DESIGN AND PERFORMANCE EVALUATION FOR FINALIZED ACTIVE TAB DRIVE MECHANISM INSTALLED IN MACH SCALED MODEL BLADE

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Abstract

JAXA has researched Active Tab as one of the active techniques for helicopter BVI (Blade/Vortex Interaction) noise reduction. A conceptual design study of Active Tab installed in a Mach scaled assumed blade was carried out. Based on this conceptual design, the first prototype of Active Tab drive mechanism was developed and evaluated. The results shown the sufficient dynamic and endurance performance. In order to better fit to the assumed blade, the second prototype of Active Tab drive mechanism with the reduced weight is designed and evaluated. The dynamic test without the simulated airload shows the sufficient amplitude, but the wave form is deformed. In order to solve the wave form distortion generated by the second prototype of Active Tab drive mechanism, the finalized version of Active Tab drive mechanism is developed. The dynamic test demonstrates the sufficient Active Tab displacement and 50 hour endurance. This confirmed that the finalized Active Tab drive mechanism has enough dynamic performance and durability for the practical use installed in helicopter blades.

1. INTRODUCTION

Among the various types of noise generated by helicopters, the BVI noise causes significant damage and cannot be well reduced by passive techniques such as airfoil/tip shape improvement. In order to resolve this BVI noise problem, many research organizations and helicopter manufactures have been working to research/develop BVI noise reduction techniques for these decades as one of the high priority technical tasks [1]-[22].

JAXA (Japan Aerospace Exploration Agency) and Kawada Industries Inc. have been working to research and develop a new active technique for helicopter noise reduction which is available to ICAO defined flight patterns, namely approach, fly over and take-off [23]. This new technique is referred as “Active Tab” [24]-[27]. The schematic view of Active Tab is shown in Fig.1. Active Tab is installed in the aft portion of the airfoil and driven back and forth dynamically to reduce BVI noise and the vibration by the blade circulation control due to the variable blade area effect.

Active Tab also can be operated statically, such as Active Tab is deployed with some displacement and fixed. This way of operation can increase the blade lift during the whole revolution of the blade so that the rotor speed can be reduced by making use of this lift increment, which is effective on the climb and fly-over noise reduction.

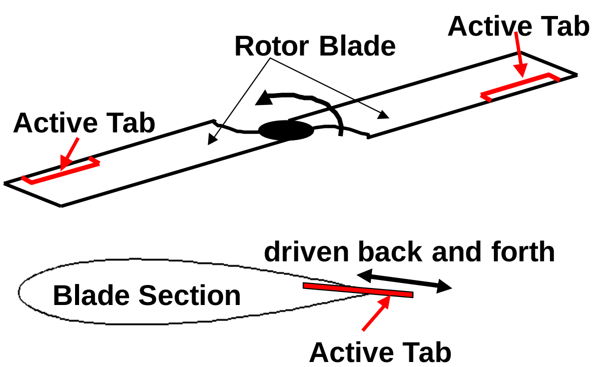


Figure 1: Active Tab concept

The outline of this research program is depicted in Fig.2. We started in 2002 to study the fundamental tab aerodynamic property by a 2D static wind tunnel test, then proceeded to a 2D dynamic wind tunnel test in 2003 to examine the tab dynamic effect [24]. This step of the study showed that a realistic size and anhedral of Active Tab has sufficient aerodynamic capability equivalent to the potential for rotor noise reduction. CFD analysis simultaneously started to propose aerodynamically effective tab geometry [28].

In 2004 and 2005, the rotor wind tunnel test using one-bladed rotor system as shown in Fig. 3 was carried out in a rotor configuration with on-blade Active Tab to evaluate Active Tab effect on rotor noise reduction and to provide the validation data for CDF code development.

