A novel mirror mount design suitable for laboratory and OEM applications

Frank A. DeWitt
JAID Technologies, Inc., 1728 Parkside Pl., Lima, NY 14485
www.jaid-tech.com

DeWitt, Frank A. " A novel mirror mount design suitable for laboratory and OEM applications," Proceedings 10747 Optical System Alignment, Tolerancing, and Verification XII, 10747-12, (19 September 2018). https://doi.org/10.1117/12.2321250

A novel mirror mount design suitable for laboratory and OEM applications

Frank A. DeWitt
JAID Technologies, Inc., 1728 Parkside Pl., Lima, NY 14485

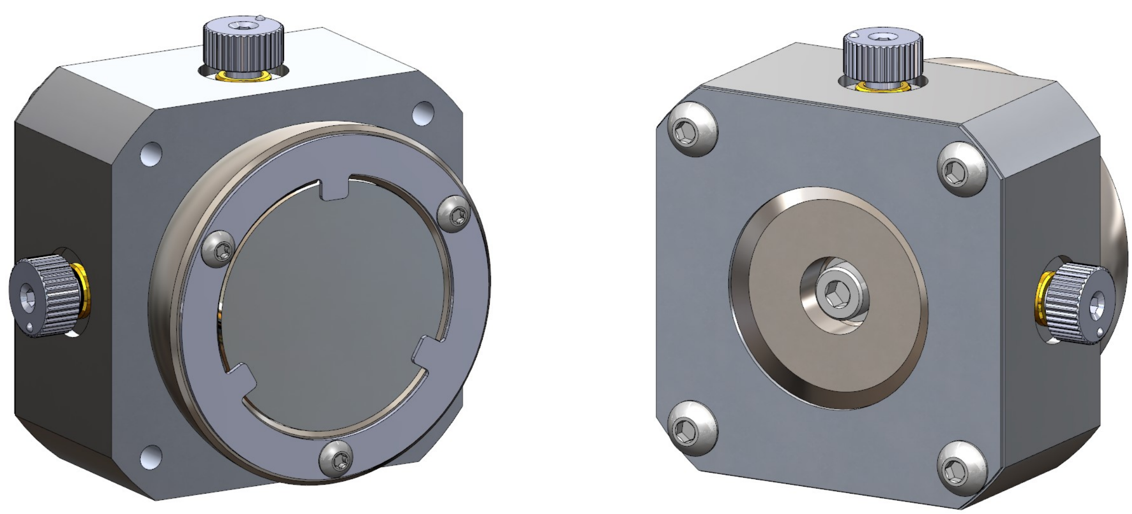
ABSTRACT

One of the most common pieces of opto-mechanical hardware is the one inch, tip-tilt, mirror mount. Though there are numerous manufacturers of these mounts the majority of the designs follow the familiar theme of a corner pivot point and two adjustable actuators located orthogonally. This type of mount (often referred to as simply a "kinematic" mirror mount) can be found in many sizes and has been tailored for many different applications. While the simple and robust design has proven effective in many circumstances there are times when it isn't ideal. Common issues with these mounts include long term stability, temperature dependent pointing and sensitivity to external shock and vibration. These shortcomings have led many to develop alternatives, which is especially true when designing for OEM applications. Though many alternatives have been devised and implemented they often lack the convenience and simplicity of the well-known form and are never broadly adopted.

This paper details an alternative design that has the potential to meet the needs of laboratory use while being equally well suited for demanding OEM applications. The design explored, addresses the common shortcomings listed while keeping to a compact and convenient form factor. The mirror mount has a virtual pivot point centered on the front surface of the mounted mirror and is fully lockable. The resulting approach is compared directly to the features and function of the familiar "kinematic" mirror mount form.

Keywords: mirror mount, kinematic, alignment, opto-mechanical, gimbal, goniometer, tip/tilt

1. INTRODUCTION



Figures 1a and 1b. Preview of the mirror mount that will be discussed in detail

The design of a new adjustable mirror mount (Previewed in figure 1) was conducted in an effort to develop a mount that is suitable for OEM applications but retains many of the best features and benefits of off-the-shelf mounts. OEM applications often require mounts that can specifically withstand the shock, vibration and temperature fluctuations encountered in shipping. With this in mind Engineers often choose to design custom mounts for each new application in order to ensure that the stability requirements will be met. However, custom mounts often are costlier and often give up on some of the conveniences offered by off-the-shelf mounts.

For the purposes of the design exercise the following list of desired attributes was developed.

