Astron. Astrophys. 283, L17–L19 (1994)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

A liquid adaptive mirror

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Received 16 December 1993 / Accepted 14 January 1994

Abstract. A new type of adaptive mirror is briefly presented. A thin film of electrically conductive, reflective liquid (like mercury) is affected by a stabilized current, while a variable magnetic field is produced at its bottom surface by a number of adjustable current coils (actuators). A demonstration of the technique has been experimentally carried out using a Michelson interferometer. The first results are here briefly described.

Key words: adaptive optics – liquid mirrors

1. Introduction

Adaptive Optics is a technique with great potential for astronomical applications. Therefore the availability of a low cost wavefront corrector could open new frontiers for several telescopes. With this goal in mind we have initiated the study of a liquid mercury mirror.

The use of liquid mirrors in astronomy has been confined to a limited number of cases: the determination of the gravitational vertical via autocollimation on a liquid mirror (Danjon 1952) and, recently, the use in true astronomical observations by means of a zenithal liquid mirror telescope (Borra et al. 1985a, 1985b, 1988, 1990; Content et al. 1989; Vasil'ev 1985).

In this letter we propose the use of a liquid mirror as wavefront corrector, with an electromagnetic coupling to deform the free surface of the liquid. As it will be clear in the following, this approach is suitable only if the liquid is characterized by low resistivity (which is not needed, for instance, in large rotating mirrors). Mercury, due to its excellent reflectivity and very low resistivity is surely one of the best candidates for this type of application.

2. Basic concepts

When two parallel wires 1m in length and 1m apart are affected by a current of 1 Ampere, a force of 2×10^{-7}N is produced on the wires themselves, as is well known.

Therefore a very simple device, sketched in Fig.1, can be used to locally deform the surface of a (low resistivity) film of liquid.

The liquid of density ρ is affecteded by a current $I_{\rm m}$ while one of the *actuators* on the bottom, electrically isolated from the liquid, is affected by a current $I_{\rm a}$. Each actuator is composed by N turns, so that, using a very rough approximation, the force between the actuator and the volume of liquid on the top of it can be expressed as:

$$F_{\rm am} = 2 \times 10^{-7} \frac{N I_{\rm a} I_{\rm m} (s/t) l}{d} \qquad (1)$$

being $I_{\rm m}(s/t)$ the fraction of current affecting the volume located over the actuator of lenght l, while d is the distance between the barycenter of the fluid volume element and the actuator itself.

In this approximation (a detailed calculation would require a complex numerical approach) a variation of height Δ on the mirror surface is obtained balancing the force $F_{\rm am}$ with the weight of the volume standing on top of the mirror nominal surface:

$$W = \rho \times \Delta l s \qquad (2)$$

From the equilibrium condition $F_{\rm am} = Wg$ ($g \approx 9.81 {\rm ms}^{-2}$) one obtains:

$$\Delta = 2 \times 10^{-7} \frac{N I_{\rm a} I_{\rm m}}{\rho g d t} \qquad (3)$$

Assuming as reasonable values $N = 50$, $I_{\rm a} = I_{\rm m} = 1$A, $d = 5 \times 10^{-3}$m, $t = 10^{-1}$m one obtains $\Delta \approx 150$nm, corresponding to a twofold wavefront deformation of $\approx \lambda/2$ for the HeNe laser wavelength.

The power dissipation P in the liquid mirror depends on the resistivity η of the liquid used, and it is given by:

$$P = I_{\rm m}^2 \frac{\eta h}{t w} \qquad (4)$$

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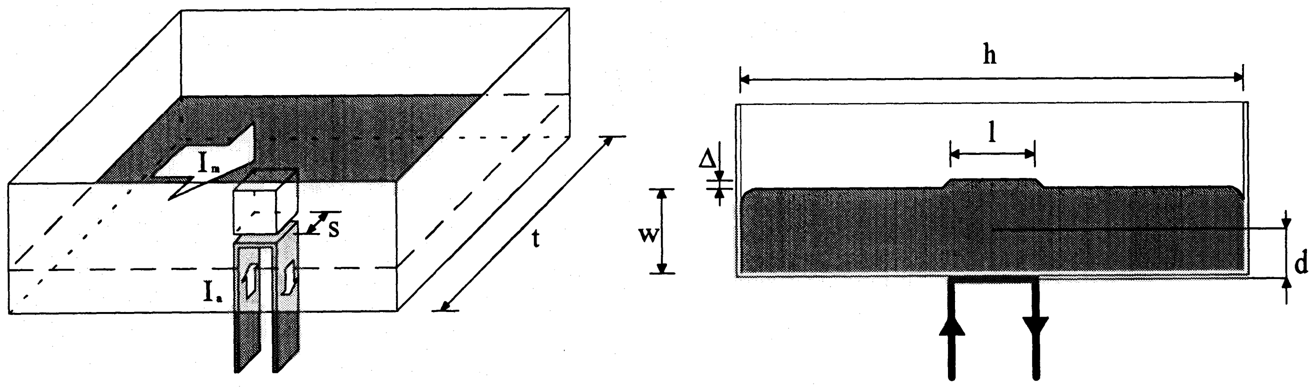

Fig. 1. A schematic layout of the deformable liquid mirror and its cross–section.

For mercury $\eta \approx 9.5 \times 10^{-7}\Omega$m, and further assuming $w = d$ and $h = t$, $P \approx 0.2$mW is obtained, namely a dissipation (and a corresponding heating) absolutely negligible.

