ACTIVE CONTROL OF SOUND RADIATION BY CONTROLLING VOLUME VELOCITY MODE

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1 INTRODUCTION

Active control of sound transmission and radiation from vibrating structure has become a very interesting research area. Especially, reduction of sound radiation from plate like structures is a challenging task from the applications of industrial point of view. Regular or periodic excitation forces are likely to be experienced by the plates when they form part of a structure. For making engineering systems quieter, researchers are studying various ways to attenuate radiated acoustic power from elastic components.

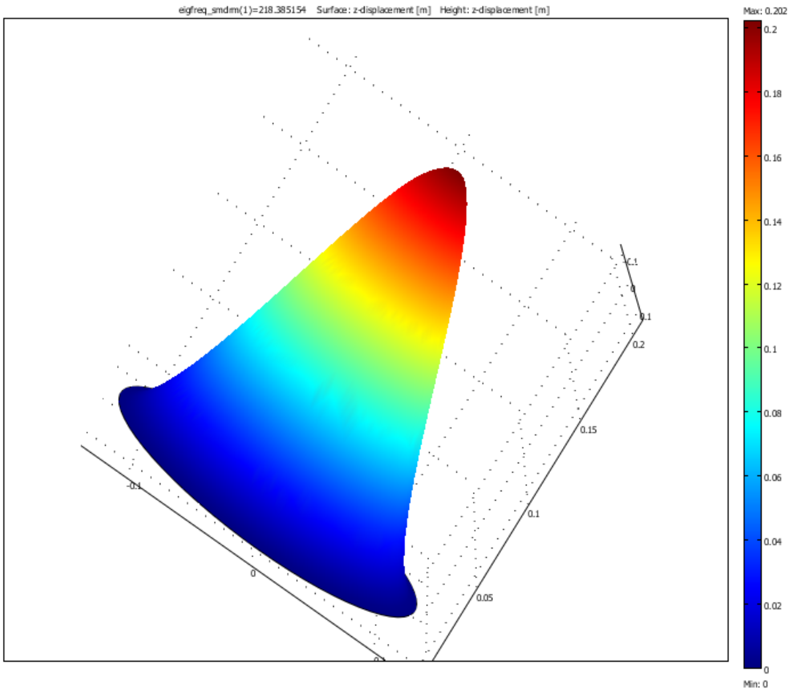
It has been seen that the use of vibration modes, which are generally used in vibration analysis and control, cause some difficulties in sound radiation analysis. Therefore, a more appropriate concept called radiation modes has been proposed by Elliot & Nelson [1]. Specific actuators for the active control systems can be designed for radiation modes to modify the structural vibration in such a way that the sound radiation will be minimized.

In addition to the secondary source, control strategy is also very important component of the active structural acoustic control. Two well known control strategies, sound power minimization and volume velocity cancellation, are generally used for the active control of radiated power. Both the control strategies are compared by Johnson and Elliot [2] in terms of reduction in radiated sound power. They found that sound power minimization strategy achieves large attenuation in sound power radiation at low frequencies while also reducing the levels of vibration and near field pressure levels by getting rid of control spillover. However, it has a physical limitation i.e., sound power is difficult to measure in practice. To get rid of this difficulty, they proposed to control the first radiation mode, which is the dominant radiator of sound power at low frequencies. At low frequencies the amplitude of the first radiation mode can be well approximated by the net volume velocity of the structure, and therefore, the cancellation of volume velocity mode is a very good strategy for the reduction of sound power radiation.

