ACOUSTIC CHARACTERISATION OF ELECTRIC CONNECTORS AND USE OF THE DATA IN TRACTOR CABIN SEA-MODELS

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ABSTRACT

Acoustical quality of a work machine cabin is a combination of many factors. In this paper the effect of sound insulation of electrical connectors on the sound pressure level of a work machine cabin is considered. The sound insulation of different plastic and alloy electrical connectors was measured by the sound intensity method in a reverberation chamber set-up. Four connectors of the same type were mounted in a heavy steel plate. By measuring the energy transmitted through the system the transmission coefficient of connectors was obtained. The experimental results were integrated to a SEA model of a cabin by converting the transmission coefficients into coupling loss factors. By choosing proper connectors and placing them carefully, the cabin sound pressure level can be reduced significantly according to a verified SEA-model.

1 INTRODUCTION

In the past, acoustical design of tractor cabins was based on noise level. Noise level was targeted to be below a certain obligatory level. Today cabin sound pressure level and acoustical quality are regarded to be important indicators of performance and comfort. Therefore, predictive approach and tools for good cabin acoustics are more and more integrated into the cabin design process.

As an acoustical system, a tractor cabin is a reciprocal to an acoustic enclosure. The transmission paths are equivalent to the transmission paths in acoustic enclosures:

(1) the acoustic path: sound radiated by acoustically induced vibration of the walls;
(2) the structure-borne path: sound radiated by mechanically induced vibration of the walls;
(3) the sealing path: direct airborne transmission through openings and leaks and transmission by sound radiation by vibrating sealing elements.

In some cases the sealing path is dominant. However, the prediction of the sealing path transmission or even its quantitative interpretation from cabin sound pressure measurements is difficult. The reasons are the lack of experimental data, the awkwardness of in-situ measurements and the complexity of predictions from a purely theoretical base. There is a need to incorporate laboratory measured sound insulation characteristics of sealing path elements to predictive sound transmission models. Examples of the problem are electric connectors used in cabin floors and walls.

2 HYBRID SEA-MODELLING OF TRACTOR CABINS

Statistical Energy Analysis (SEA) is widely used in the automobile industry to predict noise and vibration responses of passenger cars at mid and high frequencies [1]. SEA is also used in noise control engineering of rail vehicles and truck cabins [2, 3]. Recently, results of predictive SEA-modelling have been reported also concerning tractor cabin noise [4].

A convenient way to define an experiment based sound transmission path in a SEA-model is the user defined coupling loss factor. The required experimental data is the sound transmission coefficient τ. The measured τ should be transformed into the coupling loss factor η_{ij} defined from an acoustic space V_i to an acoustic space V_j, fig 1.

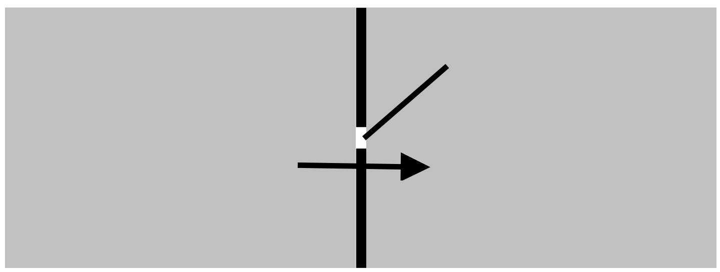

***Figure 1**. The principle of user defined coupling loss factor definition for a connector.*

The interrelation between τ and η_{ij} is [5]

$$\eta_{ij} = \frac{c_0 S \tau}{8\pi f V_i} \tag{1}$$

where c_0 is the speed of sound [m/s], S is the area [m^2] of the connector and V_i is the volume [m^3] of the source acoustic space V_i

3 EXPERIMENTAL SETUP FOR CHARACTERISING ELECTRIC CONNECTORS

A natural choice of a subsystem in a tractor cabin SEA-model is a wall system consisting typically of steel plates, glass window panes and smaller components. The sound transmission coefficient of each subsystem component is needed to characterise the coupling loss factor, which determines the transmission of energy via the subsystem.

