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Lens Centering Using Edge Contact Mounting

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ABSTRACT

This paper introduces a new type of drop-in technique used to center passively and accurately lenses in optical mounts. This novel lens mounting method is called edge contact mounting and uses the edge at the intersection of the cylindrical and optical surface of the lens as the mounting interface. By providing a spherical mounting seat for the lens on a simple standard threaded ring, it is possible to center accurately lenses of different geometries, diameters and radius of curvatures. The method allows to relax some manufacturing tolerances compared to rim contact drop-in and is not subject to a minimum clamping angle as for the surface contact mounting. This innovative lens mounting method allows to extend the centering accuracy offered by passive lens centering methods to a next level without compromise on cost and complexity.

Keywords: lens mounting, centering, alignment, edge mounting, lens barrel, ring, auto-centering, self-centering

1. INTRODUCTION

Mounting lenses accurately in an optical system is well known to be challenging. While active alignment offers high centering accuracy, it has the drawbacks of requiring sophisticated equipment and increased manufacturing time. For that reason, passive centering techniques such as the drop-in are attractive because of their cost efficiency. The drop-in method can be divided in two categories [1], [2]. The first is called rim contact mounting and uses the cylindrical surface of the lens for centering. The second drop-in category is the surface contact mounting where the lens is mounted directly on its optical surfaces. Both methods have their advantages and drawbacks. Rim contact mounting is a simple method, but requires a good control of the manufacturing tolerances to achieve acceptable centering accuracy. Surface contact mounting allows to relax some manufacturing tolerances, but requires a good control of the mounting interface accuracy and is applicable only when the clamping angle is large enough to overcome the friction between the lens surfaces and the mechanical mounting interfaces. This paper introduces a new type of drop-in mounting that is much less sensitive to the manufacturing error than the rim contact mounting, and that solves the clamping angle issue of the surface contact mounting. To perform the centering, the lens is simply dropped into a barrel with loose tolerances on the lens diameter and the barrel bore diameter. A spherical mounting seat is provided on the threaded ring and interface with the edge at the intersection of the cylindrical and optical surface of the lens. By selecting the spherical mounting seat radius specifically as per different geometrical parameters of the assembly, the lens is passively centered when the ring comes in contact with the lens. For a large range of lenses, standard ISO and ASME thread profile can be used. As a result, it is possible to center lenses accurately, quickly and at low cost. This paper presents the centering principle, centering measurement results, as well as environmental test results. The centering measurements have shown that the accuracy obtained with the edge mounting method can be compared to a case where a lens is inserted into a barrel without any radial clearance. Also, environmental tests have shown that mounting lenses on edges is robust to thermal variation, vibration and shock.

2. EDGE MOUNTING

2.1 Centering principle

To have a good understanding of the edge contact mounting principle introduced in this paper, we need first to understand how a standard threaded ring interact with the lens and the mount. Threaded ring used in typical drop-in interfaces with the lens directly on the optical surface, whether the lens is centered by rim contact or by surface contact. Thus, the ring is constrained on one side by the lens, and on the other side by the threads as depicted in Figure 1.

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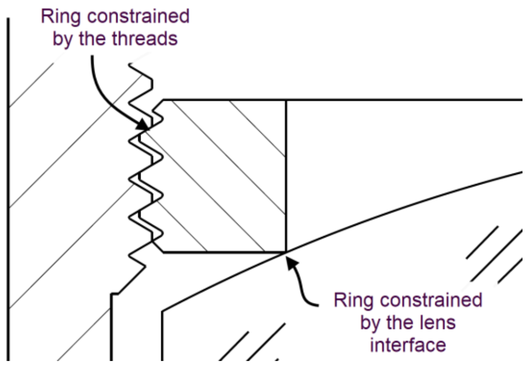

Figure 1. Threaded ring constrained by the top thread surface and by the lens optical surface.

When the clamping angle is large enough to overcome the friction force, the lens translates in order to be fully constrained by the ring seat position as shown in Figure 2. The ring seat position is directly related to the thread assembly clearance and to the thread angle of the ring. As the ring decenter within the thread assembly clearance during the tightening, the ring also tilt as per the thread angle. Consequently, the ring seat constraining the lens position is tilted and decentered, resulting in a lens centering error.

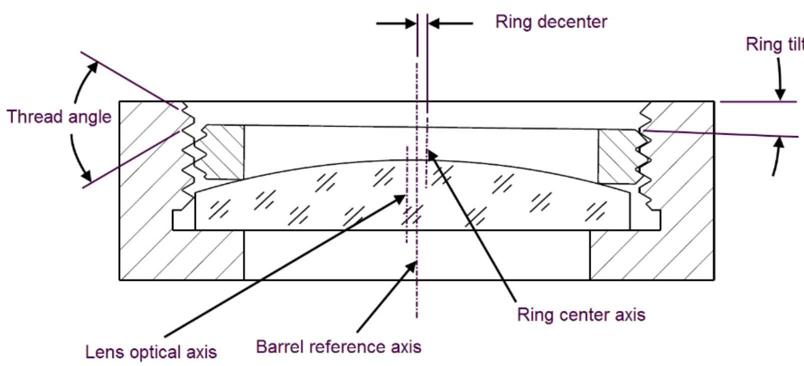

Figure 2. Relationship between the ring position and the lens centering error.