1. Adjustability of at least +/- 3° around orthogonal axis
2. Center of rotation should be located about the nominal reflection point – The center of rotation should be centered on the front face of the intended mirror position.
3. Positive locking mechanism – The mechanical structure holding the mirror should become rigid when locked and not depend on pre-load elements (e.g. springs) to hold the position.
4. Inherent insensitivity to temperature fluctuations – The design should be developed to avoid thermal induced pointing errors and long-term creep.
5. Tool-less adjustment with resolution similar to off-the-shelf offerings (e.g. 80 TPI adjusters at a sufficient distance from rotational axis)
6. Mirror should be located on front surface and be held in a semi-kinematic[1] fashion or with a comparable low-stress approach.
7. Ample and easily accessible surfaces to facilitate stable mounting,
8. Compactness – comparable to off the shelf solutions
9. Economical – competitive to off the shelf solutions in reasonable quantities

2. PICTORIAL SURVEY OF EXISTING SOLUTIONS

2.1 "Kinematic Mirror Mount"

The term "Kinematic Mirror Mount" has become synonymous with a certain style of mirror mount that is commonplace in optical labs internationally and provided by a number of manufacturers. In a 2014 Laser Focus World article, John Wallace described this style of mount as "iconic".[2] The kinematic mirror mount is likely the most used form of adjustable optical mount and the vast majority of manufacturers of opto-mechanical hardware offer some form of this mirror mount. The following figure shows one example that is offered by Standa LTD.

Figure 2. Kinematic Mirror Mount offered by Standa LTD

2.2 Flexure Based Mirror Mounts

Flexure based mounts often have a very low part count given the guiding mechanism is the flexure and is often integrated into the primary body of the mount directly. Their simplicity and adaptability make them an ideal choice for many applications and often times the flexure elements can be directly integrated into surrounding structure when used in OEM applications. Figure 3 shows an example of a flexure-based mount offered by Siskiyou Design Inc[3].

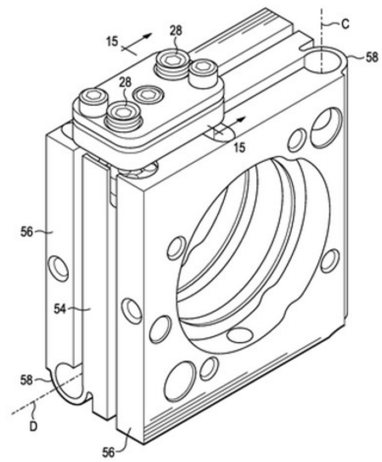


Figure 3. Flexure based mirror mount from U.S. Patent 8,925,409

2.3 Gimbal Mounts based on separate orthogonal pivots

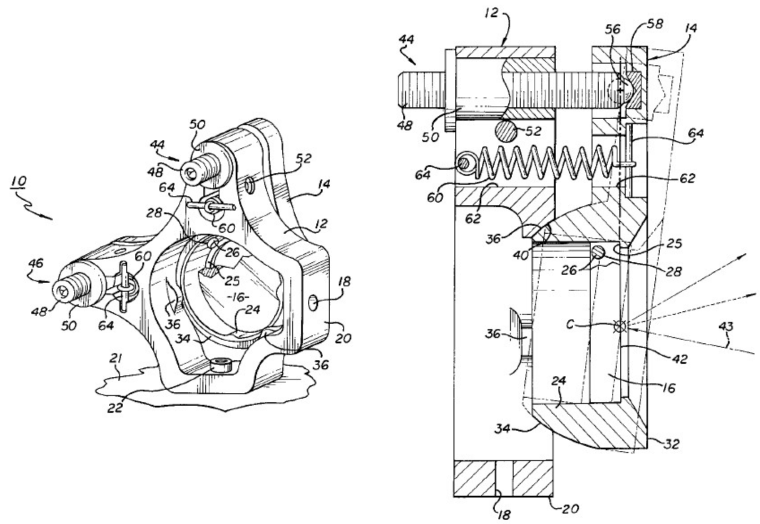
Gimbal mirror mounts have at least two intersecting axis of adjustment that pass through a common point that lies on the intended axis of the optical element. One common architecture for such a mount consists of having an inner frame that rotates about a horizontal axis and is attached to an intermediate frame. Subsequently the intermediate frame along with the inner frame both rotate about a vertical axis and attach to an outer frame. This implementation often relies on bearings, bushings, or simple mechanical elements (e.g. balls or pins in mating geometry) to create the pivot points. One advantage of this implementation is that they can be designed to offer 360° of rotation about the axis of rotation.

Two examples of gimbal mounts with separate orthogonal pivots can be seen in Figures 4a and 4b.

Figures 4a and 4b. Gimbal mounts offered by Newport Corporation

2.4 Singular spherical pivot-based gimbal mounts

An alternative to the gimbal mount architecture described in 2.3 leverages a spherical element to define a singular point of rotation about which a mount can be rotated on defined axis. Mounts of this form utilize the spherical pivot to fix 3 of the 6 degrees of freedom, namely the position of the rotating body. The angles of rotation around that pivot are then controlled with ancillary mechanisms that incorporate the means for adjustment. A clear example of such a mount can be seen in Figures 5a and 5b from US Patent 6,198,580 assigned to Newport Corporation[4].



