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Standardization of connector manufacturing processes

The use of an automated platform can save cost and improve yields, overcoming the lack of manufacturing standards.

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Fiber-optic connectors are generally thought of as commodities in today's market, yet there are no standard manufacturing processes -- an endemic problem that is impeding the growth of the photonics industry in general. This lack of standard manufacturing processes is similar to the situation in the early stage of the semiconductor industry. Not until these manufacturing processes were standardized was the platform built that enabled the widespread growth of the semiconductor industry to what it has become today.

Lack of production standards can force one of two situations. Process tolerances may be set low to get acceptable yields and low-cost products. Alternatively, process tolerances may be set too high, thereby failing good product and driving product costs up. Overlaying this with the well-known fiber-optic component customer expectation for low-costs connectors without any tolerance for reduced quality and performance, we find ourselves in a "Catch-22" situation that poses a challenge for our industry. However, this challenge can be addressed with the development of standardized manufacturing processes.

Multifiber connectors at issue

This situation is particularly acute for multifiber connectors. Multifiber connectors are an efficient means of achieving the small form factor (SFF) required as fiber port counts increase on fiber-optic equipment. Furthermore, the advantages in cost per termination are compelling when compared to the single-fiber (simplex) connector solutions.

Out of the millions of singlemode fiber-optic connectors used annually, less than 2% of the total volume consumed today is in multifiber connectors. Yet analysts agree that the largest connector growth sector expected over the next few years will be in

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

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singlemode multifiber connectors due to the cost advantages of incorporating parallelism (i.e., arrays of devices) into system designs. But scaling the fiber count within connectors introduces challenges, primarily in terms of extrinsic loss management. This is because, unlike for simplex connectors, "tuning" an individual fiber connection to minimize the extrinsic loses is not an option in multifiber connectors.

Fortunately, addressing such challenges as these in the context of a lack of standardization is possible through utilizing controlled manufacturing procedures in combination with an integrated automated manufacturing platform. As we will discuss later in this article, the right production controls can maintain stringent tolerances in connector manufacturing. In particular, the polishing process is one such step that would benefit from an automated solution. The current approach utilizes manual techniques that result in high yield losses and low throughputs due to inadequate process controls. Specifically, degradation of the polishing abrasives over time will typically widen your production curves. As the risks associated with any manual method are cost-prohibitive, an automated system with all the key process capabilities integrated on a single platform would be an ideal solution.

Another area that could benefit from some production standards is connector end-face inspection. Enhanced inspection capability would serve to reduce operator- and shift-dependent yield variations. Polished connector end-face defects such as scratches, pits, cracks, chips, and contamination very often force customers to demand that manufacturers perform 100% visual inspection, thereby driving up costs. While there are some draft criteria on the visual inspection standards of defect and contaminants on connector end-faces in the IEC and TIA standards bodies and also in Telcordia documents, the measurement methodology is typically unspecified.

The bottom line is that the current body of literature has insufficient information on process standards. Consequently, a user cannot derive process control information from the standards documentation available today. Standardized process controls will narrow production distributions and enable new space- and cost-saving connector technologies such as singlemode multifiber connectors to be more widely deployed.

Connector production

The most efficient way of ensuring a standard controlled process is by using an integrated and controlled environment (Photo 1). Note that the production cell contains three major stages in the production of the connector: polishing, cleaning, and inspection. The advantage in using these steps in an integrated platform is in the ability to fully control this environment and ensure the repeatability of the production cell.

The configuration contains five polishing tables with an automatic abrasive changer. It also contains a high or standard volume fixture between the polishing tables that is manipulated and controlled in any given sequence and motion on the polishing pads by a three-axis linear stage. Both the position and pressure applied on the connectors are controlled on line to ensure pressure buildup and profile during all polishing steps.

The cleaning platform comprises a non-contact ultrasonic cleaner, an air-jet cleaner, and a contact wiping station. The ultrasonic cleaner serves to break the Van der Waals adhesion forces between the particles and the end-face. A high-pressure air jet to evacuate particles that are not bonded follows this. Finally, a contact cleaning removes the watermarks. This practice is proven to avoid cross-contamination between steps, as well as to serve for the final cleaning prior to inspection. The inspection module is integrated to serve as a standard feedback tool for the system to capture the process results and to assist in statistical process control to ensure process uniformity and to adapt the process if necessary to avoid future misprocessing.

The industry challenge to control the process and consequently reduce cost per connector is addressed by controlling the following parameters that are typically not well controlled in a manual environment:

Precise material removal for each polishing step: All standards have stringent requirements on the ferrule dimensions after the polishing process, as well as the geometry of the endface. For example, simplex connector standards will refer to the pedestal, whereas multifiber connectors will refer to the breaking angle. Both are directly influenced by the amount of material removed during polishing. For example, in an angled single fiber connector with a cone shaped ferrule, the apex and the angle are strongly dependant on the material removal. Production statistics indicate that this is one of the key parameters affecting the geometrical yield loss.

Pressure profile control: 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. This excessive pressure results in fractures in the fiber for the connectors that were protruded and they suffer excessive stress. By controlling the pressure profile until all the connectors share the load, as well as limiting the pressure from exceeding the maximum allowable pressure, these failures are avoided.

