QUALITY ASSURANCE OF MULTIFIBER CONNECTORS

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ABSTRACT

Industry requirements for compact, high fiber count connectors in both telecom and datacom have created increased global demand for guide pin based multifiber connectors such as MTP/MPO connectors. To realize the cost/performance benefits of these type of connectors, the manufacturing processes must be precisely controlled to maintain the extremely critical tolerances of angle, alignment and height of the multiple fibers. A major part of gaining control of this process is the measurement of the endface geometry. Feedback on physical parameters such as flatness, radius of curvature, surface angle, and the protrusion of the fibers allows fine tuning of the polishing process. This hard data provides the manufacturer with a basis for quality control and crucial information for quality assurance to guarantee long term performance in the field.

The Telephone Industry Association (TIA) and the International Electrotechnical Committee (IEC) have worked in parallel on writing Fiber Optic Test Procedures (FOTP's) and defining manufacturing criteria for multifiber end face geometries. This paper discusses the role physical geometry plays in connector performance, and the parameters defined in the current industry standards for characterizing the connector in production. It shows how use of Endface Geometry Analysis can help the industry to advance its technology by improving quality, consistency, and intermateability of these intricate products.

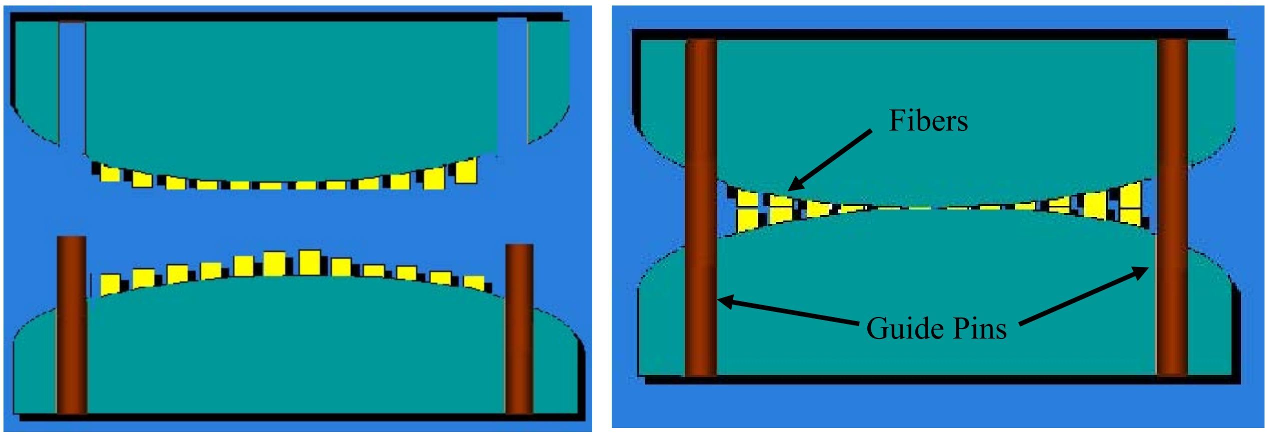
INTRODUCTION

Current multifiber connector designs allow anywhere from 2 to 72 fibers in a single ferrule to be intermated with one another. These high densities offer advantages in time, money and size for the growing demands of data hungry applications. In general, the amount of transmission loss at the fiber to fiber interface can be attributed to three main factors[1]:

1. Transverse offset
2. Fiber end gap
3. Mechanical stability

The transverse offset is the error due to misalignment of the cores. This is controlled by dimensional tolerances of the fiber and the ferrule and is separate from our present discussion. We are concerned with the polishing process which affects the fiber end gap, that is, how the fibers mate, and the mechanical stability, which relates primarily to how the ferrules mate.

