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Disruptive advancement in precision lens mounting

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ABSTRACT

Threaded rings are used to fix lenses in a large portion of opto-mechanical assemblies. This is the case for the low cost drop-in approach in which the lenses are dropped into cavities cut into a barrel and clamped with threaded rings. The walls of a cavity are generally used to constrain the lateral and axial position of the lens within the cavity. In general, the drop-in approach is low cost but imposes fundamental limitations especially on the optical performances. On the other hand, active alignment methods provide a high level of centering accuracy but increase the cost of the optical assembly.

This paper first presents a review of the most common lens mounting techniques used to secure and center lenses in optical systems. Advantages and disadvantages of each mounting technique are discussed in terms of precision and cost. Then, the different contributors which affect the centering of a lens when using the drop-in approach, such as the threaded ring, friction, and manufacturing errors, are detailed. Finally, a patent pending lens mounting technique developed at INO that alleviates the drawbacks of the drop-in and the active alignment approaches is introduced. This innovative auto-centering method requires a very low assembly time, does not need tight manufacturing tolerances and offers a very high level of centering accuracy, usually less than 5 µm. Centering test results performed on real optical assemblies are also presented.

Keywords: centering, lens mounting, alignment, self-centering, auto-centering, lens barrel, optomechanics, drop-in, active alignment, lens, centering machine, threaded ring

1. INTRODUCTION

Optical designers and opto-mechanical engineers work together to develop optical systems. Performance, manufacturability, and cost are most often the key requirements to be competitive in the market. The perfect optical system can unfortunately not be built. Even with the actual level of manufacturing sophistication, lenses and mechanical parts used to hold the optical components always present dimensional and geometric errors. This tends to degrade the performance of the theoretically perfect optical system. Considering this, an important task for the optical designers is to perform tolerance analysis in order to know the level of precision required for the manufacturing of the optical elements and for their relative positioning in the layout. Interaction with the opto-mechanical engineer is required at this stage since a complete tolerance analysis involves both optical and opto-mechanical tolerances analysis. The process requires iterations between the optical and the opto-mechanical departments. The goal of the process is the creation of the tolerance budget i.e. the allocation of the manufacturing uncertainties on the optical components and mechanical parts. It also includes the choice of the lens mounting techniques, which is of critical importance. It is not only associated with the positioning accuracy to be met, but also with manufacturing, alignment and assembly cost as well as to thermal, vibration and shock robustness.

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Common lens mounting methods can be divided into two categories. The first category uses active alignment. Most optical centering methods are based on the displacement of an image produced by the optical surface being aligned. Other optical methods rely on the deviation of a laser beam refracted or reflected by the optical surface. The methods generally involve placing the optics on a precise rotating stage presenting negligible displacements of its rotation axis. When the center of curvature of a spherical surface is placed exactly on the rotation axis of the stage, the manner that this surface refracts or reflects the rays is not affected by the stage's rotation. The distance between the rotation axis and the center of curvature is estimated with the trajectory of the image displacement or laser beam deviation. The center of curvature of the spherical surface is progressively centered on the rotation axis through an iterative process. Once centered, the lens is fixed in place with adhesive or other means. This method provides a very high level of centering accuracy, but requires expensive equipment and is typically time-consuming.

The second category can be defined as a passive centering which uses the manufacturing tolerances of the lens and the barrel to constrain the position of the lens. A common example of this mounting method is the "drop-in" technique, consisting of inserting a lens in a barrel and securing it with a retaining ring. The centering precision obtained with this technique depends mainly on the control of the gap between the lens and the barrel. To maximize the centering accuracy, this method requires good control of the lens diameter, barrel bore diameter, as well as the lens wedge.

2. LENS MOUNTING TECHNIQUES AND PERFORMANCE

Barrels are well known types of mechanical holders for lenses. The barrel axis is generally used as the reference for lens centering. The lens's optical axis is defined by the line containing the center of curvature of the two optical surfaces. An optical system consisting of a plurality of lenses is said to be centered if the centers of curvature of its optical surfaces are all located on a same axis, namely the optical axis of the system. There are different lens mounting methods used to get closer to this goal having all different advantages and disadvantages.

2.1 Drop-in

For low precision lens mount, the lens and the barrel are machined to their specified dimension with a tolerance level depending on the optical requirement. The lens is simply inserted into the barrel without alignment and the centering is controlled by the radial clearance between the lens and the barrel inside diameter (ID). In this mounting method called drop-in, the minimum radial gap must consider assembly and thermal clearances. Manufacturing tolerances on lenses and barrel bore diameters increases the worst case clearance. Typical radial clearances for the drop-in method is between 25 μm and 50 μm [1], [2]. The lens wedge manufacturing error will also affect the centering error. When centering requirements are more severe, the manufacturing tolerance of the barrel diameter, lens diameter and lens wedge need be tightened to the manufacturing limit, affecting the cost of the assembly. Also, special attention must be given to the hoop stress on lens caused by thermal contraction and CTE mismatch between lens and barrel material. Once dropped in the barrel, different types of retainers such as burnished edge, screwed flexure ring, snap ring or threaded ring could be used to secure the lens axially. This method is very convenient because it doesn't need alignment and requires a very low assembly time. The lens can also be unmounted easily for rework or maintenance.

