24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

A BLOCKED PRESSURE BASED TRANSFER PATH ANALYSIS (TPA) METHOD TO MEASURE THE SOUND INSULATION PATH CONTRIBUTIONS OF A PARTITION SUBJECTED TO AN INCIDENT AIRBORNE FIELD

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The airborne sound transmission through a building element such as a partition/panel is governed by the sound insulation of the partition, or the resistance the partition provides to the incident sound. Typically the airborne sound insulation of the wall is rated by a single number quantity given as the Sound Reduction Index (SRI) or the Sound Transmission Class (STC). However these ratings do not provide any information on the sound transmission through different paths in the partition. Such information may be useful in diagnosing weak sound insulation paths, weight optimisation, etc. The Airborne TPA method based on blocked force formulation has proven to be an effective technique to diagnose the sound transfer through individual paths. The paths can then be rated according to their sound pressure contributions. The Airborne TPA method however, can be time consuming in case of limited number of sensors and/or large size of partitions. Hence there is a need to provide a faster measurement method which would provide the diagnostic information about the sound insulation paths. In this paper, a simplified Airborne TPA approach based on measurement of blocked pressures is presented. The blocked pressure theory for the airborne sound transfer through partitions is discussed at first. Validation and diagnostic results are then presented for sound transfer through point connected dual leaf partition using the new approach. The blocked pressure method is significantly faster and can be automated. The accuracy of the measurement is dependent on the wavelength of the incident wave.
Keywords: blocked pressure, sound insulation, transfer path analysis

1. Introduction

In buildings, the airborne sound transfer from one room to other is insulated primarily by installing partitions between the two rooms. The acoustic performance of such partition structures is described by its sound insulation and is quantified by a single number rating [1] as the Sound Reduction Index (SRI) or Sound Transmission Class (STC). However little is known about the nature or performance of sound transfer paths in the partition that contribute to the total pressure in a receiving cavity. Similar problems are encountered by the vehicle acoustics industry concerning with the diagnosis of vibroacoustic performance of the vehicle. In that case, the vehicle structure is dynamically sub-structured into a source receiver system and the sources are characterised experimentally. Using TPA the source contributions are then defined. Similarly, for building acoustics, the cavity partition system can be sub-structured. The airborne source may be diagnosed using a similar experimental technique and the sound transfer through the partition can be predicted. Likewise, the sound transfer through these paths can be diagnosed and ranked according to their sound insulation performance. This forms the basis of our current work. The Airborne TPA method will be outlined in the following sections for diagnosis of sound transfer through partitions followed by its application on a dual leaf point connected partition.

1.1 Airborne Transfer Path Analysis

A TPA method is applied to a dynamic system to find the path or source contributions to a receiver structure. Thus in applying TPA method, the system is first sub-structured into a source-path-receiver model. For a room-partition-room system, the substructuring is depicted in Fig. 1 with an airborne source. Then the main aim of the Airborne TPA test is to diagnose the sound pressure contributions of different partition paths (1-n) to a receiver point.

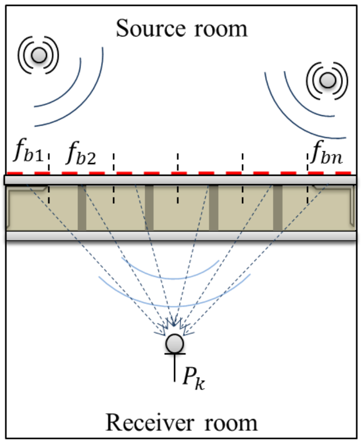

Figure 1: Schematic of the partition installed between two rooms, source room represents the source, receiver room plus partition is the receiver and the red line denotes the source receiver interface

2. Blocked force based Airborne TPA

Alike other TPA methods [2, 3], the important step of the measurement is to characterise the source. Keeping that in mind, reasonable assumptions can be made: first, that an incident airborne wavefield can be decomposed into discrete blocked forces over the plate and secondly, that the sound transfer is dominant through the partition with minimal flanking.

