



FiBO Measurement Methods and Accuracy

Measurement Standards

Standards such as TIA-455-218 (FOTP-218), IEC 61300-3-16, IEC 61300-3-17 and IEC 61300-3-23 describe how to measure the three dimensional properties of a single fiber optical connector endface. The three (3) properties measured are:

- radius of curvature
- apex offset (offset of the polish relative to the center of the fiber)
- spherical fiber height relative to the ferrule surface

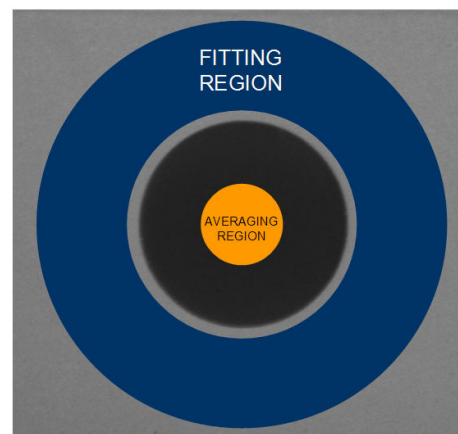
Measurement Techniques

Radius of Curvature Measurement Technique

The first step given in these standards is to get a three-dimensional map of the surface of the connector. FiBO generates this map with the technique of phase-shifting interferometry. The next step is to numerically fit an ideal sphere to the measured data. Not all of the data is used for this fitting. Only a donut-shaped slice of the ferrule called the contact zone (or fitting region) is used. The standards recommend using a slice that has an outer diameter of 250 microns and an inner diameter of 140 microns. This fitting region is used because the endface can be aspherical and using the defined region for fitting achieves better agreement between measurements by different interferometers. The radius of this fitted sphere is then reported as the measured Radius of Curvature. A typical acceptable radius of curvature range is between 7 and 25 millimeters. The following images show a connector endface with, and without, the Fitting Region displayed.



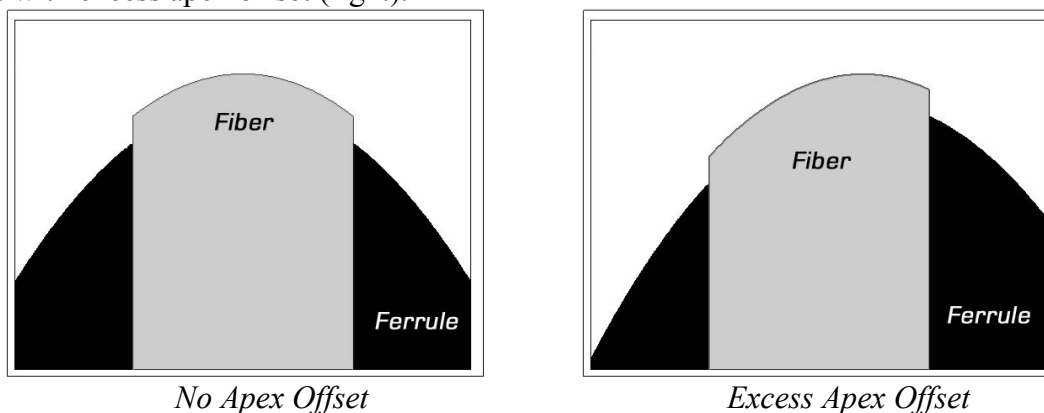
Bare Fiber Connector End



Fitting & Averaging Region

Apex Offset Measurement Technique

The linear distance in microns between the center of the fiber and the fitted sphere in the plane of the image is reported as linear Apex Offset. The following exaggerated cross-sectional diagrams of a connector endface illustrate a connector with no apex offset (left) and with excess apex offset (right).



Apex offset can be the result of incorrect polishing or, in the case of angle polished connectors, angle errors. The typical maximum acceptable apex offset is 50 microns.

Fiber Height Measurement Technique

Fiber height, in nanometers, is calculated by first subtracting the fitted sphere from the measured data. The heights in a central area of the fiber called the averaging area are averaged together. The diameter of this circle, centered on the center of the fiber, is typically 50 microns. The average height in the contact zone is then subtracted from this average fiber height. This difference is called the Spherical Fiber Height. We define Spherical Fiber Height as being positive when the fiber protrudes above the fitted sphere. A typical range for fiber height is from -125 to +50 nanometers.

Calibrating the FiBO Interferometer

There is no existing fiber connector end standard that can be used as a calibration standard or accuracy measurement standard. In order to calibrate the FiBO, PROMET International has developed its own kinematic calibration targets.

2D Calibration

The FiBO's 2D Calibration Target is made using a precision electron beam lithography technique that has an inherent 3 sigma lateral accuracy better than ± 0.15 microns. During the calibration process, the software looks for plus shaped (+) fiducials that are 125.0 microns apart in both X & Y. The 2D Calibration calculates horizontal (X) and vertical (Y) conversion factors used to convert the pixels of the camera into distance in microns.



