Extremely Large Space Telescopes and Interferometers made with flat primary mirrors

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Introduction

We have found designs for imaging telescopes and interferometers in which the primary reflecting elements are multiple flats. Such configurations may have been previously overlooked because their overall size is impractically large for ground based telescopes, and high quality flats to withstand gravitational and wind loading are not much easier to make than curved mirrors. But flats could greatly simplify the construction of large aperture space systems, built up as multiple spacecraft flying in formation. In space, large flat reflectors of high quality and extremely light weight could be simply made from thin stretched membranes. The requirements are that the membrane be of uniform thickness and that its perimeter be held in a plane. In practice, the surface would be defined by a discrete number of edge actuators, actively controlled from wavefront measurements to maintain flatness. The membranes might be formed on an optical flat of metalized plastic such as polyimide, or of metal alone. Already single membranes as large as 8 m could be made on glass flats from existing facilities, with existing vacuum coating systems.

Examples of optical systems based on flat primaries

a) 100 m filled aperture telescope

As a system example, consider a telescope with a concave 100 m, f/20 primary whose surface is approximated by 5 m flats, tangent to the desired conic of revolution. We can think of the primary as a single, continuous concave surface with a figure error in the form of quilt-like bumps of about 800 μm peak-to-valley At the quasi far-field focus, 5 m across and 2 km distant, is a secondary in the form of a concave field mirror which forms an off-axis, reduced size image of the primary. This concave collector might be built with with a curved glass membrane, rigidly supported by a two-dimensional field of actuators[1]. At the exit pupil is located a concave tertiary mirror that is made up of scalloped segments, each registered with the image of a primary flat. Think of this as a single, continuous surface with a compensating figure error in the form of dips. These correct the error of the wavefront reflected by the primary, in just the same way each instrument of the HST corrects the primary spherical aberration at a pupil image. A finite field of view is corrected, because the sine condition is obeyed to first order. Errors across the individual flat surfaces could additionally be corrected, by actively controlling the scalloped elements.

b) *100 m nulling interferometer for spectroscopy of extra-solar planets*

Our second example is a double, nulling interferometer suitable for finding Earth-like planets of nearby stars and searching their thermal emission for spectroscopic evidence of life[2,3]. Eight flats, each 8 m diameter, would be flown in formation in a line some 120 m long, perpendicular to the line of sight to the star under study. Each one would be oriented to reflect the starlight as before, into a single 8 m telescope some 2 km away. The telescope's field of view would be about 3 degrees, to catch the light from all the elements. Small scale optics near the focal plane of the collector would be used to interfere the individual beams as required. In this way, only one large precision telescope needs to be built instead of 8. The 8 flats should be much faster, lighter and cheaper to build than telescopes of the same size.

A test of a membrane flat with the HST

A useful early test of a stretched membrane flat in space could be made with the HST. A 2.5 m prototype could be readied in time for the Shuttle's 2003 servicing mission. It would be used to reflect starlight light into the HST some distance away, after it has been serviced and released. In order to eliminate vibrations, to which a large membrane will be sensitive, the prototype should also be released from direct connection with the Shuttle. The goal would be to demonstrate a steerable spacecraft with a 2.5 m flat reflector of comparable quality to HST, but weighing perhaps 10 kg, 10^{-4} of HST's mass. This degree of lightweighting would open a path to future space telescopes with 100 times larger diameter, ie 250 m.

Acknowledgements

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A linear micro-positioning actuator for ambient and cryogenic operation

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Introduction

Many space systems, especially those of gossamer construction, must rely on active control to maintain required dimensional stability. In this paper we describe a newly invented micropositioning actuator that could find many applications in such systems. The original motivation was for the positioning system in the University of Arizona's MARS mirror system (Membrane with Active Rigid support)[1]. In this concept, a thin mirror with the correct figure but too flexible to hold its shape is rigidly attached at many points to a stiff carbon composite structure. Because the structure is not stable at optical tolerance levels againt thermal or other perturbations, the two-dimensional array of attaching actuators require occasional active adjustment to maintain the mirror shape. The NMSD prototype currently being manufactured needed actuators with resolution of ~ 10 nm, stroke of several mm, zero hold power, mass of 50 g or less and operation at ambient and cryogenic temperatures.

Detailed description

The actuator takes the form of a shaft threaded into a nut which is impacted with a small mass to cause momentary rotation. A torsional spring restores the nut to its original position after each impact. The shaft is preloaded to obtain a particular frictional torque between the nut and shaft. The friction is set at a level that is lower than would be required to accelerate the shaft at the high initial angular acceleration of the nut on impact. As a result, the angular position of the shaft lags behind that of the nut, and the shaft advances or retreats. The torsional spring supporting the nut limits the rotational travel of the nut and returns it to its initial position. The stiffness of the torsional spring is set so that the deceleration and subsequent rotational vibrations of the nut do not result in accelerations that are greater than can be transmitted to the shaft by friction, so the shaft and nut then move as one. The advance of the shaft through the nut that occurs immediately after the impact is thereby preserved. The speed and momentum of the impacting mass can be adjusted to vary the relative motion of the shaft and nut and hence the step size. Motion in both the extension and retraction directions is obtained by using two separate impactors. No power is required to hold position, only to make step motions.

Cryogenic prototype

We have built a 50 g positioner with a 1/4-80 threaded shaft shown on the right in figure 1. Its two impactors are accelerated electro-magnetically. In operation at room temperature, the electrical energy per impact is about 2 mJ. The step size is quite repeatable, and can be varied from 10 to 100 nm by adjusting length of the current pulse from 1 to 2 msec. Operation continues reliably when the actuator is placed in a dewar at 77K. At this temperature, the pulse energy is much reduced because of much lower resistance of the magnet coils. The actuator continues to function with reduced step size for loads up to 20N. The full stroke is more than 1 cm.

The second actuator in figure 1 works in the same way, but incorporates an 0-80 screw and weighs only 7 grams. At the other extreme, the principle could be applied to make beefier actuators with hundreds of pounds of driving force, still free of hysteresis and with resolution of a few nm.

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