MINIMIZATION OF THE HELICOPTER MAIN ROTOR VIBRATION

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Abstract

What has been discussed in the paper are the main sources of vibration that has destructive effect on helicopter design and is the most serious cause of fatigue and cracking processes, followed by numerous pilot's and operator's injuries. A method of significant reduction in helicopter design vibrations produced by main and tail rotors has been presented. The method has been grounded on measuring - in a sequential way - the vibrations. The measurements are followed by calculating the adjustments to regulate elements of main and tail rotors.

Essential for the testing work was the ROTABS (Rotor Trim And Balance System). The effects of calculated adjustments on helicopter hovering flight and various flight speeds have been presented. The test results for numerous types of helicopters manufactured in the countries of Eastern and Western Europe are to be presented as well.

Introduction

Descriptions of how to apply vibration levels to monitor technical condition of helicopters are to be found in literature of the subject(1,2). This paper deals with a method of minimizing vibrations produced by a helicopter main rotor in course of its operation.

Variable aerodynamic and mass loadings on a main rotor and a tail rotor of a helicopter are - among other factors - of primary importance as a source of helicopter fuselage vibrations. Variable aerodynamic loadings on blades of a main rotor and a tail rotor are due to the fact that air speed and angle of attack of a blade rotating about the rotor axis depend upon attitude of this blade. The power units and the power transmission system are the sources of helicopter vibration as well. Atmospheric turbulence is still another factor that forces stochastic vibration.

Generally, vibration is one of the problems of fundamental significance for helicopter operation. It decreases fatigue strength of a fuselage structure, reliability of structural assemblies of a helicopter and its maximum flight speed. High level of helicopter vibration results also in physical and mental overloadings of evidently negative influence upon flying staff and their ability to accomplish the assigned tasks.

Frequency spectra of individual sources of the helicopter vibration show meaningful values of amplitude in a wide frequency range, i.e. from the low frequencies, of several dozen of Hz in case of power transmission systems, main rotors and tail rotors, up to the high ones, of a dozen or so of kHz in case of power units and reduction gears(3,4).

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Low-frequency vibration amplitudes are of significant influence upon fatigue strength of the helicopter fuselage structure and vibrational loadings that affect the crewmen. According to$^{(5)}$, to limit value of a low-frequency component of the vibration spectrum, oriented vertically in Z direction along the main rotor axis will be of substantial importance for improving working conditions of pilots and crewmen.

Possibilities of decreasing helicopter vibration levels under operational conditions

Helicopter vibration level depends on energy portion due to vibration that results from the above-mentioned sources, and upon flight conditions and speed. The relation has not been determined precisely because of a complex character of reasons, conditions of initiation and transmission of vibration.

There are possibilities of adjusting levels of vibration of the main rotor and a tail rotor of a helicopter under service conditions. In case of the main rotor the aim is to be reached by means of aerodynamic and mass balance, in case of a tail rotor - by means of dynamic balance. Possibilities of influencing main rotor vibration levels in helicopters of "Mi" type (in service in many countries) are very limited. Adjustments are possible using one of two structural components, i.e. either by means of trimming tabs on blades or with vertical push rods of a rotor swash-plate.

Flight tests of Mi-8 and Mi-24 were carried out, aimed at decreasing helicopter fuselage vibrations. ROTABS found its application as a diagnostic tool$^{(6)}$. Fig. 1 shows functional diagram of the system.

ROTABS has been composed of the following assemblies:

- six vibration sensors fixed to fuselage structure in a cockpit and freight compartment or passenger compartment;
- tachometer sensor fixed to a body of a clamping ring of the main rotor swash-plate;
- DASP, i.e. Discrete Analog Signal Processing unit;
- computer with some special software.