Depending on the performance requirements, the final geometry may involve a ferrule polished perpendicular to its guide hole axis (0-deg polish) or, alternatively, with a portion of its ferrule polished at an angle (8-deg polish). For either case, good physical contact and minimum required mating force can be achieved when the fiber ends of the connector are sufficiently protruded, with minimal or no recess at their core, and in the same plane. For best mechanical stability (minimal changes to connector over time and temperature variation), the critical requirement is that the endface geometry be controlled to allow the fibers and not the ferrule to be the first to contact. If all these goals are met, the fibers will align and compress uniformly to provide controlled, intimate, optical contact when connectors are mated (as illustrated in Figure 1).



Pre-Mating Mated

Figure 1.

PHYSICAL PARAMETERS

To insure good optical contact when deployed, the geometry of the ferrule surface and the fibers must be characterized and measured. At present, the following seven key physical measurements are specified by industry standards to be provided by Endface Geometry Analysis instruments:

1. Ferrule Surface Angle - in X (horizontal) and Y (vertical) axes
2. Ferrule Surface Radii – in X (horizontal) and Y (vertical) axes
3. Fiber Height
4. Adjacent Fiber Height Differential
5. Minus Coplanarity
6. Fiber Tip Radii
7. Geometry Limit

Methods for arriving at these measurements are fully defined in the IEC 61300-3-30 specification. This document also specifies the type of instrument to be used for the measurement, namely an interferometric analyzer capable of 3D non-contact surface mapping. The recommended range of values for each of these parameters (i.e.; Pass-Fail limits) are specified in IEC 61755-3-31. Two additional parameters are specified to be calculated and presented, but for which no Pass-Fail limits are defined by the industry. They are:

- Core Dip
- Fiber Array Angle – in X (horizontal) and Y (vertical) axes

TEST EQUIPMENT

An interferometric analyzer is able to make measurements of differential height as small as a few nanometers by reflecting coherent light off the connector endface and combining it with light reflecting off a reference surface to form constructive and destructive interference waves. Automated interferometric systems, such as the Norland Products GL16-AiO, are required for quantifying the multifiber connectors' complex surfaces. These use computers in conjunction with specialized electronics, often including a precision piezo stage, to capture information on the height of every point on the surface.

The latest polishing techniques produce multifiber connectors that often have extremely rough surfaces, and high fiber protrusion. To scan these types of surfaces, the interferometric microscope requires a white light scanning mode, sometimes called a broadband scanning mode, to accurately characterize the surface.

SURFACE PARAMETERS DEFINITION

Because the multifiber connector surface is not necessarily uniform from center to edge, it is important to define the measurement areas to be used in data collection towards determining the key parameters. This is necessary to assure consistency in measurements among test equipment manufacturers and end users.

Figure 1 – Contour and Profile of 4 fiber connector

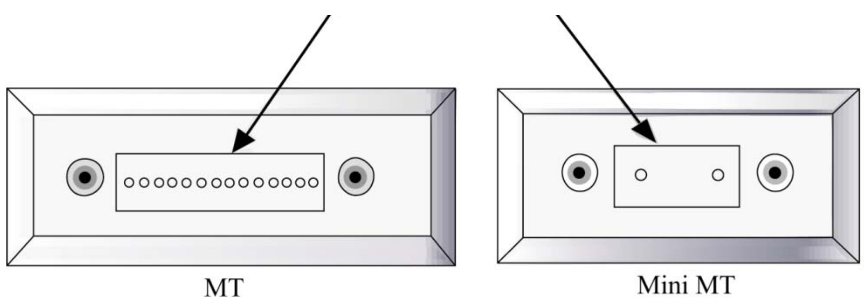


Figure 2 - Measurement Area

The Region of Interest (ROI) on a multifiber connector is defined by a rectangular area having a length - L and a width - W. Some recommended value for different ferrules are listed in Table 1. In addition to the ROI, other measuring areas must be defined to map the surface correctly. These include the Extracting Regions, Fitting Region, and Averaging Regions. The Extracting Regions are equal to 140 microns and centered on each fiber. The Extracting Regions are subtracted from the Region of Interest to form the Fitting Region. This is the area used to calculate the best fit curve or plane for the ferrule surface which is ultimately used as a reference for many of the critical Endface Geometry measurements. The Averaging Regions are equal to 50 microns and are centered on each fiber. This is the area used to calculate the height of the individual fibers.