In order to avoid lens centering error caused by the ring decenter and tilt, INO recently developed an improved surface contact drop-in lens mounting method called auto-centering [3], [4]. With the auto-centering, the thread angle of the ring is adjusted in order to meet an auto-centering condition where the ring tilt and decenter have counterbalancing effect on the lens centering. Since this method uses surface contact mounting, it allows to relax the manufacturing tolerance on the lens wedge, but it is only suitable for lenses having a clamping angle large enough to overcome the friction force during the assembly. In contrast, the edge mounting method discussed in this paper do not rely on matching the thread angle to meet an auto-centering condition for a specific lens geometry. Rather than that, the edge mounting can be used with standard thread angle by adding a spherical surface that acts as a mounting interface at the lens edge. This patent pending method [5] perfectly complements the auto-centering solution by offering the possibility to use standard threads, making this lens centering method very simple to implement. Also, there is no lens geometry limitation associated with a minimum clamping angle to be respected. In other words, the auto-centering method can be seen as a high performance solution, while the edge mounting is a little less accurate than the auto-centering, but offers a simpler implementation with no clamping angle limitation.

To avoid any confusion between these two different lens mounting methods, INO named the auto-centering method the *QuickCTR-thread* and the edge contact mounting method the *QuickCTR-edge*. Therefore, the *QuickCTR-thread* refers to surface contact mounting where the thread angle is adjusted to meet the auto-centering condition. For its part, the *QuickCTR-edge* refers to lens centering using a spherical surface on the ring that interfaces with the edge of the lens.

As mentioned previously, the edge mounting uses the edge of the lens at the intersection of the lens rim and the lens optical surface for mounting. The ring is provided with a spherical surface that interfaces with the lens edge as shown in Figure 3. By doing so, it is possible to provide a large clamping angle that does not depend on the optical surface radius of curvature. In fact, any lens shape having convex, planar or concave surface can be centered with this new method. Moreover, an optical element having two planar surfaces could also be centered passively, without the use of tight radial clearance fit.

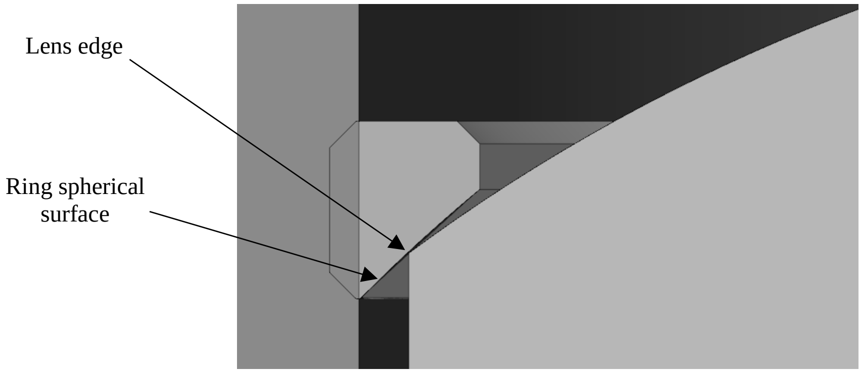

Figure 3. Lens mounted on the edge using a spherical surface on the threaded ring.

That being said, the spherical surface cannot be selected arbitrarily. As explained for standard ring, the threads assembly clearance results in a tilt and centering error of the ring. Thus, the ring spherical mounting interface will be decenter and tilted if not selected properly, resulting in a lens centering error as shown on Figure 4.

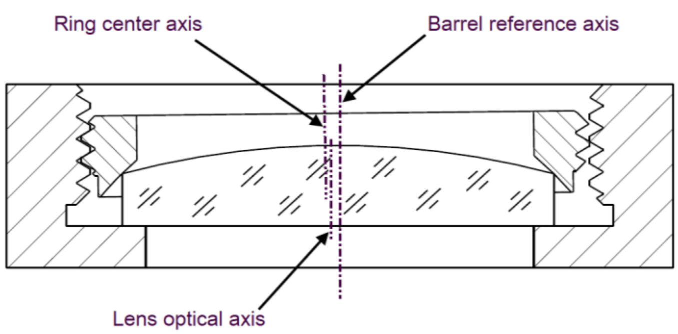

Figure 4. Decentered lens caused by an inadequate selection of the ring spherical mounting surface radius.

If the radius of the spherical surface on the ring is selected correctly, the centering of the lens will not be impacted by the ring positioning error as shown in Figure 5 where the lens optical axis is coincident with the barrel reference axis.

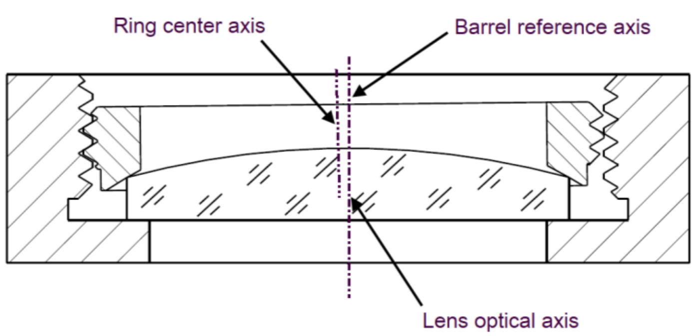

Figure 5. Centered lens provided by the correct selection of the ring spherical mounting surface radius.

This self centering can be achieved if the radius of the spherical mounting surface on the ring is selected so that the center of its radius of curvature is coincident with the effective center of curvature of the ring thread as shown in Figure 6. As a matter of fact, the ring tilt and decenter relationship from the thread assembly clearance results in a rocking movement of the ring as shown in Figure 7. By matching the spherical movement of the retaining ring with the spherical mounting interface for the lens edge, the spherical contact surface between the ring and the lens remains at a same position regardless of the motion of the retaining ring in the mount as depicted in Figure 8. In Figure 7 and Figure 8, the dark gray ring represent the ring nominal position perfectly centered on the mount mechanical axis. The light gray ring shows the ring position once decentered in the thread assembly clearance. In both figures, the barrel complementary threads are not shown for clarity.

