Strain-free mounting techniques for metal mirrors

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Abstract. The ability to produce strain free mounts for metal mirrors is shown to be feasible by the application of four principles:

- Mounting strain isolated from mirror surface
- Mirror stiffer than mount
- Mirror figured in "as mounted" strain condition
- Mount tolerances equal to surface tolerances

The application of precision diamond machining is shown to be advantageous in applying these principles. Several real mirrors are shown as examples.

Keywords: optomechanical design; metal mirrors; mounts; mirror deformation.

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CONTENTS

1. INTRODUCTION

The resurgence and growth of metal optics technology, in response to the demands of high energy laser requirements, was the subject of an issue of *Optical Engineering* in 1977.[1] The performance advantages and the cost-and-time effectiveness of precision diamond machining applied to metal optics prompted an editorial speculation of exciting developments over the next five to ten years. One report, in that same issue, by Johnson and Saito,[2] discussed applications of precision machined optics to infrared imaging systems and laid out a plan for exploitation of the technology.

One of the advantages of precision machining technology is that it has allowed improvements in methods of mirror mounting which were not possible with glass mirrors.

The engineering principles for mounting glass mirrors which have developed over the last hundred years have been constrained by the brittleness of the material. Most of the successful mounting methods, therefore, depend upon methods which avoid any stress concentrations, such as threaded holes for screws, and depend upon various methods for floatation of the mirror by mechanical hydraulic, or pneumatic means.[3,4]

Because of the fabricability of metals and their relatively non-brittle nature, we can design mirrors with integral mounts.

This paper will present the principles for engineering mirror mounts which are determinate and strain free.

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2. PROPERTIES OF METAL MIRRORS

The optical and physical properties of metals must be considered in the design of mirrors. Optically, we are concerned with the specularity and geometric accuracy, and physically we are concerned with stability and structural integrity.

The utilization of metal mirrors has been limited by the non-specular nature of polished metal surfaces. The polycrystalline form of most metals gives rise to surfaces which scatter light to an extent which makes them not suitable for most optical imaging applications. The use of amorphous platings, such a electroless nickel, corrects the problem, but at increased cost and some environmental sensitivity, due to the bimetallic effect.

Precision diamond machining, however, produces surfaces which are highly specular in most machinable metals. Aluminum and copper which are commonly used for mirrors in infrared imaging systems working in the 8 to 14 μm region, exhibit nearly theoretical specular reflection at those wavelengths. Modern CNC (computer numerically controlled) machining methods allow us to produce surfaces which are geometrically accurate to small fractions of those wavelengths, as well.

The emphasis in the paper, however, is on the physical properties of metals which contribute to the stability of optical performance.

In general, the structural requirements for optical systems are based on deformation, rather than stress criteria. The usual quantity chosen as a measure of design goodness for optical components, focal planes, and the structure which holds them together is that of microyield stress (σ_{mys}). Microyield stress (also called precision elastic limit) is the stress, in uniaxial tension, which causes a permanent strain of 10^{-6}.

Microyield stress along with other properties, such as thermal conductivity, elastic modulus, density, specific heat, and thermal expansion coefficient, can be combined to form figures of merit which give an indication of how closely a particular metal would satisfy system requirements.

Table I shows two figures of merit for several metals used for mirror substrates. The thermal stability figure of merit is a measure of the mirror's ability to maintain figure and position when subjected

TABLE I. Figures of Merit for Several Metals

Material	Thermal Stability (KE $\sigma_{mys}/(\rho c \alpha) \times 10^{-18}$)	Structural Stability ($E \sigma_{mys}/\rho \times 10^{-12}$)
Aluminum	62.	1.9
Beryllium	117.	5.3
Titanium	53.	3.8
Steel	0.91	1.0

to thermal transients. The structural figure of merit is a measure of the stability when undergoing acceleration. More complete discussions of material properties and figures of merit may be found in Barnes[5] and Miller.[6]

3. PRINCIPLES OF STRAIN-FREE MOUNTING

Metal mirrors can be mounted so they are strain free, that is, stresses below σ_{mys}, by the application of simple design principles. The validity of any particular design should be verified by finite element structural analysis under actual expected load conditions. The importance of modeling cannot be overemphasized, especially when the design is for minimum weight.