2.1 Methodology

The methodology for measurement of blocked forces has been outlined in our previous work. In short, the blocked forces can be written as,

$$\mathbf{f_{bl}} = [\mathbf{A}]^{-1}\mathbf{a}' \tag{1}$$

'f_{bl}' represent the blocked forces over the plate and a' the operational accelerations. 'A' represents the accelerance matrix consisting of FRF measurements on each path. The blocked forces map the sound field on the plate by using vibration responses instead of pressure responses by measuring structural FRF's unlike acoustic FRF's [3]. These forces also represent the averaged pressure distribution over the path area. The pressure inside the receiver room can thus be predicted as

$$\mathbf{p_p} = [\mathbf{H_{kj}}]\mathbf{f_{bl}} \tag{2}$$

'p_p' is the pressure predicted at microphone positions inside the cavity. These predicted pressures are then compared with the operational pressures at same positions to check the validity of the applied TPA method. This is called as the Pressure Validation test and results have been previously reported for predicting airborne sound transfer through a cavity backed single leaf panel and structure borne sound transmission through a dual leaf partition [5]. The pressure contributions 'p_c' of a path 'n' can then be calculated as

$$p_{c_n} = H_n f_{bl_n} \tag{3}$$

2.2 Application of Airborne TPA to a point connected partition

Fig. 2 shows the point connected partition with mineral wool infill. The point connection represents a sound bridge for sound transmission between the top plate and bottom plate. As such, the point connection could be expected to provide higher sound transmission at mid/high frequencies which is also reported [6]. The dual leaf partition was installed in the reverberation chambers at University of Salford between a source and receiving room. The final construction is shown below in Fig. 6.

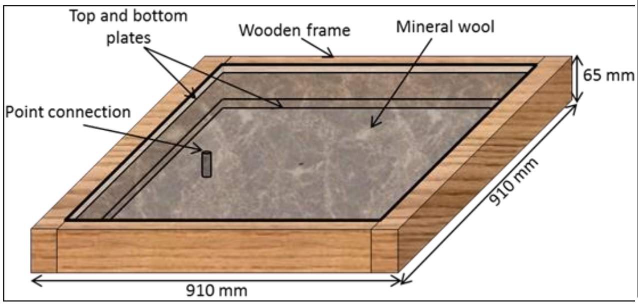

Figure 2: The dual leaf partition (grey) installed in a plasterboard structure with the filler wall (blue). The brick wall is the separating wall between the source room and receiving room

According to Airborne TPA, the FRF's and operational responses were measured for each path. A loudspeaker driven by pink noise in the source room was used to simulate an airborne excitation. Using Eq. (2-6) the pressure in the receiver volume was predicted and compared with the measured pressure at that point. This pressure validation is shown in Fig. 7.

