2022

CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF MECHANICAL ENGINEERING

DEPARTMENT OF INSTRUMENTATION AND CONTROL ENGINEERING

MASTER THESIS

BEAM STEEERING ASSEMBLY

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SUPERVISOR: Ing. Bc. Němcová Šárka Ph.D.

MASTER'S THESIS ASSIGNMENT

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Branch of study: **Instrumentation and Control Engineering**

II. Master's thesis details

Master's thesis title in English:

Beam steering assembly

Master's thesis title in Czech:

Sestava odkláněče svazku

Guidelines:

- Analysis of the beam steering requirements and the tolerances of beam aiming.
- Research of existing off-the-shelf solutions suitable for vacuum applications.
- Design of a 6" mirror holder with necessary motions (translations, rotations), fitting the existing mirror box.
- Application of adjustment elements capable of a remote control.

Bibliography / sources:

[1] Born, Wolf: Principles of Optics, 4th edition
[2] R. Kingslake: Optical System Design
[3] Williams, Becklund: A Short course for Engineers and Scientists

Name and workplace of master's thesis supervisor:

Ing. Bc. Šárka Němcová, Ph.D., Division of Precision Mechanics and Optics, FME

Name and workplace of second master's thesis supervisor or consultant:

Date of master's thesis assignment: **29.10.2021** Deadline for master's thesis submission: **20.01.2022**

Assignment valid until: ___________

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Supervisor's signature

Head of department's signature

prof. Ing. Michael Valášek, DrSc.
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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

02-11-2021
Date of assignment receipt

Student's signature

DECLARATION

I declare that I have worked on this thesis independently assuming that the results of the thesis can also be used at the discretion of the supervisor of the thesis as its co-author.

I also agree with the potential publication of the results of the thesis or of its substantial part, provided I will be listed as the co-author.

Prague, Sengunthar Jeeva Paneerselvam

ACKNOWLEDGMENT

For accomplishing this thesis, I am indebted to a few people who I would like to acknowledge here.

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Secondly, I would like the Karolina Macúchová of the Hilase centre for their invaluable and continous support in helping me build the design and optics part of the system.

Lastly, I would like to thank my family and friends for their constant encouragement and moral support they have given to me for finishing this thesis succesfully on time.

ABSTRACT (In English)

This thesis deals with the conversion of an existing one directional beam blender into automated with three directional transfers of beam. The main tasks involved will be to upgrade the opto mechanics mirror mount. The movement of the axis has been done by the use of stepper motors and the control has been achieved by using actuator. Instruction to the mirror mount will be in the form of translation and rotation will be generated automatically by using control system.

Keywords: 6” (inch) mirror, Mirror mount, Rotational motion, Translation motion, Actuator, Control System.

ABSTRAKT (In Czech)

Tato práce se zabývá konverzí stávajícího jednosměrného rozdělovače paprsků na automatizovaný se třemi směrovými přenosy paprsku. Hlavními úkoly bude upgrade opto mechaniky na zrcátko a instalace řídicího systému. Pohyb osy byl proveden pomocí krokových motorů a ovládání bylo dosaženo pomocí pohonu. Pokyny k držáku zrcadla budou ve formě překladu a otáčení bude generováno automaticky pomocí řídicího systému.

Klíčová slova: 6” (palcové) zrcadlo, Zrcadlový držák, Rotační pohyb, Překladový pohyb, Aktuátor, Řídicí systém.

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SCOPE OF THESIS WORK

The HILASE Centre has its own laboratory with an existing mirror mount that is obsolete. The main aim of my thesis is to refurbish the existing mirror mount and convert it into a new one which transfer laser beam into multiple direction.

The project would be a joint work between our Department of Instrumentation and Control Engineering and HILASE Centre with the former taking care of the mechanical construction, configuring of the electronics and control system for the mirror mount.

Scope of Work Involved is:

1. Perform a case study of the existing distribution system and identify the functioning of its key component.
2. Study the working and technologies of Mirror Mount and the components required to build new one.
3. Prepare and propose a purchase component required.
4. See the possibility of using the existing system.
5. Install the 3DOF for the system which is used to complete all the required function of the system.
6. Configure of the laser distribution system.

1. INTRODUCTION

A mirror mount is a device that holds a mirror. In optics research, these can be quite sophisticated devices, due to the need to be able to tip and tilt the mirror by controlled amounts, while still holding it in a precise position when it is not being adjusted.

An optical mirror mount generally consists of a movable front plate which holds the mirror, and a fixed back plate with adjustment screws. Adjustment screws drive the front plate about the axes of rotation in the pitch and yaw directions. An optional third actuator often enables z-axis translation.

Precision mirror mounts can be quite expensive, and a notable amount of engineering goes into their design. Such sophisticated mounts are often required for lasers and optical lines.

The most common type of mirror mount is the kinematic mount. This type of mount is designed according to the principles of kinematic determinacy. Typically, the movable frame that holds the mirror pivots on a ball bearing which is set into a hole in the fixed frame. Ideally, this hole should be trihedral. Often a conical hole is used due to easier manufacture.

The frame is pivoted by means of two micrometres or fine-thread screws. Mirror rests on a flat surface of the mirror mount. On cheaper mounts, the flat surface may be simply the material of the mount. In more expensive mounts, the flat surface (and perhaps the hole and v-groove too) may be made of a much harder material, set into the frame[11].

The reason for this strange mechanism is that the first automatic actuator contacts the fixed frame at exactly two points, these two points of contact exactly constrain the two DOF for motion of the movable frame. This leads to precise movement of the frame when the automatic actuator or screws are turned, without unnecessary wobble or friction.

A disadvantage of kinematic mounts is that the center of the mirror moves along its normal axis (were discussed in mirror mount chapter). One way of eliminating this translation along the axis is to set the actuator as well. By appropriate adjustment of actuator, the mirror can be tilted in either direction without translation. The actuator can by driven by a motor under automatic control to make this seem to the operator like simple rotation of the mirror mount. The translation can instead be eliminated mechanically by using a custom design of mirror mount, which uses two mirror that each pivot about a line running through the center of the mirror. This gives kinematically correct two-axis rotation about the center of the axis.

With these types of mirror mount, springs are needed to keep the frame pressed against the ball bearings, unless the mirror mount is designed to be used only in an orientation where gravity will keep the frame in place. Following the cantilever principle, a large mount allows finer control than a smaller one. The frames are ideally made of a light material, to make the resonant frequency of the structure high. This reduces vibration since many common sources of vibration are relatively low frequency. For stability, the fixed frame is supported by a rigid mount that is securely bolted to a supporting surface. In a laboratory environment, this is typically an optical table. A shock can cause the mirror mount to move away from the axis, but because there are hard contacts, the mirror will return to the original position, preserving the alignment.

The mount itself must avoid deformation of the mounted optics. Stress from mounting can introduce aberration in the light reflected from a mirror. In some lasers the mirrors must be easily replaced, in this case the mount needs to be designed to allow the mirror to be removed and replaced without losing the correct alignment.

2. Design Theory

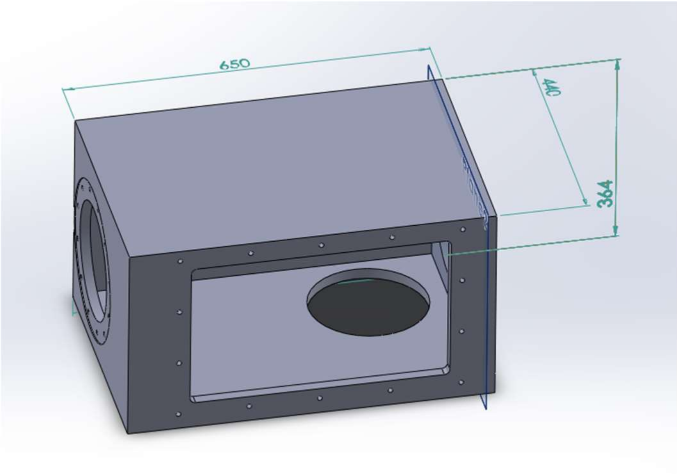

Figure 1

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As seen in the attached figure, the volume of the existing chamber is 364*440*650 mm. In addition, the shape of the laser beam from the source is 75*75 mm laser beam aperture has homogeneous energy distribution. Although there is no material restriction for the product from the starting, but it is recommended to use vacuum compatible material. Other material to be used in the system is taking under consideration for vacuum purpose.

The design is generally based on reflecting and direction diverges of laser beam onto a chamber to a purposed workstation. During the operation time of the system, it is ensured that the laser beam hits the mirror on the mirror mount, and it diverges. During without the operating time of the system, the laser beam simply enters from the source that passes out without any disturbance to the workstation.

The mirror mount will fit under the rotational stage which gives 360-degree freedom to the mount. Mount will consist of two reflective mirrors one set at 45 degrees to another is set at 90 degree and the LBDS design is designed to allow laser beam to deliver the desired workstation.

3. Operation of Laser Beam

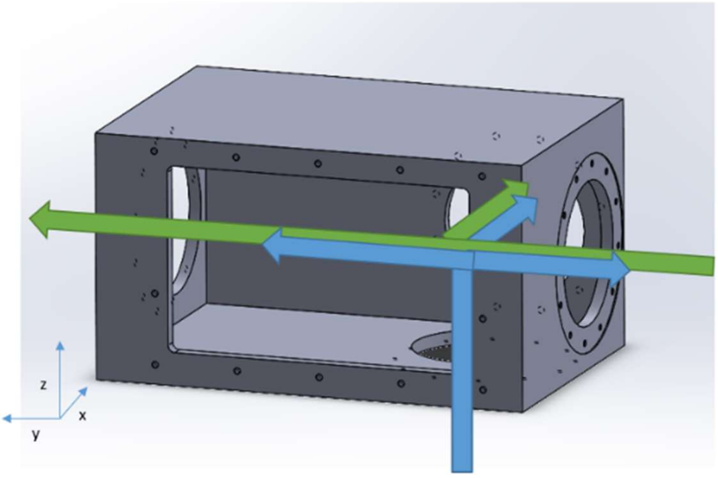


Figure2: Laser lines Overview

In the above figure, the outside view of the vacuum chamber and entrance of the laser beam to the mirror mount are seen. And the dimensions of the workstation are known from the following figure.

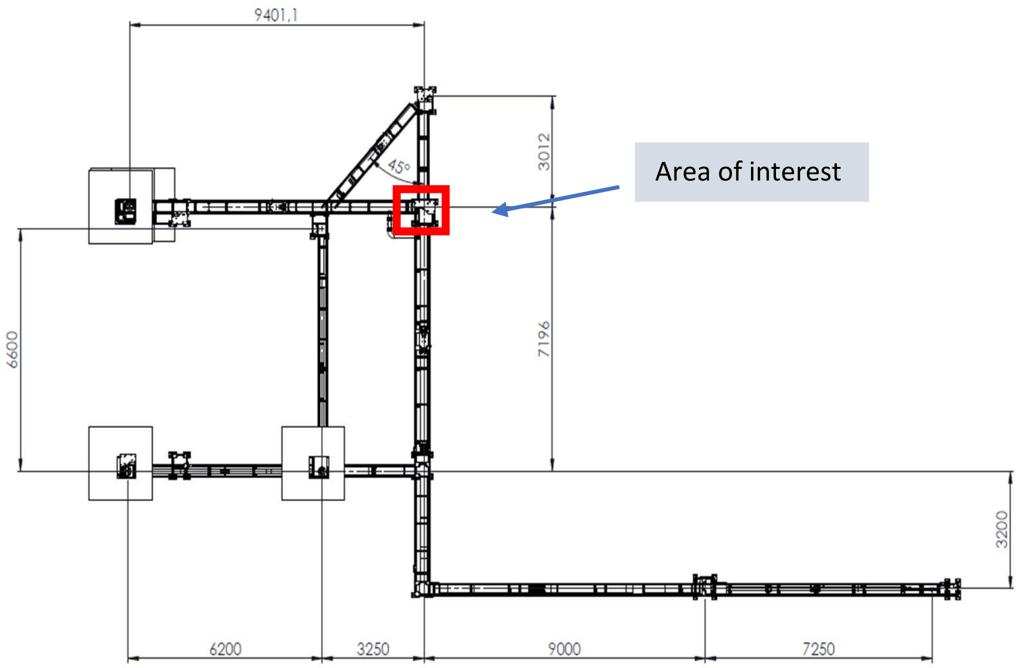


Figure3: Framework of the System

4. Overview of the LBDS

The existing system in our subject is a several year obsolete LDS which was used to transfer laser beam in single direction. Although the system is fully functional but some of the existing parts needed to be changed or replaced for our need to complete the requirement.

Overview of existing LBDS system

The below attached picture4 is framework of the existing laser beam distribution system before progress of the system. In this we notice that in this laser beam is diverges in one medium of Axis direction. So that the 45-degree angled mirror mount is not necessary. All the operation of the system is done by single mirror mount just by rotating the mirror mount into desired position of the workstation. As we seen that here there is one laser beam is passed in the system.

