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Structure-Borne Sound Isolation of Acoustic Test Chambers: In-Situ Validation

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ABSTRACT

Acoustic test chambers are used as controlled environment for measuring sound power level of diverse equipment ranging from household equipment over automobile components to whole automobiles, etc. They are also used as standard environment for diverse acoustic and vibration experiments. The background noise level inside an acoustic test chamber is a crucial factor during the sound power measurement of silent specimen or during a test on sensitive equipment. To achieve a negligible background noise level, it is inevitable to structurally isolate the acoustic test chamber from the surrounding structure. The isolation from structure-borne sound is performed using vibration isolator systems. These systems minimize the ingress of structure-borne sound in the floor and walls of an acoustic test chamber and thereby minimize the radiated airborne sound in the chamber. The elastic isolation is designed such that the natural frequency of the spring-mass system is well below the cut-off frequency of the respective acoustic test chamber.

To validate the elastic isolation of acoustic test chambers, the natural frequency of these chambers is experimentally measured on multiple installations. Performing an experimental modal analysis, the natural frequencies and mode shapes of different modes of the test chambers are extracted. It is validated that the measured natural frequency practically coincides with designed fundamental frequency. The experimental results from several acoustic test chambers are presented in this work.

Keywords: Structure-borne-sound Isolation, Elastic Isolation, Anechoic Chamber

1. INTRODUCTION

Acoustic test chambers are used as controlled environment for measuring sound power level of diverse equipment ranging from household equipment over automobile components to whole automobiles, etc. They are also used as standard environment for diverse acoustic and vibration experiments. Acoustic test chambers are broadly classified as Anechoic Chambers and Reverberation chamber. The background noise level inside an acoustic test chamber is crucial factor during the sound power measurement of silent specimen or during a test on sensitive equipment.

To achieve the negligible background noise levels, the acoustic chambers are built with high transmission loss elements. The background noise level cannot be reduced below a certain limit by further increasing the airborne transmission loss of walls and ceiling. The direct airborne transmission reaches its limit and secondary sound transmission paths dominate the sound pressure level inside the chamber. The secondary path includes the ingress of structure-borne sound in the structure and radiation of airborne sound inside chamber. To minimize the background noise level further, it is inevitable to structurally isolate the acoustic test chamber from the surrounding structure.

The isolation from structure-borne sound is performed using vibration isolation products e.g. G+H MAFUND Rubber Sheets, VIBREX Spring Strips and metallic spring isolators. These systems minimize the ingress of structure-borne sound in the floor and walls of an acoustic test chamber and thereby minimize the radiated airborne sound in the chamber. The elastic isolation is designed such that the natural frequency of the spring-mass system is well below the cut-off frequency of the respective acoustic test chamber.

Two different measurement approaches are explained in this paper. In the first approach, the efforts are dedicated towards computing the difference in structure-borne-sound level between fundament and baseplate. In the second approach, the natural frequency of the baseplate is measured using experimental modal analysis. The sequential application of the two methods allows us to identify a

dedicated demand for a retrofit solution. First, we generally detect or exclude issues with the vibration damping system of an isolated measurement chamber and investigate furthermore the detuning in case of an improper design.

2. APPROACH 1: STRUCTURE-BORNE-SOUND TRANSMISSION LOSS

2.1 Measurement philosophy and set-up

Normally the air-borne sound transmission loss is measured by exciting one side of sound isolating element and calculating difference in sound power level on either side of isolating element, on the guidelines of laboratory standard DIN EN ISO 10140-2 (1). The analogous approach is used here as described in Figure 1. The elastically isolated baseplate is the receiving side and the fundament is the source side. The fundament is excited with a standardized tapping machine and the structure-borne sound velocity level is measured on the fundament and on the elastically isolated baseplate as shown in Figure 1.

