

Further Development of the PNCA: New Panel Noise Contribution Reference-Related (PNCAR)

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ABSTRACT

The Panel Noise Contribution Analysis (PNCA) is a well-known methodology for an airborne Transfer Path Analysis (TPA) in car interior. Pressure contribution from the individual panels at a reference point can be very accurately calculated. Acoustic Trim package treatment can therefore be optimized in terms of frequency and panel area which saves money and time. The method uses only one type of sensors so called particle velocity probes for measuring source strength as well as transfer function (with a reciprocal measurement).

Traditionally the PNCA makes use of a big amount of probes at fixed points (about 50) hence non-stationary conditions can be measured as well. Typically the measurement is performed in 3 sessions resulting in 150 individual panels. Because of the low spatial resolution the method can only be used at mid-low frequency range.

The new Panel Noise Contribution Analysis Referenced (PNCAR) implements a new post-processing technique which uses a reference sensor in order to extract the relative phase information for the individual panel and frequency of interest. This technique makes it possible to use a limited amount of probes for measuring a whole car interior. Typically 11 probes are used in 11 sessions. Consequently, the methodology becomes more robust and commercially more affordable than conventional PNCA.

A real measurement in driving condition was done on the highway in order to validate the methodology. Two different approaches to apply the theory derivations are compared and discussed.

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1. INTRODUCTION

Vehicle interior noise problems in automotive industry always refer to a sound pressure at some position inside of the car.

The main goal in most of the applications is to reduce the perceived noise loudness (sound pressure) with the minor cost.

Sound source ranking enable to focus the engineering process on the main radiating panels in the car interior which saves time and money in the noise reduction process. Well established methods for sound source localization in car interior based on pressure are well described in literature [13,14,15,16,17,18]. Since the sound field of a car interior is very complex environment, pressure based techniques are not the most suitable solutions.

As it is shown in this paper the airborne TPA method provides a very quick and accurate identification of noise sources which later on allows applying an effective noise reduction treatment. The method is not limited to the automotive industry; source ranking into vibrating enclosure

is a common problem for most of moving vehicles such as airplanes, helicopters or trains.

Other advantage of the velocity based method proposed is also the possibility to use the output data from the surface velocity measurements and the acoustic transfer functions for validating FEM and BEM simulation models (model updating technique).

First of all, the theoretical base of the proposed technique is derived. Then the methodology of the measurements is described. Finally, results are presented along with a validation of the technique introduced.

2. THEORY

In order to assess the underlying theory behind panel contribution analysis into a car interior, a general approach can be taken. Let start defining a cavity **S** which surface excites the sound field when it is under operating conditions. Then, an infinitesimal small area **M** can be defined inside **S** for studying how different areas of the cavity 'contribute' to a

point at **M**. Figure 1 shows a sketch of the scenario described above.

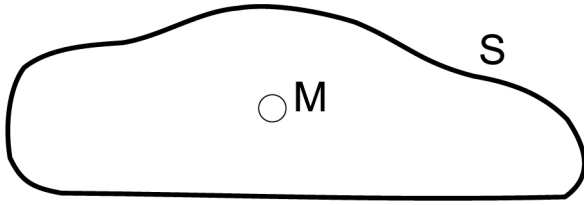


Figure 1. Schematic overview of the surfaces involved in the derivation

The theoretical derivations of an expression for calculating the pressure contribution at **M** follow Hald [7,11] and Kinsler [16]. First of all, it is necessary to define two different measurement conditions: when a monopole source at **M** is exciting the sound field (reciprocal transfer function measurements); and when the monopole is switched off and the cavity **S** is producing the noise (noise measurements).

Two set of variable can be distinguished depending on the measurement conditions. p^{TF} and u^{TF} are defined as the pressure and particle velocity during the reciprocal transfer function measurements. On the other hand, p and u are the pressure and particle velocity during the noise measurements.

