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Distributed microscopic actuation analysis of deformable plate membrane mirrors

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ABSTRACT

To further reduce the areal density of optical mirrors used in space telescopes and other space-borne optical structures, the concept of flexible membrane deformable mirror has been proposed. Because of their high flexibility, poor stiffness and low damping properties, environmental excitations such as orbital maneuver, path changing, and non-uniform heating may induce unexpected vibrations and thus reduce working performance. Therefore, active vibration control is essential for these membrane mirrors. In this paper, two different mirror models, i.e., the plate membrane model and pure membrane model, are studied respectively. In order to investigate the modal vibration characteristics of the mirror, a piezoelectric layer is fully laminated on its non-reflective side to serve as actuators. Dynamic equations of the mirror laminated with piezoelectric actuators are presented first. Then, the actuator induced modal control force is defined. When the actuator area shrinks to infinitesimal, the expressions of microscopic local modal control force and its two components are obtained to predict the spatial microscopic actuation behavior of the mirror. Different membrane pretension forces are also applied to reveal the tension effects on the actuation of the mirror. Analyses indicate that the spatial distribution of modal micro-control forces is exactly the same with the sensing signals distribution of the mirror, which provides crucial guidelines for optimal actuator placement of membrane deformable mirrors.

1. Introduction

Lightweight deformable mirrors have been researched comprehensively as key components of space-based telescopes which are of great importance for deep space exploration and earth surveillance in recent decades [1–4]. However, to overcome the packaging limitation of current launch technologies, the concept of membrane deformable mirror which may be stowed compactly and unfurled in orbit is proposed and various membrane mirror configurations are developed [5–9]. Due to the high flexibility, poor stiffness and low damping properties, these membrane optical mirrors are susceptible to environmental excitations, such as orbital maneuver, path changing, and non-uniform thermal loads, which may induce unexpected vibrations and lead to surface inaccuracy. Thus, active vibration control is crucial to these high-performance optical mirror systems so as to ensure their precision and accuracy.

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Piezoelectric materials, especially the thin film polyvinylidene fluoride (PVDF) polymeric materials which are lightweight and dynamic sensitive, have been commonly used as distributed sensors and actuators for precision sensing and control of various structures owing to their distinct direct and converse piezoelectric effect [10–15]. Sensing and control of cylindrical shells with distributed laminated piezoelectric transducers were studied their modal actuation factor, modal feedback factor and controlled damping ratios were evaluated [16–18]. Micro-control actions and distributed control effectiveness of segmented actuator patches laminated on spherical and hemispherical shells were investigated [19–22]. Dynamics and

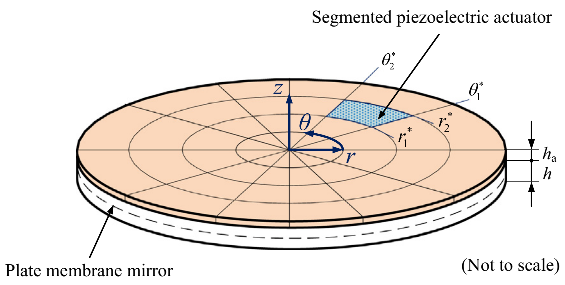

Fig. 1. A plate membrane mirror laminated with segmented piezoelectric actuators.

Table 1
Values for $(\lambda_1 a)_{mn}$ and $(\lambda_2 a)_{mn}$.

N^*/N_{cr}	m	n					
		0		1		2	
		$\lambda_1 a$	$\lambda_2 a$	$\lambda_1 a$	$\lambda_2 a$	$\lambda_1 a$	$\lambda_2 a$
0	0	3.196	3.196	4.611	4.611	5.906	5.906
	1	6.306	6.306	7.799	7.799	9.197	9.197
	2	9.440	9.440	10.958	10.958	12.402	12.402
1	0	2.954	4.840	4.478	5.895	5.822	6.971
	1	6.226	7.312	7.745	8.642	9.158	9.928
	2	9.401	10.153	10.929	11.582	12.380	12.960
2	0	2.840	6.121	4.392	6.978	5.758	7.909
	1	6.165	8.210	7.700	9.418	9.123	10.613
	2	9.367	10.824	10.903	12.177	12.359	13.496

Table 2
Values for $(\lambda a)_{mn}$.

Mode	n		
m	0	1	2
0	2.404	5.520	8.654
1	3.832	7.016	10.173
2	5.135	8.417	11.620

Table 3
Properties and dimensions of the membrane mirror model.

Parameters	Mirror substrate	PVDF layer
Young's modules Y, Y_p/(N/m^2)	1.013×10^6	2×10^9
Poisson's ratio v, v_p	0.497	0.29
Mass density ρ, ρ_p/(kg/m^3)	1020	1800
Thickness h, h^a/m	0.0015	5×10^{-5}
Radius a/m	0.1	/
Piezoelectric strain constant h_{31}, h_{32}/(C/m^2)	/	9.6×10^{-3}
Dielectric constant ϵ_{33}/(F/m)	/	8.85×10^{-11}