

Design Study and Performance Evaluation of Actuator System for Subsonic GA Wind Tunnel Testing

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Abstract:

JAXA has been conducting research and development of the on-board safety avionics technology to prevent turbulence-induced aircraft accidents (Safe Avio) that uses Doppler light detection and ranging (LIDAR) to detect the turbulence in advance and the preview controller to utilize the turbulent velocity information measured by LIDAR to attenuate the aircraft acceleration in turbulence. The preview controller should be validated by a subsonic GA (Gust Alleviation) wind tunnel testing as the first step. The high performance actuator system, which drives the control surfaces to alleviate the gust influence on the aircraft, is required to realize the wind tunnel testing. A design study, prototyping and performance evaluation of the piezoelectric actuator system installed in a model wing for the subsonic GA wind tunnel testing are carried out. The results show that the actuator system demonstrates the sufficient dynamic and endurance performances to satisfy the requirements including the $\pm 10^\circ$ wide range of the output deflection.

Keywords: GA (Gust Alleviation), Preview controller, Piezo actuator, Wind Tunnel Test

Introduction

To improve the safety of passengers and crew on the aircraft, JAXA has been conducting research and development of the on-board safety avionics technology to prevent the turbulence-induced aircraft accidents (Safe Avio) that uses Doppler light detection and ranging (LIDAR) to detect the turbulence in advance and automatically control and suppress the lurching of the aircraft [1]. In order to demonstrate one of the prime technological targets comprising of Safe Avio, a gust response and mitigation algorithm utilizing the preview controller [2] should be validated by a GA (Gust Alleviation) wind tunnel testing [3, 4]. The key components of the wind tunnel testing such as a gust generator, a dynamic supporting system, an aircraft model and an actuator system are under studying and developing to perform the subsonic GA wind tunnel testing as the first step as shown in Fig.1.

The gust generator set on the upstream side of the wing of the half model aircraft oscillates the cascade to generate specified types of the gust, then the wing model supported by the dynamic supporting system heaves and pitches responding to the gust. The control surface, the aileron, is driven by the actuator system to suppress the wing model movement controlled by the algorithm utilizing the preview controller.

A design study of the actuator system is carried out to satisfy the requirements based on the assuming wind tunnel test conditions and model wing geometry.

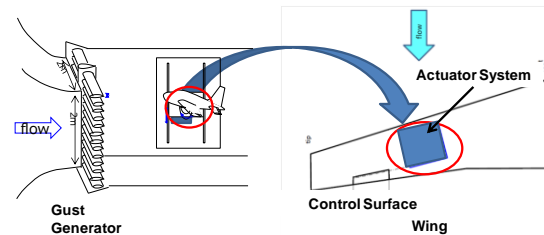


Fig. 1: Schematic view of GA wind tunnel testing

This paper describes the design study process and the results of the performance evaluation which contains the dynamic performance and durability of the actuator system.

Requirements for Actuator System

Based on the assuming wind tunnel test conditions, the requirements for the actuator system are set up as follows.

Operating performance:

Output deflection	$\pm 10^\circ$
Frequency	22Hz
Gain	-3dB
Phase	90deg

Applied loads (under which the operating performances should be satisfied.):

Static airload	0.1Nm
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Dynamic load 0.01Nm/deg
 Inertia of the control surface
 $5.6 \cdot 10^{-5} \text{kgm}^2$

Size and weight
 Spanwise 200mm
 Chordwise 100mm
 Thickness 15mm
 Weight 1kg

System Design

Fig.2 shows the proposed actuator system to be installed in a wing model for the subsonic GA wind tunnel testing. The mechanism utilizing a piezoelectric actuator is devised based on a preceding study applying a helicopter blade [5].

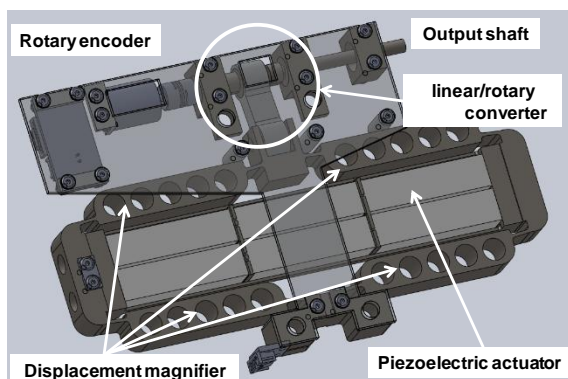
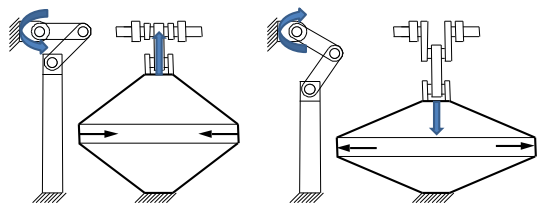


Fig. 2: Proposed actuator system for the subsonic GA wind tunnel testing

The six packs of the piezoelectric actuator generate the $144 \mu\text{m}$ linear reciprocal displacement which is magnified by the four-armed displacement magnifier by 9 times. This linear displacement is converted into the $\pm 10^\circ$ rotary reciprocal movement by the linear/rotary converter composed of the crank mechanism which is transmitted via the output shaft to the control surface of the wing as a drive force. The output deflection is measured and health monitored by the rotary encoder connected on the opposite side of the output shaft via the coupling.



