

# Scanning Lens Theory

## Overview

Off axis deflection through a focusing lens system will, in general form aberrated images in a curved plane as opposed to a more desirable flat surface. A flat field scanning lens is a specialized lens system in which the focal plane of a deflected laser beam is a flat surface. The most common uses of flat field scanning lenses are: Laser Machining, Pattern Generation, Laser Writing, Engraving and Marking. Additional subclasses of scanning lenses are F-theta lenses and Telecentric lenses.

## F-theta Lenses

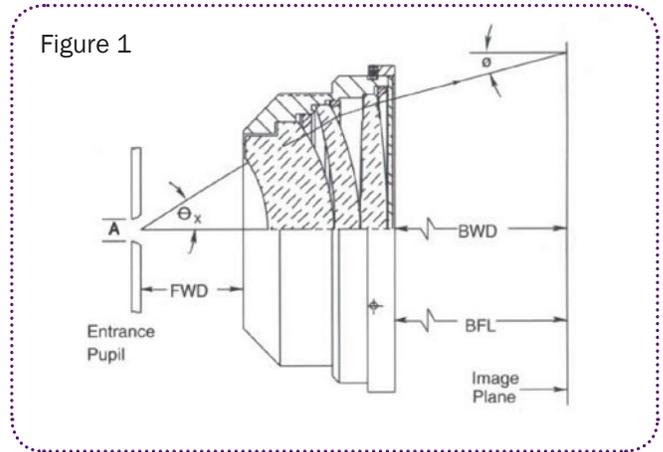
In the absence of distortion, the position of the focused spot is dependent on the product of the Focal Length (F) and the tangent of the deflection angle ( $\theta$ ). When the lens is designed with built-in barrel distortion, the position of the focused spot can then be made dependent on the product of F and  $\theta$ , thereby simplifying positioning algorithms. Lenses designed in this way are called F-theta lenses.

## Telecentric Lenses

A significant feature of scanning lenses is the angle ( $\phi$ ) at which the focused beam strikes the work surface. In a typical lens, the beam will be normal to the surface only when the input beam is propagating along the lens axis. As the laser beam is deflecting off the axis, the angle moves off normal. This affects both the spot size, which becomes elongated, and the wall angle for cutting and drilling applications. At the cost of complexity and expense, the design of the lens can be such that the beam will strike normal to the work surface over the entire scanning field. This type of lens is defined as Telecentric. Telecentric lenses are almost always larger and more expensive than standard scanning lenses.

## Deflection Angle

Figure 1 is a diagram of the standard parameters used for describing and specifying scanning lenses. The angle between the input laser beam and the lens system axis is called the deflection angle. Theta ( $\theta$ ) is the maximum deflection angle allowed before the laser beam experiences vignetting through the lens system or before the diffraction limited point is exceeded.



## Entrance Pupil

The entrance pupil defines the origin of the laser deflection as well as the acceptable beam diameter and mirror size combination. If a single mirror system is used, the mirror is placed at the entrance pupil position and the maximum usable beam diameter is equal to the entrance pupil diameter (A). If a two mirror system is used for deflection in both the x and y directions, then the mirrors are placed on either side of the entrance pupil position and as close to each other as possible. Moving the origin of the beam deflection off of the pupil position and away from the lens system effectively reduces the allowable beam diameter and deflection angle. The maximum laser beam diameter for a two axis deflection system which has been displaced a distance L from the entrance pupil is given by:

$$A' = A [1 - (2L/A) \tan \theta]$$

where  $\theta$  is half the maximum deflection, and L is the offset distance of the mirror. If the mirror is placed closer to the lens system L is a negative number and the effective aperture increases.

## Front Working Distance

The Front Working Distance (FWD) is the distance from the entrance pupil to the lens housing. In a two axis system the physical working distance is less than the actual working distance since the entrance pupil position is between the two positioning mirrors.



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## Scan Field Diameter

The scan field diameter determines many of the overall lens specifications. Once a scan field diameter is determined, it is along with the focal length defines the deflection angle required, since the focus position is portional to the product of  $F \times \theta$ .

elongated proportionally to the output scan angle ( $\phi$ ) and is given by:

$$S_e = S / \cos \phi$$

For lens systems where  $\phi$  is less than 10 degrees, the elongation is generally less than 2%.

## Back Working Distance

The distance from the work surface to the output side of the lens housing is the Back Working Distance (BWD). Depending on lens complexity and the degree of telecentricity, the back working distance can usually be specified and controlled during lens design.

## Output Scan Angle

The angle between the normal to the image plane, or work surface, and the paraxial ray of the output beam is the output scan angle ( $\phi$ ). This angle is always zero for telecentric lenses. In general  $\phi$  varies with the position of the focused spot across the work surface.

## Spot Size

The spot size will be most affected by the input laser beam diameter, divergence of the laser source, and the effective focal length of the lens system. For a diffraction limited lens coupled with a Gaussian source, the  $1/e^2$  spot size can be expresses as:

$$S = 1.27\lambda \times EFL/A$$

This equation is true for lens apertures which are 1.8 times larger than the  $1/e^2$  beam diameter. In such instances less than 0.1% of the beam intensity is truncated by the lens aperture. For a "tophat" intensity beam incident over the entire lens aperture the spot size will be approximated by the following:

$$S = 2.44 \lambda \times EFL/A$$

The previous equations predict the spot size on the axis of the scanning lens system. For non-telecentric designs, the spot size off axis will be