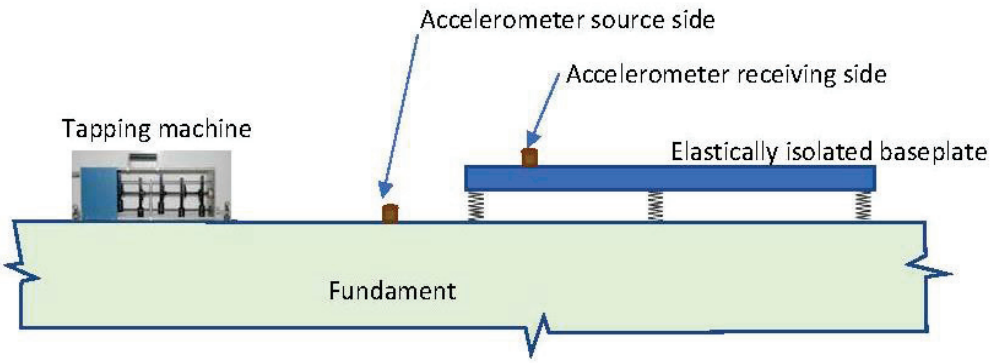


Figure 1 – Experimental set-up

2.2 Measurement results

The measurements are taken on a baseplate of an anechoic chamber. The dimensions of the baseplate are L x W x H = 7.7 x 5.3 x 0.2 m, the total mass including anechoic chamber is 32 t resulting in a designed natural frequency of the setup of approximately 4 Hz. The measurement results of structure-borne-sound velocity level are plotted in Figure 2. It is observed that the measured velocity level on receiving side is almost same as background noise level on receiving side. The curve indicates that the structure-borne-sound isolation is working as expected, but the efficiency of structure-borne isolation cannot be absolutely quantified as in the case of airborne sound.

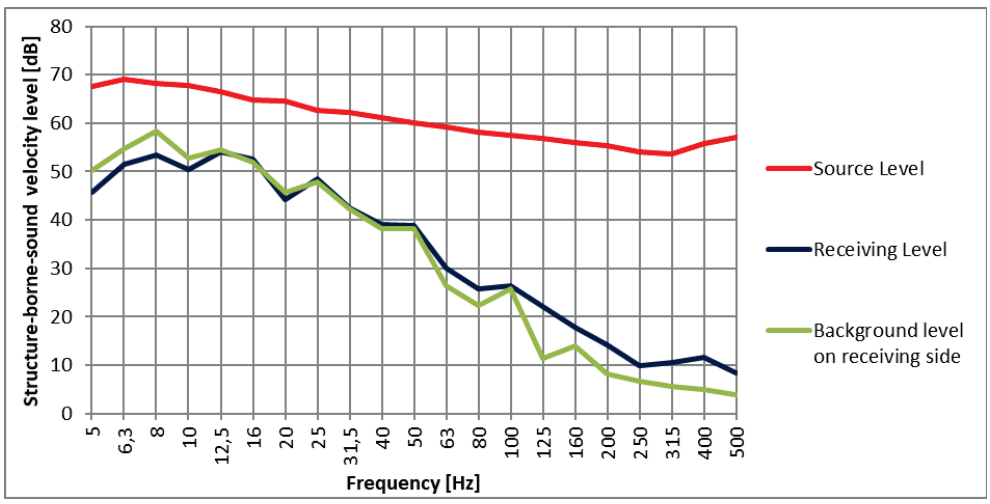


Figure 2 – Experimental results of structure-borne-sound velocity level difference

2.3 Intermediate conclusions of Approach 1

The difference in structure-borne velocity level between source and receiving side is increasing with increasing frequency. During these measurements, good scientific practice was observed while choosing a low self-noise and high sensitivity accelerometer. Despite this, the level on the receiving side is almost equal to background level. On the source side, the magnitude of excitation cannot be increased further, because the construction of standardized tapping machine is fixed. Furthermore, the level of excitation on source side is largely dependent on the impedance of fundament. A fundament on the upper floor of a multi-story building will have a higher source side excitation than a fundament that is part of earth floor. Furthermore, because of dispersive nature of structure-borne-sound, amplitude of the excited wave is largely dependent on frequency and distance from tapping machine. Therefore, the success of structure-borne-isolation cannot be quantitatively accessed using this approach.