2 EXPERIMENTAL RESULTS & DISCUSSIONS

Figure 1 shows the test set-up in which a stainless steel plate of 2 mm thickness is rigidly attached at one end of a duct. This plate is excited by a loudspeaker which is placed centrally at the other end of the duct. The physical properties of the steel plate are as follows: density 8000 kg/m^3, Poisson's ratio 0.3, and Young's Modulus 193 GPa. The duct is 7.5 m in length, 255 mm in diameter and cut-off frequency of 718 Hz. The loudspeaker has poor frequency response below 50 Hz. To generate plane wave mode in the duct, and to stay in the safe side, the system is excited from 50 to 650 Hz. The nuts and bolts are tightened by using a moment wrench (applied moment = 100 *N.m*) to get rid of the inherent bending of the plate. To verify the plane wave mode of the steel plate, the frequency response of the plate has been drawn by taking the accelerometer and laser vibrometer data. Accelerometer is placed at the centre (reference accelerometer) and laser beam of the vibrometer has been shifted from one measuring point to another.

Figure 1. Experimental Test Set-up



1^{st} mode – 218 Hz
2^{nd} mode – 550 Hz
3^{rd} mode – 615 Hz
4^{th} mode – 888 Hz
5^{th} mode – 978 Hz
6^{th} mode – 1008 Hz
7^{th} mode – 1336 Hz
8^{th} mode – 1478 Hz
9^{th} mode – 1486 Hz
10^{th} mode – 1756 Hz
11^{th} mode – 1953 Hz
12^{th} mode – 2020 Hz
13^{th} mode – 2021 Hz

Figure 2. 1^{st} Mode shape & Eigen frequencies (modelled by COMSOL Multiphysics)