2.2 Lathe assembly

The "lathe" assembly, described by Yoder [1], consists in machining the barrel to fit closely with the measured outside diameter of a lens or a set of lenses that have already been manufactured. This allows relaxing the lens diameter tolerance, but the manufacturing error of the lens wedge will still affect the centering error of the lens once mounted in the barrel. This technique, suitable for high performance optical assemblies, is very expensive and requires extreme care. Centering precision between 25 μm and 5 μm can be expected.

2.3 Active alignment

For more precision, lenses can be aligned on the barrel axis using a centering machine. The lens centering error is first measured. Then, the lens is moved to reduce de centering error. Once aligned, the lenses are generally bonded in place [3]. RTV, epoxy, and UV adhesives are commonly used for this application. This method provides high centering accuracy from 10 μm to 1 μm, but requires sophisticated equipment and intensive labor for alignment.

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2.4 Subcell lens assembly

The subcell lens assembly, also known as the poker-chip assembly, consist in bonding the lens in a cell, aligning the lens optical axis on the lathe rotation axis, and then machine the cell outside diameter (OD). The mechanical axis of the cell OD is well aligned with the lens optical axis and the subcells are dropped into the main barrel. The method is shown on Figure 1 from Fraunhofer Institute [4]. The final centering will depend on the quality of the alignment on the centering machine, on the subcell OD and on the barrel ID. Centering from 10 μm to less than 1 μm are reported for this mounting techniques [5]. Subcell lens assembly provide a very high level of accuracy but require sophisticated alignment system and a high level of tolerance control on cells and barrel diameters, resulting in expensive manufacturing cost.

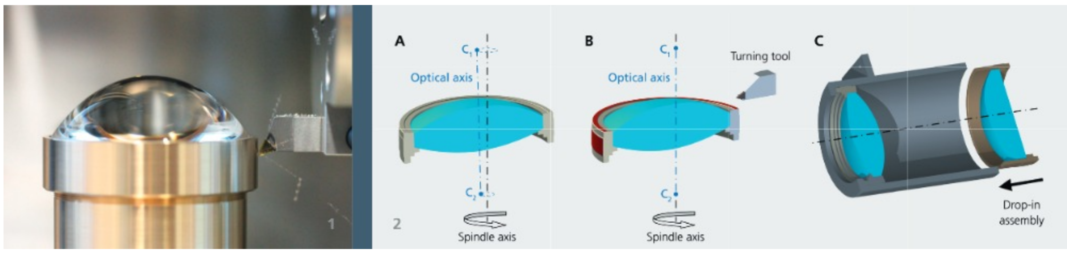

Figure 1. Subcell lens assembly process [4].

Other types of specialized lens mount, for example using flexures, are also used especially for severe environmental application such as optical systems operating at cryogenic temperatures.

This review of the different lens mounting techniques shows that an increase of centering precision results in an increase in cost and complexity.

3. DROP-IN LENS MOUNTING DETAILED ANALYSIS

Since the drop-in lens mounting method is widely used for is simplicity, a detailed performance analysis is done for this approach. As mentioned, the method relies on the control of the radial clearance between the lens OD and the barrel ID to control the lens centering. This concept can be illustrated with a plano-convex lens as show on Figure 2.

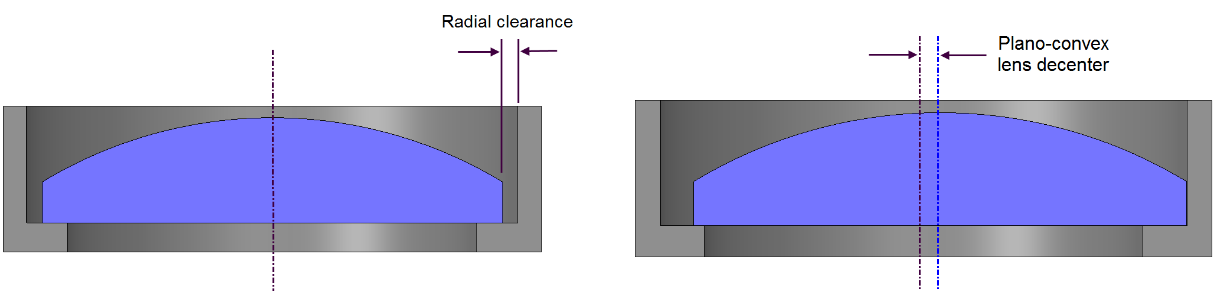

Figure 2. Plano-convex lens drop-in. (a) Centered lens, (b) Decentered lens.

