INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.4 Issue 6,

June 2016

Pgs: 50-63

# HELICOPTER VIBRATIONS – A PERSPECTIVE

**James Sathya Kumar**

*Faculty of Engineering, Christ University, Bangalore*
*Author Correspondence: Department of Mechanical Engineering, Faculty of Engineering, Christ University, Kanminike, Kumbalgodu, Mysore Road, Bangalore - 56006, Phone: 9880137226, Email address:jameskumar@hotmail.com*

## Abstract

Helicopters are versatile for a variety of roles & applications in both military and civil applications and their utility has grown many folds, over the years. The use of helicopters for relatively new applications such as air ambulance, Heli tourism, fire fighting, monitoring of traffic or forests and fires or condition monitoring of remote installations like transmission lines, oil pipe lines and so on has further given impetus to advancements in helicopter design and production. The conventional roles, as well as the new roles also demand reduced vibrations to achieve greater human comfort, better reliability of structures and systems and efficiency. Helicopters are inherently prone to higher vibration levels than the conventional Aircraft. Therefore it essential that the inherent helicopter vibrations are not only addressed in the conceptual & design stages but also in service by way of either modifications or continuous monitoring & rectification. This paper examines the sources of the higher levels of vibration and some of the alleviation techniques.

**Keywords:** Helicopter vibrations, Rotor, Vibration Absorber, Vibration Isolator

## 1. Introduction

The vibration level in helicopters is of the order of 0.05 to 0.25g, which is about five times the vibration levels encountered in fixed wing aircraft. This high vibration is due to the very construction and aerodynamics of highly varying velocity fields. Though considerable reduction in vibration has been achieved through improved helicopter designs over the past few decades, the prevailing overall levels of approximately 0.05 to 0.1 g still remain significantly higher than those of jet-engine aircraft, which are below 0.01g (Ruth Heffernan, Dominique Precetti, and Wayne Johnson, 1991, MIL H8501A, NASA). Until production helicopters can achieve comparatively lower vibration levels, research in this domain for Helicopters would continue to remain an important topic. This review paper covers the Helicopter vibrations including the sources, causes, effects on humans, structures and equipments. A survey of the existing methods of vibration alleviation is carried out to provide an overview.

## 2. Need for Helicopter Vibration Reduction

Helicopter vibration control requirements arise basically from three considerations:

(a) Comfort and tolerance of crew and passengers,
(b) Structural Integrity and fatigue damage induced by vibratory loads,
(c) Functional tolerance of equipment like power plant, accessories, instruments, navigational aids, armament and their allied controls.

The control of unwanted vibrations has assumed even greater significance in recent times as:

(a) Greater passenger and crew comfort in terms of lower NVH,
(b) Higher speeds have been envisaged for helicopters,
(c) Higher reliability and maintainability requirements,
(d) Missions like armament sorties which require low vibration levels to achieve better accuracies/ hits. Also missions like casualty evacuation require low vibration levels for obvious reasons.

Therefore, the vibration limits are specified and is monitored throughout the life of a helicopter at regular intervals.

Hence, controlling vibrations, predominantly the b/rev (b=number of blades), involves design considerations, both in rotor systems and fuselage.

## 3. Helicopter Vibration Reduction

There have been two major approaches with which the problem of vibrations control has been dealt with. The first approach corresponds to extensive use of analytical tools to yield designs of various systems of helicopter leading to lower vibration levels. This can be achieved by:

(i) Improving the rotor system design, and
(ii) Optimizing the fuselage dynamics.

The other approach is to accept the vibrations at a prescribed level and then filter them. This can be achieved by installing:

(i) Dynamic absorbers on the rotor system
(ii) Rotor system isolators
(iii) Active Control vibration reduction system.

## 4. Sources of Helicopter Vibration

### 4.1 <u>Sources of Vibrations</u>

As can be seen from the Figure 1, the Rotor induced vibrations are dominant in the entire fuselage, thus making it critical due to the vibration tolerance limits of crew, passengers, structure and equipments. Main rotor, tail rotor, drive train and the interactions are the main sources of vibrations.

