Studies on the Effects of Interfering Structural Vibrations on an Underwater Acoustic Vector Sensor

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Introduction

Accelerometer based AVS design

- An underwater Acoustic Vector Sensor (AVS) is a compact sensor that measures a four-dimensional vector quantity consisting of the acoustic particle velocity of the water medium in three dimensions and the scalar pressure.
- The acoustic particle velocity of the medium is generally measured indirectly using a tri-axial accelerometer embedded in the AVS [1][2].

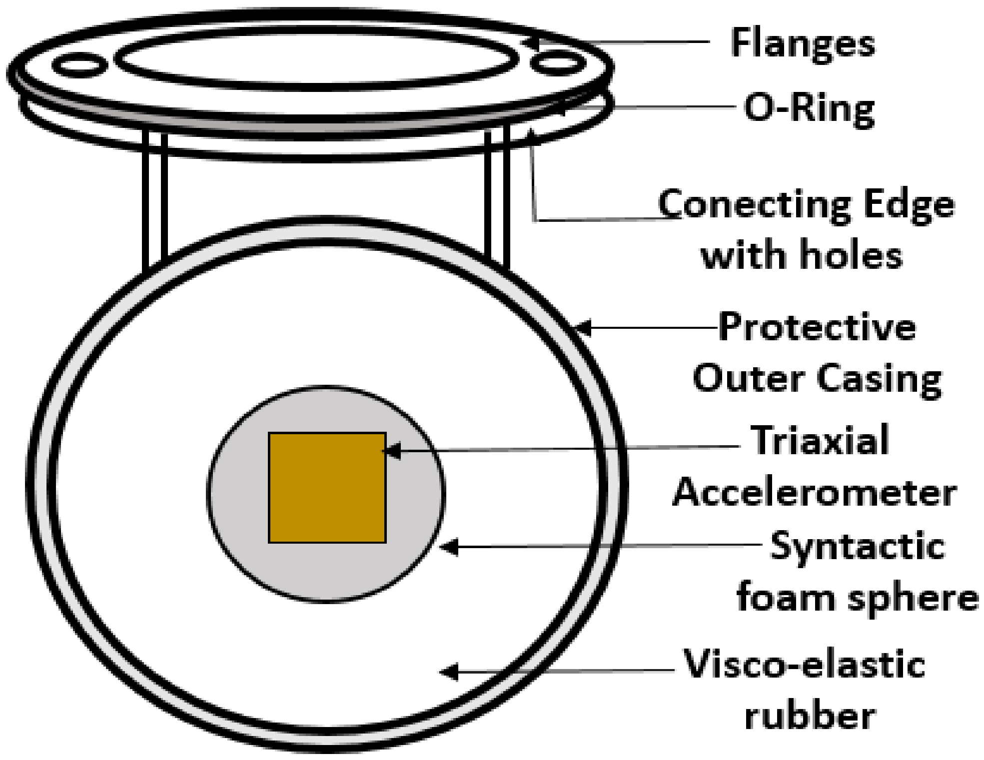

Figure 1. Tri-axial accelerometer based underwater AVS

Introduction

- It is sensitive to the unwanted mechanical vibrations especially transmitted to it through the suspending structure.
- This may affect the acoustic intensity measurement and the direction estimation of acoustic sources. Thus, it is not desirable that these structural vibrations overlap with the frequencies of the signal from the desired acoustic sources that may impose extra challenges.
- So, it is essential to understand the effects of these transmitted vibrations on the AVS, especially when it is mounted on a moving platform like an autonomous underwater vehicle (AUV).

Simulation Setup: Acoustic analysis

Table *: Simulation Parameters*

Parameter	Value
Dimension of accelerometer	0.0203 m
Density of accelerometer sensor	2640 kg/m^3
Time of study	0.004 s
Sampling Frequency	50000 Hz
Radius of AVS sphere casing	0.0185 m
Density of AVS material	1210 kg/m^3
Frequency of operation	10 to 1000 Hz
Speed of sound in water	1500 m/s
Elevation angle (θ)	90 deg
Azimuth Angle ($\emptyset$)	0:10:360 deg