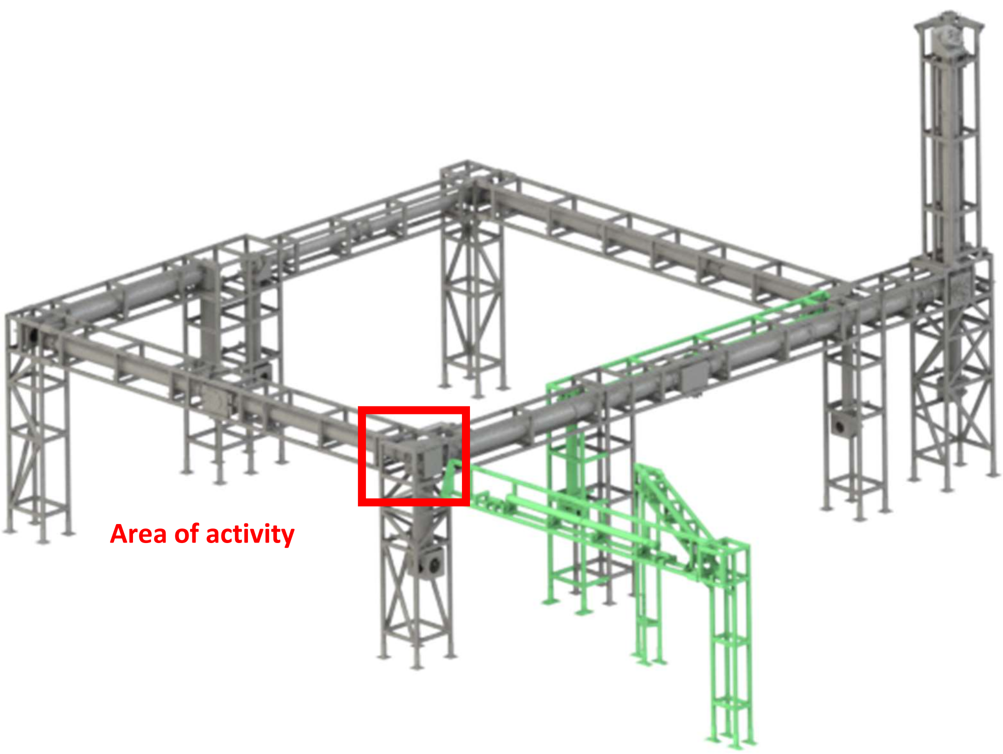


Figure4: Before progress of the system

The below attached figure5 is framework of the laser distribution system after the progress of the system. In this we see that there is two laser beam is coming out from the source alternatively one of the laser beams is entering parallel to the system that beam diverges to Y axis and x axis simultaneously and the second beam enters from the bottom of the chamber from z axis that beam is diverged into three directions of the system to the desired workstation.

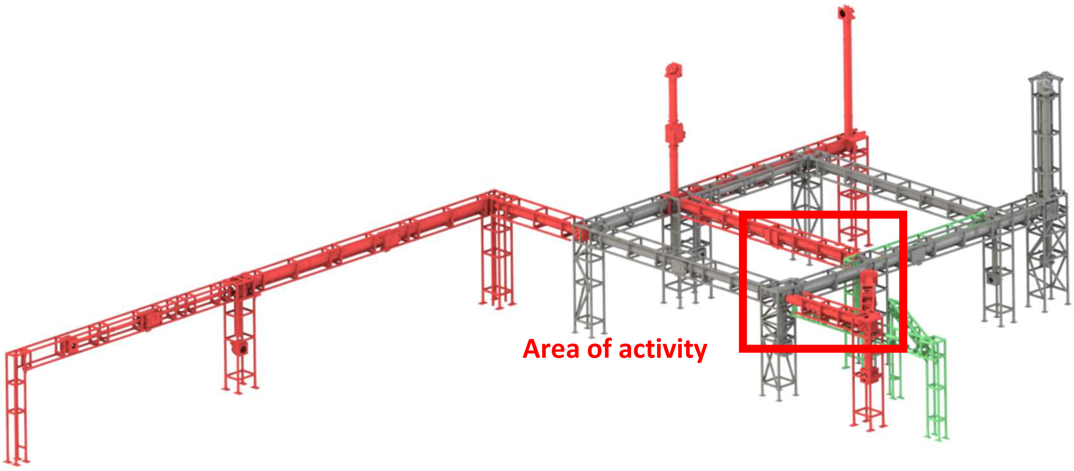


Figure5: After upgrade of the system

5. Required Direction of Laser Beam

As shown below figure6 Vacuum chamber is the part that holds the assembly together, in which the rest of the assembly is contained. There are holes on it for laser beam inlets and outlets, as well as actuator for the mirror mount.

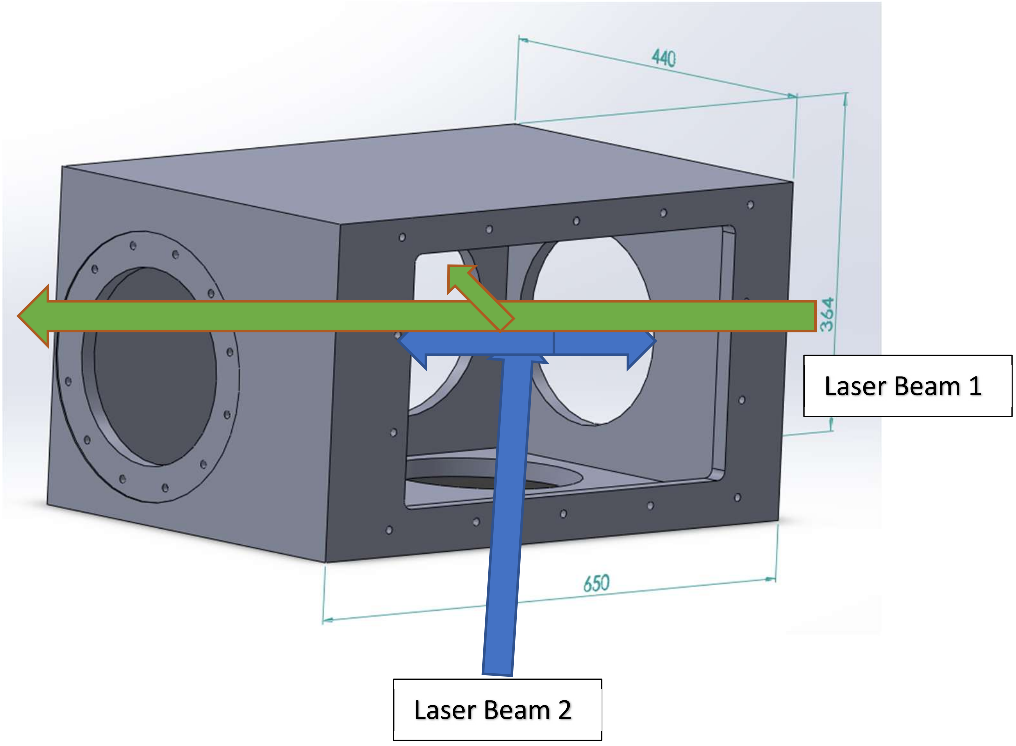


Figure6: Laser Beam Transmission

As seen in the figure6 above, the maximum outer dimension target for the vacuum chamber is provided. The dimensions are 650*440*364 mm, and the wall thickness of the object is 20 mm. Laser input is designed as 75*75 mm. Here, the area of the laser set to the object is assumed to be 106 mm diameter and it is desired to obtain a bigger dimension that the laser beam cross section dimension.

In the system, we choose existing chamber that which is already present in the Laser beam distribution system at the research center. The vacuum chamber is equipped with a breadboard used for supporting a positioning mechanism to meet requirement. The surface of the vacuum chamber is cleaned and polished to ensure from any possibility of air inside the chamber. The chamber is made by stainless steel which are operated under the vacuum environment. The vacuum chamber contains rotational, translation and mirror mount for our optimistic requirement. Then the vacuum chamber gives the output of the laser beam from the precise mechanism as per need.

The source of laser transmission will be fixed in a stationary position. Mirror mount is required to transmit the laser beam onto the different direction for purposed workstation. To do this we have to make use of necessary optics.

To complete the path of the laser beam, we will need reflecting mirror, rotational motion, translation motion and the suitable mirror mount holder which making 45° and 90° degree in the required direction to meet the requirements.

LBDS has two independent laser beams. The first green identified laser which is coming from y axis that diverges into two ways as shown in figure. For the divergence of the laser beam into x axis will turn the flat 90-degree mirror mount in 45-degree so that the laser beam diverted to the purposed direction which is on x-axis.

The second laser beam which is entering from bottom Z-axis of the vacuum chamber is identified by blue colour that laser beam is diverted into three different directions. So, to divert these beams we placed mirror mount in inclined position which makes an angle of 45-degree with adjustment screw actuator. With the axis of rotation of the mirror mount will diverge the beam into required workstations.

6. General Overview of existing Opto-Mechanical Mirror Mount

An Optical Mirror Mount is a device used in optics research that secures a mirror in place while allowing for precise tip and tilt adjustment. Optical mirror mounts are often mounted to an optical table to give a high level of vibration isolation due to the delicate nature of optics research. Mirror mounts can be manually adjusted using a micrometer head or adjustment screw, or they can be automated with a motorized actuator. Kinematic, Gimbal, and Flexure are some of the adjustment mechanisms.

6.1 Kinematic Mirror Mount

Because of their outstanding stability and inexpensive cost, kinematic mirror mounts are the most frequent. The kinematic mechanism is the best alternative for delivering the requisite performance for many today's laboratory experiments. Cross-coupled adjustment, beam translation, and limited angular travel are all disadvantages. The axis of rotation is frequently behind the optic and non-stationary in location and direction. As a result, the axes shift with each adjustment, and they no longer remain orthogonal to the optical axis, resulting in cross-coupled motion during adjustment. Second, because the axis of rotation is behind the optic when corrections are performed, the optic rotates and is translated[16].

Finally, due to the physical limitations of the springs and adjustment screws utilized, most kinematic mounts have an angular travel range of less than 10 degree. The kinematic mount's shortcomings prompted the development of the gimbal mechanism, which solved these issues.

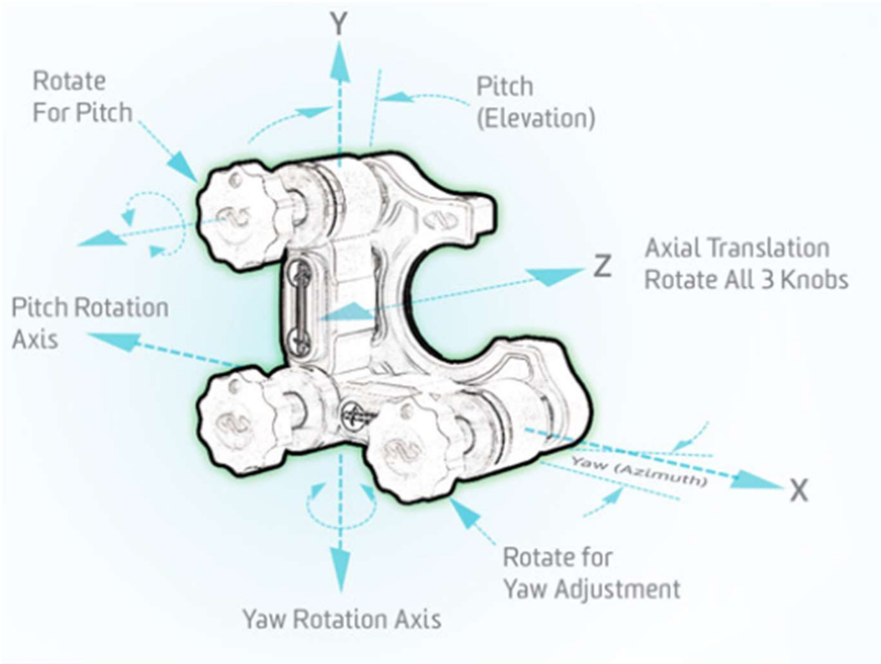


Figure7: Kinematic Mount[16]

The cone, groove, and flat mounts are the most common kinematic mounts, as shown schematically in the diagram below. Consider the optic as being connected to the three spheres in the figure's coordinate system, as well as its corresponding mount, which has the cone, vee, and flat. Three DOF are eliminated without redundancy if the optic is initially situated in the cone. With respect to some arbitrary fixed coordinate system, the position of each optical mirror mount can be specified uniquely in terms of six distinct coordinates, three translations, and three rotations. When the number of degrees of freedom and physical limitations given to a mirror mount total six, the mount is said to be kinematic. This is the same as arguing that any physical limits are unrelated. As a result, a kinematic optical mount has six independent limitations.