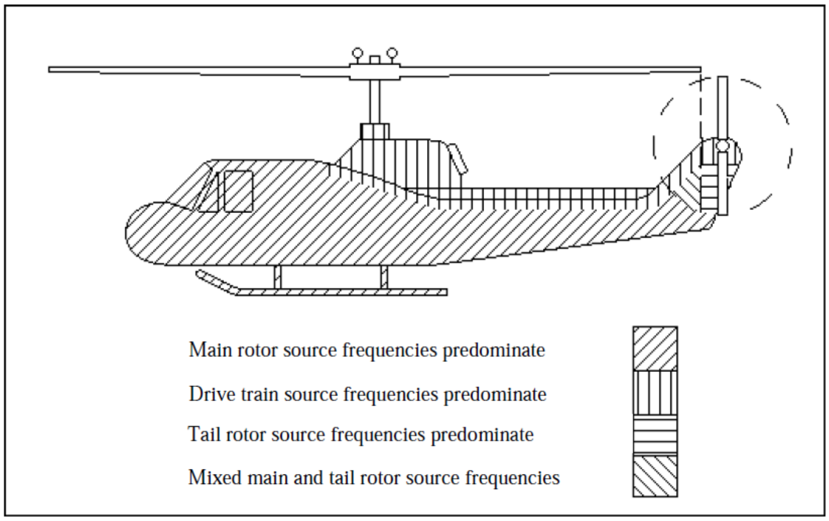



**Figure 1: Helicopter Vibration Zones (as per MIL-STD-810F)**

The main sources of vibration in a helicopter are:

(a) Main Rotor
(b) Tail Rotor
(c) Power plant and transmission systems
(d) Transient sources like controls, gusts, armament firing, etc.

### 4.1.1 Main Rotor

The main rotor is the primary sources of generation of time varying forces in a helicopter. The rotor blades are constantly in a variable velocity field due to the rotation of the blade and its simultaneous forward movement, with the incidence also varying continuously. The variable field can be visualized from the Figure 2.

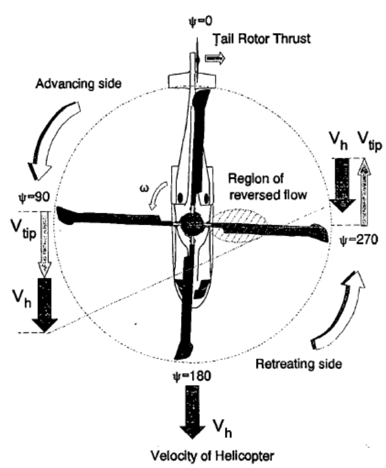


**Figure 2: Main rotor Velocity field in azimuth**

As the helicopter moves the advancing blades have a summing up of the helicopter and blade velocities, whereas the retreating blade experiences a velocity that is a difference of the same two speeds. Thus at every position in the azimuth, the blades see a completely varying velocity field. The reasons for these varying velocity fields are The transonic flow on the advancing blade, dynamic stall on the retreating blade, blade tip vortex interactions and the interference in flow due to main rotor, tail rotor, fuselage and the several structural elements of the rotor head, These unsteady aerodynamic conditions are depicted in Figure 3.

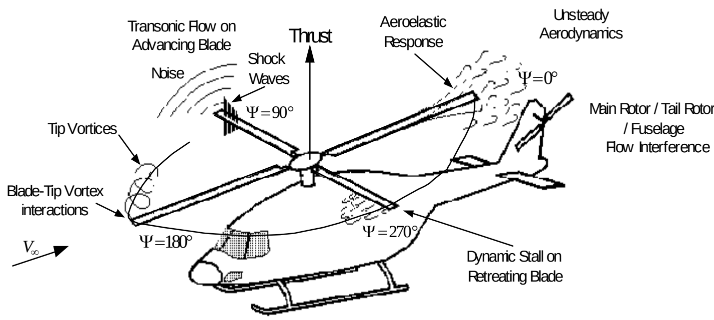



**Figure 3: Helicopter Aerodynamic Field**

Considerable non–uniformity of the induced velocity field in the flow through the rotor caused by interaction of blade vortices in low speed regimes, and variation of relative flow velocity and angle of attack in high speed regimes cause amplification of variable aerodynamic loads resulting in higher vibration levels. It is not possible to eliminate these oscillatory time varying forces, but only a reduction in their levels can be attempted.

