FIBER –TO - FIBER (MULTIMODE) SPLICE LOSS

Aim

To measure the power loss at a splice between two multimode fibers, and study the variation of splice loss with transverse, longitudinal and angular offsets.

Apparatus

Two XYZ-stacks, a rotation stage, tungsten halogen lamp/He-Ne laser, optical power meter, multimode fiber, V-grooves, etc.

Theory

In any optical fiber telecommunication link, one or more splices/joints in the fiber cable is inevitable. The predominant method for connecting optical fibers involves a butt-joint connection. Any butt-joint requires three fundamental operations: fiber end preparation, fiber alignment to micron precision and alignment retention. Demountable connections retain alignment mechanically while permanent connections retain alignment through melting and fusing of the fiber ends in a fusion-splicing machine. In any fiber joint, the fiber ends must be prepared smooth and perpendicular to the fiber axis. The next step of aligning the fiber end (to be jointed) is very crucial because any kind of misalignment would lead to a transmission loss. Loss at a fiber splice could originate from either or a combination of the following possible misalignments (see Fig. 5.1):

i. Transverse offset between the fiber ends.
ii. Angular tilt between the fiber ends.
iii. Longitudinal end-separation between the fiber end faces.

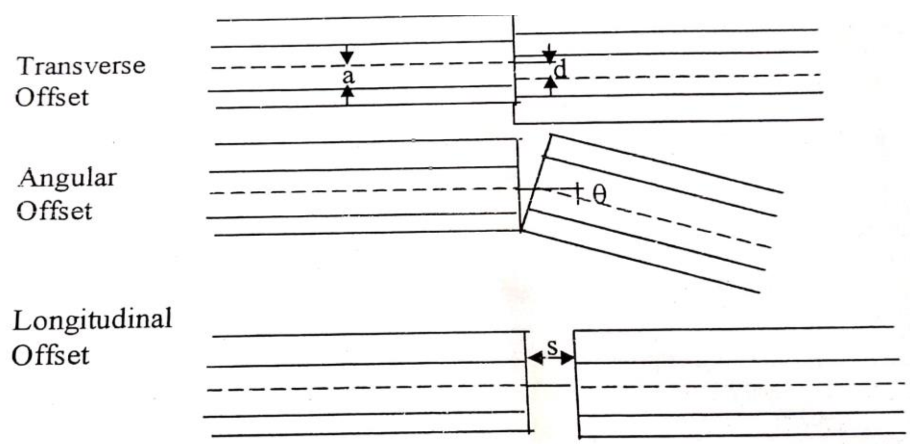

Fig. 5.1 *Three different types of offsets between the axes of the fibers at a splice-joint which may lead to a transmission loss.*

These fall under the category of extrinsic losses. In addition, either or a combination of the following may also result in a joint loss and these are sources of intrinsic loss.

i. Reflection loss at the fiber-air interfaces/
ii. Difference in characteristic parameters, e.g. refractive indices, index exponent; core dimension, etc. between the two fibers.
iii. Deformation of the end surface of fibers.

Major contributors to loss, however, at a splice are transverse offset, mismatches in core radii, and the relative core-cladding index difference (and hence NA).

An accurate model of splice loss is extremely difficult to construct. Losses at a fiber splice depend on various 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 [1]. "This model gives a very good agreement with measured splice losses both for individual parameter mismatches and for combinations of both intrinsic and extrinsic mismatches that are extremely difficult to calculate any other way" [2]. 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 [2]:

$$r_d = -0.0001 + 0.6688\left(\frac{d}{a}\right) + 4.136\left(\frac{d}{a}\right)^2 + 0.5\left(\frac{d}{a}\right)^3 \quad (5.1)$$

Where d is the transverse effect (i.e. separation between the fiber axes) and a is the core radius of the fiber. It matches splice loss according to Gaussian model within 0.01 dB upto d/a = 0.8.

It has been observed that major contributors to splice loss namely, transverse offset, core radii- and Δ mismatches between the 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 [2]:

$r = 2.0147 – 0.85k^2 – 1.035A + 5.4986\left(\frac{d}{a}\right)$ (5.2)

Where $A = \Delta_R/\Delta_r$ and $k=a_r$; subscripts R and T refer to the receiving and the transmitting fibers; the parameter Δ is defined as

$$\Delta \cong \frac{n_m - n_{cl}}{n_m}$$

Where n_m and n_{cl} are the refractive indices of the core and cladding, respectively.