This case illustrates the simplest scenario since the lens can translate on its planar surface until its edge is in contact with the barrel inner wall. Although, the radial clearance is generally one of the biggest decentering contributors with the drop-in technique, other parameters must be considered. First, since the method is based on radial positioning, the lens wedge error will also affect the lens centering relative to the barrel axis. Also, if the lens is mounted on a non-optical surface, as is the often used in the case where the lens consists of one or two concave surfaces, the perpendicularity error between the mounting surface on the lens and the optical axis will also affect the lens centering. Another contributor to

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the lens centering is the manufacturing errors of the barrel. Perpendicularity of the lens seat as well as the concentricity of the barrel inner diameter relative to the barrel references are the main mechanical contributors. Finally, when the lens is mounted on the barrel seat on a spherical surface instead of a planar surface, the lens will not translate but will roll, decentering the lens but also a tilting it. This means that the centering error of a lens dropped in a barrel is generally not as simple as calculating the radial clearance between them. Also, we need to be careful about the lens centering definition. We often think about the lens positioning error as a combination of an axial error (air gap between optical surfaces), decenter, and tilt error. This representation of the lens positioning error makes sense for optical software that applies perturbations for tolerance analysis at the lens vertex, but is not convenient for metrology or optomechanical tolerance analysis [6]. Since the optical axis of a lens is defined by the line connecting the centers of curvature of its two surfaces, it is more appropriate to define the lens positioning error as the decenter of each center of curvatures instead of the decentering of the lens element itself.

3.1 Lens wedge

The lens wedge manufacturing error affects the lens centering for the drop-in method. Figure 3 shows an example of the effect of a wedge error on a bi-convex lens where the lens mechanical axis, defined by the center axis of the edged cylindrical surface, is coincident with the barrel reference axis.

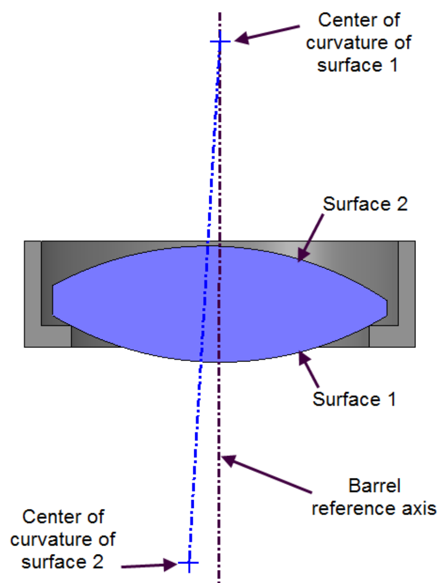

Figure 3. Lens wedge error of a bi-convex lens.

Since surface 1 is constrained by the barrel lens seat, the lens wedge will not affect the centering of this surface. The lens wedge will rather affect the centering of the center of curvature of surface 2. Equation (1) gives the relationship between the lens edge thickness difference (ETD) and the lens wedge angle:

$$\theta_{ETD} = \tan^{-1}\left(\frac{ETD}{\phi lens}\right) \tag{1}$$

Where:

- θ_{ETD} (degrees) is the lens wedge angle
- ETD (mm) is the lens edge thickness difference
- $\phi lens$ (mm) is the lens diameter

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The decenter of the lens surface 2 can be approximated by:

$$Decenter_{ETD} \approx R2 * \sin(\theta_{ETD}) \quad (2)$$

Where:

- $Decenter_{ETD}$ (mm) is the lens surface 2 decenter caused by the lens ETD
- R2 (mm) is the lens radius of curvature of the lens surface 2 (surface opposite the barrel lens seat)
- θ_{ETD} (degrees) is the lens wedge angle

3.2 Lens flat

When a lens is mounted on a non-optical surface, the centering will be affected by the manufacturing error of that surface according to the lens optical axis. For a meniscus lens mounted on a flat surface as shown on Figure 4, the lens's optical axis will be tilted as per the perpendicularity error between the flat surface and the optical axis, affecting the centering of the lens surfaces once mounted into the barrel as express by equation (3) and (4).

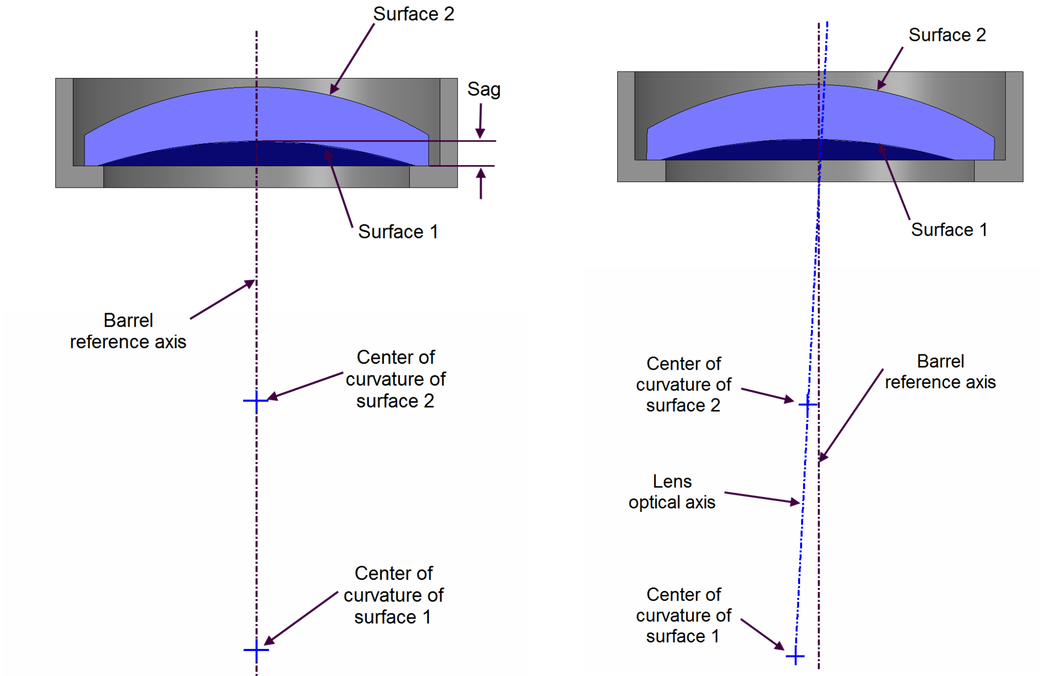

Figure 4. Effect of the manufacturing error of a non-optical lens interface. (a) Flat without manufacturing error, (b) Effect of a tilted flat on the lens centering.

