A HIGH RESOLUTION, ADJUSTABLE, LOCKABLE LASER MIRROR MOUNT*

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ABSTRACT

A description is given of a prototype high resolution, adjustable, lockable mirror mount suitable for use as a resonator end mirror mount in fieldable lasers. The prototype was vibrated to 15g levels, 10-2000 Hz, and was shown to be stable to within 1 arc second and settable to an accuracy of 10 arc seconds. Improvements to be made to the prototype are outlined which will significantly improve the accuracy without sacrificing the other attributes of the prototype.

INTRODUCTION

The advent of fieldable laser systems, such as satellite communications systems has mandated the construction of lasers that are capable of "HANDS OFF" operation even in the presence of severe vibration and temperature cycling. Since the efficiency of a laser is highly dependent upon the maintenance of alignment of the two cavity end mirrors to a high degree of accuracy, the cavity end mirror mounts are critical items. Depending upon the optical design of the particular laser, this accuracy ranges from approximately 1 arc second to about 50 arc seconds. This means that these end mirrors must be adjustable to a very precise angular orientation and then locked with a minimal positional change during the locking process.

To satisfy these stringent requirements, a set of goals was formulated for the mirror mount. A prototype lockable mirror mount was then designed, fabricated, and tested. Most of the defined requirements, or design goals, were either met or exceeded by the prototype design.

* This mirror mount was developed for the Air Force Avionics Lab., Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, McDonnell-Douglas prime contract number F33615-74-C-1028, GTE Sylvania sub-contract with McDonnell-Douglas number Y3E-247R.

DESIGN GOALS

The design goals are listed below in approximate order of decreasing importance.

Stability

As stated previously, the primary goal of the design was retention of alignment after severe vibration and temperature cycling.

Accuracy

The accuracy of an adjustment is defined as the precision to which the adjustment can be set in a single trial without overshooting the set point, plus the lockability (the maximum amount the adjustment may be disturbed when it is locked), plus the maximum amount that it may be disturbed when the adjustment mechanism is removed (in the case of removable adjustment mechanisms). In order to make the mount usable on as many lasers as possible, the mount was designed to a 1 arc second accuracy limit.

Adjustability

Adjustability is defined as the ease of adjustment of mirror orientation before locking. During the alignment of a laser, many mirror adjustments are required, especially in the case of the more developmental versions. This fact makes it very important to design the mount so that it is easily adjustable. To ensure this, it was decided that the mount would provide two perpendicular pivot axes intersecting at the center of the mirror face. This arrangement of pivot axes is the one providing the minimum theoretical "cross talk" between the axes of adjustment. In practice, other factors (mechanical tolerances for example) increase cross talk. The goal was set at 1% cross talk, a value determined to be very acceptable.

Another goal adopted to enhance adjustability was to minimize adjustment hysteresis to ensure a nearly one to one position relationship between the mirror position and adjustment knob setting.

Size and Weight

The advantages inherent in a lightweight and compact design for fieldable applications are obvious. However, there are tradeoffs to be made between this goal and the previous two goals, for a compact and lightweight design is commonly achieved by compromising accuracy and adjustability. With this in mind, a size of 2.5 inches in diameter by 1.0 inch thick was defined as the maximum envelope size which would allow the mount to conveniently mate with the greatest variety of laser structures. A weight of 8 ounces was arbitrarily chosen as an upper limit.

Range of Adjustment

The maximum range of adjustment needed in lasers is about 1.5° in either direction about each adjustment axis.

Proximity of Mirror Face to Front Surface of Mount

Since it is often desirable to mount other optical elements between the end mirrors, but close to a mirror face, it was determined that the mirror face should be located as close as possible to the front surface of the mount.

THE PROTOTYPE DESIGN

The prototype mirror mount is shown in Figures 1 and 2. The basic design approach used two gimbals and a frame connected by torsion bar pivots. The inner gimbal is connected to the outer gimbal by two torsion bars, while the outer gimbal is in turn connected to the frame by two more torsion bars (Figure 2). The frame is usually bolted directly to the laser structure. However in the case of the prototype, the frame was attached to the structure via four special flexures which allow for differential thermal expansion between the frame and the laser structure.

Torsional flexure pivots were used for their advantages of having no mechanical play, wear, or friction. These properties are essential in order to achieve low adjustment hysteresis and stability. The limited angular motion required permitted the use of these torsion bar pivots. An added benefit of the torsion bar pivots is that the adjustment return springs are provided by the torsion bars themselves. In the interest of stability, the two gimbals, the frame, and the four torsion bars are constructed as a unitary structure, machined from one piece of beryllium copper alloy, chosen for its good spring properties.

