Resolution & Detection Capability

Fiber optic connector endface imperfections, such as contamination and defects, are a major concern in optimal fiber optic network performance. To deal with this problem various microscopes have been developed for inspection of connector endfaces and connector acceptance standards have been established.

Ideally an inspection microscope would be able to catch every single imperfection on the object. But in reality all testing devices have limitations. Similar to the limited viewing ability of human eyes, a microscope also has a lower limit when viewing minute objects.

Optical Resolution (Theoretical Resolution)

Optical Resolution or *Theoretical Resolution* is a performance parameter for optical or imaging systems. It indicates the minimum distance between two adjacent points that the system is capable of resolving, or distinguishing as separate, distinct objects. The smaller the resolution value the better the capability of the optical system to show image details.[1]

In a pure lens system (for example, direct-view microscopes), the resolution is determined entirely by the lenses. Due to the nature of light diffraction, even with perfect lens quality, the lens system can only reach a limited ultimate resolution. The Rayleigh criterion is a widely adopted method for calculating this theoretical limit:

Lens resolution = 0.61 × λ (Wavelength of illumination source) /NA (the system's numerical aperture)

It can be seen from this formula that a shorter wavelength would help in reducing the resolution value. Most developers use a blue LED (~0.47 μm) as the illumination source because it is at the low end of the visible wavelength range. Thus the only variable we really need to look into is the numerical aperture (NA).

NA represents the opening angle of the incident light cone in front of the microscope. It is calculated as $NA=(D/2)/f$ *where D* is the effective light spot diameter on the first lens and *f* is the focus distance of the optical system. As a result, the wider the cone angle or the greater the NA value, the better the resolution will be.

[1] An imaging system may actually consist of several individual parts such as lenses, camera sensor and display. Each of these contributes to the optical resolution of the system. We will discuss impact of cameras and displays on resolution later.

