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Performance Evaluation for Active Tab 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 is carried out. A single stacked piezo actuator stored in a casing inside the blade generates a linear reciprocal movement, which is magnified by an amplifier. Then, Active Tab is driven via a pivot in a rotationally reciprocal mode. The drive mechanism of Active Tab has a practical size to be completely stored inside the assumed blade. Based on the conceptual design, a prototype of Active Tab drive mechanism is developed and evaluated. A dynamic test demonstrates that the target Active Tab displacement 24mm at 2/rev (44Hz) is achieved and a 35 minute continuous operation does the endurance without adverse characteristics of heat accumulating in the drive mechanism.

INTRODUCTION

Among the noises 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.

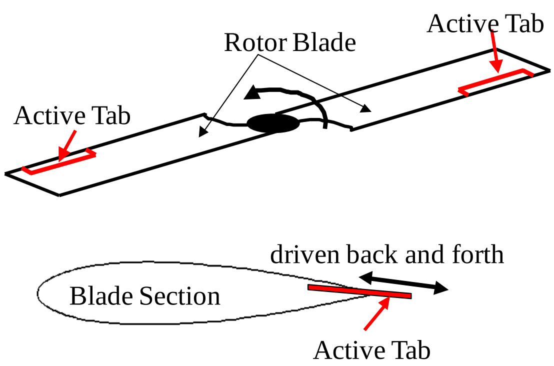


Figure 1: Active Tab concept

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 [21]. 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].

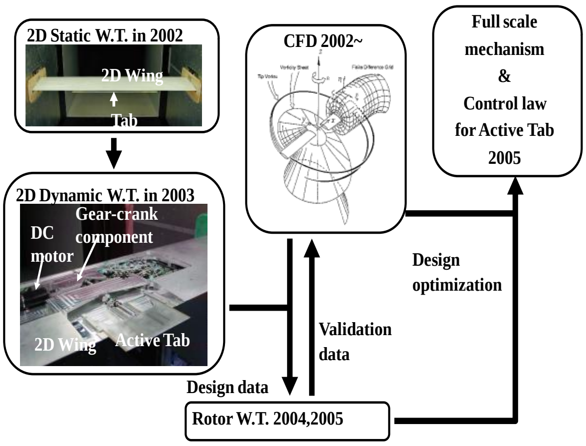


Figure 2: Active Tab research program

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.

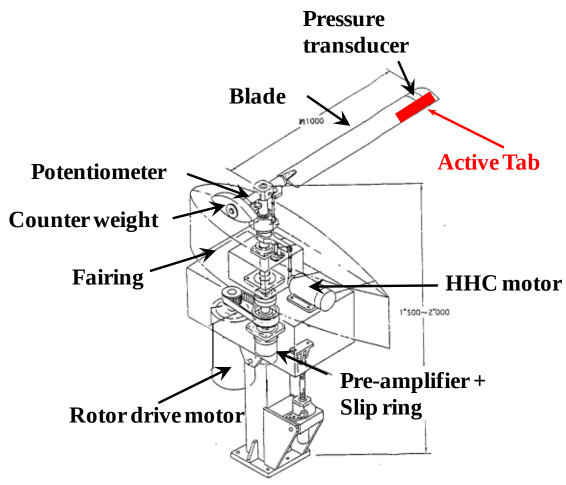


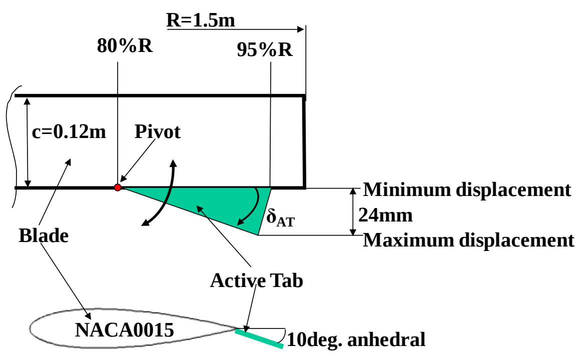
Figure 3: One-bladed rotor system with Active Tab

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, a proto type of the drive mechanism of Active Tab is developed based on this conceptual design study and its operational performance is evaluated. This paper presents the outline of the conceptual design and the results of the performance evaluation of the developed drive mechanism of Active Tab.

ASSUMED BLADE AND ACTIVE TAB GEOMETRY



Rotor speed : 1333rpm
Rotor radius : 1.5m
Blade chord : 0.12m
Plan form : rectangular
Airfoil : NACA0015
Twist : -8deg. linear

Figure 4: 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.4.