3D Calibration

The 3D Calibration performs a 3D measurement (as described above) on a spherical target with a known radius. The calibration calculates what the radius would measure using the nominal value of the peak wavelength of the illumination LED and compares it to the known value. The resulting ratio is stored as the 3D calibration and takes care of any shift in the LED wavelength and non-uniformities in the interfering light beams.

The 3D Calibration Target is a precision made plano-convex lens. The radius of the curved side of the lens is precisely measured on a commercial interferometer fitted with a motorized slide with an encoder that has a resolution of 6.7 microns. This interferometer and slide are calibrated with a lens with a NIST-traceable radius of 10.00mm.

Measurement Accuracy Claims

Accuracy is a measure of how close a measured value is to the true value. In order to define accuracy of a measurement, a known value from a standard must be compared to the measured value. Because there is no fiber connector measurement standard we have to use other measurements to estimate a level of accuracy.

Ferrule Radius of Curvature Accuracy

Ferrule Radius of Curvature Measurement Examples

Measuring the Radius of Curvature of the 3D Calibration Target immediately after calibration gives measurement values less than 0.01 mm from the target's value.

We have measured the Radius of Curvature of the ferrule of a connector end using dozens of different FiBOs that had each been calibrated with a different 3D calibration target. The standard deviation of these Radius of Curvature measurements is less than 0.1mm.

A Gauge study was performed with ten (10) different connector ends with different Radii of Curvature measured on three (3) FiBO units three (3) times each. The average standard deviation for each connector's radii on the three (3) different FiBOs was less than 0.1mm.

Ferrule Radius of Curvature Accuracy Estimate

Using our calibration technique and these measurement examples as well as others we estimate our Ferrule Radius of Curvature Measurement Accuracy (1 sigma) as less than 0.25mm.

Spherical Fiber Height Accuracy

Fiber Height Measurement Examples

We have measured the Fiber Height of a connector end using dozens of different FiBOs that had each been calibrated with a different 3D calibration target. The standard deviation of these Fiber Height measurements is less than 1.5nm.



A Gauge study was performed with ten (10) different connector ends with different Fiber Height measured on three (3) FiBOs three (3) times each. The average standard deviation for each connector's Fiber Height on the three (3) FiBOs was less than 2.0nm.

Fiber Height Accuracy Estimate

Using our calibration technique and these measurement examples as well as others we give our Spherical Fiber Height Measurement Accuracy (1 sigma) as less than 2.5nm.

Apex Offset Accuracy

The Apex Offset measurement uses both a three-dimensional measurement and a two-dimensional measurement to find the value. The measurement takes the difference between the X, Y center of the fitted sphere found with a three-dimensional measurement and the X, Y center of the fiber found with a two-dimensional measurement.

The Apex Offset is also affected by any angle errors in how the connector is held in the connector adapter relative to the interferometer. FiBO adapters are manufactured with an angle error less than 1 minute which translates to a few microns of Apex Offset error from adapter to adapter.

Apex Offset Measurement Examples

We have measured the Apex Offset of a connector end using dozens of different FiBOs that had each been calibrated with a different 2D and 3D calibration target. The standard deviation of these Apex Offset measurements is less than 1.5 microns.

A Gauge study was performed with ten (10) different connector ends with different Apex Offsets measured on three (3) FiBO units three (3) times each. The average standard deviation for each connector's Apex Offset on the three (3) FiBOs was less than 1.0 micron.

Apex Offset Accuracy Estimate

Using our calibration technique, adapter to adapter errors, and these measurement examples as well as others we give our Apex Offset Measurement Accuracy (1 sigma) as less than 3.0 microns.

Fiber Diameter Accuracy

The Fiber Diameter measurement is strictly a two-dimensional measurement that is accomplished by the software determining the diameter for a circle it finds for the fiber in the captured image.

Fiber Diameter Measurement Examples

We have measured the Fiber Diameter of a connector end using dozens of different FiBOs that had each been calibrated with a different 2D calibration target. The standard deviation of these Fiber Diameter measurements is less than 0.25 microns.



A Gauge study was performed with ten (10) different connector ends with similar Fiber Diameters measured on three (3) FiBO units three (3) times each. The average standard deviation for each connector's Fiber Diameter on the three (3) FiBOs was less than 0.1 micron.

Fiber Diameter Accuracy Estimate

Using our calibration technique, and these measurement examples as well as others we give our Fiber Diameter Measurement Accuracy (1 sigma) as less than 0.35 microns.

Other Measurements

FiBO Code does not measure or report the Fiber Radius of Curvature (which is not in any measurement standard).

FiBO Code does report Ferrule Roughness and Fiber Roughness but there is no fiber connector roughness standard against which to compare our measurements and thus we are not able to offer a good accuracy estimate at this time.

Measurement Accuracy Estimates Summary

Measured Parameter	Estimated Accuracy
Ferrule Radius of Curvature	< 0.25mm
Spherical Fiber Height	< 2.5nm
Apex Offset	< 3.0 microns
Fiber Diameter	< 0.35 microns

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