The design principles to be followed are:

- Isolate the mounting strain path from the mirror surface. The maximum mount strain will usually be at mounting screw threads or clamps. This should be isolated from the mirror surface by appropriate geometry.
- The mirror should be a stiffer spring than the mount. This will allow any loads which are developed to deform the mount in preference to deforming the mirror. The designer must consider alignment stability in the geometry of the springs.
- The mirror should be figured in the same strain condition as the final mount. This can be most readily accomplished by simulating the final system mounting surface in the optical finishing process. Diamond machining is easily adapted to this approach since the forces produced by the cutting tool are much less than the forces produced by conventional polishing laps, obviating the necessity for special supports during figuring.
- The mounting surfaces should be flat and coplanar to the same tolerances as the surface figure. This can be most readily achieved by diamond machining the mounting surfaces.

A schematic representation of the application of these principles to a mirror (Fig. 1) illustrates, by a simple slot located between mounting screws and the mirror surface, the isolation of mounting strain and a flexural spring to deform preferentially to the mirror surface.

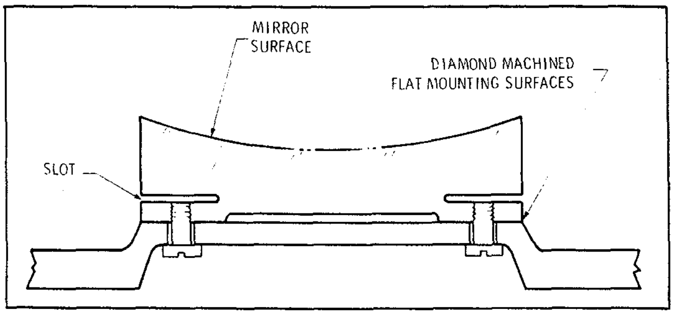

Fig. 1. Mirror mount schematic.

4. EXAMPLES

These design principles may best be illustrated by examining several examples of mirrors that have performed successfully.

- Rectangular parabolic mirror (Fig. 2). This early design has mounting surfaces on tabs attached to a very still hub. It is effective, but it is also a complex machining problem.

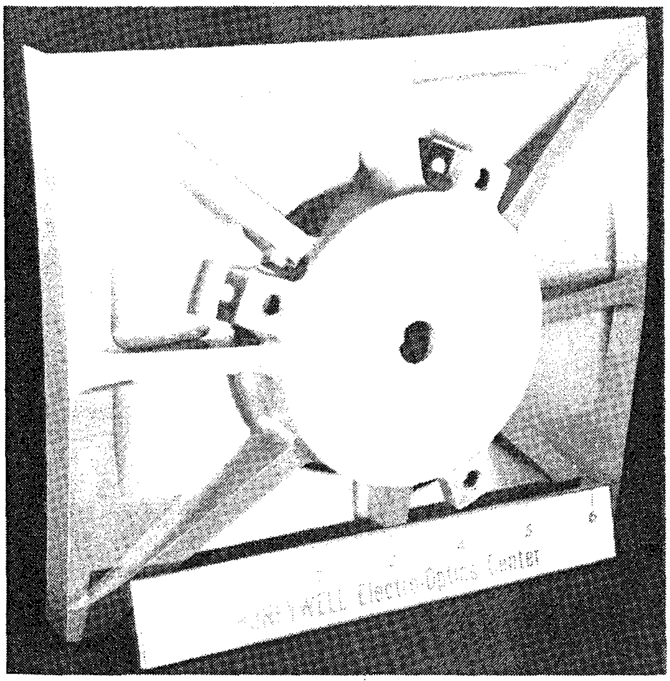

Fig. 2. Early strain-free mount design.

- Generalized aspheric with central perforation. (Fig. 3). These two mirrors are identical except for the material. One is copper and the other aluminum. The improved mounting design shown is machined by one operation with a core drill.

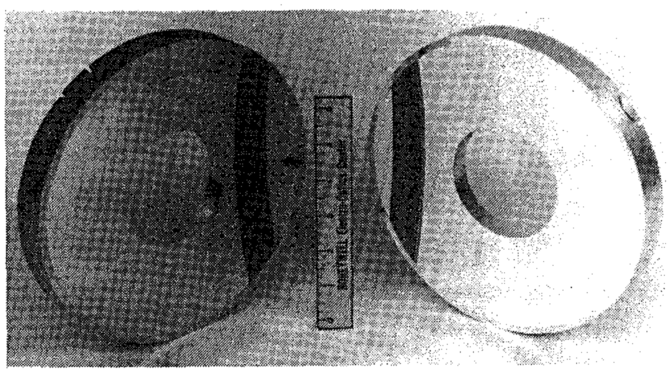

Fig. 3. Aluminum and copper mirrors showing improved flexures.