Figures 5a and 5b. Example of a mirror mount based on a spherical pivot joint

3. A DISCUSSION OF THE DESIGN REQUIREMENTS IN LIGHT OF COMMONLY AVAILABLE SOLUTIONS

3.1 Adjustability of +/- 3° around orthogonal axis

All of the designs surveyed offer reasonable adjustment ranges and are compatible with this requirement.

3.2 Center of rotation should be located about the nominal reflection point

The gimbaled designs are capable of achieving this. However, the kinematic and flexure-based designs do not provide this functionality. The importance of this design requirement varies by the intended use in a given implementation. Often times the adjustment sequence can be designed such that angular errors can be dealt with in priority to translational errors so a slight beam shift (“beam walk”) caused by a combined translation and angular change of a mirror rotating about an off-axis point is an acceptable consequence. However, in some application such a beam shift will force multiple iterations within the alignment sequence in order to achieve the desired result.

3.3 Positive locking mechanism

The locking mechanisms employed for the various approaches vary a great deal by manufacturer however some broad statements can be made. In general, the moving portion of a kinematic mount is not locked relative to the static portion directly. Instead the positions of the actuators are locked. This helps to prevent accidental miss-alignment and some mechanisms of drift but still relies on the force of the preload mechanisms (e.g. springs) to hold the moveable portion of the mechanism against the intended datum surfaces. The lack of a positive lock of the mechanism itself creates an opportunity for the mechanism to become unseated in the presence of shock or vibration.

In addition, when the actuator mechanisms are in the long-term structural path any lubricants used within the actuator can be a source of long term drift. Lubricants provide an intermediary substance between the mating mechanical components and over time the lubricants can migrate from hydraulic pressure causing the thickness of that layer to reduce or be completely eliminated. When this occurs the absolute position of the lubricated elements can change relative to each other, resulting in a small changing in angle and/or position.

3.4 Inherent Temperature Insensitivity

Mounts that include the actuator in the final, locked, structural path are very unlikely to use materials with the same coefficient of thermal expansion throughout and in fact most fine threaded actuator mechanisms utilize dissimilar materials to avoid gulling. When materials with varied coefficients of thermal expansion are used in the structural loop the differential expansion of the components can cause angular changes within the mechanism. In addition, repeated temperature cycling can result in drift as surfaces expand it different rates against each other.

Some manufacturers offer high stability versions of their mounts that utilize stainless steel alloys vs. the more common and less expensive aluminum alloys. The lower coefficient of thermal expansion of the stainless steel helps to minimize thermally induced drift but often times alloy differences and lubrications still exist and need to be dealt with.

3.5 Tool-less adjustment with high resolution actuators

All of the designs evaluated are compliant with this requirement. Most manufacturers offer multiple styles of actuators and some can even be motorized or have piezo style actuators installed. A common technique is to offer knobs that will accept a hex driver or make the knobs removable so that a hex driver can be inserted. This allows tool-less adjustability but also provides a method for reducing the size of the mount by minimizing or even eliminating the adjustment knob volume.

3.6 Low Stress Mirror Mounting (e.g. semi-kinematically)

When used in the context of mounting optical elements a kinematic approach implies a design that avoids over-constraint. Any time an optical element is mounted in an over-constrained fashion there exists the possibility that bending forces will be exerted on the element and cause distortion. Many manufactures now offer mirror mounts with systems that minimize the effects of mounting stresses. One of the most common embodiments is to rest the mirror on three points (or small pads) and then capture the mirror with another three points directly opposing the first three, but on the opposite side, as to avoid any induced bending. An example of this approach can be seen in Figure 4b

While many solutions have been implemented to limit the stress exerted on an optical element there are very few that reference the position of the optical element off of the front (reflective) surface (especially in the smaller mirror mount sizes). It is more common to hold the element by the edges or position the element by the back surface. These solutions do well at maximizing the useable aperture of the optical element but stability can be sacrificed. If the back surface is used then there will likely be a differential thermal expansion between the mirror substrate and the optical mount which can lead to temperature induced issues. Locating the mirror by the reflective surface is even more relevant for a gimbal style mount where the desire is to position the rotation point around the center of the front surface. If the back surface is used then thickness changes in the mirror will compromise this geometric relationship.

3.7 Stable mounting options offering multiple options

Traditionally mirror mounts are often mounted on optical posts. This is quick and convenient for lab setups but not ideal for OEM applications. Often times when commercially available mirror mounts are used in OEM applications extra features are required to securely locate the mirror mount within the OEM assembly. To avoid this, it is desirable that the intended mounting surfaces have more than one fastener location and for the surface to be proud and easily accessible. In addition, it is highly desirable for the mount to offer multiple mounting surfaces to maximize the flexibility for use within the assembly.