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.

REQUIREMENTS

Based on the experimental results [24]-[27], the requirement for Active Tab is set up as follows.

Active Tab :

- Span length : 80-95%R
- Displacement : 24mm
- Frequency : 2/rev

Instrumentation :

- Active Tab displacement
- Hinge moment

CONFIGURATION SELECTION

Types of drive mechanism

As the initial step of the conceptual design, four types of the drive mechanism are considered and merits and demerits of each type are discussed to select the proper solution for Active Tab system.

The first type

is the piezo actuator with elastic hinges as shown in Fig.5. The displacement generated by the piezo actuator is augmented by the double armed amplifier. There is a difference in stiffness between the two arms, which transforms a liner movement from the actuator into a rotary displacement of the arms around the pivot and Active Tab is driven back and forth. 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.

The merit of this type is that the elastic hinge can significantly reduce the free play which can be easily generated by the conventional mechanism such that using bearings. Another merit is that the target Active Tab displacement can be obtained by the lower actuation power. The challenging part is that the size (thickness) of the piezo actuator must be less than the blade thickness which is 0.12m *0.15=0.018m, although this challenge can be accomplished by using the existing stack piled piezo unit.

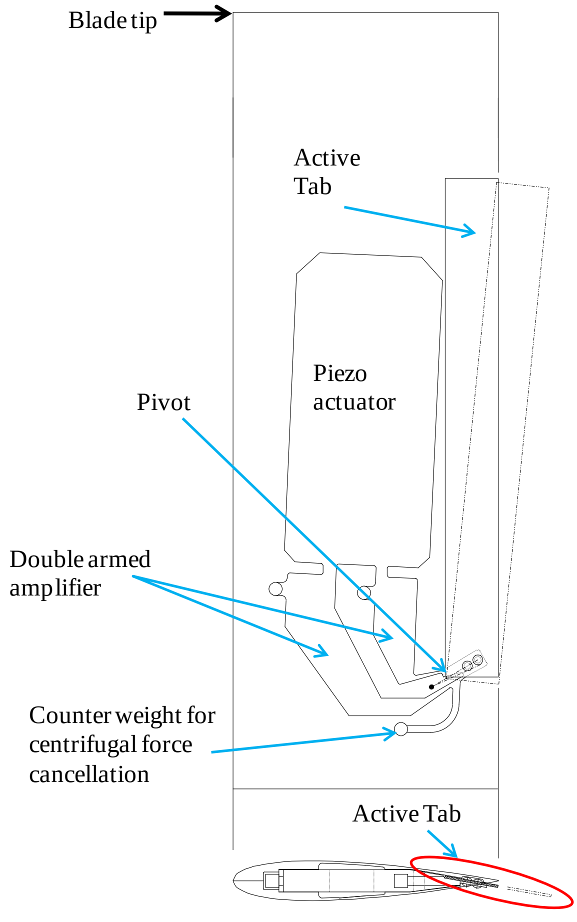


Figure 5: Drive mechanism : piezo actuator with elastic hinges

The other three types proposed as the

candidates are;

The second type:
the servo motor with an eccentric cam

The third type:
the bell crank driven by linear motors

The fourth type:
the electro-magnetic solenoid with a sheet spring

The details of mechanical features and merits/demerits of these types are described in [29].

Trade off

The trade off to select the proper type of Active Tab drive mechanism among the four is carried out with respect to the following points of view;

- operability at high frequency
- tolerance to centrifugal force
- controllability of Active Tab displacement
- size to be installed in the blade

The rating of each type of Active Tab drive mechanism following these points of view is tabulated in Table 1.

Table 1: Rating of the four drive mechanisms

Candidate #	operability at high frequency	tolerance to centrifugal force	controllability of Active Tab displacement	size to be installed in the blade	Total
#1Piezo act. + elastic hinge	3	2	3	2	10
#2 Servo motor + eccentric cam	3	1	1	2	7
#3 linear motor + bell crank	2	2	2	2	8
#4 Solenoid + sheet spring	1	3	2	2	8

Summarizing the merit/demerit or advantage/disadvantage description shown in [29] for each type of Active Tab drive mechanism, the first type, the piezo actuator with elastic hinges as shown in Fig.5 is considered the best among the four candidates. Especially, the small amount of the free play by the elastic hinges of this type is the most important factor to realize Active Tab drive mechanism to be stored in the blade.