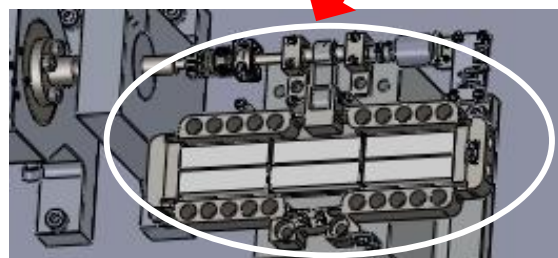
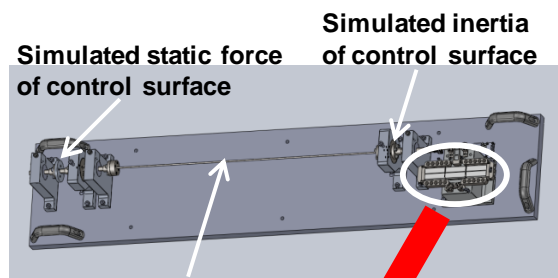
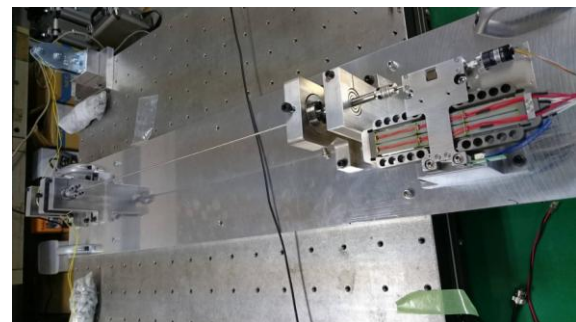
(a) Actuator shrinking (b) Actuator extending

Figure 3: The operating principle of the actuator system

The operating principle of the actuator system is shown in Fig.3. When the piezoelectric actuators are shrinking as shown in Fig.3 (a), the four-armed displacement magnifier is growing vertically. This input to the linear/rotary converter is transformed into the output shaft rotation. The opposite sequence of the movement of the actuator system happens in the actuator extending process as shown in Fig.3 (b).

Performance Evaluation

The two types of tests, namely a dynamic test and an endurance test, are conducted to examine and demonstrate the operating performance of the actuator system.



Actuator system

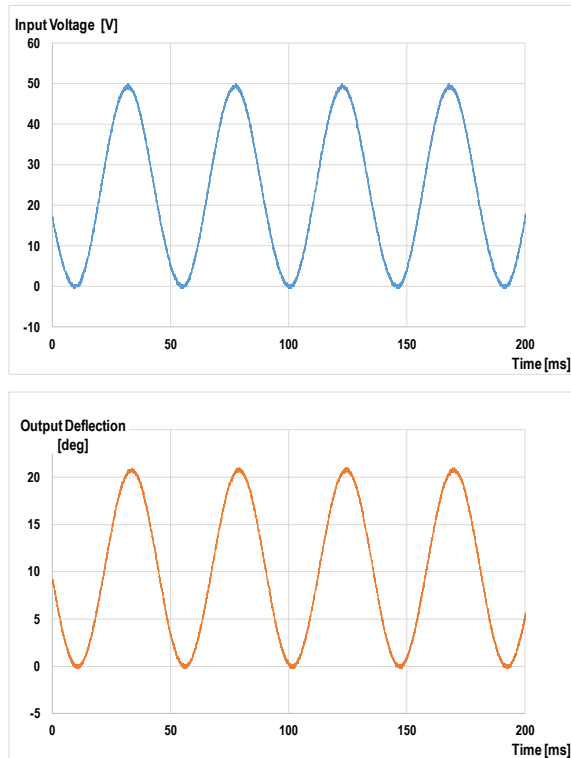
Fig. 4: Set up of dynamic and endurance tests

Fig.4 shows the set up for the dynamic and endurance tests. The prototype of the actuator system is installed with the loadings of simulated inertia, dynamic and static forces of the control surface during the wind tunnel testing. The inertia of the control surface is simulated by the mass with the

