Lightweight Acoustic Potential of helicopter main gearbox components made of composite materials

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Introduction

Lightweight structures for high-technology applications increasingly have to fulfil high demands not only on low constructive weight and adequate stiffness but also on reduced vibration and sound radiation. Especially carbon fiber reinforced composites offer a high vibro-acoustic lightweight potential with a high material damping and high stiffness besides low mass [1, 2]. Here, the reduction of the noise levels inside the passenger cabine of a helicopter is exemplarily chosen in order to demonstrate this lightweight acoustic concept [5]. The high sound pressure level is generated by the main rotor, the tail rotor, the turbine, and the main gear box. The main gear box is usually directly located on top of the passenger cabin (see Figure 1) and is one of the most dominant noise sources.

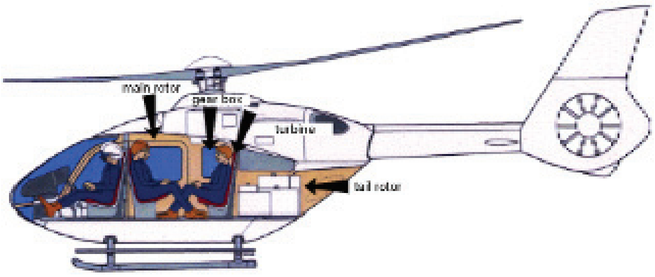

Figure 1: Sketch of a helicopter showing the typical noise sources shaping the sound field inside the cabin [5]

This report describes the work on the development of vibro-acoustically optimized multi-layered composites components aimed for a helicopter main gear box with a reduced sound emission.

Motivation

In the near field of the main gear box sound pressure levels can be measured of up to 105 dB(A) with discrete frequency components 10-15 dB(A) above the broadband noise level. These discrete frequencies are excited by the gear meshing inside the gear box. Contrary to applications in the automotive field, the helicopter operates at a constant revolution speed and orientation during flight. That means the gear meshing frequencies are stationary. They occur typically in the frequency range between 800 Hz and 4 kHz. Through the short airborne transfer path between gear box and cabin the cabin structure is excited by the sound emission radiated from the gear box housing.

In a complex numerical FEM/BEM analysis, the excitation and sound radiation of the housing due to the gear meshing was examined for a helicopter main gear box manufactured by ZF Luftfahrttechnik GmbH (ZFL). The analysis indicated a high sound radiation in some areas of the housing (see Figure 3) for certain gear meshing frequencies. In these areas, the housing has some lids required for maintenance purposes [5]. To reduce the sound radiation of these surfaces at the gear meshing frequencies, a new design for the lids in lightweight composite construction was developed and its acoustic potential was identified.

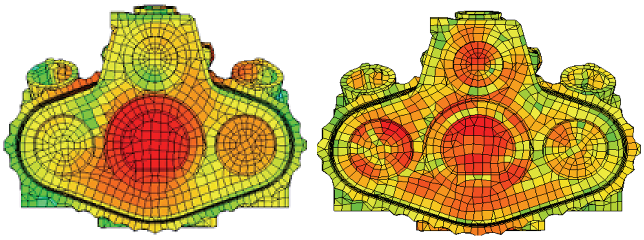

Figure 3: Results from the numerical analysis of the sound radiation from the lower gear box housing at two different gear meshing frequencies (red indicates high sound radiation levels)

Design of composite lids

Carbon fiber reinforced composites offer a high vibro-acoustic potential. The specific combination of different materials and the large variety of design variables gives the possibility to synergetically achieve the pretentious demands on coupled dynamic and acoustic properties.

For the proof of concept of pre-selected designs, three simplified gear box lids (SGLids) were designed and manufactured in order to evaluate the lightweight acoustical potential of composite materials and different designs.

Figure 4: Composite simplified gear box lids (SGLids)

Figure 4 shows the manufactured composite SGLids of type stringer, sandwich and laminated carbon-fiber-reinforced polymer (CFRP, epoxy-matrix). The use of fibre-reinforced composite material in combination with an adapted design leads to a mass reduction of up to 50% compared to an aluminium lid as the reference design.

