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Light Weight Structural Elements with Functional Surfaces

Introduction

Future light weight structural elements with functional surfaces for space applications or high precision stages for lithography and measurement have to fulfill mechanical and thermal requirements with respect to precision, stiffness, low weight and long-term stability. In applications that combine precision and dynamics, higher eigenfrequencies can be obtained and the low moment of inertia permits higher accelerations.

Common Practice

The material selection for lightweight structural components has to consider low densities and high stiffness as well as dimensional stability under environmental conditions like gravity, vacuum or changing temperatures. A mass reduction can be achieved by removing material around the neutral plane that contributes little to the bending stiffness of the structure. The state-of-the-art for passive weight reduction is to create cavities within the structure. Either a contoured rear surface or a sandwich design is suggested by /1/.

Though a design with an open rear surface has a lower rigidity than those with a closed back side it is commonly used. This method shifts the neutral plane to an unfavorable position. So the structure is light weighted at the expense of its bending stiffness.

The weak spot of sandwich assemblies is the interface between the lamination and the core material. The joint is not reliable with respect to the mechanical and the thermal demands over a longer period of time.

Monolithic Lightweigth Structure with Closed Front and Back Surface

A promising and cost effective approach to reduce the mass of the structure but to retain the bending stiffness is to drill holes in one direction or as an orthogonal pattern along the neutral plane. The result is a kind of cross vault with an advantageous stress distribution and a reduced print through effect during surface finishing. A weight reduction of up to 60% can be accomplished while the monolithic structure maintains the mechanical and thermal long-term stability of the solid material. As a further advantage both surfaces are aligned and can serve as functional areas. FEM calculations show that the deflection of a solid oval plate with the dimensions 178 mm x 146 mm x 12 mm

under gravity is fife times higher than the deflection of an equal, but 60% weight reduced plate with drilled holes. Contouring the back surface reduces the deflection under gravity load to the half, compared to the solid plate.
Metals, glass-ceramics or glass are promising materials for light weight mirror applications. Especially for lithography applications, low thermal expansion materials like Zerodur® or ULE™ are demanded. These hard and brittle materials can be machined using CNC grinding or ultrasonically supported milling processes. A following acid etching process removes the damaged surface and reduces the number of microcracks. The risk of stress induced crack growth is reduced significantly.

Applications

At the Fraunhofer IOF the above discussed approaches have been applied in several systems. Lightweight metallic mirrors for the use in optical instruments, with plane, special or aspherical functional surfaces were manufactured by single point diamond turning. Typical applications for lightweight mirrors are space telescopes and scanning mirrors for dynamic purposes. Figure 1 shows the PISTON mirror unit for the Large Binocular Telescope (LBT), which was realized in cooperation with the Max Planck Institute for Astronomy. It employs the material removal in the neutral plane for an effective mass reduction. Although the mirror was light weighted for a better dynamic performance, a minimal form irregularity of better than PV $\lambda/10$ @ 633 nm was achieved in the manufacturing process. The form accuracy in fig. 1 shows the starting print through of the bore structure with peak to valley values around 30 nm.

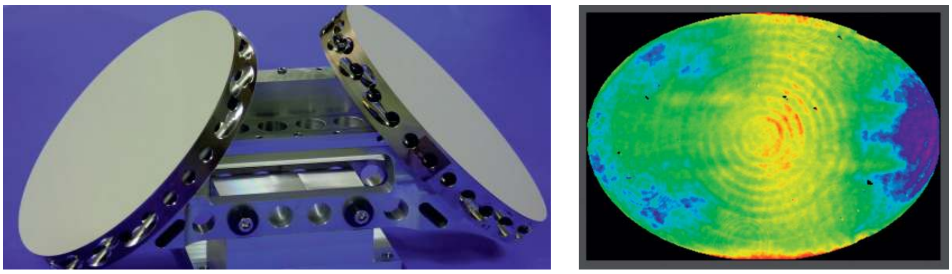

Figure 1

Piston Mirror Unit for LBT and
Form accuracy after surface finish (PV~ 30 nm; rms ~ 5 nm).

For applications in e-beam lithography and future EUVL, large electrostatic wafer chucks are used. A lightweight design was realized by applying the bore hole technology. A flatness of better than 500 nm across the 12-inch area was obtained.

References:

[1] Yoder, Paul R.: Mounting Optics in Optical Instruments, SPIE Press, 2002

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