Simulation Setup: Acoustic analysis

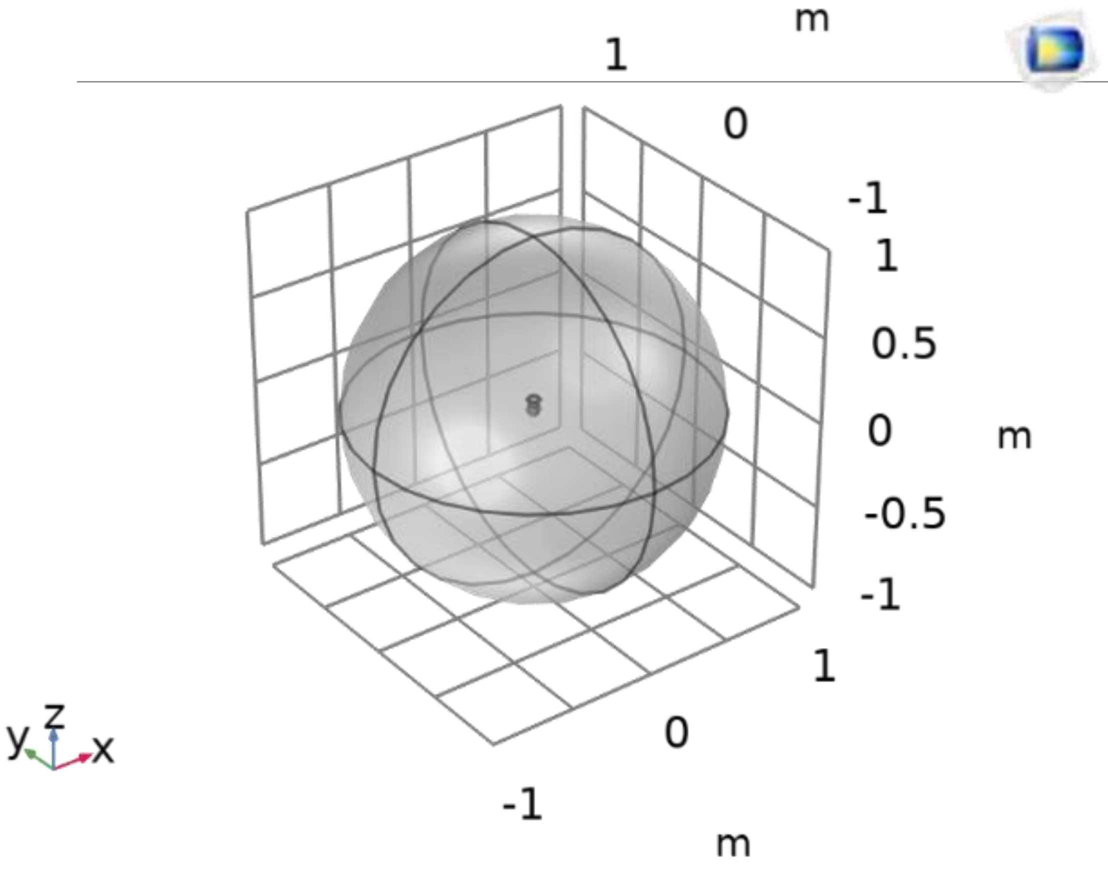

Figure 1. *3D model meshed for acoustic analysis.*

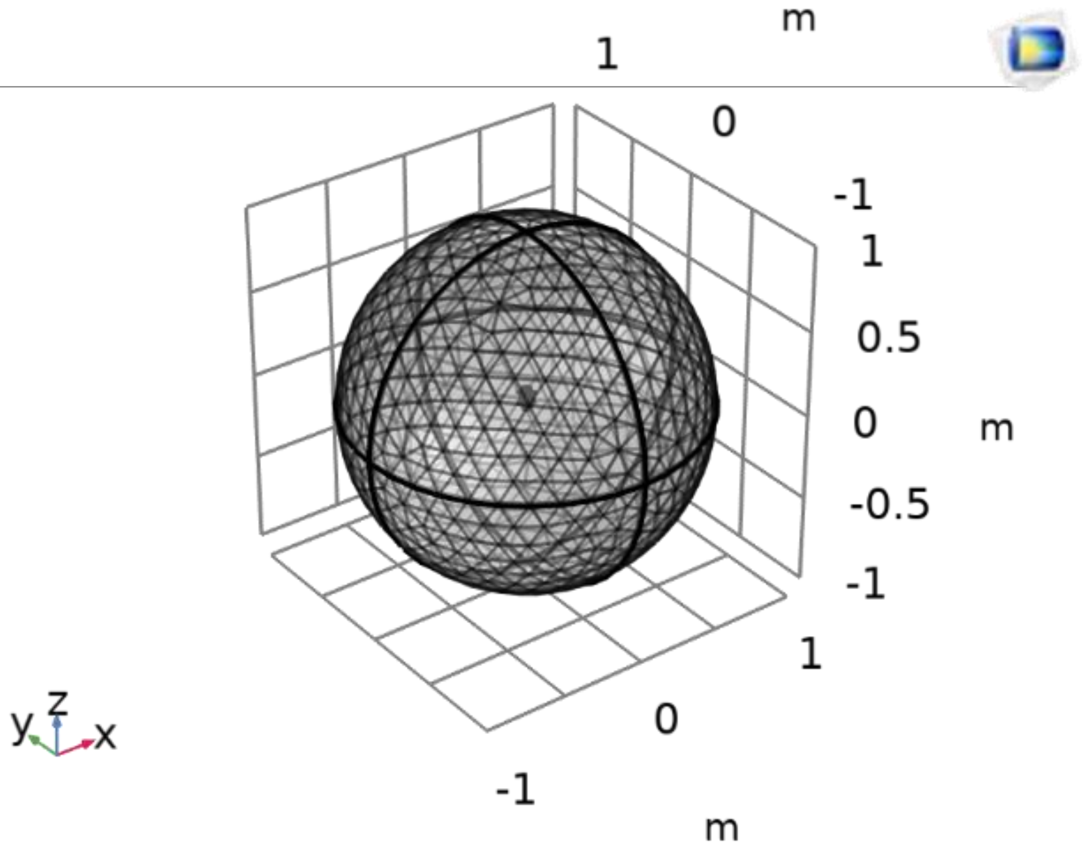

Figure 2. 3D model meshed for acoustic analysis

Simulation Result: Total Acoustic Pressure Field

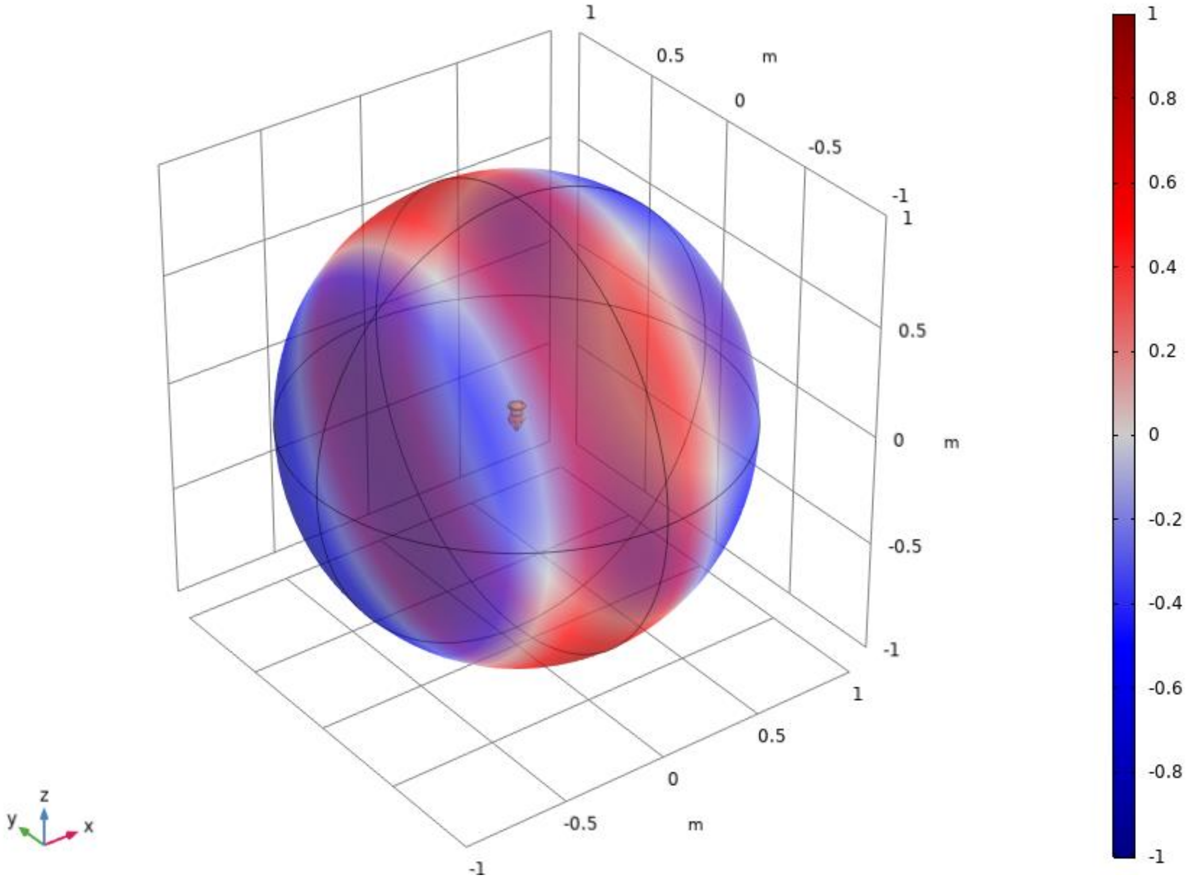

Figure 3. Total acoustic pressure field in the model (source angle =0 degrees).