The adjusting screws (80 threads/inch) are threaded into bosses attached to the outer frame (Figure 1). The outer gimbal adjusting screw bears directly against the outer gimbal. The inner gimbal adjustment screw passes through the gimbals to bear on an adjustment tab (Figure 2) that is bolted directly to the inner gimbal. This is done to allow the point of contact to be nominally on the pivot axis of the outer gimbal, to minimize the cross talk. If the inner gimbal adjusting screw were mounted on the outer gimbal instead of the frame, there would theoretically be no cross talk. However, in practice, this causes severe cross talk due to random forces from the operator's hand being transmitted to the outer gimbal during adjustment.

After final machining, each pair of torsion bars is given a permanent two degree twist rotating each gimbal toward its adjustment screw. This provides the spring bias necessary for $\pm 1.5^{\circ}$ rotation about the straight ahead position.

Figure 1. Back Side of Prototype Mirror Mount.

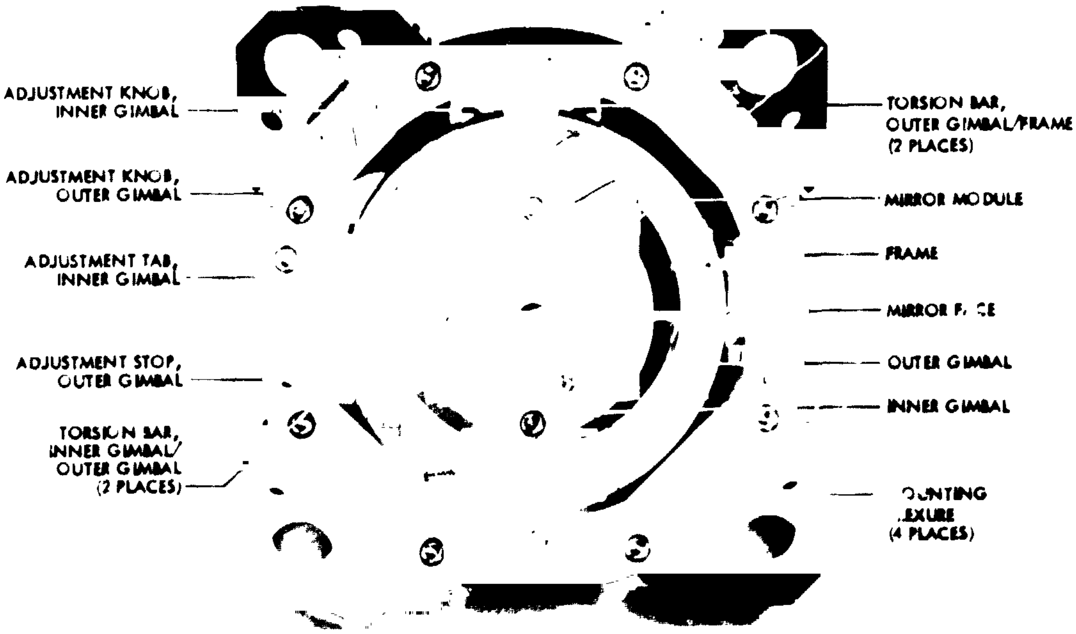

Figure 2. Front Side of Prototype Mirror Mount.

The torsion bars are 0.125 inch long with a rectangular cross section. This cross section is .050 inch by .025 inch with the longer dimension parallel to the adjusting screws. These dimensions were chosen to limit the axial translation of the mirror during adjustment to approximately 10^{-5} inch, while providing 3.5° of rotation and an acceptable spring rate. The maximum axial translation of the mirror over 3° of rotation is about 1.2×10^{-5} inch, while the torsional spring rate for a pair of torsion bars is 2.7 in.oz./deg. This design results in the pivot axes being only 0.025 inch behind the front face of the mount itself.

There are four locking mechanisms on the mirror mount, two to lock the inner gimbal to the outer gimbal, and two to lock the outer gimbal to the frame (Figure 1). Since all four mechanisms are essentially identical, only one, an inner gimbal lock, will be described in detail. This lock is shown in Figure 3. It consists of only three parts, a boss bolted to the inner gimbal, a clamp bolted to the outer gimbal, and a locking screw.

