Test Summary: Spool Skew and Strain Measurements Using the Optical Backscatter Reflectometer

Introduction

Luna Technologies has performed a series of tests to demonstrate the capability of the Optical Backscatter Reflectometer (OBR) as a tool for optical fiber spool characterization in support of TIA-455-38. Skew and strain measurements were performed and the results are reported herein. All measurements were acquired using a standard OBR.

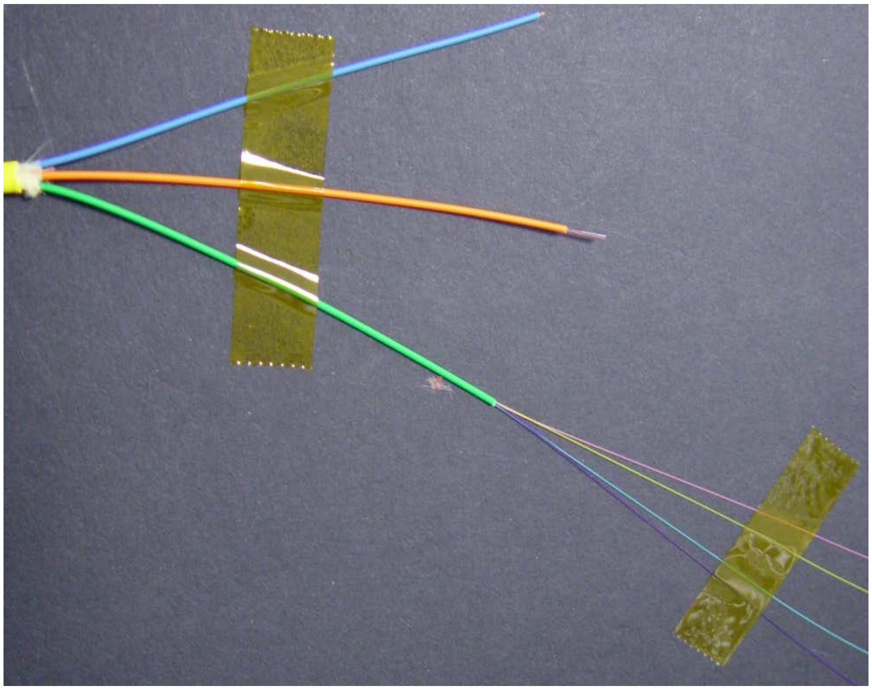
Spool Description

The spools provided were of varying materials from various suppliers with length ranging from 640-800 meters. Table 1 summarizes the key characteristics.

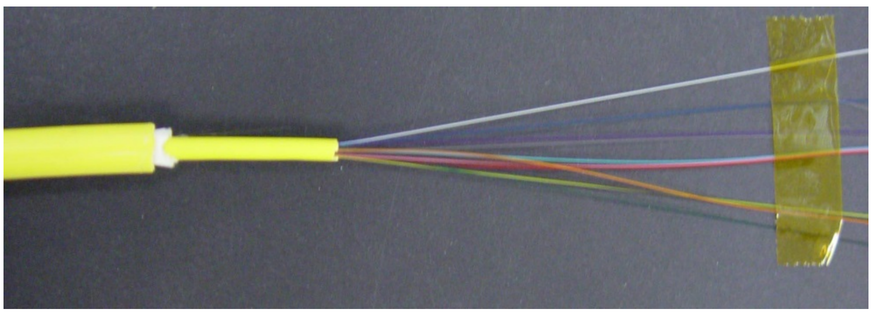
Table 1 Spool Description

	Spool A	Spool B	Spool C
DOM	12/5/2007	12/26/2007	7/3/2007
Length (m)	653.5	780.9	701

