A sound perception approach inside a mechanical shovel cabin

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Introduction

Perceptive approaches can complete physical studies in a very useful way, allowing to reach a target expected by customers more quickly.
The subjective result can be linked to physics trying to relate it to one or several indicators representing the processed signals. This correlation then allows to identify the physical parameters characterizing the studied noise annoyance, and thus to identify annoying frequencies and annoying sources, and increase the efficiency of the resolution of the formulated problem.
In this paper, the application of a process of sound perception on an industrial object is presented with the will to reach the targeted physical objectives. This work is from a study carried out in the frame of a collaboration with the Volvo Compact Equipment company, a manufacturer of mechanical shovels. In this paper our objectives are :

1. Definition of the useful frequency bands, intervening in sound perception and thus allowing to choose a physical modeling method adapted to the problem.
2. On a complete machine, the manufacturer wanted to have a predictive model of sound pleasantness at his disposal and identify the elements of the machine contributing to annoyance so as to establish an hierarchical approach of noise reduction inside the cabin.

Part I : cabin system in laboratory [2]

The structure of the studied mechanical shovel is made of a cabin linked by four mounts to a chassis excited by an engine (figure 1a).

Figure 1: Studied mechanical shovel
(a): studied cabin in the laboratory **(b):** complete machine

Physical studies established from this machine have emphasized the importance of the vibro-acoustic transmission between the chassis and the cabin through the mounts ; a modeling of the cabin excited by the mounts has been suggested in order to assess the acoustic contribution of some modifications. The model is made of a finite and boundary element approach (FEM/BEM), allowing to get an access to the inner noise from a vibratory computation of the cabin submitted to a mechanical excitation transmitted through the mounts. In this case, the contribution of the subjective approach to the physical analysis concerns the definition of useful frequency bands, in which all the modifications are sensitive at the level of sound perception ; the interest of such a modeling can thus be assessed.
The acoustic pressure developed from different rotational speed of the engine have been measured with the simulating dummy head. Each sound file has then been filtered through low and high frequency filters and has generated several sound files which have been characterized in dB_A. The most influential frequency band can be identified from the sound level in dB_A when both defined frequency fields from both filtering are gathered. It concerns the [800 Hz-3200 Hz] interval.
A dissimilarity and preference test has then been initiated between all the filtered sounds with respect to the original sound. The overall frequencies being lower than 3200 Hz have to be taken into account so that the similarity of sounds from filtered sound files can be correct with respect to the original sound ; low frequencies are important in this case.
An analysis similar to the previous one has allowed to show that the participation of low frequencies (<400Hz) is of major importance in the assessment of acoustic pleasantness, using the results of the preference test.
A FEM/BEM physical modeling is thus very useful at the level of sound perception when it is aimed to low frequencies even if the global level in dB_A remains not very sensitive.

Part II : Analysis on a complete machine

On a complete machine (figure 1b), a predictive model of sound pleasantness has to be obtained and the elements of the machine contributing to annoyance have to be identified. Three sound sources participating to the contribution of noise inside the cabin have been identified ; it concerns : the heat engine, the hydraulic pump, and the hydraulic distribution.

A/ Preference model construction [1]&[3]

The analysis parameters being used are :

1. The rotation velocity of the engine : low speed (≈920trs/mn), maximum speed (≈2300trs/mn) .
2. The hydraulic load : 1 and 2 movements,
3. The cabin configuration : completely closed, and completely opened (windows and door).

Ten sounds to be analyzed have been selected, with three repeated pairs and three equivalent pairs (2 similar sounds) have been added to the 45 pairs of the 10 sounds, constituted with the Ross series. About thirty listeners have participated to both tests (dissimilarity and preference). It can be stated that the closing of the mechanical shovel passenger compartment increases sound pleasantness from the average score of the obtained preference and that the increase of the rotation velocity diminishes it.

The research of a preference score correlation with a linear relation of one of the computed parameters has given no satisfactory result (R^2 maxi =0.53 with loudness or level en dB_A). A correlation of this pleasantness has then been searched with a linear combination of two metrics. The best obtained correlation corresponds to a linear correlation with both a dB_B level and the intelligibility (ANSI S3.5); this latter parameter plays an important role as it is found several times in the 5 best combinations.

