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Effect of the adhesive layer on the unimorph deformable mirror

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ABSTRACT

As the thickness of the adhesive layer between the mirror and the actuator decreases and the performance requirements of the unimorph deformable mirror (DM) increase, stricter control on the adhesive layer thickness and Young's modulus is necessary. In this paper, a finite element model (FEM) for the unimorph DM with an adhesive layer is obtained. Based on the model, the influence of adhesive layer thickness and Young's modulus on the deformation is studied. Also their influence on the adhesive's maximum shear stress is analyzed. In the meantime, the design principles of the adhesive layer thickness and Young's modulus are established with the restrictions of shear failure and the maximum displacement. As a result, different adhesive Young's modulus has corresponding requirements for the upper and lower thicknesses (<20 μm) to obtain 85% maximum displacement. Then, DMs with four different mirror thicknesses are fabricated for verification experiments. The experiments results can be matched with the simulation results. Finally, the thickness in the spin coating process of adhesive layer is explored. The adhesive layer thickness can be controlled within 12.1 μm, and the deviation of uniformity is better than ±2%.

1. Introduction

In recent years, adaptive optics (AO) is widely applied in the fields of wave-front aberration correction of the laser beam, high-resolution imaging of the human eye retina, beam quality improvement of terrestrial telescopes and beam focusing performance improvement of synchrotron radiation light source [1,2]. The adaptive optics system includes three parts: wave-front detection, wave-front control and wave-front correction. As the main component of wave-front control, DMs can be divided into electrostatic drive, electromagnetic drive, piezoelectric drive and so on. The unimorph DM becomes a mainstream due to its advantages of long stroke, simple fabrication and low cost [3–6].

Spatial distribution of the electrodes, the structure of the piezoelectric ceramic and the mirrors, the edge support and so on are the main factors that affect the static and dynamic characteristics of the DMs. The factors can be analyzed and optimized with the finite element analysis (FEA) method. The traditional FEA model of a DM is an electro-elastic coupled model, which consists of the piezoelectric disk and the mirror only. The effect of the adhesive layer between the piezoelectric disc and the mirror disk is not taken into account by the traditional models because its thickness is considered to be very thin [7–10]. However, as the manufacturing process of the mirrors and the piezoelectric disk is increased, and the thickness

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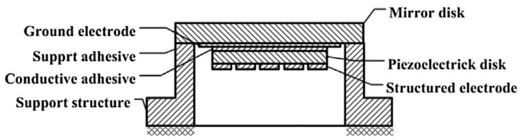

Fig. 1. Structural illustration of the unimorph DM.

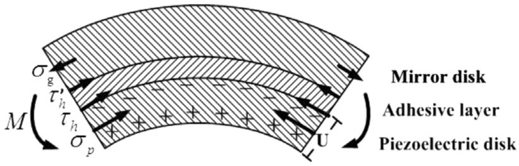

Fig. 2. Schematic illustration of deformation principle unimorph DM.

of the layer structure is continuously reduced, the influence of adhesive layer on the DMs is becoming prominent. The model without the adhesive layer will greatly reduce the simulation accuracy and increase the design error. So the adhesive thickness should be in strict control, and it is necessary to study the glue process.

In this paper, a finite element model (FEM) of the unimorph DM with the adhesive layer is applied to analyze the influence of adhesive Young's modulus and thickness on the deformation in detail. The maximum shear stress is calculated by different parameters of adhesive layers, so the optimal design parameters of the adhesive layer without shear failure are obtained. In order to verify the simulation results, four prototype DMs are manufactured. In addition, the control technique of the adhesive layer thickness is investigated.

2. Finite element model of unimorph DM

The basic physical structure of unimorph DM is showed in Fig. 1. From top to bottom it includes the mirror disk, ground electrode layer, conductive adhesive layer, actuator disk (piezoelectric disk), structured electrode layer and support. The bottom of support is fixed, and the rest parts are rigidly connected.

The operation principle of the DM is based on the transverse reverse piezoelectric effect of the piezoelectric ceramics. With the external electric field, the electrical energy is converted to mechanical energy to drive the mirror to deform [11]. Simplified unimorph DM belongs to laminated structure, and the adhesive layer is placed between the mirror disk and the piezoelectric disk (see Fig. 2). When some voltage U is applied to the piezoelectric ceramic, transverse stress σ_p is generated on the ceramic immediately. Also adhesive layer adjacent surface shear stress τ_h and the shear stress τ'_h close to the mirror are generated. The piezoelectric ceramic and the adhesive layer are deformed transversely, but the mirror remains unchanged. For this reason, the bending moment M is made by the lateral dimension variation so the mirror is deformed. Meanwhile, the corresponding stress σ_g in the mirror is coursed. The stress transferring is a gradually reduction process especially along the adhesive layer thickness direction. Therefore, the mirrors' deformation will definitely be different with the adhesive layers of different thickness.

The model's simulation analysis here is performed by the COMSOL Multiphysics FEM software package. Among the process, the 3D solid model of the DM is generated from Solidworks software. Each part of the structure uses a free-cut tetrahedral element. Moreover, different sizes of elements are employed for components of different dimension. Finally, the model is meshed into approximately 200,416 elements. In the analysis, the structured electrode area is applied a voltage to obtain its influence function. Fig. 3(a)–(c) shows the result of grid division and the influence function for central electrode applied 400 V.

3. Verification of DM's FEM

3.1. Analysis object

In order to verify the validity of the FEM, experiments are compared the simulations. The analysis object is a 19-unit unimorph DM with an effective aperture of 30 mm. Similarly, a prototype DM is fabricated, and the layer structure is presented in Fig. 4. Detail material properties are listed in Table 1. The back of the PZT-5H is distributed evenly 18 sectorial electrodes and a circular center electrode. The mirror surface accuracy PV value is less than 1 λ with double-sided polishing. Taking the #1, #2 and #8 electrodes as the research representations, the influence functions of the DM are tested by a Shack-Hartman wave-front sensor (WFS) and compared with the simulation results.