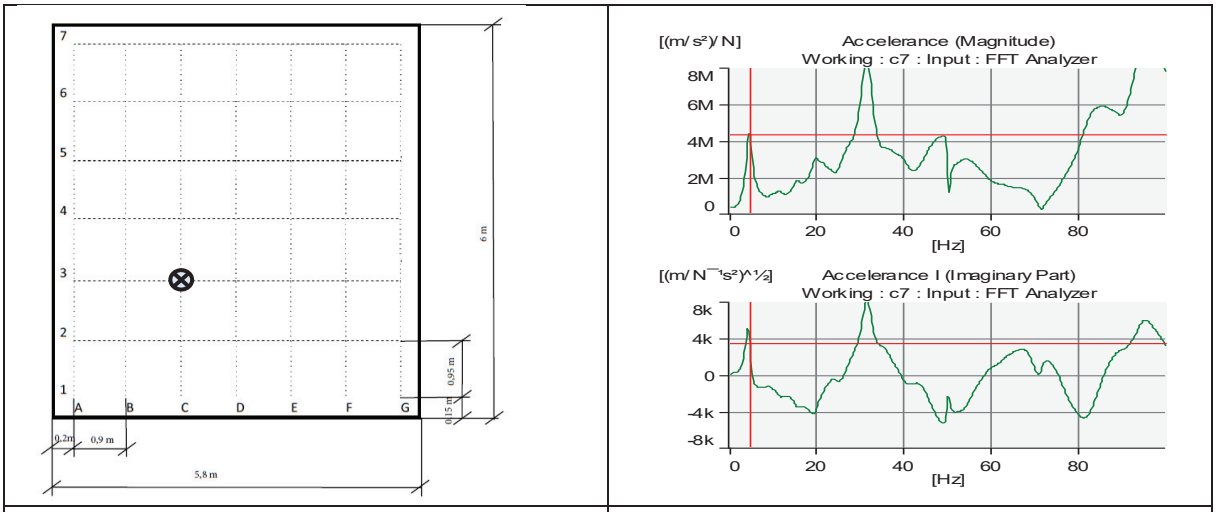
3. APPROACH 2: MEASURING FUNDAMENTAL FREQUENCY OF VIBRATION

3.1 Measurement philosophy

The fundamental frequency of elastic isolations is designed based on the cut-off frequency f_c of the isolated test chamber and the dominant excitation frequency outside the test chamber. The cut-off frequency of a chamber depends on the lining depth in case of anechoic chamber or the volume of a chamber in the case of a reverberation chamber. It defines the lowest measurable frequency band of the airborne sound inside the chamber. The dominant excitation frequency outside the chamber is imposed by installed aggregates outside of test chamber.

To clearly differentiate between rigid-body-vibrations and bending vibrations of the baseplate, a detailed modal analysis of the baseplate is performed. A virtual grid is marked on baseplate as shown in figure 3. The intersection points of this grid are excitation positions. One asymmetrically located grid-point on the baseplate is selected as accelerometer position, which can be excited at all possible frequencies in the frequency range of interest. The accelerometer is glued on the baseplate at the selected position for all impulse excitations.

The plate is excited by the impulse hammer at all grid positions and a FFT analysis is performed in the frequency range from 0 Hz to 100 Hz. The inertance is defined as cross correlation between acceleration and force (2). The frequency response spectrum of each impulse-response combination is plotted as magnitude of inertance and imaginary part of inertance. Using the quadrature picking method (3), the natural frequency and mode shapes are extracted. The peak in the magnitude of inertance indicates the natural frequency of the baseplate. The imaginary part of inertance at the corresponding frequency indicates the relative modal displacement at the excitation position. A typical result of inertance is presented in figure 3. Using this information, the natural frequencies of vibration of the baseplate and their corresponding mode shapes are extracted as shown in figure 5.