Ferrule type	Length – L, microns	Width – W, microns
MT	2900	675
MiniMT	900	675

Table 1.

Ferrule Surface Angles – The angle of the ferrule end face (in X and Y) with respect to the angle of a plane perpendicular to the guide holes. In practice, the guide holes are not necessarily parallel to one another, so it is necessary to use the average angle of the two guide hole axes. Determining this average angle must be accomplished by means of a mount calibration since the connector is fixtured to the test instrument via its guide holes (or, in the case of measuring connectors with guide pins already in place, via its guide pins).

Ferrule Surface Radii – The curvature of the Ferrule (in X and Y), determined by fitting an ideal (i.e.; purely mathematical) bi-paraboloid shape to the actual surface of the connector over the ROI. From this best-fitting bi-paraboloid, radius of curvature in each of its axes is a good estimation of the ferrule endface's actual radii.

Fiber Height – The height of each fiber end face (using data in its Averaging Area) vs. that of a reference surface. That reference surface is found by fitting a plane to the ferrule endface over the ROI (with fiber regions already excluded from the data). The calculation is performed by first mathematically removing Ferrule Surface Angles from the data (transforming the data by "taking the tilt out"). By removing this variable, it provides for more repeatable measurements of the fiber height. This can also be justified in use because even if the endface is not perfectly perpendicular to the alignment pins, for very small angles there is some ability of the connectors to autolevel on mating. That is, they will position themselves to provide the most stable contact. This is due to the slight amount of movement available between the alignment pins and guide holes. It is important to reiterate that this only holds for very small angles of polish (i.e.; no more than 0.3 deg).

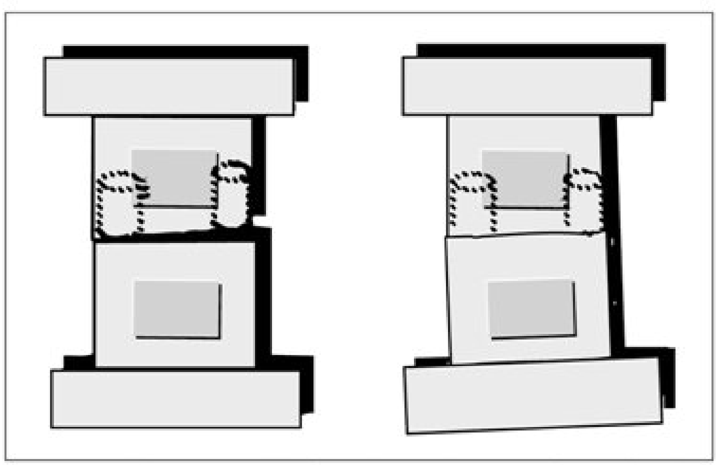


Figure 3. Autoleveling of Multifiber Connectors for Small Angles

Adjacent Fiber Height Differential – The largest of all height differences between any two adjacent fibers, including between fibers in adjacent rows (for the multirow connector case).

Minus Coplanarity – The distance between a plane (that best fits all the fiber tips of a product under test) and the least-protruded fiber tip of that connector. This measurement is made in a direction aligned with the guide hole axes in order to duplicate mating conditions.

