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Establishing A Low-Power
Fiber Optic Cable Facility

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MASTER

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A E R O S P A C E

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Abstract

The capability for the manufacture of fiber optic cables for low-energy applications was established at AlliedSignal Inc., Kansas City Division. The processes for mounting the most common optic connectors were developed and characterized.

Summary

This project establishes a manufacturing capability for manufacturing low-power application fiber optic cables in a manufacturing department at AlliedSignal Inc., Kansas City Division (KCD). The basic work involved the development of a connector mounting process for the six most commonly used connectors applicable to WR use. These connectors are STC-ss, SMA-ss, Mini-BNC, AT&T STC, NTT-FC, and SMA-ceramic.

Unique processes developed include the following.

- the use of tube clamps on stock cable during the initial connector mounting.
- Special cutting fixtures were developed to trim the Kevlar reinforcing member easily, neatly, and consistently.
- All critical stripping dimensions were identified for mounting connectors.
- Critical parameters were identified and characterized which would create good, consistent fiber-to-connector bonding. This included the development of encapsulation/adhesive application techniques.
- Crimping techniques and critical crimping parameters were investigated. Tooling was designed and fabricated which would yield acceptable crimps.
- Cleavers designated with a fiber "pulling" concept were found to be superior.
- Polishing techniques which yield consistently good fiber ends using a Buehler Fiber Optic polisher were developed.
- An acceptance test check system was established for optic cables.
- A rework procedure for polishing broken fiber at the ferrule face was developed using a modified sewing needle to apply a controlled minute drop of reinforcing epoxy.

Discussion

Scope and Purpose

The primary objective of this work is to establish a manufacturing capability at KCD to fabricate fiber optic cables for low-energy applications in support of the current and anticipated direct optical initiation (DOI) and laser diode ignition (LDI) work. Low-power cables are defined in this report as cables whose optical power density within the fiber is in the $\text{kw} \cdot \text{cm}^{-2}$ range. The work encompasses the two areas of manufacturing, process development and characterization (PC&C) and the associated inspection and gaging. The tasks include the following.

Manufacturing Processing

- Fiber (fiber cable) handling, stripping, cutting, and cleaving
- Mounting fibers (cable) in connectors
 - Identification and control of critical dimensions
 - Potting, bonding, and crimping
 - Cleaning
- Polishing fibers
- Interconnecting fiber cables/splices
 - Identification and control of critical dimensions
 - Potting, bonding, and crimping
 - Cleaning
- In-work test check
- Rework guidance for new and field return cables
- Training of manufacturing operators
- Marking and packaging (general)

Gaging and Inspection

- Polished fiber length in connector
- Visual inspection
- Fiber cable transmission loss
- Training of inspection operators
- Establishment of lot acceptance test guidance (TMS)

Activity

Preliminary to this endeavor was the establishment of a fiber optic cable fabrication facility in the cable manufacturing area (see Figure 1).

Figure 1. Fiber Optic Cable Fabrication Facility

Seven types of optic connectors were identified by Sandia National Laboratory/New Mexico (SNL/NM) as considerations for WR applications. These are STC, SMA 905/ss, SMA 906/ss, SMA/ceramic, NTT-FC, AT&T ST II (ceramic), and Mini-BNC.

The establishment of cable building capabilities is basically the development of connector mounting processes. These processes evolved beginning with the manufacturer's prescribed method of mounting and progressed, after evaluation, to adapting or modifying these commercial processes and developing new ones as needed. A typical connector mounting flow chart is shown in Figure 2.

Figure 2. Typical Connector Mounting Flow

Prep Connectors

Stainless Steel STC

The fiber exit end of the ferrule on stainless steel connectors is manufactured unpolished. This rough machine finish surface greatly increases the difficulty of subsequent fiber end polishing. When polishing a rough ferrule end, "large" steel particles break off and embed in the fiber end, thus increasing the amount of polishing required to achieve a clean fiber end. Because of this difficulty, all stainless steel connectors are polished as a preparatory operation. Cleaning of fiber hold after polishing is not necessary.

In addition, the bonding material (epoxy) forms a much more uniform bead at the fiber exit on smooth surfaces than it does on rough ones. This smooth surface also allows the cleaving tool's blade to slide smoothly and close to the mating surface.

