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Optimal Design of Compliant Trailing Edge for Shape Changing

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Abstract

Adaptive wings have long used smooth morphing technique of compliant leading and trailing edge to improve their aerodynamic characteristics. This paper introduces a systematic approach to design compliant structures to carry out required shape changes under distributed pressure loads. In order to minimize the deviation of the deformed shape from the target shape, this method uses MATLAB and ANSYS to optimize the distributed compliant mechanisms by way of the ground approach and genetic algorithm (GA) to remove the elements possessive of very low stresses. In the optimization process, many factors should be considered such as airloads, input displacements, and geometric nonlinearities. Direct search method is used to locally optimize the dimension and input displacement after the GA optimization. The resultant structure could make its shape change from 0 to 9.3 degrees. The experimental data of the model confirms the feasibility of this approach.

Keywords: adaptive wing; compliant mechanism; genetic algorithm; topology optimization; distributed pressure load; geometric nonlinearity

1 Introduction

As conventional airfoil contours are usually designed with specific lift coefficients and Mach numbers, they could not change in accordance with the environment changing. Siclari and Austin[1] indicated that the variable camber trailing edge would produce the drag about sixty percent less than the conventional fixed camber airfoil.

There are three methods used to design variable camber wings. Of them, one is conventional hinged mechanism, which, however, will create discontinuities over the wing's surface leading to earlier airflow separation and drag increase. The others are smart material and the compliant mechanism, of which both could realize smooth shape changing. Nevertheless, compared to the compliant mechanism, the smart-material-made actuators have many disadvantages, such as deficient in energy, slow in response, strong in hysteresis, limited by temperature, and difficult to control too many actuators. Musolff[2] from Industry University of Berlin used Ni-Ti shape-memory-alloy wire to make an adaptive variable camber wing, which could quickly change its shape, but could not perform highly frequent alteration because of its resilience dependent on the heat exchange with the outside environment.

Compliant mechanism is a kind of one-piece flexible structure, which can transfer motion and power through its own elastic deformation. It is not only flexible enough to deform, but also has enough stiffness to withstand external loads. Thanks to its joint-free nature, it does not have the troublesome problems confronted by conventional mechanism,

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such as friction, lubrication, noise and recoiling, thereby achieving smooth shape changing.

In 1994, Kota[3], a professor from University of Michigan, firstly pointed out that compliant mechanism could be used to control static shape changing under the sponsorship of the Air Force Office of Scientific Research in USA. Saggere and Kota[4] suggested a new method to design compliant adaptive structures, which made the least square errors between the shape-changed curve and the target curve as the objective function for optimization. Based on their work, Lu[5] put forward a load path representation method. However, her work was limited to only linear analysis under consideration of nodal loads. Good[6] from Virginia Polytechnic Institute of State University used the compliant mechanism and the Moving Asymptotes method to design the fuselage tail within the allowable range of its tip maximal deflection. Kota and Hetrick[7] in 2004 designed a compliant trailing edge on the base of the F16's data, which can change from 0° to 15° and obtained a patent. Campanile[8] from German Aerospace Center presented a modal procedure to design synthetic flexible mechanisms for airfoil shape control, and pointed out that the future research should take into account the airload and the geometric nonlinearity. Buhl[9] from Risø National Laboratory of the Wind Energy Department in Denmark used the SIMP method and geometrically nonlinear finite element method to design compliant trailing edge flaps. FlxSys Inc in 2006 produced an adaptive compliant wing, which stood the test on the White Knight airplane. The results indicated that the compliant trailing edge could change ±10°[10]. In China, the research of adaptive wing has been concentrated on smart material and conventional mechanism. Few people, it seems, have worked on designing adaptive wings with the compliant mechanism. Yang is an exception. He analyzed the active aero-elastic wings based on the aero-servo-elasticity technology[11]. Chen and Huang separately investigated the morphing of the compliant leading edge from the viewpoints of discreteness and continuity[12-13].

This paper presents a method to design the shape changeable structure by MATLAB and ANSYS associated with distributed compliant mechanism on the base of the ground structure approach and genetic algorithm (GA) taking into account the external distributed loads and geometric nonlinearity.

2 Optimization Process

2.1 Defining the trailing edge model and objective function

As shown in Fig.1, both curves represent two ideal shapes of the trailing edge in the different flying states. One side (*A* point) of the structure is supposed to be fixed, and the other side (*B* point) to be sliding horizontally.

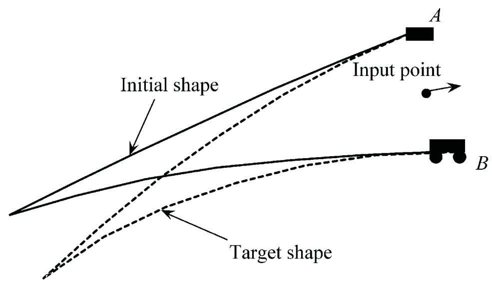

Fig.1 Initial shape and target shape.

Firstly, the design domain should be defined by the initial curve shape, the input location and the boundary conditions. Then, it is divided with a beam element network simulating the bird's feather as shown in Fig.2. This is termed the partial ground structure method.

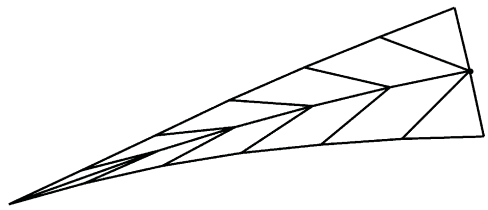

Fig.2 Discretization of the design domain.

The simplest and most effective way to manufacture the planar compliant mechanism is to use wire-cutting technology. In the optimization program, all the elements are of rectangular beams with