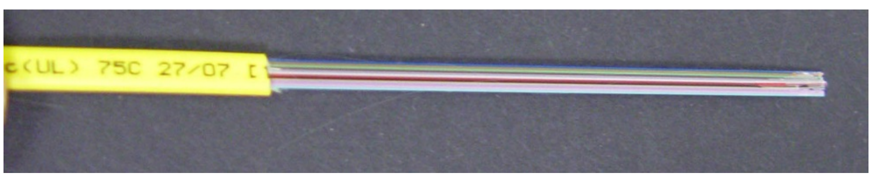
The spools had varying jacketing and layering methodologies used during manufacturing. Spool A involved placing three concentric bundles of fiber of presumed equal grouping into a master jacket with insulation stuffing between the bundles as illustrated in Figure 1a below. Spool B consisted of a dual-layer, concentric jacketing construction style with the optical fiber all grouped within the inner layer (see Figure 1b). The third spool had an optical fiber ribbon encased in a single jacket as seen in Figure 1c.



a) Spool A: Jacketing contained three bundles with each bundle containing several optical fibers.



b) Spool B: Had two concentric jackets, with isolative material in-between layers.



c) Spool C: Ribbon cable, single layer jacket.

Figure 1. Various jacketing styles of the spools provided for testing

Skew

Test setup:

The Optical Backscatter Reflectometer (OBR) and accompanying PC were setup according to Chapter 2 of the OBR User Guide. The fibers under investigation were cleaved and spliced to a single mode optical lead with an APC connector to enable mating to the front panel of the instrument, as illustrated in Figure 2. To enable accurate length measurements, it was necessary to measure the lead fiber prior to the splicing process. Length measurements were then obtained according to reference [1] for a subset of the leads on the spool (A total of five fibers per spool were included in the skew test investigation).

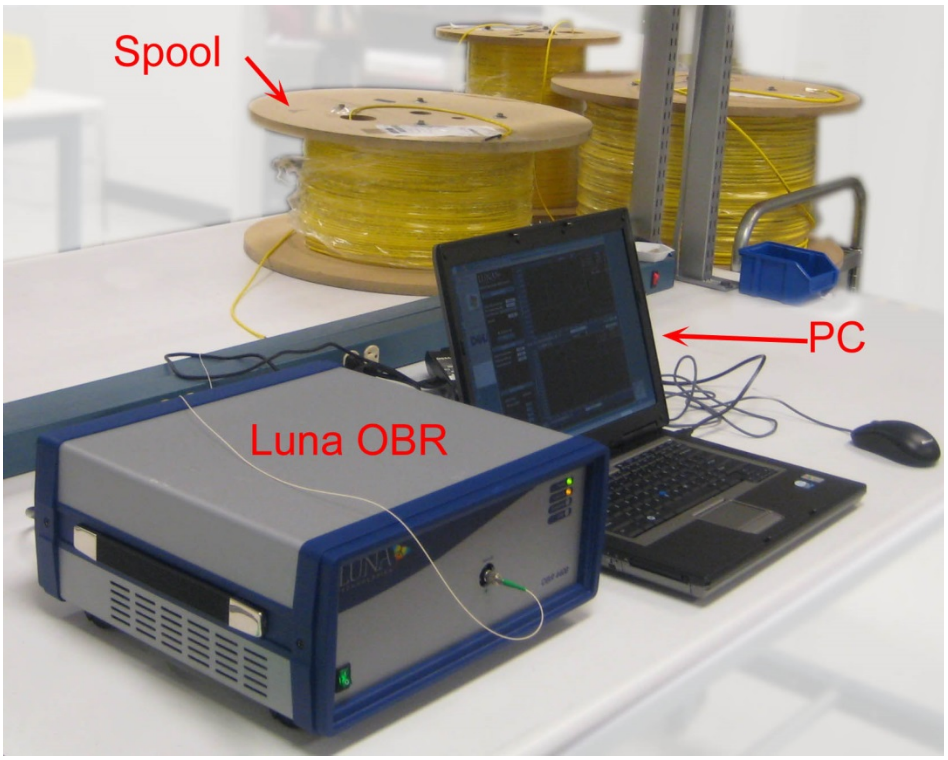


Figure 2. Luna Technologies' Optical Backscatter Reflectometer interrogating an optical lead in a ~750m fiber spool

[1] Skew and Strain measurements using the Optical Backscatter Reflectometer to Support TIA FOTP 455038

Measurements:

In order to measure skew in each spool it was necessary to measure the time of flight (TOF) of the optical fibers within the spool under investigation. The TOF of the lead was then subtracted from the overall spool TOF. The calculation of the skew was then performed according to;

$$Sk_i = \frac{\Delta t_i - \Delta t_{\min}}{\frac{c \cdot}{N \cdot M} \cdot \sum_{i=1}^{M} \Delta t_i} = \frac{\Delta t_i - \Delta t_{\min}}{L_{avg}} \tag{1}$$

where $Sk_i =$ The skew for fiber *'i'*

$\Delta t_i =$ The TOF to the end of the fiber. (½x10^{-3} the TOF as measured by the OBR) [picoseconds]

$\Delta t_{\min} =$ The minimum TOF measured of the fibers in the cable

c = The speed of light (299,792,458 m/s)

N = The Effective fiber group index as specified by manufacturer

M = The number of fibers

L_{avg} = The average length of the cable (Gage length), May use manufacturer specified length [meters]

Figure 3 through Figure 5 shows the skew measurements calculated for Spools A-C respectively. Spool A was measured to have the largest skew, whereas Spool C (Ribbon fiber) had the smallest skew.

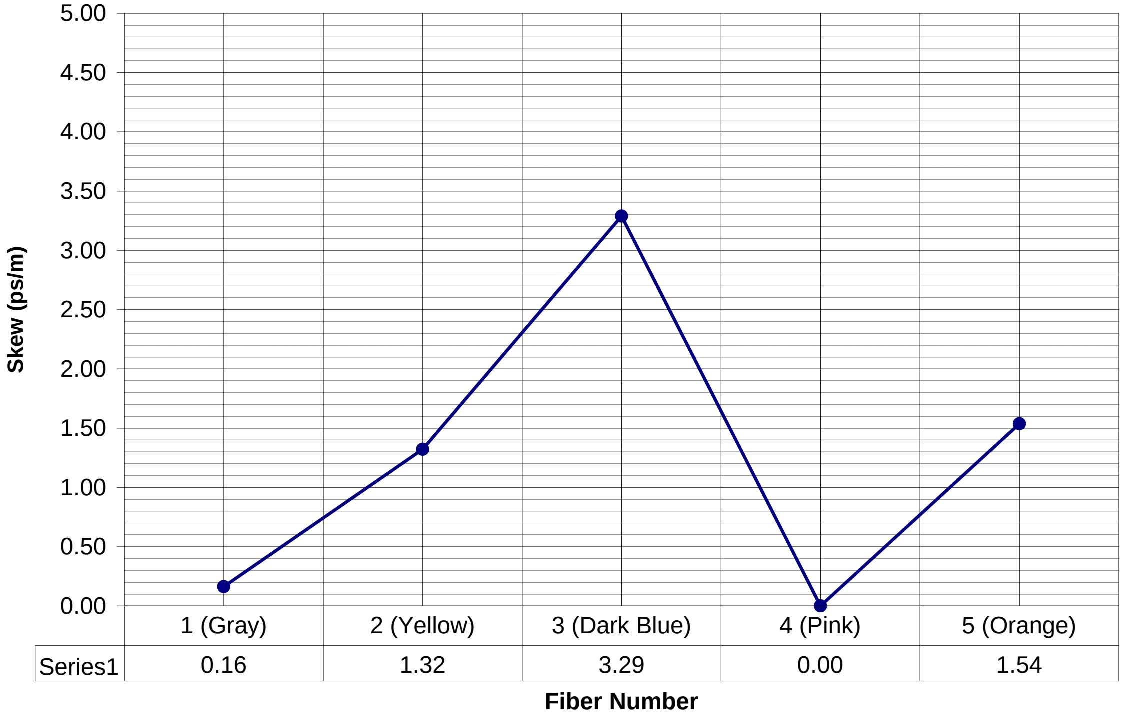


Figure 3. Spool A Skew as a function of fiber number, L_{avg} =645 meters

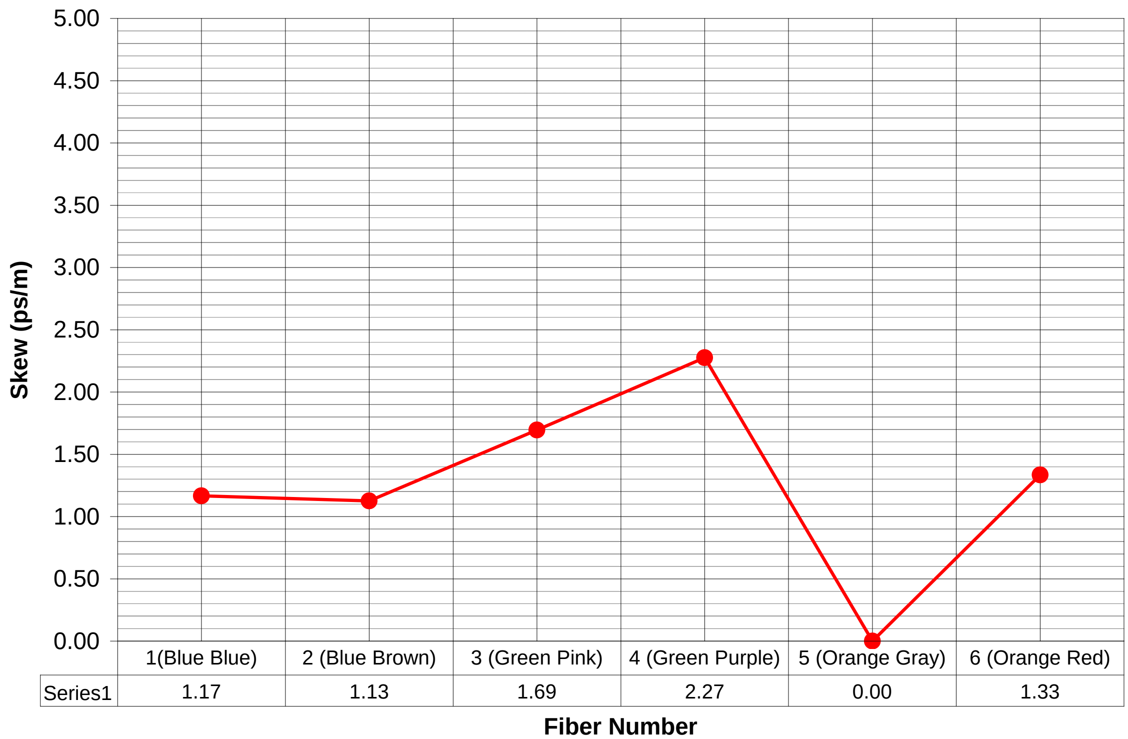


Figure 4. Spool B skew as a function of fiber number, L_{avg} =780 meters

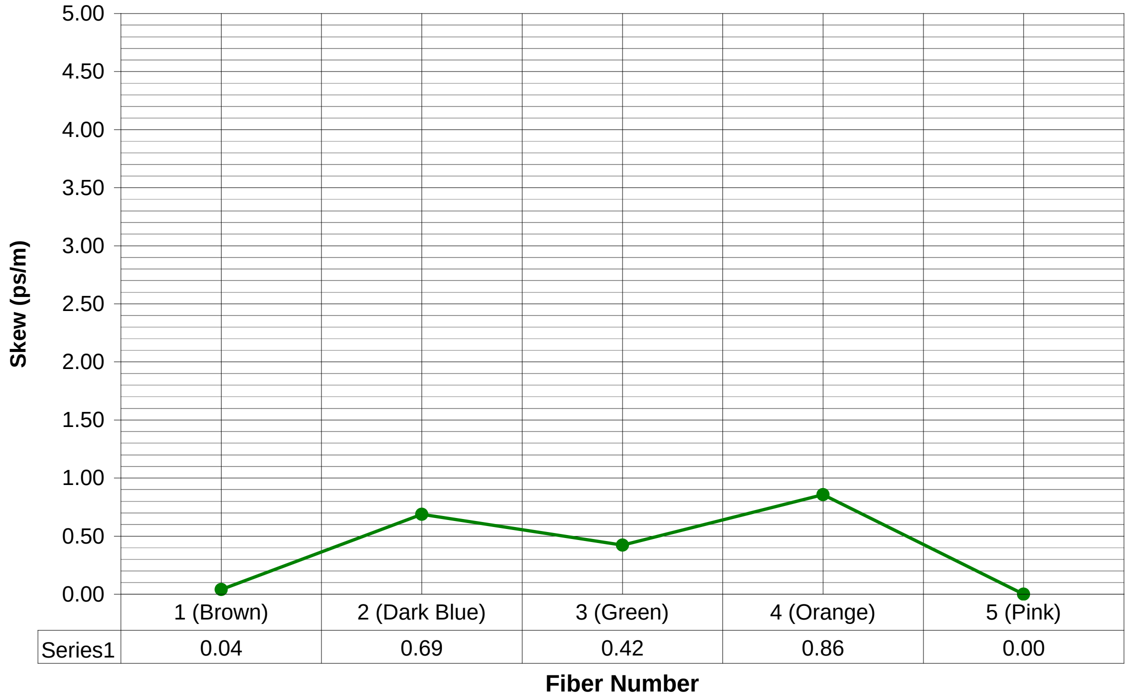


Figure 5. Spool C skew measurement as a function of fiber number L_{avg} = 702 meters

Strain

Test Setup

In this test the Optical Backscatter Reflectometer (OBR) was configured to make high resolution, short range (less than 30 meters) measurements. Again, the instrument and accompanying PC were setup according to Chapter 2 of the OBR User Guide. A polyimide coated, single mode (SMF-28) fiber was cleaved and spliced to an optical fiber lead with an APC connector to enable mating to the front panel of the instrument illustrated in Figure 6. A custom fixture0.3174 m long (shown in Figure 6) with three micrometer stages was used to accurately calculate fiber elongation. Two micrometers are used to vertically and horizontally align the fiber mount points on the fixture, while the third micrometer is used to precisely elongate the fiber. Knowing the precise change in length over the total length of the fixture allows for accurate calculation of applied strain for measurement comparison. To reduce drift effects due to possible fiber slippage and to avoid crushing the fiber at the mount points of the stage, cardboard pads cut into small squares were glued to the fixture, sandwiching the fiber at an axial offset equal to the gage length of the strain fixture. The pads were then affixed to the fixture using the clasp stands on either end of the stand, thus securing the optical fiber.