3.8 Compact and Economical

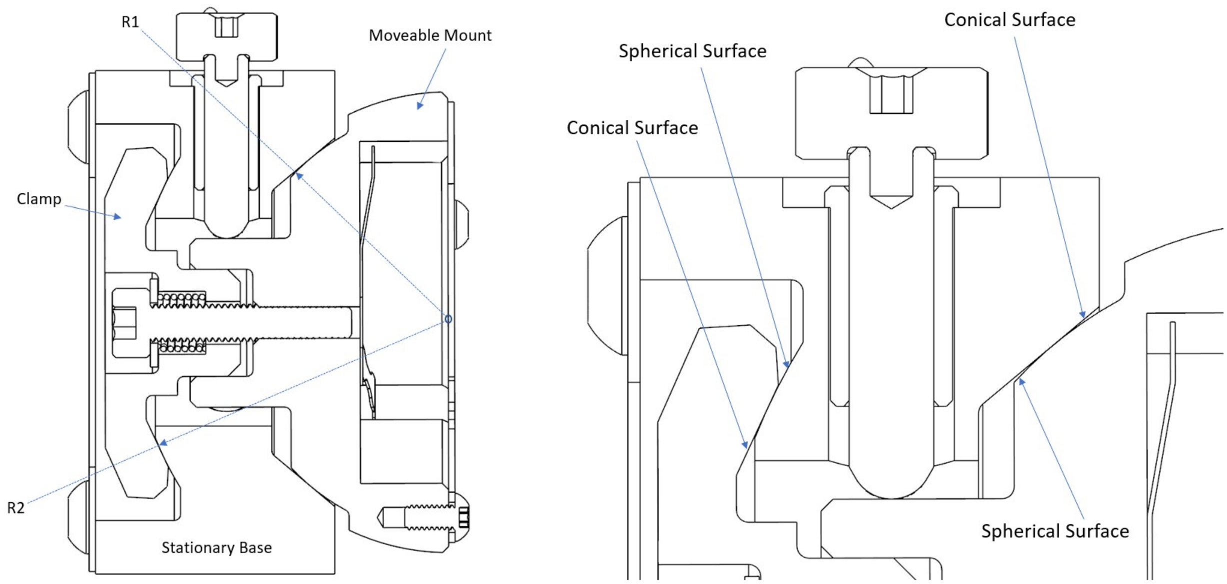
One of the driving factors behind the success of the kinematic mirror mount has been its compact form factor and low part count to provide an economical solution. Often these factors are as important as functionality and performance. These same factors have also traditionally limited the success of gimbal approaches as they are often more complex and require a larger footprint within a system for implementation. For a new design to compete well in this space it will need to be compact and affordable.

4. A NEW APPROACH

4.1 Guiding Geometry

The proposed mount starts with the common spherical interface that consists of a spherical surface engaged in a concave conical surface. If the sphere and the conical surface have perfect form then line contact will exist between the two surfaces. This in and of itself isn't novel and has been used in many designs in the past. However, in the proposed design a second spherical interface, similar to and concentric with the first is implemented. The second spherical interface provides a means of locking the mechanism directly and without the application of any moments that would serve to change the alignment in the locking action. The described geometry can be seen in Figure 6. [5]

Figure 6a shows a cross-section through the adjustable mirror mount first depicted in Figure 1 and Figure 6b shows a magnified view and indicates the spherical and conical surfaces present in the implementation.



Figures 6a and 6b. Cross-section views of the spherical interfaces

Also evident in the Figure 6a is a central fastener (socket head cap screw) that can be used to clamp the assembly within the stationary portion of the mount. Given that the two spherical interfaces share a common center of rotation (see R1 and R2 in Figure 6a), the clamping force will have no effect on the alignment. Underneath the head of the fastener is a compression spring that serves to provide a preload force. This preload force keeps the moveable mount seated in the concave "socket" that is integrated into the stationary base. The preload is necessary during adjustment but once in the final position the structure is locked and the preload is no longer necessary.

To accomplish a controlled adjustment of "tip" and "tilt" fine pitched actuator screws have been incorporated into the design. One such actuator screw can be seen in Figure 6a. It is important to note that the fine pitched actuator screw exerts a force normal to an axis of symmetry that would run through the center of rotation and the mirror held within the mount. By orienting the actuator screws nominally perpendicular to the afore mentioned axis the forces of the screws and their own preload mechanism do not have a significant impact on the force holding the moveable portion to the stationary portion. To put it another way, the force exerted by the adjustment screws are not fighting the preload force in any significant way.