SYSTEM DESIGN

The selected drive mechanism of Active Tab is shown three dimensionally in Fig.6.

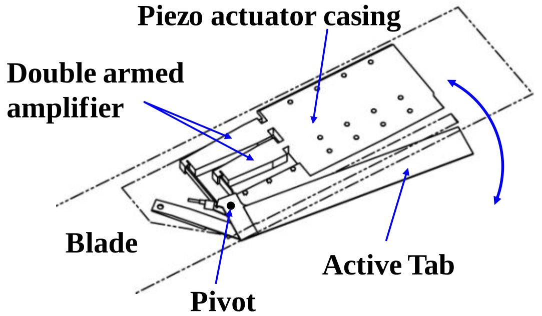
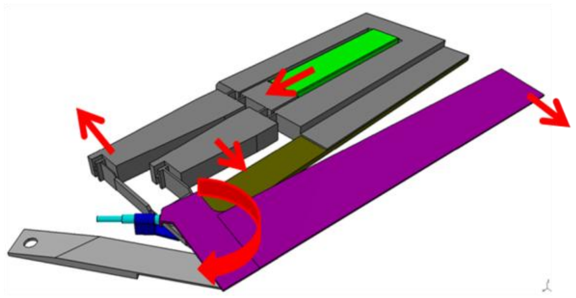
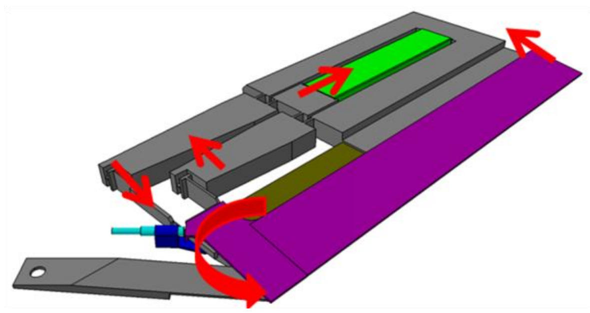


Figure 6 : Drive mechanism of Active Tab

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.



(a) Active Tab spreading process



(b) Active Tab retrieving process

Figure 7: Active Tab deployment sequence

The sequence of Active Tab deployment is shown in Fig.7. The process of Active Tab spreading is depicted in Fig.7(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. 7(b).

Counter weight for centrifugal force cancellation

The counter weight is connected to the amplifier arm in order to cancel the centrifugal force acting about the pivot as shown in Fig.8.

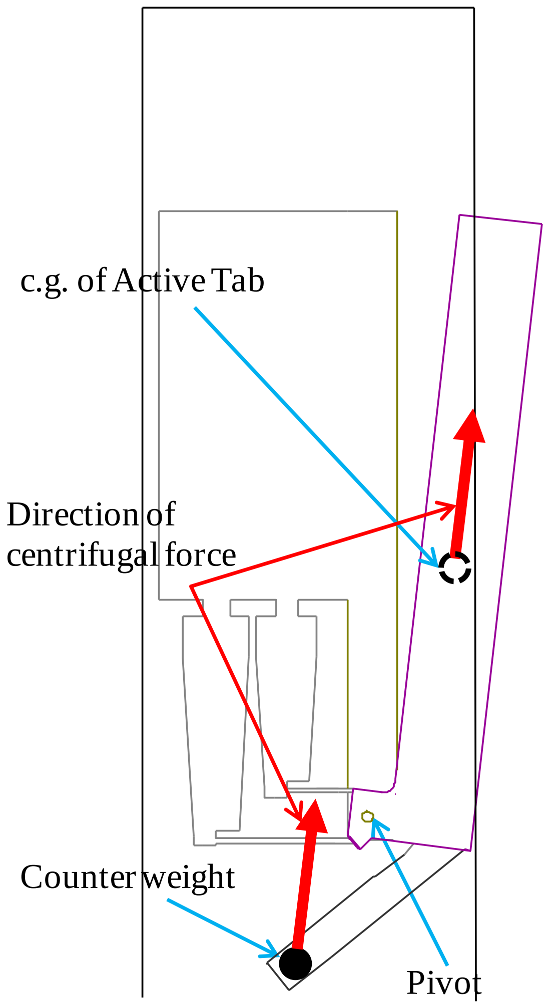


Figure8: Counter weight installation

The centrifugal force is reduced by the counter weight at the cost of increased inertia. As the centrifugal force is one of the dominant factors for constructing the drive mechanism, the counter weight can be an essential component of the drive mechanism.