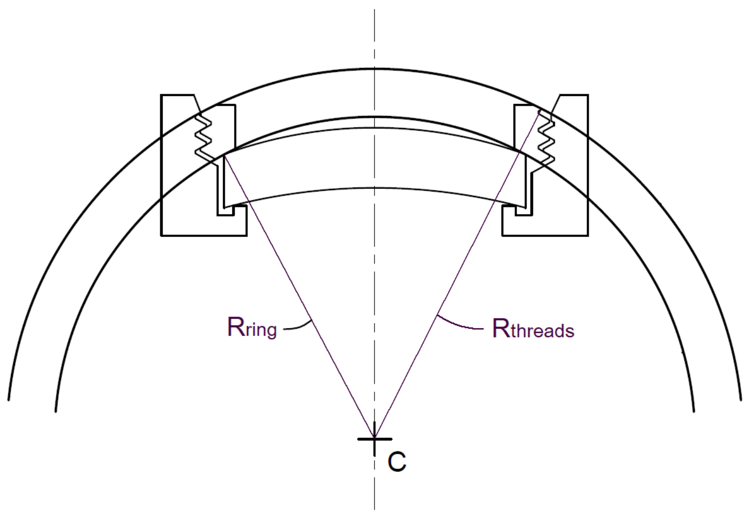

Figure 6. Ring spherical mounting surface center of curvature coincident with the ring rocking movement center of curvature.

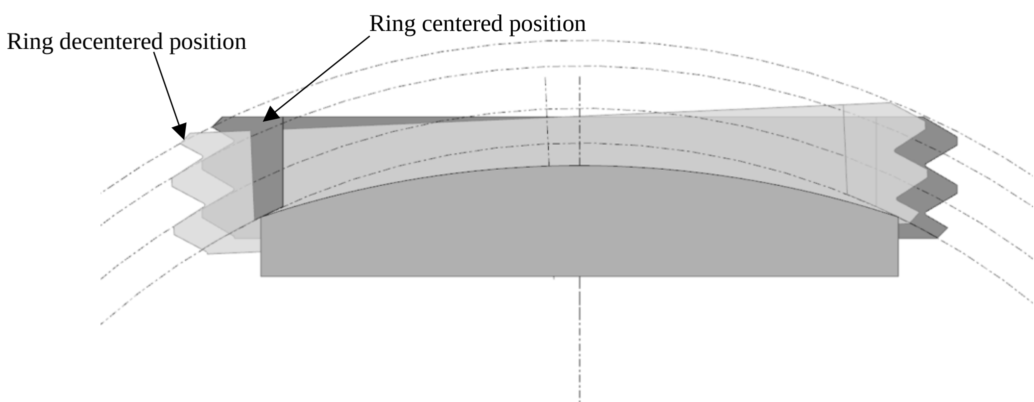

Figure 7. Threaded ring rocking motion within the thread assembly clearance.

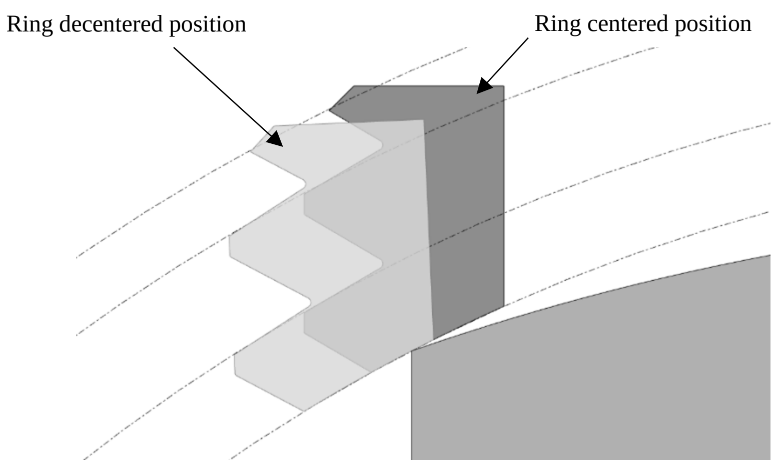

Figure 8. Ring spherical mounting surface not impacted by ring decenter and tilt.

The following equation is used to select the appropriate spherical radius of curvature to center lenses passively with edge contact mounting. The parameters involved in equation (1) are shown in Figure 9. When the radius of the spherical mounting surface on the ring is selected as per equation (1), its radius of curvature (R_{ring}) is coincident with the effective center of curvature of the ring rocking movement (R_{thread}) as shown previously in Figure 6.

$$R_{ring} = \sqrt{\left[\frac{d_{ring}}{2tan\left(\varphi_{threads}/_{2}\right)} - h - T/2\right]^2 + Y^2} \quad (1)$$

where:

- R_{ring} is the radius of curvature of the abutment surface of the retaining ring;
- d_{ring} is the major diameter of the retaining ring;
- φ_{thread} is the value of the thread angle;
- Y is the half-diameter of the lens mounting edge;
- h is the distance between (i) the first point of contact of the barrel threads with the ring threads next to the optical element and (ii) the point of contact of the retaining ring with the lens edge contact line;
- T is the distance between (i) the first point of contact of the barrel threads with the ring threads next to the optical element and (ii) the last point of contact of the barrel threads with the ring threads farthest from the optical element diametrically opposite to the first point of contact.