4.2 Stability

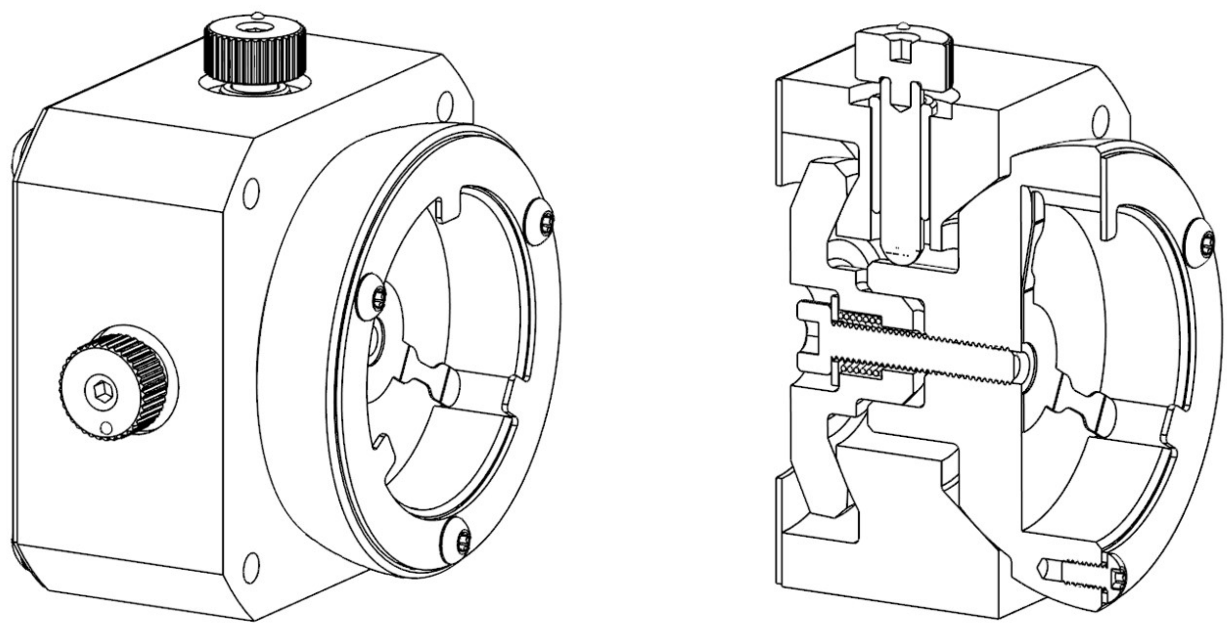
The mount has been designed to meet the demanding stability requirements of a precision OEM optical system. In the case of the proposed design stability includes a natural insensitivity to temperature change, long term creep, and or vibration.

Because the clamping mechanism acts on the guiding interface directly the actuator screws are not needed once the final position has been achieved and the position locked. In some cases, it may be beneficial to remove the screws entirely (for reuse elsewhere) or back them off as to prevent the possibility of an over-constrained condition. Once the adjustment screws are disengaged the structural loop consists of the moveable mount, stationary base and clamp. When the design is implemented such that these three parts are made from the same material (or from materials with predominantly similar coefficients of thermal expansion) temperature changes will cause the entire assembly to scale (grow or shrink) but there will be no asymmetric forces that would cause the pointing of the mount to change. The symmetry of the mount leads to an inherently insensitive mechanism.

The mount is also very rigid in its locked state. While many mounts lock the actuator screws, this mount locks the mechanism itself. Fairly high clamping forces can be exerted without changing the pointing of the mount and once clamped the assembly acts as one monolithic part.

4.3 Mirror Mounting

The proposed design includes a method for mounting the mirror within the mount whereby the mirror is located on the front surface by three contact points. Furthermore, the mirror is held against the three contact points by a single spring element that acts in three locations directly opposing the three fixed points. The position of the preload spring ensures that there isn't any inherent bending imparted on the mirror substrate. The spring element ensures that suitable force is exerted to hold the mirror in place but allows for the mirror to expand and contract at a different rate than the mount thus avoiding thermally induced distortion. Figures 7a and 7b depict the mirror mounting features.



Figures 7a and 7b. Detailed views of proposed mount

In most cases it is not necessary to restrain the mirror in the radial directions. In normal circumstances the localized frictional forces will keep the mirror in position. In extreme case an external shock could cause a slight lateral movement but this is unlikely to change the alignment appreciably because the front surface is normally precisely flat. If the optic in the mount is not flat and radial motion is of concern the thick walls around the optic can accommodate features for radial retention or the optic can be bonded in place with a suitable compound.

4.4 Ease of use

A goal of the design was to provide ample mounting surfaces and fastener locations to ensure that the mount could be rigidly affixed to the surrounding structure. At the same time, there was a desire to keep the mount compact as to maximize the number of places it could be integrated. The final design provides three separate and orthogonal faces that can be used for mounting.