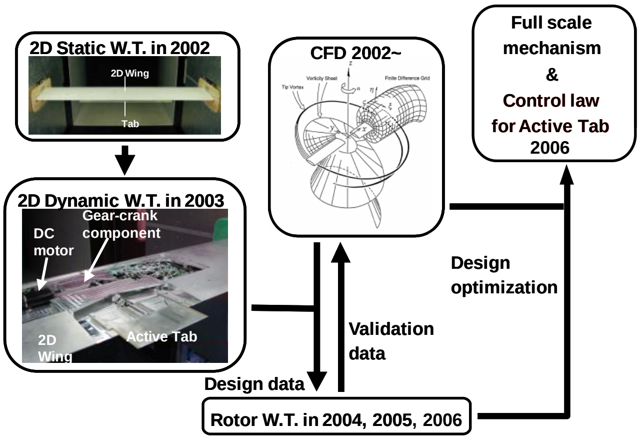


Figure 2: Active Tab research program

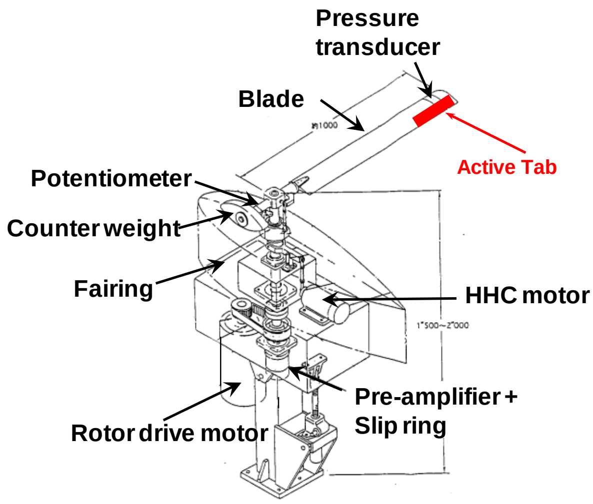


Figure 3: One-bladed rotor system with Active Tab

It is demonstrated by this wind tunnel test in a rotor configuration that Active Tab has the efficient capability to control the rotor noise about 3dB and that Active Tab is one of the promising techniques for rotor noise reduction [25], [26].

The next step is established to demonstrate Active Tab capability on a Mach scaled condition because the above mentioned rotor wind tunnel test was carried out by a one-bladed rotor system as the first step to evaluate Active Tab performance on low subsonic test conditions where the blade tip speed is less than 100m/sec.

A conceptual design study of Active Tab in order to be installed in a Mach scaled assumed blade is carried out [29]. Then, the first prototype of the drive mechanism of Active Tab shown in Fig.4 is developed based on this conceptual design study [30].

A single stacked piezo actuator stored in a casing generates a linear reciprocal movement, which is magnified by the double armed amplifier and transformed into a rotary displacement of the arms around the pivot Then, Active Tab is driven via a pivot in a rotational reciprocal direction. A counter weight is connected on the opposite side of Active Tab across the pivot in order to cancel the centrifugal force acting about the pivot.