ROTABS calculates values of parameters for adjusting trimming tabs of rotor blades and vertical push rods of a swash-plate. Analysis of motion dynamics of a helicopter considered a rigid body with six degrees of freedom gives grounds for these calculations The adjustments made may result in decreasing dynamic influence of the main rotor upon the helicopter's structure, followed by its vibration level decrease. Results of measuring vibration accelerations serve as a basis for the software to calculate linear vibration amplitudes for: roll axis X-FWD, pitch axis Y-LAT and yaw axis Z-VERT, as well as angular vibration in respect of these axes: roll (X), pitch (Y), yaw (Z) - respectively (see Fig. 1).

Procedure of measuring and then minimizing vibration of the first helicopter of every type is usually carried out in two stages. At the first one, matrices of influence of a change in: a trimming tab angle (alternative A), and a swash-plate push rod length (alternative B) upon changes in vibration amplitude values is to be determined for every blade individually. The task calls for performing, for each alternative separately, hovering and flights with some selected, pre-set speeds of a helicopter.

Analysis of the recorded measuring results on vibration accelerations gives the software program good grounds for calculating optimum values of parameters for adjusting a trimming tab and a push rod for every rotor blade individually. Then, on the same grounds, the program develops forecasts on how values of linear and angular vibration amplitudes will change for the adjustments made. ROTABS receives this stage as a "learning process", i.e. it "learns" how to estimate dynamic characteristics of a given type of a helicopter.

The second stage needs one flight to be performed in order to check the efficiency of the adjustments and accuracy of the forecast on changes in vibration levels.

Minimization of vibrations in every subsequent helicopter of a given type requires then only two flights to be performed, the first one aimed at determining technical condition and calculating optimum values of parameters for regulating the trimming tabs and vertical push rods, whereas the second one - to check the correctness of the adjustments made.

ROTABS renders some choices possible, i.e. a choice of space for vibration minimization (the space being freely oriented in respect to the helicopter) and a choice of flight speed (one or more), for which maximum vibration decrease is required.

Results

Figures 2÷4 and 5÷7 give exemplary effects of minimizing vibrations of main rotors of Mi-8 and Mi-24 helicopters. The results were obtained for hovering out of ground effect (Hover OGE) as well as for flight with speeds most common in operational practice with these types of helicopters.

Helicopters of the above-mentioned types flew their missions before and after adjusting their main rotors. Parameters for the adjustments were calculated using ROTABS. Maximum decrease in vibration was assumed for the vertical direction (VERT) - see Fig. 1. Comparison of vibration levels for the vertical (VERT), measured before and after the adjustments, shows that for the pre-set flight conditions a considerable vibration decrease was achieved: 5÷10 times in case of Mi-8 and 1.5÷2.5 times in case of Mi-24. Figs 8÷10 illustrate effects measured for AS 332 Super Puma, Figs 11÷13 - for MBB BK 117. In both instances the adjustments were carried out using ROTABS(6).

From the analysis of results of reducing vibration for the vertical direction Z (VERT) it appears that in case of AS 332 Super Puma the vibration level was decreased twice whereas in MBB BK 117 - 4÷32 times. However, it should be noted that before adjusting the main rotor AS 332 Super Puma showed 2÷4 times lower vibration level than MBB BK 117.

The hitherto experiences with ROTABS applied prove that - due to limitations on the one hand and required precision of adjusting the main rotor parameters on the other hand - it is undoubtedly much more difficult to reduce low levels of helicopter vibrations under operational conditions.

Conclusion

Application of ROTABS enabled a significant decrease in vibration in Z direction (VERT) in case of helicopters Mi-8 and Mi-24 under testing. Such results were obtained despite a limited range of ROTABS use due to disability to improve - under operational conditions - mass balance of the main rotor blade in helicopters of the types mentioned. The test work carried out until now indicates that improvements of the method of minimizing helicopter vibration using ROTABS will serve their purpose. Special attention should be paid to meeting requirements on accuracy of adjusting push rods and trimming tabs of main rotor blades, as calculated by a computer.