3.1 Definitions

The sound transmission coefficient τ of a structure is defined as the ratio of energy transmitted through the structure to the incident energy on the structure. As the sound transmission loss TL is defined as $TL = -10\log_{10}(\tau)$, the sound transmission coefficient of a structure is obtained by measuring the sound transmission loss.

When the sound transmission loss of a structure consisting of different components is known, the transmission coefficient of each component is obtained as

$$\tau_{comp} = \frac{A_{tot}\tau_{tot} - \Sigma A_i \tau_i}{A_{comp}} \tag{2}$$

where τ_{comp} and A_{comp} are the transmission coefficient and the area of the component in question. $\Sigma A_i \tau_i$ represent the area-weighted transmission coefficient of the surrounding structure. A_{tot} and τ_{tot} are the measured values for the total structure.

3.2 Measurement Setup and Instrumentation

A typical electrical connector used in tractor cabin constructions is made of plastic or alloy metal, frame thickness being 1…2 mm. The connector is attached to a base plate. The diameter of a single connector is only 40…50 mm. Usually the area of the connector is small in comparison to the base plate.

A reverberant chamber setup was used to measure the sound transmission loss of a 3 mm thick steel test plate with the connectors (fig. 2). A heavy damping treatment was applied to the plate to reduce the effect of natural mode vibrations and increase the sound insulation. The size of the plate was 970mm x 970mm with a 350mm x 350mm aperture in the middle of the plate. The connectors were mounted on a 400mm x 400mm plate (3 mm thick steel) which was bolted to the aperture. This enabled easy and quick swapping of connectors. Also the sound insulation of the solid steel plate could be measured easily.

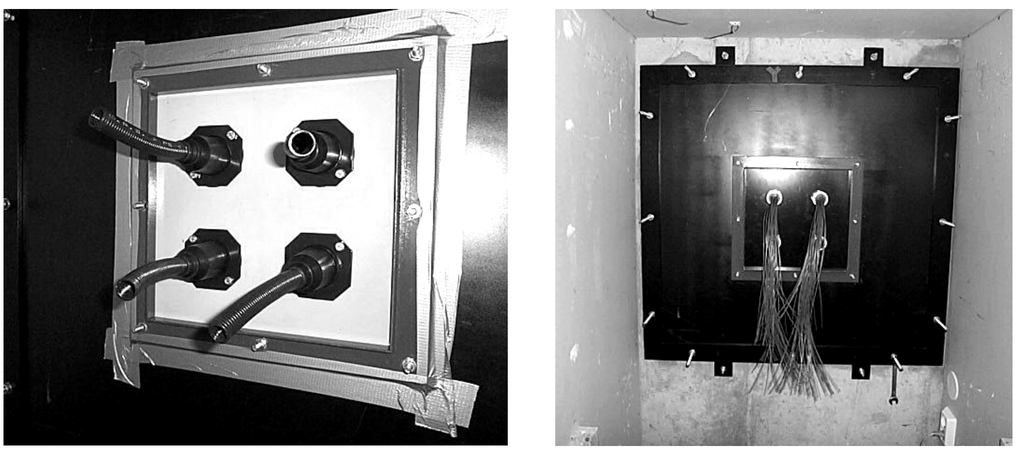

Figure 2. *The mounting of four connectors to the test assembly (left). The test assembly seen from the source room (right).*

The small reverberant chamber was used as a source room. A B&K type 1001 sound source with B&K type 4205 amplifier was used to produce the reverberant field. White noise signal was used. A B&K pressure microphone type 4134 with Larson Davis type 3200 RTA was used to detect the sound pressure in the source chamber. As the dimensions of the chamber were of the order 1m x 1 m x 2 m, the sound field was considered to be sufficiently diffuse above 300 Hz, based on eigenmode-analysis and test measurements.