- Wave propagation is simulated in acoustic analysis to compute the pressure and acceleration measurements at the AVS deployed in water medium.
- For far-field environment, AVS is enclosed by a sphere of radius 1m, filled with water. Perfectly Matched Layer (PML) is used, which acts like an absorbent material for acoustic waves.
- A background pressure field of 1Pa is applied at this sphere.
- We can observe the total acoustic pressure field moving in x-direction.

Simulation Result: Probed signals at the three orthogonal axis of accelerometer & hydrophone

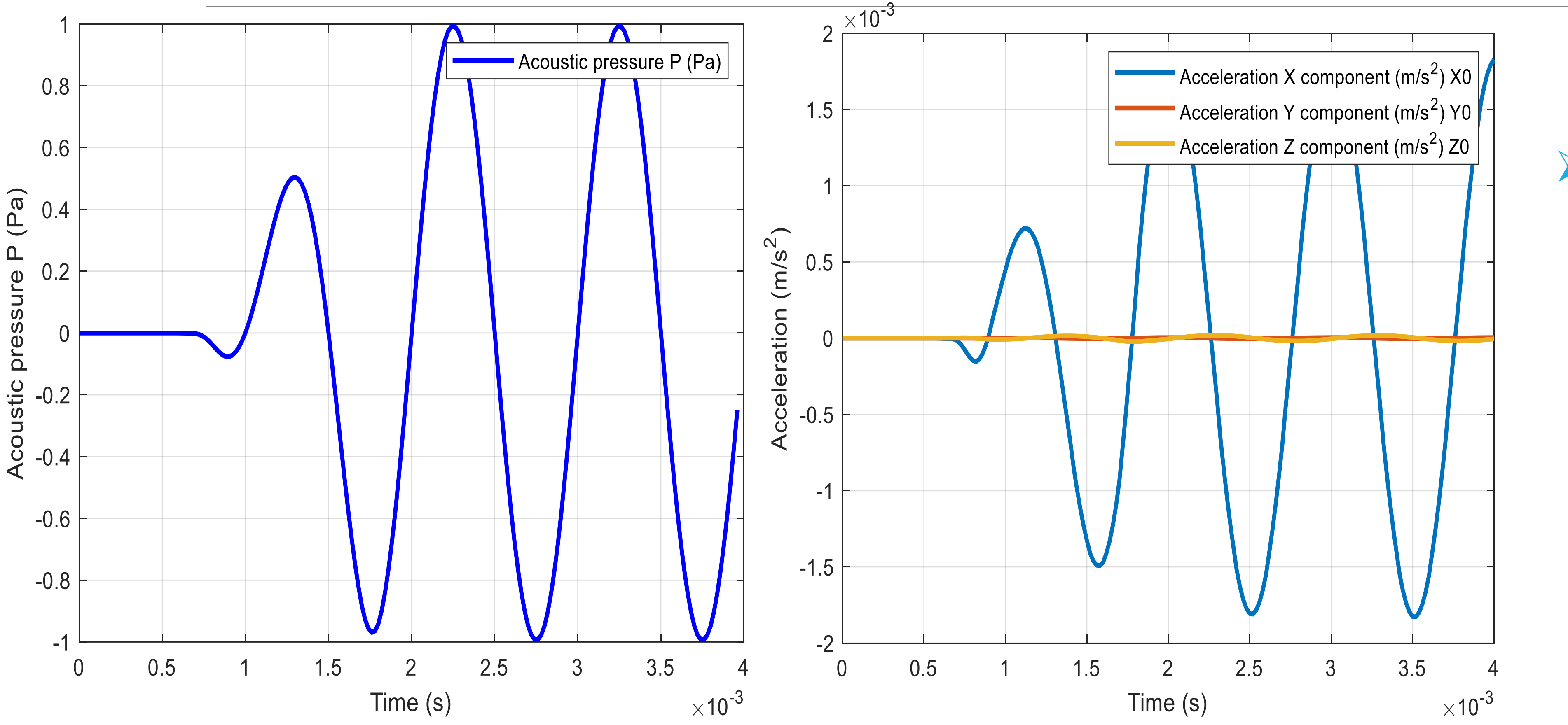

Figure 4. Plot of pressure and acceleration measurement obtained in acoustic domain.

- These probed signals are stored for all the azimuth angles varying from 0 to 360 deg with step size of 10 degrees and at each frequencies (10Hz, 100 Hz, 500 Hz & 1000 Hz).

