ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

# A STUDY ON LOW-VIBRATION ROTOR BLADE DESIGN FOR HELICOPTER BY USING TAPERED MASS DISTRIBUTION METHOD

Deog-Kwan Kim*[1], Keun-Woong Song[1], Youngjung Kee[1], Joune-Ho Kim[1] and Gene Joo[1]

[1]Korea Aerospace Research Institute, Rotor System Department
45 Eoeun-Dong Yuseong-Gu, Daejeon, 305-806, Korea
shine@kari.re.kr

## Abstract

The main rotor system is a major vibration source for helicopter as it flies in hover and forward flight condition. This vibration makes pilots and passengers uncomfortable in flight and also the fatigue life of structural components shortened. So, low vibration design for rotor is very important in the early development phase. To achieve low vibration rotor, the first approach method is to reduce the original vibratory source at the design phase by applying low vibration blade design concept. The second approach method is to apply anti-vibration device to helicopter. Usually the first method is more recommendable to reduce vibratory source since it has no additional weight penalty and no power penalty. On the other hand, the second method is usually recommended at the latter stage of development due to its weight and power penalty. One of the low vibration methods is a well-matched mass and stiffness distribution which is especially linearly tapered along the radial direction of rotor blade and can be applicable in the early development phase.

In this study, design concept for low vibration blade was introduced. This is to apply tapered mass distribution method for reducing blade vibration. These days, composite materials are widely used for helicopters, especially blades, and they are used to blade sectional design. In addition, these design works were done by using CORDAS which was developed in KARI. After design of full size low vibration blade, the small-scaled blade was designed and tested to verify low vibratory characteristics by comparing with an existing bench blade. These tests were performed by using the KARI GSRTS and LSWT. The test results of small-scaled low vibration blade were compared with those of the small-scaled bench blade. The improvement of vibration reduction was achieved about 10%~20%.

## INTRODUCTION

The vibration problem has been one of the main design issues so long time. Therefore, it is necessary to solve these vibration problems during helicopter development. This vibration reduction can improve crew efficiency, safety operation, comforts of passengers and reliability of avionics, mechanical equipment and the fatigue lives of structural components. One of the major vibration sources is rotor system. Many studies on the reduction of helicopter vibration have been done up to date. One of them is to use passive methodologies such as vibration isolator, bifilar, DAVI, etc [1]. Other is to use active methodologies such as higher harmonic control, using active actuators, trailing-edge flap and active twist blade [2]. In this study, one of the passive methods was used to reduce rotor generating vibration source. This method is to apply the low vibration design concept at the early stage of development process. This is so effective method applicable in early design stage that control mass and stiffness distribution well. In other words, some amount of vibration reduction can be achieved by tapering of blade mass and stiffness distribution. The improvement of vibration reduction by using blade tapered mass distribution is characterized by the separation of the second and third flapping mode frequencies in the frequency diagram, called Campbell-spoke's diagram [1]. In this study, this tapered method was used to reduce the rotor blade vibration. At the first, the full-size low vibration blade which can be applicable to helicopter similar class to Super Lynx, gross weight (5,125kg) was designed. Since KARI has information on the technical data for a bench blade, the possibility of vibration reduction for new blade could be checked by comparing campbell-spoke's diagram each other. Next, the small-scaled blade was designed and tested to be verified by using KARI GSRTS [3] which has been a small-scaled rotor test system installed in KARI. The hub type used in this study is a hingeless hub system. This hub has no flap and lag hinge [4]. Two those of composite small-scaled blades were designed and fabricated. One of them is called as a bench blade which is paddle-shape and has general mass and stiffness distribution which is designed by using small-scaling method. The other is called advanced tapered blade which has advanced planform and tapered mass distribution in order to acquire the low vibration characteristics. To accomplish tapered mass distribution along the blade span, the composite materials were used to design small-scaled blade and the sectional design of this blade was done by using CORDAS which was developed in KARI [5]. Composite material has own flexibility on directional tailoring along the blade span. In this paper, through comparing these test results of two blades with each other, the improvement on vibration reduction will be verified. [6-7]

## MASS TAPERED BLADE DESIGN

There was a full-size bench blade which was similar to BERP III blade. This blade was developed by Westland through British Experimental Rotor Program [8]. The low vibration blade design for the present study started from the use of the technical blade data obtained from Super Lynx Offset Program [9]. Advanced tapered blade was designed by applying mass tapered distribution to the existing bench blade and was compared with an existing bench blade. The mass distribution of this new low vibration advanced tapered blade has more gradient characteristics along the blade radius rather than that of the bench blade. This method was well-known and used as one of passive method to reduce vibration. So, in this study, the Campbell-spoke's diagram was used to verify and check the possibility of vibration reduction. The mass of 54.68%R rotor station was increased to amount of 50% compared to that of the existing bench blade by adding glass fabric material at the inner side of spar. The Mass of 82.7%R rotor station was decreased to amount of 20% compared to that of existing bench blade by removing foam and replacing an existing glass fibres with new carbon fibres. After that, the mass distribution of middle section of blade was linearly distributed. The mass distributions of two blades were compared. These results were shown in figure 1.