The energy transmitted through the test plate was measured with a Larson Davis intensity probe type 2260 and Larson Davis 3200 RTA applying 1/12 -octaveband filtering. Semianechoic room was used as the receiving room. Based on the assumption of diffuse field in source room, the sound transmission loss of mounting plate with connectors can be determined when the intensity of the transmitted sound L_I and the sound pressure in the source room L_p are known. Sound transmission loss is obtained as [6]

$$TL = L_p - L_I - 6 \quad [dB] \tag{3}$$

From this equation the transmission coefficient of the total test plate can be deduced by using definition of transmission loss. When the transmission coefficient of the test plate assembly without connectors is known, the transmission coefficient of a single connector can be calculated.

3.3 Validity of the Measurements

From the definition of τ it follows that negative values of transmission coefficient are obtained when the value of the numerator on the right-hand side of eq. 2 is less than 0. This may be the case when measured values are used and the dynamical properties of a solid structure do not accurately represent those of the structure surrounding the component. The area-weighted transmission coefficient of connectors must be high in order to reduce the error caused by approximating the transmission coefficient of the surrounding structure with the τ of a solid structure.

In this work a choice was taken to mount four similar connectors to the measurement plate. The area of connectors was quadrupled and the limit for smallest reliably measurable transmission coefficient was decreased. Despite this negative values of τ were obtained in some frequency bands (fig.4).

The uncertainty of the measurement system was estimated by calculating the total differential. The transmission loss was regarded as a function of the measured sound pressure level in the source room (P), sample area (A) and the measured transmitted intensity (I). The standard deviations of the measurement results δP and δI were calculated. The error made in measuring the area δA was estimated. Based on these input uncertainties the standard uncertainty of the measured TL was calculated. The upper limit of measurement uncertainty obtained with this procedure is presented in figure 3.

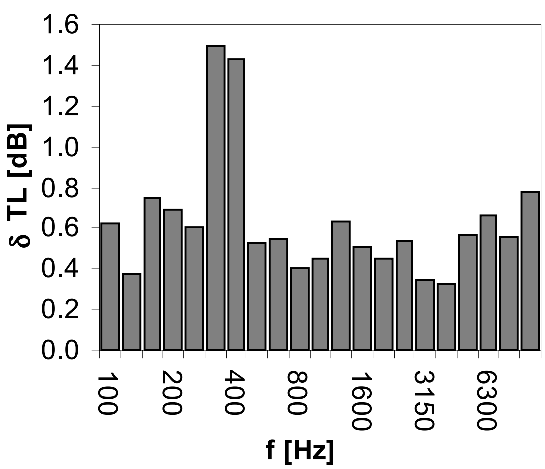

***Figure 3**. The measurement uncertainty of the system, here given as the deviation of transmission loss.*

The most significant factor affecting the measurement uncertainty is the non-diffuse character of the sound field in the source room due to small volume of the room. The geometry and vibration response of the sample plate may also affect the uncertainty. The effect of these factors can be seen as rather large deviation at frequencies 315 Hz and 400 Hz. The negative values of transmission coefficient obtained are most likely due to error made in approximating the τ of the surrounding structure by the transmission coefficient of a solid steel plate. The uncertainty of the system is well within the limits of international standards. The measured values of the transmission coefficient can be regarded as reliable enough considering the needs of modelling application.

4 MEASUREMENT RESULTS

Examples of measured sound transmission coefficients for three connectors with different degree of wiring are shown in the figure 4. At some frequencies the transmission coefficient values are quite remarkable.