Simulation Result: Beampattern for the x- and z-channels of AVS

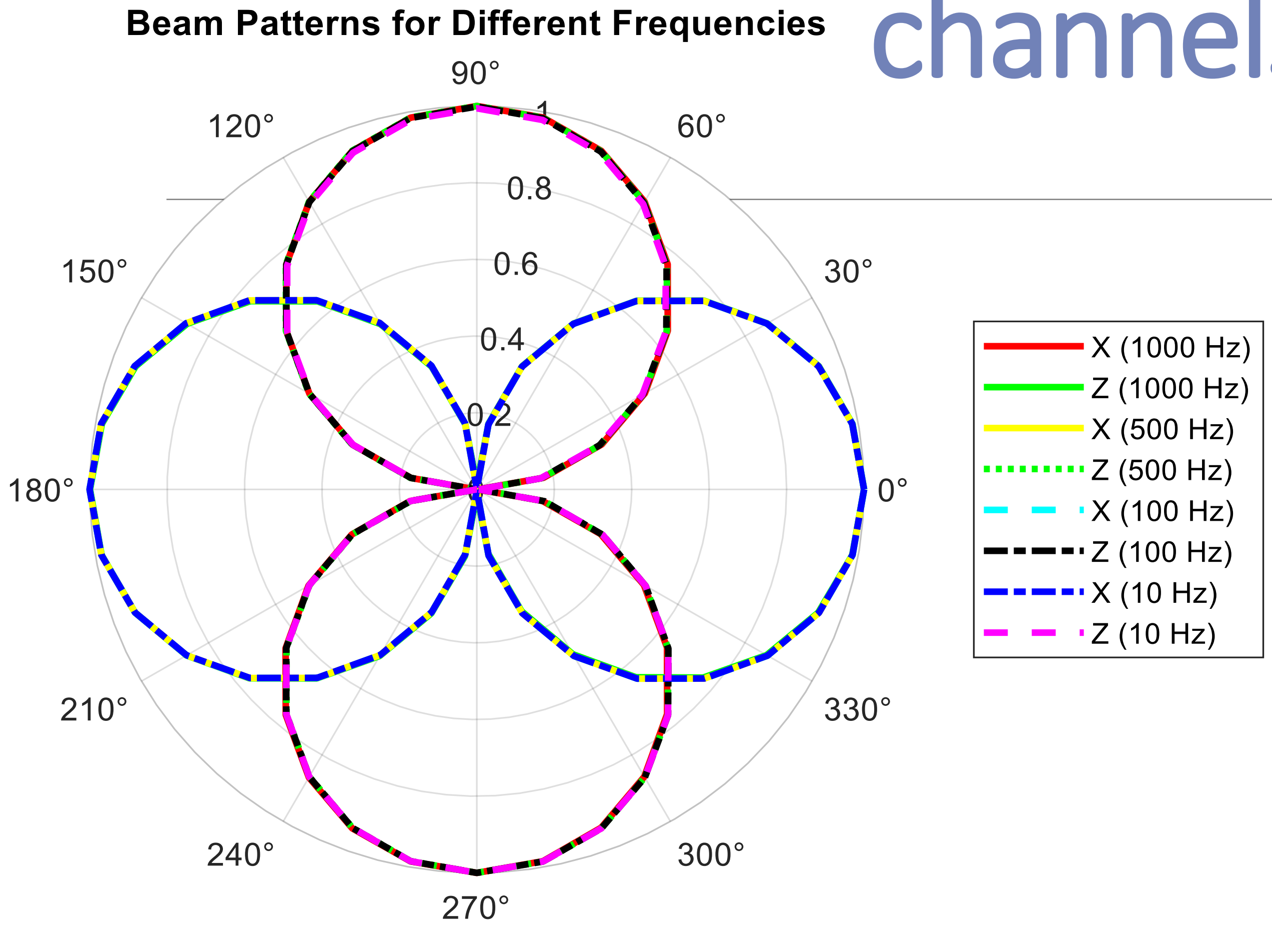

Figure 5. Beampattern of x- and z- channel of AVS in azimuth plane at frequencies 10Hz, 100 Hz, 500 Hz & 1000 Hz and source angles varying over 0 to 360 deg with step size of 10 degree.

- Additionally, we plotted the beampattern for the x- and z- channels of AVS in the azimuth plane at frequencies of 10Hz, 100 Hz, 500 Hz, and 1000 Hz, varying the source angles from 0 to 360 degrees with a step size of 10 degrees.
- It is to be noted that these beampatterns closely adhere to the ideal cosine pattern expected from the particle velocity sensor. thus verifies the AVS performance over the frequency range 10 to 1000 Hz.