As have been pointed out by Hald, for deriving an expression which describes the fundamental relation of panel noise contribution analysis it is necessary to start using the definition of acoustic reciprocity [16],

$$\int_{\mathbf{M}} (p^{TF}u - p u^{TF})d\mathbf{M} + \int_{\mathbf{S}} (p^{TF}u - p u^{TF})d\mathbf{S} = 0 \quad (1)$$

The integral of particle velocity u across the entire surface **M** will be zero due to there is no net energy going throughout **M** during the noise measurements. Furthermore, the pressure p can be integrated over **M** during the noise measurements obtaining the reference pressure p_r . Besides, integrating the particle velocity **M** over during the transfer function measurement will lead to obtain the volume velocity of the monopole source Q . This leads to

$$-p_r Q + \int_{\mathbf{S}} (p^{TF}u - p u^{TF})d\mathbf{S} = 0 \quad (2)$$

Consequently, the pressure at the reference position can be defined as

$$p_r = \int_{\mathbf{S}} \left(\frac{p^{TF}}{Q}u - p \frac{u^{TF}}{Q} \right) d\mathbf{S} \quad (3)$$

Equation 3 presents the base equation of many velocity-based panel noise contribution methods. It relates the

pressure at the reference position p_r with the combination of particle velocity and pressure along with acoustic transfer functions p^{TF}/Q and u^{TF}/Q measured across the whole cavity **S**.

So far, arbitrary signals have been considered on the derivation but for real scenarios it would be necessary to deal with random signals [17]. Moreover, Equation 3 cannot be used directly because the source velocities are recorded along multiple sessions such that the global phase differences between source velocities are unknown. To solve these problems, Equation 3 is rewritten firstly multiplying by the complex conjugate version of the pressure reference p_r^* and then taking the expected values $E(\dots)$ of the different terms,

$$E(p_r p_r^*) = \frac{1}{A_m} \int_{\mathbf{S}} E \left(\frac{p^{TF}}{u_m} \right) E(u p_r^*) - E \left(\frac{u^{TF}}{u_m} \right) E(p p_r^*) \quad (4)$$

where u_m is the particle velocity at **M** during the transfer path measurements; and A_m is the area of **M**.

Next, Equation 4 can be expressed by a combination of auto spectras and cross-spectras, i.e.

$$S_{p_r p_r} = \frac{1}{A_m} \int_{\mathbf{S}} \frac{S_{p^{TF}u_m}}{S_{u_m u_m}} S_{u p_r} - \frac{S_{u^{TF}u_m}}{S_{u_m u_m}} S_{p p_r} d\mathbf{S} \quad (5)$$

where $S_{p_r p_r}$ is the autospectrum of the pressure reference; $S_{p^{TF}u_m}$ is the cross spectrum between the pressure at **S** and velocity at **M** both during the transfer function measurements; $S_{u_m u_m}$ is the autospectrum of u_m ; $S_{u^{TF}u_m}$ is the cross spectrum between the velocity at **S** and velocity at **M** both during the transfer function measurements; $S_{u p_r}$ is the cross-spectrum between velocity at **S** and the reference pressure; and $S_{p p_r}$ is the cross spectrum between the pressure at **S** and pressure at **M** both when the cavity is exciting the sound field.

In practical cases, the surface **S** has to be discretized by dividing it into a limited number of panels N . Consequently, Equation 5 leads to

$$S_{p_r p_r} = \frac{1}{A_m} \sum_{n=1}^N \left(\frac{S_{p^{TF}u_m}}{S_{u_m u_m}} S_{(u p_r, n)} - \frac{S_{u^{TF}u_m}}{S_{u_m u_m}} S_{(p p_r, n)} \right) A_n \quad (6)$$

where A_n defines the area of each panel n .

The interior surface of the car could be assumed acoustically rigid such that the normal velocity of **S** is nearly zero during the transfer path measurement. Based on this assumption the right term of Equation (6) could be neglected. Further investigation of the effects of this assumption is given in the following sections.