FIBER GEOMETRY: RESULTS OF AN INTERNATIONAL INTERLABORATORY MEASUREMENT COMPARISON

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Improvements in technology have led to a tightening of tolerances for optical fiber geometrical parameters. This, in turn, has led to the need for improved measurement accuracy. Of the geometrical parameters, cladding diameter accuracy has been technically the most difficult to improve. Accuracy on the order of ±0.1 μm is needed for the industry to comfortably meet specified tolerances of ±1.0 μm.

In order to compare results with previous interlaboratory comparisons, we report average measurement spread per fiber, for each measured parameter. We obtain this number, for a given parameter, by first calculating the sample standard deviation for each fiber. We then calculate the arithmetic average of these standard deviations. Although this is not a statistically valid overall measurement spread, it does give an indication of the relative agreement among participants.

In 1989, the Consultative Committee on International Telegraph and Telephony (CCITT, now the International Telecommunication Union - ITU) completed and reported on an international interlaboratory comparison of fiber geometry measurements.[1] The average measurement spread per fiber for mean cladding diameter was 0.38 μm and deemed to be unacceptably high. Each participant received a separate set of fiber specimens, so measurements were not made on the same fiber ends. Longitudinal nonuniformity could have therefore influenced the results. The high measurement spread pointed to the need for all measurements to be made on the *same* cleaved fiber ends and also to the desirability of some type of calibration artifact.[2]

In North America, a second interlaboratory comparison was coordinated by the National Institute of Standards and Technology (NIST) for the Telecommunications Industry Association (TIA) and reported on in 1992.[3] Participants serially measured the same cleaved fiber ends, which could be retracted into an aluminum housing for protection between measurements and during shipping. These housings use a brass barrel that is moved to extend or retract the fiber and is marked to identify the angular orientation of the fiber. The housed fiber specimens became the basis for the NIST calibration artifact or Standard Reference Material (SRM), which became available to the industry in late 1992.[4]

The average measurement spread per fiber for mean cladding diameter measurements in the 1992 comparison improved to 0.15 μm. There were also reductions in the measurement spreads of the other measured parameters: cladding noncircularity and core/cladding concentricity error. Participants' cladding diameter measurements were also compared to measurements made by the NIST contact micrometer, which is the measurement method for characterization and certification of the SRMs. The contact micrometer is accurate within ±0.045 μm (3 standard deviations) for mean cladding diameter measurements on the housed specimens.[5] The cladding diameter measurement spread observed in the 1992 study was largely due to systematic differences between participants, and further improvement in this spread was anticipated with the use of calibration artifacts such as the NIST SRMs.

The present ITU international comparison was administered by NIST, with help from regional coordinators in Europe and Japan. Housed fiber specimens were again used. Because the housed fibers could become damaged with repeated shipping, and in order to complete this comparison in a reasonable time, three sets of specimens were prepared for three different regions: North America (A), Europe (E), and Pacific (P). Each set contained seven housed fiber specimens, including both very nearly circular and noncircular (up to 1.5 %) fibers. All fibers were measured by the NIST contact micrometer, to allow for inter-regional comparison. As of this writing, twenty-two participants have reported results; the number should approach thirty by completion of the comparison. Of the current twenty-two, twenty used the gray scale measurement method,[6] and two used image shearing.[7] Of the gray scale participants, three used home-made test sets, while the others used commercial test sets from three different commercial vendors.

Table 1 shows the average measurement spreads per fiber, for each of the three measured parameters, for the present as well as the previous comparisons. It also breaks down the present results into the three regions. With the use of the housed fiber specimens, the spreads for cladding noncircularity and for core/cladding concentricity error have improved significantly for all three regions since the 1989 comparison. In North America, where the NIST SRMs are in widespread use for calibration, the average spread per fiber for mean cladding diameter measurements has again improved, to 0.08 µm. The European and Pacific spreads remain higher, both at ≥0.30 µm, although both deserve qualification. In Europe, many of the participants are now calibrated to the National Physical Laboratory (NPL) in the United Kingdom, through a program similar to the NIST SRMs,[8] involving either fiber or chrome-on-glass artifacts. If we include data from only those participants, the European spread improves to 0.07 µm. In the Pacific, only two Japanese participants are calibrated to a national standards laboratory, by use of fibers certified by the Japanese Quality Assurance Organization (JQA). Furthermore, a couple of Pacific participants (including one of the above-mentioned calibrated Japanese participants) reported compatibility problems between the fiber housings and their test sets, so they could not easily and confidently measure the housed fiber specimens. In a separate comparison, on three different non-housed fiber specimens measured by the NIST contact micrometer and the Pacific participants, a corresponding spread of roughly 0.11 µm was obtained. Also, while virtually all data from North American participants have been received, there are several European and Pacific participants, from whom we anticipate data, who have not yet received or measured the comparison fibers.

