École Polytechnique Fédérale
de Lausanne

Optical Engineering: Multimode Fibre

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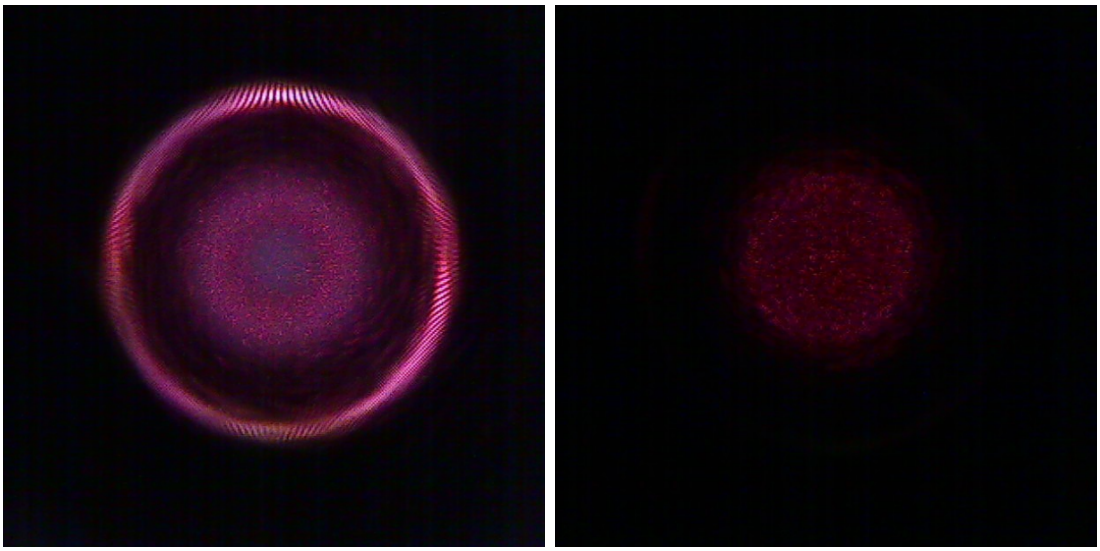
Abstract

First we determine the numerical aperture of the fiber using a collimated laser searching the angle of acceptance (NA = 0.5). In the second experience we calculate the NA measuring at different position the diameter of the point on the sensor (NA = 0.36). Then we compare the transmission properties of the fiber with different sources of light (halogen, LED, laser). Finally we measure the injection efficiency of a LED source with a large and a small numerical aperture ($r = 6.244$ and $r = 2.516$ without dark noise correction).

1 Procedures and results

1.1 Evaluation of the numerical aperture with skewed rays

To determinate the maximum angle of acceptance α_{max}, we angle a laser source from the fibre optic axis. α_{max} is the angle when the circle disappears.



(a) Halogen. (b) LED.

Fig. 1: Injection at different angles to determine the angle of acceptance.

The full angle of acceptance $2\alpha_{max} = 60°$. The center of the beam is still slightly visible after 30°. There may be modes that aren't transmitted at the same angle. The NA is calculated with the acceptance angle α_{max} with an error of 4°.

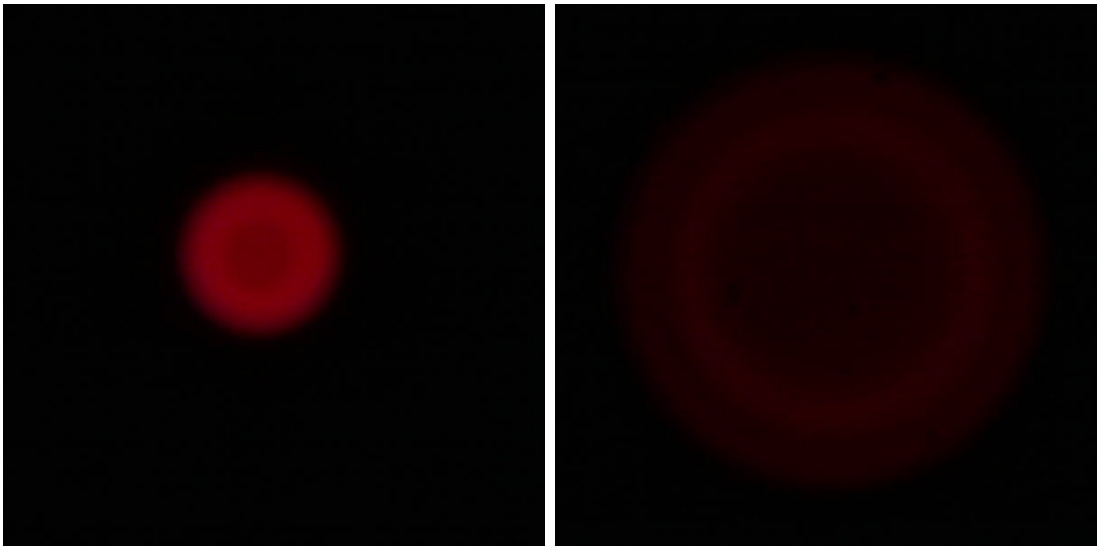
$$\mathrm{NA} = n \sin(\alpha_{max}) = \sin 30° = 0.5 \tag{1}$$

$$\Delta\mathrm{NA} = \frac{\partial \mathrm{NA}}{\partial \sin(\alpha_{max})} \Delta \sin(\alpha_{max}) = 0.06 \tag{2}$$

The datasheet shows NA = 0.22. The circle at 30° is just perceptible, therefore the acceptance angle is already passed. It matches at the angle limit where the intensity of the beam is conserved. In the picture at 25° we can see light between the center beam and the circle. The angle is small enough so that beams can be transmitted without reflecting.