Stainless Steel SMA

The ferrule length requirement (MIL-F-49291) on mounted SMA connectors is very tight, as

shown in Figure 3. SMA type connectors are prepped by grinding or polishing the ferrules down to the upper limit of the required length. To accomplish this task, a Buehler Fiber Optic Polisher with a 15- μ m lapping disk is used. In addition to the benefits previously mentioned for connector prepping of stainless steel connectors, preassembly polishing of SMA connectors allows the use of pull-type fiber cleavers, discussed later. Polishing is minimized to the point that lapping paper greater than 0.3 μ m is unnecessary and undesirable.

Figure 3. Ferrule Length Requirement on Mounted SMA Connectors

Cable End Clamp

To prevent the loose fiber from slipping within the cable core, it has been the common practice in the optic community to tie a knot at the cable end opposite the connector mount. Since this technique is difficult to control and can allow damaged fiber to be built into the finished product, an alternate technique was found. A nylon tube clamp is used in lieu of the knot. This clamp imparts an easily discernible dent in the cable end, which is eventually cut off along with the attached clamp.

Figure 4. Nylon Tube Clamp

Trim Kevlar

A number of techniques for trimming the reinforcing Kevlar member to length were investigated. Basically, these involved the use of various types of scissors which are commercially available with jaws ranging from serrated tool steel to ceramic. The method which produced the best and most labor efficient cuts was one using a razor blade on a special design hand fixture. See Figure 5.

Each tool is designed for a particular connector type, thus eliminating the need of an operator to measure and mark the Kevlar prior to cutting. The results are repeatable and uniform Kevlar cuts with no strands.

Figure 5. Kevlar Cutting Fixture

Buffer Strip

Initial study indicates that the strip length of the buffer is critical to the working life of cables subjected to environments having harsh vibration or shock. The fiber core is susceptible to fracture if not butted up to the fiber exit hole in the ferrule. See Figure 6.

See Figure 7 for optimum strip dimensions.

Adhesive Assembly

To have a good encapsulation and adhesion process of the fiber-to-connector assembly, a consistent amount of

Figure 6. Buffer Termination

encapsulation at the fiber exit void of air bubbles is required. To accomplish this a metered dispenser (OFTI-EpoxEase) tool loaded with a blunt nose syringe and an O-ring is used. See Figure 8.

Crimping

The connectors under consideration for WR use are manufactured with a standard "one size fits all" crimping sleeve. The exceptions are the NTT-FC and the AT&T STC II connectors that for the initial SNL/NM lower-power applications have crimp sleeves too large in diameter for the required stock cable. Special attention should be given to this situation on upcoming cable designs. See Table 1.

For quality control, the Kevlar is slightly exposed adjacent to the connector to allow an inspector to verify that a sufficient amount of Kevlar is present under the crimp sleeve (see Figure 9).

The previously mentioned Kevlar cut fixture is designed to incorporate this concept.

A tabletop crimper, illustrated in Figure 10, was fabricated incorporating a Pro-Crimp Manual Crimping Press (Shattuck Industries 88-2550) and a set of standard dies (MIL-T-22520 type).

Note that a connector holding detail was incorporated which allows the operator to easily push the fiber into the connector during crimping.

In order to accumulate data which will aid in the design of a characterization plan, an experiment was conducted which pull-tested Ensins-Bickford stack cable (HCL-M0100T-C01US-12) mounted to OFTI STC connectors. The experiment was conducted as shown in Figure 11. The results are shown in Figure 12. Note the conclusions.

- The test shows that the addition of an adhesive to the crimp maximizes the Kevlar-to-connector bond.

Connector Type	A
STC-ss, SMA-ss	1.1
Mini-BNC	1.0
AT&T STC	.55
NTT-FC	1.20
SMA-ceramic	.875

Figure 7. Optimum Buffer Lengths

Figure 8. Injection of Adhesive into Connector Ferrules

Table 1. Connector Comparison

Connector	Connector Barrel OD (mm)	Typical Sleeve Measurements (mm)		Recommended ID (mm)
		ID	OD	
SMA 906/ss	3.1	3.3	3.9	
SMA 905/ss	3.1	3.3	3.9	
SMA ceramic	3.1	3.3	3.9	
Mini-BNC	3.1	3.3	3.9	
STC	3.1	3.3	3.9	
NTT-FC	3.85	4.35	5.22	4.05
AT&T STC	2.75	3.52	4.12	2.77

Figure 9. Kevlar Crimp Termination

Figure 10. Tabletop Crimper

- A round crimp is superior to a hexagon crimp.
- The test does not show that one adhesive in a crimp is superior to another. The experiment indicates only that there are weak spots on the Kevlar. Future characterization experiments will have to

be designed to explain the distribution of the pull data of various adhesives.