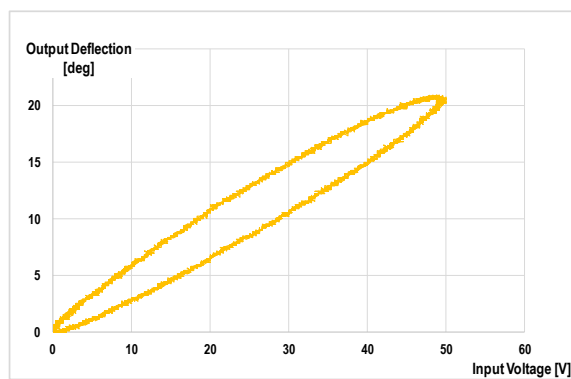
equal inertia moment around the output shaft. The dynamic force is done by a piano wire with the equal torsional stiffness. The static force is done by the initial torsion deflection added to the piano wire.

Dynamic test

This test is carried out to evaluate the operability of the actuator system on the target condition.



(a) Output deflection of the actuator system and input voltage : time history



(b) Hysteresis of output deflection of actuator system with respect to input voltage

Figure 5: Dynamic characteristics of the actuator system

Input voltage= 0 to 50V
Actuator frequency=22Hz
with simulated applied loads

For this objective, the actuator system is operated with input voltage 0 to 50V at 22Hz with the simulated applied loads.

Fig.5 shows the dynamic test result. This figure denotes the dynamic behaviour of the actuator system measured by the encoder and optics with the simultaneously measured input voltage to the actuator. As shown in Fig.5 (a), a little more than 10deg output deflection of the actuator system at 22Hz is obtained, which satisfies the requirement mentioned above.

Fig.5 (b) shows the hysteresis of the actuator system output deflection with respect to the input voltage. This hysteresis can be coped with the feedback controls to eliminate during the practical use of the actuator system in the wind tunnel testing.

Endurance test

This test is to demonstrate the durability of the drive mechanism and to examine the heat accumulating characteristics with respect to the operation time. For this purpose, the actuator system drive mechanism is continuously operated with input voltage 0 to 50V at 22Hz with the simulated applied loads.

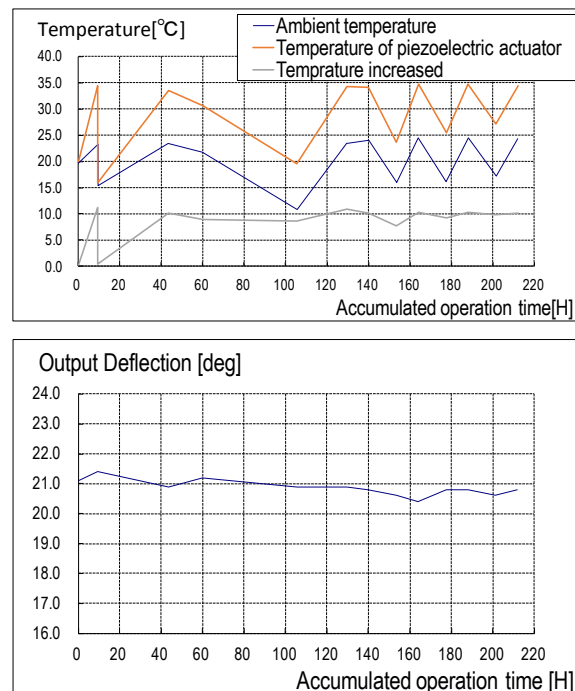


Figure 6: Temporal variation of piezo actuator surface temperature and output deflection of the actuator system

Input voltage= 0 to 50V
Actuator frequency=22Hz
with simulated applied loads

Fig.6 shows a temporal variation of temperature measured on the surface of the piezo actuator and the actuator system output deflection for the 200 hour of the operation. The temperature increases sharply after the activation to 35degC, but varies mildly along with the surrounding air temperature thereafter. It is demonstrated that the actuator system worked successfully for 200 hours without the significant temperature increase or the deterioration of the actuator system.

Fig.7 shows the thermograph of the actuator system during this test when the maximum temperature is observed.



Fig. 7: Thermograph of actuator system

These results confirm that the actuator system has enough durability for the practical use installed in the wind tunnel testing without any adverse characteristics of the heat accumulation and the mechanical troubles.

Conclusions

Summarizing the results, the followings are concluded by this study.

1. The actuator system complying of the piezoelectric actuator, the amplifying mechanism and the linear/rotary movement converter is developed based on the design study to satisfy the requirements for GA wind tunnel testing and the wing model in which the actuator system is installed.
2. The developed actuator system is evaluated by the dynamic test which demonstrates that the actuator system achieves 10deg output deflection at 22Hz under the specified simulated applied loads such as the static/dynamic airloads and the inertia of the control surface.

3. The actuator system worked successfully for 200 hours without the significant temperature increase or mechanical troubles in the endurance test. This confirmed that the actuator system has enough durability for GA wind tunnel testing.

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