c

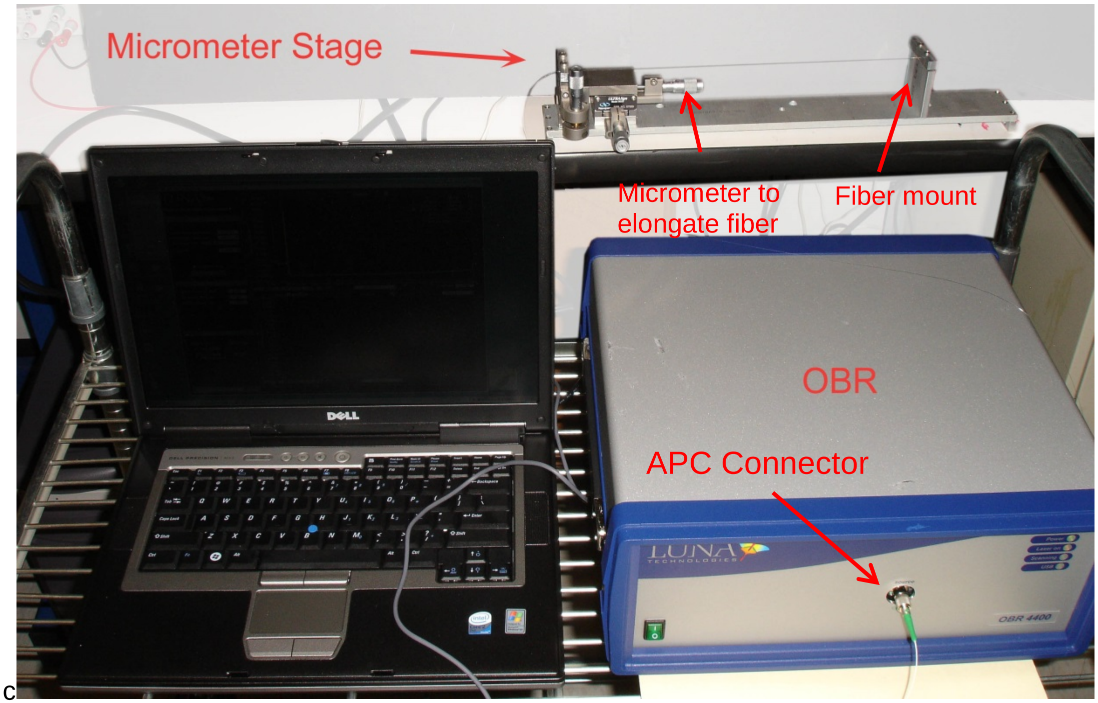


Figure 6. Instrument setup for controlled strain measurements

Measurements

To measure the distributed strain according to TIA-455-38[2], it was necessary to determine the stress optic correction factor (k)[3] . The constant was computed by applying a known strain onto the optical fiber and solving equation (2) below.

$$k = \left(t_{str} - t_{ref}\right) \cdot \left(\frac{c}{L \cdot N}\right) \cdot \left(\frac{1}{\varepsilon}\right) \quad (2)$$

Where $t_{str} =$ Measured delay time (strained) [seconds]

$t_{ref} =$ Measured delay time (reference) [seconds]

$L =$ Specimen gage length [meters]

N = is the Effective fiber group index as specified by manufacturer

$\varepsilon =$ Know strain input where $\varepsilon = \frac{\Delta L}{L}$

$\Delta L =$ is the known change in length [microns]

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[2] Equation obtained from the "Measurement of Fiber Strain in Cables Under Tensile Load", TIA-455-38, TIA Document, pg 10

[3] See ref [1] section 5.1 for more information.

The stress optic effect was determined to be 0.772. The optical fiber was then strained to various known strain states, recording the TOF at each strain state as illustrated in Figure 7.

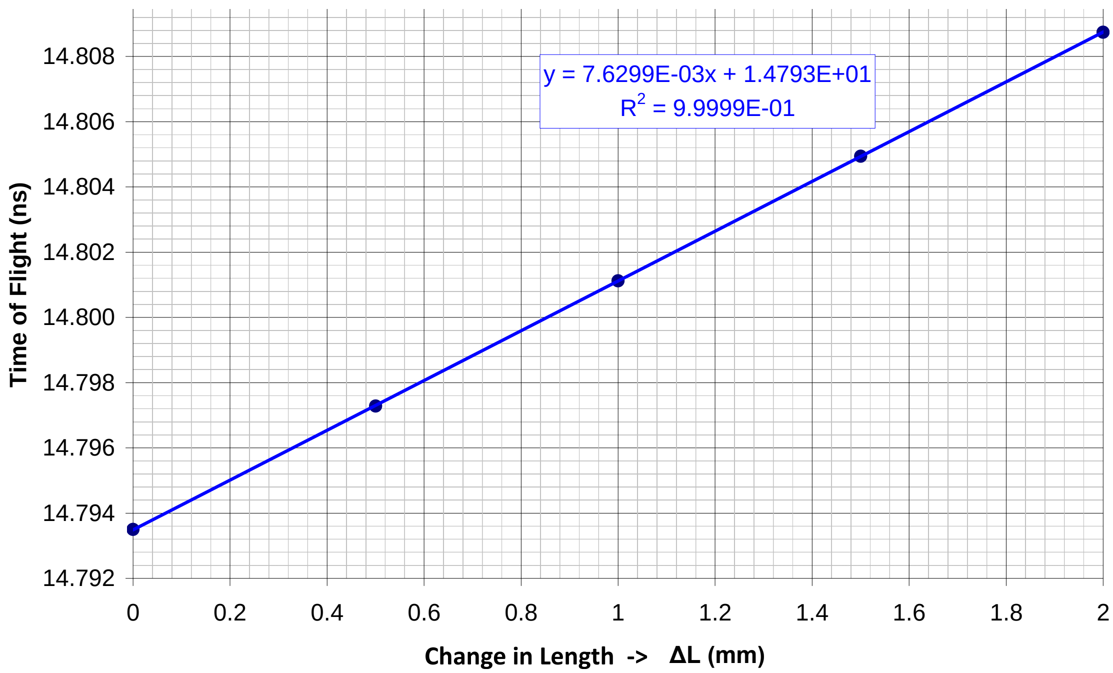

Figure 7. The measured time of flight at various stages of fiber elongation

The measured length change was determined by;