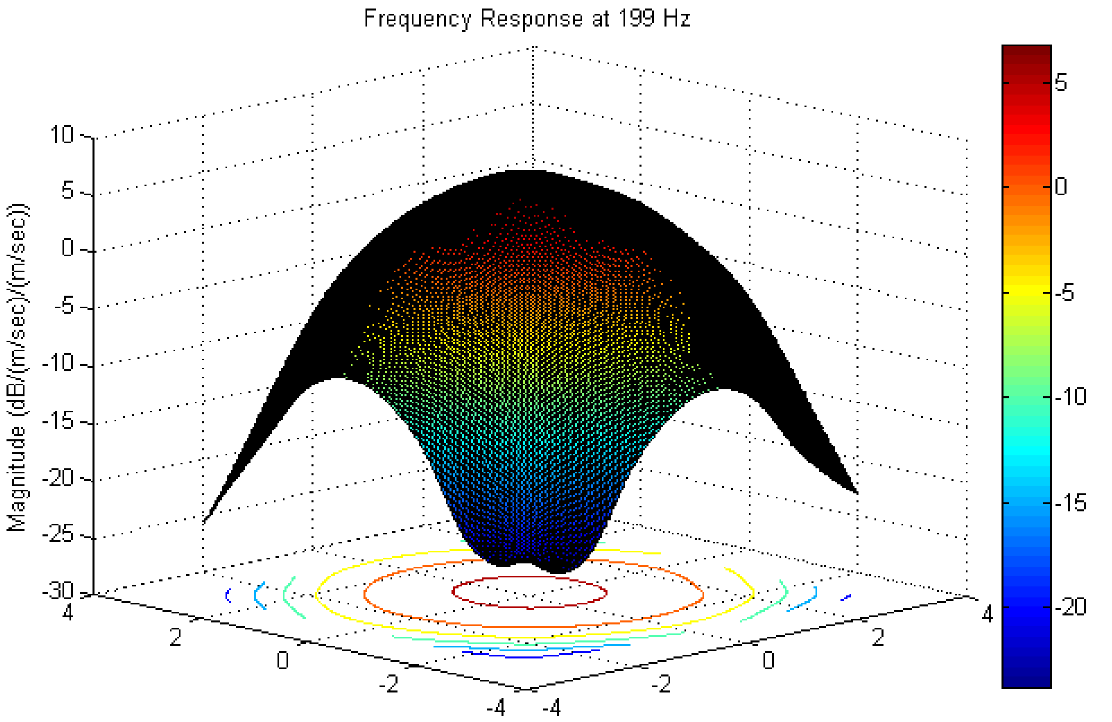


Figure 3. Magnitude response at 199Hz

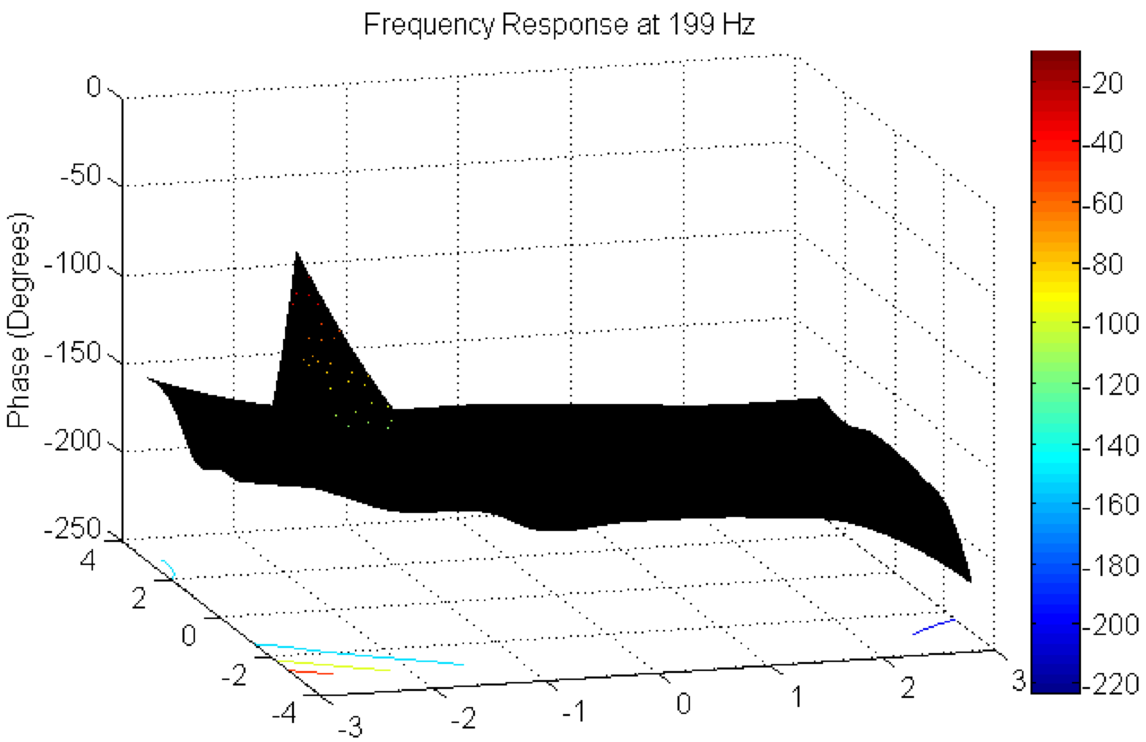


Figure 4. Phase response at 199Hz

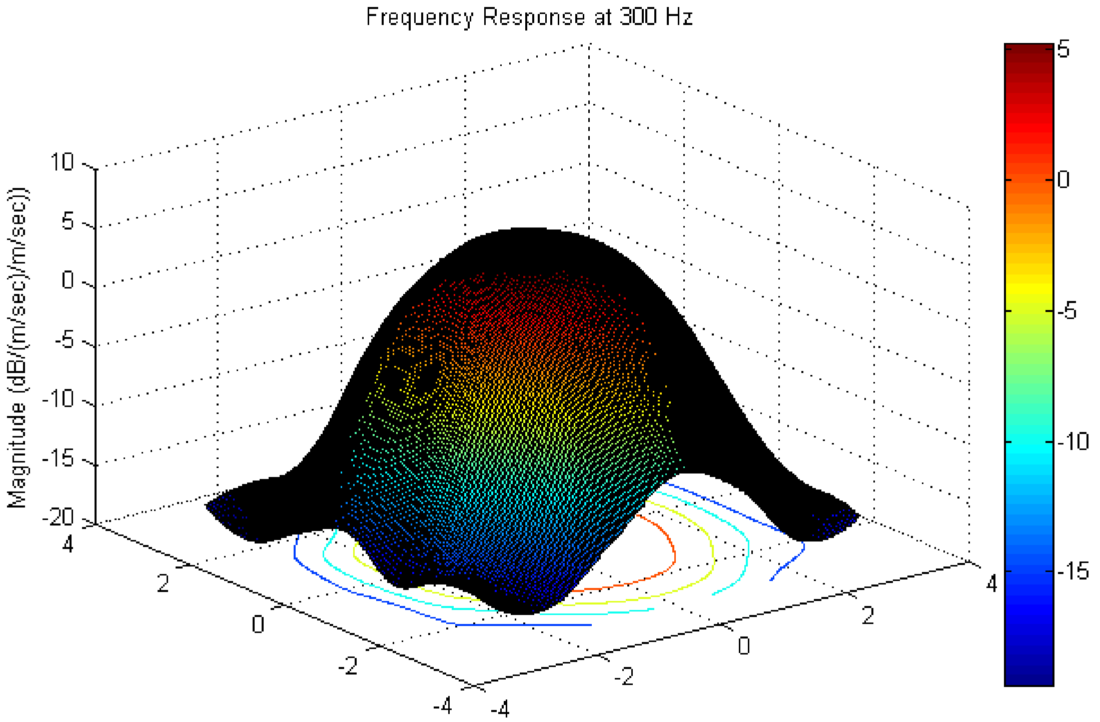


Figure 5. Magnitude response at 300Hz

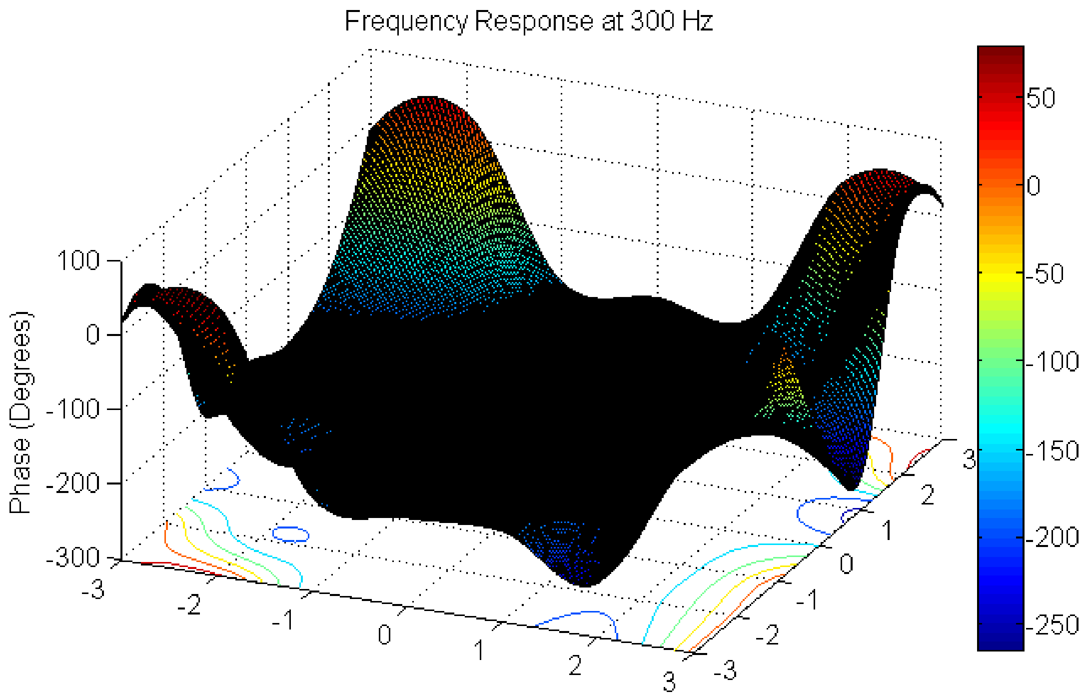


Figure 6. Phase response at 300Hz

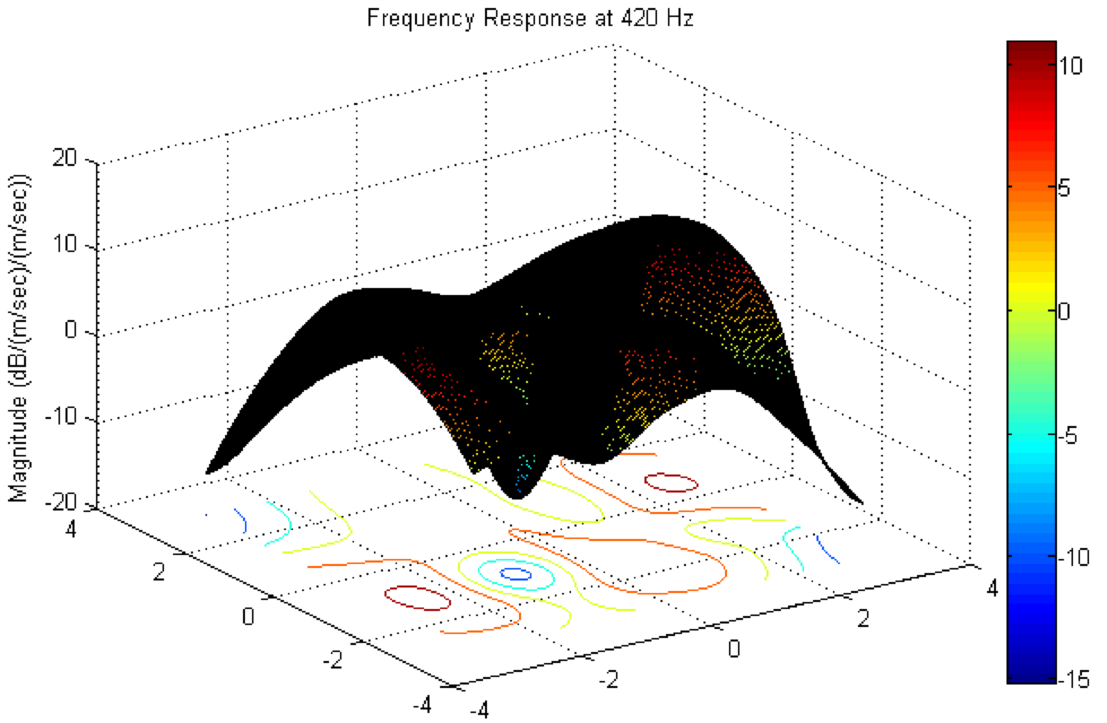


Figure 7. Magnitude response at 420Hz

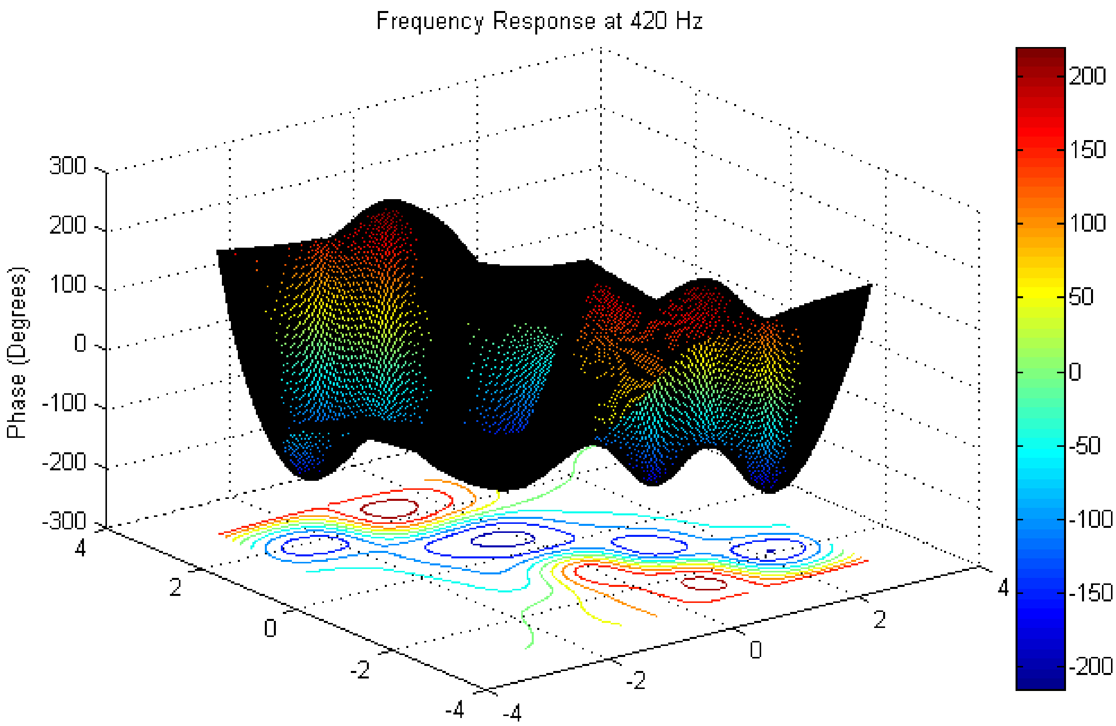


Figure 8. Phase response at 420Hz

The magnitude and phase response of the steel plate are drawn at three arbitrary frequencies taken in the excitation range, which are shown in Figures 3, 4, 5, 6, 7 & 8. It is very well-known that the pressure at each and every point of the plate is same in a plane wave excitation. Therefore, the plate should vibrate only in odd