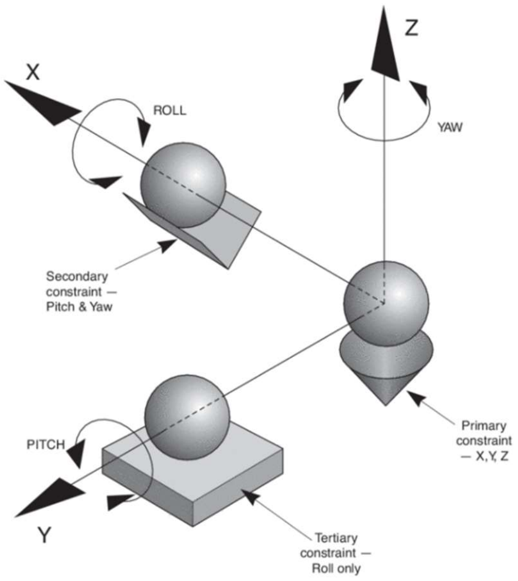


Figure8: DOF of Kinematic Mounts[16]

Increased stability, distortion-free optical mounting, and, in the case of a kinematic base, detachable and repeatable repositioning are all advantages of a kinematic mount. With the mount shown above, it's easy to envisage the plate containing the cone, vee, and flat thermally expanding at a different rate than the optic without causing the optic to deform. Simply put, the mount would grow around the ball and cone. The second and third balls, respectively, would slide on the groove and flat. If the mount, on the other hand, was non-kinematic and the plate expanded or contracted along the x axis, the optic would warp because the second ball could no longer slide in the groove.

The optic can still revolve freely around all axes at this time. The second sphere is then inserted into the groove that is aligned with the cone. As illustrated in the diagram, this restricts or eliminates two more degrees of freedom: pitch and yaw. To avoid over-constraining one or more of the translation degrees of freedom, the groove must be aligned towards the cone. Finally, there is just one degree of freedom left to constrain, which is the ability to roll about the x-axis. The third sphere is seated on the flat to achieve this. This is a kinematic mount since it has six non-redundant constraints.

Suprema Zero Drift Thermally Compensated Mirror Mounts are an excellent choice for use with extremely flat mirrors. To hold mirrors in a way that does not cause optical distortion, Zero Drift technology has been paired with a low wavefront distortion (LWD) retainer. It uses an axial three-point mounting approach to hold optics with tight flatness tolerances gently but securely. When compared to traditional stainless-steel mounts, these mounts also have kinematic features that adjust for temperature-induced alignment drift, resulting in improved optical pointing stability.

6.2 Gimbal Mount

The axes of rotation in a gimbal mechanism are orthogonal and fixed in space. As illustrated below Figure9, the rotation axes cross at the center of the front surface of the optic in the mount, allowing for non-coupled rotation adjustment of the optic while simultaneously eliminating beam translation. Gimbal mounts also offer substantially longer travel ranges than their kinematic equivalents. Many gimbal designs feature a full 360 degrees of angular movement in both axes since the rotation is often directed by an axel. In the other hand, are typically larger and more expensive[16].

Attaching a screw drive to the second and third spheres to offer angular adjustment of the optic with regard to the base is a standard way to make kinematic mounts adjustable. The position and orientation of the mount's rotation axis is one disadvantage of this sort of mount. They are frequently non-stationary and behind the optic. The axes, in other words, move with each change. This raises two issues that must be addressed.

First, because the axes move, they do not remain orthogonal to the optical axis, resulting in cross-coupled motion. Simply rotating in one of the orthogonal directions to the optical axis necessitates modifying both kinematic mount axes.

Second, because the axis of rotation is behind the optic when corrections are performed, the optic rotates and is translated. The use of a gimbal mount solves both issues.

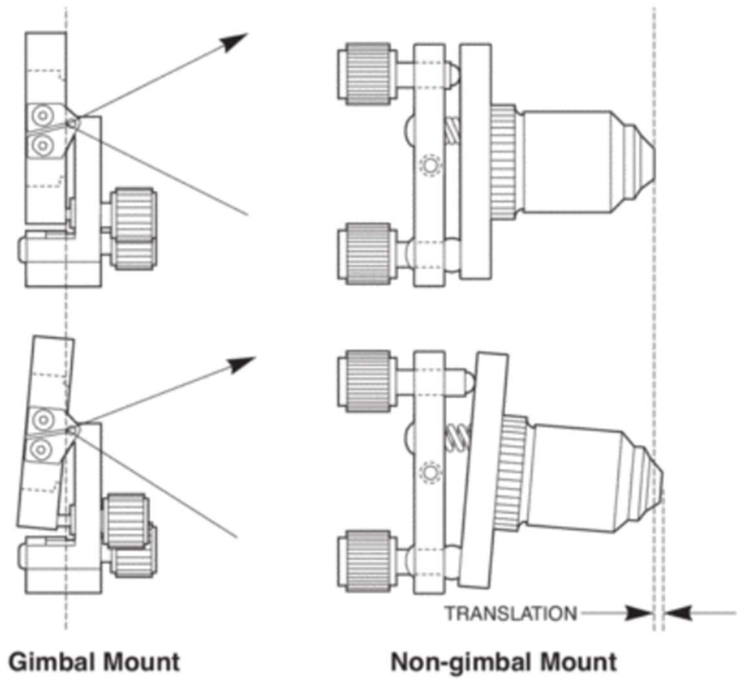


Figure9: Gimbal Mounts[16]

As a result, hybrid systems have arisen that combine the best features of kinematic and gimbal mechanisms, providing the stability and low cost of a kinematic design while avoiding cross coupling and beam translation.

6.3 Flexure Mount

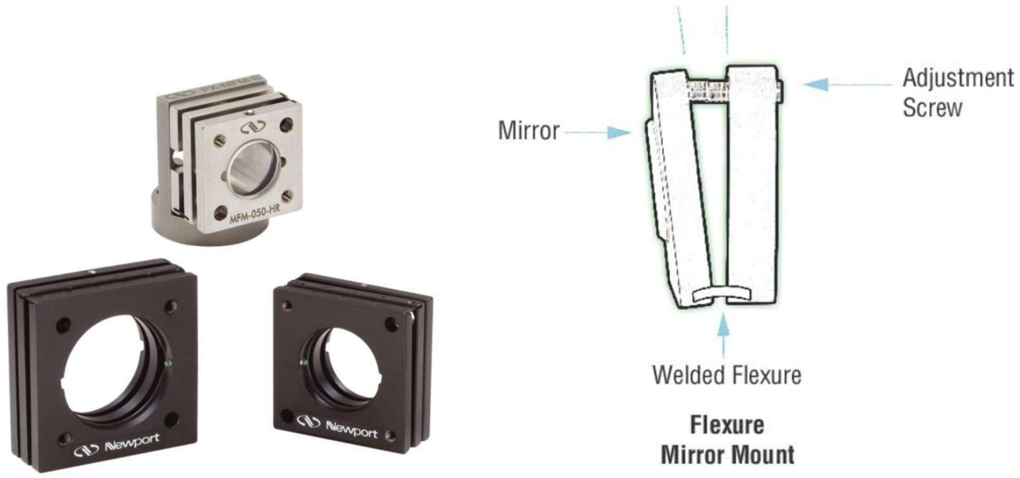


Figure10: Fixture Mount[16]

A flexure is a positioning device that provides angular translation by using the elastic deformation of a material. Mounts with a flexure mechanism have a small footprint and are shock resistant due to their welded unibody design[16].

As a result, flexure mounts are commonly used in instrumentation and other similar systems. The flexure mount has a smaller travel range than a kinematic mount and is more prone to alignment drift due to temperature changes.

7. Types of Driver (Actuator) Manual and Automatic

7.1 Allen-Key Drive

Allen-style mirror mounts Key drives are utilized in set and forget. The lack of a knob helps to prevent unintentional manipulation. Allen key adjusters can be used in tight spaces where a person's hand is too big to fit, and they're usually available in lockable variants.

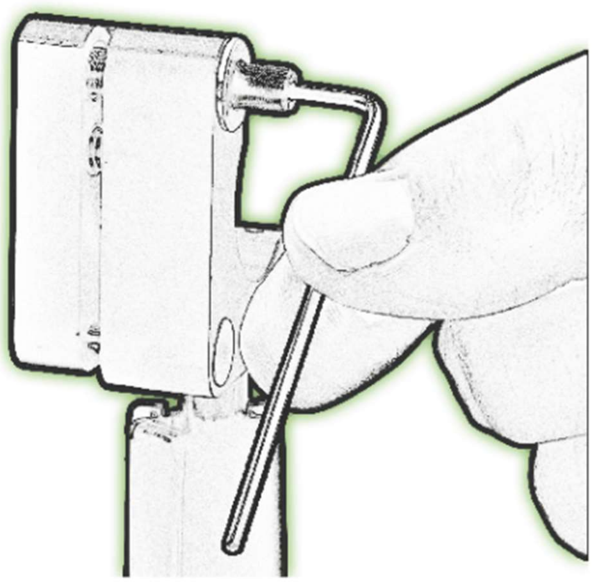


Figure 11

7.2 Knob Drive

Mirror mounts with knob drives are best for situations that require frequent adjustments. Keep in mind that the diameter of a knob impacts the sensitivity of the adjustment. Knobs with a larger diameter provide more sensitivity, but they also take up more space. An Actuator

Knobs that also be connected to an Allen-Key drive to adjust the mount knob in the mentioned figure12.

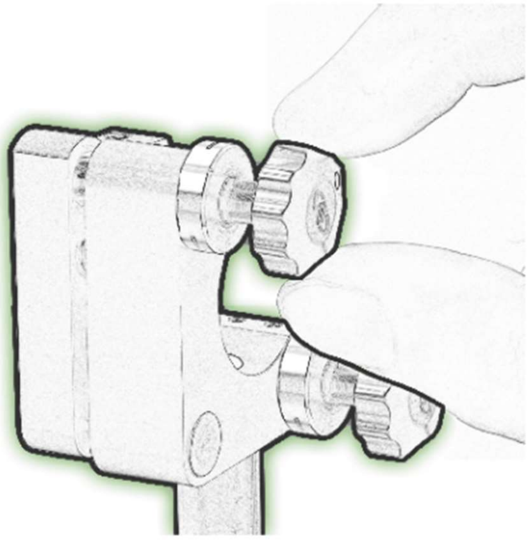


Figure 12

7.3 Micrometer Head Drive

Mirror mounts with Micrometer Head drives should be used for applications where exact position needs to be recorded and referenced. When mounting the micrometer head, it is fixed with its stem. Therefore the secured stem clamping method without affecting inside mechanism. It have a novel thumbscrew locking mechanism that clamps a non-threaded portion of the screw from side.

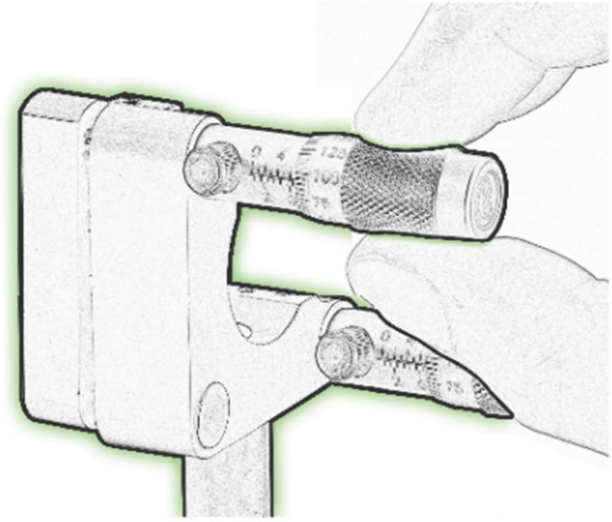


Figure 13

7.4 Motorized Linear Actuator Drive

Mirror mounts with Motorized Linear Actuators can be used for automated positioning where reaching an Allen-key or knob may be difficult and in vacuum application. Here we may also be able to make more precise adjustments when using a linear actuator with a motion controller.

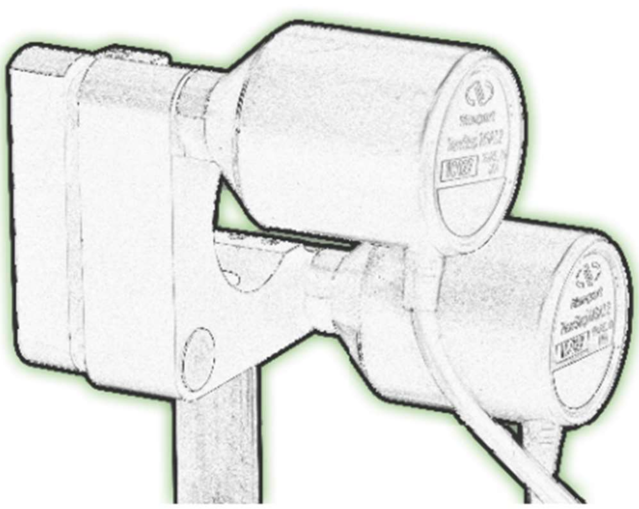


Figure 14

8. Mirror Mount Material Characteristics

8.1 Stiffness

The amount of stress (force/area) required to create a particular amount of strain is measured by stiffness. The equation $\sigma = E\varepsilon$, where σ and ε are stress and strain, respectively, and E is Young's Modulus, which is material dependant, is proportional and relates them. For larger values of E, a material is stiffer, and for lesser values, it is more compliant. Stainless steel, for example, is approximately three times stiffer than aluminum (see below table 1). Aluminium, on the other hand, has 1.3 times the flexibility of brass. When it comes to settling time or vibration immunity, specific stiffness is crucial. Higher specific stiffness means higher resonance frequencies, shorter settling times, and less vibration disturbance. The fundamental resonant frequencies of components with the same form and particular stiffness will be the same.