3. Experimental verification

A very simple experiment was set–up in order to demonstrate the feasibility of this technique. A small pot (of approximate size $h = 75$mm $\times$ $t = 60$mm) was filled with a $w \approx 3$mm mercury layer. To avoid spurious vibration of the liquid, mercury was damped (Vis 1986; Walkling 1986) using glycerine; in this condition Archimede's force should be taken into account subtracting in eqs.(2,3) the glycerine density $\rho_{\rm gly}$ from mercury's $\rho_{\rm Hg}$.

A single turn coil ($N = 1$) was placed on the bottom face of the pot, having $s \approx 4$mm and $l \approx 6$mm.

The measurements of the submillimetric variation of the mirror surface were performed analyzing the interferograms obtained from a Michelson interferometer where one of the two reference mirrors was replaced by the mercury layer. The Michelson interferometer could cover only a small strip of the mirror surface. In Fig.2a and Fig.2b the observed fringes are approximately superimposed on the coil. In Fig.2c the wavefront difference along the x axis, between the conditions $NI_{\rm m}I_{\rm a} = 0.0{\rm A}^2$ and $NI_{\rm m}I_{\rm a} \approx 48.6{\rm A}^2$ is reported together with the formal errors ($\pm\sigma$) obtained along the y direction. The interferograms were reduced as usual, following the prescriptions given in Takeda et al. 1982 and Roddier & Roddier 1987.

Using eq. (3) a deformation of the liquid surface of $\Delta_{\rm th} \approx 440 \pm 50$nm should be obtained, while the measurement give $\Delta_{\rm m} \approx 475 \pm 190$nm, in good agreement with the predicted value.

4. Conclusions

The concept of the electromagnetic deformation of a liquid mirror has been experimentally demonstrated. A first agreement with the theory has been established by a rough estimation of the deformation.

In order to validate the use of this technique for adaptive optics applications a number of items need further developement, both from the theoretical and practical point of view.

The bandwidth of this device is actually unknown. A number of variables can affect the temporal behaviour of an electromagnetic driven liquid mirror: viscosity, characteristics of the oil–damping (if any), thickness of the interested fluids and so on. For a review of the mercury characteristics of related interest see also Borra et al. 1992.

Another unknown item is the *influence function* (Tyson 1991) shape that can be *modelled* via a number of parameters, such as the detailed shape of the coil actuators and the possibility to vary the thickness of the mirror modifying the shape of the pot bottom.

Obviously this device can work only in a horizontal position. This means that it can be used efficiently at Coudé foci, or at Nasmyth stations of altazimuthal telescopes like the TNG.

Moreover using transparent electrodes one could drive the mirror surface via electrostatic forces, or control the surface deformation via capacitance measurements.

Another possible application for this technique could be the use in rotating Liquid Mirror Telescopes (Borra et al. 1989) in a way similar to the Active Optics techniques employed in thin solid mirrors.

Work is now in progress to try and find answers for all the above mentioned open points.

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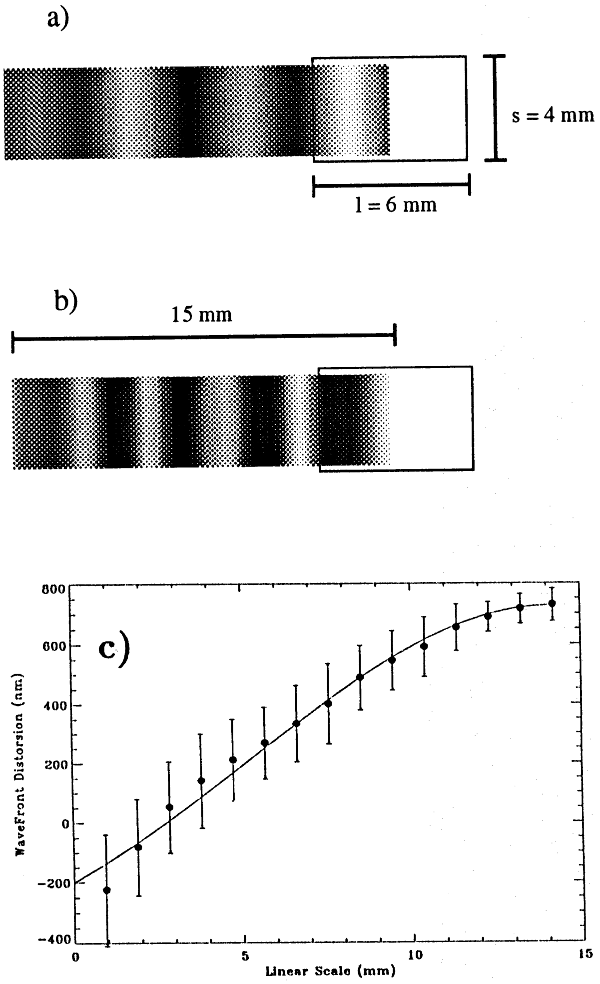

Fig. 2. Fringe patterns for **a)**: $NI_mI_a = 0.0A^2$, **b)**: $NI_mI_a \approx 48.6A^2$; it can be easily recognized the different position and density of the fringes; **c)**: the wavefront differences between the conditions (a) and (b). The empty box corresponds to the position of the actuator with respect to the pattern.

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Acknowledgements. Special thanks are due to C. Barbieri and F. Rampazzi for useful hints and careful reading of the manuscript, and to E. Bellettato, of the Astronomical Observatory of Rovigo, Italy, for manufacturing most of the pieces used in the experimental set–up.

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