Imaginary grid on baseplate	Magnitude and imaginary part of inertance

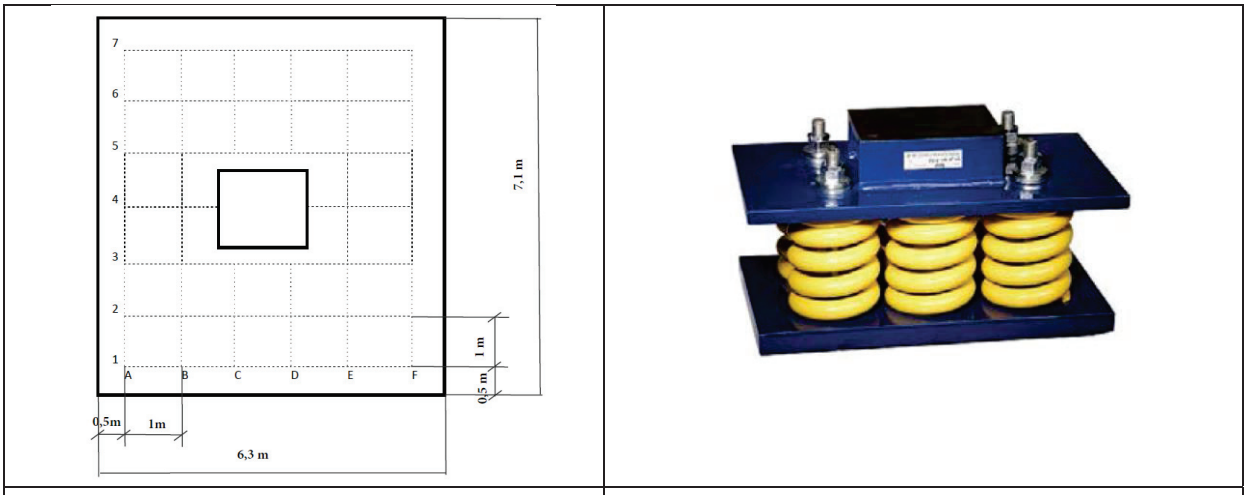
Figure 3. Virtual grid on a baseplate and inertance results of experimental modal analysis

3.2 Measurement results

Using this approach, the fundamental frequency of elastic isolation is measured in the case of three different baseplates and they are compared with the respective design fundamental frequencies.

3.2.1 Measurements on a baseplate isolated using metallic spring system

The measurements are performed on a baseplate of an anechoic chamber, which is designed to perform acoustics measurements on automobile components. The anechoic chamber is built on a reinforced concrete baseplate of 35cm thickness and isolated using a G+H FU metallic spring system. The dimensions of the baseplate are L x W = 7.1 x 6.3 m. The chamber is built up by a combination of sound damping panels and wedge absorbers. The mass of the baseplate including the anechoic chamber is 57 t and the design natural frequency of the isolation is approx. 4 Hz. The measurement grid on baseplate is shown in figure 4.



Imaginary grid on baseplate	G+H FU metallic spring system

Figure 4 – Measurement on a baseplate insulated using metallic spring system

The results of modal analysis are presented in figure 5. The measured fundamental frequency of whole-body-motion is f_1 = 4 Hz and it coincides with the designed natural frequency. Furthermore, the tilting mode natural frequency (f_2=19.5 Hz) and first bending mode natural frequency (f_3=31Hz) are extracted from the modal analysis as shown in figure 5.