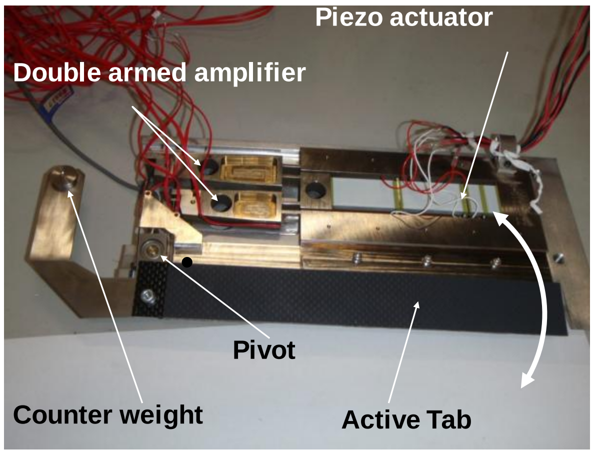
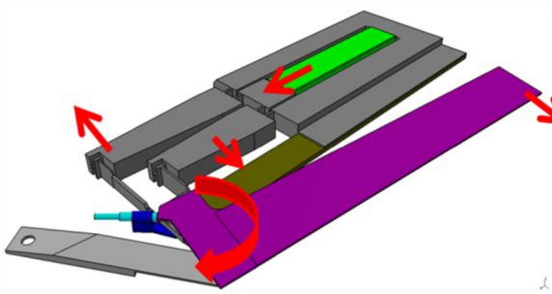
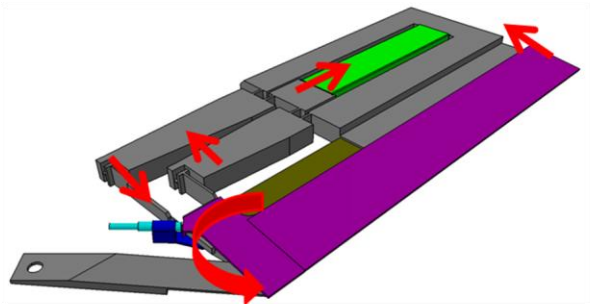


Figure 4: First prototype of Active Tab drive mechanism

The sequence of Active Tab deployment is shown in Fig.5. The process of Active Tab spreading is depicted in Fig.5(a). At first, the piezo actuator (green part) extends. This movement opens apart each arm (gray parts) of the amplifier, which generates a torque around the pivot in the direction of making Active Tab (purple part) rotationally spreading around the pivot. The opposite happens in the retrieving process which is initiated by the piezo actuator shrinking as depicted in Fig. 5(b).



(a) Active Tab spreading process



(b) Active Tab retrieving process

Figure 5: Active Tab deployment sequence

The performance of the first prototype of Active Tab drive mechanism is evaluated and demonstrated that 28mm displacement of Active Tab drive mechanism at 2/rev with a fair waveform is obtained, which satisfies the requirement for this Active Tab drive mechanism.

Active Tab drive mechanism worked successfully for 35 minutes with a nonsignificant temperature increase at 44.4Hz. This confirmed that Active Tab drive mechanism has enough durability for the practical use installed in helicopter blades without any adverse characteristics of heat accumulation[30].

This first prototype is a demonstrator for the mechanical feasibility consisting of the piezo actuator, the double armed amplifier and the pivoted tab. The weight of this prototype is so heavy to be installed in an assumed blade with structural safety. In order to better fit to the assumed blade, the second prototype of Active Tab drive mechanism with the reduced weight is designed and evaluated.

Fig.6 shows the developed second prototype of Active Tab drive mechanism which is geometrically suitable to the assumed blade[32]. Several wires shown in this figure are for the power supply to the piezo actuator and for the eddy current sensor. Almost all of the instrumentations are removed in Fig.6 to make it clear the outline of each component in the drive mechanism.

The performance evaluation is carried out by this prototype in an isolated configuration with a simulated blade