Cleaving

Cleaving is the single most important process in the fabrication of fiber optic cables. An initial study indicated that a cleaving tool that imparts a constant and controlled pull (no bending) on the fiber during scribing yields the only acceptable cleaving process. With only a few exceptions, all cleaves done in this initial study with a pull-type tool are as follows.

By comparison, the nonuniform stress on the fiber by other types of cleavers will yield a variety and range of cleaves. The type of variance and range shown in Figure 13 is undesirable for WR production.

The cleaver chosen is an Ensink-Bickford CT-2 (see Figure 14). This tool is designed to grasp and pull the fiber with a constant tension controlled by interchangeable springs and cleaving the fiber flush to the connector ferrule with a diamond blade. The unit comes with mounting features for SMA and STC connectors only. Details to mount Mini-BNC and NTT-FC connectors had to be specially designed and fabricated.

Polish

The majority of connector end polishing in the production department is performed using a Buehler Fiber Optic Polisher. See Figure 15.

The established process varies from the prescribed manufacturer's instructions as follows.

- The connector holding arm is positioned to polish 0.001 inch from ferrule using a wire check buzzer.
- The right polishing wheel is the primary polisher. The left wheel is used for repolish or rework since it is factory-mounted approximately 0.005 inch closer to the connector holding arm.

3 each 30-inch, 3 each 15 inch, and 4 each 5-inch stock cable with the outer insulation stripped in the center and the glass fiber removed were pull-tested to determine the Kevlar breaking (range) strength.

The test samples were fabricated using 10-inch stock cable with the glass fiber removed and an OFTI STC connector mounted as shown below.

10 each with a single 0.139-inch round diameter crimp with no adhesive on the Kevlar-to-sleeve crimp.

10 each with a single 0.139-inch round diameter crimp with no adhesive on the Kevlar-to-sleeve crimp

10 each using HYSOL White Epoxi-Patch as an adhesive to bond the Kevlar to the connector at the crimp.

10 each using DEVCON 5-minute epoxy as an adhesive to bond the Kevlar to the connector at the crimp.

10 each using Optical Fiber Technologies EPO-TEC 353ND epoxy as an adhesive to bond the Kevlar to the connector at the crimp.

5 each with a single 0.128-inch hexagon crimp with no adhesive.

Figure 11. Preliminary Crimp Pull Test

Figure 12. Results of Pull Test

- Only 0.3- μ m lapping paper is used.

Inspection

Cables are inspected for obvious defects. The polished ends are examined using a Cleav-Chek Interferometer. All units having less than perfect fiber cores are rejected.

At the present time, there exist no minimum power transmission requirements. A "test check" using an LED power source and meter by Laser Precision Corporation is therefore being used to identify units whose transmission properties are below the normal levels. The test procedure is shown in Figure 16.

Rework

It is a common occurrence for the delicate stripped fiber to break prior to cleaving. A process has therefore been developed to complete cables having this damage. See Figure 17. Note that a very minute amount of encapsulating material is required to cap the end of the broken fiber to minimize the "grinding" off of the excess fiber end. To accomplish this end, a sewing needle with the eye partially machined off works ideally to supply very small amounts of material to the cap. See Figure 18. The cap material is cured with

Figure 13. Undesirable Variance

the connector ferrule pointing down.

Accomplishments

A facility for the fabrication of low-power fiber optic cables has been established at AlliedSignal's Kansas City Division. All basic required tooling, clean benches, and acceptance test check systems have been designed, fabricated, or procured.

Future Work

The fiber optic connector industry requires that the ferrule length of SMA connectors be

Figure 14. Typical Pull-Type Cleaver

Figure 15. Buehler Fiber Optic Polisher

very tightly controlled for the connector to function properly. Following these guidelines, Mil Spec requires the ferrule length to be 0.3858 inch to 0.3863 inch (0.38605 ± 0.00025). Because only pressure sensitive depth gages are available commercially, the design and fabrication of a ferrule length measuring gage is required.

1. Build test Cable

2. Measure test cable

3 Add mating connectors to test cable center.

4 Measure Cable and test cable

5. Note: Loss = (test cable measurement) - (cable and test cable measurement)

Figure 16. Test Procedure

Figure 17. Rework Procedure

Figure 18. Technique for Applying Minute Amounts of Encapsulant

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