1.2 Measurement of the numerical aperture

We determine the numerical aperture measuring the diameter of the light disk. The same measurement is made at different distances between the output of the fiber and the sensor. With the relation between the distance and the diameter we obtained the NA.



(a) At fiber exit. (b) 2 mm from fiber exit.

Fig. 2: Measurements at different positions relative to the exit of the fiber.

The diameters $d_I = 2.835\,\mu\text{m} d_{I,px}$ with an error of $\Delta d_{I,px} = 20\text{px}$.

$$\Delta d_I = \Delta d_{I,px} \frac{\partial d_I}{\partial d_{I,px}} = 56.7\,\mu\text{m} \tag{3}$$

Relative position (mm)	diameter (px)	(mm)
0	184	0.52
0.5	253	0.72
1	323	0.92
1.5	392	1.11
2	449	1.27
2.5	524	1.49
3	597	1.69

Tab. 1: Diameter of the spot at different distances from the fiber exit.

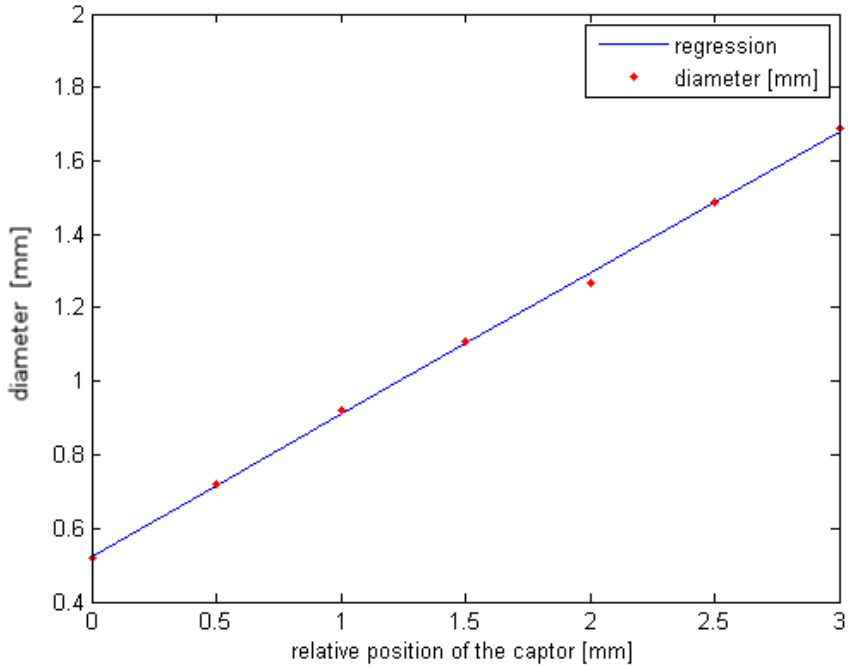


Fig. 3: Linear regression of the values in table 1 to determine the angle of acceptance.

By the linear regression, NA $= 0.36$ with a standard deviation of $\sigma = 0.012$. It allows to determine the angle of acceptance $\alpha = 21°$ and $\Delta\alpha = 1.01°$ (which corresponds to $\frac{\alpha}{\Delta\alpha} = 4.8\,\%$). These values do not correspond to the datasheet. Maybe we used the wrong fiber in the experiment or we measured wrong. Another possibility is that we measured light that was injected in the cladding of the fiber instead of the core.

1.3 Injection for different sources

(a) Halogen. The halo is due to light being injected into the cladding.

(b) LED. Almost no light in the cladding.

(c) Laser. The speckles are due to interferences and only appear when injecting coherent light.

Fig. 4: Injection of different sources.

1.4 Measurement of relative injection efficiency

We injected the laser source with different *NAs* at the image side and measured the relative intensity over the whole image. The measurements could have been improved by doing the in a darker room and cooling down the setup to avoid the *dark noise*.

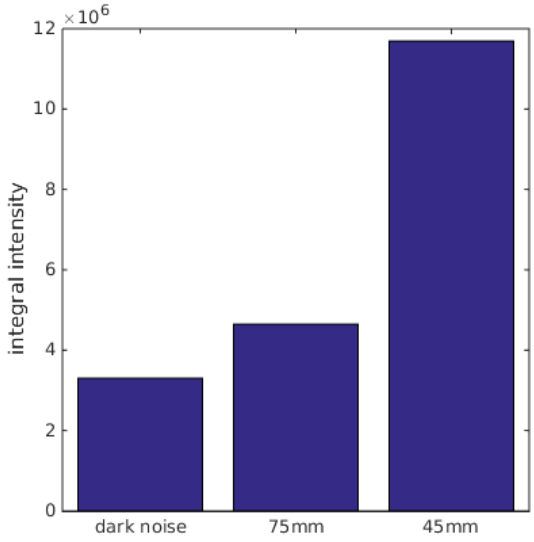


Fig. 5: Integral intensities of two different injection conditions and the dark noise. The intensity labeled *45mm* was measured when the light was injected with *higher* NA at the image side.

Ratio *without* dark noise correction	2.516
Ratio *with* dark noise correction	6.244

Tab. 2: Ratios of the integral intensities between the two different injection conditions. With and without dark noise correction.

2 Discussion and conclusions

Comparing our results to the datasheet for the multimode fiber showed us that our results were too high. This can be due to a suboptimal setup, injection of light into the cladding, and reflections at the entry of the fiber. One also might suppose that the datasheet gives a guaranteed angle of acceptance and that some fibers may be slightly better.