Concept of experimental verification

For an investigation of the vibro-acoustic behaviour of the composite SGLids, a test stand was designed, which is aimed to represent the main airborne excitation path existing in the helicopter. The test stand consists of a polymer concrete plate including a steel ring for clamping the SGLids (Figure 5). This test set-up allows a force excitation of the SGLids by means of a shaker for vibro-acoustic measurements, e.g. an experimental modal analysis or sound intensity measurements.

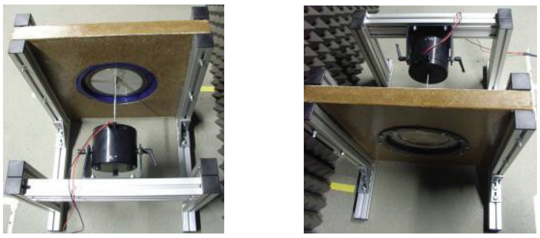

Figure 5: Test stand for vibro-acoustic investigation of the different SGLid designs

Results of the vibro-acoustical investigations

The comparison of the designs is based on measured eigenfrequencies, the corresponding mode shapes, and the measured sound intensity. Figure 6 shows exemplarily the determined Modal Peaks Functions (MPF, sum of Frequency Response Functions squared relating to number of all measurement points) of the reference aluminium lid and sandwich SGLids as a result of the experimental modal analysis.

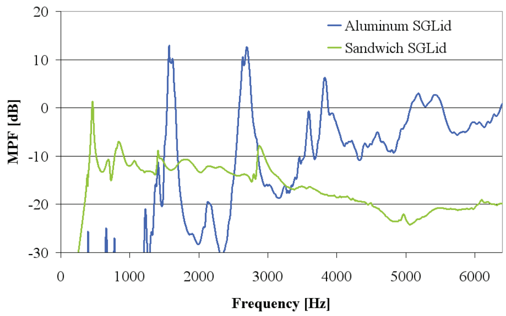

Figure 6: Comparison of the Modal Peaks Functions for the aluminium and sandwich SGLid

The sandwich SGLid shows the lowest first eigenfrequency due to the separate vibrations of the face sheets. At high frequencies, the sandwich SGLid exhibits a smooth curve on a lower level without noticeable resonance peaks compared to the aluminium reference design. This effect is mainly caused by the high damping of the sandwich core material. Consequently, this high material damping of the MPF of the Sandwich gives a valuable contribution to reduce the sound radiation [3, 4].

The radiated sound power was calculated from the measured sound intensity of the mechanically excited SGLids (see Figure 7). The sound power levels of the sandwich SGLid are significantly lower than those of the aluminium lid within the investigated frequency range. This causes an overall reduction of the sound emission of 5.6 dB. Although lightweight structures tend to increased sound radiation levels due to their low forces of inertia, the sandwich SGLid compensates this effect by its high material damping (see also [3, 4]).

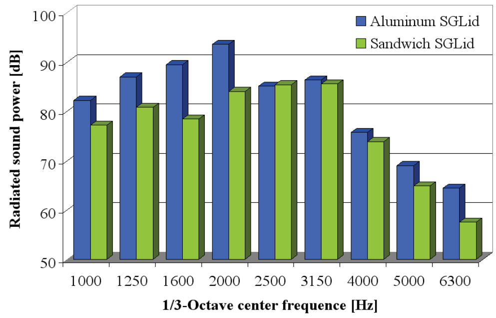

Figure 7: 1/3 octave analysis of the radiated sound power for the aluminium and sandwich SGLid

Conclusions and outlook

The use of sandwich composite material instead of aluminium for SGLid can reduce the total sound power level up to 5.6 dB while having only 50% of weight. This reveals the high vibro-acoustic potential of tailored sandwich composite materials for lightweight applications with high damping properties and low sound radiation.

Based on the results of this study, two SGLids were designed and manufactured as a replacement for the standard aluminium lids. These SGLlids are currently evaluated in full load test runs with a prototype main gear box on the ZFL test stand.

Acknowledgement

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