Real-time automation controls multifiber-connector production

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Multifiber termination technology faces many challenges to compete with single-fiber solutions. A controlled manufacturing process for multifiber connectors can enable high yields with consistent and tighter geometrical tolerances.

Connectors with 8, 12, 24, or more fibers in a single ferrule, termed multifiber connectors, have distinct advantages for use in optical communications for small-form-factor (SFF) connections. Mainly, cost per termination and form-factor efficiency are evident compared to single- and dual-fiber solutions. Use of multifiber connectors in the industry, however, is relatively low (less than 5% of the total connector market on a volume basis), because the connection is inferior in performance compared to single-fiber connections, and more complex to produce.

Higher insertion loss (IL) and back reflection (BR) are inherent in scaling the fiber count per connection, primarily because of geometrical inaccuracies of the connection. Extrinsic loses—such as transverse offset, tilt, and gap—generate more IL and BR in multifiber connectors than in single-fiber connectors. A controlled manufacturing procedure that will maintain consistent and tighter geometrical tolerances can meet these performance challenges.

The challenge in multifiber connectors is mechanical alignment of multiple fibers vs. active alignment used for OEM optical interconnects. Mechanical alignment can cause transverse offset of the fiber. The resulting extrinsic insertion loss is described as:

$$\bar{L} = \frac{34.7}{\pi\omega^2}\left(\bar{\delta}_1^{\,2} + \bar{\delta}_2^{\,2} + \bar{\delta}_3^{\,2} + \bar{\delta}_4^{\,2}\right),$$

where δ_1 is the deviation of the fiber hole center, δ_2 is the deviation caused by clearance between the fiber and the fiber hole, δ_3 is the deviation caused by clearance between the pin and the pin hole, δ_4 is the fiber core eccentricity, and ω is the mode-field radius of the fiber.[1]

The overall deviation affects the core transverse offset. For single-mode fiber $\omega = 4.05$ µm, typical values for multifiber connectors are $\delta_1 = 0.35$ µm, and $\delta_2 = \delta_3 = \delta_4 = 0.2$ µm. For single-fiber (simplex) connectors, $\delta_1 = 0.35$ µm and $\delta_2 = \delta_4 = 0.2$ µm. Simplex connectors must maintain tight tolerances for δ_1, δ_2, and δ_4 on a single fiber only. A major advantage of single-fiber connectors is that they can be tuned if an offset is present, whereas for multifiber, high performance depends on maintaining a low transverse offset.

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FIGURE 1. An automated platform for polishing, cleaning, and inspection of connectors includes process technology and supporting servo-motion control and software for adaptive process control.

Minimal air gap in the connection is also required to achieve high performance. To maintain minimal IL, protrusion uniformity and end-face angular accuracy are required. These parameters are not considered in the simplex model.[2]

The mechanism allowing physical contact of the cores in the simplex model is related to the convex shape of the ferrule while the contact is concentrated in the center. The ferrule is spring-loaded, which creates high pressure at the point of contact in the center of the ferrule. The high pressure creates deformation that yields an approximately 225-µm area of contact with typically 2300 kg/cm^2 of pressure.[3] This phenomena allows revision of the Telcordia undercut specification (GR-326 issue 3) to depend on the ferrule radius of curvature.

To maintain physical contact in multifiber connectors, fiber protrusion must be created. Undercut is not allowed. Higher protrusion allows compensation of the inaccuracies of the end-face geometry, such as angular accuracy and protrusion uniformity.

INSPECTION HURDLES

Final inspection requirements for multifiber connectors are somewhat redundant given the existing process statistics. For each termination, visual optical inspection, and interferometric and optical-performance measurements must be done.

Visual optical inspection ensures performance reliability. Glass material is brittle, and defects tend to propagate with time. In addition, silica bonds weaken in the presence of moisture and under stress. Consequently, pits and scratches are risks for product reliability, even if the existing performance is within specifications. Furthermore, scratches and low surface quality can act as reservoirs of contaminants and increase the losses as a result of light-scattering.[5]

Fiberoptic production must be inspected visually, functionally, and via interferometric measurements.

Interferometric measurements assess the geometric integrity. Three-dimensional interferometric profiling of large areas assesses the protrusion, protrusion uniformity, radius of curvature, and apex offset. Optical testing indicates that the existing performance is within specification. This gives an overall performance result at a given time rather than an indication of the product reliability. Consequently, fiberoptic production must be inspected visually, functionally, and via interferometric measurements.

AUTOMATED SOLUTIONS

The technical challenges of the polishing and inspection process can be addressed by an automated and adaptive process-control system. In polishing, ferrules and abrasives are relatively stable, but the media may degrade. Repeatable results require control of the polishing process—the only remaining variable. The process is time and pressure controlled. Furthermore, the process is labor intensive and labor dependent.

Media degradation in polishing results in a slightly different process for every batch whereas labor-dependant processes result in random performance depending on shift changes.

Real-time adaptive control over these parameters has several benefits. The first is prevention of overuse of polishing media. Predefined pressure and linear speed determine the polishing rates in a given media. Wear of the abrasive is reflected by degradation in the polishing rates. Determination of a minimal allowable rate for a media will prevent overuse of the media and consequently affect the device quality.