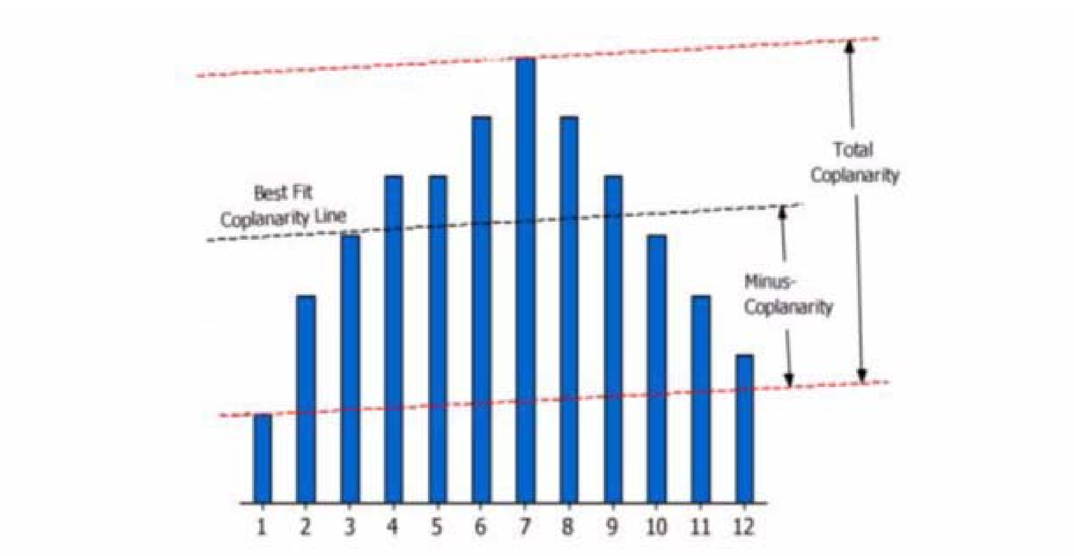


Figure 4.

The amount of required mating force is directly proportional to the minus coplanarity of the fibers tips (as illustrated in the table below).

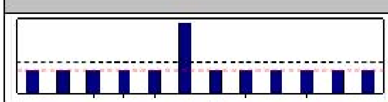
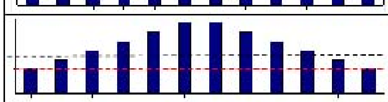
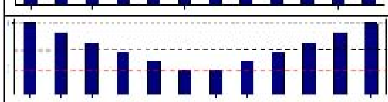
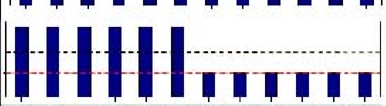
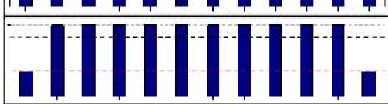
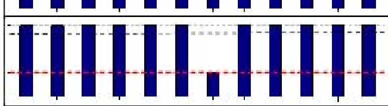
Fibre Height Distribution	Normal Force (N)	Total Coplanarity (µm)	Minus Coplanarity (µm)	Max Height Difference (µm)	Adjacent Height Difference (µm)	RMS Height Deviation (µm)
	1.7	0.500	0.042	0.500	0.500	0.479
	3.7	0.500	0.217	0.500	0.200	0.580
	4.7	0.500	0.250	0.500	0.100	0.592
	6.0	0.500	0.250	0.500	0.500	0.866
	8.9	0.500	0.417	0.500	0.500	0.645
	12.3	0.500	0.458	0.500	0.500	0.479

Table 2. Force vs. Minus Coplanarity (Note: Coplanarity line was constrained horizontally for purpose of analysis.)[3]

Fiber Tip Radii – The curvature of each fiber, determined by fitting an ideal sphere shape to the actual surface of each fiber (using data in its Averaging Area).