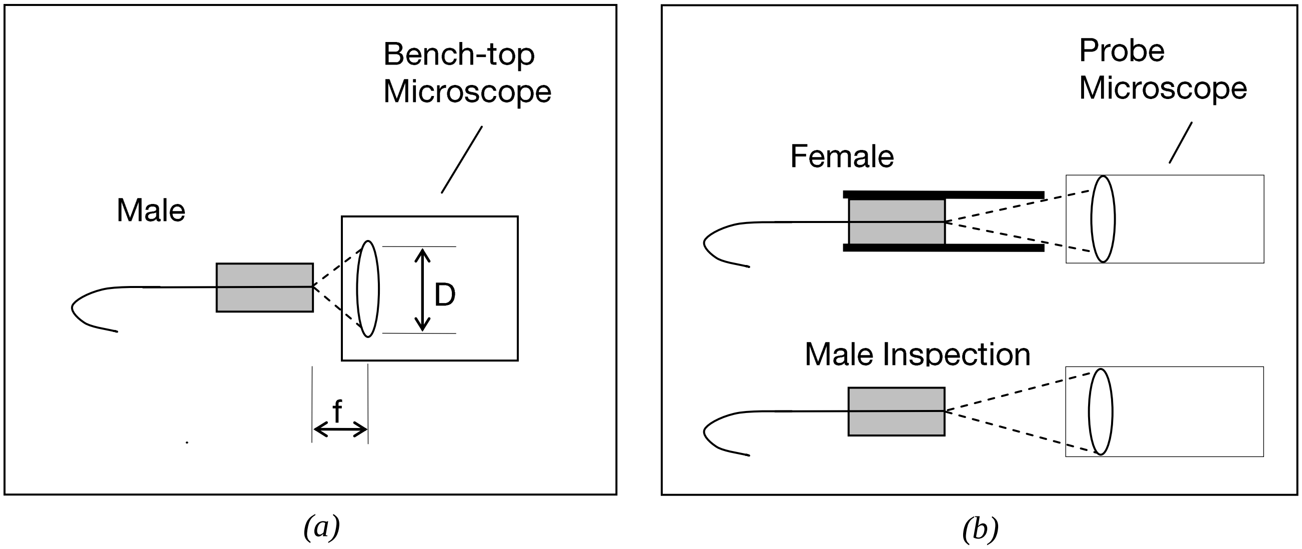


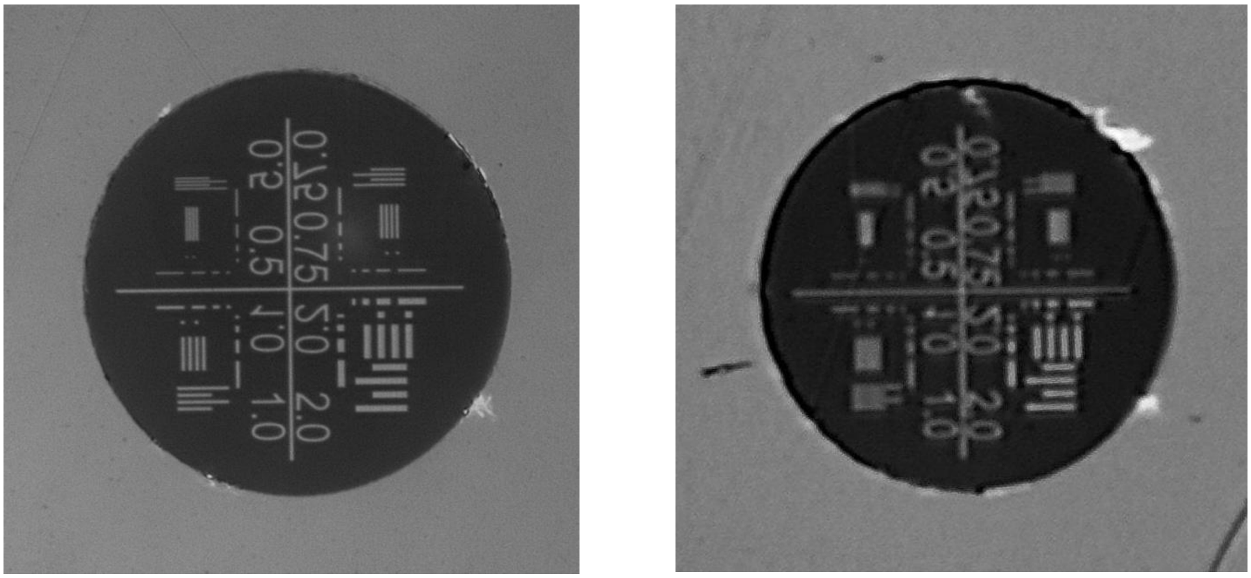
Figure 1. *Numerical aperture of the incident light cone*

From *Figure 1*, we can see that the *D* and *f* in a bench-top microscope are less constrained than they are with a probe microscope. Since probe microscopes need to be used for inspecting female (in-adapter) connectors, in which the connector surface is recessed in a narrow and long sleeve channel, the cone angle is significantly restricted by the sleeve. Using 2.5mm sleeve as an example, the sleeve constraint restricts the NA to ~0.19 (thus a probe resolution to ~1.5μm). As for 1.25mm sleeves, the NA is even more restricted because its diameter/length ratio is a little smaller.

The same probe microscopes are commonly used to inspect male connectors as well. In order to keep a similar imaging result, the 'male tips' are generally designed so as to keep the focusing distance *f* *(Fig. 1b)* the same as for 'female' connector inspection. The light diameter *D* on the first lens will also be similar because the lens must be small in order to keep the probe head compact. As a result *(Fig. 1b)*, male connector inspection may gain a little more NA but it is not significant.[2]

[2] A dual microscope device, such as ViewConn® Plus, has a separate optical structure for viewing male connectors. Without the probe's size constraints, the NA can be larger and the resolution significantly improved.

The images in *Figure 2* show the resolution using a bench-top microscope *(Fig. 2a)* and a probe microscope *(Fig. 2b)*, respectively. The resolution of a microscope is determined by the finest group, in which the microscope can resolve all the separate lines.[3] In *Figure 2*, the bench-top microscope shows an excellent resolution close to 0.5μm while the probe microscope only shows a resolution <2μm, but >1μm.



(a) Bench-Top Microscope *(b) Probe Microscope*

Figure 2

Detection Capability

As stated above, optical resolution indicates the capability of a microscope in resolving two separate adjacent points. But for inspecting connector cleanliness, the most important thing is to see small objects, rather than resolve them. For this reason, we frequently refer to *Detection Capability* or *Detectable Resolution* to specify how small a particle can be detected by an inspection microscope.

