INTERFACE FORCES IDENTIFICATION USING COMPONENT TPA IN-SITU METHOD FOR TRANSFER PATH ANALYSIS (TPA)

Hamdi Ben Amar*[1], Raef Cherif†[1], and Yacine Yaddaden ‡[1]
[1]Université du Québec a Rimouski.

1 Introduction

The marine transport industry uses a lot of subsystems such as engines, that produce tonal vibrations which propagate through different paths into the receiving structure. TPA methods are mainly used to solve NVH problems using substructuring applications. The most challenging part of a TPA analysis is estimating the equivalent forces at the contact points between the active and the passive side which require numerical inversion of some matrices. Matrix inversion could pose problems due to the ill-conditioning leading to inaccurate results. In this paper, a TPA model is established for an academic system consisting of two plates linked by four springs. Several parameters are studied and discussed to improve the equivalent forces identification, such as the singular value rejection, and the number and position of indicator points.

2 Theoretical background

2.1 Component TPA In-situ Method

Component TPA In-situ Method allows performing operational tests on the assembled product AB to obtain equivalent forces between the active (A) and the passive (B) side, avoiding dismounting of any part [1].

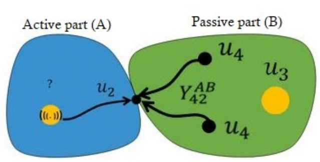

Figure 1: In-situ method.

The Component TPA In-situ Method defines the response of the target points u_3 (node 3) by multiplying the equivalent forces f_2^{eq} on the surface (node 2) to the transfer mobility matrix Y_{32}^{AB}, as given by the following expression [1]:

$$u_3 = Y_{32}^{AB} f_2^{eq} \quad (1)$$

The calculation of f_2^{eq} involves operational data of indicator points (node 4) measured at a series of locations close to the contact points between the active and the passive side. The equivalent forces are given by the following expression [1]:

$$f_2^{eq} = [Y_{42}^{AB}]^{+} u_4 \quad (2)$$

where $[Y_{42}^{AB}]^{+}$ and u_4 are respectively the pseudo-inverse of the transfer mobility function.

2.2 Matrix conditioning

Component TPA In-situ Method requires inverting the transfer mobility matrices Y_{42}^{AB} which could lead to erroneous results if they were ill-conditioned. The condition number reflects how well-conditioned a matrix is. It is a property of the matrix and its expression is given by [2]:

$$Cond_2(A) = \frac{max(Singularvalue(A))}{min(Singularvalue(A))} \quad (3)$$

where the subscript 2 indicates the 2-norm. A lower condition number indicates a better conditioned matrix. In case of ill-conditioned matrices, singular value rejection is applied.

2.3 Singular value decomposition

SVD of a matrix A with dimensions m*n is the factorisation in the following form [3]:

$$A = USV^T \quad (4)$$

With U an m*m unitary matrix, S an m*n diagonal matrix with non negative real numbers and V^T the transpose of an n*n unitary matrix [3] . The diagonal elements of $S(S_{ii}, 1 \leq i \leq min(m,n))$ are the singular values of A. The inverse of the matrix A is given by [2]:

$$A^* = VS^*U^T \quad (5)$$

With S* is an n*m diagonal matrix and its diagonal elements are given by:

$$S_{ii}^* = \begin{cases} \frac{1}{S_{ii}} & \text{if } S_{ii} > 0 \\ 0 & \text{else.} \end{cases}$$

3 Numerical study

In this section, the Component TPA In-situ method was applied to an academic system (figure 2). It consists of two aluminum plates linked by four springs. The upper plate (free boundary conditions) represents the active part and the lower plate with clamped edges represents the passive part. The upper plate was chosen to be stiffer than its lower counterpart to imitate the dynamic behavior of a Ship's engine.Their properties are given in Table 1. A point load was applied to the upper panel along the Z axis.The numerical model was developed with Simcenter 3D-Siemens software, and the simulations have been performed using Modal Frequency Response solution, with a frequency step of 2 Hz over a frequency range

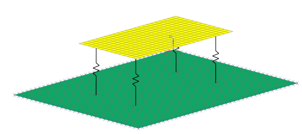

Figure 2: The academic system

---

*benh0063@uqar.ca
†Raef_Cherif@uqar.ca
‡Yacine_Yaddaden@uqar.ca

from 0 to 3000 Hz.

Table 1: Physical Proprieties.