$$\Delta L = \left(t_{str} - t_{ref}\right)\cdot\left(\frac{c}{N}\right)\cdot\left(\frac{1}{k}\right) \tag{3}$$

Figure 8 shows the measured length as a function of the induced length using the custom strain stage. It is noticed that the slope approaches “1” showing minimal error in the measurement.

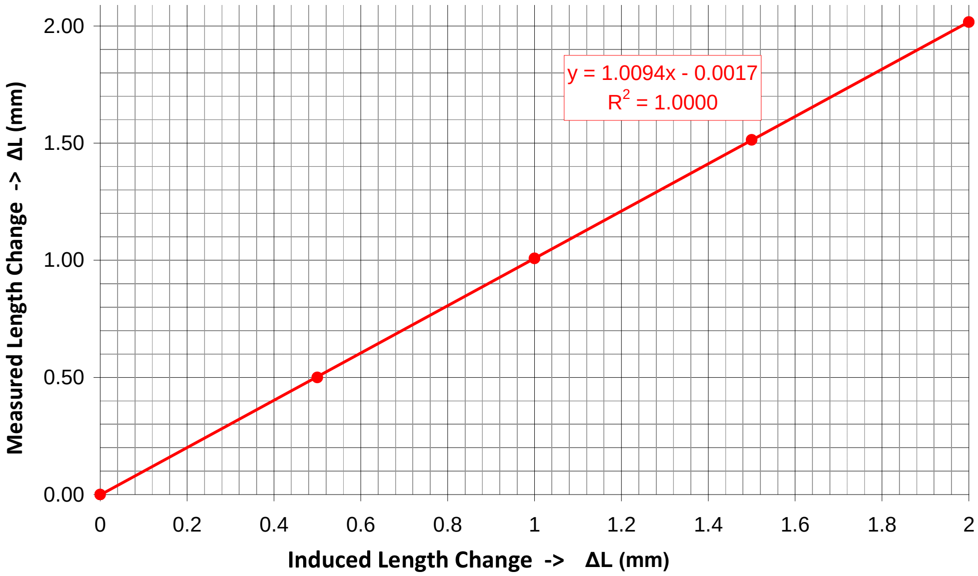

Figure 8. Measured length change versus induced length change

The strain was then determined by

$$\varepsilon_{str} = \frac{\Delta L}{L} = \left(t_{str} - t_{ref}\right) \cdot \left(\frac{c}{L \cdot N}\right) \cdot \left(\frac{1}{k}\right) \tag{4}$$

Figure 9 shows the strain as a function of the induced length change (ΔL).

