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Partial filling of a honeycomb structure by granular materials for vibration and noise reduction

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ABSTRACT

In this paper, the damping effect of granular materials is explored to reduce the vibration and noise of mechanical structures. To this end, a honeycomb structure with high stiffness is used to contain a granular filling which presents the possiblity for the distribution of the granular material to be designed. As a particular application example, the oil pan bottom of a combustion engine is used to investigate the influence on the vibration behavior and the sound emission. The effect of the honeycomb structure along with the granular mass, distribution, and type on the vibration behaviour of the structure is investigated via laser scanning vibrometry. From this, an optimized filling is determined and then its noise suppression level validated on an engine test bench through measurements with an acoustic array.

1. Introduction

In the development of machines, the reduction of the vibration and the noise emission is an important task alongside the optimization of power and efficiency. Hence, in many industrial applications, an increasing amount of attention is being paid to the vibratory and acoustic behaviour of systems, particularly in how it relates to the comfort, efficiency, and safety of the user. In general, there are two major means through which vibration and sound suppression is enacted: active and passive. Active methods typically employ one or more actuators and sensors, that work in conjunction with a controller to create a reaction to the vibration of the structure. This typically has a high associated cost however, as additional components need to be installed into the system, along with a computer in order to generate the control. In contrast, passive control concepts typically involve either modifications to the structure, or the application of additional dampers. In this paper, a passive damping concept using granular materials in conjunction with a honeycomb structure is presented.

For particle dampers, the damping effect is thought to arise through the friction and impacts that occur between the particles during vibration. In several studies, the efficiency of particle dampers has been shown for several specific applications [1,2]. Bajkowski et al. [3] filled a beam with particles of different shapes and showed that edgy particles are preferred when a high level of damping is required. Particle dampers have also been investigated numerically, where the discrete-element method is mainly used [4–6]. However, the number of real world applications in which particle dampers have been

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used is significantly lower. One example application of particle-based dampers is that of Heckel et al. [7], in which particle dampers were used to reduce the vibration behavior of an oscillatory saw. In the study by Pöschel et al. [8], the vibration of the handle of a medical instrument was reduced through the use of particle dampers. In a study of Duvigneau et al. [9], it was shown that sand was very effective in reducing the amplitude of vibration. It was also shown that the high vibration reduction cannot be explained simply by the higher mass, as a filling of the same mass of water had a much lower influence on the vibration. Furthermore, it was shown that the location of the granular filling clearly had an influence on the vibration behavior. However, due to the use of one large cavity, a specified distribution of the particles inside of the cavity could not be achieved as movement of the particles inside the cavity could not be suppressed.

For this reason, a honeycomb structure is employed in this paper to contain the granular filling. As honeycomb structures consist of many small cavities, they show great promise in the area of particle dampers as the distribution of the granular material within the structure can be defined. Hence, it could be possible to reduce some chosen modes of vibration individually. Honeycomb structures also show the additional well-known advantage of possessing a high stiffness to weight ratio, which is desirable in most applications. A few previous vibration suppression studies have employed honeycomb structures, where for example, Li et al. [10] combined a honeycomb structure with foam and achieved a good noise reduction. In a study by Wang [11], solid metallic balls were placed inside of a honeycomb structure, and showed a vibration reduction effect, which monotonically increased with the number of inserted balls. The combination of honeycombs and soft hollow particle dampers by Michon et al. [12] also demonstrated a high reduction in the vibration. Panossion [13] combined honeycombs and particle dampers for a beam and carried out a numerical and experimental investigation.

In this paper, the potential of defined partial fillings of a honeycomb structure by granular materials is investigated for a specific application example, that of an oil pan bottom. The oil pan was chosen due to the fact that it is an important component of the overall acoustical behavior of a combustion engine [14]. The sound reduction of engines is also of interest as regulations governing the allowable volume of automobiles continues to be tightened by legislative authorities [15]. As a secondary parameter, the sound of an engine also affects the perceived quality of a vehicle, which not only improves the vehicles' comfort, but also influences customers purchasing decisions. Of course, the sound emission of an oil pan can also be improved through either passive or active means. A good passive method for noise reduction is that of encapsulation, such as the double-layered foam employed by Duvigneau et al. [16]. However, encapsulation requires additional installation space and increases the overall mass of the system. Another passive possibility to improve the sound emission is through optimization of the structure [17]. In contrast, active methods have also been pursued to improve the sound emission of an oil pan. These have mainly been carried out with piezoelectric actuators and sensors, such as by Ringwelski et al. [18] and Heintze and Rose [19].

Here, the vibration and noise reduction capability of a honeycomb structure filled with granular material is investigated. With the aid of a laser scanning vibrometer, the vibration behaviour of the new oil pan bottom is determined and compared to the original oil pan bottom. Then, the influence of the mass of the granular material and its location inside the honeycomb structure is investigated. This leads to an attempt to determine the optimal distribution of the granular material through both numerical and experimental means. Next, different types of granular filling are examined with respect to their efficiency in reducing the amplitude of vibration of the structure. Finally, the sound reduction of this honeycomb oil pan bottom is validated on an engine test bench at three fixed operating points.

2. Design of the honeycomb bottom and experimental setup

The original oil pan consists of two parts, an upper and a lower part that are connected by bolts, which can be seen in Fig. 1(a). In all of the experiments, the upper part remains unchanged, while the bottom is replaced by the honeycomb structure, which can be seen in Fig. 1(b). This structure consists of two aluminum plates, with the aluminum honeycomb in between. The first plate (the top one) is 2 mm thick and is used to seal the oil pan and prevent any oil leakage. This plate is connected via countersunk bolts to the upper part of the oil pan, using the same holes as the original bottom. The large hole in this plate that can be seen in Fig. 1(b) is required for the mounting of the oil sensor. The second plate, which is integrated with the aluminum honeycomb structure, has a thickness of 1 mm. The honeycomb itself is 10 mm high, with a vertex to

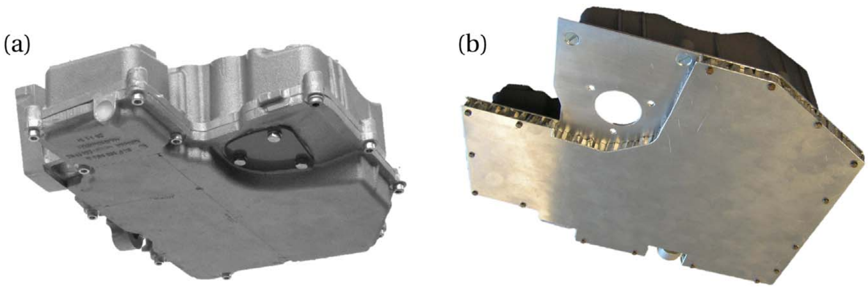

Fig. 1. (a) Oil pan with the original bottom; (b) Oil pan with the honeycomb bottom.