$$Decenter_{LensSurface1} = (R1 - Sag) * \sin(\theta_{flat}) \quad (3)$$

$$Decenter_{LensSurface2} = (R2 - Sag - CT) * \sin(\theta_{flat}) \quad (4)$$

Where:

- $Decenter_{LensSurface1}$ (mm) is the lens surface 1 decenter caused by a tilt on the lens mounting flat
- $Decenter_{LensSurface2}$ (mm) is the lens surface 2 decenter caused by a tilt on the lens mounting flat
- R1 (mm) is the lens radius of curvature of the lens surface 1
- R2 (mm) is the lens radius of curvature of the lens surface 2 (surface opposite the barrel lens seat)
- Sag (mm) is the distance from the surface 1 vertex to the flat plane
- CT (mm) is the lens center thickness
- θ_{flat} (degrees) is the angle between the lens optical axis and the barrel reference axis (caused by the flat tilt)

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3.3 Lens roll

When a lens is dropped into a barrel on a spherical surface instead of on a flat surface, the lens will not simply translate within the radial clearance range as shown on Figure 2, but will roll on the barrel lens seat around the center of curvature of surface 1 (surface in contact with the barrel seat) as illustrated on Figure 5.

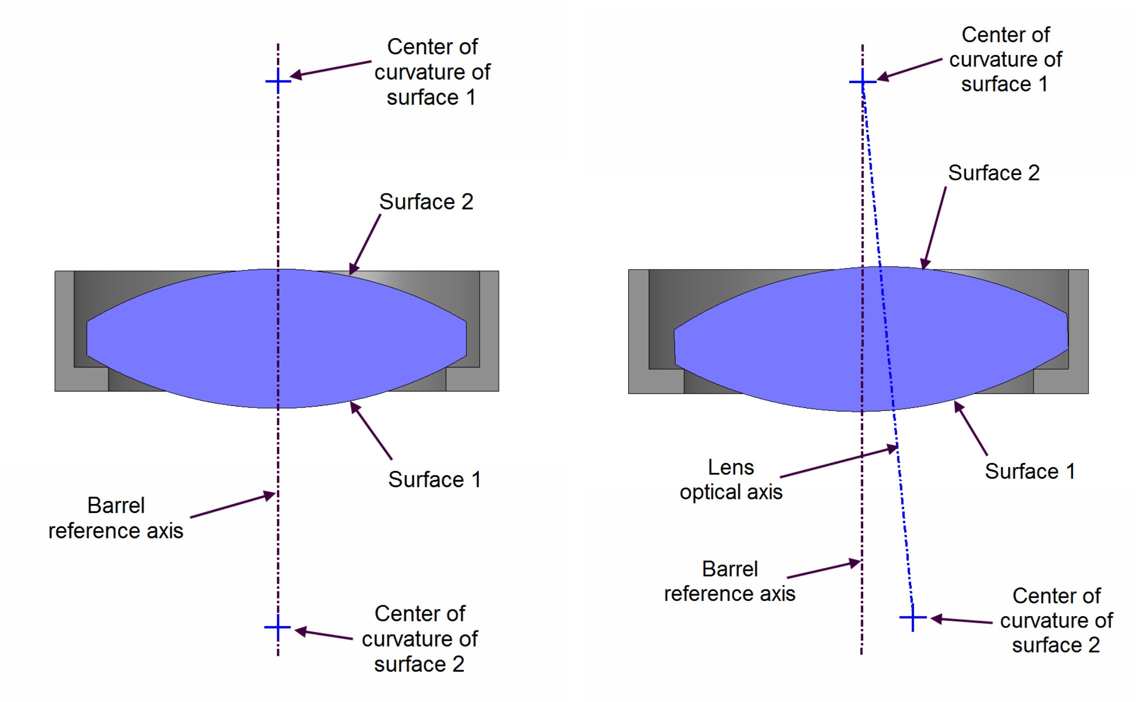

Figure 5. Lens roll. (a) Centered lens, (b) Effect of the lens roll on the centering.

