Numerical Aperture of A Plastic Optical Fiber

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Abstract: - To use plastic optical fibers it is useful to know their numerical apertures. These fibers have a large core diameter, which is very different from those of glass fibers. For their connection a strict adjustment to the properties of the optical systems is needed, injecting the light inside and collecting it outside so as not to increase the losses resulting of their strong absorption. If it is sufficient to inject the light at the input with an aperture lower than the theoretical aperture without core stopping, it is very useful to know the out numerical aperture which is varying with the injection aperture and the length of the fiber, because the different modes may be not coupled and are not similarly absorbed. Here I propose a method of calculating numerical aperture by calculating acceptance angle of the fiber. Experimental result shows that we measure the numerical aperture by calculating the mean diameter and then the radius of the spot circle projected on a graph paper. We also measure the distance of the fiber from the target (graph paper). Then make a ratio between the radius of the spot circle and the distance. From here we calculate the acceptance angle and then numerical aperture by sin of acceptance angle.

I. INTRODUCTION

In optics, the **numerical aperture** (**NA**) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. By incorporating index of refraction in its definition, NA has the property that it is constant for a beam as it goes from one material to another provided there is no optical power at the interface. The exact definition of the term varies slightly between different areas of optics. Numerical aperture is commonly used in microscopy to describe the acceptance cone of an objective (and hence its light-gathering ability and resolution), and in fiber optics, in which it describes the cone of light accepted into the fiber or exiting it. Numerical aperture refers to the maximum angle at which the light incident on the fiber & is totally internally reflected and it can be transmitted properly along the fiber. It is shown by Figure1.

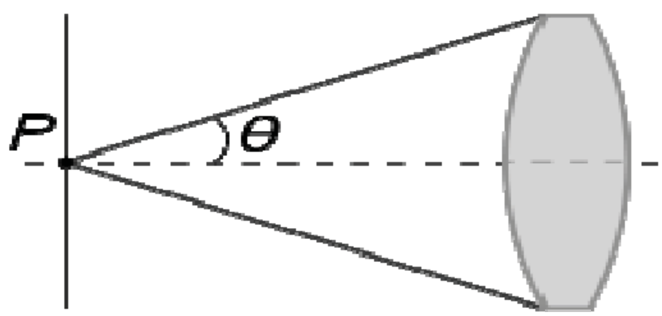

Figure1

The following figure shows that an incident light ray is first refracted and then undergoes total internal reflection at the core–cladding interface. However, that works only if the incidence angle is not too large.

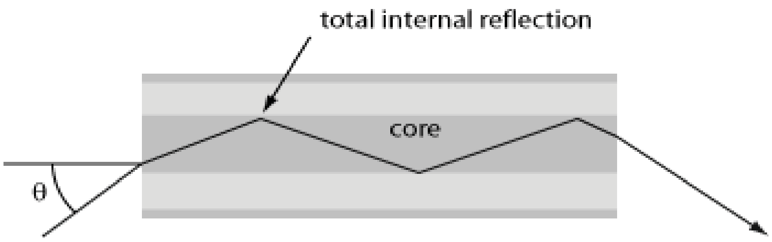

Figure2

In most areas of optics, and especially in microscopy, the numerical aperture of an optical system such as an objective lens is defined by

$$NA = n \sin \theta$$

where *n* is the index of refraction of the medium in which the lens is working (1.0 for air, 1.33 for pure water, and up to 1.56 for oils; see also list of refractive indices), and *θ* is the half-angle of the maximum cone of light that can enter or exit the lens. In general, this is the angle of the real marginal ray in the system. Because the index of refraction is included, the NA of a pencil of rays is an invariant as a pencil of rays passes from one material to another through a flat surface. This is easily shown by rearranging Snell's law to find that n sin θ is constant across an interface.

II. THEORITICALLY ANALYSIS OF NUMERICAL APERTURE

Consider an optical fiber having a core of refractive index n_1 and cladding of refractive index n_2. Let the incident light makes an angle i with the core axis as shown in figure (3). Then the light gets refracted at an angle *θ* and fall on the core-cladding interface at an angle where,

$$\theta' = (90 - \theta) \text{......................} \quad (1)$$

By Snell's law at the point of entrance of light in to the optical fibre we get,

$$n_0 \sin i = n_1 \sin \theta \text{.......................} \quad (2)$$

Here n_0 is the refractive index of the medium outside the fiber. For air $n_0 = 1$.