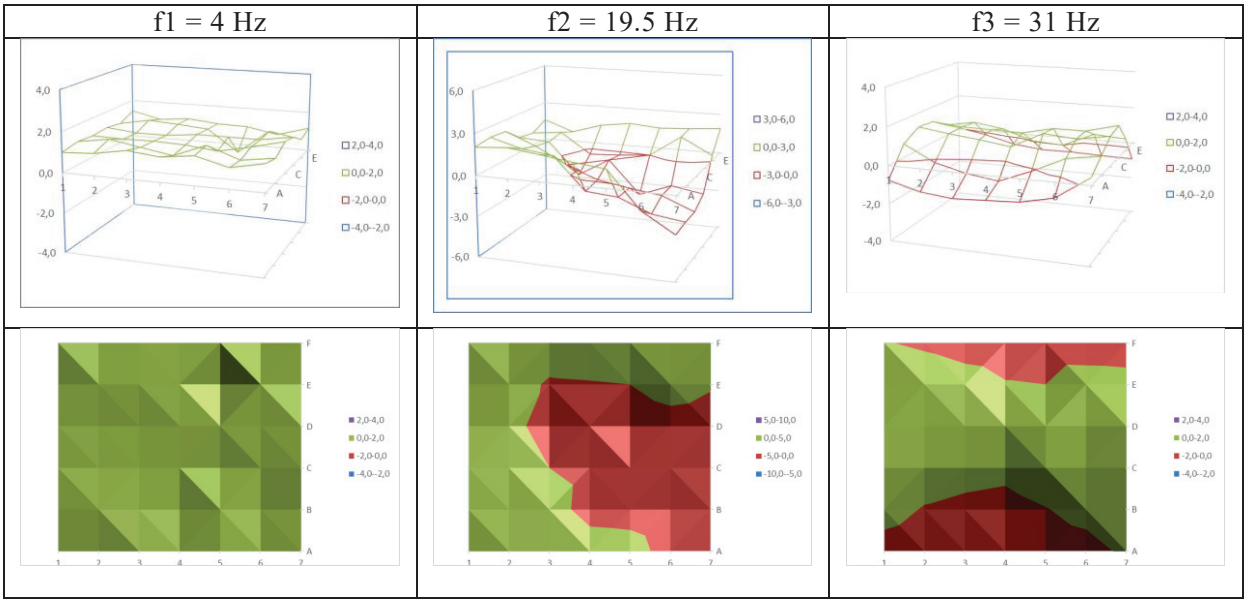
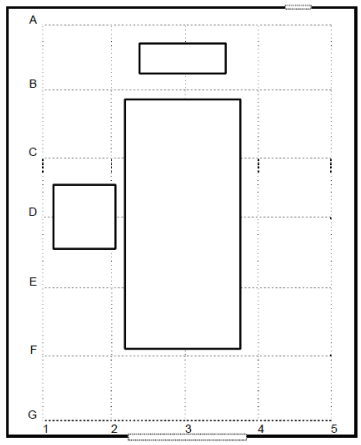


Figure 5 – Natural frequencies and mode shapes of base plate, metallic spring system

3.2.2 Measurement on a baseplate isolated using VIBREX spring strips system

As a second object, an acoustic vehicle chassis dynamometer with f_c = 100 Hz is selected. The chassis dynamometer is built as a room-in-room concept and the weight of the inner room including baseplate, massive walls and ceiling is approximately 365 t. The dimensions of the baseplate are L x W x H = 13.3 x 10.6 x 0.4 m. The baseplate including inner structure of the anechoic chamber is isolated from the fundament using G+H VIBREX spring strips system as shown in figure 6. The design natural frequency of isolation is approximately 10 Hz. To perform the modal analysis, a virtual grid is marked on baseplate at approximate distances of 2 m, as shown in Figure 6.



Imaginary grid on baseplate	G+H VIBREX spring strips

Figure 6 – Measurement on a baseplate isolated using VIBREX spring strips system

The measurement results are presented in figure 7. The first natural frequency of the baseplate is observed at 11.75 Hz. From the mode shape, it is observed that it is rigid-body-translatory mode in vertical direction. The small difference between designed frequency and measured frequency is caused by the missing mass of the wedge absorbers and the ventilation system inside the anechoic chamber at the measurement stage. The tilting-mode frequency is observed at 17.75 Hz and first bending vibration mode is at 28.6 Hz as shown in figure 7.

