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Ruggedized Lens Metrology

The Ruggedized Lens Metrology Whitepaper discusses what the term Stability Ruggedized means and to what extent lenses that have been ruggedized can eliminate detrimental effects such as pixel shift that results from external shock and vibration placed on the imaging system. This whitepaper explains pixel shift and how it affects an imaging system, how Edmund Optics Stability Ruggedized lenses are designed to minimize the effect of pixel shift, and the metrology methods used to ensure that these Stability Ruggedized lenses meet their specified performance.

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RUGGEDIZED LENS METROLOGY Edmund Optics® WhitePaper

TESTING STABILITY RUGGEDIZED IMAGING LENSES

Stability ruggedized lenses can maintain their optical pointing of an exposure in environmental shock and vibration. This pointing advantage can increase the accuracy in collected imaging applications such as measurement and gauging, 3D stereo vision, robotics and sensing, autonomous vehicles, and object tracking. For example, many 3D imaging systems rely on calculating the centroids or geometric centers of the objects in the device's field of view. Centering algorithms are sensitive enough to determine positions smaller than one-tenth of the sensor pixel size [1]. This means that very small motions of lens elements due to vibration and shock can cause an imaging algorithm to lose accuracy or go out of calibration.

A shock is any kind of short duration, high-acceleration loading on a system. Shock loading is usually specified in Gs, or multiples of acceleration due to gravity (9.81 m/s²). Typical shock levels are range from 10 Gs to well in excess of 50 Gs. In most applications, the duration of the shock is just as important as the magnitude for developing specifications. For example, aerospace typically experience a standard 3 Gs of acceleration during a launch, however the shock experienced by a lens when it is dropped a few inches onto a table can easily exceed 35 Gs.

Edmund Optics offers three types of ruggedization in our fixed focal length imaging lenses: Inherent Ruggedization, Ingress Ruggedization, and Stability Ruggedization. Here we explore the advantages of Stability Ruggedized lenses in preventing image shift due to shock environments, such as those found in high volume manufacturing or in the body of an aircraft (Figure 1). This includes a look at the root cause of pixel shift, and outlines the challenges of inherently measuring very small lens motions.

What is Pixel Shift?
Pixel shift occurs when individual lens elements in a system move with respect to the assembly. The lateral motion of these elements will cause the outgoing image to shift both in position and angle. The amount of shift scales with the magnification of the lens:

$$\Delta x_p = \Delta x_e \times (1 + m) [2]$$

where Δx_e is the magnitude of image shift on the sensor, Δx_p is the magnitude of the lens element shift in the lens barrel, and m is the magnification of the lens element as it relays the image through the system. Inside a lens assembly with multiple elements, these effects can accumulate as they propagate through the system. Figure 2 shows how this effect can stack up. It is important to note that both the top and bottom systems can still meet other system level specifications such as MTF. This is because all optical systems are designed to perform "on axis"; that is, when considering the relationship between the lenses and barrel.

Figure 2: Degree of image shift for a lens system. Top: A standard lens system. Bottom: A stability ruggedized lens system [2].

In a typical optical assembly, resistance to shock forces is generated by Newton's second law of motion, which states that acceleration is proportional to mass. In a standard lens barrel, a retaining ring provides a restraining force to a lens, and the force of friction keeps the lens in place. This is stated mathematically as:

$$F = \mu N M a_{max}$$

where F is the preload, μ is the coefficient of friction between the lens and the retaining ring, N is the mass of the element, and a_{max} is the maximum acceleration that the lens element can experience before it moves. This equation has some predictive drawbacks to that it can be difficult to correctly measure the preload and friction coefficient.

Figure 1: In lengths of aerospace where applications are vital to mission performance, shock and vibration are dealt by ensuring performance through design activities.

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