Detection Capability and Optical Resolution are strongly correlated: a better Optical Resolution always corresponds to a better Detection Capability. But, the latter always gives a better number than the former because of its lower requirement. For instance, a microscope with limited resolution, say 2μm, may still show object points down to 0.5μm size. This fact can be seen by looking at the dashed lines/dots in *Figure 2b*. The 0.5μm dashed lines/dots are still visible despite the blurring.

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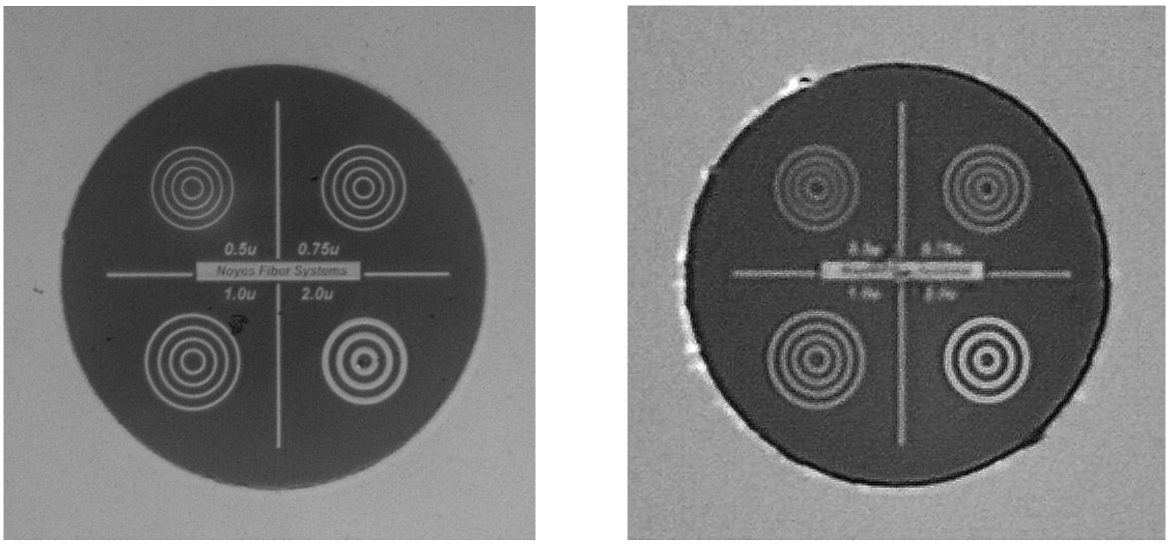
[3] The object is a Resolution Target etched on the AFL Noyes artifact ferrule. In this artifact, there are four groups of lines with different line widths/spacing, corresponding to four different grades of resolutions, 2μm, 1μm, 0.75μm and 0.5μm.

Another AFL Noyes artifact ferrule with *ring-type* pattern is also often used for determining the Detection Capability of a microscope. As can be seen from *Figure 3*, the bright lines (rings) in this artifact are quite far apart from each other in *Fig. 3a*. Each ring is clear, and width differences are readily apparent. *Fig. 3b* shows that the probe microscope with 2μm resolution can still identify each of the 1μm/0.75μm/0.5μm rings although they are all blurred to a greater width (close to, but still slightly narrower than, the width of 2μm rings).[4]



(a) Bench-Top Microscope *(b) Probe Microscope*

Figure 3

Video Imaging Systems

For systems such as video microscopes, in addition to the lens limitations, the camera sensor and display need to be considered. For instance, if the field of view (FOV) of a video microscope is 800μmx600μm while its display has pixels only 640x480 (VGA), there is no chance for such a system to reach a 1μm resolution under its full FOV.

Display size, contrast, and illumination can also be factors in evaluating real-world Detection Capability. No matter what the Optical Resolution, if the human eye cannot see the information, it has little value.

[4] It should be noted that human eyes are more sensitive to thin lines in comparison to tiny dots of similar size; so strictly speaking the *ring-type* artifact is more informative in identifying a detection capability for lines (scratches).

Conclusion

Optical Resolution is a theoretical parameter in optics. It defines the system's ability to resolve adjacent objects. But for fiber connector inspection, the most important thing is "not missing imperfections" rather than "resolving imperfection details". Therefore, Detectable Resolution is, in fact, a more informative parameter when specifying a connector microscope.

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