Simulation Setup: Structural vibration analysis

Model 1: Without Suspending Rod

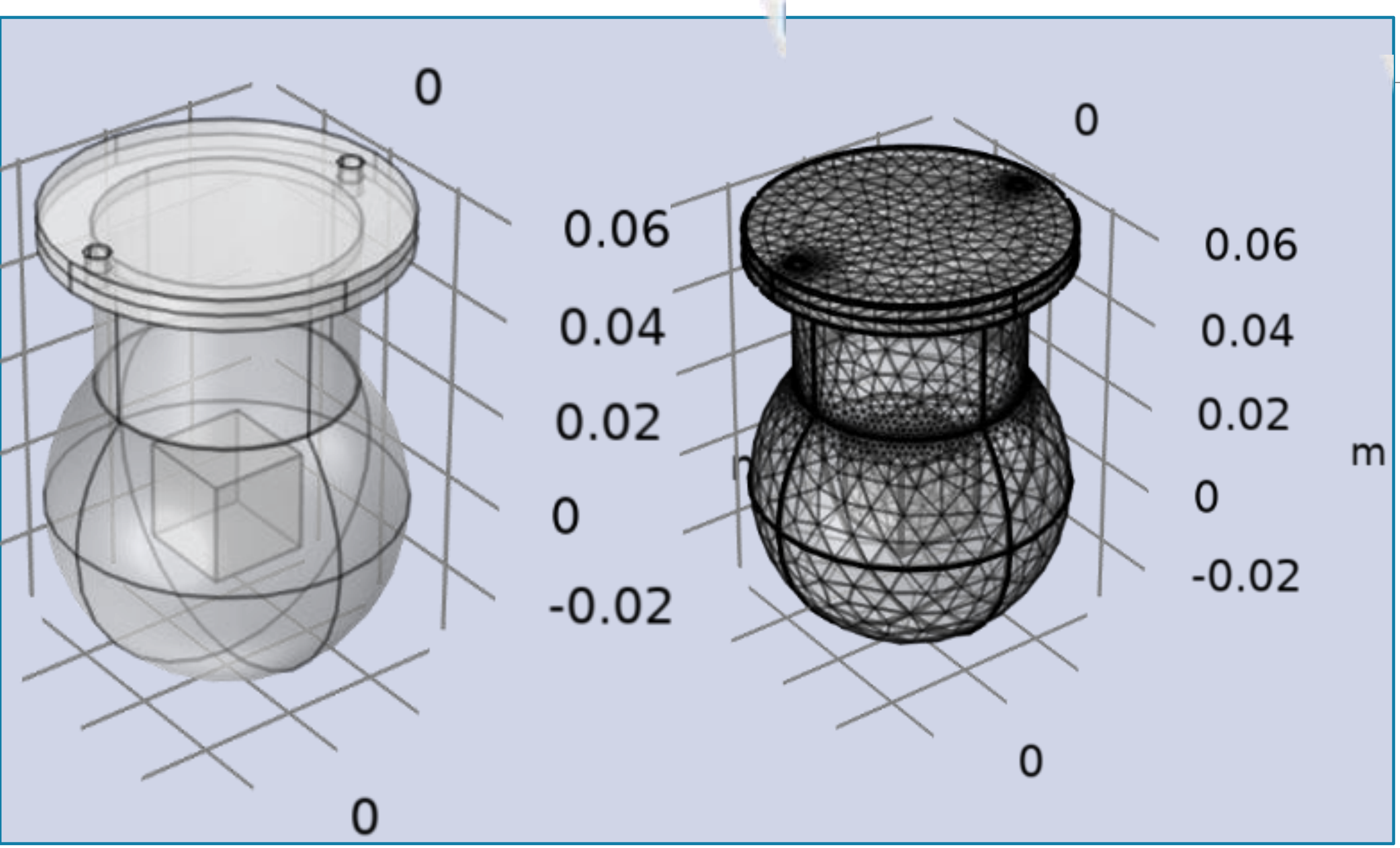

Figure 6. 3D geometry of the AVS model

Model 2: With Suspending Rod

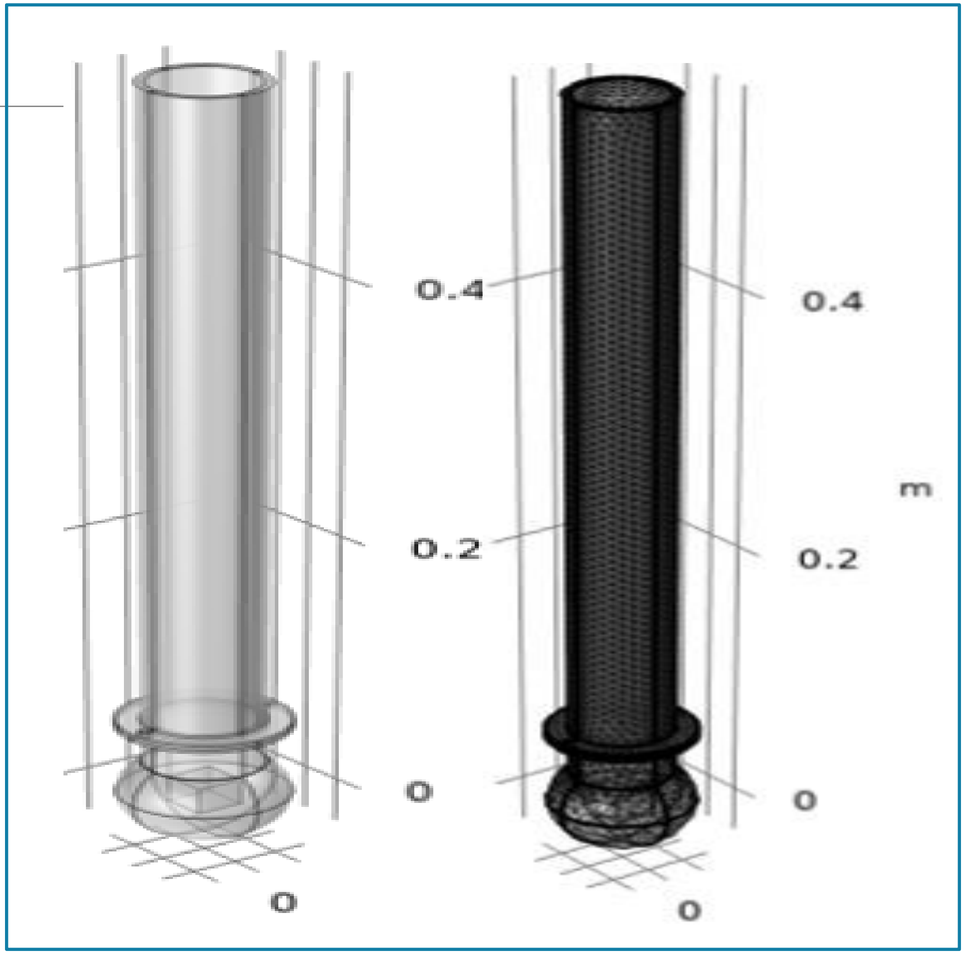

Figure 7. AVS with suspending rod structure: 3D geometry

Simulation Result: Eigen frequency analysis (model 1: Without Suspending Rod)