For angular offsets, transmission loss (in dB) may be approximately estimated from the following expression valid for step-index fibers [3,4]:

$r_\theta = 10\log_{10}\eta$ (5.3)

$\eta = \frac{16\left({n_1}/{n_2}\right)^2}{\left[1+\left({n_1}/{n_2}\right)\right]^4}\left[1 - \frac{n\theta}{\pi n_1 (2\Delta)^{1/2}}\right]$ (5.4)

where n_1 is the core refractive index, n_2 is the refractive index of the medium between the two fibers 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 [5,6]

$r = 10\log_{10}\left[1 - \frac{s}{a}\frac{2}{\pi(NA)^2}\left\{sin^{-1}(NA) - NA\sqrt{1 - (NA)^2}\right\}\right]$ for $s/a \ll 1$ (5.5)

For parabolically graded-index fibers, corresponding expression is given by [5,6]:

$r_s \approx 10\log_{10}\left[1 - \frac{1}{2}(NA)\left({S}/{a}\right)\right]$ (5.6)

We may note here that all the formulae [Eqs. (5.1) – (5.6)] are based on certain assumptions/models and care should be exercised while attempting any comparison of measurements with these theoretical expressions. Fusion splicing is the most widely used technique to permanently join two fibers. It is accomplished by localized heating (through an electric arc) of the interface between two butted and pre-aligned fiber ends. A high-voltage electric arc generated between electrodes melts the fiber ends, and fuses them permanently as soon as the voltage is switched off. In the design of any such fiber fusion-splicing machine it is essential to have a prior knowledge of the factor that may lead to splice loss. In order to minimize splice loss, it is essential to understand relative affects of different local splice loss contributors. To appreciate it, the following experiment may be performed.

Procedure

The experimental set up is shown in Fig. 5.2. Light from a tungsten halogen lamp is launched into a piece of multimode fiber. Cladding mode strippers should be applied at the input and exit ends of this fiber, henceforth this fiber will be referred to as transmitting fiber.

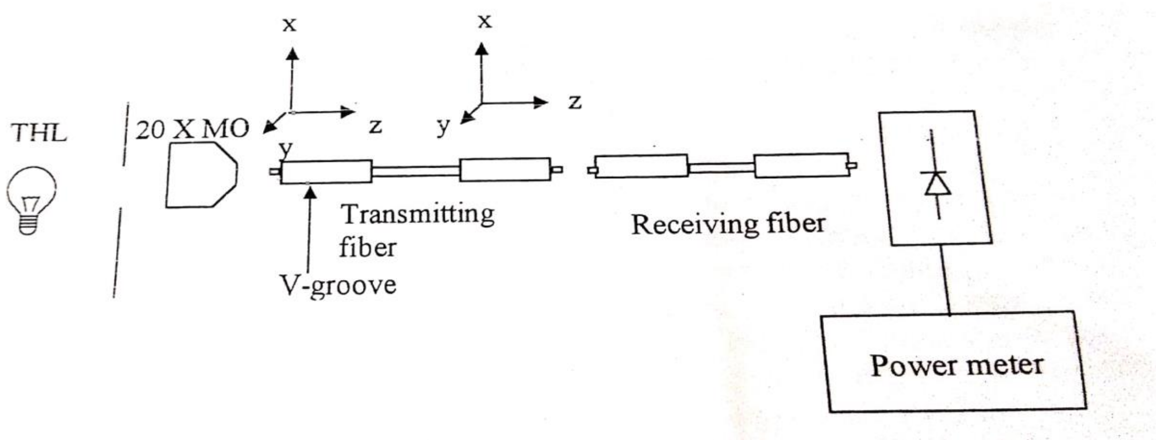

Fig. 5.2. *Experimental set up to measure fiber to fiber (Multimode) splice loss*