Geometry Limit – The unitless figure of merit developed for the purpose of integrating multiple physical variables into a single measure. To establish limits of acceptance on end-face geometry, a mathematical system model was developed to estimate the minimum normal force required to achieve physical contact across an array of mated fibres. This model takes into account various factors including:

- Fibre tip compression and axial stiffness
- Elastic, foundational deflection of the ferrule structure
- Rotational stiffness of the system
- Frictional resistance between the alignment pins and holes
- Variation in end-face geometry dimensions

For a ferrule with a single row of fibres, there are three dominant end-face dimensions that influence the minimum mating force needed to assure physical contact:

- Ferrule Surface X Angle (SX)
- Minus Coplanarity (CF)
- Fiber Tip Radii average (RF)

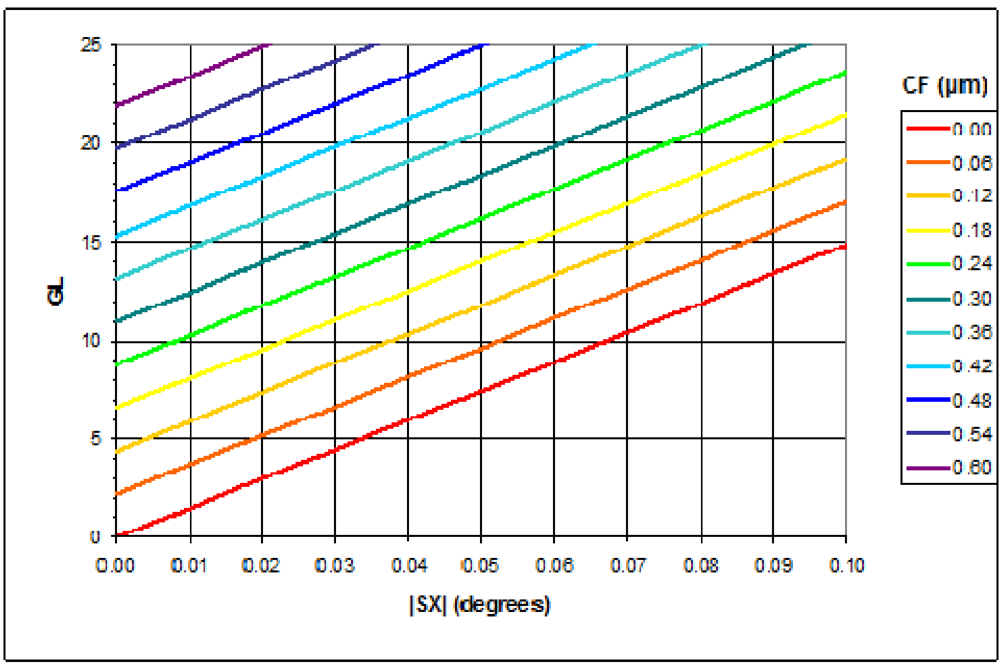


Figure 5: Geometry Limit, GL, needed to mate 12 fibres, as a function of absolute X-angle, SX for different magnitudes of minus coplanarity and **flat fibre tips.**