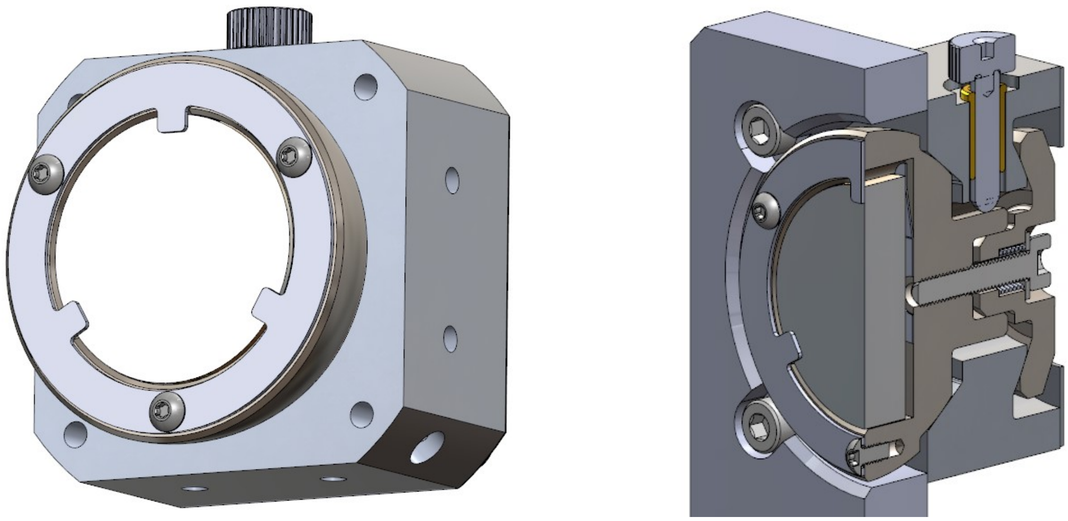


Figure 8a and 8b. Depiction of mounting surfaces

The front mounting surface creates a unique mounting option among adjustable mirror mounts. The mount can be rigidly mounted to the face of a frame or plate such that the mirror surface is located coincident with the face of the plate or frame. This can be a useful feature for initial setup and alignment and provide a stable and compact implementation. A further possible advantage of mounting on the front face as shown in Figure 8b is that the mirror could extend into a predominantly sealed area while leaving the adjustment mechanism exposed. This could assist in creating an optical cavity that is sealed from contaminants while maintaining the ability to adjust the mechanism.

In addition, the design could be altered to accommodate specific functionality. For instance, the current adjustment knobs were chosen for their small size but larger ones could be used for situations where an increased mechanical envelope is allowable. Figure 9 shows the nominal dimensions for a mount capable of accommodating a 1" diameter mirror.