modes. The plate is modelled in COMSOL Multiphysics to find out the natural frequencies and mode shapes of the plate. The first mode shape and natural frequencies of the steel plate are shown in Figure 2. The second structural mode occurs around 550 Hz, which can be seen from Figure 2. So, from theoretical point of view the plate should vibrate like a piston up to 550 Hz. However, the plate vibrates like a volume velocity mode at lower frequencies, which can be clearly observed from frequency response plots. Up to 199 Hz (Figures 3 & 4), the plate clearly vibrates like a piston having the phase, which is almost at zero degree (except at one point due to the measurement error). One can see by looking at the experimental results that the plate vibrates at first mode till 300 Hz (Figures 5 & 6), even though there are some distortions at the four corners of the plate. However, the mode shape of the plate is largely deviated from the piston like shape after 300 Hz, which can be seen from the frequency response Figures 7 & 8 drawn at 420 Hz.

3 CONCLUSIONS

In this work, an experimental study has been made to get a clear picture of the volume velocity mode (approximation of the first radiation mode). It has been already shown by many researchers theoretically that this mode should be the main target for the active control of sound power radiation. It can be concluded that the plate vibrates like a piston at the lower frequencies. However, the magnitude and phase responses are deviating from the piston shape at higher frequencies even if the excitation is acoustic plane wave at these higher frequencies. For this behaviour there are several reasons, which can be derived from the experimental study. The most important are:

i. Nuts & bolts insert some sort of non-linearity on the plate for which reason the plate is not vibrating symmetrically.
ii. Practical difficulty to find a plate which is fully homogeneous and isotropic.
iii. Environmental factors also influence the measurement readings as the system is very sensitive.
iv. Effect of the weight of the accelerometer at higher frequencies.

Therefore, one should keep an eye of the obvious non-idealities of the test system, if doing similar type of experiment.

ACKNOWLEDGEMENT

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2. Johnson M E & Elliot S J, Active control sound radiation using volume velocity cancellation, *J Acoust Soc Am* **98**(1995)4, 2174-2186.