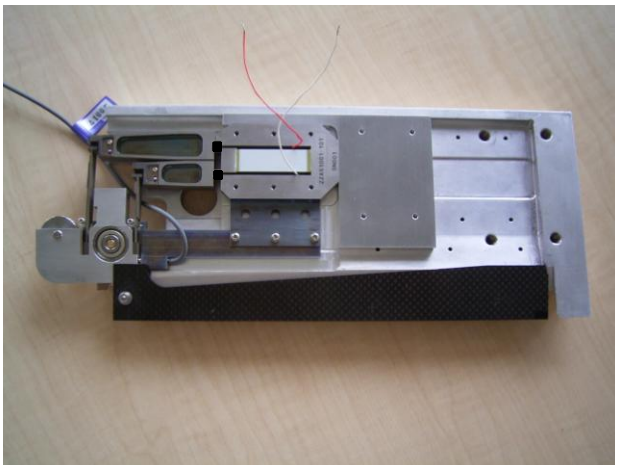


Figure 6: Second Prototype of Active Tab drive mechanism with simulated blade

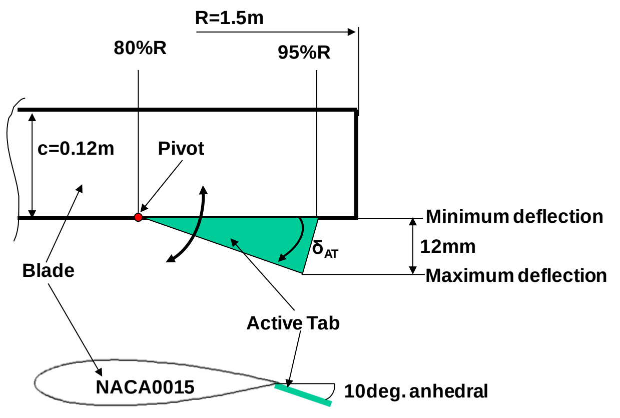
The developed second prototype of Active Tab drive mechanism worked successfully for 82 hours with a nonsignificant temperature increase in the endurance test.

The dynamic test demonstrates that Active Tab drive mechanism achieves 14mm displacement at 2/rev, which satisfies the requirement. But some wave form distortion is observed probably caused by the friction between the blade inner surface and Active Tab.

In order to solve the wave form distortion generated by the second prototype of Active Tab drive mechanism, the finalized version of Active Tab drive mechanism is developed.

This paper presents all the process of design and evaluation for the finalized Active Tab drive mechanism.

2. ASSUMED BLADE AND ACTIVE TAB GEOMETRY



Rotor speed : 1300 rpm
Rotor radius : 1.5m
Blade chord : 0.12m
Plan form : rectangular
Airfoil : NACA0015
Twist : -8deg. linear
Anhedral: -10deg.
Hub type: teetering

Figure 7: Active Tab installation

Based on the achievement of wind tunnel test by one-bladed rotor system, the features of Active Tab for the Mach scaled blade are defined and its schematic drawing is shown in Fig.7.

The tab is fan-shaped so that the extended area generated by the tab operation is made larger in the outer portion of the blade where the dynamic pressure is higher than that in the inner portion. A 10deg. anhedral angle is put to the tab so that the tab effect to the blade lift increment is augmented. This Active Tab is pivoted at its apex to 80%R location of the blade. NACA0015 is selected as the airfoil of the blade in order to provide as large thickness to store the drive mechanism of Active Tab as possible without significant disadvantage to the maximum lift of the blade.

3. REQUIREMENTS

Based on the experimental results [24]-[27], [30],[32] and the analytical prediction [31], the requirement for the finalized Active Tab is set up as follows.

Active Tab :
Span length : 80-95%R
Displacement : 12mm
Frequency : 2/rev (43.3Hz)
with 20N simulated lift acted on tab

Instrumentation :
Active Tab displacement
Hinge moment
Output displacement of the double armed amplifier
Actuator displacement
Input voltage to actuator

The required displacement of the second prototype of Active Tab is reduced to 12mm from that of the first prototype (24mm) [30]. In order to reduce the weight of the drive mechanism, the piezo actuator is downsized based on the analytical parametric study to define the minimum Active Tab displacement holding the sufficient noise reduction capability [31]. This requirement for the displacement is also applied to the finalized Active Tab.

The 20N simulated lift acted on tab is added to the condition based on the test result of the second prototype [32] to demonstrate proper operability of the finalized Active Tab drive mechanism.

4. SYSTEM DESIGN

The schematic view of Active Tab drive mechanism is shown in Fig.8.