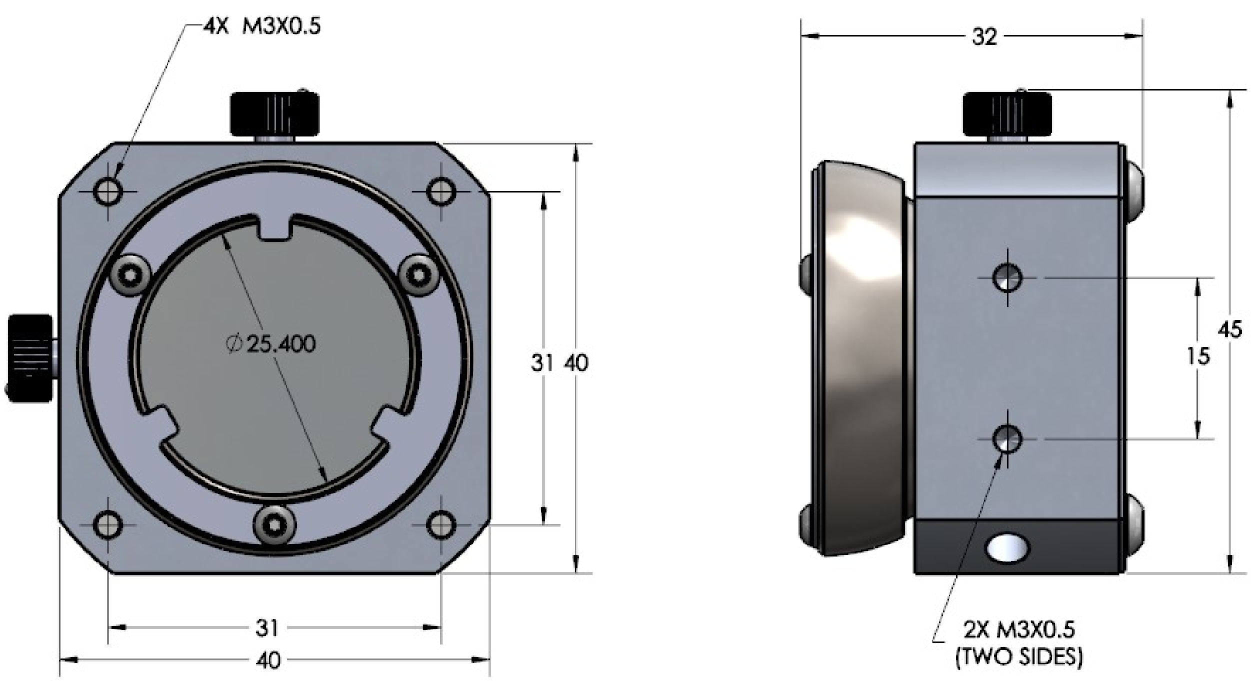


Figure 9. Dimensioned drawing (dimensions shown are in millimeters)

4.5 Economics

There are three primary parts to the proposed mount (moveable mount, stationary base, clamp) to be considered as the major cost elements. Of those three parts the stationary base is the most complex. All three parts are primarily turned parts with varied amounts of secondary machining. While a detailed cost analysis has not been completed it should be apparent that the costs will be quite competitive to other mounts in similar volumes especially mounts that provide gimbaled motion.

4.6 Summary of design goal compatibility

The proposed mirror mount meets the goals that were initially envisioned, as outlined in the introduction. Adherence with the established set of requirements positions it well to meet the demands of OEM environments without sacrificing usability and features that customers have come to expect.

5. DERIVATIVE DESIGNS

5.1 A platform with three axis rotational adjustability

Figures 10a and 10b depict a derivative design where a surface with a standard hole pattern has been introduced for mounting a variety of devices or items and a third adjustment actuator has been added to provide a third, finely adjustable rotational axis.