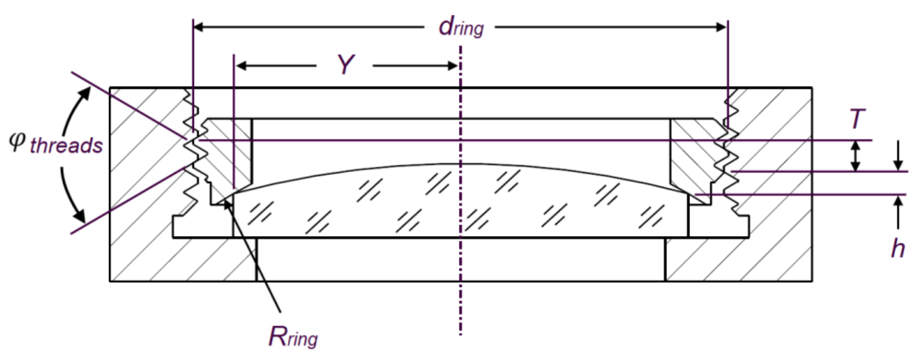

Figure 9. Edge mounting ring spherical radius calculation parameters.

Since the play between the retaining ring and the barrel is relatively small, the ring spherical surface that provides the lens centering can also be approximated to a conical surface such as a chamfer. The inclination angle α of the abutment surface with respect to a transversal plane of the cavity (a plane perpendicular to the center axis) can be computed using equation (2):

$$\alpha = sin^{-1}\left(\frac{Y}{R_{ring}}\right) \tag{2}$$

where:

- α is the inclination angle of the abutment surface with respect to the transversal plane of the cavity;
- Y is the half-diameter of the lens mounting;
- R_{ring} is the radius of curvature of the abutment surface of the retaining ring as define above by equation (1).

2.2 Lens mounting edge

In general, lenses are provided with chamfers to avoid sharp edges, minimizing the risk of chipping or cracking the edges. The chamfers are most of the time machined on the lens at the edging stage as shown in the figure below from Karow. As a result, the chamfers are uniform and completely concentric to the mechanical axis of the lens [6]. The angle of the chamfer is typically 45 degree. In the case of concave surface, it is also common to see flat surface perpendicular to the lens axis instead or in combinations with chamfer. The result of the edging and beveling manufacturing process is that the edge at the intersection between the cylindrical and the optical surface of the lens offers a precision reference for mounting.

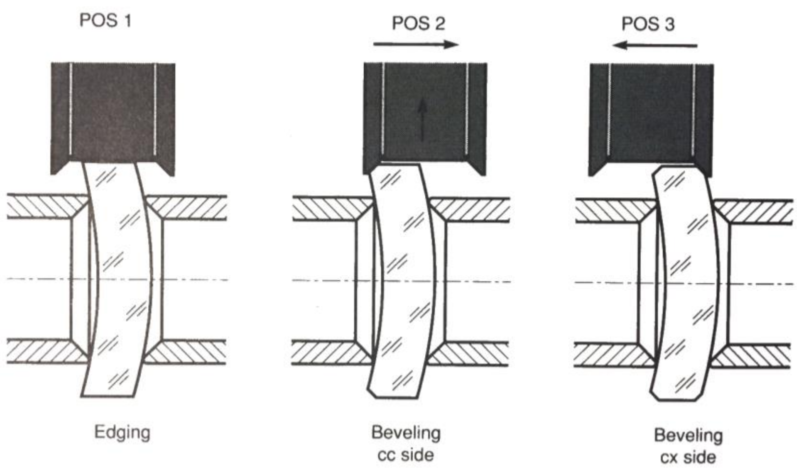

Figure 10. Edging and beveling with compound wheels [6].

When the lenses are chamfered and when ISO or ASME standard thread profile having 60 degree angle are used, the contact between the lens and the ring occurs at the intersection between the optical surface and the bevel surface of the chamfer as shown in the Figure 11.

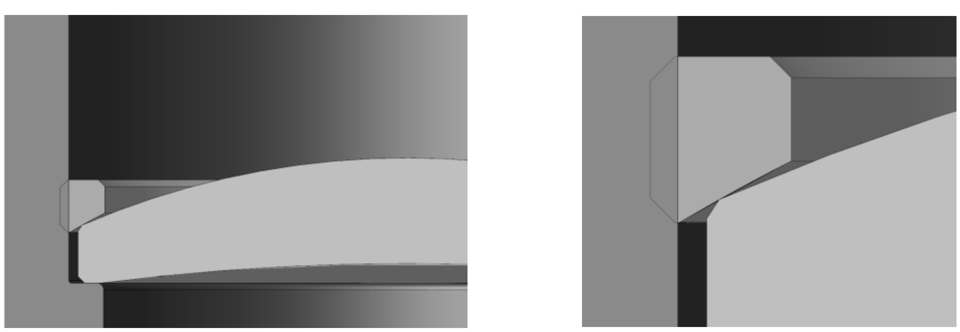

Figure 11. Edge contact at the intersection between the optical surface and the bevel surface.

To have a local contact angle on the ring that matches the 45 degree bevel angle, it is possible to use a larger thread angle. This has the advantage of providing a large surface of contact between the lens and the ring, resulting in an improved robustness for environmental constraints such as temperature variations, shocks, and vibrations. Having a larger contact area between the lens and the ring helps to minimize the mechanical stress on the lens while minimizing the risk of chipping the edge of the lens. For severe environmental requirements, it would be advantageous to make a larger bevel than usual on the lens to increase the contact area between the ring and the lens as shown in Figure 12.