	Young Modulus (GPa)	Model Density (kg/m3)	Poisson's Ratio	DLF(%)	Length (m)	Width(m)	Thickness (m)	Mass (Kg)
Upper plate	73.1	2730	0.33	2	0.25	0.1	0.04	2.73
Lower plate	73.1	2700	0.33	2	0.5	0.3	0.01	4.05
Isolators	3D Spring ; Stiffness : Kx = Ky = Kz = 5E7 N/m STIFFNESS IS APPLIED ONLY ON X, Y , Z AXIS							0

The singular value rejection approach was applied to the ill-conditioned matrices that have high condition numbers' values. It is advised to neglect the lower singular values during the process of inversion by defining a threshold for the condition number and reject the lower singular values accordingly [3]. It is suggested that regularization is necessary for condition numbers value higher than 1000, regularization is recommended for condition numbers between 100 and 1000, and no regularization is needed for condition numbers lower than 100 [4]. With consideration of these criteria, S^* is therefore defined as:

$$S^*_{ii} = \begin{cases} \frac{1}{S_{ii}} & \text{if } S_{ii} > \frac{S_{11}}{100} \\ 0 & \text{else.} \end{cases}$$

4 Results and discussion

In this section, numerical results concerning the application of the Component TPA In-situ Method to the academic systems are presented. First, a comparison between two matrix inversion approaches: direct inversion and singular value rejection were applied. These two approaches are compared with the reference test which is a direct result of the finite element analysis.The figure 3 represents the velocities of a target point along the X, Y, and Z axes.

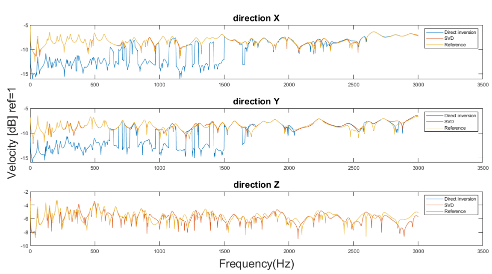

Figure 3: Comparison between SVD method and direct inversion.

The results show that the SVD method and direct inversion method are almost identical, especially along the Z direction which is dominant since the excitation is along the Z axis. This is due to the fact that the error in numerical simulations is limited. However, along the X and Y axes, the error is much higher since these directions are non-dominant. SVD is more accurate, especially for frequencies lower than 1500 Hz. Figure 4 presents the condition number of each matrix. Matrices of frequencies higher than 1500 have a condition number lower than 350. A Singular value rejection process is necessary for these matrices. The influence of the number and position of the used indicator points in the inversion matrix is discussed in what follows. For each path, 8 indicator points were selected, 4 in the neighborhood of

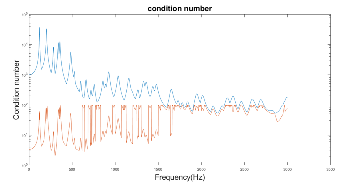

Figure 4: Condition number.

each path (orange color) and 4 farther away (yellow color), as shown in figure 5.

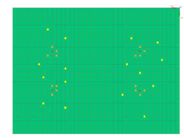

Figure 5: Indicator points

The average error with the reference test was established.

Table 2: Average error.

	neighborhood points	far points
1 per path	2.31e-3	2.40e-3
2 per path	1.80e-3	1.26e-3
3 per path	1.34e-3	9.47e-4
4 per path	1.26e-3	9.37e-4

As table 2 mentions, the more indicator points defined the less the average error gets. For practical cases, it is advised to use more than two indicator points per path. Two is sufficient in case of tight budgets and difficulties in mounting the measurement devices. In the case of using one indicator point per path, it is advised to define the points in the neighborhood of each path, and for the other cases, it is advised to define the points on the entirety of the contact surface.

5 Conclusions

This article investigated the accuracy of the Component TPA In-situ Method to predict the behaviour of an academic system. Various parameters were discussed to enhance the process of equivalent forces identification. The results show that it is advised to apply the singular value rejection process and to apply at least two indicators per path on the entirety of the contact surface.

References

[1] Maarten V van der Seijs, Dennis de Klerk, and Daniel J Rixen. General framework for transfer path analysis: History, theory and classification of techniques. *Mechanical Systems and Signal Processing*, 68:217–244, 2016.

[2] Wei Cheng, Yapeng Chu, Xuefeng Chen, Guanghui Zhou, Diane Blamaud, and Jingbai Lu. Operational transfer path analysis with crosstalk cancellation using independent component analysis. *Journal of Sound and Vibration*, 473:115224, 2020.

[3] Wei Cheng, Diane Blamaud, Yapeng Chu, Lei Meng, Jingbai Lu, and Wajid Ali Basit. Transfer path analysis and contribution evaluation using svd-and pca-based operational transfer path analysis. *Shock and Vibration*, 2020, 2020.

[4] Nicolas Bert Roozen, Quentin Leclere, and Céline Sandier. Operational transfer path analysis applied to a small gearbox test set-up. In *Acoustics 2012*, 2012.