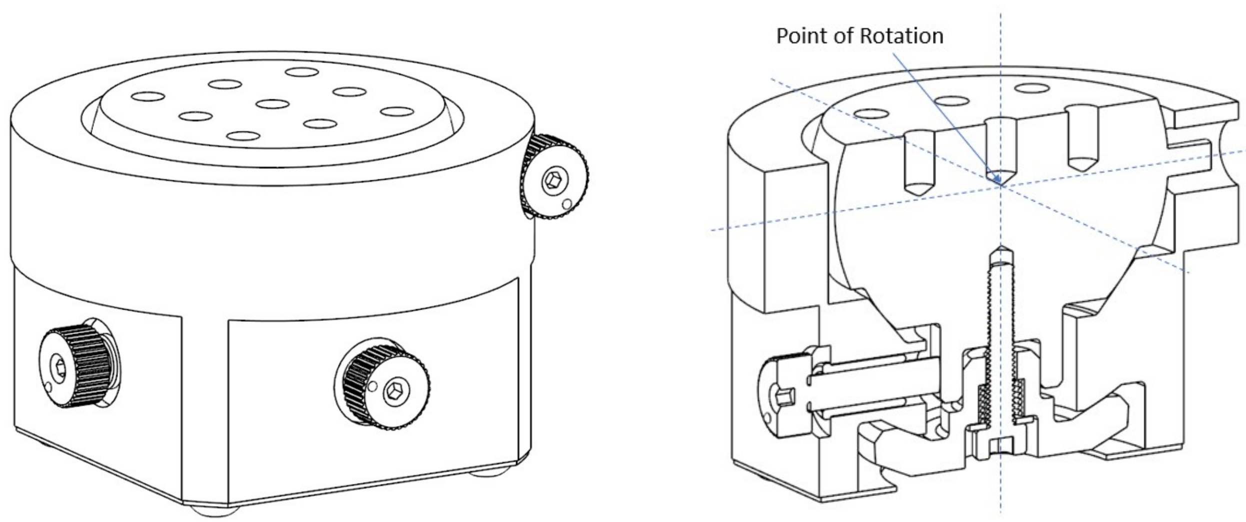


Figure 10a and 10b. Detailed views of platform version of mount

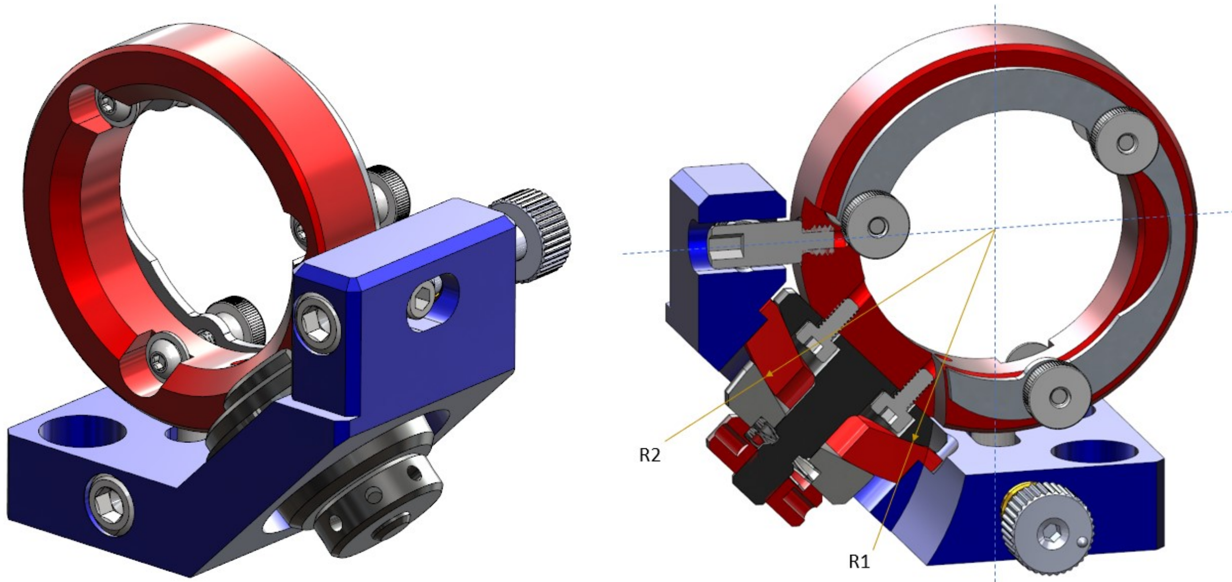
This embodiment maintains the same spherical interface and locking mechanism and provides a compact convenient platform to facilitate 3-axis rotational adjustment.

5.2 A compact design suitable for use with beam-splitters and other transmissive optics

The initial embodiment of the design was developed primarily as a mirror mount. However, tip / tilt style optical mounts are also used with beam-splitting elements, filters, or other transmissive elements for which the initial design is not well suited. One possible approach is to mount the transmissive optical element within a frame mounted normal to the platform of the mount depicted in Figure 9. However, the point of rotation for that style mount is below the surface and some of the advantages of the spherical interface approach are lost.

In order to address these shortcomings an alternative implementation was developed that moves the spherical interface off the intended optical axis. A spherical interface has been maintained to guide the motion of the mount around a common rotation point. In addition, the lock that incorporates a secondary spherical interface concentric with the first has been incorporated as well.

Figure 11a shows the mount and Figure 11b shows the same mount with a cut-away portion as to reveal the spherical interfaces.



Figures 11a and 11b. Detailed views of derivative design

A mounting ring is provided that locates the optic on the front surface through contact in three defined areas. A thin secondary ring clamps the optic in place with three opposing areas. The rotational point is located in the center of the mounting ring and coincident with the front surface of the clamped optic. The spherical interface again locates the position of the optic and constrains the three translational degrees of freedom. There are two actuators that confine "tip" and "tilt" and the final rotational angle (a rotation about an axis concentric with the mounting ring) is constrained by limiting the motion of the pins the actuators press against to only be along the axis of the slot they are located in.

Another feature of this embodiment of the mount design is the large aperture available even with incident angles of 45°. Specifically, the design shown in Figures 11a and 11b can pass a 13mm diameter beam at a 45° angle without clipping.

6. SUMMARY

A brief survey of existing optical mirror mount designs has been provided as background for the introduction of a novel optical mount design. The newly developed mirror mount has been specifically designed to possess a unique feature set intended to optimize the mount for integration into OEM systems. The guiding geometry of the mount has been further explored and derivative designs introduces to provide many of the same features and advantages to other common applications.

REFERENCES

[1] Yoder, Paul R. Jr., *Design and Mounting of Prisms and Small Mirrors in Optical Instruments*, SPIE Optical Engineering Press, Bellingham, 132 (1998)

[2] Wallace, John, "Photonics Products: Mounts and Accessories: Tip/tilt, mirror mounts deliver accuracy, stability," www.laserfocusworld.com, vol 50, issue 11 (2014) https://www.laserfocusworld.com/articles/print/volume-50/issue-11/features/photonics-products-mounts-and-accessories-tip-tilt-mirror-mounts-deliver-accuracy-stability.html

[3] Hodge, Robert B., Hodge, Robert S. Positioning apparatus. U.S. Patent 8,925,409, July 6, 2011

[4] Dallakian, Armen Yu. Gimballed optical mount. U.S. Patent 6,198,580, August 17, 1998

[5] DeWitt, Frank A. Optical Mount. U.S. Provisional Patent Application 62/700,017, July 18, 2018