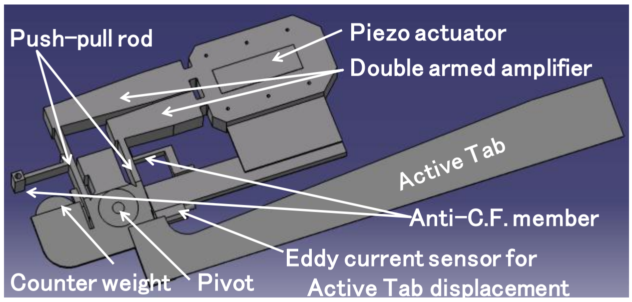


Figure 8: Active Tab drive mechanism

A single stacked piezo actuator stored in a casing generates a linear reciprocal movement, which is magnified by the double armed amplifier. Then, Active Tab is driven via a pivot in a rotational reciprocal direction. Each arm of the double armed amplifier is supported by an anti-C.F. member to prevent the bending causing less torque input to the pivot.

The sequence of Active Tab deployment, the counter weight for the centrifugal force cancellation and the counter measure for the friction generated between the tab and the blade inner surfaces are the same ones as the first and the second prototype2 [30, 32].

5. FINALIZED ACTIVE TAB DRIVE MECHANISM

5.1. Layout

In order to solve the wave form distortion generated by the second prototype of Active Tab drive mechanism, the finalized version of Active Tab drive mechanism is developed as shown in Fig.9 which is geometrically suitable to the assumed blade.

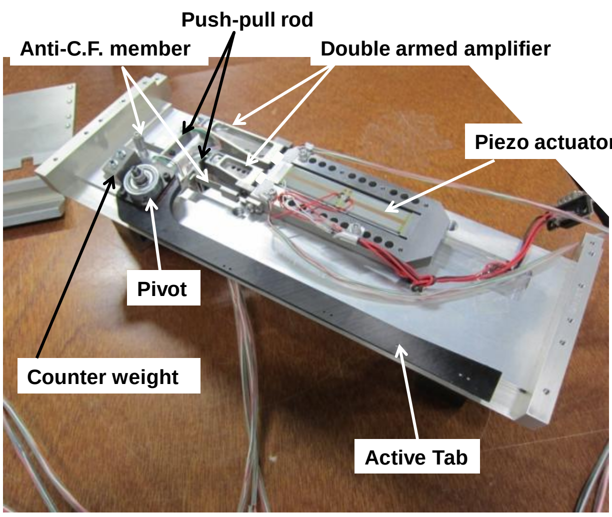


Figure 9: Finalized Active Tab drive mechanism with simulated blade

The finalized Active Tab drive mechanism has the lager flapwise stiffness of the tab, higher powered actuator and larger sized pivot to support the air load acted on the tab than those in the second prototype.

5.2. Instrumentation

All the measurements other than the input voltage to the actuator are measured by strain gauges in the finalized Active Tab drive mechanism. The position of the strain gauge for each measuring item is shown in Fig.10.

The unsteady Active Tab displacement is measured by the strain gauge on the shorter push-pull rod. The hinge moment by those on the longer push-pull rod, the output displacement of the double armed amplifier and the actuator displacement by those on the base portion of the double armed amplifier.

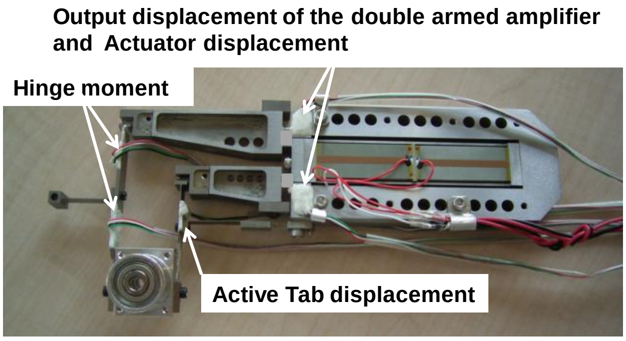


Figure 10: Strain gauge position for instrumentation

6. PERFORMANCE EVALUATION

The two types of tests, namely a dynamic test and an endurance test, are conducted to examine and demonstrate the performance of the drive mechanism in the same manner as the first and the second prototypes [30, 32].