The optical axis tilt angle can be calculated using equation (5):

$$\theta_{roll} \approx \tan^{-1}\left(\frac{\Delta r}{R1}\right) \tag{5}$$

Where:

- θ_{roll} (degrees) is the angle between the optical axis and the barrel reference axis (caused by the lens roll)
- Δr (mm) is the radial clearance between the lens and the barrel
- R1 (mm) is the lens radius of curvature of the lens surface 1 (surface in contact with the barrel lens seat)

If lens seat interface is perfect, the centering of the lens surface 1 will be perfectly centered on the barrel reference axis. The decentering of the lens surface 2 for a bi-convex lens rolling on the barrel seat is given by the equation (6):

$$Decenter_{LensSurface2} = (R1 + R2 - CT) * \sin(\theta_{roll}) \tag{6}$$

Where:

- $Decenter_{LensSurface2}$ (mm) is the lens surface 2 decenter caused by the lens roll
- R1 (mm) is the lens radius of curvature of the lens surface 1 (surface in contact with the barrel lens seat)
- R2 (mm) is the lens radius of curvature of the lens surface 2 (surface opposite the barrel lens seat)
- CT (mm) is the lens center thickness
- θ_{roll} (degrees) is the angle between the optical axis and the barrel reference axis (caused by the lens roll)

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3.4 Barrel error

The lens centering quality will also be driven by the manufacturing errors of its barrel. A concentricity error of the barrel lens seat with respect to the barrel reference axis will affect the centering of the lens surface 1 as shown on Figure 6 (a). The tilt error of the barrel lens seat with respect to the barrel reference axis will affect the centering of the lens surface 1 as show on Figure 6 (b).

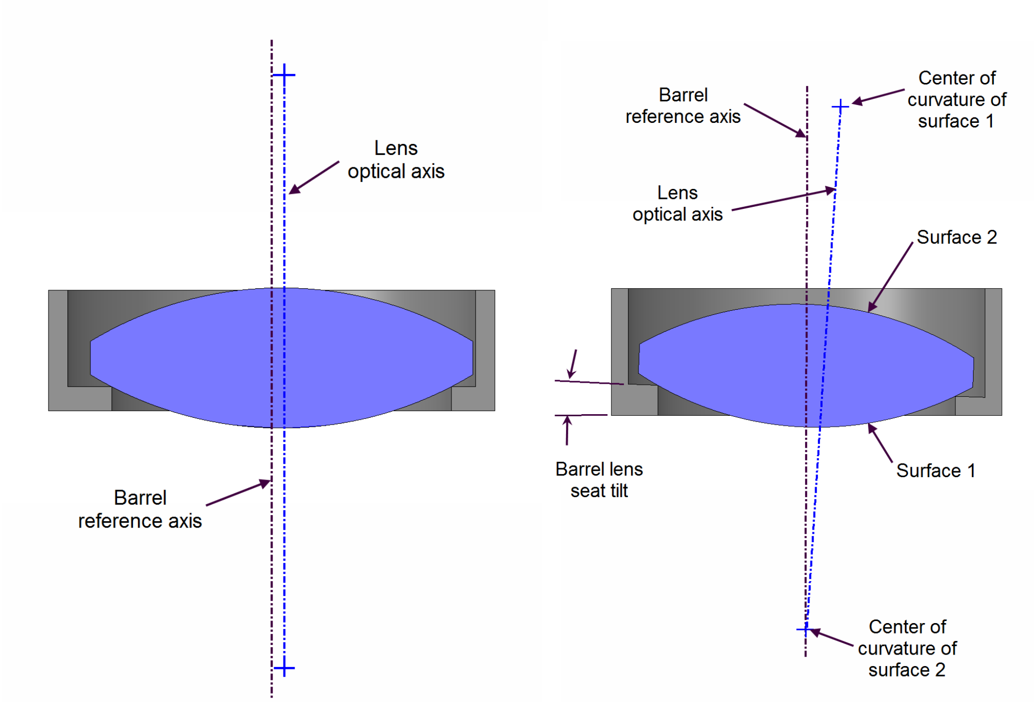

Figure 6. Barrel lens seat manufacturing error. (a) Decentred barrel lens seat, (b) Tilted barrel lens seat.

A spherical lens surface mounted on a decentered barrel lens seat will have the same centering error as the barrel lens seat:

$$Decenter_{LensSurface1} = Decenter_{BarrelSeat} \tag{7}$$

Where:

- $Decenter_{LensSurface1}$ (mm) is the lens surface 1 decenter caused by the decenter of the barrel lens seat
- $Decenter_{BarrelSeat}$ (mm) is the decenter of the barrel lens seat

The decenter of a spherical lens surface mounted on a tilted lens barrel seat can be expressed by equation (8) from DeWitt [8]:

$$Decenter_{LensSurface1} = \sqrt{R1^2 - Y^2} * |\sin(Tilt)| \tag{8}$$

Where:

- $Decenter_{LensSurface1}$ (mm) is the lens surface 1 decenter caused by the tilt of the barrel lens seat
- R1 (mm) is the lens radius of curvature of the lens surface 1 (surface in contact with the barrel lens seat)
- Tilt (degrees) is the tilt of the barrel lens seat
- Y (mm) is the half diameter of contact of the lens surface 1 (surface in contact with the barrel lens seat)

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3.5 Drop-in lens centering considering all contributors

All the errors discussed for the drop-in lens mounting method affect the final lens position as show on Figure 7. All the lens centering errors can be easily summed to get the worst case centering error. For more realistic error prediction, the centering error of each lens surface should be calculated statistically considering the manufacturing error distribution as well as the error's orientation [6], [7].