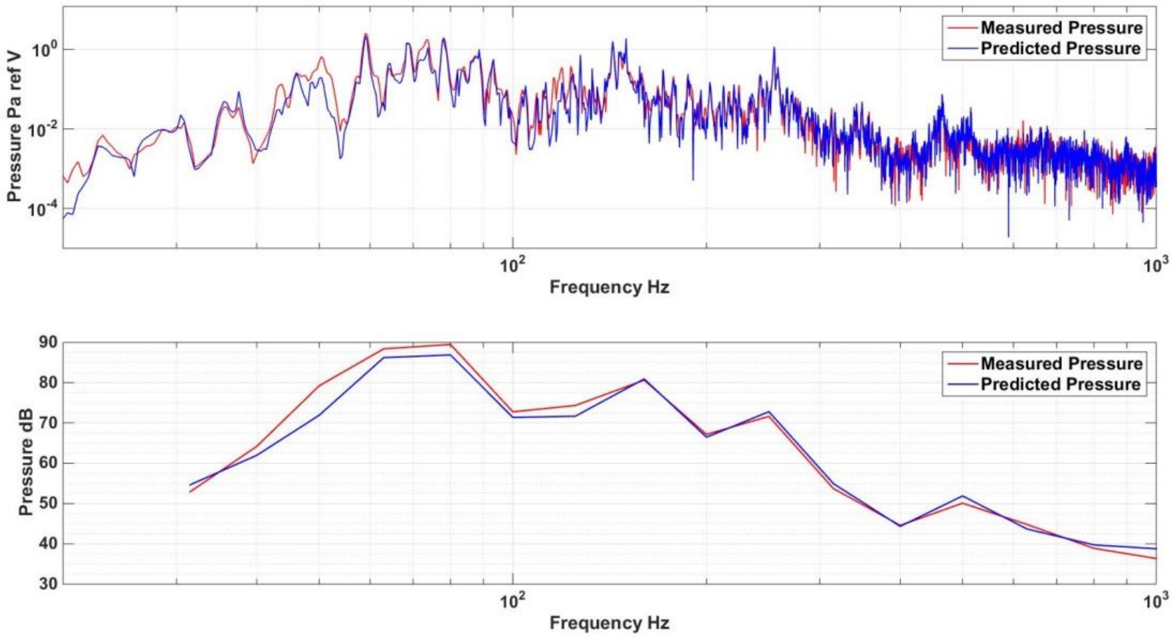

Figure 3: Pressure validation results for point connected partition with airborne excitation, top plot represents narrow band comparison, and bottom plot represents comparison in one-third octaves.

In Fig. 7, it can be seen that the predicted pressure matches well with the measured pressure up to 900 Hz and thus the method is validated. After 900 Hz, the discretisation assumption fails and more blocked pressures (paths) are needed to predict the high frequency response. After the pressure validation, the sound pressure contributions of individual paths were calculated as per Eq. (3). These sound pressure contributions are a diagnostic measure of the relative sound insulation of each path and can be used to rank each path. Fig. 8 shows the path contributions of all paths (minus the point connection path) compared with the total pressure. The point connection did not affect the pressure contribution below 600 Hz and results above 600 Hz are hence presented. Interestingly, in the 600-900 Hz region, it can be seen that the point connection has a minimal effect (~0.5 dB) on the sound transfer. The point connection might make a significant difference to the sound transfer at high frequencies which could in principle be measured by a finer measurement grid on the partition.

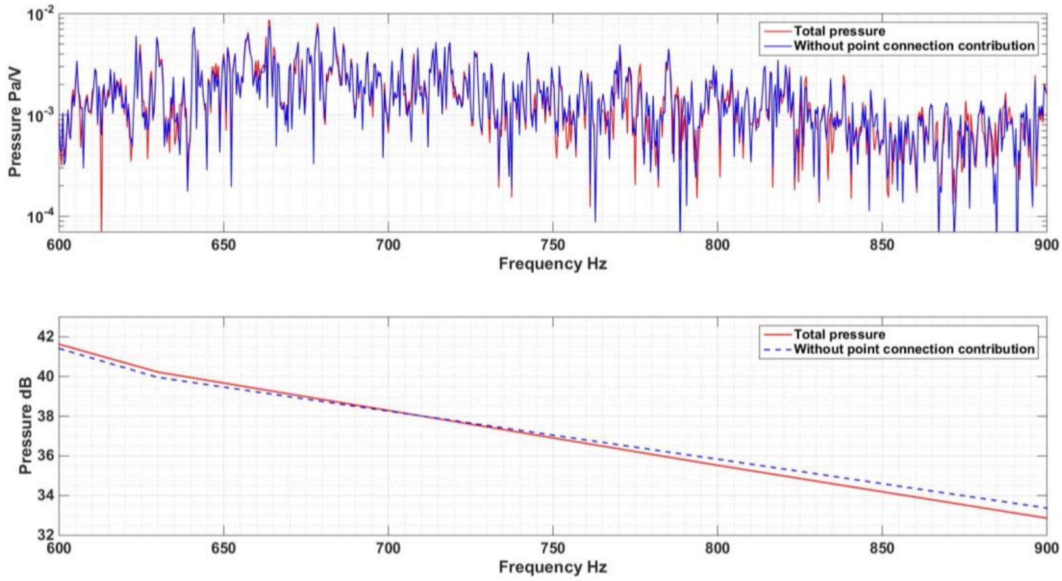

Figure 4: Total pressure contribution of the partition compared with the total pressure contribution without the point connection contribution, top plot represents narrow band comparison, and bottom plot represents comparison in one-third octaves

3. Blocked pressure based Airborne TPA

Due to the nature of airborne excitation which is continuous over the partition surface, a number of measurement positions are required all over the partition surface which makes the measurement of blocked forces quite tedious. In our previous work [7], the direct measurement of blocked forces was discussed for an unbaffled plate excited by an airborne source. The blocked pressure (blocked force/path area) at the interface was expressed as the difference of pressures around the path. The following section describes the theory for direct measurement of blocked pressure on a baffled panel.