The second benefit of real-time adaptive control is precise material removal for each polishing step. The nominal amount of material to remove using each abrasive can be controlled according to a given degradation profile. Automation can maintain the total amount of material to be removed in a certain grit size. Each polishing step creates a damaged layer that is a function of the polishing media and the material being polished. Every polishing step has to remove at least the damaged area.

Another benefit is control of the pressure profile. The pressure peaks introduced to the connector in the first polishing stage are a result of high tolerances in the protrusion of the ferrules. This causes some of them to bear the entire load before all of the ferrules meet the surface. The excessive pressure results in fractures in the fiber for the connectors that were protruded. These failures are avoided by controlling the pressure profile until all the connectors share the load, and keeping the pressure from exceeding the maximum allowed.

Finally, automation allows reduction of operator-to-operator variations. During stock removal, the control of the amount of material removed is vital, whereas during protrusion creation the pressure control is more important since little material is removed.

Special care should be given to the cleaning process in between steps and final cleaning. We recommend three cleaning steps. First is the use of an ultrasonic cleaner using deionized water and detergent to remove debris, chemical adhesion, and Van der Waals adhesion. Second, high air pressure (preferably dry) evacuates particles that are not bonded to the end face. Finally, a dry cloth removes water-marks (see Fig. 1).

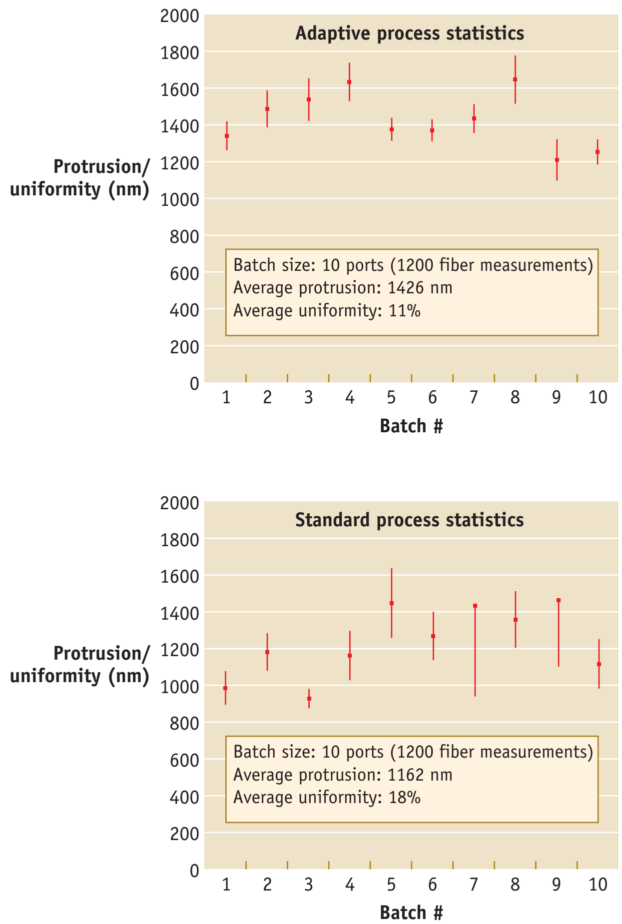

FIGURE 2. Adaptive process-control statistics (top) show more uniformity than standard time-control process statistics (bottom).

INSPECTION REQUIREMENTS

For reviewing defects, 1-µm resolution is vital; however, the ability to detect the defects depends on the illumination and CCD detector quality of the microscope. Sufficient pixel density is required to detect a defect on screen. Manual detection typically requires 3- to 4-pixel coverage, whereas digital analysis can enhance images to 1 to 2 pixels (in width) or even subpixel resolution to detect defects in high correlation rates.

Equation 2 describes the resolving power dependence on the objective numerical aperture (NA):

$$R = \frac{1.22}{2 * NA}\lambda$$

where *R* is the resolving power of at least 1 µm; *NA* is the optical-microscope objective numerical aperture; λ is the reflective wavelength from the objective (in the mid-visible range near 550 nm). Based on this, we recommend using 0.4 NA and 400× magnification to have both the pixel density and resolving power required.

A split test was performed to assess the variances between standard process control and an adaptive process control (APC). The controlled parameters used in the APC were linear polishing velocity, pressure, material removal, and polishing removal rates. These parameters are assumed to have a direct affect on process performance (Cpk). The controlled parameters in the standard process (commonly used in the industry) were force and polishing time. These parameters have an indirect affect on the process performance.

In the results, average protrusion and protrusion uniformity values were higher and better met the specification in an adaptive process (see Fig. 2). This is related to using the protrusion-forming films with optimal and consistent parameters of material removal and the proper pressure. These results indicated more consistency, given the same process used.

A slurry-based process probably would have increased the protrusion values for both the standard and the adaptive processes even more. Other issues that were assessed were surface quality comparison and consumption of abrasives, and both were found to be better, given the same process. WDM

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ACKNOWLEDGMENT

The author wishes to thank Matt Brown from US Conec for helping with materials and information used these experiments.

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