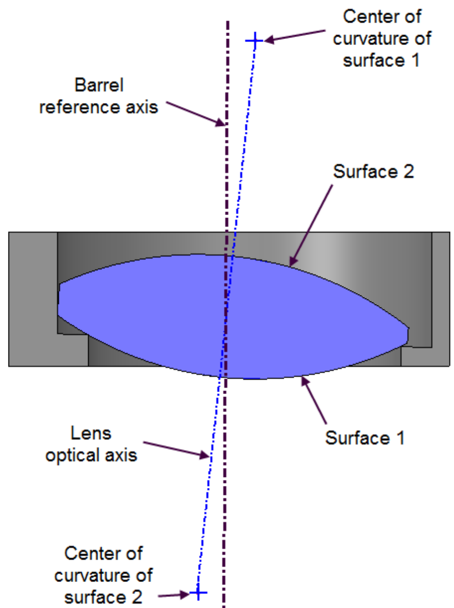

Figure 7. Drop-in lens centering with all main contributors.

3.6 Optical surface mounting

Mounting lenses directly onto optical surfaces has the advantage of not requiring accurate lens edging or tight diameter tolerances. This has been well explained by Yoder and is greatly shown in Figure 8 from reference [1].

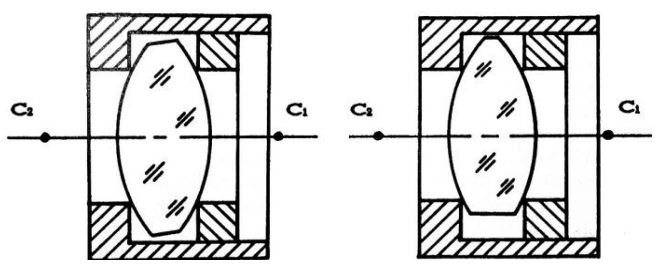

Figure 8. Optical surface mounted lens not influenced by edging error [1].

To provide a good centering accuracy, the mechanical seat of both lens surfaces needs to be perfectly concentric and perpendicular to the optical axis. This method is used for lens manufacturing at the edging process and often called the bell clamping method by lens manufacturers. Another consideration required for optical surface mounting is that the lens clamping angle need to be large enough to overcome the friction force, allowing the lens to roll or translate in order to be fully constrained by mechanical interfaces. This refers to the centrability criterion. The clamping angle can be expressed as:

$$\alpha = \sin^{-1}\left(\frac{Y_{c1}}{R_1}\right) + \sin^{-1}\left(\frac{Y_{c2}}{R_2}\right) \tag{9}$$

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where:

- α (degrees) is the lens clamping angle defined by the surface tangents at the Y_{c1} and Y_{c2} radius;
- Y_{c1} (mm) is the half-diameter of contact of the first surface S1 of the optical element with the seat;
- Y_{c2} (mm) is the half-diameter of contact of the second surface S2 of the optical element with the retaining ring;
- R_1 (mm) is the radius of curvature of the first surface of the optical element; and
- R_2 (mm) is the radius of curvature of the second surface of the optical element.

Figure 9 shows the parameters involved in the clamping angle calculation.

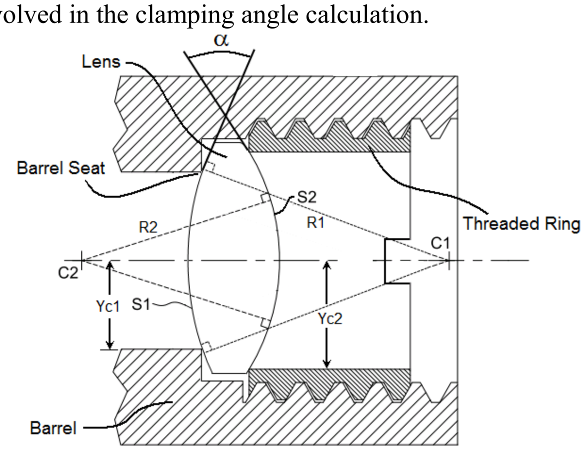

Figure 9. Criterion of centrability parameters

In the drop-in method, the first optical mounting interface is the barrel lens seat. The second is the retainer which axially constrains the lens on the barrel seat.

3.7 Centering of the lens surface in contact with the barrel lens seat

When good manufacturing practices are used, the concentricity and the perpendicularity errors involved in constraining the lens position are very low, typically on the order of a few microns (2-3 µm). These tight geometric tolerances are easy to achieve for a single setup machining process using a CNC lathe without taking any special care. When the part is unmounted from the CNC lathe, for example to flip the part, the repeatability of the chuck will induce concentricity and perpendicularity errors between the features machined in the different setups. In that case, concentricity error around 25 µm can be expected.

Table 1 presents centering measurements for the lens surface in contact with the barrel lens seat. Measurements have been done for 50 mm lenses having different radius of curvature and using the same barrel.