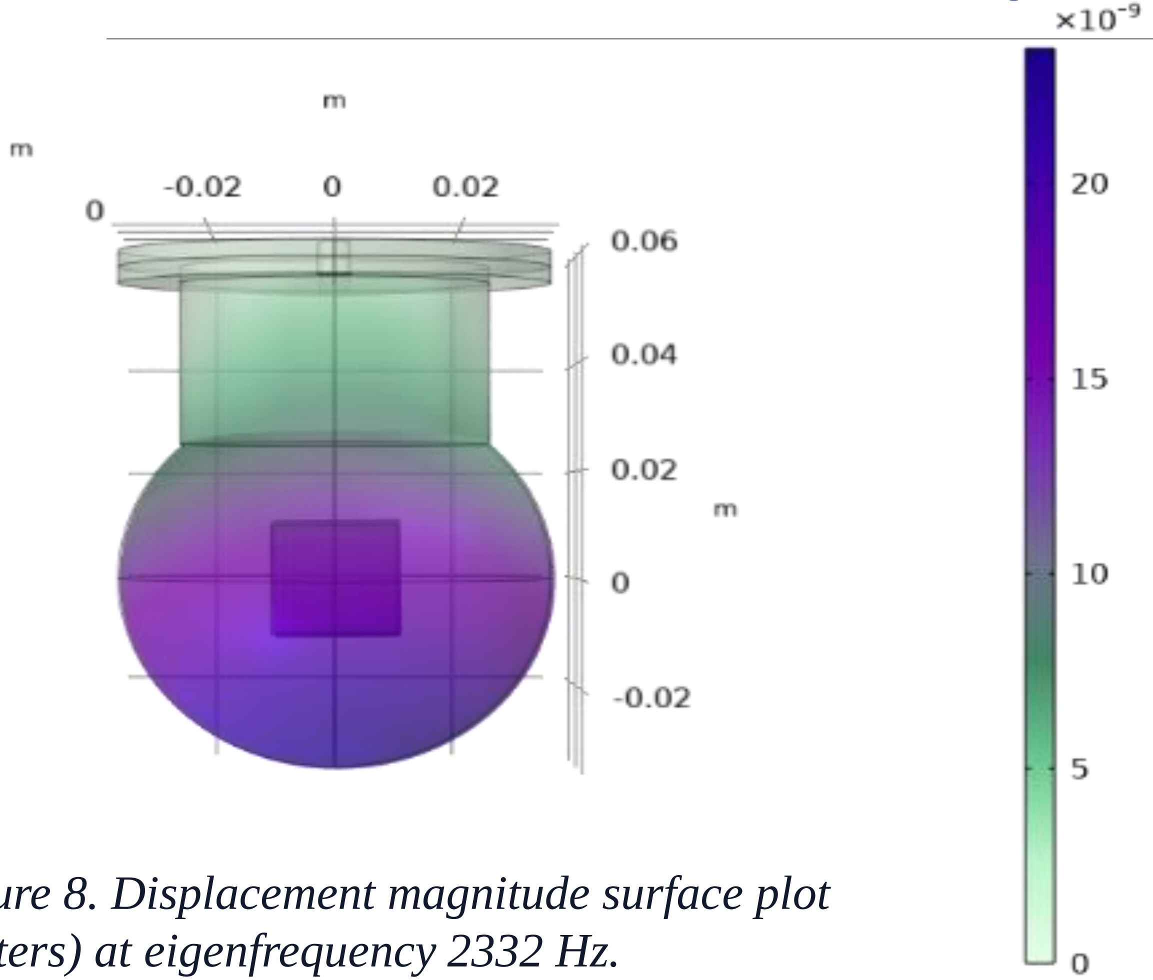

Figure 8. Displacement magnitude surface plot (meters) at eigenfrequency 2332 Hz.

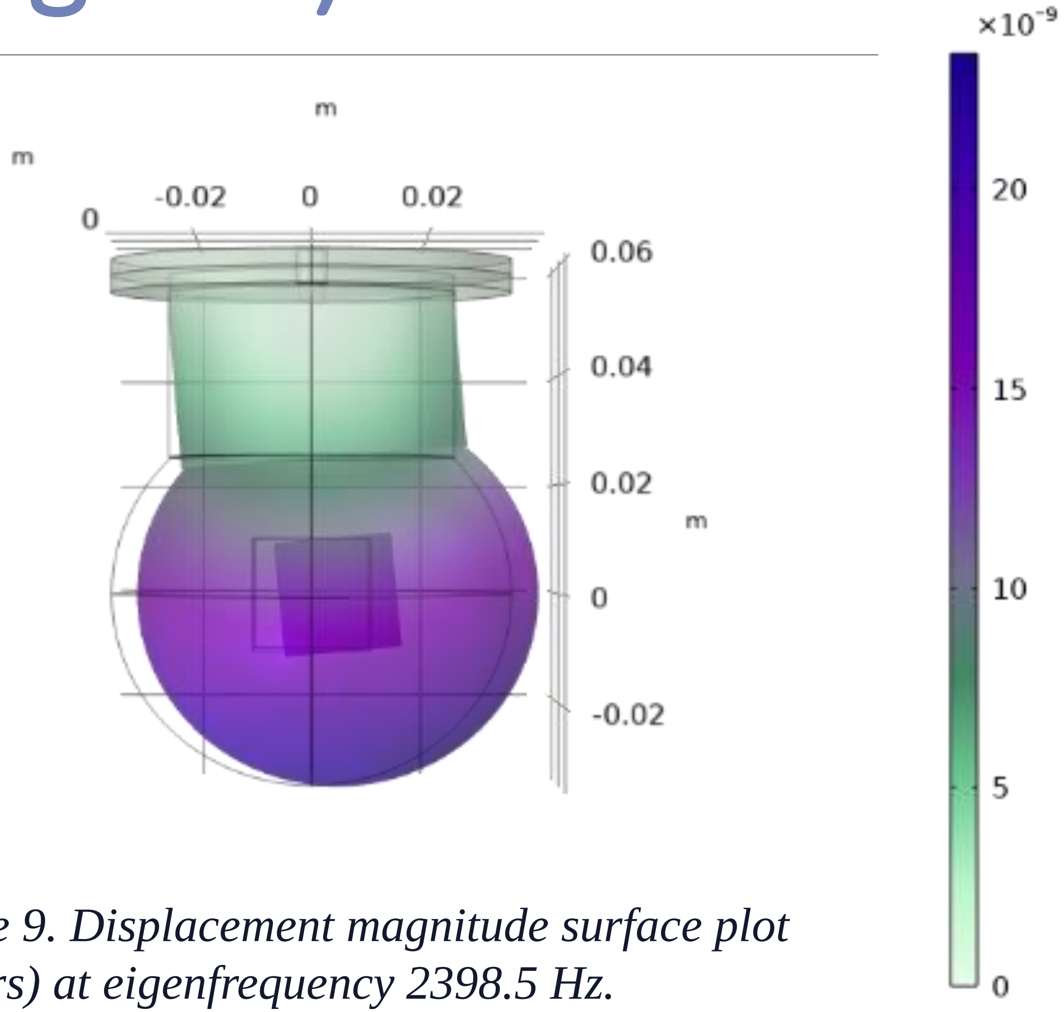

Figure 9. Displacement magnitude surface plot (meters) at eigenfrequency 2398.5 Hz.

Simulation Result: Eigen frequency analysis (model 2: With Suspending Rod)