Vibrations with frequencies bnΩ (=N) arise due to (bn±1) Ω cyclic and bnΩ collective aerodynamic and inertial excitation on blades where n=1,2,3,….. In a rotor system if each blade is not matched aerodynamically and inertially with the other, vibrations with all harmonics of Ω arise. The N per revolution oscillation is depicted in Figure 4

The N per rev vibration is a natural effect of the blade's motion around the rotor head, and is intrinsic, as is the 1 per rev of the blade in flapping. The rotor delivers a root shear to the head that sums at the head to the n per rev vibration in the static system. These root shears are increased by stall, compressibility and blade dynamic responses. They have nothing to do with track and balance at all.

This vibration is intrinsic, and cannot be eliminated, only minimized or absorbed. The hinge offset increases the amount of root shear delivered by the blade, and the number of blades reduces the root shear delivered by each blade. Generally, the n per rev drops geometrically as the number of blades is increased, so that the natural n/rev vibration for 5 blades is a very small percentage of the magnitude of that for 2 blades.

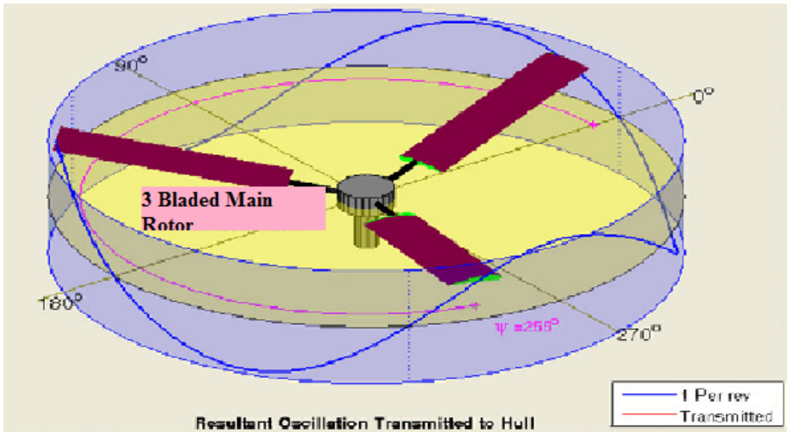



**Figure 4: Resultant N/rev transmitted vibration.**

Since higher harmonics of blade loading are of lower magnitude compared to lower harmonics, vibratory loads of frequency nb Ω on the fuselage decreases with increase in number of blades. In other words, an absorber attached to a 4 bladed rotor head will see 3 per rev and 5 per rev vibrations, and the transmission will see the sum of these two as a 4 per rev. Generally, the n/rev for a 2 or 3 bladed helicopter is high, and for more than 5 blades is very low The distance between rotor plane and fuselages has a bearing on the magnitude of vibrations due to downwash. In general, greater the distance between fuselage and rotor, lesser the oscillatory pressures and hence lower noise and vibration levels.

### 4.1.2. Tail Rotor

Like the main rotor, the tail rotor blades are also in a variable velocity field. Also, the tail rotor blades may at times be in the wake of the main rotor. These will give rise to alternating loads on the blades. Any inertial imbalance will further add to the alternating forces on the system. Oscillatory structural loading of tail rotor are significant upto frequencies of 150Hz. The natural frequencies of drive system, fuselage and tail rotor may be in close proximity to tail rotor frequencies which may result in beating phenomenon. Also the response of fuselage to maneuver and gusts can induce considerable exciting forces on tail rotor.

### 4.1.3. Power plant and transmission systems:

Power plant and transmission systems consist of the reduction gear boxes from engine to main and tail rotors, drive shafts, clutch assembly etc. Tolerances in manufacturing of rotating components and in-accurate balancing during assembly lead to inertial imbalance. This imbalance causes vibration of transmission system and power plant with frequency in the order of rotor speed/shaft speed and its harmonics.