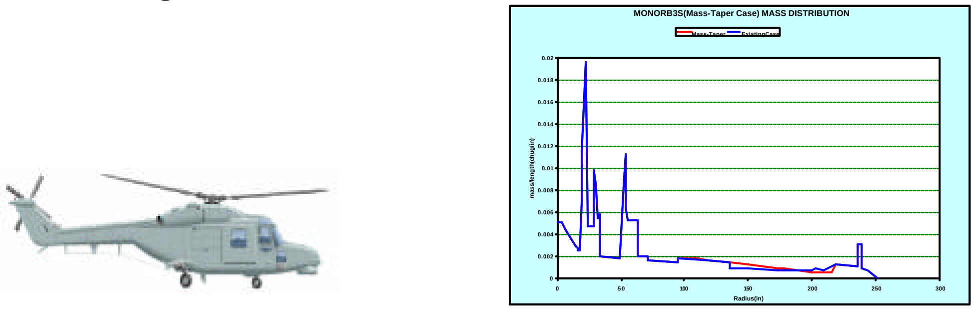


*Figure 1 – Mass Distribution of BERP Blade & Low-vibration Blade*

At the first stage of design, the improvement of vibration reduction is characterized by the separation of the second and third flapping mode frequencies in the frequency diagram (Campbell-spoke's diagram). Now, the movement of second and third flapping mode frequencies in Campbell-spoke's diagram could be checked. From this slight movement of the meeting point into lower rpm, the possibility of low vibration transmitted to fuselage could be predicted. The Campbell-spoke's diagram was shown in figure 2. For the purpose of verifying this vibration reduction possibility, two types of small-scaled blades were designed. The rotor was scaled down in order that the KARI's facilities could be used to test model rotor. The amount of scaling was 1/6. By testing these two types of small-scaled rotors, the improvement of low vibration could be verified. So, in the next section, the details of model blade would be described.

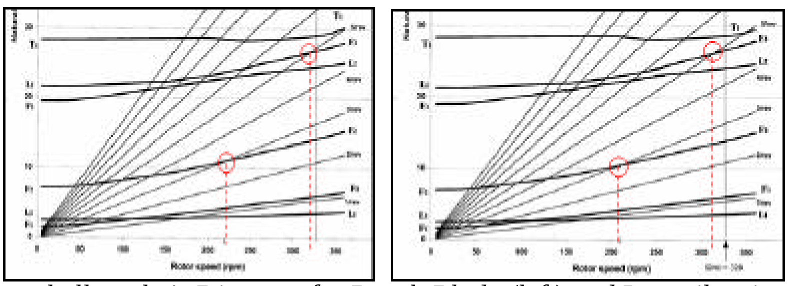

*Figure 2 – Campbell-spoke's Diagram for Bench Blade (left) and Low-vibration Blade (right)*

## MODEL ROTOR

There were two types of model rotors. The bench model rotor was scaled down from BERP blade. The advanced tapered model rotor was scaled down from low vibration blade achieved by mass tapered distribution. These rotors adopted the same hingeless hub system. The size of model rotor is 2.13 m diameter. In this section, major parts of hingeless hub used in the model rotor were described. And the main characteristic of bench blade was explained with some configuration and sectional properties. Finally, the advanced tapered blade was explained with some configuration and sectional properties also.

### Hingeless Hub Model

The hub size was determined by the 1/6 scale data obtained from the rotor size of full scale Super Lynx. The diameter of hingeless hub model is about 457mm. The detail was already described in the reference [8]. So, brief description was introduced here. Major components of this hingeless hub system are hub plates, feathering hinge and flexure. Specially, the feathering hinge assembly is composed of tie-bar rounded by high strength steel wire (304V), needle-roller bearings to allow free rotating and housing to wrap the tie-bar and bearing. The flexure was designed by using torlon which was one of the engineering plastic to meet 1$^{st}$ lag frequency requirement, 0.6~0.8Ω. Details of the hingeless hub configuration were shown in figure 3.