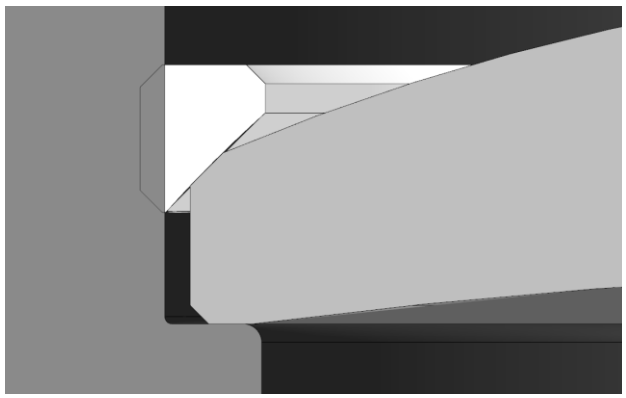

Figure 12. Robust mounting using contact between the lens bevel surface and the ring mounting surface.

In case where standard 60 degree thread angle wants to be used, it is also possible to use special bevel angle such as 60 degree as shown on the left figure below from Karow [6]. This has the advantage of providing a large surface of contact between the lens and the ring while using standard threads for the mount and the ring.

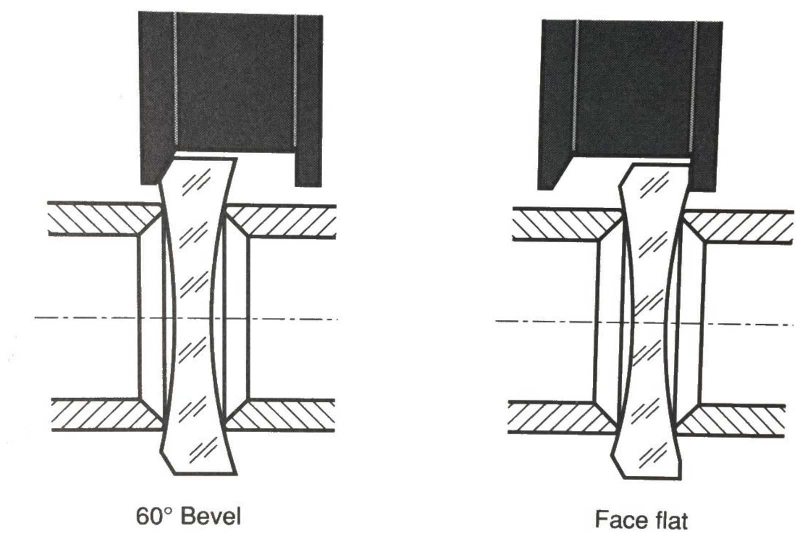

Figure 13. Special bevels and face flats ground with compound wheels [6].

2.3 Lens manufacturing tolerance

Since the lens is mounted at the intersection between the optical surface and the rim cylindrical surface, the lens manufacturing error between the rim cylindrical surface axis and the optical axis of the lens will impact the centering error of the lens once mounted into the barrel. This is why it was mentioned previously that the auto-centering method using surface contact mounting is more accurate than the edge contact mounting. For a lens perfectly edged without any edge thickness difference (ETD), the centering error for both methods would be very similar. Despite the fact that the lens wedge add a centering error for lenses assembled using the edge mounting, the average centering accuracy could be approximated to a case where a lens is mounted using drop-in without any assembly clearance between the lens and the mount. There is only the wedge error from lens fabrication that affects lens centering once assembled. Therefore, there is a significant improvement in centering compared to the drop-in method based on assembly clearance. In fact, there is always a minimum assembly clearance required for standard drop-in. In addition to this minimum clearance, the lens and barrel diameters manufacturing errors also contribute to increase this minimum assembly clearance, resulting in a larger lens centering error. The figures below show the effect of a lens wedge on the centering for the edge mounting method. On the left figure, the lens optical axis is coincident with the mount mechanical axis since there is no wedge error on the lens. On the right figure, the lens is wedged. Since the ring spherical mounting surface stays centered on the barrel axis, the lens translates on the planar surface until the lens is fully constrained by the interface between the lens edge and the ring spherical surface. This results in a centering error of the lens with respect to the mount reference axis.

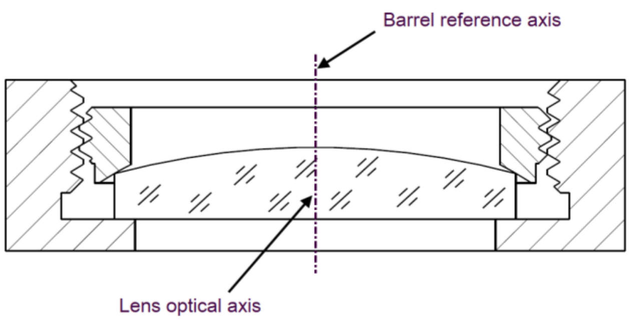

Figure 14. Effect of the lens wedge on the centering for the edge mounting method. (Left) Lens without wedge manufacturing error, (Right) Lens with wedge manufacturing error.

It is therefore possible to compute the centering error of a lens mounted using edge mounting for a given lens wedge manufacturing error. As a rule of thumbs, this error can be approximated as the lens wedge angle. More specifically, the centering error is a function of the lens wedge error, the lens geometry (i.e. bi-convex, plano-convex, meniscus, plano-concave, bi-concave), optical surface geometry (i.e. convex, planar or concave optical surface), the lens diameter, and the lens radius of curvatures. The figures below show examples of centering errors as a function of the radius of curvatures for two different lenses. Both lenses are plano-convex with diameters of 25 mm and 50 mm. The centering error is caused by a lens manufacturing error ETD of 10 µm, which corresponds to a precision grade lens wedge tolerance as per Optimax Systems Inc. manufacturing tolerance chart [7].

