5. Splice Loss in Multimode Fiber

(Dated: January 19, 2021)

I. OBJECTIVE

To determine the numerical aperture of given multimode and single mode fibers from the measurements on the far field.

II. APPARATUS

1. Optical breadboard
2. He-Ne Laser and Laser aligner
3. Microscopic objective (20X) and holder
4. xyz-translational stage
5. Pin hole photodetector with multimeter and holder
6. fiber chucks
7. post bases and posts
8. Multimode fibers of same NA and appropriate length
9. Fiber cleaver
10. Rotation stage
11. V-grooves

III. THEORY

In fiber alignment, i.e. on joining the two ends of fiber, there can be misalignment and that leads to error. While joining two ends of an optical fiber, there can be different kind of offsets e.g - Transverse offset, Longitudinal offset, Angular offset, Numerical aperture offset, concentricity offset, core diameter offset, etc.
As we are using different chucks of same multimode fiber, therefore we get rid of all the offset related to the structure of the fiber. So,in this experiment, three of these offset are studied, which are:
1. Transverse Offset
2. Angular Offset
3. Longitudinal Offset
These kind of offsets are known as extrinsic offsets as they happen due to physical error rather than the structural error of fiber.

Losses at a fiber splice depends upon a lot of factors like mode power distributions, attenuation, and mode coupling characteristics of the fibers. These characteristics are difficult to measure experimentally and hence several approximate models have evolved in the literature to estimate splice losses in multimode fibers. Most successful attempt in this direction has been the phenomenological model of a Gaussian power distribution. In practice for a splice between two identical fibers, the following empirical but approximate expression for splice loss (in dB) due to transverse offset has been found to be accurate:

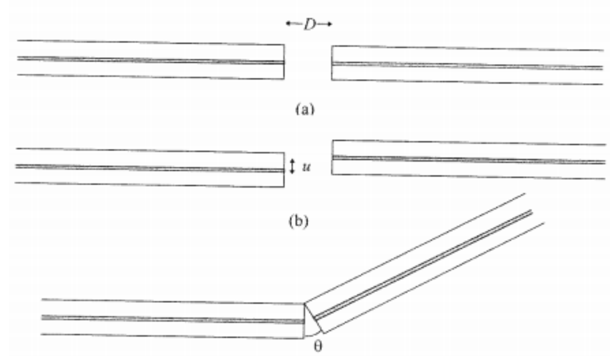

FIG. 1. Different types of offset

$$\Gamma_d = -0.0001 + 0.6688\left(\frac{d}{a}\right) + 4.136\left(\frac{d}{a}\right)^2 + 0.5\left(\frac{d}{a}\right)^3 \quad ....(1)$$

where d is the transverse effect and a is the core radius of the fiber.
It has been observed that major contributors to splice loss namely, transverse offset, core radii and Δ mismatches between transmitting and receiving fibers do not combine linearly. However, the following approximate relation may be used to model splice loss due to simultaneous presence of all the three factors:

$$\Gamma = 2.0147 - 0.85k^2 - 1.035A + 5.4986\left(\frac{d}{a}\right) \quad ......(2)$$

where, $A = \frac{\Delta_R}{\Delta_T}$ and $k = \frac{a_R}{a_T}$; subscripts R and T refer to the receiving and transmitting fibers; the parameter Δ is the same that we calculated in previous experiment.Here, A and k, both are equal to 1 as we are using parts of same fiber. Therefore, the eq.(2) changes to:

$$\Gamma = 2.0147 - 0.85 - 1.035 + 5.4986\left(\frac{d}{a}\right)$$

$$\Gamma = 0.4797 + 5.4986\left(\frac{d}{a}\right)$$

For Angular Offsets, transmission loss (in dB) may be approximately estimated from the following expression valid for step-index fibers:

$$\Gamma_\theta = 10 log_{10}\eta \quad .....(3)$$

$$\eta = \frac{16(n_1/n_2)^2}{[1+(n_1/n_2)]^4}\left[1 - \frac{n_2\theta}{\pi n_1(2\Delta)^{1/2}}\right] \quad .....(4)$$

where n_1 is the core refractive index, n_2 is the refractive index of the medium between the two fibers (which is air) and Δ is defined above. If the end-faces of two step-index fibers to be jointed are longitudinally separated by an amount s, transmission loss (in dB) can be approximately expressed as:

$$\Gamma_s = 10log_{10}\left[1 - \frac{s}{a}\frac{2}{\pi(NA)^2}sin^{-1}(NA - NA\sqrt{1-(NA)^2})\right]..$$

For parabolically graded-index fibers, corresponding expression is given by:

$$\Gamma_s \approx 10log_{10}\left[1 - \frac{1}{2}(NA)\frac{s}{a}\right] \quad fors/a << 1 \quad .....(6)$$

IV. PROCEDURE FOLLOWED

Light was coupled into one multimode fiber in the similar manner as it was done in the previous experiment to obtain maximum coupling. Another fiber was placed on a z translation stage, which was mounted on top of a micrometer translation stage. The fibers were positioned such that they were as close as possible to each other longitudinally and in transverse manner(both vertically and horizontally). And the other end of the receiver fiber was placed in front of photodetector. Then, the translation stage was slowly moved in order to get maximum output at the output end of the receiving fiber. That position was taken as zero, then the micrometer stage was moved in such a way that fiber centers of both fiber were getting misaligned. Micrometer reading and corresponding power reading were taken as shown in Table I
Then translation stage was placed such that the receiving fiber can be moved longitudinally. Then fibers were aligned with zero misalignment. Then micrometer stage was moved and corresponding power is noted down. The readings are in Table II.
Then the micrometer stage was removed and rotational stage was fixed on the optical breadboard in order to measure the angular offset. The fiber was to be mounted on the rotational stage such that the end of the fiber is at the center of the rotational stage. In absence of the proper mounting post, an improv mounting post was made as shown in fig.2 and fibers were aligned to get 0 misalignment and then the stage was rotated and readings were taken as given in Table III.