The various factors which affect the transmission of exciting forces and moments from rotor to the fuselage are shaft mass and stiffness distribution, location of bearings and their stiffnesses, coupling locations and their misalignments, engine location, mounting and its inertial characteristics.

#### 4.1.4. Transient Sources

Transient excitations in a helicopter arise due to armament firing, sudden control movements and gusts. The frequency of excitation corresponds to armament firing rate. Optimization of fuselage dynamics for all armament configurations is necessary to limit the vibration level due to firing.

Gusts and atmospheric turbulence are not substantial in normal helicopter operations but they become prominent for rotors with high advance ratios. Gust response depends on various factors like gust loads, rotor penetration time, ramp length of gust and flap response.

These sources not only give rise to oscillatory motion within the sources themselves, but also give rise to large amplitudes of motion in some other components of the helicopter.

It is evident from the above that since the vibratory amplitudes are nothing, but the free and forced responses of the helicopter structure to the excitations caused by the sources mentioned above. These vibrations in general cannot be eliminated, but can only be minimized.

The harmonics of the blade that passes through the rotor head to excite the fuselage are listed below:

**TABLE (A) EXCITING BLADE HARMONICS**

| | **Rotor head force** | **Frequency** | **Contributing blade force** | **Contributing forcing frequency** |
|---|---|---|---|---|
| **a)** | Vertical force | nb Ω | Transverse force | nb Ω |
| **b)** | Lateral force | nb Ω | Inplane force | (nb±1) Ω |
| **c)** | Longitudinal force | nb Ω | Inplane force | (nb±Ω) |
| **d)** | Torque | nb Ω | Inplane moment force | nb Ω |
| **e)** | Pitching moment | nb Ω | Pitching moment flapping moment transverse moment | (nb±1) Ω |
| **f)** | Rolling moment | nb Ω | Pitching moment flapping moment transverse moment | (nb±1) Ω |

### 4.2. Vibration Levels

The vibration spectrum in a Helicopter has several dominant frequencies. Figure 5 depicts the Vibration Amplitude spectrum of a typical Helicopter. The amplitude of fundamental N/rev are dominant and harmonics beyond third level have comparatively lower amplitudes.

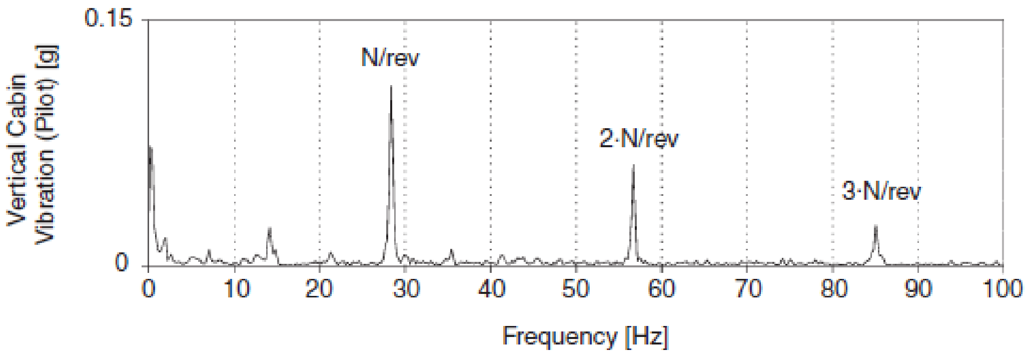



**Figure 5: Vibration Amplitude Spectrum for BO 105 in Level Cruise Flight**

(Dieterich, 1998)

With considerable increase in the forward speeds of helicopters, the vibration levels at higher speeds has also become important. Figure 6 depicts the typical variations of vibration level with airspeed of helicopter.