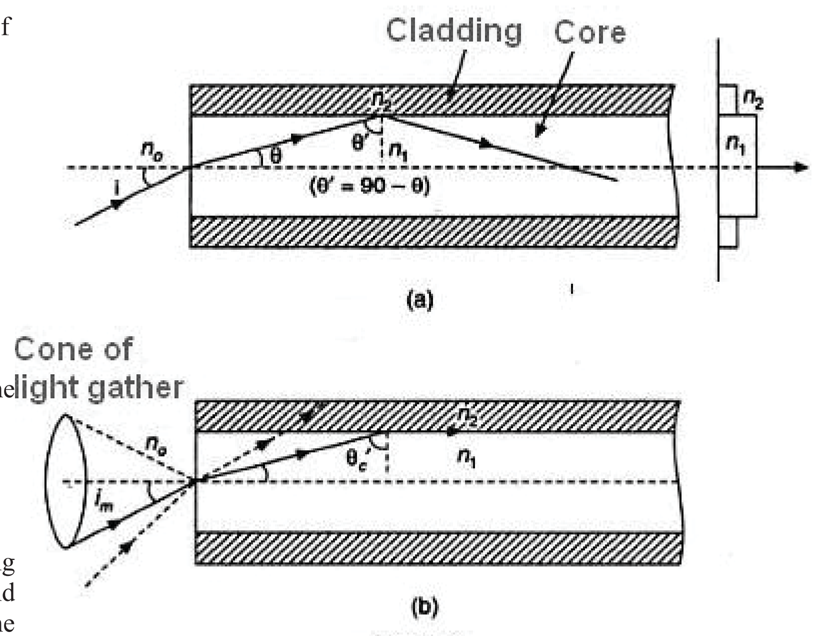

Figure 3.

When light travels from core to cladding it moves from denser to rarer medium and so it may be totally reflected back to the core medium if *θ′* exceeds the critical angle θ'_c. The critical angle is that angle of incidence in denser medium (n1) for which angle of refraction become 90°. Using Snell's laws at core cladding interface,

$$n_1 \sin \theta'_c = n_2 \sin 90$$

Or,

$$Sin\, \theta'_c = \frac{n_2}{n_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Therefore, for light to be propagated within the core of optical fiber as guided wave, the angle of incidence at core-cladding interface should be greater than θ'_c. As incident angle i increases, θ increases and so θ' decreases. Therefore, there is maximum value of angle of incidence beyond which, it does not propagate rather it is refracted in to cladding medium (fig: 3(b)). This maximum value of i say i_m is called maximum angle of acceptance and n_0 sin i_m is termed as the numerical aperture (NA).

From equation (2),

$$NA = n_0 \sin i_m = n_1 \sin \theta = n_1 \sin(90 - \theta_c)$$

$$Or\ NA = n_1\, Cos\, \theta'_c = n_1 \sqrt{1 - Sin^2 \theta'_c}$$

From equation (2)

$$\sin \theta'_c = \frac{n_2}{n_1}$$

Therefore,

$$NA = n1 \sqrt{1 - \frac{n_2^{\ 2}}{n_1^2}}$$

Or,

$$NA = \sqrt{n_1^{\ 2} - n_2^{\ 2}}$$

The significance of NA is that light entering in the cone of semi vertical angle i_m only propagate through the fibre. The higher the value of i_m or NA more is the light collected for propagation in the fibre. Numerical aperture is thus considered as a light gathering capacity of an optical fiber. Numerical Aperture is defined as the Sine of half of the angle of fibre's light acceptance cone. I.e. NA= Sin θ_a where θ_a, is called acceptance cone angle.

Let the spot size of the beam at a distance d (distance between the fiber end and detector) as the radius of the spot(r).

Then, $$\sin\theta = \frac{r}{\sqrt{r^2 + d^2}}$$

$$n \sin \theta_{max} = \sqrt{n_{core}^2 - n_{clad}^2};$$

In laser physics, the numerical aperture is defined slightly differently. Laser beams spread out as they propagate, but slowly. Far away from the narrowest part of the beam, the spread is roughly linear with distance—the laser beam forms a cone of light in the "far field". The relation used to define the NA of the laser beam is the same as that used for an optical system,

$$NA = n \sin\theta$$

But θ is defined differently. Laser beams typically do not have sharp edges like the cone of light that passes through the aperture of a lens does. Instead, the irradiance falls off gradually away from the centre of the beam. It is very common for the beam to have a Gaussian profile. Laser physicists typically choose to make θ the *divergence* of the beam: the far-field angle between the propagation direction and the distance from the beam axis for which the irradiance drops to $1/e^2$ times the wave front total irradiance. The NA of a Gaussian laser beam is then related to its minimum spot size by

$$\mathbf{NA} \simeq \frac{\lambda_0}{\pi w_0},$$

Where λ_0 is the vacuum wavelength of the light, and $2w_0$ is the diameter of the beam at its narrowest spot, measured between the $1/e^2$ irradiance points ("Full width at e^{-2} maximum of the intensity"). This means that a laser beam that is focused to a small spot will spread out quickly as it moves away from the focus, while a large-diameter laser beam can stay roughly the same size over a very long distance.