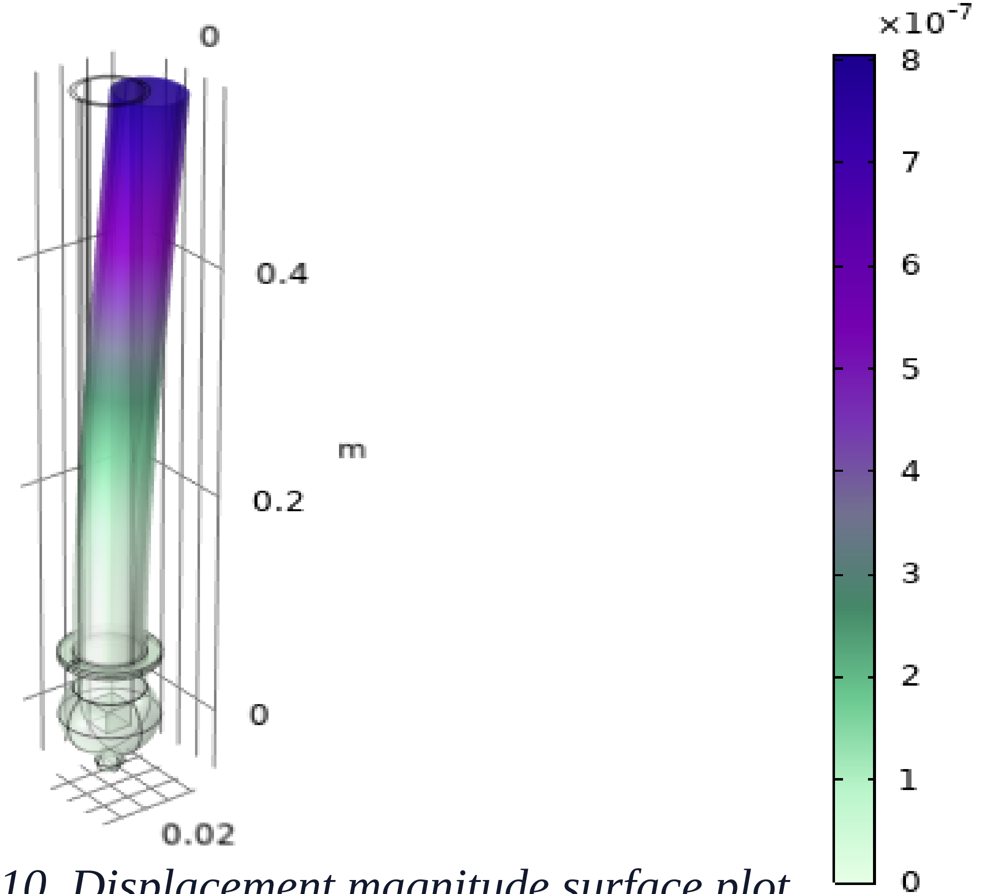

Figure 10. Displacement magnitude surface plot (meters) at eigenfrequency 144.16 Hz.

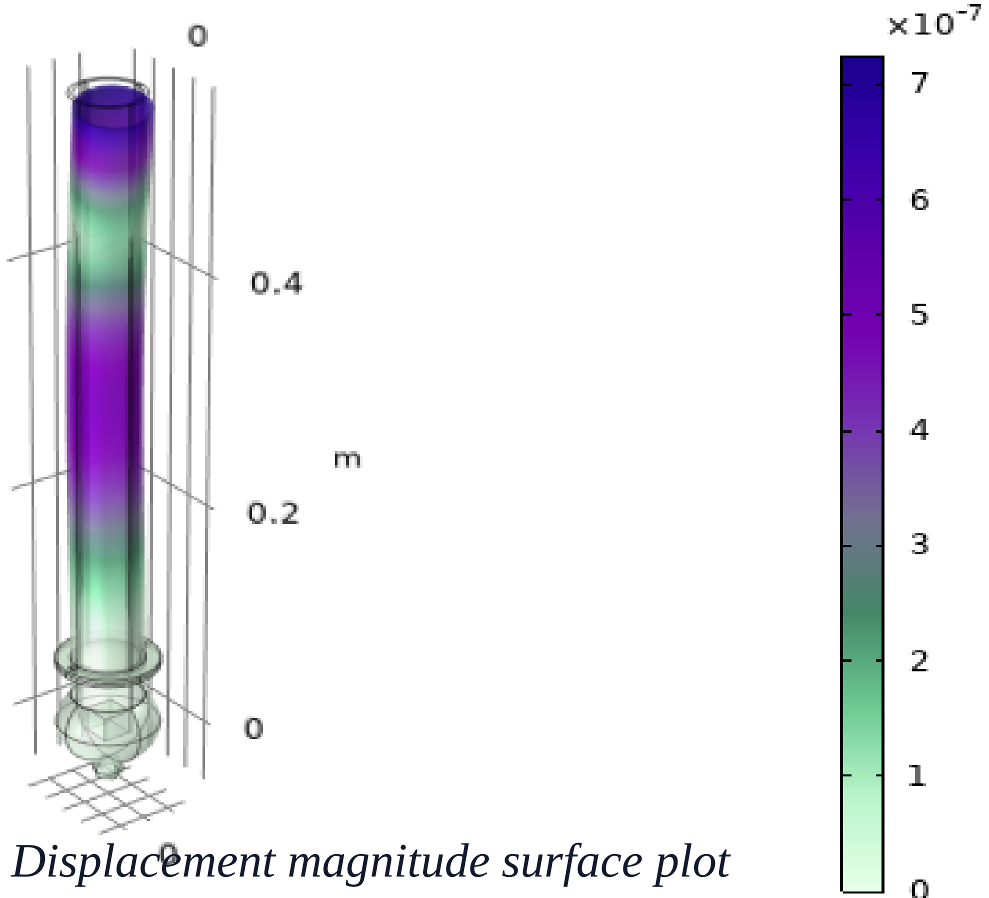

Figure 11. Displacement magnitude surface plot (meters) at eigenfrequency 875.78 Hz.

Simulation Result: Eigen frequency analysis (model 1: Without Suspending Rod)

Table *: Eigen frequency values obtained for model 1*

Sr. No.	Eigenfrequency (Hz) for model 1
1	2332.1
2	2398.5
3	5184.6
4	7405.7
5	10367
6	10401
7	26251
8	26333
9	28014
10	35282
11	38409
12	38583

Simulation Result: Eigen frequency analysis (model 2: With Suspending Rod)

Table *: Eigen frequency values obtained for model 2*

Sr. No.	Eigenfrequency (Hz) for model 2
1	144.157
2	144.161
3	875.779
4	875.808
5	1589.004
6	2337.824
7	2337.916
8	2516.898
9	3163.250
10	3164.153
11	4334.022
12	4334.269

Simulation Result: Eigen frequency analysis

- It can be observed that the maximum displacement experienced is 0.8 micrometers for model 1 and 20 nanometers for model 2, both of which are relatively small.
- Notably, in model 2 with rods, the displacement at the AVS body is nearly negligible, except at the eigenfrequency of f=3163.3 Hz & f=3164.2 Hz, where some displacement is evident.
- Eigen frequency analysis of AVS with and without the suspending rod structure is carried out for better understanding of the resonant frequencies and mode shape present.
- Also the eigenfrequency analysis generates a reduced order model (ROM) based on which further computations are done.

Input Random Excitations as Interfering Vibrations Sources

- Once ROM is generated, for further computations, random excitations are introduced into the structure via rigid connectors.
- These random excitations are applied in the form of PSD in the x- and z- directions.
- For our analysis purpose we have considered the frequency range 10-1000Hz which usually covers the vibration of sources from the propulsion system , machinery and some resonant frequencies of the suspending structure.
- Several variations in the range 10 Hz to 1000 Hz are taken into account to ensure a comprehensive analysis.
- Figures 12-16 illustrate the PSD of these input loads for different combinations considered.