- Planar mirror and mount (Fig. 4). The mount serves as an intermediate structure between the mirror and the rest of the system. It has semi-kinematic adjustments for alignment, which are not visible in this illustration.

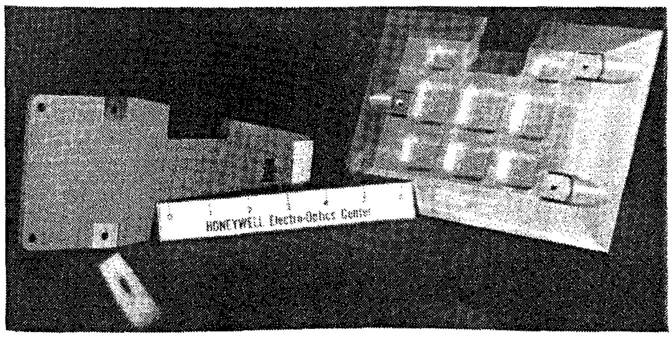

Fig. 4. Mirror mount and rear of planar mirror with diamond machined mount interface.

- Front mounting parabolic mirror (Fig. 5). The mounting pads on the base of this parabolic mirror are located at a diameter greater than the OD of the mirror itself. The machining of the mounts can be accomplished on the same machine setup as the mirror surface, thereby eliminating the need for alignment adjustments.

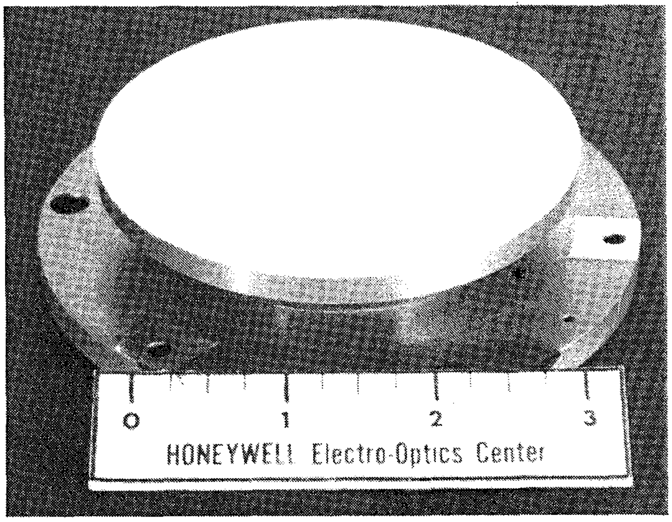

Fig. 5. Paraboloid with front mounting pads.

- Ultimate strain free mount (Fig. 6). The parabolic primary mirror is an integral part of the sensor housing. It is diamond machined directly in its final location. There is no need for alignment or other adjustments.

5. ACKNOWLEDGMENTS

The development of the mounting concepts and principles described in this paper resulted from the ingenuity and skill of many people at Honeywell Electro-Optics Center. Particular recognition should go to Walter Luban.

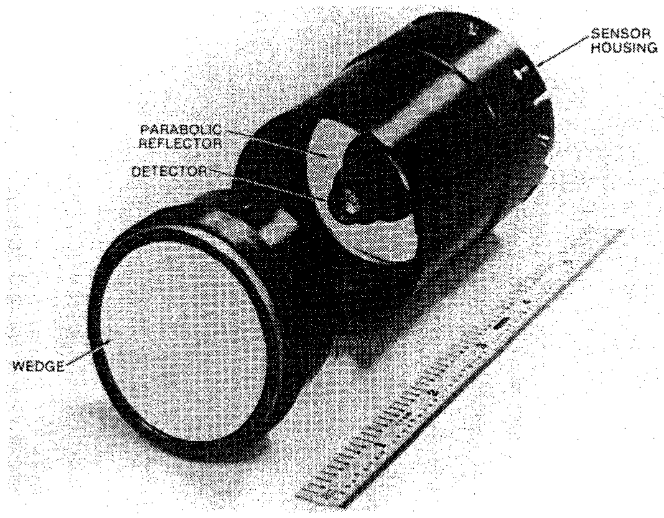

Fig. 6. Paraboloid machined integral to housing—no mount required.

6. REFERENCES

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