Figure 1 shows the cladding diameter results for the present comparison, as a plot of offsets from NIST contact micrometer values versus participant. Up to seven points are plotted per participant, representing the seven fibers in each set of measurement specimens. The participants are grouped by region. Filled-in circles show gray scale participants who are calibrated by means of a NIST SRM. Filled-in squares show gray scale participants who are calibrated to NPL. Filled-in diamonds show gray scale participants who are calibrated to JQA. Open stars show gray scale participants who reported compatibility problems between their test sets and the fiber housings. Other gray scale data are denoted by open squares. Open triangles denote the two participants who used the image-shearing method. This graph clearly shows that those participants who are calibrated to one of the national standards laboratories are usually in better agreement than those who are not; in some cases, the improvement is nearly an order of magnitude. Agreement generally appears to be just as good for noncircular fibers as for circular ones. One unexplained observation, presently under study, is that most of the participants calibrated to one of the national standards laboratories have positive offsets from the NIST contact micrometer. In other words, they systematically measure slightly higher than the contact micrometer.

Two other meaningful quantities can be calculated from the statistics of these measurement offsets. For each participant, an average offset (average of the seven plotted offset values) can be calculated, as can the standard deviation of the seven offset values about that average. The average offset indicates systematic offset from the NIST contact micrometer, and when compared to the same quantity for other participants, it indicates the extent of systematic disagreement between them. The magnitude of this quantity can be minimized by calibration. The second quantity, the participant offset standard deviation or offset spread, is a reflection of, among other things, the participant's random uncertainty; this value would not be expected to improve with calibration. For most of the participants who are not calibrated to one of the national standards laboratories, the absolute values of their average offsets, what we call their offset magnitudes, are greater than their offset spreads. Such participants could be anticipated to benefit significantly from calibration. All participants who are calibrated to one of the national standards laboratories have offset magnitudes of ≤0.16 µm, and all but three have <0.1 µm.

Table 2 shows the average participant offset magnitude and average participant offset spread from the present comparison: overall, broken down into the three regions, and for only those participants who are calibrated to one of the national standards laboratories. The same numbers from the 1992 TIA North American comparison are also shown. In North America the average offset magnitude has reduced from 0.114 µm in 1992, when there were no SRM calibrations, to 0.073 µm in the present comparison in which nearly all of the North American participants are calibrated by means of SRMs. The European average offset magnitude is somewhat higher, apparently due to the few European participants who are not calibrated to NPL. If we include only those who are calibrated to NPL, the number reduces to 0.071 µm. The average offset magnitude is also higher in the Pacific, where only a couple of participants so far are calibrated to any national standards laboratory. Again, the higher average offset spread in the Pacific is likely due to those test sets that had difficulty measuring the housed fiber specimens.

In conclusion, this comparison shows better agreement among participants, for all three fiber geometry parameters, than did the 1989 comparison. Where there are substantial disagreements, they seem to be systematic; this was not always the case in the 1989 comparison, where there was more random spread in the data. Those participants whose test sets are calibrated to one of the national standards laboratories, through calibration artifacts, generally show significantly better agreement.

ACKNOWLEDGMENTS

Thanks to: all participating laboratories in the United States, Canada, United Kingdom, France, Italy, Finland, Netherlands, Sweden, Japan, and Australia; to John Baines of NPL for coordinating and overseeing the European measurements and to Masaharu Ohashi of NTT for coordinating and overseeing the Japanese measurements; to Bill Kane and Tom Hanson at Corning, Inc. for keeping us aware of ITU goals and deadlines and for reporting the results; to Casey Shaar of Photon Kinetics for providing the prototype design of the fiber specimen housings; to Steve Mechels of NIST for his expert end-preparation on the measurement specimens.

