Control Surface of Flying Robot using Piezo-Electric Composite Actuator

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Abstract

In this study, a new type of control surface for a flying robot was designed and manufactured using piezo-electric composite actuator. This study aims to develop lightweight and excellent smart actuators in order to replace conventional hydraulic/pne -umatic actuators, and to apply the developed actuators to the actuation systems. The piezo-composite actuator was composed of a piezo-electric ceramic layer, a carbon/epoxy layer and glass/epoxy layers. A simple model of control surface was manuf -actured and evaluated through experiments.

Introduction

In this study, describes the procedures of design, manufacturing of smart structure application of the piezo-composite actuator with the application devices, we found that the possibility of piezo-composite actuator could be used as a control surface of flying robot.

It is expected that piezo-composite actuator has a possibility to be used not only as a guided small flying robot but also as a control surface actuator of small missile through the miniaturization of power supply and control system.

Design Procedure and Manufacture system

1.1 *Analytical Design Model for Piezo-composite Actuator*

Newly developed structure with intelligent material depends more on numerical analysis or experiment than analytical method. Yet, designing an efficient system, the need a performance analysis through analytical method applied to the actuator. We proposed an analytical model for designing of layered actuator. [1]~[4]

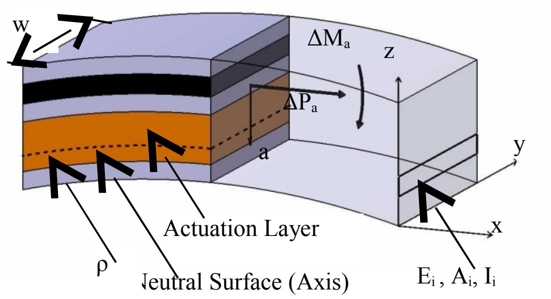

Figure 1: Schematic of the curvature change of a laminated beam with electro active layer.

Eq. (1)~(3) shows the curvature change of the laminated beam that can be formulated using the simple beam deformation theory when a pure bending moment is applied, as

$$\Delta k = \frac{1}{\Delta \rho} = \frac{\Delta M_a}{D} = \frac{a \cdot \Delta P_a}{D} \qquad (1)$$

For an actuator with unit width the change in the curvature can be expressed as

$$\Delta k = \frac{a \cdot \Delta P_a}{D} = \frac{a}{D} E_a \cdot d_{31} \cdot \Delta V \qquad (2)$$

where, a/D is the coefficient of an actuator per unit width. Equation (2) can be written in a simple expression as

$$\Delta k = C_{ua} \cdot E_a \cdot d_{31} \cdot \Delta V \qquad (3)$$

In case of same composite ceramic wafer being used, the moment arm length which formed the flexural neutral surface of the actuator beam to the center of the actuating layer must be as large as possible to produce a larger actuating moment, which means that the actuating layer should be placed on one of the outer surfaces. In addition, the total bending stiffness of an actuator section should be small so a large curvature change may occur for a given actuation moment.

1.2 *Lift, Drag, Moment Calculation for Control Surface*

Under the subsonic air flow condition as shown in Fig. 2 and 3, the aerodynamic forces and moment produced on the control surface can be calculated using equations (4) and (5).

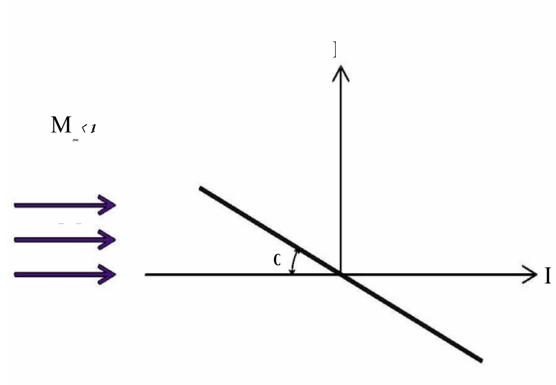

Figure 2: Plane on aerodynamics in air flow caption style.