Minimization of vibration levels in helicopters Mi-8 and Mi-24 was performed for a lower number of flights than in case of efforts to make adjustments on AS 332 Super Puma and MBB BK 117. In both the cases ROTABS found its application. Results obtained with Mi-8 and Mi-24 helicopters give grounds to continue works on implementing the system to operational practice.

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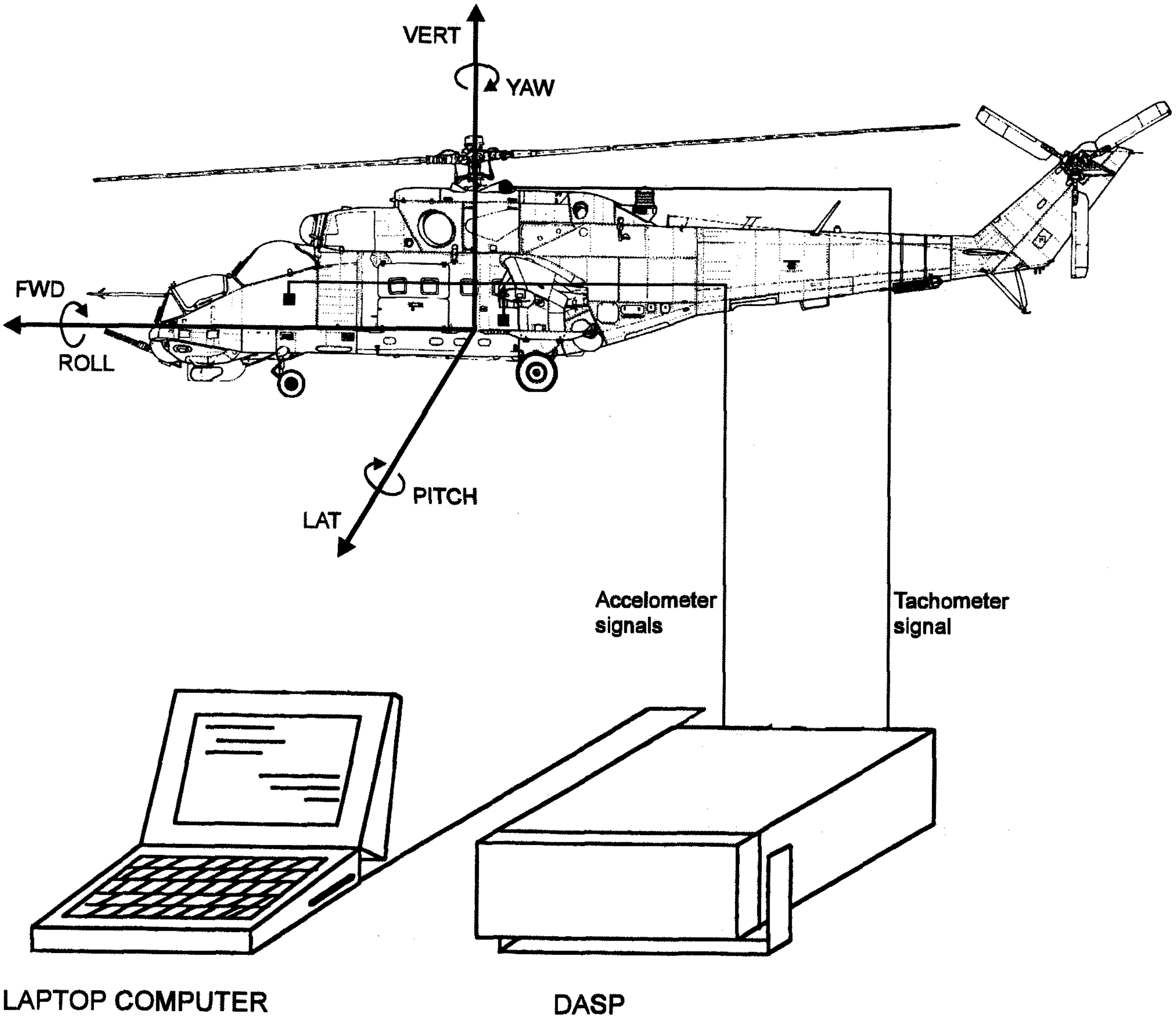

Figure 1. ROTABS system configuration and co-ordinate system for helicopter vibration measurments.