8.2 Thermal Expansion

Temperature fluctuations cause a mounting component's size and form to alter. The size and form of the component, as well as the degree of temperature change and the material employed, all influence the size and shape change. The equation relating dimensional change to temperature change is $\Delta L = \alpha L \Delta T$ where α is the material dependent coefficient of thermal expansion.

Stainless steel has a thermal expansion that is nearly half that of aluminum. When the mounting component is used in an application that requires interferometric stability, this can be critical. When there is a non-uniform temperature variation across the component, aluminum is the best choice.

Because aluminium's thermal conductivity is ten times that of stainless steel, heat can be dispersed more quickly, minimizing the magnitude of thermal gradients and deformation. The coefficient of thermal expansion divided by the coefficient of thermal conductivity is related to the distortion induced by non-uniform temperature variations.

In a non-uniform temperature environment, aluminum distorts on the order of three times less than stainless steel.

8.3 Material Instability

The term material instability refers to a change in physical dimension over time, often known as cold flow or creep. The time it takes to witness this creep in aluminum and stainless steel might range from months to years.

In most cases, the component's mechanical design contributes far more to the component's instability than the material choice. The lubrication on the micrometer's threads, for example, can migrate with time, causing the micrometer to shift slightly.

Aluminium: Aluminium is a lightweight material with a good stiffness-to-weight ratio that is resistant to cold flow or creep. It has a high thermal conductivity and a moderately high coefficient of thermal expansion, making it a desirable choice for applications with thermal gradients or where rapid acclimation to temperature changes is necessary. Aluminium is a versatile material that is easy to machine, inexpensive, and frequently used in component structures. In a laboratory setting, even when the surface is uncovered, aluminum does not rust and is generally corrosion-resistant. When anodized, it has a beautiful polish. Anodized surfaces, on the other hand, are extremely porous, rendering them unsuitable for usage under high vacuum. Unfinished aluminum surfaces are required for vacuum applications.

Stainless Steel: Steel has a high modulus of elasticity, which provides it with excellent stiffness (almost three times that of aluminum) and material stability. It also has half the thermal expansion of aluminum, making it a great choice for laboratory situations with consistent temperature variations. Steel takes substantially longer to machine than aluminum, making steel components far more expensive. Steel corrosion is a severe issue. Stainless steel alloys are resistant to corrosion, unlike other steels. Stainless steel is well suited to high vacuum applications, although additional aspects must be considered in the components design.

8.4 Exterior Finish

Aluminium that has been anodized has high corrosion resistance and a nice surface. On optical mounts, black is the most common color. The surface of the anodized aluminum is extremely porous. As a result, in high vacuum applications, only unanodized aluminum is used. This porosity, on the other hand, produces a matte surface that does not specularly reflect light, which adds to its usefulness in optical mounting. Anodizing hardens the surface, making it more resistant to scratches and damage.Parts made of steel are usually plated or painted. Chrome, nickel, rhodium, and cadmium are common platings. To avoid rust, screws and mounting hardware are frequently given a black oxide finish. Components that have been painted should be avoided. Paint will eventually flake off, polluting the positioner's optics or moving parts.

Other steel alloys rust, while stainless steel alloys don't. They're extremely clean materials that don't require any additional surface protection. A surface that has been glass-bead blasted will have a dull finish that does not reflect light well.

8.5 Vacuum Compatibility

For high vacuum and ultra-high vacuum systems, stainless steels and aluminum are the most prevalent materials. Aluminium alloys are another type of material that is commonly utilized. Unless the alloys contain higher quantities of zinc, they are machinable and have low outgassing. Because the oxide layer traps water vapor, the items must not be anodized. Anodizing also renders the surface non-conducting, preventing it from charging up in electrostatic systems. Alochroming is the greatest treatment since it seals the surface, making it hard and conductive. Its outgassing rate is significantly lower than that of untreated aluminum. Aluminium and its alloys have low strength at high temperatures, deform when welded, and are difficult to weld with other material. Aluminium has a high thermal conductivity, is corrosion resistant, and has a low hydrogen solubility. Aluminium's usage in bakeable applications is limited because to its loss of strength at high temperatures, but it is useful for large-scale systems due to its lighter weight and lower cost than stainless steel.

Mirror mounts are the most stable and easiest to line because they are composed of stainless steel in our LDB system. Because stainless steel is three times stiffer than aluminum, it flexes less and allows for better alignment. The coefficient of thermal expansion of stainless steel is lower than that of aluminum, making it more stable during temperature changes.

Parameter	Steel	Aluminium
Young's Modulus (stiffness), E, (Pa)	1.93e+11	7.2e+10
Thermal Expansion, a (1/K)	258.48	262.26
Thermal Conduction, c (W/mk)	26.98	179.88
Specific Stiffness, E/ρ	2.5394737e+13	2.7692308e+12
Relative Thermal Distortion, a/c	9.58	1.46
Density, ρ, (kg/cc)	0.0076	0.026

Table1: Parameters of materials

9. Mirror Mount and Assembly Components for the System

9.1 Translation Stage

In this section, the mirror and some parts used in its assembly will be examined. Motorized actuator, pad for holding and some fixing elements. The mirror is a moving part so therefore some mounting and moving elements have been designed for its fixation. This ensures a compact movement[6].

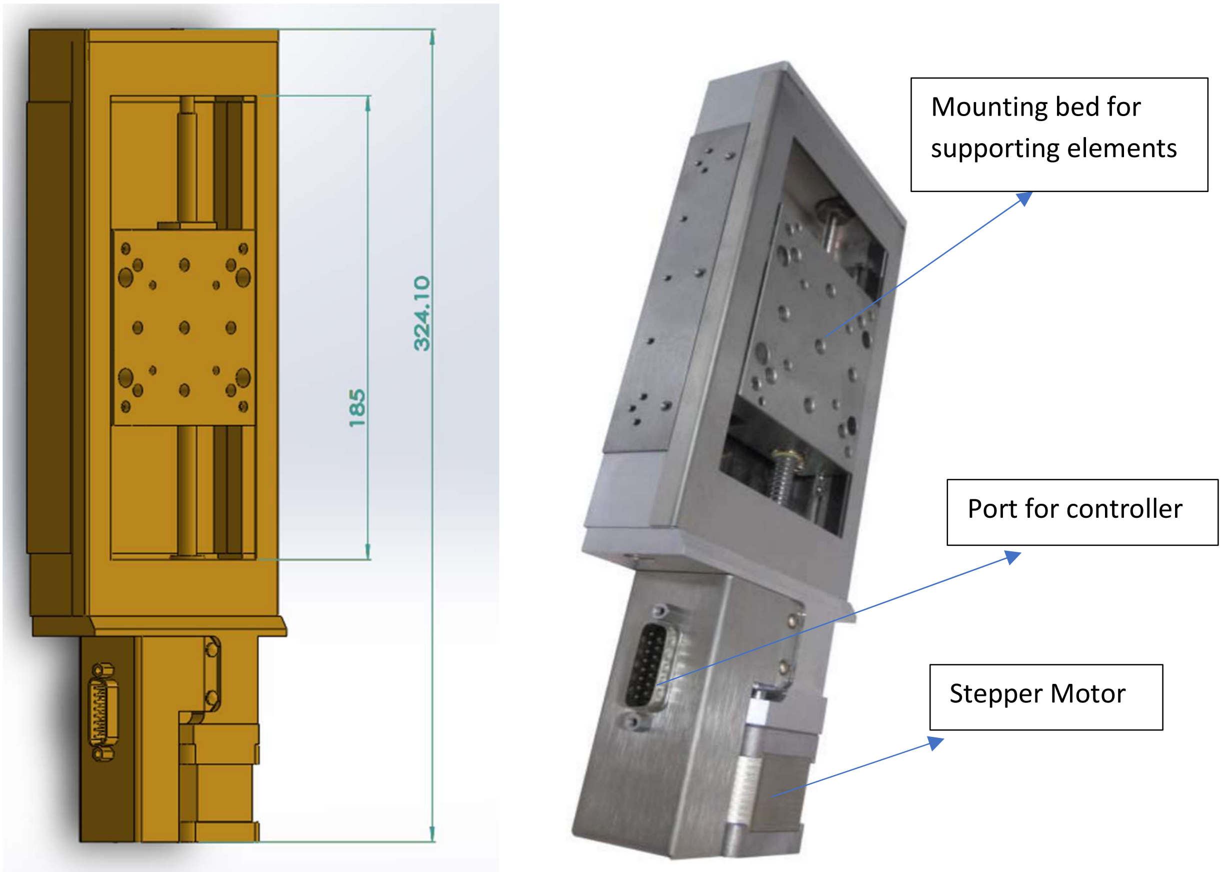


Figure 15: Model of Linear Actuator[6]

Linear Actuator has a stepper motor and the circular motion produced by this motor is converted into linear motion on the actuator. The linear actuator used in the design can be found widely in the market and its table on it can move displacement of approximately 100 mm expected from the mirror due to design. There are many holes on it both for mounting to the bread board and for mounting mirror elements to the actuator. Its material is aluminium alloy and stainless steel. Maximum speed of actuator is 10mm/s. Remaining all parameters is described in the below table.

This stage incorporates a low-profile design with excellent stiffness and thermal stability, making it ideal for environments where temperature is not very well controlled. The high output torque of the stepper motor minimizes the risk of lost steps and provides optimum MIM. It also features a diamond-corrected lead screw, and a precision lapped nut which includes anti-backlash preloading and a sophisticated decoupling system.

Specifications:

Model	UTS
Travel Range	100 mm
Maximum Speed	10 mm/s
Maximum Load	15 – 20 kg
Thread Type	M4 and M6
Compatibility	Vacuum
Accuracy, Typical	±1.7 µm
Actuator	Stepper Motor
Weight	3.3 kg
Mfg	Newport

Table:2

9.2 Rotational Stage

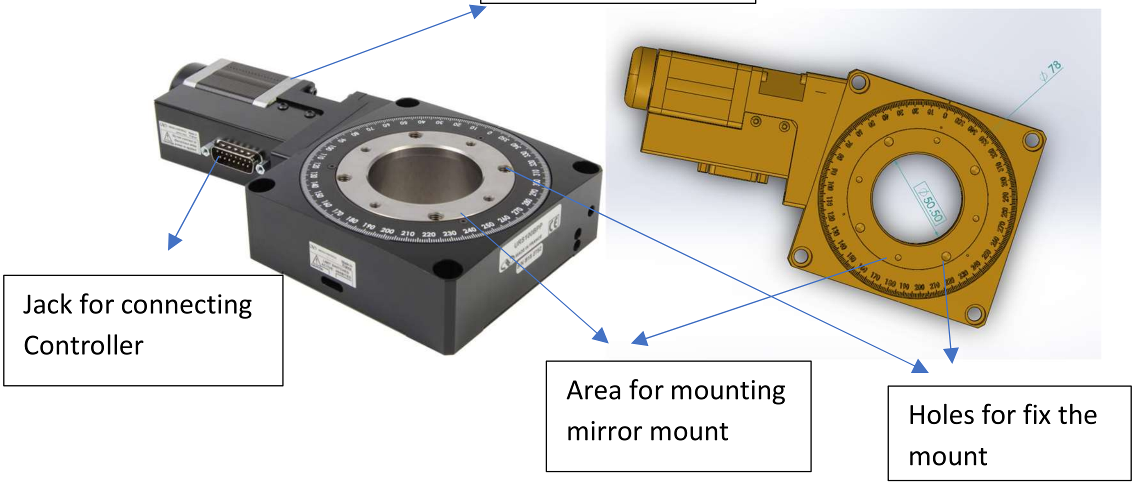


Figure 16: Rotation Stage [11]

The Rotation Stage indicated above allows for precise 360° continuous movements. It fits the needs of a wide range of research and industrial applications, as well as other linear stages. This stepper motor is a more cost-effective option for less demanding applications. Low noise operation and very small incremental motions are ensured when combined with motion controllers with high micro-step capability. The stepper motor variants do not use encoder feedback and instead rely on the number of commanded steps and micro-steps to arrive at a position[11].

The stepper motor is connected directly to the worm screw using a patented bellows coupling with high torsional stiffness for this purpose, obviating the requirement for a gear or belt drive. The stepper motor's high output torque reduces the danger of lost steps and ensures strong linearity between requested micro-steps and real stage motion.

A patented 4-point contact ball bearing is used in all rotation phases. The stage's unique 2-piece design creates a low-profile compact platform with great stiffness, durability, and wobbling and eccentricity. In comparison to conventional designs that only have 2 or 3 mounting holes, the slanted worm screw configuration provides for four symmetric mounting holes. This allows the stages to support higher or off-cantered loads more effectively. Furthermore, the worm gear's adjustable preloading system was modified to provide backlash-free operation with an MTBF (mean time between failures) of 20,000 hours.