Table 1. Centering measurement of a lens surface mounted on the barrel seat

Lens diameter (mm)	Radius of curvature (mm)	Lens surface centering error (um)	Lens surface tilt (arcmin)
50	64.6	0.4	0.02
50	64.6	1.9	0.10
50	64.6	1.7	0.09
50	64.6	2.1	0.11
50	64.6	1.9	0.10
50	90.4	3.4	0.13
50	90.4	2.1	0.08
50	90.4	2.4	0.09
50	90.4	2.1	0.08
50	90.4	2.1	0.08

Lens diameter (mm)	Radius of curvature (mm)	Lens surface centering error (um)	Lens surface tilt (arcmin)
50	129.2	5.3	0.14
50	129.2	7.1	0.19
50	129.2	6.0	0.16
50	129.2	6.0	0.16
50	129.2	6.8	0.18
50	258.4	9.0	0.12
50	258.4	8.3	0.11
50	258.4	9.0	0.12
50	258.4	8.3	0.11
50	258.4	7.5	0.10

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These results show that we can expect very good centering for lens surfaces mounted on barrel seats that have been machined in a single setup with the barrel reference. We can notice that the decenter increases as the radius of curvature increases. This comes from the barrel seat tilt, and can be explained by equation (8). For the same tilt of the barrel seat, the decenter of the lens surface in contact with the barrel will increase as the radius of curvature increases. For that reason, it is more appropriate in some cases to speak in terms of optical surface tilt instead of surface decenter. We can notice in Table 1 that the surface decenter expressed in surface tilt is similar for each lens radius. The relationship between the surface tilt and the surface decenter is:

$$LensSurfaceTilt = \sin^{-1}\left(\frac{Decenter}{RadiusOfCurvature}\right) \tag{10}$$

It is to be noted that a centering error of 9 µm measured for the lens having a radius of curvature of 258.4 mm corresponds to a very large radius as shown on Figure 10. Generally, centering below 5 µm can be expected for the lens surfaces in contact with the barrel seat. According to equation (8), a small radius is less sensitive to barrel seat tilt errors, providing lower centering errors than a large radius. This is an interesting fact since the decenter of small radius lens is generally more sensitive than a large radius lens for optical performance.

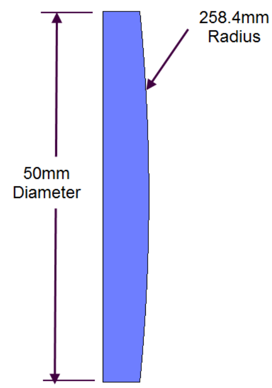

Figure 10. Large radius lens

3.8 Centering of the lens surface in contact with the retaining ring

In the case of the drop-in lens mounting technique, the second lens surface is constrained axially by a retainer. Threaded rings are the most common type of retainer used for lens mounting. Table 2 presents centering results for spherical convex lens surfaces in contact with the threaded ring. The measurement have been done for lens diameter of 25 mm and 50 mm having a radius of curvature ranging from 31.0 mm to 129.2 mm. Also, the lenses used for these tests meet the centrability criterion. This means that the lenses have clamping angles large enough to overcome the friction force and allow them to move under the axial force induced when the ring is threaded into the barrel. The radial clearance between lenses and barrel IDs was large enough to ensure that the lens was only constrained on the optical surfaces by the barrel lens seat and the threaded ring. The radial clearance in the thread between the ring and the barrel was around 60 µm.

Table 2. Centering measurement of a lens surface in contact with the threaded ring

# of measurment	Mean (µm)	Min (µm)	Max (µm)	Std deviation (µm)
36	48.9	8.2	144.2	36.1

Measurements results show that the use of the threaded ring to center the optical surface in contact with the threaded ring does not provides good centering accuracy. This explains why the radial clearance between the lens and the barrel needs to be control by tight manufacturing tolerances when the drop-in method is used. Moreover, since this mounting method relies on the lens rim for centering, the ETD needs also to be well toleranced since it will also affect the centering of the optical surfaces in contact with the ring. It is to be noted that the misalignment of the lens surfaces in contact with the ring do not affect the centering of the lens surface in contact with the barrel seat.

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4. AUTO-CENTERING

It has been shown that the centering of the lens surface in contact with the barrel seat can be expected to be very good, below 5 µm (except for very large lens radii), when good manufacturing practices are used. This high centering accuracy can be achieved by taking advantage of the high precision level of the geometrical tolerances that are provided without taking any special care when barrels are manufactured in a single setup on a CNC lathe machine. On the other hand, the surface of the lens on the opposite side of the barrel seat need to be controlled by dimensional tolerance such as lens and barrel bore diameter. These dimensional tolerance need special care to be well controlled and increase the manufacturing cost, in opposition to the geometrical tolerance.

The drop-in method is very simple to implement and requires a very short assembly time. Also, it does not require expensive alignment equipment. The drawback of this low cost mounting method is the poor centering accuracy. When more centering accuracy is needed, tight tolerances must be used and the method becomes expensive. Active alignment becomes a better alternative to increase the centering precision but requires alignment time, making that solution not effective for the manufacturing cost.

To overcome the disadvantage of the classical lens mounting method, INO has developed a patent pending lens mounting technique that provides the simplicity of the drop-in while offering the accuracy level of active alignment. The auto-centering method is based on the use of the geometrical relationship between lens diameter, lens radius of curvature and the thread angle of the retaining ring. The barrel thread angle and the spatial profile of the peripheral region of the lens surface are selected to create auto-centering conditions whereby any decentering of the retaining ring results in a corresponding tilt that has a counterbalancing effects on the centering of the optical element.

