Elongated Focus elements application notes

Introduction

An elongated focus element creates a Bessel Beam, which can then be focused using an external lens. When focused, Bessel beams have a far longer depth of focus compared to a Gaussian beam, with a corresponding decrease of energy density at focus. This application note is meant to aid the user's understanding of the functionality and considerations when using a diffractive elongated focus element.

Operation Principle

One can explain the performance of an elongated focus DOE by using a model of a multifocal lens. A diffractive multifocal lens is a commonly used optical element in laser applications and eye surgery (where the intraocular lens is normally a multifocal lens). Basically, a multifocal element splits an incident beam into a few portions and adds to each portion a different optical focusing power, so that each portion is focused a different position along the optical axis. The Elongated focus element works similarly, but instead of discrete splitting to a specific number of foci, it generates a continuous function. Thus, the incident beam focuses continuously along the optical axis. Conceptually one could describe this as if a very large amount (infinite) of portions of the input energy are focused on different position very close (infinitesimal distance) to each other along the optical axis, creating the elongated focus effect.

Note: it’s important to understand that each discrete portion has a small depth of focus. So for each plane along the optical axis a small amount of energy will be in focus and the rest of the energy will be out of focus. The energy that is not in focus appears as low energy rings or lobs around a high central spot.

Theory

For a normal Gaussian laser beam, the depth of focus is defined as
the depth of focus can be defined by the following formula:

$$\boldsymbol{DOF_{\Delta} = 2Z_{R_x}\sqrt{\frac{1}{(1-\Delta)^2} - 1}} \qquad \qquad \boldsymbol{Z_{R_x} = \frac{\pi d^2}{4M_x^2\lambda}}$$

- $\boldsymbol{Z_{R_x}}$ is Raleigh length
- $\boldsymbol{M_x^2}$ is Beam quality factor for axis x
- $\boldsymbol{d}$ is the beam diameter at e^{-2}
- Δ **-** is the energy density drop

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Using a diffractive Elongated Focus (EF) element, this limit can be bypassed. When using EF, the length of the focal region is determined by the element angle, the external lens focal length and the beam diameter.

In theory it is possible to make a design to generate a very long depth of focus, but at the cost of reduced energy density in the central spot. This reduction is what will limit the usefulness of such design. Typically, a small focus elongation is sufficient to improve the process, without making significant changes in the optical setup. This can be achieved without the need of replacing the laser to or changing the focal distance.

Changing the depth of focus

The depth of focus is scalable for different focusing lenses per the following relation:

$$\frac{1}{\Delta} = \left[\frac{(\Delta_0 + f_{r0}) \cdot f_{r0}}{f_r^{\,2} \cdot \Delta_0} - \frac{1}{f_r}\right] \cdot \frac{\lambda_0}{\lambda}$$

Where

- Δ: is the depth of focus
- Δ_0: is the initial depth of focus
- λ: is the operating wavelength
- λ_0:is the initial wavelength
- f_r: is the EFL of the system
- f_{r0} is the initial EFL of the system

Another option to change the DOF is by varying incident beam size.

$$\Delta = \frac{w}{w_0}\Delta_0$$

Where ***w_0* – is the initial beam size**

For small changes in the depth of focus we suggest using the binary type elements. The depth of focus of these element increases by a factor ~1.5x compared to the system depth of focus without them.

Basic rules:

1. Increasing EFL = DOF increases
2. Increasing beam size = DOF decreases

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Examples:

Example 1: Elongated focus VS Gaussian beam

- Gaussian beam 5 mm
- EFL 50 mm
- Wavelength 532 nm

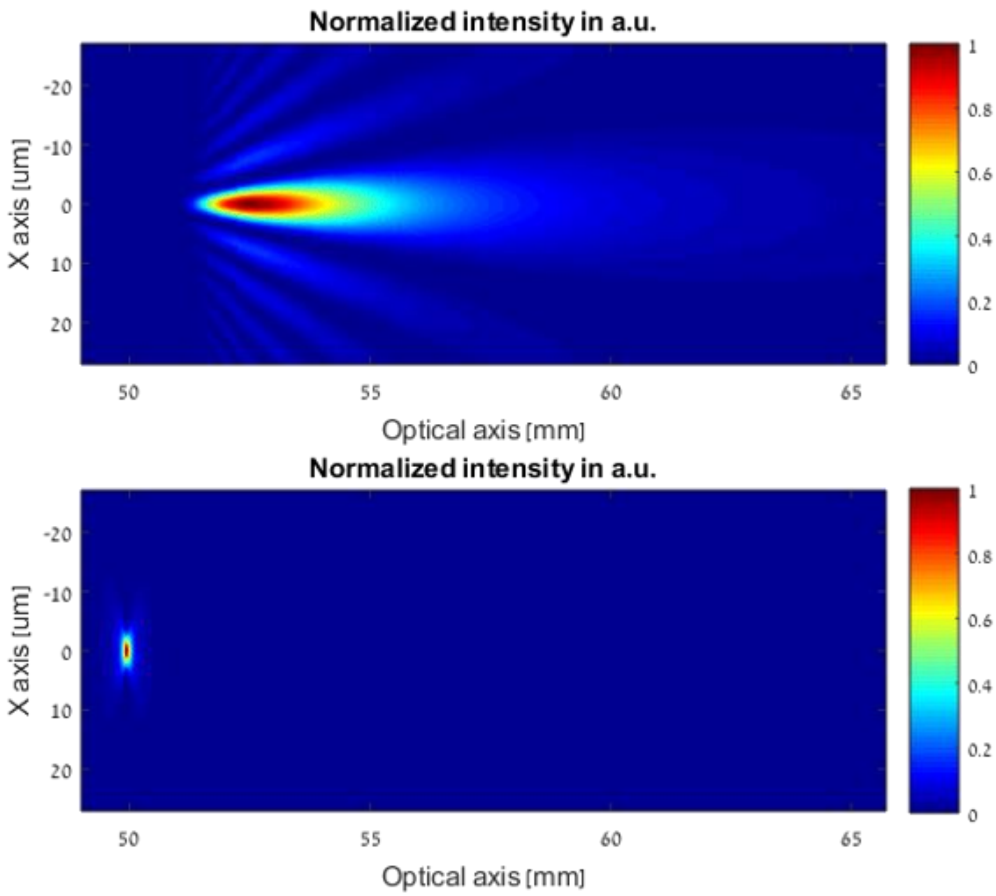

Figure 1: Upper image using Elongated focus element, lower image Gaussian only

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Example 2: Comparison of DOF for different incident beam sizes

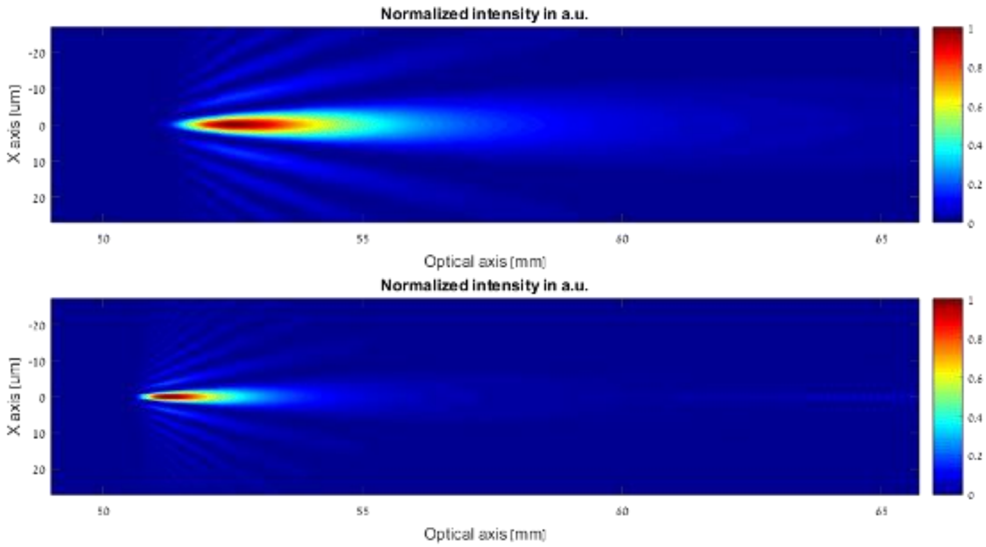

Figure 2: Upper image beam size 5 mm, lower image beam size 10 mm

Example 3: Using different EFL

EFL 100 mm

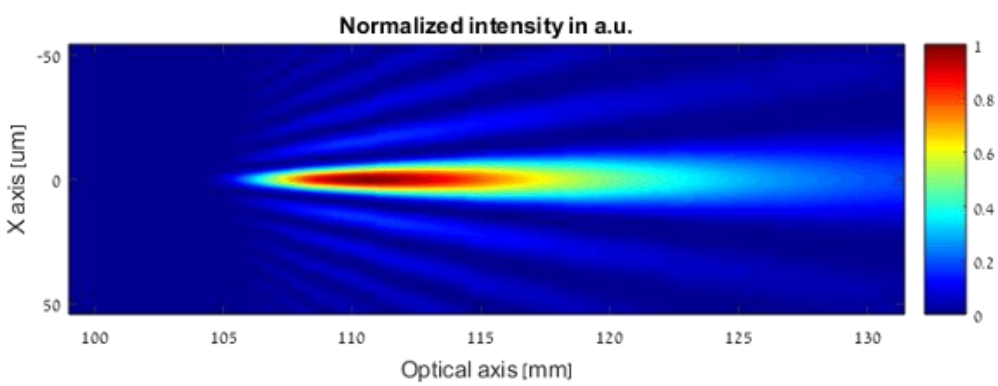

Figure 3: Intensity distribution generated with elongated focus element on the X-Z plane

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