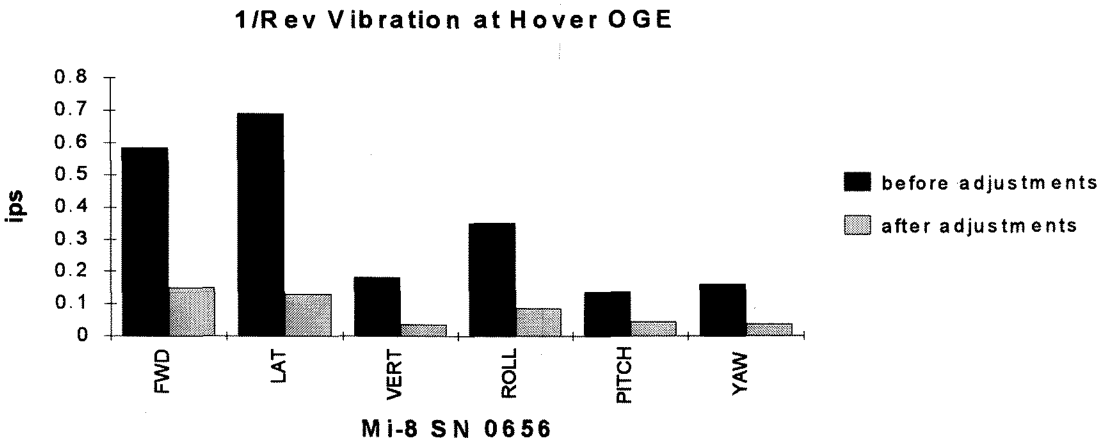

Figure 2. Vibration level of Mi-8 at Hover OGE.

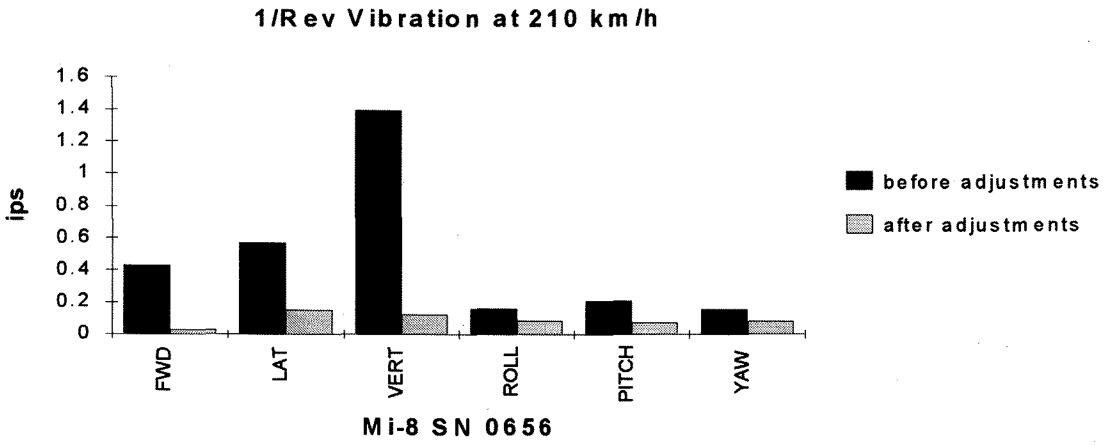

Figure 3. Vibration level of Mi-8 at 210 km/h.