Specifications:

Angular Range	360°
Maximum Speed	40°/s
Thread Type	M6
Compatibility	Vacuum
Accuracy, Typical	±28.8 s = 1728 min of arc
Actuator	Stepper Motor
Weight	2 kg
Mfg.	Newport

Table:3

9.3 Mirror Mount

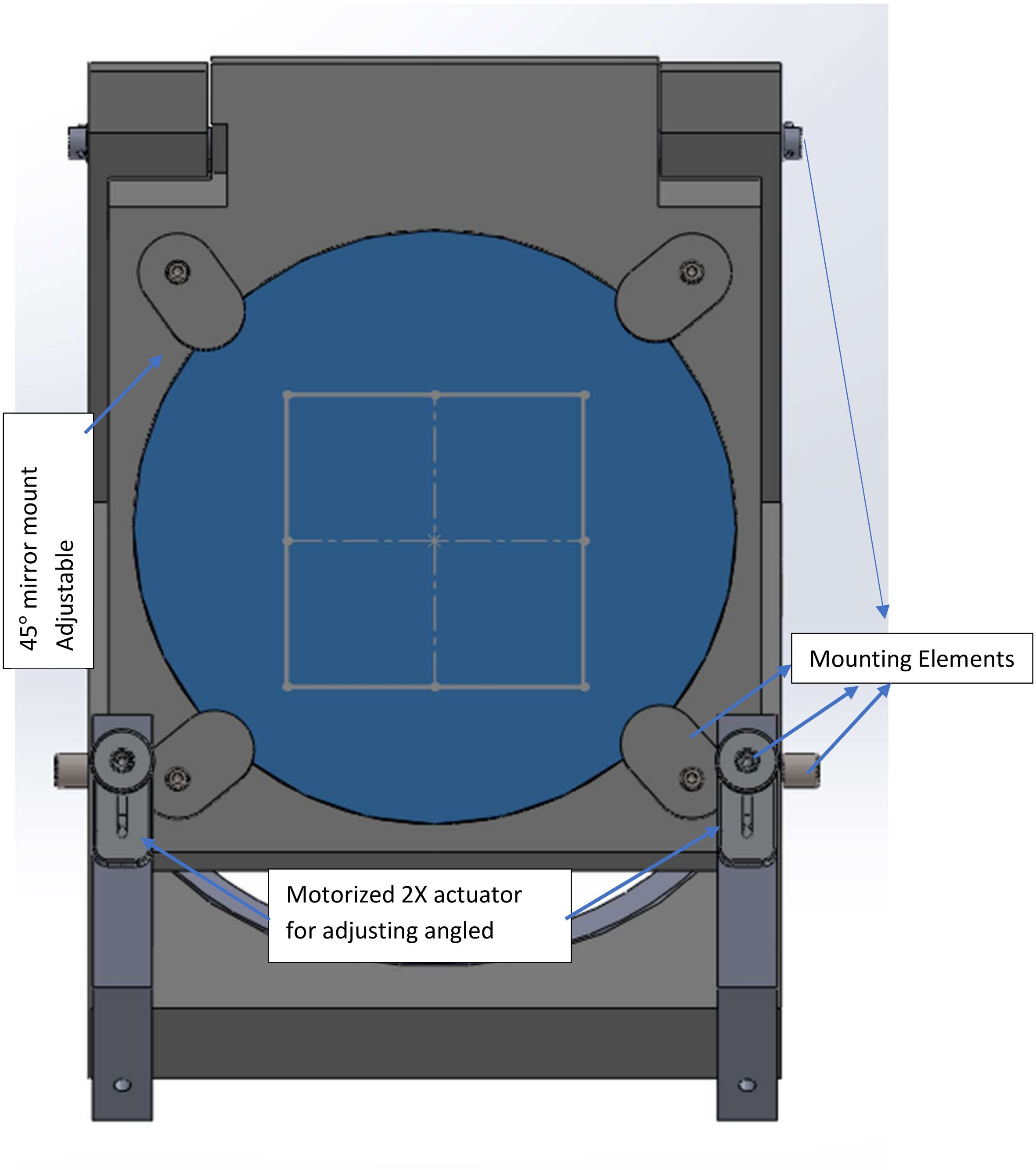


Figure 17: Mirror Mount

In this section, the mirror and some parts used in its assembly will be examined. Mirror mounting consists of mirror, holding pad, motorized actuator, and some fixing elements. The mirror is a moving part and therefore some mounting elements have been designed for its fixation. This ensures a compact movement[4].

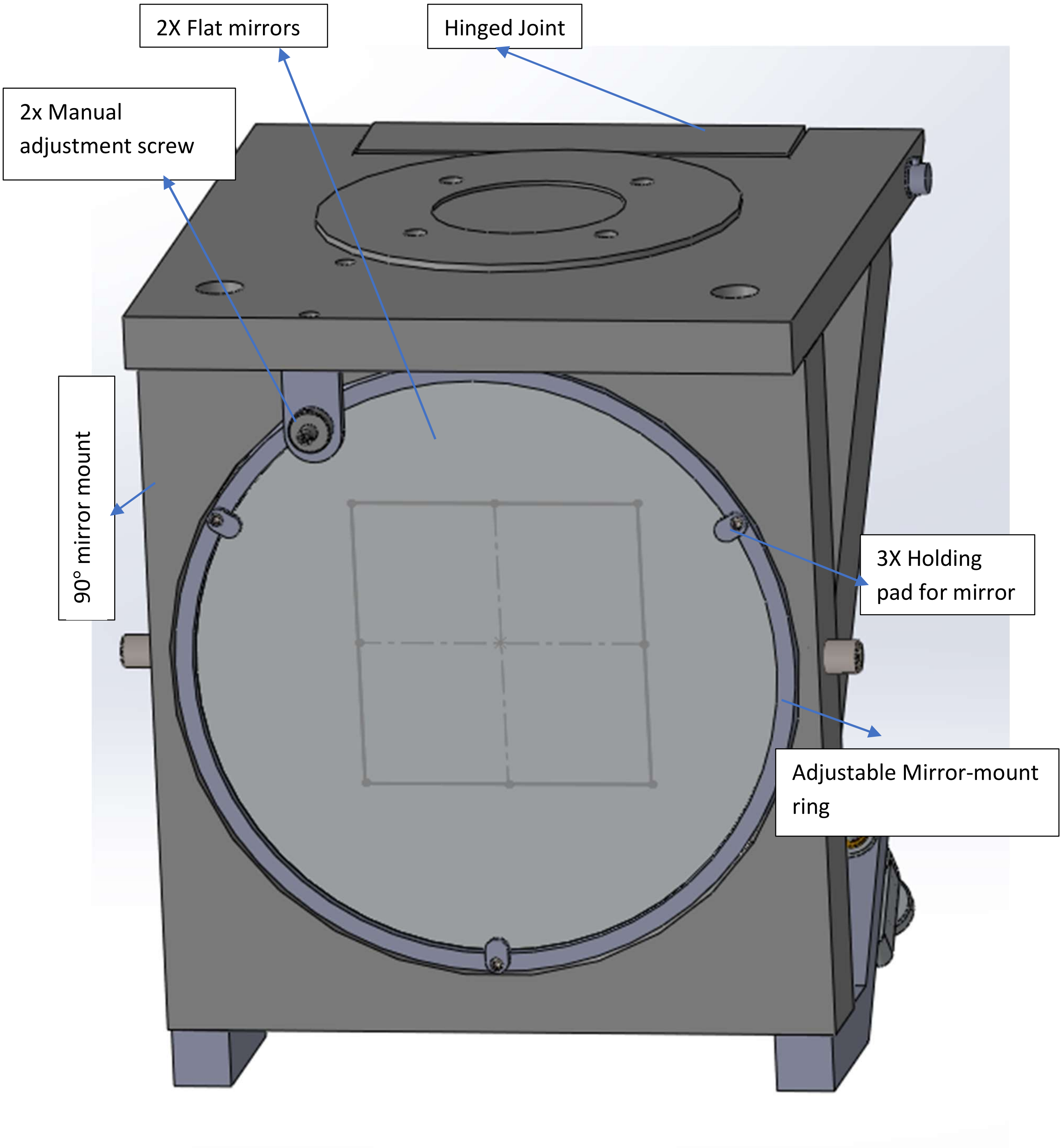


Figure 18: Opto-Mechanical Mirror Mount

The goal of the LBDS is to allow an automatic configuration of the laser beam to the purposed station. Here, the mirror is used to change the direction of the laser beam. The mirror is mounted in the mirror mount on desired position and the mirror mount is mounted on the rotation stage. To hold the mirrors in position, we used the mirror holders as shown in the image above. The holder will hold the mirror that is straight in front of the laser beam. The mirror will receive the laser beam and transmit it to the other mirror held by holder to work station. This selected mirror mount has two mirror holders one is in 90° and another 45°. The 90° mirror holder has a manual adjustment screw which make the mirror holder to 0-5° adjustment range and for 45° angular mirror mount also has a adjustment range with automatic actuator from 0-10°. so that which satisfies all required condition as per our requirement. That can be adjusted to ensure that the laser beam travels in a proposed line.

Then propagation of the mirror mount is to change the direction of the laser beam. The flat mirror is used for the optical path. This system varies by DOF of the adjustment of the laser beam. Then the mirror mount is mounted on the vacuum chamber to the system.

Specification of mount:

Optics Diameter	6”(152.4 mm)
Mechanism for 45°	Automatic
Mechanism for 90°	Manual
Angular range for 45°	±0°-10°
Angular range for 90°	±0°-5°
Mounting Thread	M6
Mounting	Base Plate

Table:4

10. Supporting Elements.

10.1 Breadboard for Optical Mount

Breadboard allowing components to be mounted on it. It is mounted at the top of the chamber on the desired position. It consists of M6 screw thread through holes, where we mount the supporting system with the mounting plate.

The breadboard features having multiple mounting holes, which are counterbored to create an uninterrupted surface of the application. The mounting holes are located at some distance on the breadboard as in figure19. The mounting holes may be used to attach the breadboards to optical tables, mounting posts, brackets, or a variety of other surfaces or mounts.

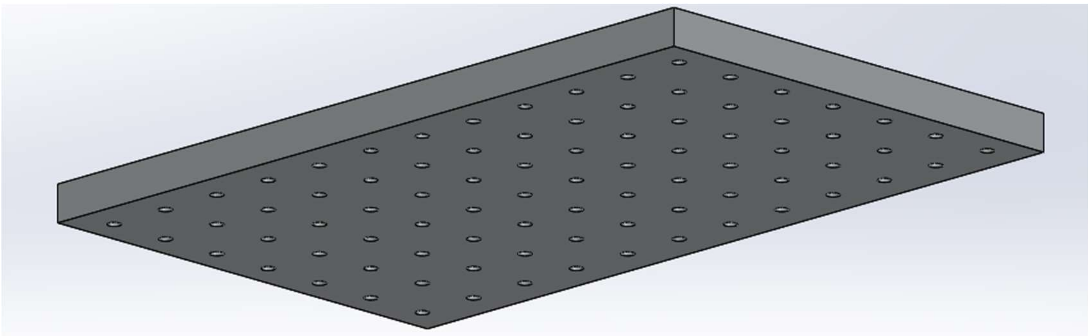


Figure 19: Breadboard for fix components

10.2 Reflective Mirror

Mirrors are probably the most commonly used optical elements in laboratory and their quality, performance, and reliability are key to the success of the experiment. Here we must determine the mirror selection according to the laser parameters. The mirror we choose should be suitable for operation in this wavelength range. Another factor in laser selection is the energy in the pulse. While trying to optimize the design, the ideal mirror diameter of 152.4 mm (6" inch) is given. The thickness of laser mirrors is usually 6 times smaller of the diameter. We assign our mirror thickness as 20mm[18]. The mirror will propagate the laser beam from the laser tube and onto the reflecting mirror.

These mirrors are having 152.4mm diameters and can be placed in the mirror mount. Both the mirror has aluminium coating surface and Fused Silica substrate material. Fused Silica, is optically clear and features excellent resistance to abrasion and high durability, making it the best choice for vacuum applications. And this flat round mirror is mounted in the mirror holder on the rotation stages.

Specification of Mirror:

Model	152.4mm
Thickness	20mm
Wavelength Range (nm)	400-2000
Coating	Aluminum
Quantity	2 Pieces
Shape	Round Flat mirror

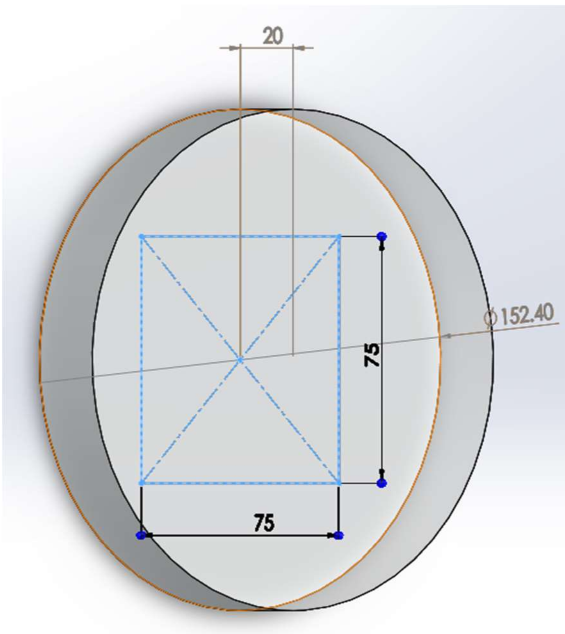


Figure 20: Flat Reflective mirror

10.3 Controlling the Mirror Mount with Motorized Actuator

The Motorized actuator is used to control short pulses of torque. The motor is firmly connected with the screw and the thread and nothing else so that the pulse is absorbed by friction.

