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A concept for a membranous floating mirror

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Abstract. We present the principle of a membranous mirror, free-floating at its edge and tied at its center. Its shape is controlled from a control surface, which is itself a membrane. This surface has autonomous integrated means for measuring, analysing and acting upon the mirror. We discuss the possibility of building gound-based or space telescopes using this concept.

Key words: telescopes — space vehicles

1. Introduction

A large number of proposals have been made to build large primary telescope mirrors or adaptive mirrors using circular membranes, usually controlled by electrostatic forces (see e.g. Labeyrie 1979). A related concept uses a rotating mirror made from ferrofluid mercury shaped by magnetic forces (Shuter & Whitehead 1994). In most proposals, the deformable membrane is attached at its edges to the supporting structure. This is difficult to implement in practice. Also, the control surface is rigid thus heavy.

In order to get rid of these difficulties, we propose a pre-shaped membranous mirror tied only at its center to the supporting structure and floating freely at its edges. It is secured and maintained in its requested shape by the repulsive/attractive actions of a number of electrostatic actuators located on an associated control surface. This surface is itself a membrane attached by its center to a support (Fig. 1). In Sect. 2, we consider the behavior of such a system in a gravity field, with a control surface integrated with the support. A space version is considered in Sect. 3, with a floating control membrane tied only with its center. Section 4 contains a short discussion of the control system, and Sect. 5 is the conclusion.

2. A floating membranous mirror under gravity

It is easy to conceive that one can build a telescope mirror floating on electrostatic actuators located on a parallel control surface when this mirror is horizontal, its axis being oriented vertically (Fig. 1). When the telescope is tilted, the mirror is distorted by gravity as well as the control membrane. The shape of mirror can be measured by a wave-font analyser using a star or an artificial laser star in the same way as in adaptive-optics telescopes, and corrected by the actuators. This method also corrects for the gravitational distorsion induced by the spacer which connects the mirror and its control surface to the structure of the telescope.

The shape of the mirror is determined both by the original shape of the unstressed membrane, and by the constraints due to gravitational and restoring forces. It is thus of importance to pre-shape the membrane accurately. One can consider making such a membrane by depositing some material on a surface. Replicae made by deposition on solid surfaces are usually very similar to the master surfaces, and can reach optical quality. One may also consider depositing the material on the liquid surface of a rotating mirror (Borra 1992), with the advantage of obtaining automatically a parabolic surface of high quality. Some simple precautions allow to correct for the effect of the Coriolis force when large diameters are required.

Although the proposed membranous-mirror telescope can work in principle in the absence of important external perturbations due to wind or to vibrations (which are also harmful for liquid rotating mirrors), there are limitations due to the membrane itself. The material of the membrane has limited resistance to tension, compression and buckling in relation with the spacer. This limits the diameter of the mirror even if distorsion is well compensated for. In this respect, such a membrane will behave considerably better in space, in the absence of gravity.

3. A membranous telescope in space

As suggested before, the proposed concept should work better in space due to the absence of gravity and (to some extent) of external perturbations. However, in order to be transported and deployed in orbit, a large-size membranous telescope has to be folded if manufactured on the Earth. Previous authors have not considered this problem

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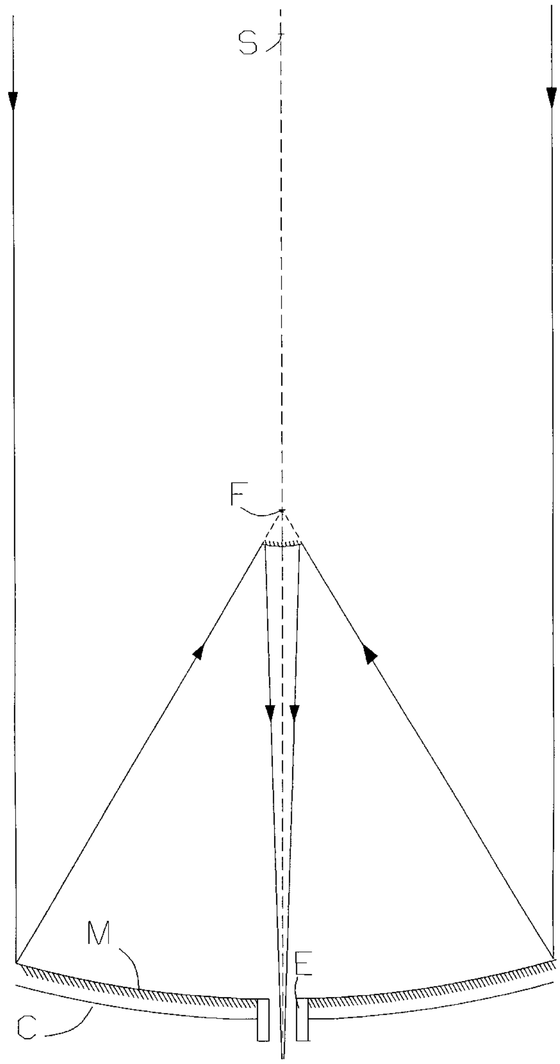

Fig. 1. Concept of a telescope with a controlled membranous primary mirror. The primary mirror M is separated by a small space from a parallel control membrane C which contains electrostatic actuators as elements of printed circuits. Both are connected by a spacer E to the frame of the telescope (not represented). F is the focus and S the center of curvature of the mirror. The surface is measured by a wave-front sensor (not represented) as for adaptive-optics telescopes

in detail: for example, Labeyrie (1979) suggests manufacturing in space without going into detail.