6.1. Dynamic test

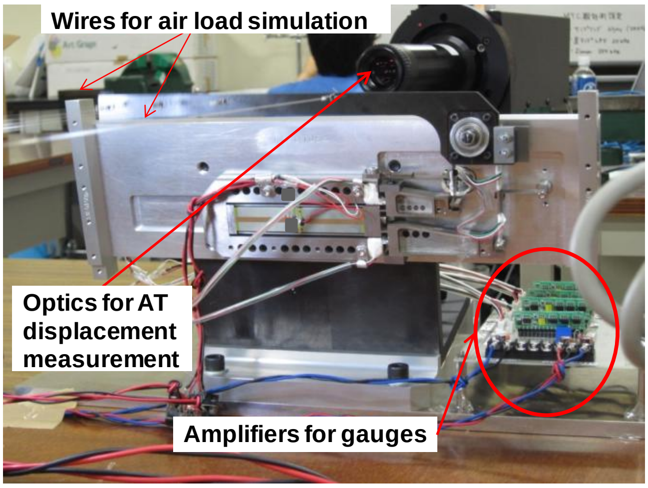
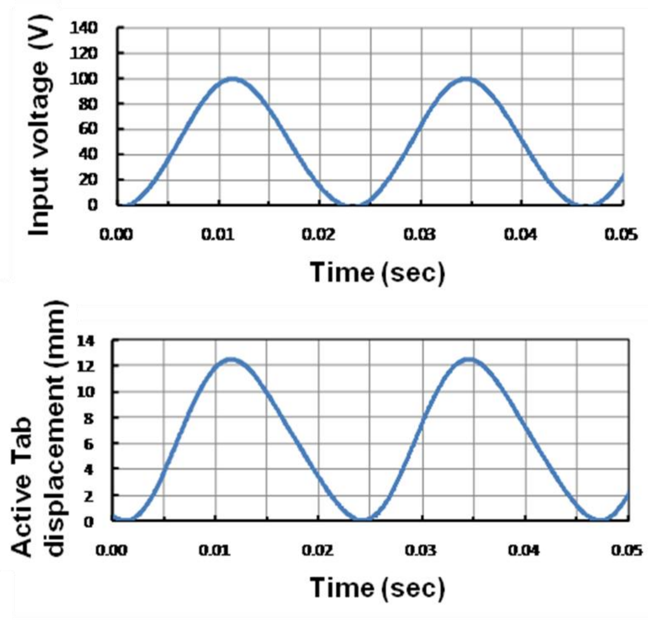


Fig.11: Set up of dynamic and endurance tests

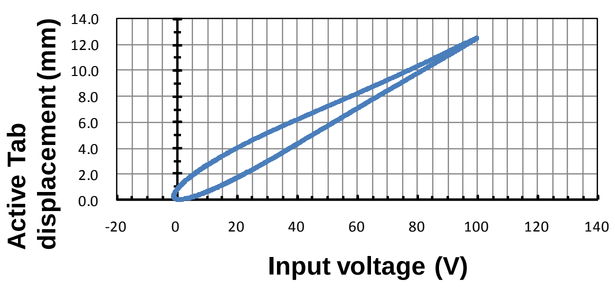
This test is carried out to evaluate the operability of Active Tab drive mechanism on the target condition. For this objective, Active

Tab drive mechanism is operated with input voltage 50V+/-50V at 2/rev (43.3Hz) with 20N simulated lift acted on tab.

Fig.11 shows the set up of the dynamic test. The endurance test described later is also carried out by this set up.



(a) Active Tab displacement and input voltage :time history
0: Active Tab is completely retrieved.
+: Active Tab is deployed.