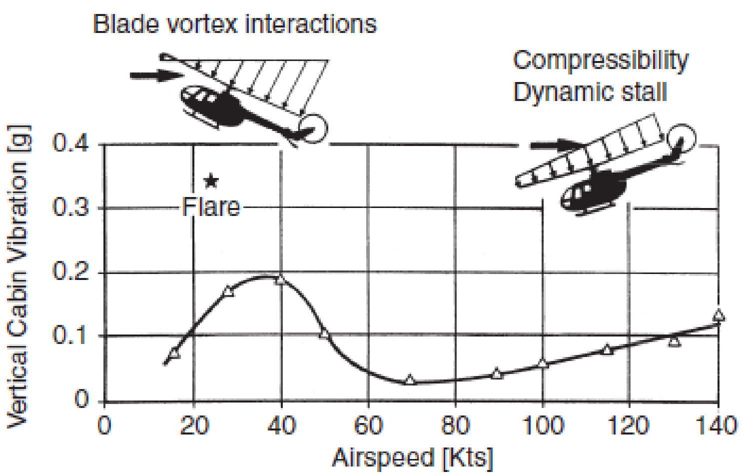



**Figure 6: Vertical Cabin Vibration in BO 105 as a function of Airspeed**

(Strehlow et al, 1992)

The vibration levels achieved in production Helicopters has been showing a downward trend due to the multi-pronged research to minimize the vibrations not only at source but all along the vibration path. The early standards of NASA and MIL-H8501A were considered as the benchmarks for vibration level comparisons over the past three decades. The vibration levels have been controlled through various techniques and hence a down trend is observed over the years as depicted in Figure 7- Fuselage Vibration level). Though still higher, the helicopter vibration levels are approaching the vibration levels in level in fixed wing Aircraft, over the years , due to an array of measures to mitigate vibration at source, in the vibration path and fuselage as well as localized points

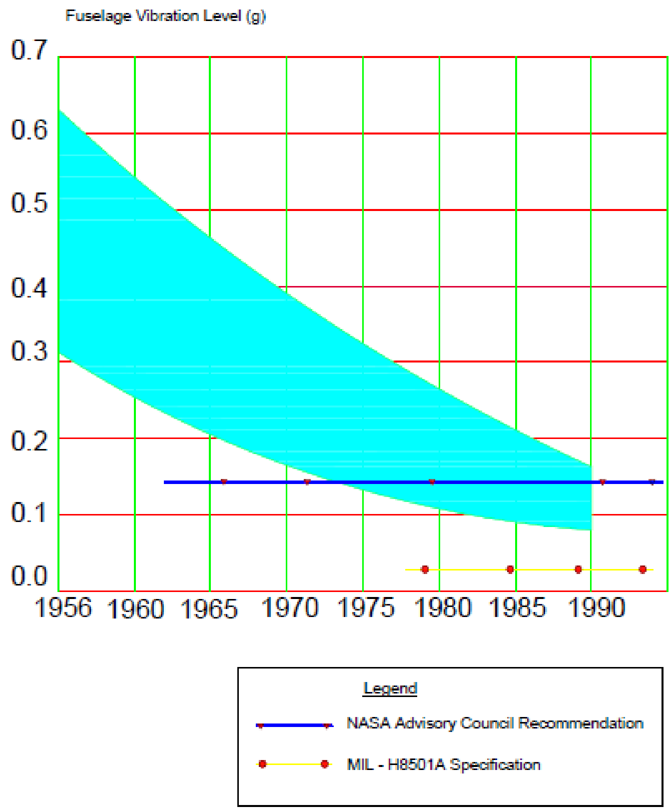



**Figure 7: Fuselage Vibration level**

(Reichert, 1981)

## 5. EFFECT OF VIBRATIONS ON HUMAN BODY

The effect of vibrations on humans and equipments has been studied in great detail over the years and several standards have evolved. Henning E. von Gierke & Anthony J. Brammer , (Harry's Shock & Vibration Handbook) have critically examined the various types and nature of the psychological effects and physiological damages on the human body due to vibrations and shock. The work also covers the low frequency susceptibility of various parts of body. As the frequency range of vibrations in Helicopters is relatively low, human body is prone to these vibrations, with resultant detrimental effects.

Staves AJ, 1973, concluded that vibration is a very possible cause of helicopter accidents due to pilot error, based on helicopter simulator studies on pilot performance as influenced by noise, vibration, and fatigue. The exposure was to vibrations (at 17 Hz) ranging from 0.1 to 0.3 g, and noise stimuli varying between 74 (ambient) and 100 dB. Despite reports of extreme fatigue on these long flights, the crew performance did not degrade. It was concluded that the subjects did suffer from lapses resulting in abnormally poor performances & if such lapses occurred in actual flight, they could possibly explain the many "pilot error" accidents.