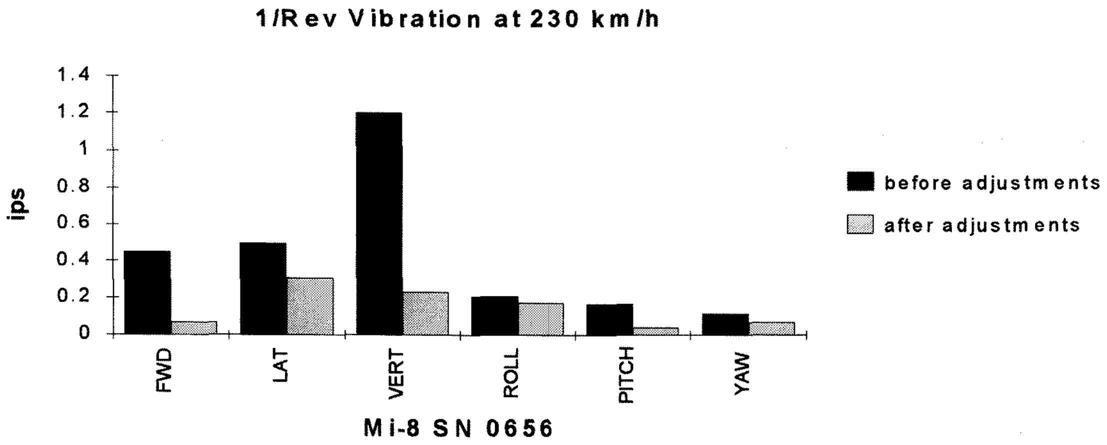

Figure 4. Vibration level of Mi-8 at 230 km/h.

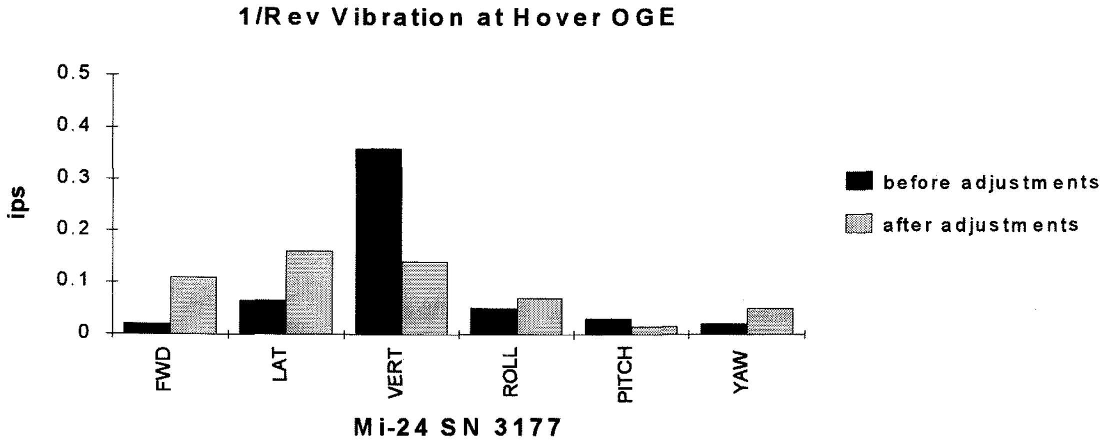

Figure 5. Vibration level of Mi-24 at Hover OGE.