Dissimilarity test results have also been used to define a perceptive space (with the principal component analysis method) , and then to search a correlation between the dimensions and the preference score. The research of a correlation between each dimension and one of the computed parameters has given no satisfactory results (R^2<0.6). The first dimension is well correlated (R^2=0.96) with both the dB_B level and the intelligibility and the second dimension is correlated (R^2=0.9) while using a combination of two parameters with a linear combination of the dB_B and dB_A levels.

Both dissimilarity and preference tests have allowed to build a preference model ruled by the dB_B and the intelligibility (figure 2) :

$$Preference = 0.81(dB_B) + 0.41(Intelligib.) - 69.8 \quad (1)$$

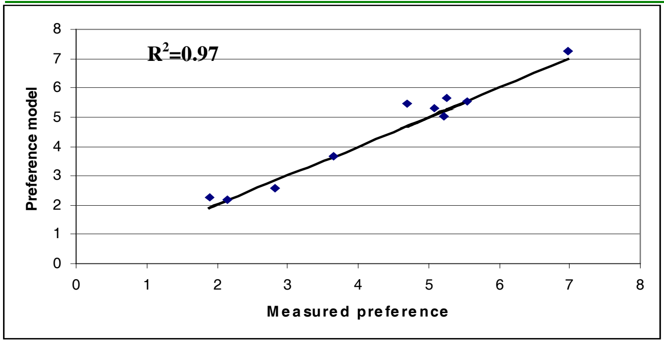

Figure 2: Computed preference score according to measured preference scores

However, it seems paradoxical that the increase in the dB_B level improves sound pleasantness. Actually, these two parameters are linked (in a no linear way), and there must be boundary values from the dB_B level, especially from which the model is no longer valid. It is the purpose of the following paragraph being dedicated to both the validation and the use of this model to identify the elements of the mechanical shovel participating to noise annoyance.

B/ Model validation and application [4]

Five configurations of acoustic measurements have been used while proceeding to an hydraulic coupling between two machines : engine alone, engine coupled to the pump (without any distribution), engine with the distribution (without the pump), distribution alone and lastly the normal functioning (engine + pump + distribution). The parameters of the study are : the rotational speed of the engine (slow or maxi running), the opened or closed cabin, and with or without any hydraulic load. All these configurations and variations of parameters have constituted about thirty sound files; about twelve have been extracted from them and will be used to assess the validity of the preference model (1).

A preference test has allowed to have an access to the preference score measurement of these 12 sounds thanks to about thirty listeners. A very good correlation between computed and measured preference scores is noticed, except for sound 1 which seems to be under-assessed by the preference model (1).

Eleven sound files obtained from a filtering of sound n°12 have been constituted so as to define the validation boundaries of this model. This filtering can make the dB_B level vary without involving the intelligibility and inversely too much as it is based on B weighting definition fields of both the ear and the intelligibility. These twelve sounds have been submitted to about twenty listeners through a preference test ; it can thus be concluded that the model is valid for the dB_B sounds included between 75.5 and 86.4 dB_B.

One of the works on this model has corresponded to the study of the contribution of mechanical shovel elements (engine, pump, distribution) over sound annoyance. An access to the value of the preference score of each sound and then an assessment of the correlation between the parameters of the model and the different measured configurations while computing both the dB_B level and the intelligibility of the thirty sounds or so observed at the beginning of the experiment can be made. The engine + pump configuration is the most appreciated one ; at the level of parameters : the slow running rotational speed of the engine, the closed cabin and the presence of a movement constitute the basic preference of listeners. With the engine, the presence of the distribution has nearly no influence on the intelligibility of the overall structure, but increases the dB_B level, whereas the presence of the pump determines the intelligibility and has nearly no influence on the dB_B level.

The acquired sound files of the three separated sources have been obtained while using a filtering allowing to extract the noise of the pump from the engine + pump structure. This very difficult manipulation has been validated while assessing the reconstituted noise through the gathering of the three sources with the actual measured noise in a perceptive way. Some manipulations can be simulated from the sources so as to estimate their effects over sound annoyance. An interesting manipulation has consisted for instance in a simulation of an overturning of the pump (-3dBlin), which has allowed to increase the intelligibility of the overall structure by 5%, without having any influence on the dB_B level and to increase sound pleasantness.

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