The human tolerance limits to the vibration is depicted in Figure 8.

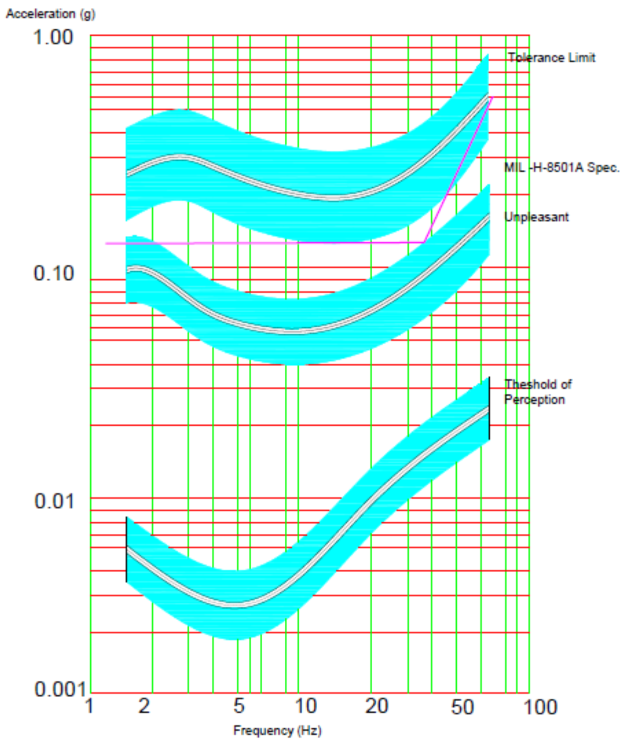



**Figure 8: Human Response to Vibration (Goldman, 1948)**

**TABLE (B) EFFECT OF VIBRATIONS ON HUMAN BODY**

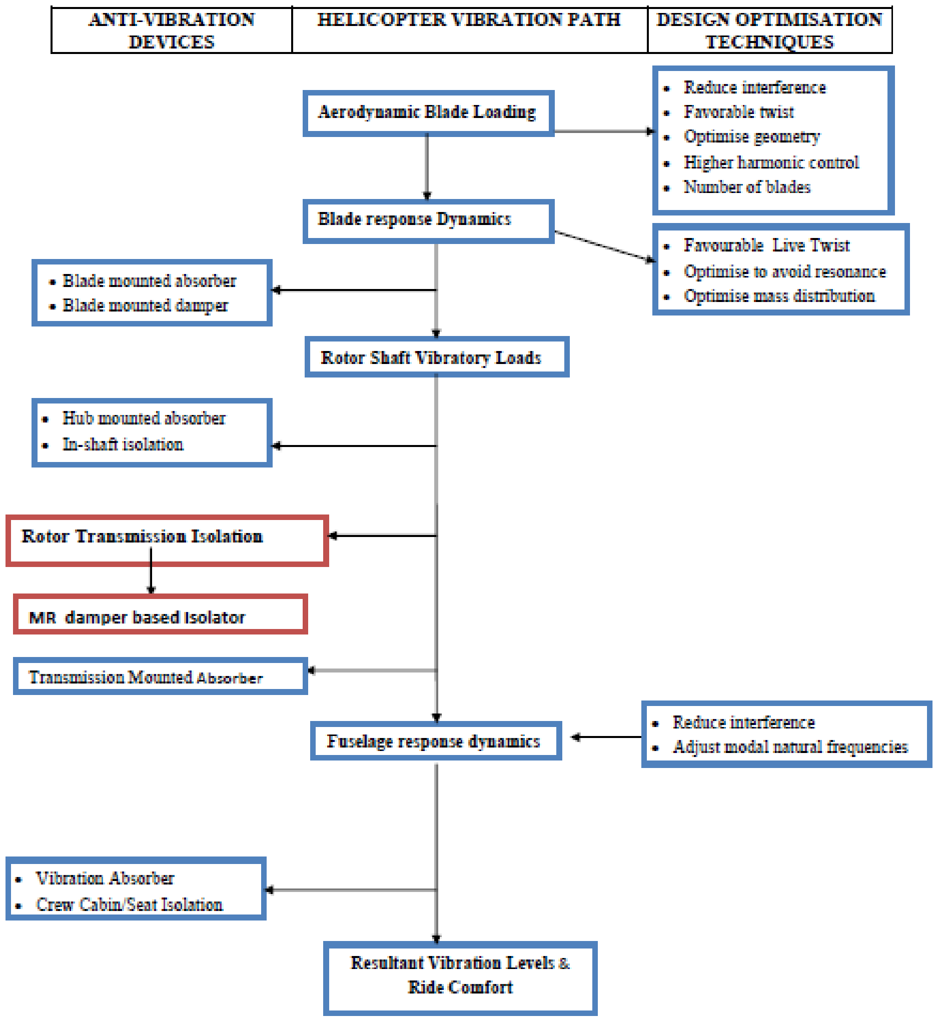
| Sl No. | Frequency ( Hz) | Part of the body susceptible to excitation |
|---|---|---|
| **a)** | < 1 | Annoyance and airsickness |
| **b)** | 3 – 6 Hz | Thorax, abdomen system |
| **c)** | 20 – 30 Hz | Head, neck & shoulder system |