In this case,

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$$(4)\qquad L = \frac{1}{2}\rho_\infty V_\infty^{\,2} S C_L \quad and \quad D = \frac{1}{2}\rho_\infty V_\infty^{\,2} S C_D$$

$$(5)\qquad C_L = 2\pi\alpha \quad and \quad C_D = C_d + \frac{C_L^{\,2}}{\pi e AR}$$

with the following flight condition, where

$M_\infty = 0.5$ (at sea level), $\alpha = 10^\circ$

When the chord length of control surface is 3 in and span length is 3 in.

Moment can be calculated using equation (6).

$$(6)\qquad Moment = aL + bD$$

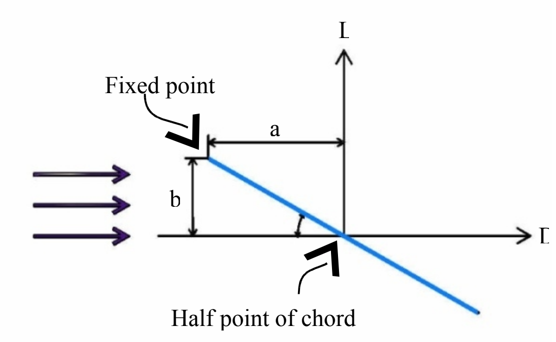

Figure 3: Moment of fixed wing section.

By using (4)~(6) equation, calculate lift and drag can be calculated as follows,

Flight condition

$M_\infty = 0.5$ (at sea level), $\alpha = 10^\circ$

Chord length = 3 in, span = 3 in

Lift	25.37 lb (112.8 N)
Drag	8.86 lb (41.4 N)
Moment	26.23 in·lb (2.25 N)

Table 1: Shows the result of under subsonic flow.

Manufacturing of Actuator

Fig. 4 show the lay-up structure of the piezo-composite actuator. [6]

Table 2 is the material properties used by for piezo-composite actuator.

Properties	Piezo-Ceramic	Carbon-Epoxy	Glass-Epoxy
E_1(GPa)	59.9	231.2	21.7
E_2(GPa)	59.9	7.2	21.7
G_{12}(GPa)	23	4.3	3.99
ν_{12}(GPa)	0.3	0.29	0.13
α_1($\times10^{-6}$/°K)	2	-1.58	14.2
α_2($\times10^{-6}$/°K)	2	32.2	14.2
d_{31}(10^{-10}/V)	-190	-	-
ρ(g/cm^3)	7.8	1.51	1.91

Table 2: Basic properties of actuator

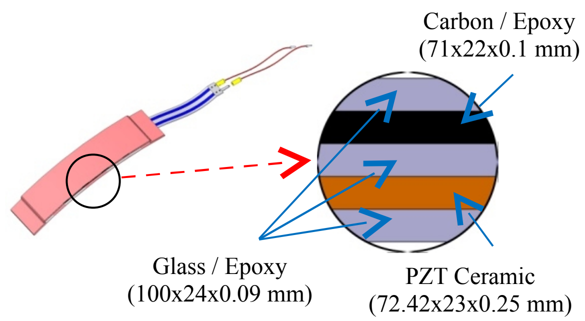

Figure 4: Piezo-composite actuator.

Experiments and Results

To evaluate the actuation performance of the manufactured composite actuator, an actuator testing system was constructed as shown in Fig. 5. The system consisted of an actuator jig, a high voltage signal function generator (TD-2 Power Supplier, Face International Co.), and a digital camera for capturing image and image scan program (AutoCAD).

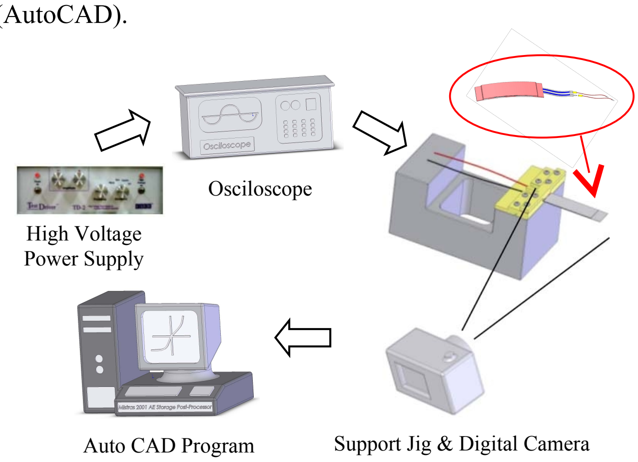

Figure 5: Experimental setup for actuating test.