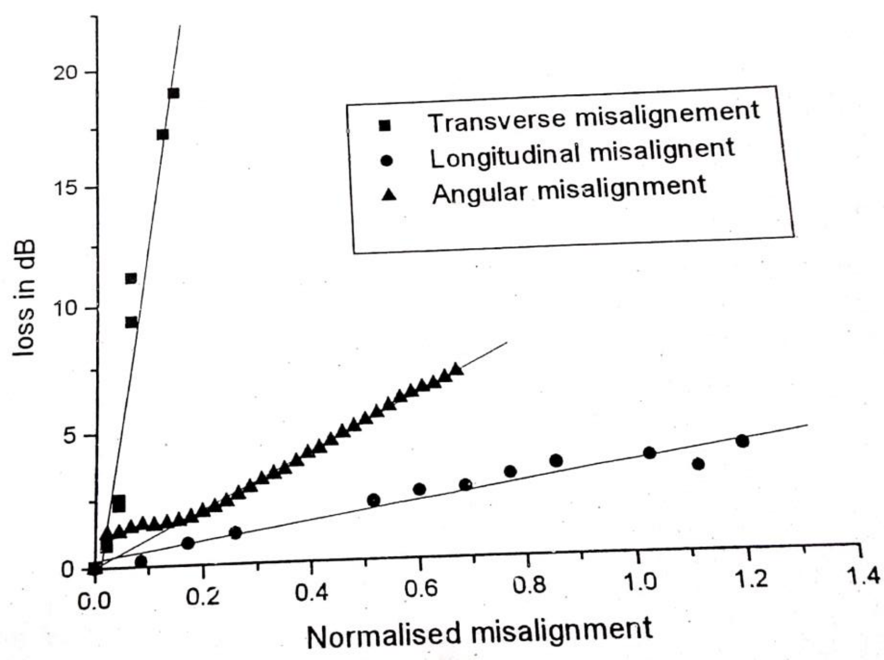

Fig. 5.3. *Typical results of splice losses due to various offsets between two multimode fibers.*

A second piece of (preferably identical) multimode fiber, referred as the receiving fiber, is then brought near the output end of the transmitting fiber. Input end of the receiving fiber is mounted on a XYZ translation stage, the other end of this fiber is coupled to an optical power meter. One/two drops of cladding mode stripper is once again applied, as before, near the two ends of the receiving fiber. The XYZ translation stages are manipulated to induce any offset loss between the fibers. In actual practice for measuring transverse offset loss, it is recommended that the receiving fiber be moved away from the transmitting fiber (in the transverse direction) till the power meter reading reduces to almost zero (i.e. registers only ambient light). The receiving fiber's input end is then gradually moved into the field of view of the transmitting fiber to couple light from the transmitting fiber and the power meter reading is noted. The fiber could be moved in steps of one division of the graduated scale on the translation stage, and at each step the power meter reading is recorded. This procedure is continued till the receiving fiber once again get out of the field of view of the transmitting fiber so that the power meter only registers background ambient light. The so tabulated readings of power meter versus linear position of the receiving fiber across the joint are then used to draw a graph between these two measurement parameters. Detected power can be further converted to a dB-scale by normalizing the power meter readings for each offset reading with the power meter reading for zero misalignment between the fibers, which would obviously correspond to the maximum of the power meter readings. In a similar manner, the measurements could be repeated for offsets in the two other orthogonal directions. If the fiber is perfectly circularly symmetric, then one of these two last measurements should yield results almost identical to the previous one. On the other hand, the third set of measurement, which would correspond to a longitudinal offset, the results would be quite different compared to transverse offset. These measurements would reveal that longitudinal offset is more tolerable than transverse offset in terms of achieving a low loss fiber joint.

Tolerance to any angular offset on a plane between the fibers can likewise be obtained by mounting the input end of the receiving fiber at the center of a graduated turn table (i.e. fiber is initially aligned in the $_{xy}$ plane with a gap of 2-3 $_{\mu m}$ (along $_z$) from the receiving fiber at the centre of the rotational stage. The output end of the transmitting fiber is mounted on a V-groove, which is freely suspended without contacting the rotational stage. Power coupled across the joint is then measured and recorded as a function of angular offsets. Angular offset is induced between the fiber ends by means of the rotational stage on which the receiving fiber is mounted. As before, care should be taken to use cladding mode strippers during the measurements.

Observations

1) **Transverse Misalignment:**

Least count of micrometer screw =

Maximum power for zero misalignment =

S.No.	Micrometer reading (μm)	Power meter reading (μW)	Normalized power	Loss (dB)

2) **Longitudinal Misalignment:**

Least count of micrometer screw =

Maximum power for zero misalignment =

S.No.	Micrometer reading (μm)	Power meter reading (μW)	Normalized power	Loss (dB)

3) **Angular Misalignment:**

Least count of rotation stage =

Maximum power for zero misalignment =

S.No.	Reading on the rotation stage (degrees)	Power meter reading (μW)	Normalized power	Loss (dB)

Results and Discussions

Make a comparative study of loss tolerance to various offsets between two fibers at a joint and highlight at ones that are most critical in the design of low loss fiber jointing machines. Some specimen results of splice loss measurements made on multimode fibers as a function of offsets are shown in Figure 5.3. It can be readily seen that splice loss is most sensitive to transverse misalignments. For a 20% offset (relative to core diameter 50 μm), splice loss is about 0.4dB. As already stated before, transverse off-set is the major contributor to splice loss and hence in the design of any splice machine one is required to take extreme care to avoid any potential source of transverse misalignment.