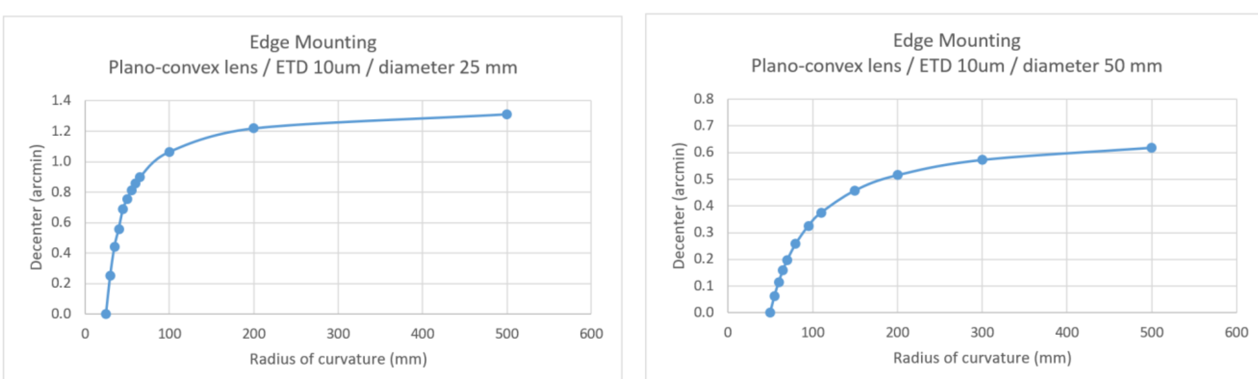

Figure 15. Example of edge mounting centering error caused by a lens ETD manufacturing error of 10 µm. (Left) 25 mm diameter plano-convex lens, (Right) 50 mm diameter plano-convex lens.

It can be seen from the graphs that the centering is more accurate for small radius and increase as the radius gets larger. This is explained by the fact that when the radius of curvature of the lens is getting closer to the auto-centering condition, the lens centering becomes less sensitive to lens wedge manufacturing error. In fact, the auto-centering theory states that there is a combination of geometrical parameters involving the thread angle, the lens diameter and the lens radius of curvature that provides a self centering of the lens [2], [3], [4]. If the ring spherical radius of curvature is the same as the lens radius of curvature, then the auto-centering condition is met and the lens wedge does not have any impact on the lens centering. Therefore, it is possible to adjust the lens wedge manufacturing tolerance during the tolerancing process to balance the manufacturing cost and the centering accuracy depending on the lens sensibility to the wedge error.

The level of centering accuracy shown in Figure 15 is very good for passive lens centering. Such kind of centering accuracy would be almost impossible to achieve with drop-in using rim contact for centering, and even more difficult to reproduce in a production environment. These results are reported in tilt unit, which makes more sense to compare centering error for different radius of curvatures. Figure 16 shows the relationship between the tilt and the decenter of a spherical surface.

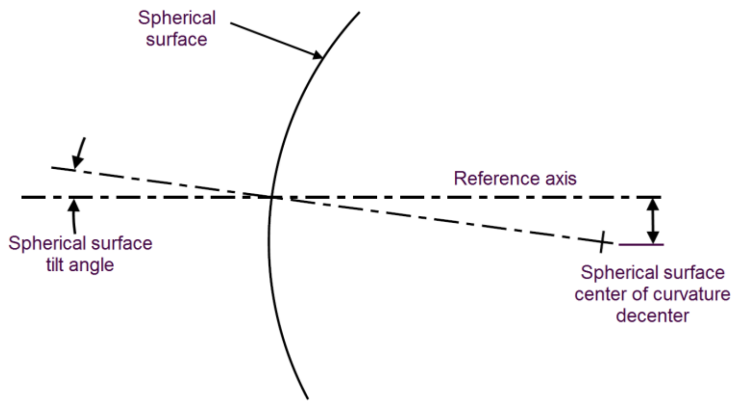

Figure 16. Relationship between spherical surface tilt and decenter.

For comparison purpose, it is possible to compute the centering error in µm using equation (3).

$$Lens\ Surface\ Tilt = sin^{-1}\left(\frac{Decenter}{Radius\ of\ Curvature}\right) \tag{3}$$

For example, a centering error of 0.6 arcmin for a radius of curvature of 40 mm, as shown on the left graph, results in a centering error of 7 µm. For a centering error of 0.3 arcmin and a radius of curvature of 80 mm, as shown on the right graph, the centering error is also 7 µm. As the radius of curvature increase and get closer to a planar surface, the centering error expressed in terms of micrometers loose sense and the centering error is better represented in terms of surface tilt.

2.4 Self-centering criterion

To allow centering, the contact angle between the ring-lens interface and the optical surface supported on the barrel seat must be large enough to overcome the friction and allow the lens to slide radially when the ring exerts an axial force on the lens [2]. For edge contact mounting, the clamping angle is generated by the ring spherical mounting surface radius that interfaces with the lens edge as shown in Figure 17.

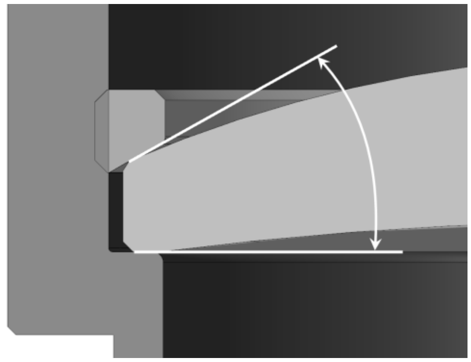

Figure 17. Edge mounting clamping angle.