Instrumentation

Fig.9 shows the instrumentation of the Active Tab drive mechanism satisfying the requirements as described above.

The hinge moment is measured by the strain gauges on the two arms of the amplifier. The difference between the two gauge output is reduced to quantify the hinge moment. The output displacement of the double armed amplifier is also measured by these strain gauges. The eddy current displacement sensor measures the unsteady Active Tab displacement.

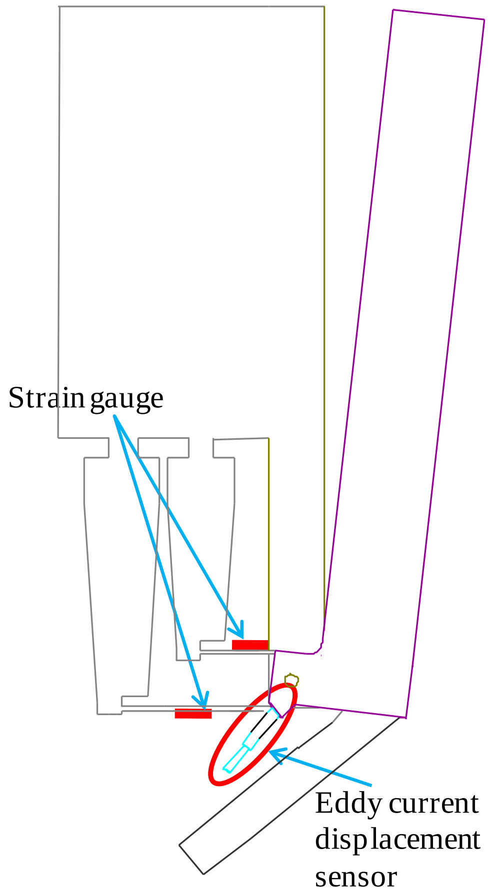


Figure 9: Instrumentation of Active Tab drive mechanism

Friction reduction for Active Tab operation

Fig.10 shows the opening of the trailing edge part of the blade near Active Tab with the friction reduction measure.

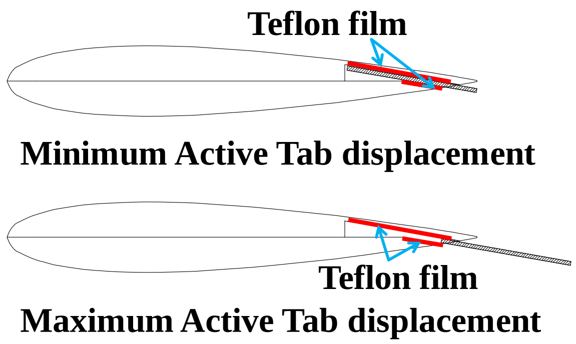


Figure10: Friction reduction measure for Active Tab operation

The aerodynamic lift acts on Active Tab, which pushes up/down Active Tab to the inside structure of the blade. The friction force acting between Active Tab and the inside structure may prevent the smooth operation of Active Tab or even causes the abrasion damage on Active Tab. In order to reduce this friction force, Teflon film is put on the surfaces of the inside structure of the blade. The advantage of this solid lubrication measure is free from lubrication maintenance such as oiling and greasing.

PROTOTYPE OF ACTIVE TAB DRIVE MECHANISM

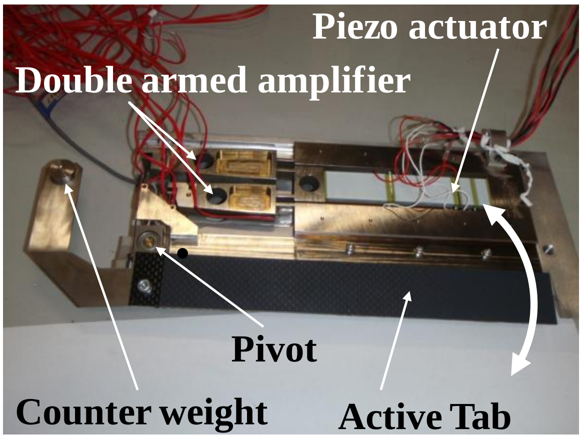


Figure 11: Prototype of Active Tab drive mechanism

Fig.11 shows the developed prototype of Active Tab drive mechanism which is geometrically suitable to the assumed blade mentioned above. Several wires shown in this figure are for the power supply to the piezo actuator and for instrumentations.

The performance evaluation is carried out by this prototype in an isolated configuration without a simulated blade.