3.1 Blocked pressure measurement

Consider a partition (Fig. 1) with surface area S subjected to an airborne excitation. By applying the airborne TPA method, the source can be substituted by ‘n’ blocked forces over ‘n’ sound transfer paths of equal area ‘dS’. The blocked forces are written as

$$\mathbf{f_{bl}} = [\mathbf{A}]^{-\mathbf{1}}\mathbf{a}' \quad (4)$$

The same blocked forces can also be written as,

$$\{\mathbf{f_{bl}}\} = [\mathbf{Y}]^{-\mathbf{1}}.\{\mathbf{v}'\} \quad (5)$$

$$\{\mathbf{f_{bl}}\} = [\mathbf{Z_c}].\{\mathbf{v}'\} \quad (6)$$

Z_c represents the impedance of the coupled source receiver system and input-output relationship characteristic of the system. As the source (air) is not disconnected from the partition during the mobility (or accelerance) measurements, the impedance matrix obtained is a combined impedance of the plate and the air together. Hence the impedance can be broken down into individual impedances of the source (air) and the receiver, a partition in this case as,

$$\mathbf{Z_c} = \mathbf{Z_{partition}} + \mathbf{Z_{air}}$$

Eq. (6) can now be written as,

$$\{\mathbf{f_{bl}}\} = \left[[\mathbf{Z_p}] + [\mathbf{Z_{air}}]\right].\{\mathbf{v}'\}$$
$$\{\mathbf{f_{bl}}\} = [\mathbf{Z_p}].\{\mathbf{v}'\} + [\mathbf{Z_{air}}].\{\mathbf{v}'\} \quad (7)$$

$\mathbf{Z_p}$ represents the in vacuo plate impedance which could in principle be measured if the source (air) is disconnected from the receiver (partition). Similar exercise is adopted in classical TPA techniques where a structural source can be disconnected from the receiver for the mobility measurements, which on inversion gives the receiver impedance. This receiver impedance combined with the operational responses on the source receiver interface provides the contact forces applied by the active source on contact with the receiver. Similarly, the first term in Eq. (7) corresponds to a case of classical TPA approach where the in-vacuo partition impedance is combined with the operational responses on the partition. Hence it should represent the contact forces f_c of the airborne excitation on the partition.

$$\therefore \{\mathbf{f_c}\} = [\mathbf{Z_p}].\{\mathbf{v}'\}$$

Hence Eq. (7) can be written as,

$$\{\mathbf{f_{bl}}\} = \{\mathbf{f_c}\} + [\mathbf{Z_{air}}].\{\mathbf{v}'\} \quad (8)$$

Now, for air or fluids, an acoustic impedance is usually defined which is the ratio of pressure at a point in the acoustic volume to the volume velocity of a source exciting the volume (Pa.s/m^3). Acoustic impedance is easy to measure however it is not consistent with the units of mechanical impedance and cannot be used for Z_{air}. Thus Z_{air} cannot be measured, however with careful assumptions Z_{air} can be neglected due to two reasons-first, the mass loading of air on the partition can be neglected as the plate is massive compared to air and secondly, air is not rigidly coupled to the partition unlike a structure borne source, and can move out laterally during FRF measurements. By neglecting Z_{air}, we can neglect the second term of Eq. (8) which gives us blocked forces approximately equal to the contact forces.

$$\mathbf{f_{bl}} \approx \mathbf{f_c}$$

Dividing both sides with the path area 'dS' we get,

$$\mathbf{p_{bl}} \approx \mathbf{p_c}$$

Hence in the case of airborne excitations, the contact pressures are approximately equal to the blocked pressures. These contact pressures can be measured directly by a mic against each path on the source side, and be substituted for blocked forces, potentially saving time in extensive FRF measurements and ensuing inversion process.

3.2 Methodology

To check if the source side contact pressures on a baffled partition represent the blocked pressures, a pressure validation can be performed on the partition using the source side pressures as the blocked pressure. Eq. (2) used to predict a pressure in the receiver cavity using blocked forces can then be formulated using blocked pressures as,

$$\mathbf{p_p} = [\mathbf{H_{kj}}]\, \mathbf{p_b}.\boldsymbol{dS}$$
$$f_{bl} = p_b.dS \qquad (9)$$

In Eq. (9), the blocked force vector f_{bl} is written as a product of the blocked pressure vector p_b and the path area dS. Now consider a dual leaf/layer partition as shown in Fig. 5 consisting of two panels separated by an air cavity.