For a standard ISO and ASME 60 degree thread profile, the clamping angle formed by the ring spherical surface is around 30 degree, which is sufficient to overcome the friction force for all lenses mounted on a planar or a convex surface on the barrel seat. If the lens is mounted on the barrel seat on a concave surface, it may happen that the clamping angle is too small to allow centering of the lens. To increase the clamping angle, the lens can simply be mounted on the barrel seat on a ground flat surface rather than on the optical surface. In this case, the clamping angle required to ensure centering is met for all lens geometries. Another solution could be to use a larger thread angle, such as 90 degree instead of 60 degree, to increase the clamping angle if it is preferable to mount the lens on the concave optical surface rather than on a ground flat. Thus, there is no minimum clamping angle limitation with the lens edge contact mounting. In fact, it would be possible to center passively a window shaped optical parts with this method. For example, it would be possible to center accurately any planar optical component such as a pinhole mask or a reticule on the axis of an optical system.

3. TESTS

3.1 Centering measurements

Several centering measurements have been performed with the edge contact mounting method. Table 1 presents centering measurements at the center of curvature of the optical surface in contact with ring using the edge mounting method. The measurements were performed with plano-convex, meniscus, plano-concave, and bi-convex lenses having different diameters and radii of curvature. N-BK7, Fused Silica and Calcium Fluoride lenses have been tested. This data provide information about the centering accuracy for different lens geometries, the centering repeatability of assemblies using the same parts as well as manufacturing reliability for a production of a few units. A TRIOPTICS OptiCentric® MOT 100 (centration measurement instrument) having an estimated overall accuracy of ±0.05 arcmin was used for the measurements.

Table 1. Centering measurement of a lens surface in contact with the threaded ring using edge contact mounting

# of measurements	*Min (arcmin)*	*Max (arcmin)*	*Mean (arcmin)*	*Std deviation (arcmin)*
94	*0.04*	*2.49*	*0.81*	*0.55*

The lenses used for these tests are commercial lenses having a wedge tolerance of 3 arcmin. Despite this loose lens wedge tolerance, the results presented in the Table 1 are quite accurate. Commercial lenses have been used for these tests because of the stock availability and the low cost. As discussed in section 2.3 on the effect of lens manufacturing tolerance, centering accuracy would be improved significantly by the use of precision or high precision wedge tolerance when required.

During the test, a N-BK7 plano-convex lens with MgF2 coating having a diameter of 50 mm and a radius of curvature of 129.21 mm have been shown to have a wedge error close to the measurement error. As a result, this lens has shown a very good centering accuracy with the edge mounting method as it can be seen from the measurement results in Table 2. The centering measurements have been repeated 6 times to show the mounting centering repeatability. For each measurement, the lens was removed from the barrel and reassembled inside the same barrel using the same ring.

Table 2. Results of repeatability of a lens having a negligible wedge error

# of measurements	*Min (arcmin)*	*Max (arcmin)*	*Mean (arcmin)*	*Std deviation (arcmin)*
6	*0.07*	*0.1*	*0.08*	*0.01*

3.2 Environmental tests

In addition to the lens centering accuracy, another very important aspect of lens mounting is the robustness to environmental constraints such as thermal variation, shock and vibration. Typically, thermal stress is the most severe environmental constraint imposed to a lens assembly. Aluminum mounts are often used for several reasons such machining ease, low density, thermal conductivity, and corrosion resistance. Most of the time, aluminum has a coefficient of thermal expansion (CTE) relatively high compared to typical glass material. As a result, the aluminum mount exert pressure on the optical components at low temperature. Since this thermo-elastic stress is considered to be the principal risk for glass fracture with this mounting technique, low temperature thermal test has been performed on several lens assemblies using edge contact mounting. The cold temperature test has been performed on 6 different lenses having diameters of 25 mm and 50 mm, and different materials such as N-BK7, Fused Silica and Calcium Fluoride. N-BK7 is a common material, Fused Silica has a very low CTE, and Calcium Fluoride is used for a broad range of ultraviolet, visible, and infrared applications. The test has been performed as per MIL-STD-810G, Method 502.5, -40C, 1 cycle for 24hrs. A first centering measurement has been performed prior the environmental test. Then, the centering was verified after the cold temperature test. There was no significant observable decentering caused by the environmental test. Variations of each measurement was of the same order of magnitude as the measurement error. Also, the test has shown that there is no damage induced to the lenses and the mechanical parts.

In addition to the low temperature thermal test, a lens barrel including a 25 mm diameter N-BK7 lens has been tested in shock and vibration. The lens barrel has been dropped from 1 meter high on the three axes on a 2’’ thick hardwood backed by concrete. The vibration test has been performed as per MIL-STD-810G, Method 514.6, General minimum integrity exposure, One hour per axis, rms = 7.7 g’s. Once again, there was no damage induced to the lens and to the mechanical parts.

For these tests, commercial lenses have once again been used and the contact between the lens and the ring was done at the chamfer edge as depicted on Figure 11. Although the environmental testing have shown a good robustness for edge contact mounting, it would be possible to be even more robust by mounting the ring surface on the lens chamfer surface as discussed previously and shown in Figure 12.

4. APPLICATIONS

4.1 Lens assemblies

A typical application for centering lenses with the edge contact mounting method is the stepped barrel design. In such design, lenses are mounted in a single barrel on seats having different diameters. Each lens is secure in place and centered using an edge mounting ring as shown in Figure 18. This type of lens assembly is often used for applications such as photographic objective, binocular, and IR camera objective. In addition to lens centering, this mounting method can be used to center any type optical components. The optical element may for example be a lens, a mirror, a diffractive optical element (DOE), a pinhole or an assembly of such components.