III. EXPERIMENTAL ARRANGEMENT AND RESULT

Following Fiber-optic components are required for completing the experimental set-up: (I) He-Ne Laser with SMA Connector, emitting at a Wavelength of 632.8 nm. (II) 1 mm core step index plastic fiber (III) Circle target, 5 mm spacing. (IV) Ruler. (V) Post (VI) Post holder. The light from laser enters into the optical fiber. The light emitting from the optical fiber is projected on a graph paper. We will get a spot circle on the graph paper and we measure the mean diameter and radius of this spot circle. We also measure the distance from the end portion of the optical fiber to the graph paper. Then we measure the acceptance angle. From this acceptance angle we measure the numerical aperture. The experimental set up is shown by Figure 4. If the radius of the spot circle is denoted by r and distance is denoted by d then

$$\tan \theta_a = r/d$$

$$\text{And } \theta_a = \tan^{-1} (r/d)$$

This θ_a is the acceptance angle and we calculate the numerical aperture by $\sin \theta_a$.

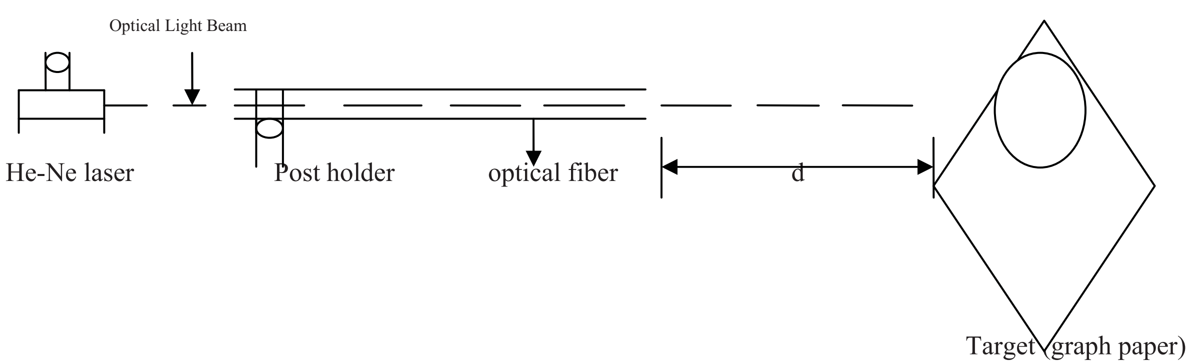

Figure 4

Table1: Experimental Result

We vary the distance from the target (graph paper) to the optical fiber and then measure the height and length of the circle projected on the graph paper. Then calculate the acceptance angle. From acceptance angle we calculate the numerical aperture.

Distance(cm) (d)	Mean Diameter(cm)	Radius of the circle(cm) (r)	Acceptance angle(θa)	Numerical aperture(NA= sinθa)	Mean numerical aperture
1. 0.5	(0.8+0.8)/2	0.40	38.65°	0.624	
2. 0.8	(1.264+1.264)/2	0.632	38.30°	0.619	
3. 1.0	(1.6+1.6)/2	0.80	38.65°	0.624	
4. 1.2	(1.896+1.896)/2	0.948	38.30°	0.62	
5. 1.4	(2.24+2.24)/2	1.10	38.13°	0.617	0.625
6. 1.6	(2.528+2.528)/2	1.264	38.308°	0.638	
7. 1.8	(2.808+2.808)/2	1.504	39.69°	0.638	
8. 2.0	(3.16+3.16)/2	1.58	39.30°	0.638	

IV. CONCLUSION

Multimode fibers propagate more than one mode. Multimode fibers can propagate over 100 modes. The number of modes propagated depends on the core size and numerical aperture (NA). As the core size and NA increase, the number of modes increases. Typical values of fiber core size and NA are 50 to 100 μm and 0.20 to 0.29, respectively. A large core size and a higher NA have several advantages. Light is launched into a multimode fiber with more ease. The higher NA and the larger core size make it easier to make fiber connections. During fiber splicing, core-to-core alignment becomes less critical. Another advantage is that multimode fibers permit the use of light-emitting diodes (LEDs). Single mode fibers typically must use laser diodes. LEDs are cheaper, less complex, and last longer. LEDs are preferred for most applications.

Numerical Aperture (NA) is the light gathering ability or capacity of an optical fiber. More the NA, the more efficient will be fiber. It is also known as figure of merit. NA is related to refractive index of core (n1), cladding (n2) and outside medium (n0) as NA = $\sqrt{n1^2 - n2^2}/n0$.If the medium is air then n0 =1, then NA = $\sqrt{n1^2 - n2^2}$

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