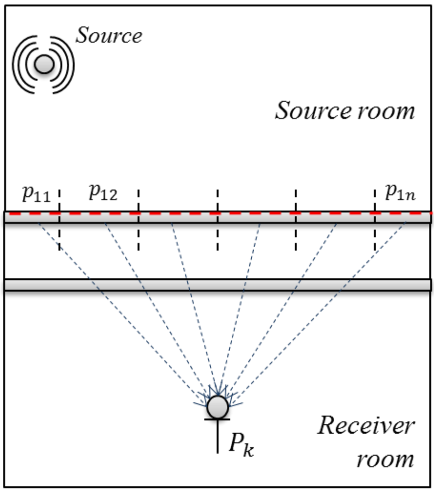

Figure 5: Pressure at a point 'k' in the receiver volume shown as a resultant of sound contributions from top panel paths of the partition 'S'. Dashed red line denotes the source-receiver interface. Source describes an airborne source exciting the partition from source side

When the airborne source in the source room is active, the pressure field on the top panel can be written in discrete form as,

$$\{p_1\} = \{p_{11}, p_{12}, \dots, p_{1n}\}_{nx1} \qquad (10)$$

p_{1n} represents the pressure acting on a path 'n' of the top panel from the source side. As the source side is physically accessible, pressure measurements can be performed when the airborne source is active. As these pressures represent the source, they should represent the blocked pressure as discussed earlier. To see if these pressures represent the blocked pressures we can predict a pressure at a point 'k' in the receiver room and perform a pressure validation. Using Eq. (8), we can write

$$\mathbf{P_k} = \{\mathbf{H_{k,A}}\}_{\mathbf{1xn}}.\{\mathbf{p_1}\}_{\mathbf{nx1}}.\boldsymbol{dS} \qquad (11)$$

$\{\mathbf{H_{k,A}}\}$ represents the vector consisting of vibroacoustic transfer functions for 'n' paths to point 'k' in the receiver room

3.3 Application on a dual leaf partition

The dual leaf partition shown in Fig. 2 was used to test this methodology. The partition was installed as shown in Fig. 2 with one panel facing the source room and other panel facing the receiver room. For the FRF test when the source is inactive, only vibroacoustic transfer functions were measured from the panel facing the source room to a point in the receiver room. Next using a loudspeaker driven by a pink noise excitation the source side pressures acting on the source side panel were measured. The pressure was also measured at the point in the receiver volume for comparison with the predicted pressure as required for pressure validation. All pressure measurements were referenced to the driving voltage of the loudspeaker to obtain synchronous measurements. Once the vibroacoustic transfer functions and source side pressures were measured, the pressure at the receiver point was predicted using Eq. (9). The predicted pressure was compared with the measured pressure at the same point and the results are shown in Fig. 6.

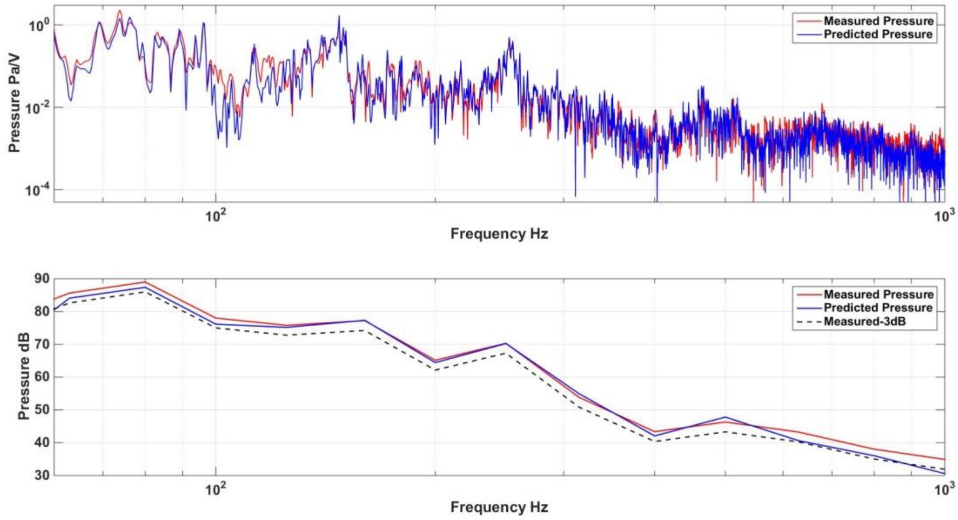

Figure 6: Pressure validation using source side pressures and vibroacoustic transfer functions to predict the receiver side pressure (in blue) compared to the measured pressure (in red). Top plot represents narrow band comparison, and bottom plot represents comparison in one-third octaves