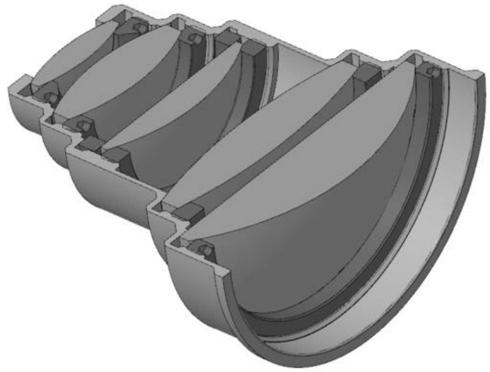

Figure 18. Stepped barrel lens assembly.

4.2 Lens tube systems

Another interesting application of the edge contact mounting method is for lens tube systems which are often used in laboratories and for prototype development as sown in Figure 19.

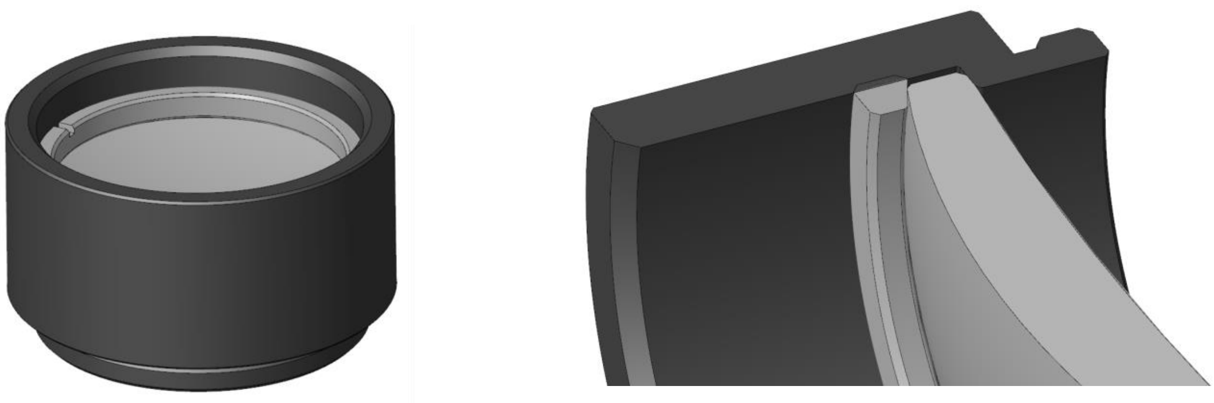

Figure 19. Edge contact mounting used in lens tube systems.

The edge mounting makes possible to center lenses having different radii of curvature without having to change the thread angle. The same ring can therefore center lenses of the same diameter having different geometries and different radii of curvature as shown in Figure 20.

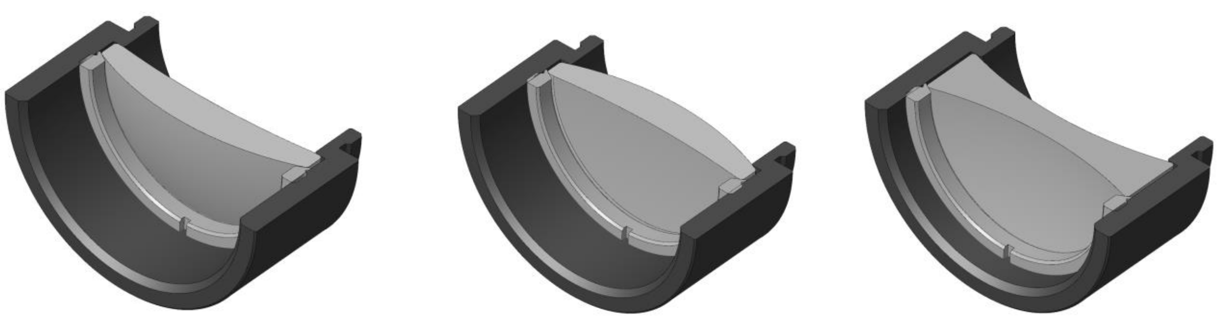

Figure 20. Different lens geometry centered by the same tube and ring using the edge mounting.

This means that lens tube systems used in combination with any commercial lenses having diameters of 12.7 mm, 25 mm and 50 mm could be passively and accurately centered at a low cost using an edge contact mounting ring. As a result, simply by using this new type of ring, the centering accuracy of commercial lens assembly would be improved significantly, offering for the first time a low cost solution for prototypes that needs lens centering accuracy. By providing accurate laboratory optical assembly, the edge mounting principle would reduce the alignment time, leaving more time to perform tests and science, which is the ultimate goal of laboratory optical setup.

In complement to the edge mounting ring, INO developed a solution to mount tubes to each other with a simple standard thread with a centering accuracy around 5 µm. The use of INO edge mounting ring in combination with self-centering tube principle offers a new solution for accurate lens tube systems. The lens tube systems developed at INO uses the same threads such as 0.535”-40, 1.035”-40 and 2.035”-40 that are commonly used by commercial lens tube systems. This means that INO tubes and rings are fully compatible with commercial optomechanical parts, optical accessories, and commercial lenses.

5. CONCLUSION

This paper has presented a new lens mounting method to center passively and accurately lenses in optical mounts. This improved drop-in technique uses a spherical mounting seat provided on the threaded ring that interface with the lens edge at the intersection of the cylindrical and optical surface of the lens. This new method offers typical centering error in the range of 1 arcmin for custom lens design. In addition to this outstanding accuracy for a passive lens centering method, the edge contact mounting is so simple to implement that it has absolutely no impact on the machining and on the assembly compared to standard drop-in. Not only does it not change the production method, but it also relaxes the manufacturing tolerances on the lens diameter and on the barrel bore diameter. It also offers a simple solution to improve the centering accuracy of commercial lens mounted in tube systems for prototype development. This innovative lens mounting method allows to extend the centering accuracy offered by passive lens centering methods to a next level without compromise on the cost and complexity.

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