10.3.1 Application

Nowadays, motorized actuator is widely used in an application where transferring, distributing and in precise application.

Actuator are used in automatic controlled devices ranging from automotive applications, medical implants, industrial machines in day-to-day consumer electronics.

10.3.2 Basic Structure of Motorized Actuator

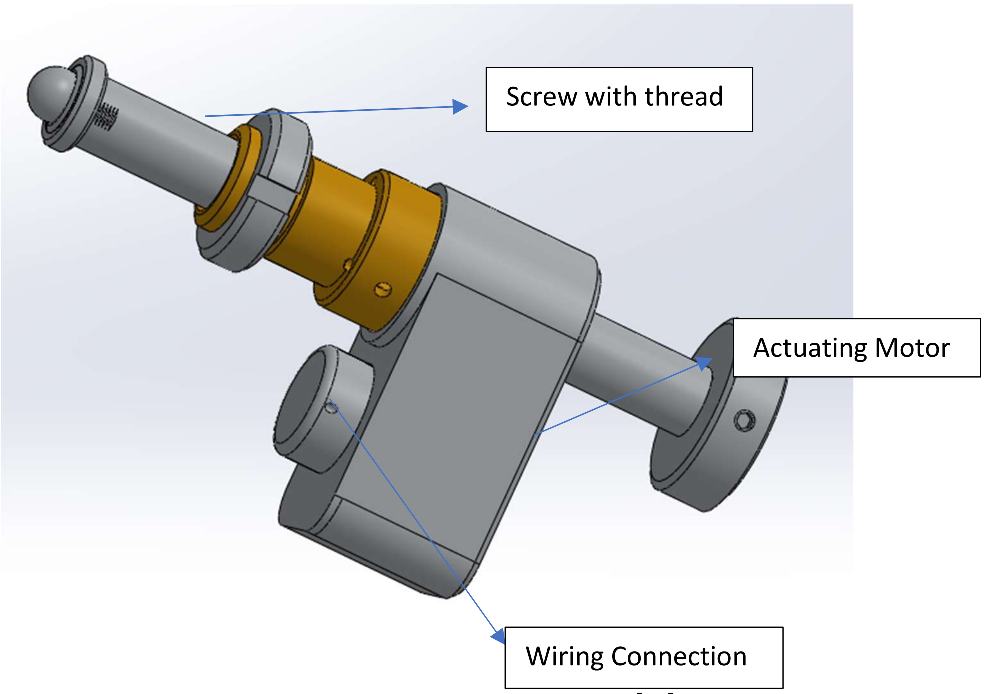


Figure21: Motorized actuator[13]

The described Vacuum Compatible Actuator has approx 25.4 mm travel and is an ideal device for motorizing fine-positioning in the opto-mechanical mirror mount systems. It has better than 30-nm resolution with minimal backlash and can exert a 22-N force. Moreover, it has exceptional long-term stability and the ability to hold their position with no power applied. These all features make the actuator unique among motion-control devices and ideal for typical set-and-hold request.

In case of manufacturing error, the 45°adjustment will be with 0-7° of tolerance so that it can be adjusted with automatic actuator even after the assembly inside the vacuum chamber and for 90° also having a adjustment with manual actuator. As shown in the figure 17&18 the mirror mount will be L shaped with one mirror being fitted in the stable position with manual adjustments locking screw and one being hinged to overcome the manufacturing tolerance if any[13].

Such applications include precision control of sample holders inside cold and/or vacuum chambers, hands-off adjustment of hard-to-reach mirror mounts (like those in the centre of a large setup), or adjustments of optical mounts that are sensitive to forces applied while twisting a knob for instance optimizing the alignment of adjusting the pointing of a beam over a long distance[13].

10.3.3 Motion Control System

An automated motion control system consists of three main components: a motion controller, a motor driver or amplifier, and a motion device. The primary purpose of a motion controller is to control the dynamics of the motion device. The motor driver converts the command signals from the motion controller into power signals required to move the motor. The motion device is any mechanical device that provides motion and is actuated by a motor. Such motion devices typically contain feedback devices to provide information such as position and velocity to the motion controller. In this section, motion devices are discussed first and mainly in the context of manual positioning. This discussion is equally applicable to automated positioning and motorized drivers and electronic controllers are then detailed.

➢ Motion Control Devices

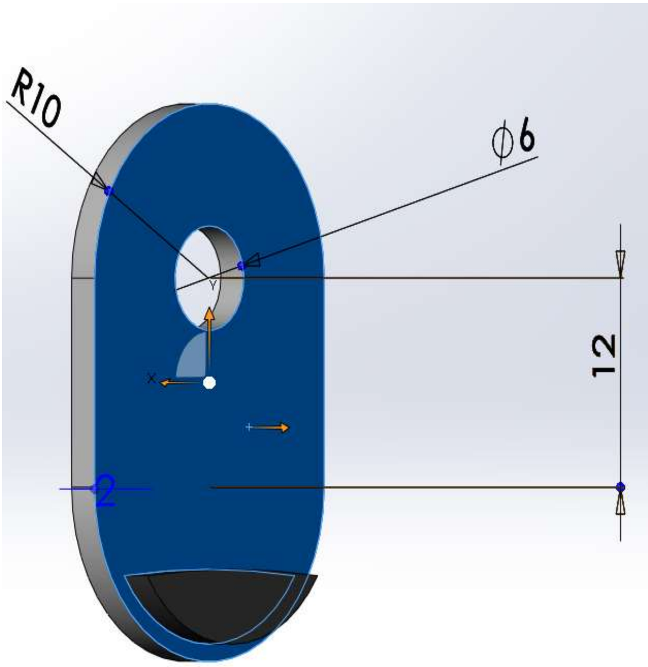
Motion devices are mechanical positioning devices such as linear translation stages, rotation stages, and linear actuators. While the specifications of a stage or actuator are important selection criteria, they may not be exhaustive enough or directly applicable for each application. For this reason, it is important to have sufficient understanding of the inherent abilities of the components that make up a stage. This section provides a brief discussion of the most common components used in high precision positioning equipment with their pros and cons. The main components of a motion device are the materials used for the body construction, the mechanism that enables translation or rotation, and the drive mechanism[15].

Each material used for mechanical components in motion control has its own unique set of advantages and disadvantages. Table below shows a summary of the properties of the most used materials in motion mechanics. Stiffness is a measure of the amount of force required to cause a given amount of deflection. Young's modulus is a material-dependent constant that quantifies the stiffness with large values indicating greater stiffness. Thermal expansion is the change in size or shape of an object, such as a stage, due to a change (increase or decrease) in temperature.

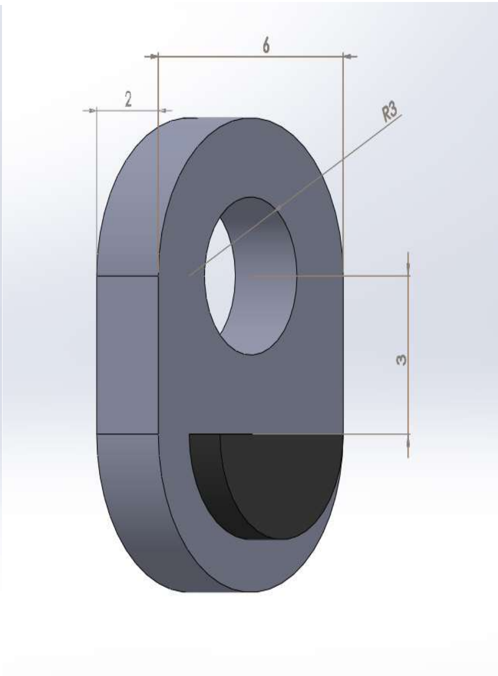
Actuators also allow for indirectly driving a stage but are typically externally coupled and therefore, provide flexibility in terms of matching a particular stage with the desired drive mechanism. Manual actuators are simple, low-cost options for positioning and can be described as a high sensitivity lead screw with a knurled knob. Unlike the lead screw system described above, the nut of the screw is fixed to the stage body, and the adjustment screw itself moves back and forth. Springs press the carriage against the screw tip to make good contact and to preload the screw and eliminate backlash. Micrometer heads are the adjustment mechanism of choice if accurate position read-out or repeatable positioning is needed. Standard metric micrometer heads feature a scale in units of 10 µm but, with an additional vernier, can reach a resolution of 1 µm. When resolution of much less than one micron is needed, a differential screw is recommended. These devices use the difference between two screws of nearly the same pitch to produce very fine motion.

Motorized linear actuators provide the ability to motorize manual linear translation stages for remote or computer control. Such actuators can either use the lead screw mechanism or can utilize the piezoelectric effect, which exploits interactions in certain crystalline materials to produce mechanical movement when an electric field is applied. These piezo actuators can achieve resolution of a few tens of nanometers and are sometimes referred to as nanopositioners. This increased resolution typically comes at a cost of reduced speed and/or travel range.

11. Mirror Holding Clip



11.1



11.2

Figure22

Holding clip is made by hard material which is used to hold the mirror in the mirror mount. At the tip of the holding pad there is soft material Kapton so that the mirror in the mirror mount will set perfectly. Holding pad is fixed into the mirror mount with suitable Screw. The above figure22 shows the dimension of the holding clip for the mirror in the mirror mount.

12. Mounting Elements for Assembly

12.1 For Rotation

The Rotating Mounting Plate is a solid top mounting plate for the rotation stage. It has M6 CLR tapped holes. The mounts also incorporate slotted holes that, together with their adjustable positioning, allow flexibility when the breadboard is secured to an optical table or other work surface. The Figure 23 shows attachment plate of translation stage for rotation stage[1].

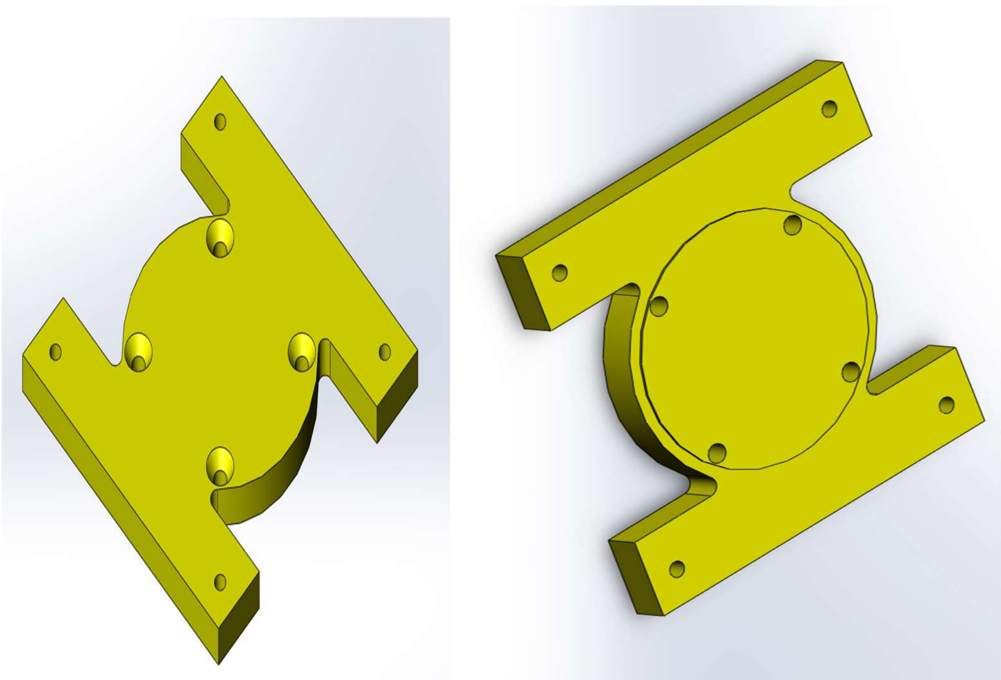


Figure 23: Base plate for rotation

12.2 Mirror Mount Configuration

The below shown figure is a holder type which is used to fix the mirror mount for desired position. The holder plate is attached to fix the mirror mount is fixed with the rotation motion. Main feature which should consider in the Mirror Mount Configuration is proposition view, requirements, and system performance. While mounting mirror mount in the system for operation we must follow accuracy, error, thermal stability, misalignment and buckling of base plate. Then at the end the mirror mount base plate is attached with the required position.