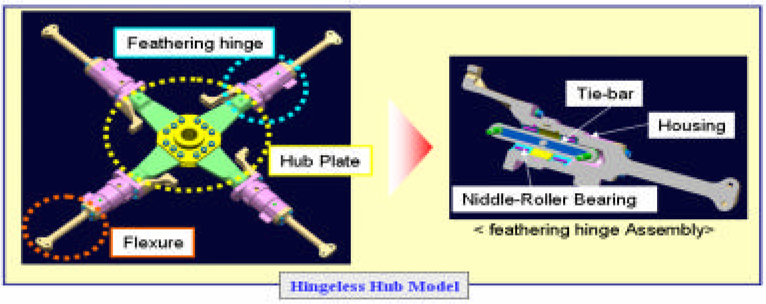


*Figure 3 – Detailed Configuration of hingeless hub system*

### Bench Blade

The bench blade has a paddle-type tip shape. The chord length is variable from 84%R to Tip. This blade was designed by using 3 different types of airfoils. The radial position of airfoil and airfoil type is similar to BERP III of Lynx. This bench blade was designed by scaling method to be matched with froude scaled value of BERP of Lynx [9]. This blade had an similar dynamic characteristics of Lynx. The blade design and the calculation of sectional properties such as mass distribution, centre of gravity, sectional stiffness, etc. were obtained by using CORDAS [5]. The mass and stiffness distribution of this bench blade was obtained from the BERP blade by froude scaling.

The sectional property was matched as possible as similar to design value. The brief summary of mass and flatwise stiffness distribution was showed at Figure 5.

### Advanced Tapered Blade

The advanced blade has a paddle-type tip but has a kink to reduce noise. The chord length is also variable from 84%R to Tip. This blade was designed using 3 airfoils which are same with above bench blade. This advanced tapered blade was designed also by scaling method to be matched with froude scale of low vibration blade. The sectional construction of advanced tapered blade and the rotor system was shown in Figure 4.

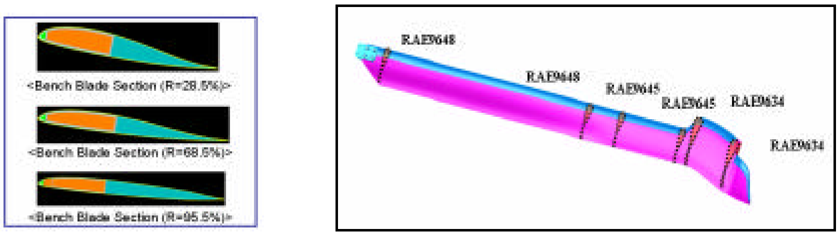


*Figure 4 – Blade sectional construction of advanced tapered blade*

The brief summary of mass and flatwise stiffness distribution was summarized and compared with that of the bench blade at Figure 5.

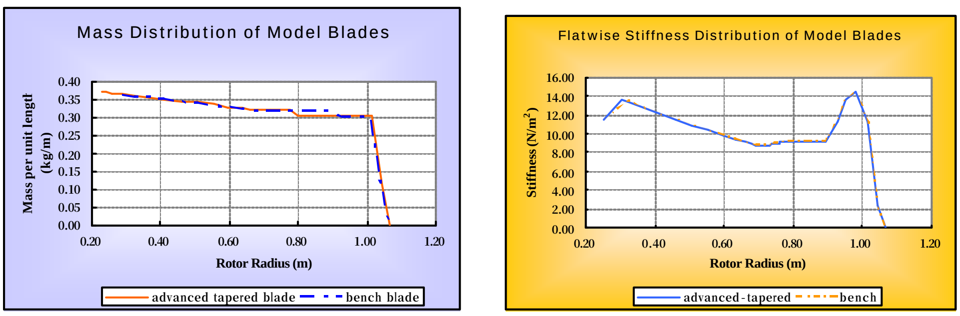


*Figure 5 – Blade sectional properties of bench blade and advanced tapered blade*

## ROTOR TEST FACILITIES IN KARI

### KARI GSRTS

KARI General Small-scaled Rotor Test System (GSRTS) was established in 1999. This rotor test rig has the function of performance test by mach scale test and aeroelastic test by froude scale. The hover and forward flight test for small rotor can be conducted under those conditions. The hover test is usually conducted in ground safety fence. The general view was shown at figure 6.