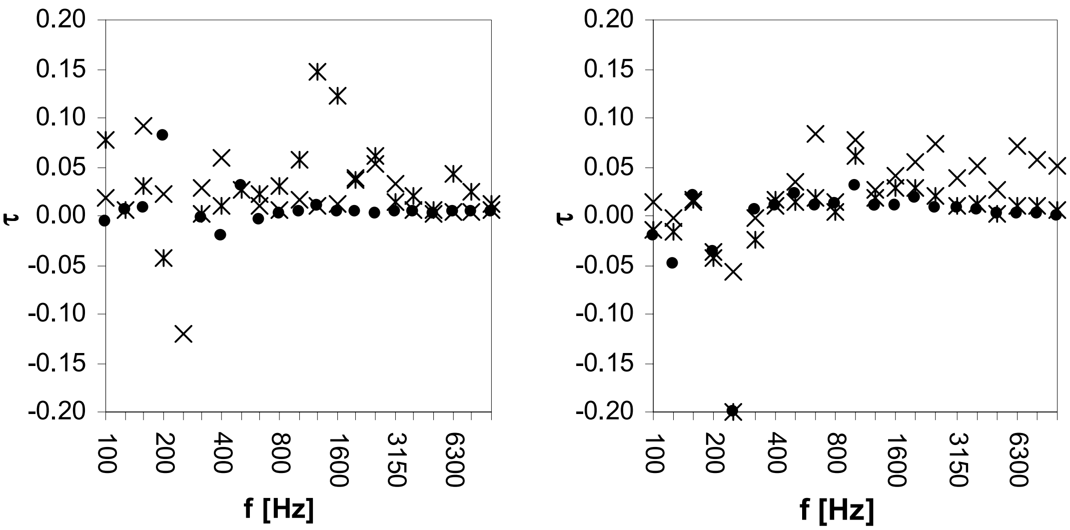

Figure 4. *LEFT: The sound transmission coefficient of three different connectors. Key: plastic connector without sealing rubber (x), alloy connector (∗), plastic connector with rubber sealing (dot). RIGHT effect of wiring on the transmission coefficient: plastic connector, no wiring (x); half of the holes wired (∗), fully wired (dot).*

5 THE APPLICATION OF MEASURED DATA IN SEA-MODELS

One of the strengths of SEA-modelling is its effectiveness in transfer path ranking. If the transmission characteristics and the external acoustic excitations are correctly defined, it is straightforward to calculate the sound power inputs into the cabin space. An example of this is shown in figure 5. In the model the acoustic space below the cabin is used as the source space V_i

The most important sound power input paths into the cabin are

(1) the resonant path due to the radiation from flexural modes of the cabin floor;
(2) the mass-law path due to the non-resonant transmission through the floor;
(3) the user defined sealing path through three electrical connectors mounted to the floor.

In this case the connector path is non-significant below 800 Hz. From 1000 to 3150 Hz it is the most important path. This is natural since electric connectors and leaks in general do not transmit effectively at low frequencies.

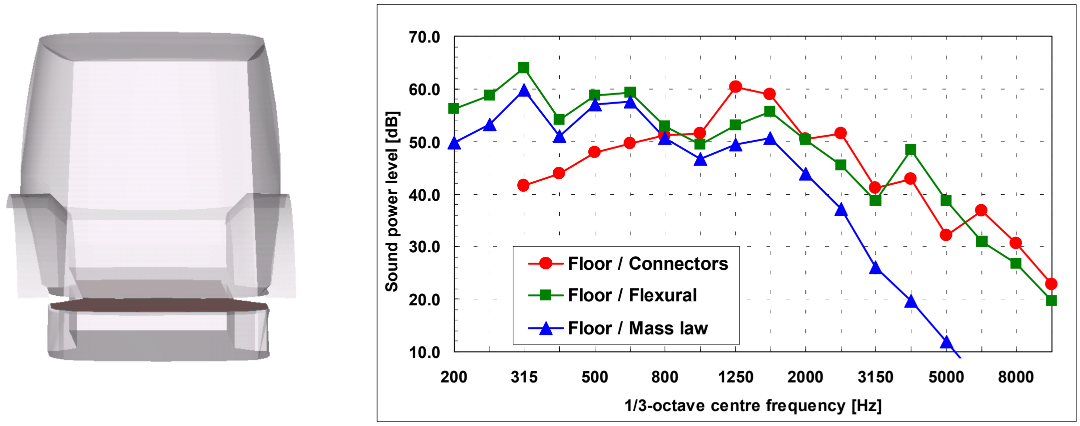

***Figure 5**. Example of a tractor cabin AutoSEA2 model and electric connector source ranking. Only three subsystems are shown.*

6 CONCLUSION

An experimental method for characterisation of electrical connectors and other locally acting components was developed. It is reliable enough for predictive modelling purposes. It enables quantitative ranking of sealing transfer paths using SEA-modelling of tractor cabins and similar structures.

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