As the inner gimbal rotates within the outer gimbal, the boss translates up and down between the wings of the clamp as shown in Figure 3. When the locking screw is loose, the boss fits between the wings with approximately .0001 inch clearance on each side. This allows adjustments to be made with no friction being introduced by the locking mechanisms. The locking screw passes through a small clearance hole in one wing of the clamp, through a large clearance hole in the boss, and is threaded into the opposite wing of the clamp. When the locking screw is tightened, the wings are drawn together to clamp the boss between them. Each wing has a thin section to provide flexibility in the direction parallel to the locking screw. If the clearance between the wings and the boss is the same everywhere, there will be no net moments, or forces, exerted between the inner and outer gimbals as the locking screw is tightened. The only forces exerted on the boss will be the equal and opposite forces acting on each side of the boss in a direction parallel to the adjusting screw. For thermal stability, the clamps and boss are made of beryllium copper to match the gimbal and frame. The locking procedure consists simply of tightening the two outer gimbal locking screws followed by the two inner gimbal locking screws. After the locking screws are tightened, the adjusting screws are removed to create a smaller package and to avoid the screws shaking loose during vibration.

With the adjusting screws removed, the mount weighs about 5 oz., and is 2.5 inches in diameter and 0.7 inch thick overall.

EVALUATION OF THE PROTOTYPE

The prototype mount met or exceeded nearly all design goals. It was vibrated at 15g levels from 10-2000 Hz and temperature cycled through a $100^{\circ}C$ temperature range with no change in setting observed using apparatus with a resolution of about 1 arc second. It is very compact (2.5 inches diameter, 0.7inch thick) and light (5 ounces). It has a 3 degree range of adjustment and the cross talk was determined to be less than 1% with a one to one relationship between adjusting knob position and the mirror settings. In addition

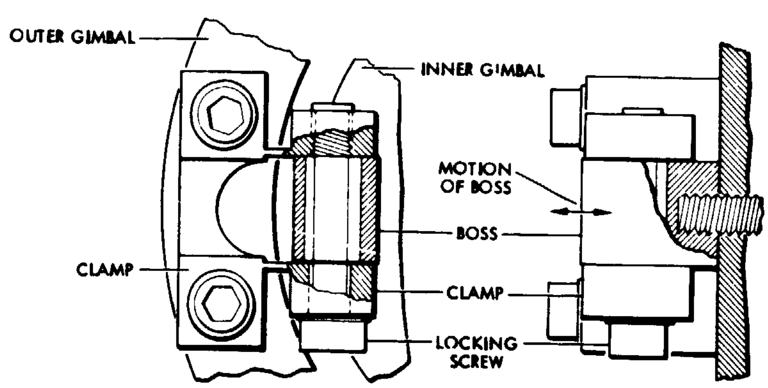

Figure 3. Locking Mechanism, Inner Gimbal.

the mirror face is very close (.025 inch) to the front surface of the mount.

The adjustability of the mount is good and it is possible to set it to within one arc second without overshoot. However, when it is locked, a change in setting occurs which is greater than that desired, especially when locking the inner gimbal. In addition, when the adjusting screws are removed, further motion occurs. These effects combine to reduce the total accuracy of the mount to about 10 arc seconds. This accuracy makes the mount usable in most lasers but prevents its use in those requiring very accurate mirror settings.

The motion upon locking has been determined to be caused primarily by misalignment between the locking clamps and their respective bosses. The reduced performance of the inner gimbal locks as opposed to the outer gimbal locks is caused by the closer spacing of the inner gimbal torsion bars and locks. The torsion bars for the inner gimbal are only 1.2 inches apart and the two locking screws are only 1.0 inch apart. The problem is made evident when it is noted that, with the locks this close together, a motion of only 2.5 millionths of an inch at the lock causes the mirror to rotate about 1 arc second.

The motion resulting from the removal of the adjusting screw occurs as the load previously supported by the adjusting screw is taken up by the previously unloaded locks.

PROPOSED IMPROVEMENTS

A new revised design has been created that should improve the accuracy of the mount without compromising a significant number of the other goals. This design employs Bendix flexure pivots instead of torsion bars. These have a torsional spring rate about one order of magnitude smaller than the torsion bars used in the prototype. This will considerably reduce the load transferred to the locks upon removal of the adjustment mechanism. In addition the locks will be reconfigured to make them stiffer when locked and much easier to align.

Changes will be made in the configurations of the gimbal and the frame to allow all four pivots and locks to be located at the extreme edges of the mount. This at least doubles the spacing of each pair of locks and pivots. This change is allowed by the use of separate flexures which allows greater latitude in the design of the gimbals and frame. This change alone should increase the accuracy by at least a factor of two.

CONCLUSIONS

The prototype mirror mount discussed in this paper has passed severe environmental tests. It is lightweight, compact and easy to adjust so long as the accuracy required is no better than 10 arc seconds. The goal of one arc second accuracy should be reached by a new prototype that will be undergoing test at the time of publication of this paper.