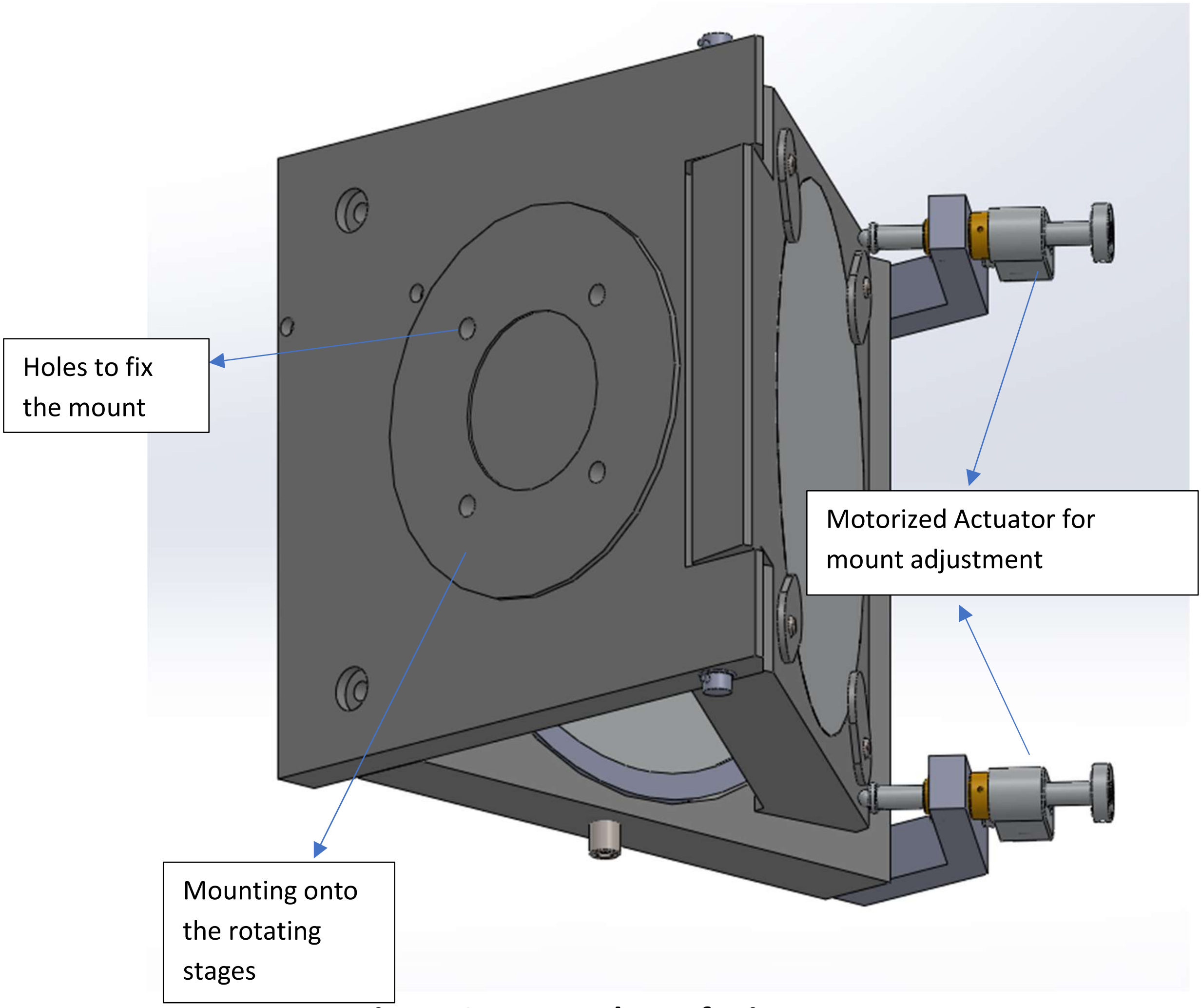


Figure 24: Base plate of mirror mount

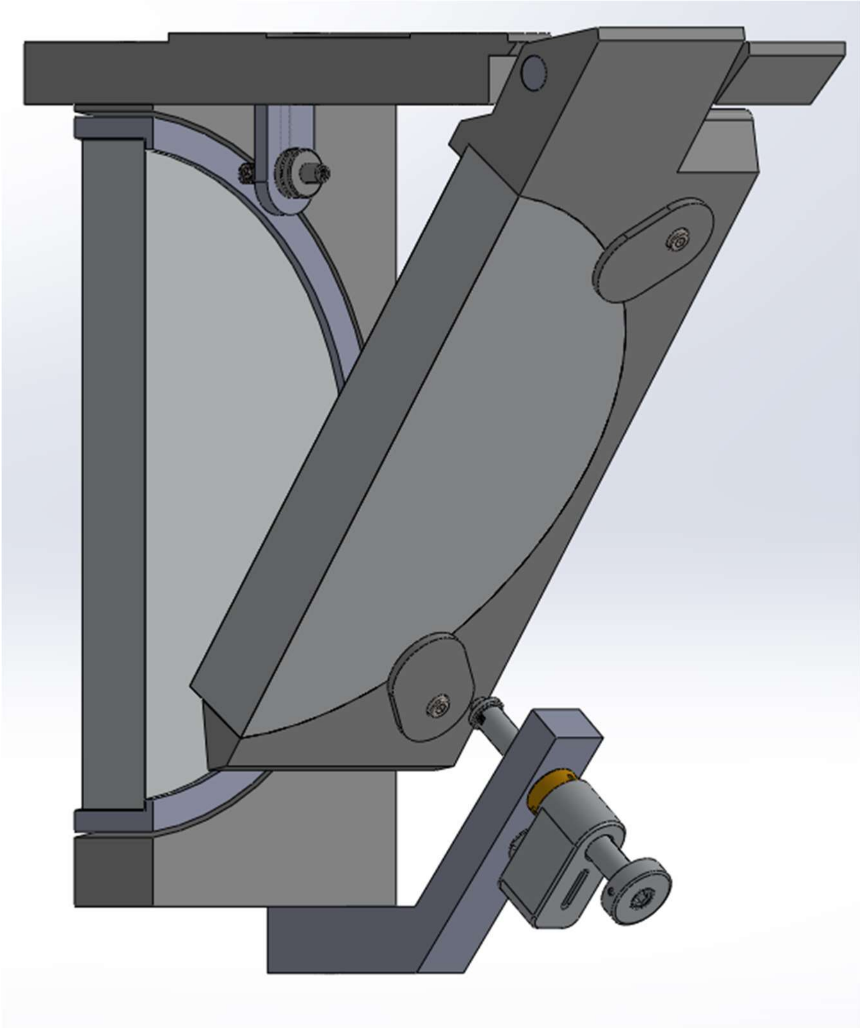


Figure 25: Base Plate of rotation stage

(Sectional view)

12.3 Range and Sensitivity of Adjustment Screw

The adjustment range dictates how much angular adjustment is made, while the sensitivity defines how little an adjustment can be made. The smallest angular adjustment in the mirror mount can make is calculated as adjustment sensitivity. It is calculated by dividing the distance from the rotation axis of the actuator axis by the inverse tangent of the adjuster's minimal incremental movement (MIM). The adjuster's minimum incremental movement is determined primarily by the TPI of the screw. TPI stands for threads per inch and is the number of threads over 1 inch imperial size of the screw.

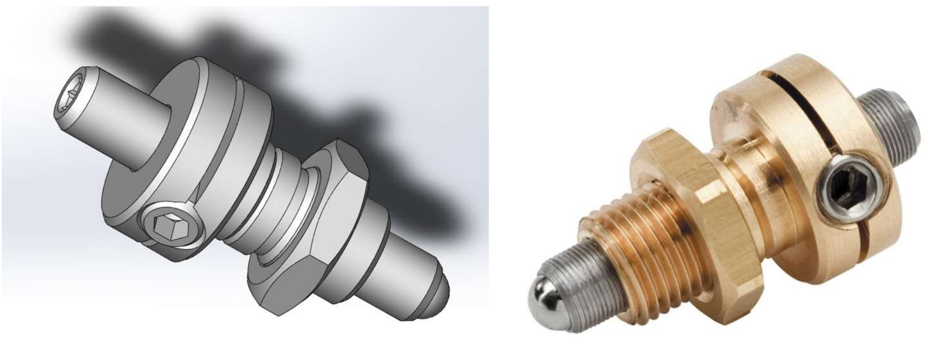


Figure 26: Lead Screw

Precision rolled threads on the Hex Adjustment Screw AJS 8-100[19] allow for extraordinarily smooth adjustment and higher sensitivity than ordinary micrometers. By tightening a setscrew, the thread-pitch lock prevents the adjustment screw from spinning. Adjusters with a high TPI offer a distinct advantage in terms of sensitivity and alignment time. The distance from the rotation axis to the actuator axis: R = 74.88mm. The threads-per-inch (TPI) value of the adjustment screws: TPI = 100.

$$\text{MIM} = \frac{1/TPI}{360} = \frac{1/100}{360} = 27.78e^{-6}\ \text{in} \sim 0.00071\text{mm}$$

Adjustment sensitivity of mirror mount

$$\tan^{-1}[\frac{MIM}{R}] = \tan^{-1}[\frac{0.00071}{74.88}] = 0.000543\text{mm} \sim 0.11\ \text{arc sec.}$$

13. Electrical Wiring Feedthrough Connection (Not in scope of work)

Electrical feedthroughs are components that allow electrical power to be transferred into and out of a vacuum chamber. Metal joints make up electrical feedthroughs, while an insulator, usually ceramic or glass, provides electrical insulation between the electrical conductor and the chamber. Electrical feedthroughs must often withstand high temperatures and high pressure in addition to providing ultra-high vacuum environment.

Figure 27

Electrical feedthroughs[14] with plug connections have electrical contacts and accept a plug connector on the air side without exception. On the vacuum side, some varieties are built to accommodate a plug connector as well. This electrical feedthrough category is perfect for transmitting several signals for power supply, measurement, and control into a vacuum system in a space-saving manner.

- **Wiring Connection Parameters**

Housing	stainless steel
Conductor material	beryllium-copper (gold plated)
Insulation	PEEK
Temperature range	-50 °C to 150 °C
Strain-relieved	yes

Table 5

14. Transition of Laser Beam to Desired Workstation

Entrance of beam 1 from Y axis it directly goes out from the chamber.

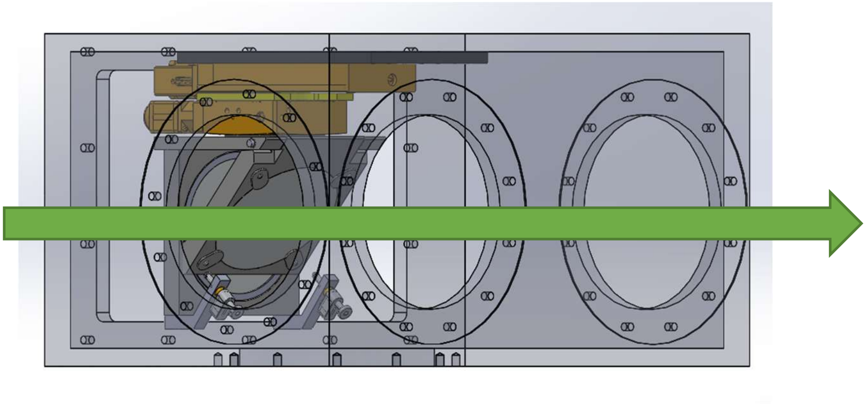


Figure 28

Entrance of beam 1 from Y axis and it reflects into X axis coordinates. The reflective laser beam clear aperture tolerance is ±5mm so the minimum adjustment sensitivity of the mirror angular position is 0.03° = 1.8 min of arc i.e. 5mm at 9 m distance.

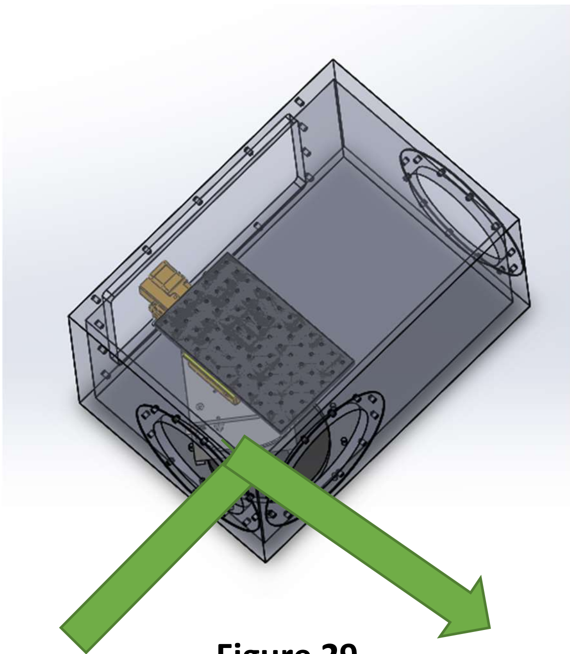


Figure 29

Entrance of beam 2 from Z axis and diverts onto Y axis in right side of the vacuum chamber.