| | | |
|---|---|---|
| **d)** | 60 – 90 Hz | Eyeball resonance |
| **e)** | 100 – 200 Hz | Lower jaw skull system |
| **f)** | 300 – 400 Hz | Skull |

However, apart from the frequencies of excitation, the amplitudes also have considerable bearing on the effects. The threshold of instrument unreadability is specified as 0.5 g to 1.0 g. In view of these considerations, the permissible vibration levels have been specified at 0.15 g as per MIL-H-8501A and at 0.02 g as per NASA specifications. However, in UTTAS/AAH program, vibration requirement of 0.05 g was realized with excessive weight penalty. So a vibration level of 0.1 g was accepted with reduced weight penalty.

Hitherto, flights at cruising and maximum speeds were considered critical, as they formed longest part of flight regimes. But with the advent of terrain flying and NOE (Nap of the earth) manoeuvres/flight to enhance survivability by avoiding detection, vibration level requirement in low speed maneuvering flight has become essential.

If the vibration level exceeds the permissible value at locations such as pilot and passenger seats, equipment and armament mounting points, then it is necessary to introduce some vibration control methods to reduce the vibration levels. The various approaches for vibration control is shown in Figure below:




It is seen from Figure that, there are mainly five main ways, by which one can try to reduce the level of vibrations. These are,

(i) Reduction of aerodynamic excitation
(ii) Improved blade design
(iii) Absorbers
(iv) Isolators
**(v)** Fuselage dynamics optimizations

## TABLE C – ABSORBERS/ ISOLATORS IN HELICOPTERS

| Sl No. | Vibration control Approach | Helicopter were used |
|---|---|---|
| **1.** | Centrifugal pendulum Absorber | Boeing Vertol 347, OH – 6A, BO- 105 C |
| **2.** | Bifilar absorber | Sikorsky S – 58T, S-61, S-67,S-70, S-72, S-76 |
| **3.** | Bearingless Hub Absorber | Bell model 412, model 206 IM |
| **4.** | Fixed Frequency Hub Absorber | Lynx |
| **5.** | Focus Pylon | Bell TH-57, 206A, OH-58A, OH-4A |
| **6.** | Nodal Beam | OH-58A, 206A, 214A, YAH-63, AH-1J (Seat only) |
| **7.** | Dynamic Antiresonant vibration Isolator DAVI | KAMAN's HTK, HOK, K-17, Boeing Vertol's BO-105, UH-1H, UH-2 |
| **8.** | Hydraulic Antiresonance Isolator | BK-117 |
| **9.** | Barbeque Isolation | Puma |
| **10.** | Liquid Inertia Vibration Eliminator (LIVE) | Bell 206 B |
| **11.** | ALH Dhruv | Active vibration control systems (AVCS) Antiresonant Isolation system |