Adaptive process control: As the abrasives degrade, removal rates vary with time, resulting in process variations when time-based control is used. Furthermore, overuse of the abrasives might result in misprocessing. Utilizing adaptive process control based on material removal and pressures monitoring ensures that as long as the abrasive is functional, it can be used. This type of control maximizes the use of abrasives as well as avoids misprocessing.

Standard and enhanced inspection: Manual inspection suffers from non-quantified decision-making that strongly affects the yields and consequently the cost of connectors. Moreover, decision-making for process improvement is more difficult using manual methodologies for inspection. Manual inspection is also limited to the reflective image on the CCD, which is not consistent even within the same microscope configuration. The illumination changes with any surface or environment changes, causing in some cases the reflected light to scatter differently. The required resolving power should be at least 1 µm to be able to detect standard defined scratches. For this matter, both the pixel coverage of the image and the numerical aperture of the objective should be designed accordingly. For manual inspection, pixel coverage of typically 3-4 pixels is required to detect a defect with high correlation rates. However, digital enhanced analysis requires only 1-2 pixels and in most cases sub-pixel is sufficient. To avoid scattered light, a normalized image will be processed to ensure each image's illumination is normalized to the previous image. Enhance algorithms also ensure that surface irregularities will be more evident on screen and easily detected (Photos 2a and b).

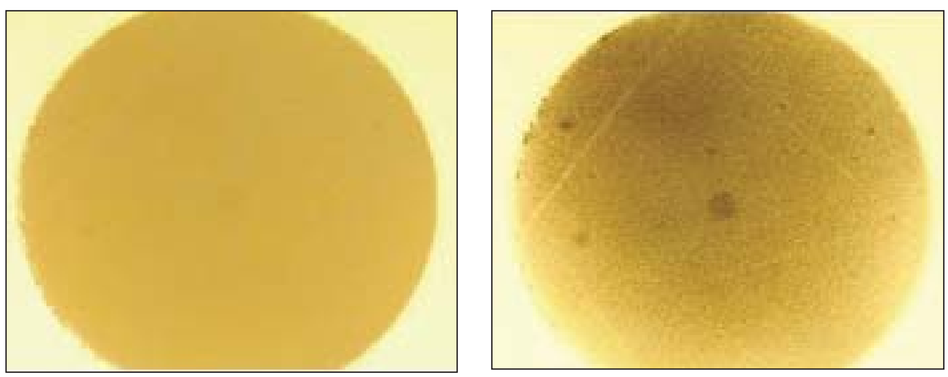

Photo 2. (a) Image taken with vision system using 20X objective, bright field illumination. (b) Same device after applying contrast enhancement algorithm.

Statistical process control: With an automated approach, process control information is not only based on the accurate and quantitative analysis performed during the inspection; the information is based on batch size statistics rather than single sample measurements. This enables higher resolution and confidence in decision-making. For example, if the defect count per connector increases negligibly during each batch, manual inspection of each connector wouldn't necessarily lead to any decision. However, by looking at batch statistics, defect count variations are more discernable and enable predictions of process degradations with higher correlation rates. This would give an advanced indication of a misprocess.

Results

Measuring the geometrical integrity of the endface of the connectors indicates major improvement in the distribution of the results, as the table below demonstrates.

Table 1: Industry standards vs. typical results with adaptive process control

Parameter	Industry Standard	Adaptive Control Results	
		Average	Standard Dev
Apex [microns]	>50	23	13
Apex [degree]	8 (avg.), ±0.25 (stand. dev)	8	0.16
ROC [mm]	7-25	9	0.7
Ra [nm]	Unspected	18	5

Typical manual processes have a combined yield of 85-90% and the consistencies of these values are not stable. Automated process control gives first-pass yields typically around 95% and higher consistently. Moreover, Cpk values from the automated process control are 1.5, indicating process performance that is strongly within industry standards. ("Cpk" is an ASQC-defined parameter used in statistical process control; a Cpk value of 2.0 is equivalent to 6 sigma process control. For more on this parameter, visit http://www.pqsystems.com/cpk-ppk.htm.)

In general, we find that the major cost savings from using an automated process are in:

- Yield improvement of typically 10%.
- Consumables cost reduction by 30%.
- Manual labor savings of 60% for the polishing-cleaning-inspection production cell.

While total annual cost saving will be dependant on the device cost and volumes, typical total annual cost savings will reach $214,000 for simplex singlemode connectors in production volumes of 500,000 units and $144,000 for multifiber singlemode connectors volumes as low as only 20,000 annually. These calculations assume a labor rate of $5/hour; device cost of $3 for SC singlemode and $35 for MT singlemode; and a total capital depreciation over 3 years. The entire cost of ownership model with all other assumptions is available by contacting the authors at the phone number below.

Summary

Yields and cost improvements garnered from the adaptive process control are compelling even in today's market, which is characterized by low volumes of a high mix of different connector types. However, standardization will move today's high-mix/low-volume market toward a high-volume/low-mix market in the future. Adaptive process control, in combination with an integrated automated manufacturing platform, is the first step toward implementing standardized manufacturing processes. Narrowed production distributions resulting from standardized process controls will enable lower-cost fiber-optic components such as singlemode multifiber connectors to be more widely deployed in the future.

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