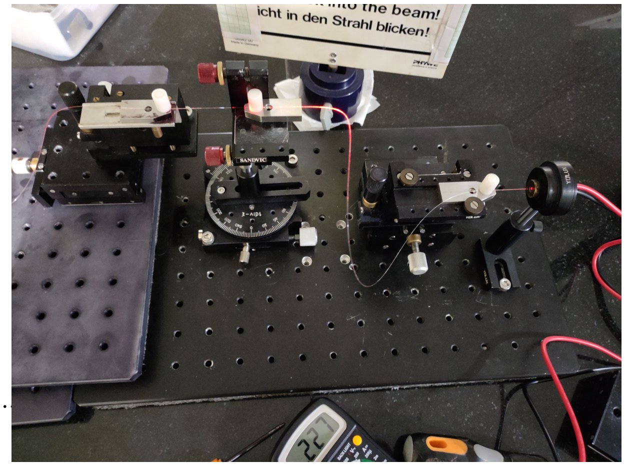

FIG. 2. Different types of offset

V. EXPERIMENTAL DATA

A. Transverse Offset

TABLE I. Transverse Offset

Micrometer reading	Voltage reading in multimeter (V)	Normalized power	Loss in dB
0.981	0.275	1	0
0.98	0.267	0.94266	0.256429
0.979	0.24	0.76165	1.182429
0.978	0.223	0.65757	1.820557
0.977	0.208	0.57209	2.425387
0.976	0.123	0.20005	6.988552
0.975	0.050	0.33058	14.80725
0.974	0.012	0.00190	27.20303

B. Longitudinal Offset

TABLE II. Longitudinal Offset

Micrometer reading	Voltage reading in multimeter (V)	Normalized power	Loss in dB
0.496	0.252	1	0
0.503	0.238	0.891975	0.496472
0.518	0.223	0.783085	1.061914
0.527	0.212	0.707735	1.501294
0.535	0.202	0.642542	1.920983
0.548	0.178	0.498929	3.0191611
0.566	0.15	0.354308	4.506186
0.578	0.129	0.262046	5.816217
0.585	0.120	0.226757	6.444386
0.593	0.100	0.15747	8.028011
0.606	0.090	0.127551	8.943161
0.617	0.078	0.095805	10.18612
0.623	0.072	0.081633	10.88136
0.647	0.058	0.052973	12.75945
0.736	0.035	0.01929	17.14665
0.875	0.020	0.006299	22.00741
1.179	0.01	0.001575	28.02801

C. Angular Offset

In this one we take readings of rotational stage.

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TABLE III. Angular Offset

Rotational stage reading (degree)	Voltage reading in multimeter (V)	Normalized power	Loss in dB
220.4	0.216	1	0
220.6	0.209	0.9362	0.2861
220.8	0.203	0.8833	0.5392
221.2	0.192	0.7901	1.0231
221.4	0.17	0.6194	2.0801
221.6	0.154	0.5083	2.9387
221.8	0.133	0.3791	4.212
222	0.095	0.1934	7.1346
222.2	0.086	0.1585	7.9991
222.4	0.07	0.105	9.7871
222.6	0.047	0.0473	13.247
222.8	0.036	0.0278	15.563
223	0.028	0.0168	17.746
223.2	0.018	0.0069	21.584

VI. GRAPHS AND CALCULATIONS

Now, we took values r, s and θ and normalized them in order to obtain the following graph using the values from Table I, II and III.

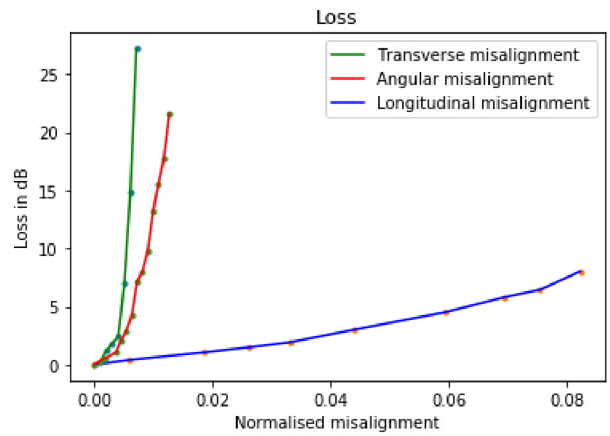

FIG. 3. Different types of offset

VII. RESULT AND DISCUSSION

From the graph above we can see that the loss is different in all three types of offset.
Transverse offset gives the maximum loss and longitudinal offset gives the least amount of loss when the misalignment is of same magnitude.
However, the loss in Angular offset is much greater than expected, as it should be nearer to longitudinal loss than Transverse loss. The reason why it happened was because the proper instrument for angular offset was not available and hence the fiber end was not on the axis of rotational stage as it should have been.

[1] YOLUX setup manual,*School of Physical Sciences,NISER*

[2] A.K Ghatak and K. Thyagarajan,*Introduction to Fiber Optics*, Cambridge University Press,Cambridge(1998)