It is not immediately possible to fold a concave foil: trying to fold it into a plane will produce pleats which will induce permanent strains, especially if the membrane is deployed in orbit. This difficulty can be minimized through the use of a folding mould as illustrated by Fig. 2. Assume that the concave membrane is divided into circular rings of equal height e along the symmetry axis. These rings can "projected" on a flat surface by "turning over" every other ring, starting with the central portion, thus producing circular pleats. The concave surface so "projected" is contained between two parallel planes separated by a distance e. One can build a flat, corrugated mould shaped as the folded surface upon which the mirror will be applied. The angles formed by the junction of the projected portions will be replaced on the mould by portions of tori with the largest possible radii, as shown in Fig. 3: this will minimize the folding stresses within the limits of reversible elasticity. One can then roll the mould with the mirror applied upon it around a diameter in order to obtain a cylinder that can be easily transported and brought to space. After deployment of the surface and separation of the mirror from the mould, the mould itself can remain in space. The control membrane can itself be folded on the mould in the same way as the mirror membrane, and deployed at the same time. A rough shaping of the control membrane is performed by electromagnetic action from the mould, and the accurate control of the mirror by electrostatic action from the control membrane as described it will be discussed now.

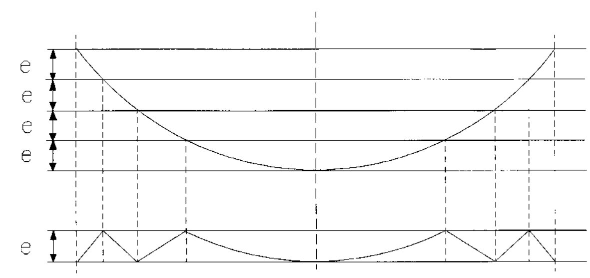

Fig. 2. Principle of folding a concave membrane. See text

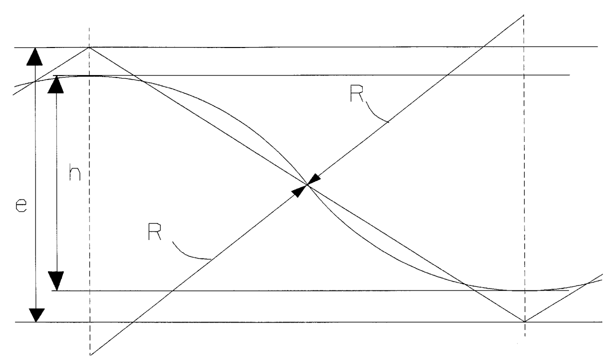

Fig. 3. The folding mould has a smooth surface in order to avoid creating pleats on the mirror membrane. The curvature radius R has the largest possible value allowed by the height $h \leq e$. See text

4. Controlling the mirror shape

We now describe in some detail how the membranous mirror can be shaped actively. The control membrane should contain actuators with a density compatible with the thickness of the mirror and the required accuracy. It can be made as a printed circuit on which the necessary electronic components have been implanted: these components should contain space measuring devices, actuators (probably electrostatic) and some associated electronics. On the ground, the respective curvatures and the distance between the mirror and the control membrane should be such that the mirror assumes its original shape through the compensation of its gravitational distorsion by the electrostatic restoring forces. These parameters are function of the weight of the mirror per unit surface and of the electrostatic voltages that can be sustained by the control membrane.

Deformations of the mirror will be induced by temperature effects. A local heating of a thin meniscus induces a decrease in the curvature radius, while cooling increases the radius. Such a heating will be produced by the energy released by the control system. This will have to be taken into account when building the system and in particular the control membrane.

Vibrations generated by the environment (sound, wind, etc.) on the mirror and the control surface have to be studied carefully. For the moment, this is a major unknown of our concept. It will probably be necessary to correct locally for these vibrations through a fast–response servo control, separately from the general surface control.

In space, the control might be considerably simpler than on the ground. The ensemble of the two membranes (or more exactly three surfaces with the mould) can be considered as an interactive system in equilibrium around a natural shape. The local thickness of the system, and consequently the general change of the shape of the mirror can be simply controlled by changing the relative electrostatic potential of the two membranes and the electromagnetic field from the active mould.

5. Conclusion

We have presented a concept for a large telescope whose primary mirror is a thin reflecting membrane. The shape of the mirror is controlled by electrostatic actuators located on a parallel control membrane. Such a telescope could be built on the ground or as a deployable telescope in space. We show how the mirror of a space telescope, if constructed on the ground, can be folded, transported and deployed. Many studies remain to be done on this concept. Their results should allow to estimate the accuracy which can be reached. According to the results one could contemplate building radio, submillimeter, infrared or even optical and ultraviolet telescopes.

References

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