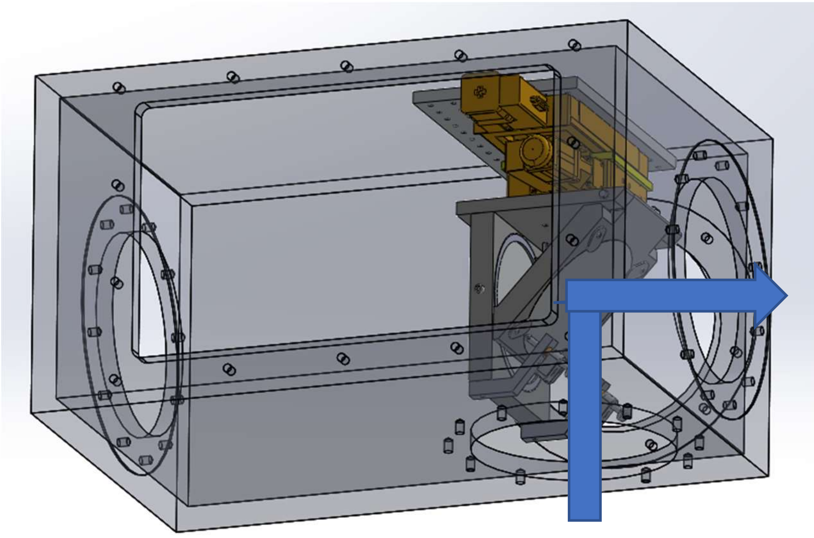


Figure 30

Entrance of beam 2 from Z axis and diverts onto Y axis in Left side of the vacuum chamber.

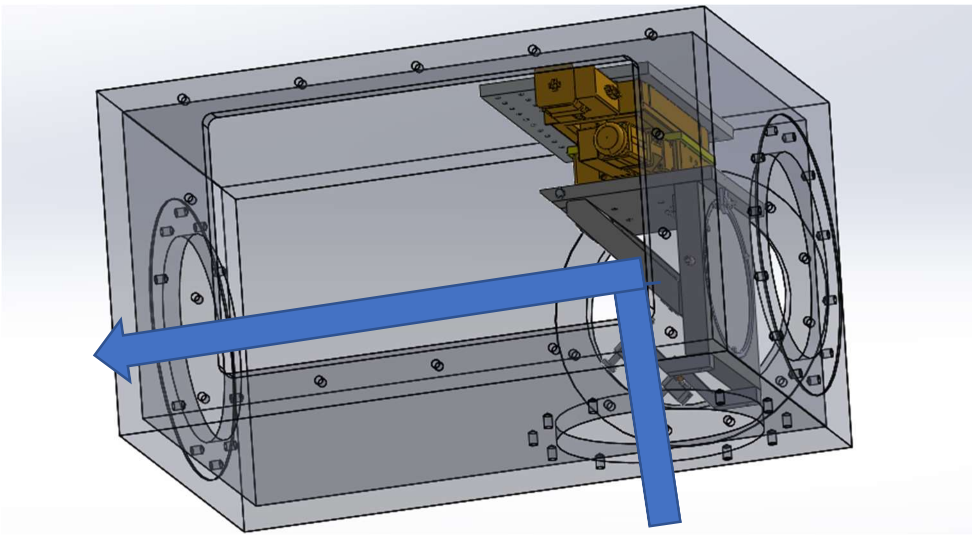


Figure 31

Entrance of laser beam 2 from Z axis and diverts onto X axis coordinate.

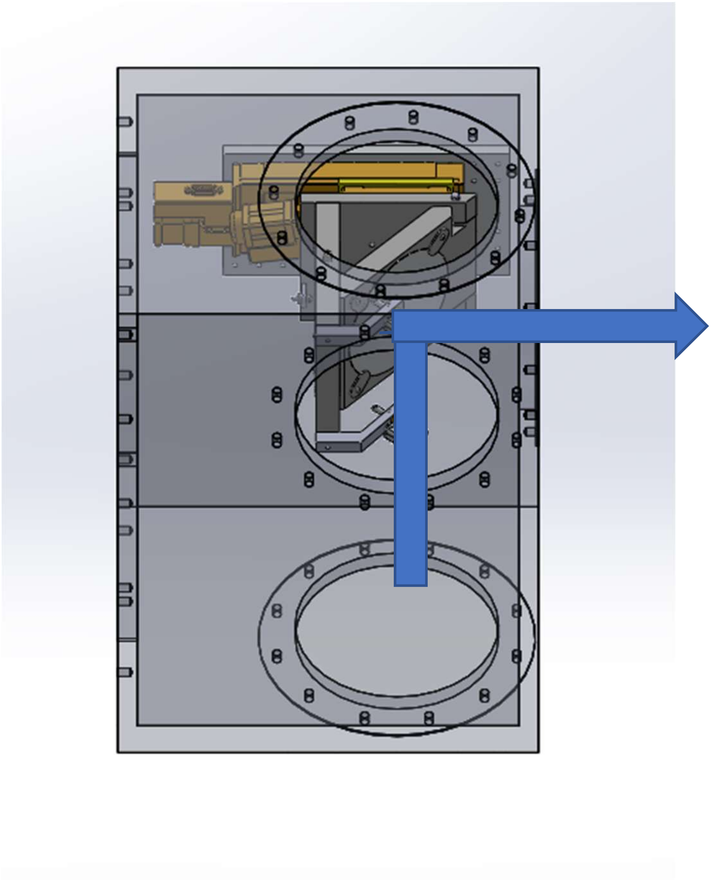
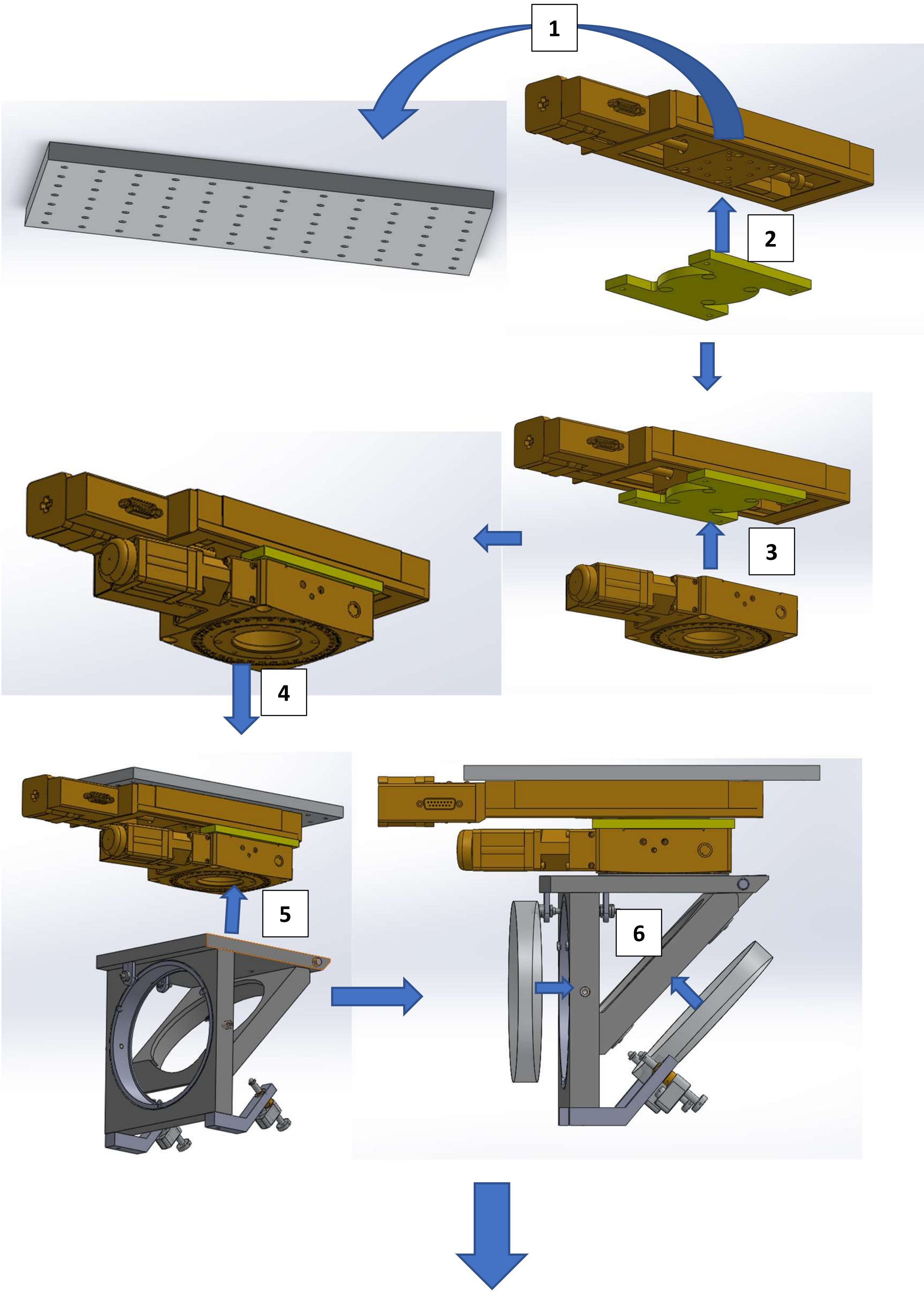


Figure 32

13. Assembly Procedure of the System



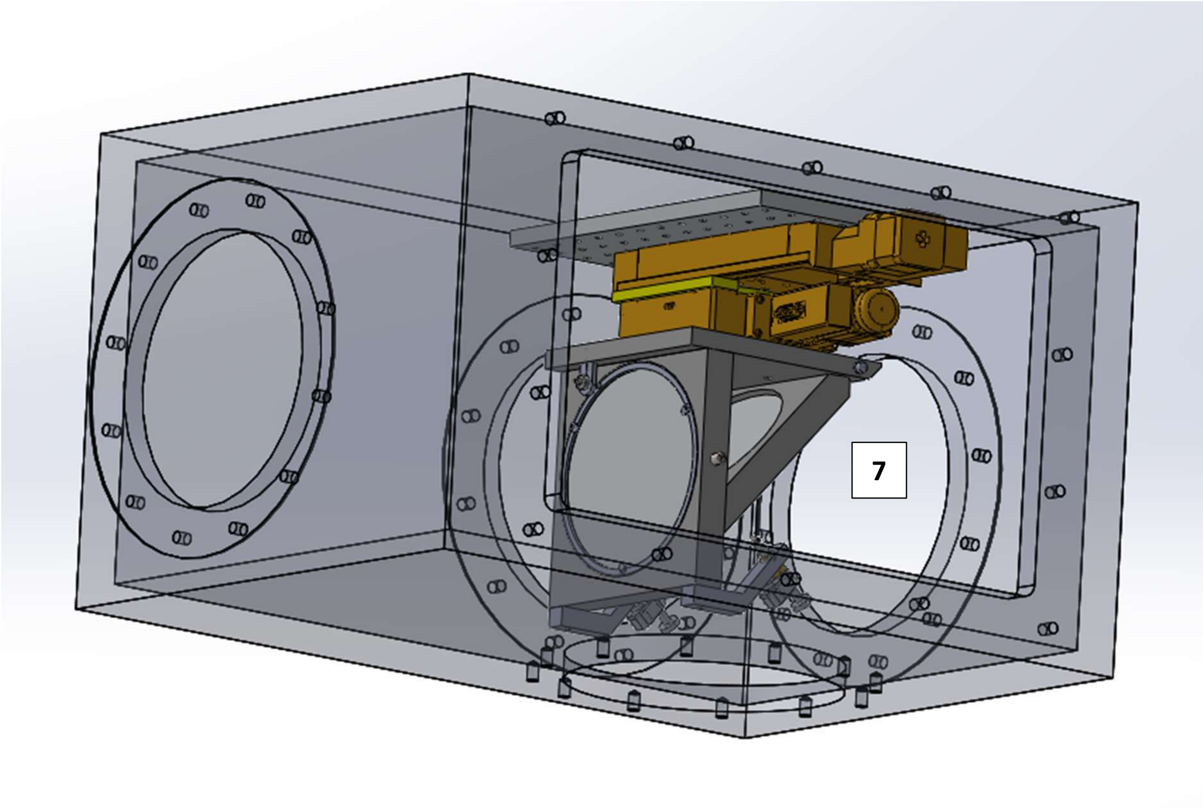


Figure 33

CONCLUSION

The goal of this thesis was to convert an obsolete one directional LDS into a multi directional transfers of laser beam.

A case study of the existing system before the upgradation were discussed in chapter 4. At prior, the operation of the laser beam and their parameter were discussed for the system. Existing opto-mechanical mirror mount research has been done and their specification were discussed. After the detailed study, the mirror mount designed has been initiated as per our requirements. For this, the improvement on the design is carried out by the actuator. Then the characteristics of the material were discussed. After deciding on the general design, the desired position of the mirror mount were designed.

Thereafter, the assembly components for the system were examined. There specification and other parameters of the components are defined then the proposition of the design is explained. Then the supporting elements model for the mirror mount has been obtained. Then the supporting elements is mounted on the mirror mount with well defined manner for the system.

Finally, the assembly procedure for the system has been figured out some of the components are widely available in the optics market and their feature parameters are defined for the system.

Working on this thesis was a very great learning experience for me. Throughout the course of working on this thesis, I encountered many difficulties and challenges. In overcoming them, I sharpened my problem-solving skills and experienced engineering. This thesis has been an excellent example of application engineering and I aspire to continue my career in it.

List of Figures

List of Tables

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ABBREVIATIONS

LBDS	Laser Beam Distribution System
DOB	Degree of Freedom
TPI	Threads per inch
MIM	Minimum incremental movement
LWD	Low Wavefront Distortion
MTBF	Mean Time Between Failure

APPENDIX ON CD

1. Design of LDS (Laser distribution system) solid works file.
2. Electronic version of the Master Thesis