Table 3 presents centering measurements at the center of curvature of the optical surface in contact with ring using the auto-centering technology. The measurements have been performed with plano-convex, meniscus and bi-convex lenses having different diameters and radius of curvatures. These data provides information about the centering accuracy for different lens geometry, the centering repeatability of assemblies using the same parts as well as the manufacturing reliability for a production of a few units. A TRIOPTICS OptiCentric® MOT 100 (centration measurement instrument) having an estimated overall accuracy of ±1µm was used for the measurements.

Table 3. Centering measurements of lens surface in contact with the threaded ring using auto-centering

# of measurment	Mean (µm)	Min (µm)	Max (µm)	Std deviation (µm)
121	3.0	0.7	6.5	1.4

These 121 different measurements showed a centering accuracy of 5.8 µm at 2σ. This centering precision, which is comparable to the one achievable with active alignment methods, is performed in a few seconds. The lenses were simply dropped into the barrel and secured with a threaded retaining ring meeting the auto-centering condition.

The red dots in Figure 11 are the results in terms of centering precision obtained with the traditional drop-in technique, relying on the retaining ring for centering and using a standard thread. The blue dots show the results of INO's auto-centering technology. For the same amount of assembly time, INO's method gives results that are 10 to 20 times more precise, at a similar operating cost.

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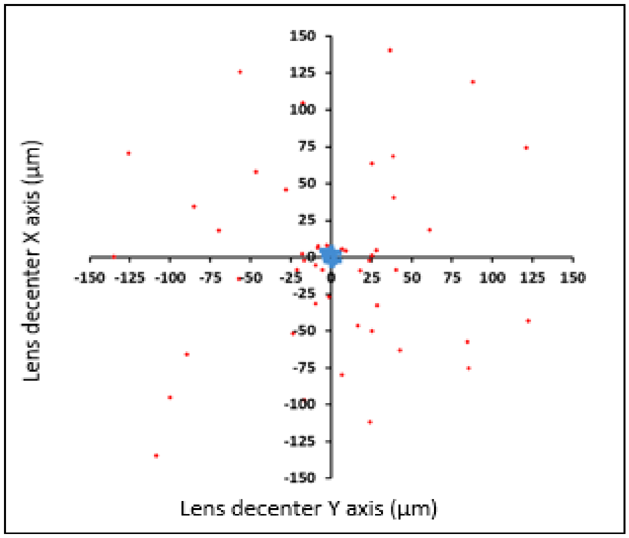

Figure 11. Centering comparisons between drop-in and auto-centering.

The red dots in Figure 12 represent the precision obtained with a manual lens alignment machine, and the blue dots show the results of INO's auto-centering technology. Both methods have comparable precision, however these results were obtained faster using INO's method, while the overall cost (operations and tooling assets) was considerably lower.

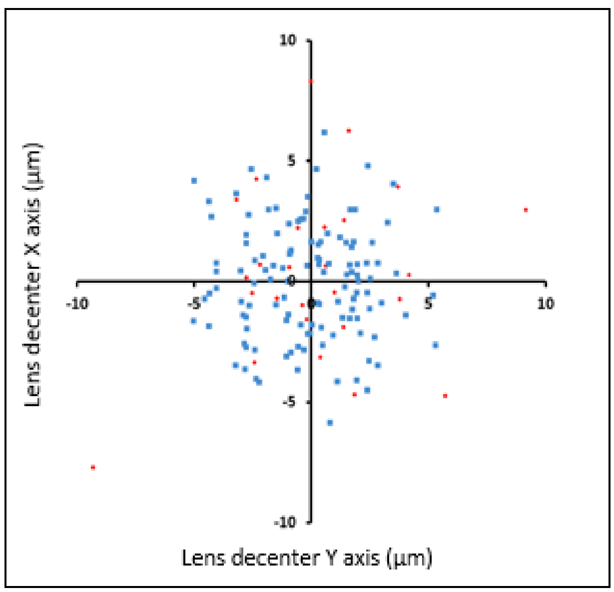

Figure 12. Centering comparisons between the active alignment and auto-centering

In addition to the high centering accuracy provided by the auto-centering lens mounting method, it takes a very short time to assemble, it relaxes lens diameter tolerances, lens wedge tolerances, and barrel bore diameter tolerances. The method can be used for spherical, aspherical, and cylindrical lenses as long as the centrability criterion is met. Different lens shapes such as plano-convex, bi-convex, plano-concave, bi-concave, positive meniscus, and negative meniscus can be mounted with the auto-centering method.

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5. CONCLUSION

A review of the most common lens mounting methods has been done and has shown that as the centering accuracy increases, the manufacturing and alignment costs also increase. The drop-in lens mounting method has been analyzed in detail. Mounting lenses on their optical surfaces presents significant advantages but, even if the barrel seat provides a very good centering reference for the first lens surface, the retainers that constrain the lens axially don't provide a good reference for centering the second lens surface. This requires the use of the lens rim to limit the lens decenter and tightens manufacturing tolerances on lens diameter, lens wedge, and barrel bore diameter.

An innovative lens mounting method that alleviate the drawbacks of common mounting method was presented. The method can be used for almost all geometries and provides lens centering typically less than 5 µm. The method does not require active alignment or tight manufacturing tolerances, and it is very quick to assemble. As this technique is easy to implement, it is perfectly suited for new product developments, for both small and large productions.

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