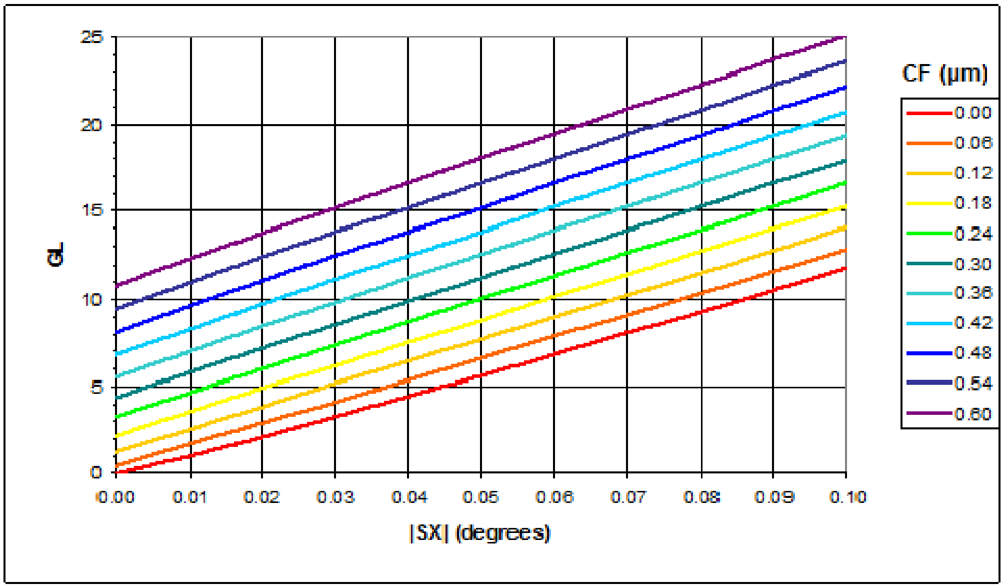
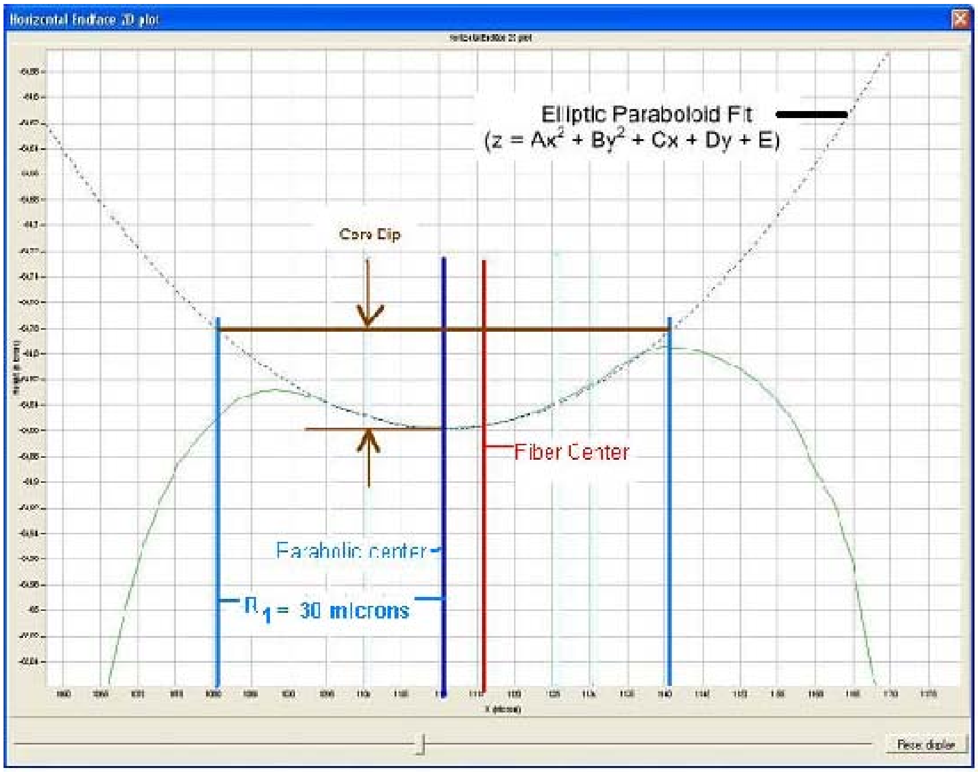


Figure 6: Geometry Limit, GL, needed to mate 12 fibres, as a function of absolute X-angle, |SX| for different magnitudes of minus coplanarity and **1 mm fibre tips**.

NOTE: At present, this parameter is defined by industry specifications to be calculated only under certain circumstances. Specifically, GL is calculable when more than half of the connector's fibers have Core Dip that are less than 10nm, or else are negative Core Dip (i.e.; no Core Dip). Also, the current industry documents only define an allowable maximum GL (for Pass-Fail testing purposes) for connectors with a single row of 4, 8, or 12 fibers.