f1 = 11.75 Hz	f2 = 17.75 Hz	f3 = 28.6 Hz

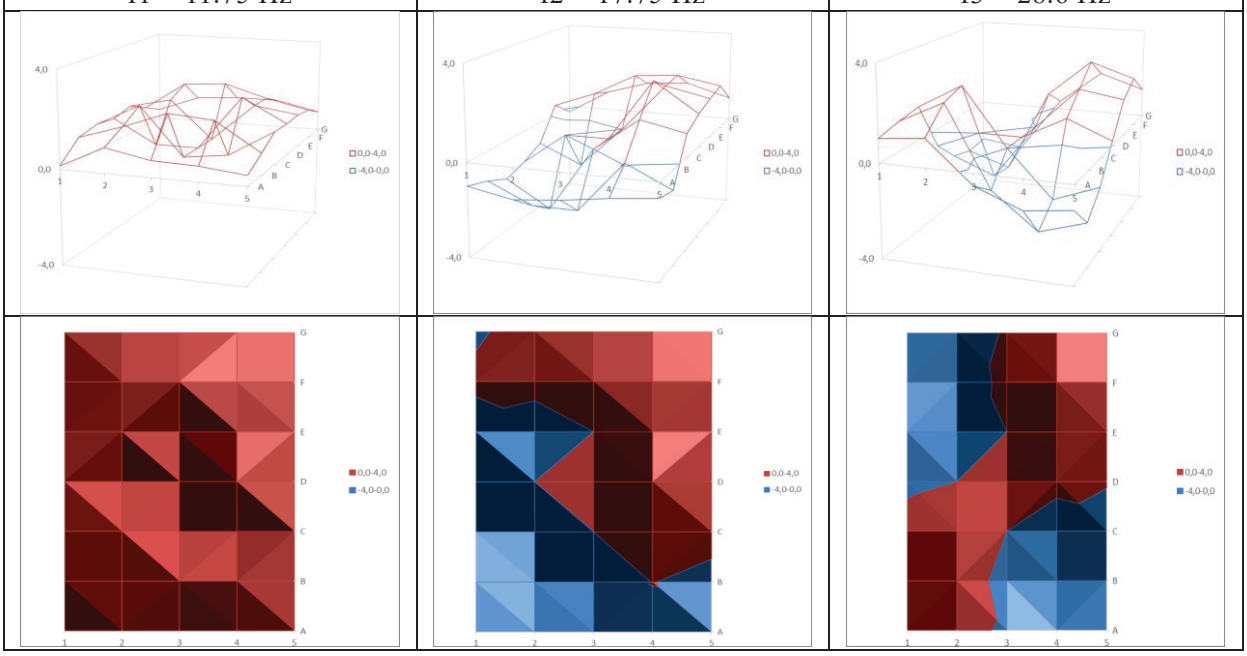
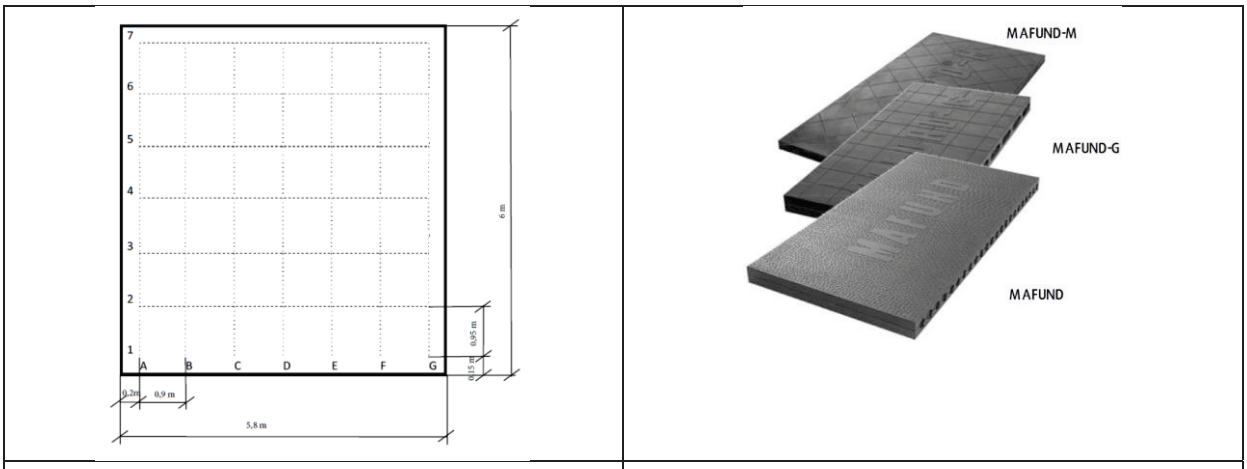


Figure 7 – Natural frequencies and mode shapes of base plate, VIBREX spring strips system

3.2.3 Measurement on a baseplate isolated using G+H MAFUND rubber sheets system

The third anechoic chamber is designed for measuring the sound power level of household equipment with f_c = 100 Hz. Because of stringent requirements on the background noise level, the anechoic chamber is built with the room-in-room type construction. The baseplate carrying the internal cladding with a flat panel system is isolated from its building using a G+H MAFUND rubber sheet system as shown in figure 8. The dimensions of the baseplate are L x W x H = 6 x 5.8 x 0.25 m. The mass of baseplate including the anechoic chamber is 38 t resulting in a designed natural frequency of the isolation of approximately 21 Hz. To perform the modal analysis, a virtual grid is marked on the baseplate with approximate distances of 1 m, as shown in Figure 8.