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.

Dynamic test

This test is to demonstrate the operability of Active Tab drive mechanism on the target condition. For this objective, Active Tab drive mechanism is continuously operated with input voltage 35V+/-14V at 2/rev(44.4Hz) as a nominal operation condition.

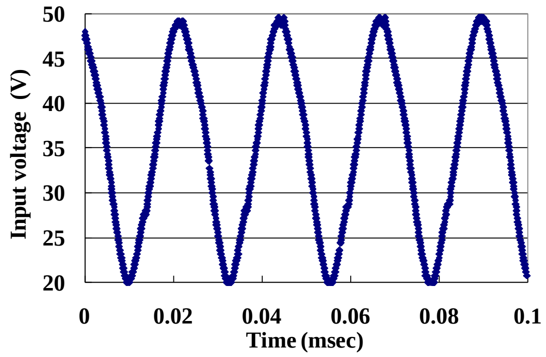
Fig.12 shows the dynamic test result. This figure denotes the dynamic behavior of Active Tab drive mechanism measured by the input voltage to the piezo actuator and the consequently generated displacement of Active Tab.

The fair sinusoidal waveforms can be observed in the input voltage to the piezo actuator as shown in Fig.12 (a) and in the displacement of Active Tab as shown in Fig.12 (b). As shown in Fig.17 (b), 28mm displacement of Active Tab drive mechanism at 2/rev is obtained, which satisfies the requirement mentioned above.

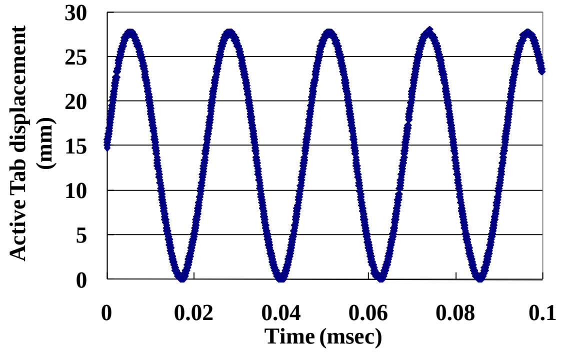
Examining the waveform distortion which can be caused by some unexpected frequency components other than 2/rev, the displacement of Active Tab (Fig.12 (b)) is frequency analyzed and shown in Fig.12 (c). This figure shows that the intentionally generated 2/rev component is dominant and the other components are negligible.

This reason is estimated that the drive mechanism contains a single piezo actuator, which can output a very pure response to

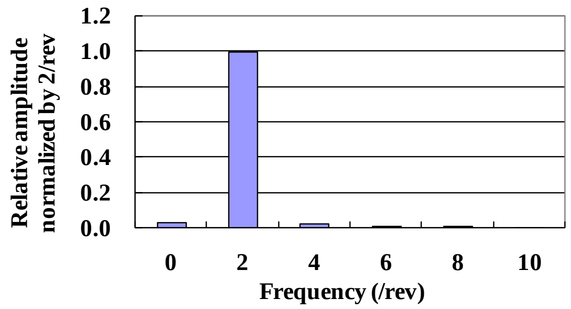
Active Tab, different from the case of two piezo actuator type Active Flap drive system [14], [15].



(a) Input voltage to piezo actuator



(b) Active Tab displacement



(c) Frequency analysis of Active Tab displacement

Figure 12: Dynamic characteristics of Active Tab drive mechanism input voltage=35V+/-14V Active Tab frequency=2/rev(44.4Hz)

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 35V+/-14V at 44.4Hz.

Active Tab drive mechanism worked successfully for 35 minutes with a nonsignificant 2degC temperature increase.

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.

CONCLUSIONS

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

1. The piezo actuator with elastic hinges is selected out of the four candidates as the drive mechanism of Active Tab by the trade off carried out with respect to the following four points of view;
   -operability at high frequency
   -tolerance to centrifugal force
   -controllability of Active Tab displacement
   -size to be installed in the blade

2. Based on the conceptual design study, a prototype of Active Tab drive mechanism is developed and the performance is evaluated. 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.

3. Active Tab drive mechanism worked successfully for 35 minutes with a nonsignificant 2degC temperature increase with input voltage 35V+/-14V 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.

FUTURE WORKS

In order to thoroughly examine and enhance the performance of the prototype of Active Tab drive mechanism, the systematic evaluation including the static/stiffness test and the dynamic test with simulated aerodynamic and centrifugal forces are the main events in the next step.

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