Core Dip – As implied by the name, Core Dip is a lower endface height in the core region as compared to the cladding area. Thus, Core Dip is a positive value when there is a dip, but negative when the core is higher than the surrounding cladding. The core material in a fiber tends to be softer than the clad material and therefore polishes away quicker than the cladding material. Also, the larger the core (e.g.; multimode fibers vs. single-mode), the more likelihood of Core Dip occurrence.

Core Dip is measured by finding an ideal paraboloid surface that most-closely fits the actual fiber tip within an industry-defined diameter, centered on the fiber core. A plane is then found that passes through points on this ideal paraboloid at a specified radius away from the fiber center. The Core Dip is the difference between the height on the plane at coordinates matching the position of the fiber center vs. the height of the lowest point on the fitted paraboloid. See the following image illustrating this calculation. R1 in the illustration is specified by the current IEC industry specification to be 15 µm (i.e.; Core Dip fitting diameter of 30 µm). Note that Core Dip is calculated in a direction perpendicular to a plane fit to the ferrule.



$$\text{CORE DIP} = (2R_1^2)\,\frac{(A+B)}{4}$$

Figure 7: Paraboloid Fit Method for Core Dip calculation

Fiber Array Angles – The angle of a plane (in X and Y) that best fits all of a connector's fiber endfaces. These angles are measured relative to a plane perpendicular to the average axis of the connector's two guide holes. For the case of a connector with only one row of fibers, the fiber array's Y Angle is set the same as the Ferrule Surface Y Angle, since not enough data exists from one row of fiber endfaces alone to give an accurate and repeatable measure of their Y angle. As illustrated in the following figure, (though uncommon) the Fiber Array angles can be different from the Ferrule Endface angles, depending on polishing procedure used.

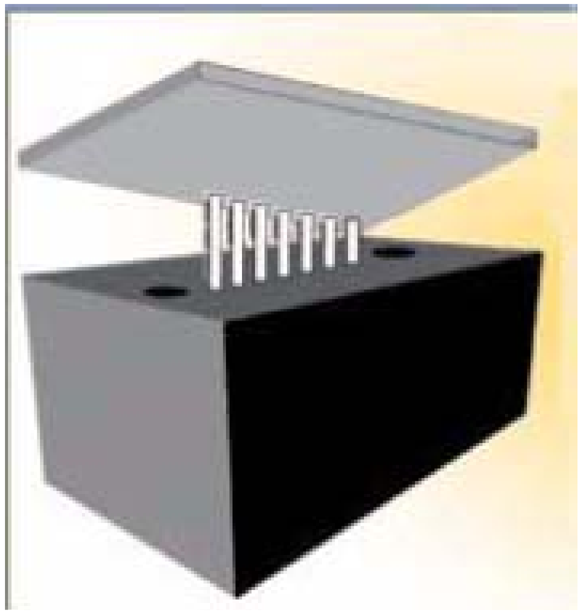


Figure 8.

SUMMARY

In summary, the fiber optics industry is improving multifiber connector quality by exploring which key physical parameters need to be measured and the best way to measure them. We have concentrated our discussion on the MT type ferrule but similar definitions can be applied to other multifiber connectors. This is an evolving process that requires constant re-evaluation as new technologies are developed and tested. With the proper definitions and standards for the polish geometries and procedures, manufacturers can make multifiber connectors providing good physical contact with low attenuation and return loss which will stand up to the long term demands faced by fiber systems.

REFERENCES

1. J. Kevern, D. Harper "Multifiber Connector Endface Attributes for Optimal Connector Performance," Proceedings from 1996 Electronics Components and Technology Conference. IEEE Catalog No. 96CH35931, pp 936-941.
2. D. Knasel, T. Satake "Low Loss, Single Mode Multifiber Connectors," Proceedings from NFOEC96, September 1996, Denver CO.
3. 2007, Tycoelectronics communication regarding their Mating Force study and proposal for a new parameter to control protrusion variation.