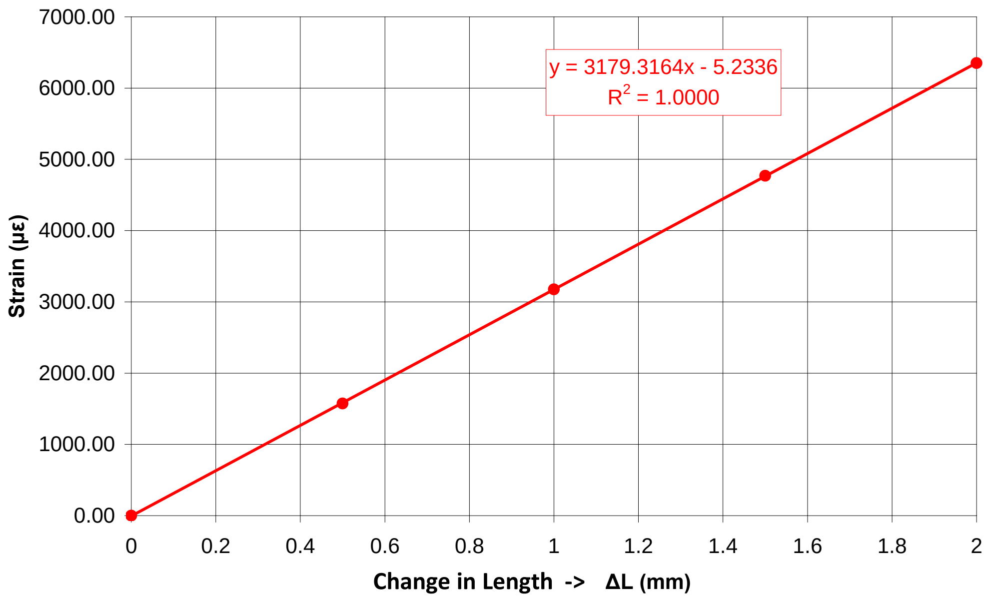

Figure 9. Strain as a function of induced length change of a polyimide coated single mode fiber

Figure 10 shows computed strain as a function of position at the induced length changes using advanced features of the OBR. We notice the strain values are similar to those computed and displayed in Figure 9 above.

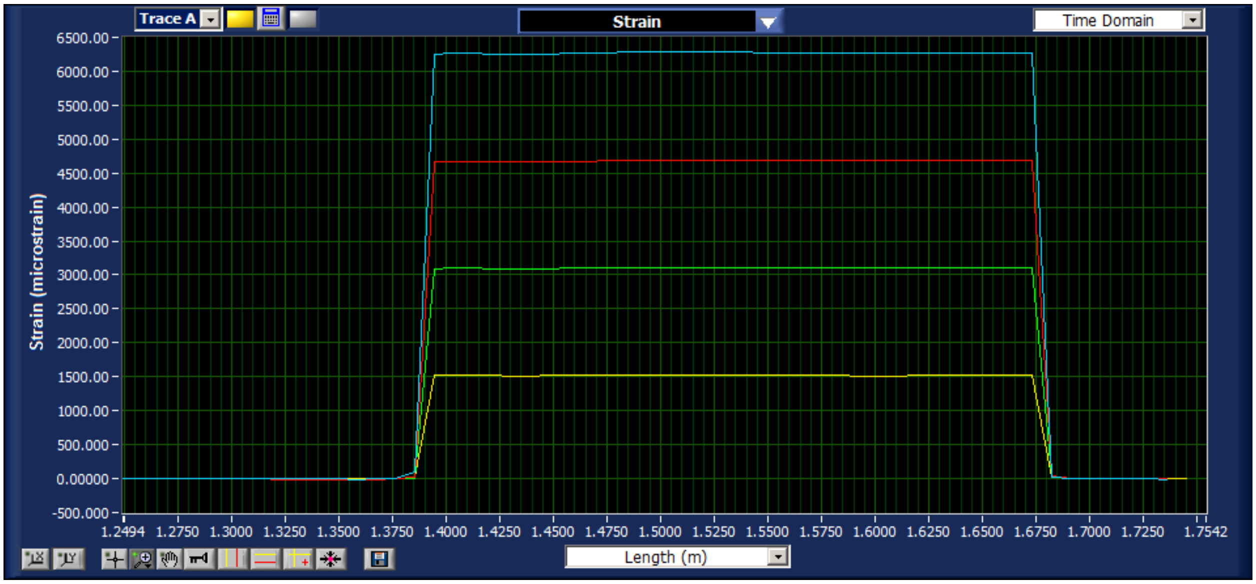

Figure 10. Strain as a function of position as measured by the OBR

Summary and Conclusion

Luna Technologies performed skew measurements on a subset of fibers of three spools of lengths ranging from 640-800 meters. Strain measurements were successfully demonstrated using a custom strain stage with micrometers. Results presented in this engineering note show that the OBR can be used to characterize fiber spools for strain and skew at large lengths with an unprecedented level of accuracy.

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