAP TO PROTECT FIBER WHILE GRINDING AND POLISHING

Fig. 6. Cross Section of Fiber in Jeweled Ferrule
Fig. 7. Polishing Disc with Polishing Pad
If possible, at various stages of the lapping process, it is desirable to back-light the fiber to ensure that there are no fractures.

After completion of the grinding process, wash the polishing tool thoroughly so grit will not be transferred to the polishing cloth. The ferrule and fiber end-face may be cleaned with a camel hair brush or Q-tip in water and alcohol and then blown dry.

Polishing of Ferrule and Fiber End-Face

The connector is mounted in the polishing fixture and secured. Polishing is accomplished by working the polishing disc in the motion of an asterisk (Figure 8) on a Beuhler "Texmit Polishing Cloth" saturated with 1 µm alumina polishing compound. After completion, wash thoroughly and blow dry. If possible, backlight the fiber to observe the finish.

Section V. Testing Procedures

The connector attenuation measurements were performed by terminating one meter lengths of ITT T-1011 PCS Fiber with Amp Optimate, ITT-FON, ITT-FOT, and Deutsch DWool-084 optical-lensed connectors. All test pairs (one meter lengths of fiber with optical connectors on each end) were terminated according to the procedures described in Section IV. After each termination, the fiber end-face was backlighted to inspect for fractures or edge chipping (see Figure 9). The measurements were performed as shown in Figures 10a and 10b using a HeNe laser and an optical multimeter. After mating, the test fiber connector end was rotated 360° to obtain the maximum and minimum attenuations clearly showing the problem of core concentricity.

Section VI. Mode Stripping of PCS Fiber

An experiment was performed to determine the necessity of mode-stripping the jumper fiber to prevent coupling of its cladding modes to the core of the test fiber. This was found to be unnecessary since it did not cause any measurable difference in attenuation when compared to the unintentional mode-stripping introduced during the process of terminating the jumper with FON and FOT optical connectors.
Fig. 8. Diagram of the Motion in Which the Polishing Disc Is Worked
Fig. 9. Photomicrograph of a Back-Lighted Polished Fiber End
Fig. 10. Block Diagram of Connector Attenuation Apparatus (a) with PCS Jumper (b) with Test Fiber
Figures 11a and 11b show that the amount of cladding energy coupled to the core of the test pair was minimal compared to the amount of energy coupled when the original cladding remained intact. Mode-stripping of the jumper fiber was accomplished by removing a 1-inch section of protective jacket near the exit end of the fiber and exposing the polymer cladding. Then the cladding was treated with a thin film of recladding material to ensure that the core was not exposed to the high refractive index oil used to strip the cladding modes.

Section VII. Test Results

A. ITT Cannon's FON and FOT Connectors

Table I gives the results of the ITT Cannon FON and FOT connector experiment. The factor which contributed most to the attenuation was core misalignment. This was due to variations in thickness of the recladding material. The connector attenuations for test pairs 5 and 6 were much higher than for the other pairs. These were reclad with silver-filled epoxy. This epoxy is unsuitable for recladding for at least two reasons. One is the scattering of radiation from the spherical silver particles, and the second is the high index of refraction of the epoxy.

In some optical fiber interconnections, an index matching fluid is used to improve the junction performance. When this was used in the connector-to-connector interface of this experiment, an additional reduction in attenuation of approximately 1.0 dB was observed. Approximately 0.4 dB of this reduction was due to the elimination of Fresnel reflection of the air-glass interface.

B. Deutsch-Lensed Connectors

The results of the Deutsch connector attenuation experiment are also given in Table I. The losses are substantially higher than specified by the manufacturer. This was due to cleaving the PCS fiber with the hand-held tool which permitted the plastic cladding to overlap the core. However, the coupling losses could be reduced further if the apex of the molded lens were designed to accept a 200 micron core diameter fiber. The current connector anticipates a 50 to 63 μm core and 125 μm O.D. fiber.
Fig. 11. Cross Section of (a) Terminated PCS Fiber with Original Cladding (b) Reclad Terminated PCS Fiber
TABLE #1
Minimum ($\alpha_{\text{min}}$) and Maximum ($\alpha_{\text{max}}$) Attenuation for the Connectors Under Test

<table>
<thead>
<tr>
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<th>FOT.</th>
<th>DEUTSCH</th>
<th>AMP</th>
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<td></td>
<td>$\alpha_{\text{MIN}}$</td>
<td>$\alpha_{\text{MAX}}$</td>
<td>$\alpha_{\text{MIN}}$</td>
<td>$\alpha_{\text{MAX}}$</td>
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<td>3.2</td>
<td>4.5</td>
<td>5.6</td>
</tr>
<tr>
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<td>3.2</td>
<td>4.6</td>
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</tr>
<tr>
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<td>4.2</td>
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<tr>
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<td>12.0</td>
<td>18.2</td>
<td>20.4</td>
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C. AMP Optimate Connectors

The results of the AMP Optimate connector attenuation experiment are shown in Table I. Two factors contributed to high losses. One was the fiber edge chipping due to the resiliency of the recladding material and the thermoplastic connector. The second was the spreading of recladding and plastic ferrule over the core during the grinding and polishing.

Section VIII. Summary and Conclusions

This paper concerns itself with termination of PCS fibers and the selection of connectors that are best suited for Sandia's needs. There are two major problems in terminating these fibers. One is due to the variation in the thickness of the recladding material. The second is due to the weak bond between cladding and epoxy. These drawbacks are not easily eliminated because of the properties of the polymer recladding materials. A plastic clad that is mechanically superior to the ones that are now in existence would be desirable. However, under the test conditions described in the preceding sections, the ITT-FONs and FOTs were found to exhibit the lowest losses of the four connectors evaluated.

All connectors evaluated exhibited much higher attenuations than were specified by the manufacturer. This was expected since they were designed to terminate glass-clad silica, not plastic-clad silica fibers.

IX. References


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