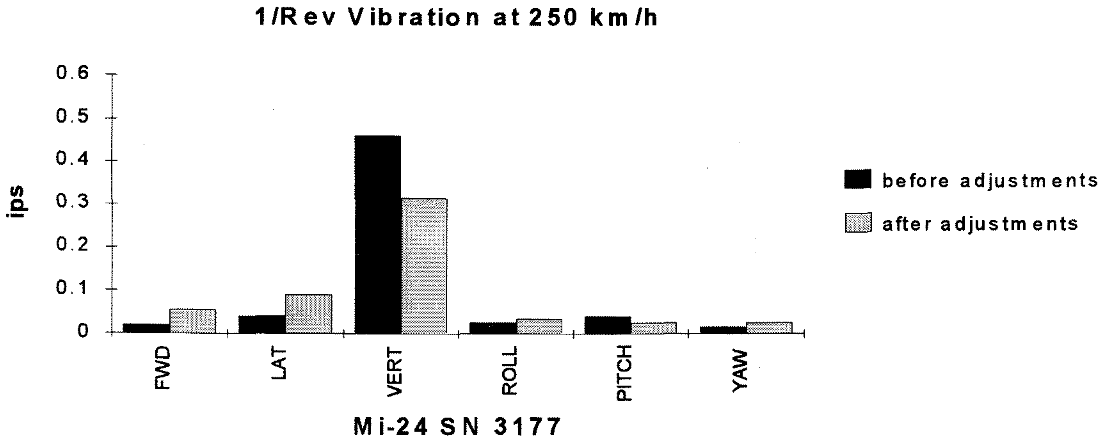

Figure 6. Vibration level of Mi-24 at 250 km/h.

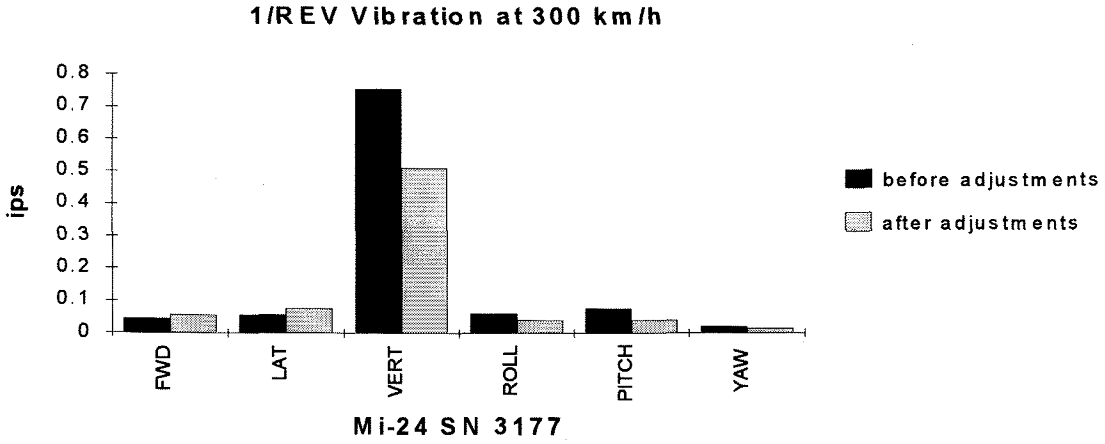

Figure 7. Vibration level of Mi-24 at 300 km/h.