(b) Hysteresis of Active Tab displacement with respect to input voltage

Figure 12: Dynamic characteristics of Active Tab drive mechanism

Input voltage=50V+/-50V
Active Tab frequency=2/rev (43.3Hz)
with 20N simulated lift acted on tab

Fig.12 shows the dynamic test result. This figure denotes the dynamic behavior of Active Tab drive mechanism measured by the generated displacement of Active Tab with simultaneously measured input voltage to the actuator. As shown in Fig.12 (a), a little more than 12mm displacement of Active Tab drive mechanism at 2/rev is obtained, which satisfies the requirement mentioned above. This figure also shows the slight wave form distortion at the minimum Active Tab displacement where Active Tab is almost retrieved into the blade.

Fig.12 (b) shows the hysteresis of Active Tab displacement with respect to input voltage. As shown in this figure, the hysteresis is observed at the minimum Active Tab displacement, which is consistent to the slight wave form distortion in the time history Fig.10 (a). This hysteresis can be coped with the feedback controls to eliminate during the practical use of Active Tab in the blade.

6.2. 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, Active Tab drive mechanism is continuously operated with input voltage 50V+/-50V at 43.3Hz with 20N simulated lift acted on tab.

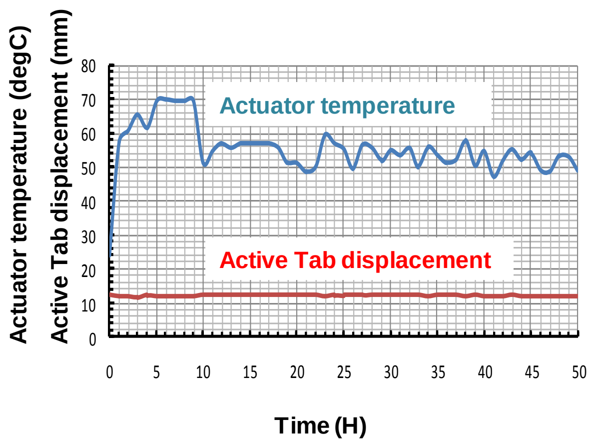


Figure 13: Temporal variation of piezo actuator surface temperature and Active Tab displacement

Input voltage=50V+/-50V
Active Tab frequency=2/rev (43.3Hz)
with 20N simulated lift acted on tab

As shown in Fig.13, Active Tab drive mechanism worked successfully for 50 hours with nonsignificant temperature increase and deterioration of Active Tab displacement. Fig.13 shows a temporal variation of temperature measured on the surface of the piezo actuator and Active Tab displacement for the 50 hour of the operation. The temperature increases sharply after the activation, saturates to 50-60 degC and hold this value during the operation.

This confirmed that Active Tab drive mechanism has enough durability for the practical use installed in helicopter blades without any adverse characteristics of heat accumulation and the mechanical troubles.

7. CONCLUSIONS

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

1. In order to solve the wave form distortion generated by the second prototype of Active Tab drive mechanism, the finalized version of Active Tab drive mechanism is developed. This drive mechanism has the lager flapwise stiffness of the tab, higher powered actuator and larger sized pivot to support the air load acted on the tab than those in the second prototype.

2. The dynamic test demonstrates that the developed finalized Active Tab drive mechanism achieves 12mm displacement at 2/rev with 20N simulated lift acted on the tab, which satisfies the requirement. But the slight wave form distortion at the minimum Active Tab displacement where Active Tab is almost retrieved into the blade is observed caused by the hysteresis. This hysteresis can be coped with the feedback controls to eliminate during the practical use of Active Tab in the blade.

3. Active Tab drive mechanism worked successfully for 50 hours with a nonsignificant temperature increase and without the mechanical troubles in the endurance test. This confirmed that the finalized Active Tab drive mechanism has enough durability for the practical use installed in helicopter blades.

8. FUTURE WORKS

The dynamic test with simulated aerodynamic and centrifugal forces for this finalized Active Tab drive mechanism is the main event in the next step.

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