### 6. CONCLUSION

The helicopter vibrations consists of primarily two types of vibrations- the unavoidable N/rev vibrations, which can only be minimized and not eliminated and the other arising out of imbalances and attributable reasons such as blade track and individual blade mass imbalance. The various methods available for mitigation of vibration right from design to the in-service operation of the helicopter are possible in helping vibration alleviation through the life cycle of helicopters. It has been observed that complete vibration control is always associated with weight penalty and system complexity. Trade-offs between residual vibration level and growing system complexity is typical of current helicopter designs.

**REFERENCES**

1. Gessow A , Myers GC, 1999, Aerodynamics of the Helicopter, Fredrick Ungar Publication

2. Saunders. GH, 1975, Dynamics of Helicopter Flight, John Wiley & Sons,

3. Wayne Johnson, 1995, Helicopter Theory, Princeton University Press,.

4. FAA Part 29 Airworthiness Standards: Transport Category Rotorcraft

5. ALLAN M. STAVE, Sikorsky Aircraft ,The Effects of Cockpit Environment on Long- Term Pilot Performance HUMAN FACTORS. 1977, 19(5),503-514

6. Brown D A Anglo-Italian EH10 1 Prototype Expanding Envelope in Early Flights Aviation and Space Technology, Nov 1987

7. Hooper W E, The Vibratory Airloading of Helicopter Rotors Vertica, Vol. 29, No. 4, pp 4-30, 1984

8. G.Reichert – Helicopter Vibration Control – a survey, Vertica, Vol.5. 1981.

9. R G Loewy – Helicopter Viberations – A Techanological perspective, JAHS Vol.29. OCT 1984.

10. RH Blackwell Jr – Blade Design for Reduced Helicopter Vibration, JAHS Vol 28, July 1983.

11. Robert B Taylor – Helicopter Vibration Reduction by Rotor blade modal shaping, 38th ANF of AHS, May 1982.

12. CE Hammond – Loads Reduction using Higher Harmonic blade Pitch, 36th ANF of AHS, 1980.

13. Marcel Kretz, and Marc Larche – Future of Helicopter Rotor Control, Vertica, Vol.4,1980.

14. Kenneth R.Reader, Douglas G.Kirkpatrick, and Robert –M-Williams, - Circulation Controlled Rotor.

15. HW Hanson and NJ Calapodas – Evaluating of the Practical aspects of Vibration Reduction Using Structural Optimisation Technique, 35 ANF of AHS, May 1979.

16. M.-N. H. Hamouda and G. A. Pierce. "Helicopter Vibration Suppression Using Simple Pendulum Absorbers on the Rotor Blade." Journal of American Helicopter Society, Vol. 29, No. 1, 1994, pp. 19-29.

17. Rene.A.Desjardins and W.E.Hooper – Helicopter Rotor Vibration Isolation, Vertica 34th ANF of AHS,Vol.2, no.2, 1978.

18. Edwin R Chubback - Analysis and design of a multiaxis Vibration Isolator for missile pods mounted on Army Helicopters, Ad 001459, Aug 1974.

19. Balke R W – Development of Kinematic Focal Isolation System for Helicopter Rotors, 38th shock vibration symposium, Nov 1968.

20. David Shipman – Nodalisation applied to Helicopters , 28th ANF of AHS, May 1972.

21. D R Halwes – Live Liquid Inertia Vibration Eliminator, 36th ANF of AHS, May 1980

22. Brown D A Anglo-Italian EH10 1 prototype Expanding Envelope in Early Flights Aviation and Space Technology, Nov 1987

23. Hooper W E, The Vibratory Airloading of Helicopter Rotors Vertica, Vol. 29, No. 4, pp 4-30, 1984

24. King S P The West/and Rotor Head Vibration Absorber Design, Principles and Operational Experience Vertica, Vo!. 11, No. 3, pp 437-446, 1987

25. ISO 2631 Guide for the Evaluation of Human Exposure to Whole Body Vibration International Standards Organisation, No. 2631, 1974.