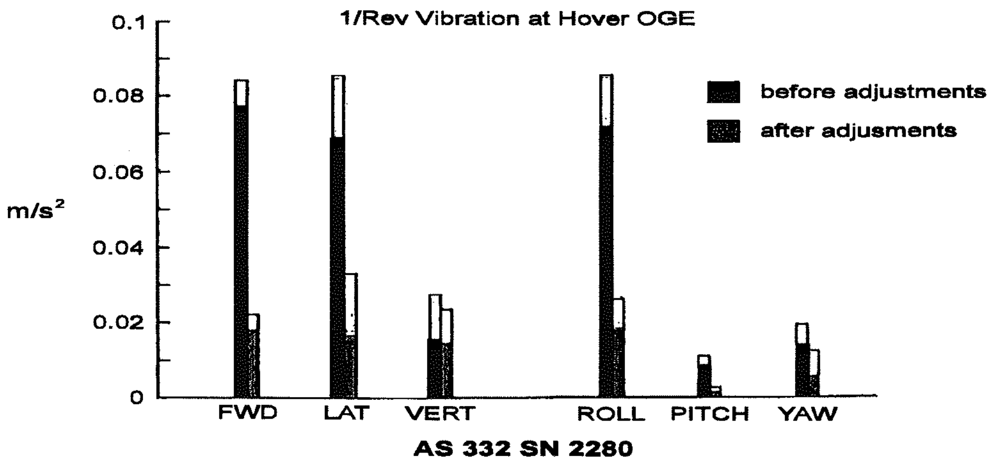

Figure 8. Vibration level of AS 332 at Hover OGE

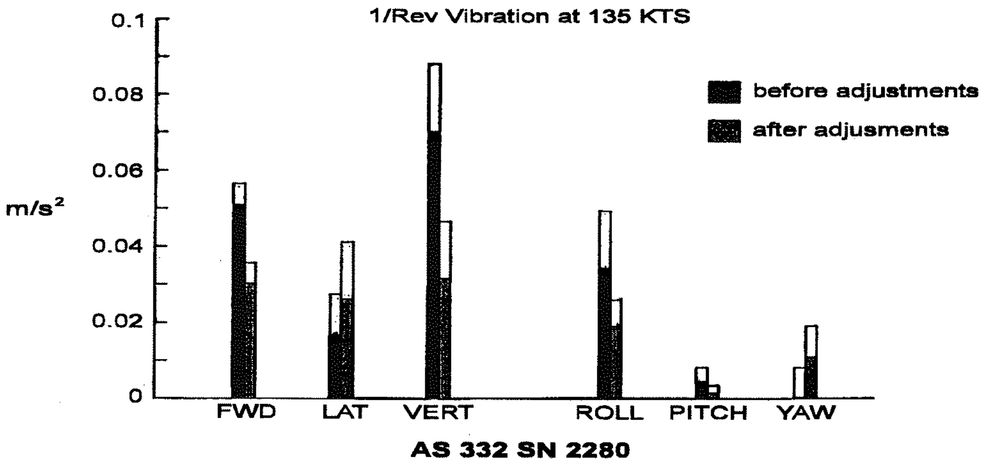

Figure 9. Vibration level of AS 332 at 135 KTS

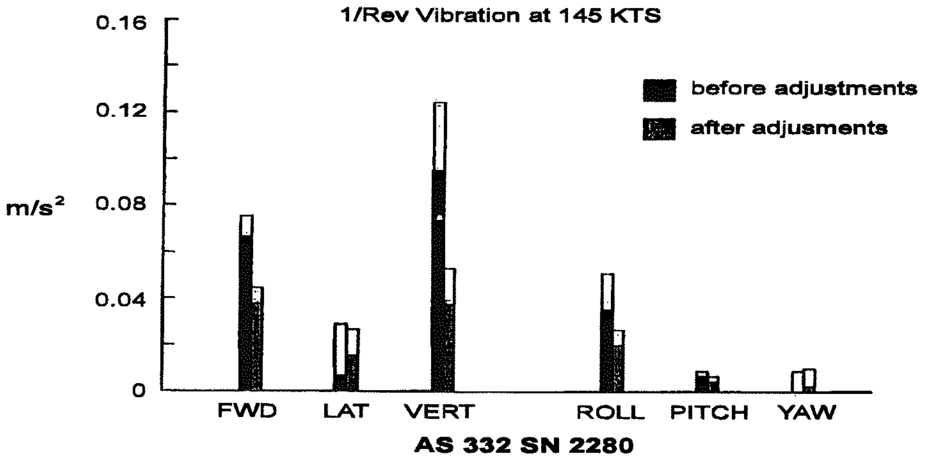

Figure 10. Vibration level of AS 332 at 145 KTS