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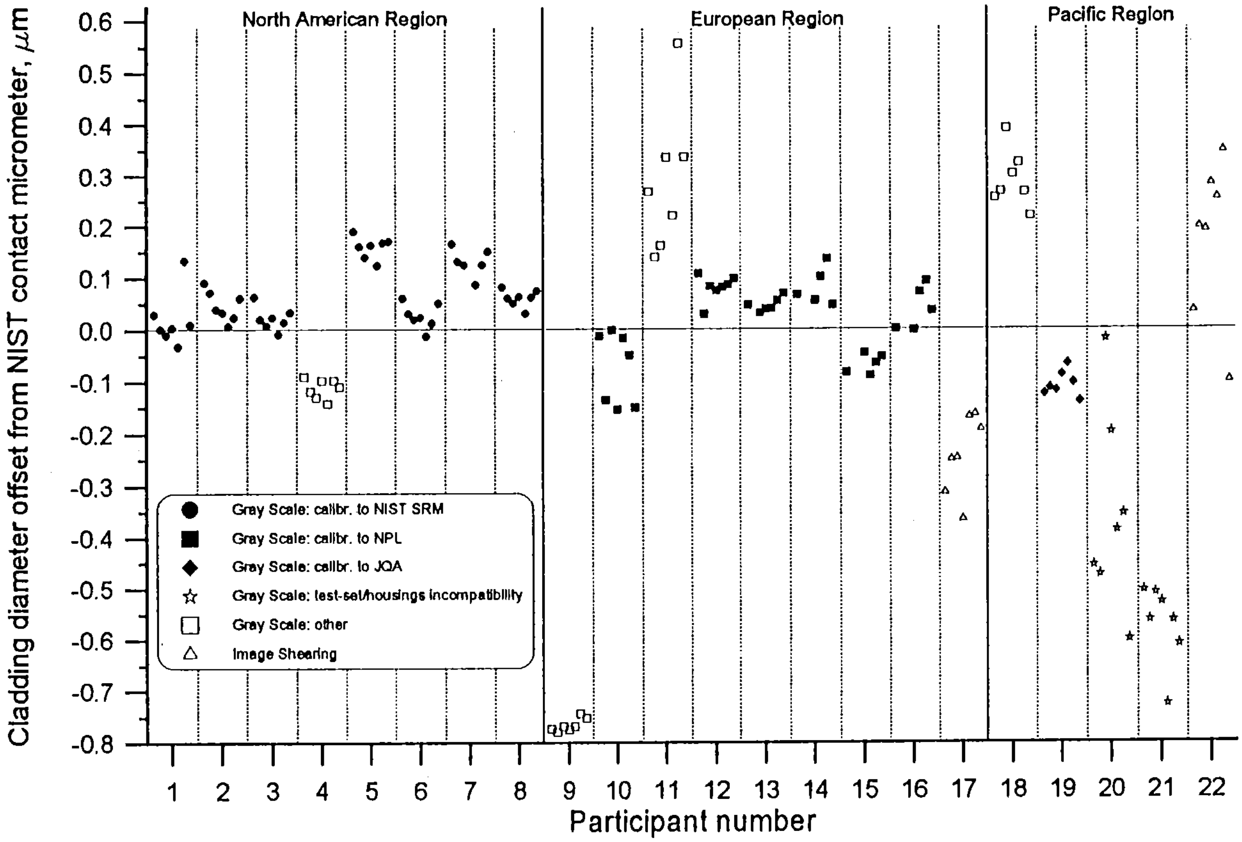

Figure 1 Offsets of participants' mean cladding diameter measurements from NIST contact micrometer. Up to seven points plotted, for each participant, represent the seven fibers in the measurement samples.

Average Measurement Spreads per Fiber			
	Cladding Diameter, µm	Noncircularity, %	Concentricity Error, µm
'89 CCITT Comparison	0.38	0.27	0.17
'92 TIA (North American) Comparison	0.15	0.05	0.04
Present Comparison	0.24	0.09	0.08
"A"	0.08	0.05	0.06
"E"	0.30	0.11	0.12
"P"	0.33	0.12	0.07

Table 1 Average measurement spreads per fiber (arithmetic average of standard deviations for each of the fibers), for all three measured parameters, for the current comparison, as well as past comparisons. Current results are also broken down by region: North America (A), Europe (E), and the Pacific (P).

Average Statistics for Participants' Cladding Diameter Offsets from NIST Contact Micrometer		
	Average Offset Magnitude, µm	Average Offset Spread, µm
'92 TIA (North American) Comparison	0.114	0.032
Present Comparison	0.171	0.052
"A"	0.073	0.027
"E"	0.188	0.048
"P"	0.299	0.101
those calibrated to nat. standards labs (all regions)	0.069	0.030

Table 2 Average cladding diameter offset statistics per participant for current comparison (overall, regional, and only those calibrated to national standards laboratories) and '92 North American comparison. Average offset magnitude is the average of the absolute values of participants' average offsets from NIST contact micrometer. Average offset spread is the average of the Participants' standard deviations about their average offsets.