### KARI LWST

KARI LSWT (Low Speed Wind Tunnel) was established in 1998. The type of LSWT is single returned. The overall dimension is about 32m x 13m x 83m (W x H x L). The main structure is welded steel plate. The width and height of maximum cross section are 11.5m and 8.6m. The flow straighteners are 3 screens (1.6mm mesh) and 9.5mm x 305mm Honeycomb. KARI has an experience for various model types of wind tunnel test such as airplane, car, ship, motorcycle and etc. The main specification of KARI LSWT is described in reference [7].

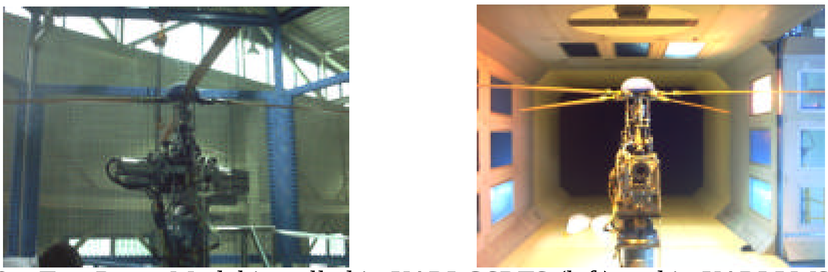

*Figure 6 – Test Rotor Model installed in KARI GSRTS (left) and in KARI LWST (right)*

## TEST RESULTS FOR MODEL ROTOR

### Hover Results

The test for hover flight condition was done in KARI GSRTS. The collective angle was controlled at -2, 0, 2, 4, 6 and 8 degrees. In this test, the load level was checked and compared. The advanced tapered blade has lower load level at each collective pitch angle. The comparison results were shown in figure 7.

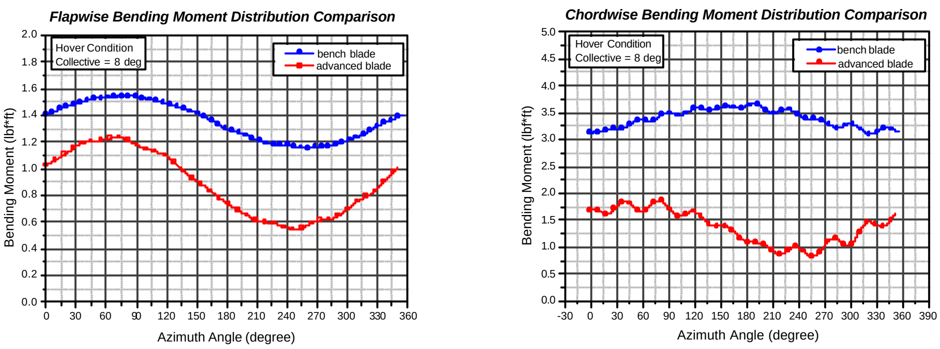


*Figure 7 –Vibratory Loads Comparison on condition collective angle=8 deg, at $m = 0.1$*

## Forward Flight Results

The vibrating load was mainly generated by rotating blade in the forward flight condition due to periodic aerodynamic forces and the unsymmetric characteristics of flow. To verify the vibration reduction effect in the forward flight condition, there were chosen two flight test conditions that were advance ratio ($\mu$) 0.1 and 0.25. The collective angle was controlled at -2, 0, 2, 4, 6 and 8 degrees at each forward flight speed. The main load component to affect vibration is flapwise, chordwise bending moment and torsional moment. These vibratory loads were compared to each other at each flight condition. About 30% vibratory load reduction was achieved at $\mu$=0.1 and 10% vibratory load reductin was achieved at $\mu$=0.25 in flapwise and chordwise bending moment. The 10% torsional moment reduction was achieved at $\mu$=0.25. But the torsional moment at $\mu$=0.1 has some different tendency. So, the torsional vibratory moment has a little effect on vibration reduction due to mass tapered distribution compared to flapwise and chordwise bending moment. Details of the test results were shown Figure 8 and Figure 9.