One end of the actuator was fixed using the 92mm span jig in fixed cantilever-like condition. The Angle change of the actuator was measured to observe the change of angle of attack of the control surface.

The actuator was excited by a power supply system within a range of voltage where no domain switching phenomenon happens. For the actuator, the voltage range was from -400V to +150V

The actuation performance of actuator is compared, for the condition without load and with 50g(gram) load in Table 3.

	Weight(g)	Voltage(V)	Angle change(°)
Actuator	0	-400	5.72
	50	+150	5.64

Table 3: Angle change for piezo-composite actuator

Modeling of Control Surface

1.3 3D Modeling

Fig. 6 shows the shell-joint models described using 3D design program.

Generally, the tip-joint type is suitable for a structure, with big displacement and small force, while the shell-joint type is suitable for a structure, with the big force and small displacement.

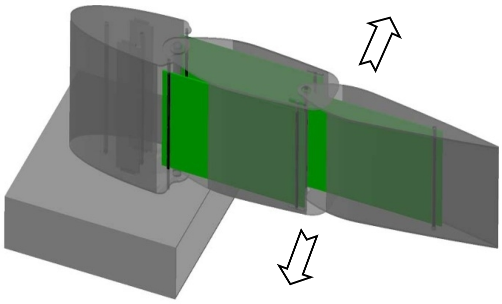

Figure 6: Structural application model using piezo-composite actuator

The two application methods have both advantages and disadvantage, but sufficient performance verification and necessity terms desired should be filled before the application of control surface using piezo-composite actuator. [7]~[13].

1.4 Controller for control surface

MIPAD was developed to be controlled by a radio controller and powered by a battery so that it can be applied to remote systems in small size and light weight.

Figure 7: The implemented hardware of MIPAD (100mm x 40mm, 53.3g).

The implemented hardware of MIPAD is shown at Fig. 7. The main circuit of driver is miniaturized and by using a small step-up power chip10 and a high voltage analog OP amplifier Moreover, it is designed to be operated in 4.5V~7.5V range battery for mini mobile applications. The driver has a +5V power for digital device operation, and ±15V power suppliers for analog filter. Three power transformer chip sets were utilized for +5V, +12V and ±250V driving power respectively. The design of power system is presented in Fig. 8. [5]

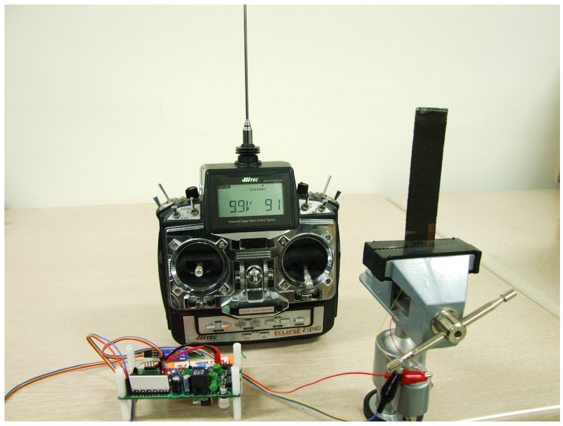

Figure 8: MIPAD power system

Conclusion

This paper describes the procedures of designing and, manufacturing smart structure application of the piezo-composite actuator with performance evaluation and comparison method. From the test results of the application, we found the possibility of piezo-composite actuator used as a control surface of small flying robot.

It is expected that piezo-composite actuator has a possibility to be used not only as a small flying robot but also as a control surface actuator for a small missile control surface through the miniaturization of power supply and control system.

Acknowledgment

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