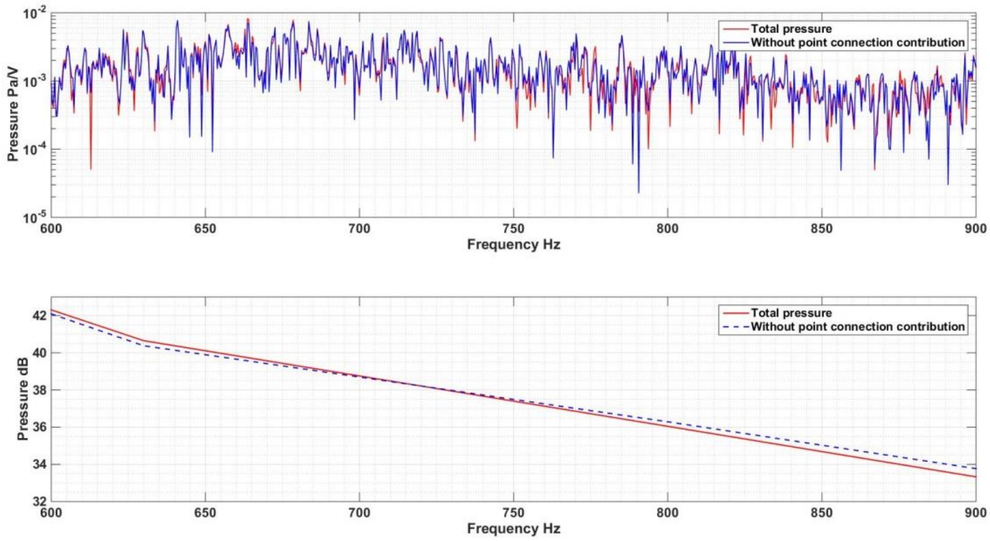

Figure 8 – Total pressure contribution of the partition compared with the total pressure contribution without the point connection contribution, top plot represents narrow band comparison, and bottom plot represents comparison in one-third octaves

From Fig. 6, it is evident that the pressure validation using source side pressures is successful, and accordingly the source side pressures should represent then the blocked pressures. Above 1000 Hz, the predicted pressure deviates further from the measured pressure due to insufficient sampling at higher frequencies (small wavelengths) and it is expected that a finer grid size would allow prediction of the pressure contribution. As the method is validated, the individual path contributions can then also be found using Eq. (3) but using blocked pressures (or source pressures) instead of the blocked forces. This is shown in fig. 8 which shows a similar picture of the point connection contribution to that observed in fig. 4. Overall this method highlights the potential of Airborne TPA utilising blocked pressures for diagnosing the in-situ sound transmission paths in a multi-layered partition. It should also be noted that unlike blocked force Airborne TPA described in section 2, no accelerance measurements are performed and hence the method is significantly faster.

4. Conclusions

A novel application of TPA-the Airborne TPA has been developed and tested for diagnosis of airborne sound transfer through building partitions. Two variants of the method were discussed-using blocked force and blocked pressures to characterize the source. With blocked force TPA, the incident airborne wavefield (source) can be mapped onto the partition (receiver) using blocked forces, which are then used for predicting the sound transfer through the partition inside a cavity. The method was validated for airborne sound transfer through a point connected dual leaf partition. The method requires an inversion process and is tedious. For airborne sound transmission through dual leaf partition, the point connection did not make any significant contribution to the total sound transfer till 900 Hz. A finer grid can be used to investigate the diagnostics at high frequencies however the method can become tedious with many measurement points as is required for high frequencies. The blocked pressure TPA method is a direct method and much faster than Blocked force measurement. This method does not require any accelerance measurements and is thus faster than conventional the blocked force TPA method. With the blocked pressure method, only vibroacoustic transfer functions need to be measured in the FRF measurement test. If a volume velocity source and scanning laser vibrometer is available the vibroacoustic transfer function can be measured reciprocally by the principle of vibroacoustic reciprocity. This would make the measurements much faster, automated and non-invasive to the test structure.

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