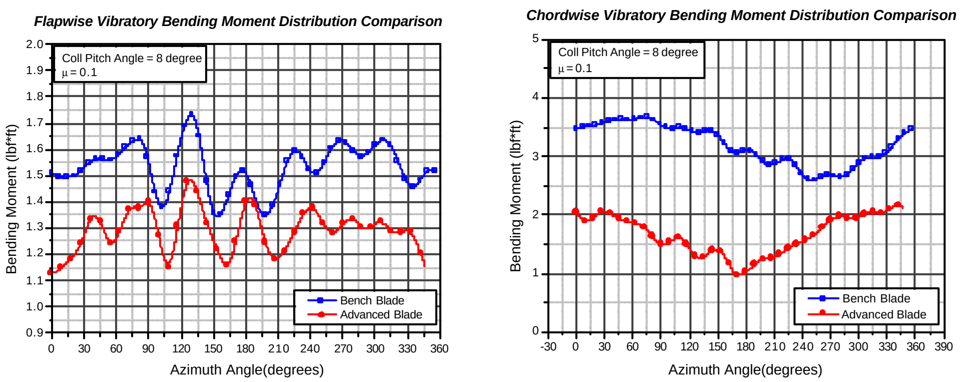


*Figure 8 –Vibratory Loads Comparison on condition collective angle=8 deg, at m = 0.1*

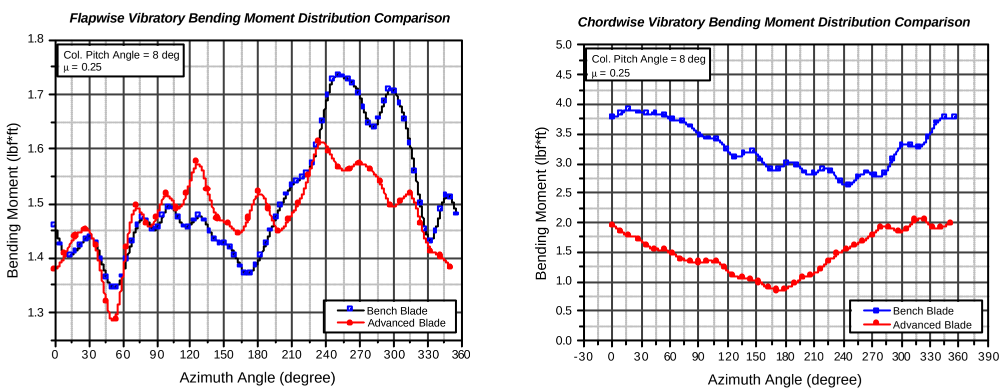


*Figure 9 –Vibratory Loads Comparison on condition collective angle=8deg, at m = 0.25*

## CONCLUSIONS

In this study, one of low vibration reduction method for helicopter rotor system was showed and verified by doing small-scaled rotor test. The mass tapered distribution method has some effective results on low-vibration blade at the early design stage. Specially, vibration reduction effect achieved in the flapwis and chordwise vibratory bending moment. This mass tapered design can be still effectively applied to composite blade design without any penalty of weight and power which is a key element in the application of active vibration control. Also, composite materials which are very popular to blade in these days are used to blade sectional design. The improvement of vibration reduction was achieved about 10%~20%. This technology achieved in this study can be expected to be applied to the future national project such as low vibration blade design and Korean Helicopter Program (KHP).

## REFERENCES

[1] A. R. S. Bramwell, G. Done, D. Balmford, “Bramwell’s Helicopter Dynamics”, ButterworthHeinemann, pp 297-316 (2001)

[2] F. K. Straub, “A feasibility study of using smart materials for rotor control," Smart Materials and Structures 5(1), pp. 1-10(1996)

[3] G. Joo, J.M. Kim, D.K. Kim, “ Development of KARI’ s General Small-scaled Rotor Test System”, the 7th Symposium on Aircraft Development Technology, April, pp 400-pp409(2000)

[4] Wayne Johnson, ‘ Recent Development in the dynamics of advanced Rotor System(II)’ , Vertica Vol 10(1986)

[5] D. K. Kim, G. Joo, “Developmenent of the Composite Rotor blade Design and Analysis Software(CORDAS)”, the proceedings of the KSAS Spring Annual Meeting, April, pp 344-pp347(1999)

[6] Benton H. Lau, N. Griffiths et al. ‘ Performance and Rotor Loads Measurements of Lynx XZ170 Helicopter with Rectangular Blades, NASA TM 104000 (1993)

[7] D.K. Kim, J.H. Kim, et al. ” A Study on Aeroelastic Stability Improvement of Hingeless Hub System in Hover and Forward Flight Using Composite Materials”, the 31st European Forum, Florence, Sept. 2005

[8] R.E. Hansford, "Rotor Load Correlation with the British Experimental Rotor Program Blade" J. American Helicopter Society, Vol. 32, No. 3, July 1987

[9] John Perry, Robert E. Hansford, et. al, “Technology Transfer Seminar through Offset Program”, GKN-Westland, 1999