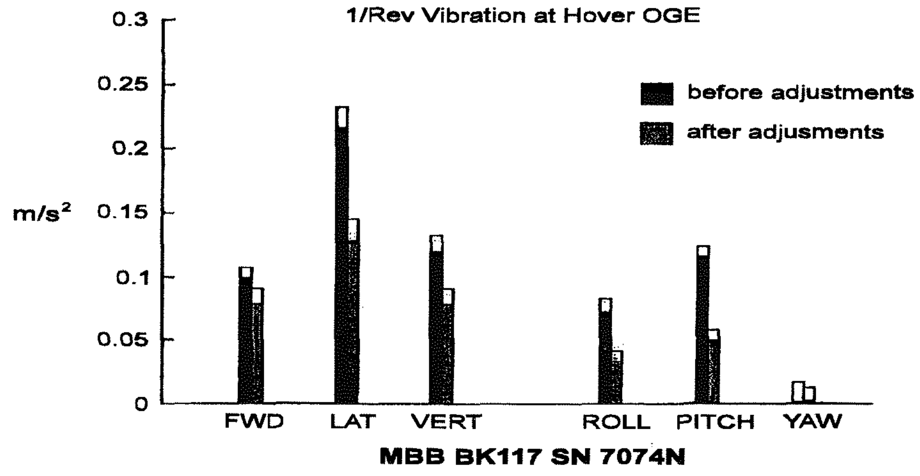

Figure 11. Vibration level of MBB BK 117 at Hover OGE

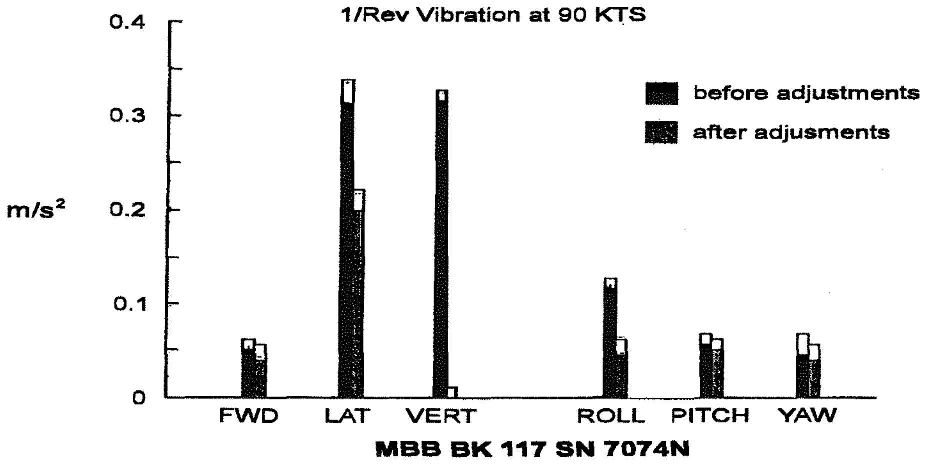

Figure 12. Vibration level of MBB BK 117 at 90 KTS

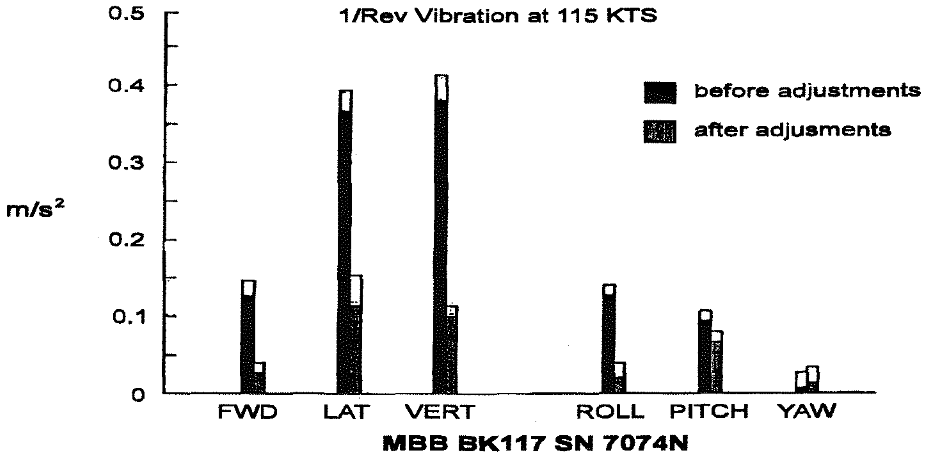

Figure 13. Vibration level of MBB BK 117 at 115KTS