Imaginary grid on baseplate	G+H MAFUND rubber sheets

Figure 8 – Measurement on a baseplate isolated using MAFUND rubber sheets system

The natural frequencies of vibration of the baseplate and their mode shapes are presented in Figure 9. The first fundamental frequency is observed at 22Hz and the first tilting frequency is observed at 26 Hz. The first bending mode of vibration is observed at 35 Hz and the breathing mode of the baseplate is observed at 46 Hz as shown in figure 9. Considering the missing mass of the absorbing system inside the anechoic chamber at the time of measurement, the fundamental frequency of spring-mass system practically coincides with the design natural frequency.

f1 = 22 Hz	f2 = 26 Hz	f3 = 35 Hz	f4 = 46 Hz

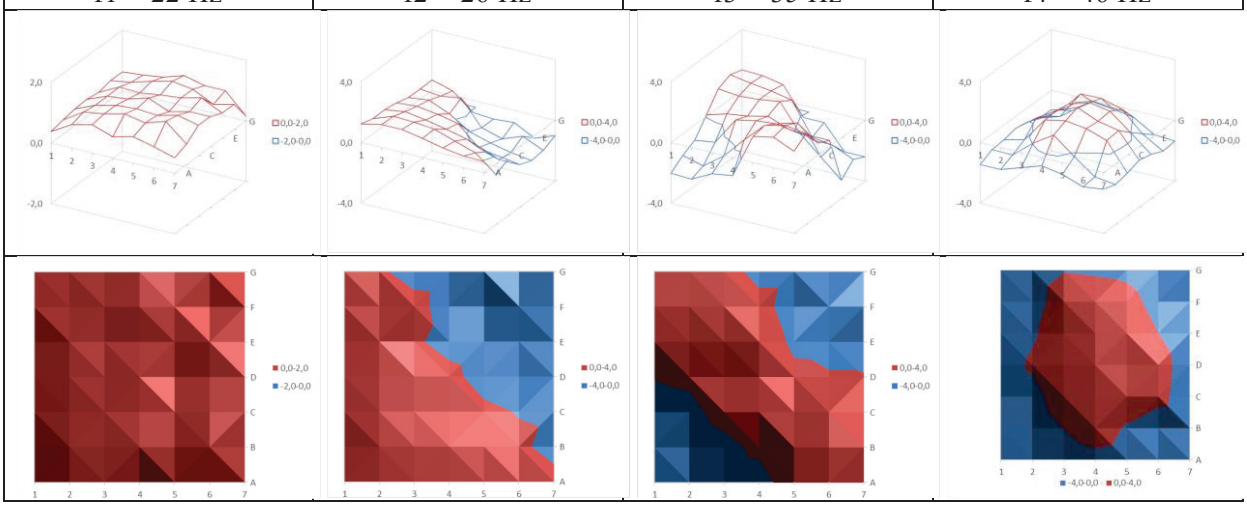


Figure 9 – Natural frequencies and mode shapes of base plate, MAFUND rubber sheets system

4. CONCLUSIONS

Taking measurements of structure-borne-sound velocity levels of source and receiving side and computing the difference, it can be qualitatively checked, if the isolation of a baseplate from its fundament is properly designed. However, a quantitative measurement of the actual efficiency cannot be done.

A second approach shows that the fundamental frequency of spring-mass system can be accurately measured. It is verified for three different types of vibration isolating systems that the measured fundamental frequency practically coincides with the designed natural frequency of a given baseplate-isolation-system. The robustness of both methods allows us to offer the combined package as a service to identify the existence of vibration isolation issue, followed by a classification of the severity of a system's detuning. Based on this quantification, we can rectify the tuning of a given spring-foundation-chamber setup to its desired parameters

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