1. Flat shape vibration source within frequency range of 300-700 Hz

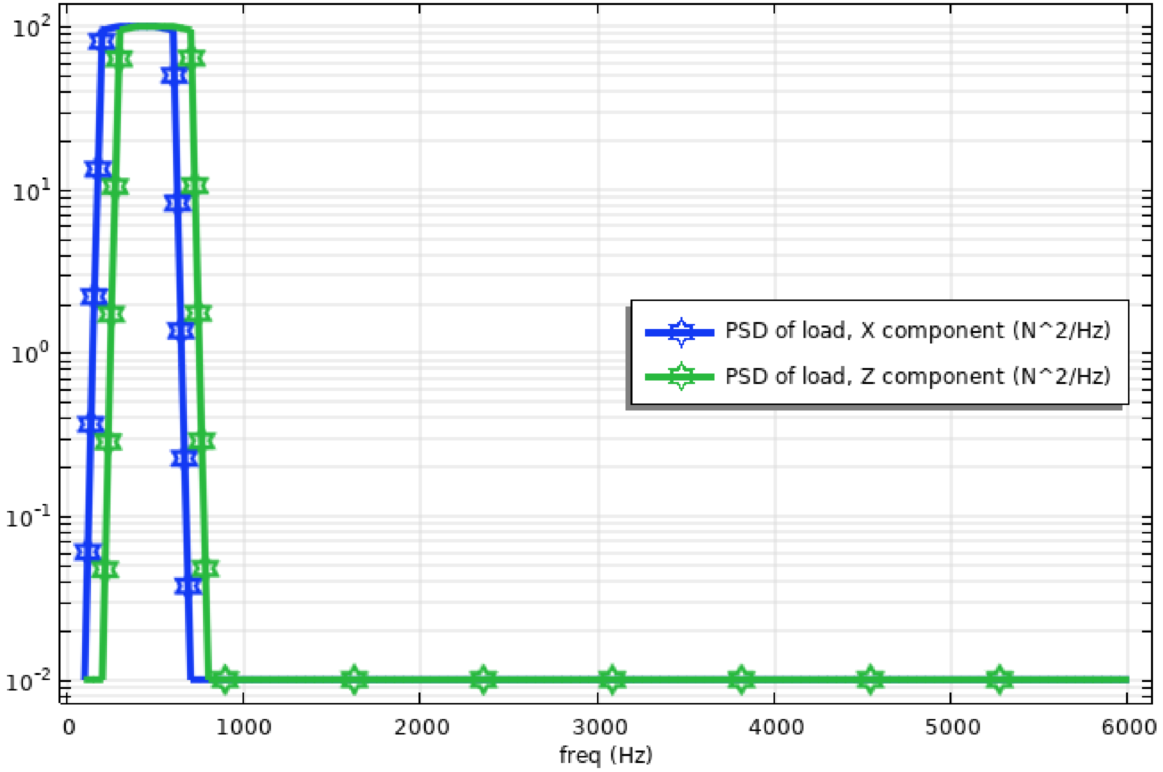

Figure 12. PSD of loads applied (N^2/Hz) (y-axis in log scale).

Input Random Excitations PSDs

2. Tonal vibration source case

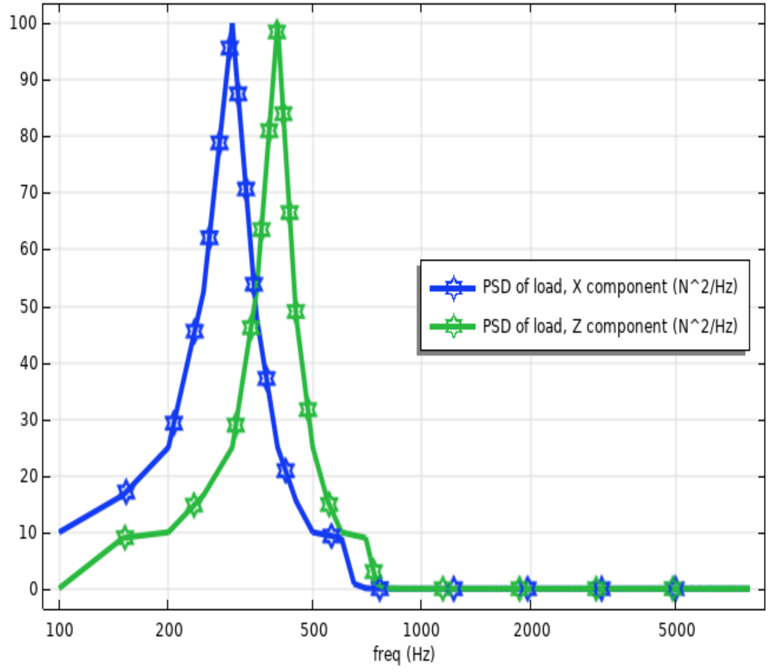

Figure 13. PSD of loads applied (N^2/Hz).

3. Vibration sources present at the higher frequency end of the 10-1000Hz band.

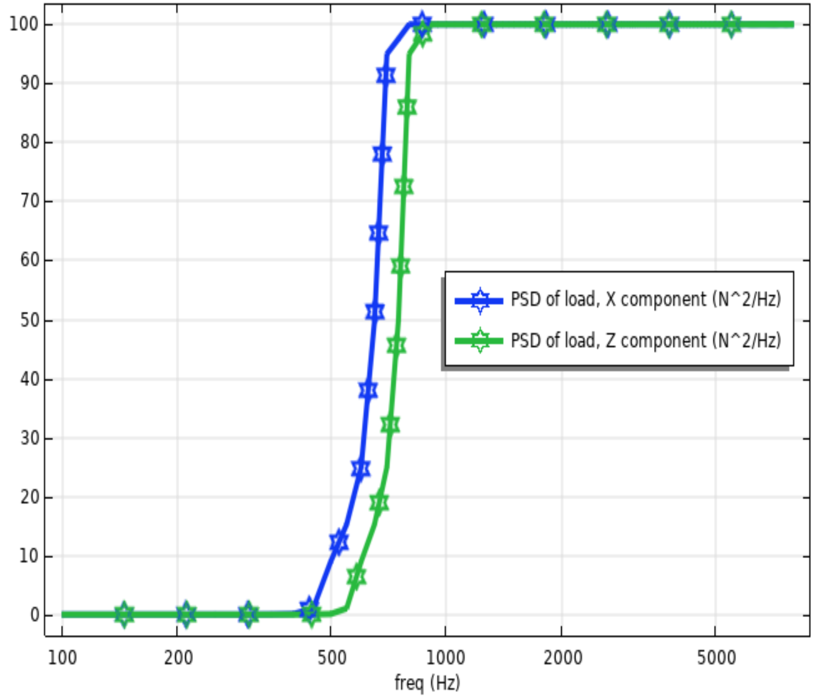

Figure 14. PSD of loads applied (N^2/Hz)

4. Vibration sources present at the lower frequency end of the 10-1000Hz band.

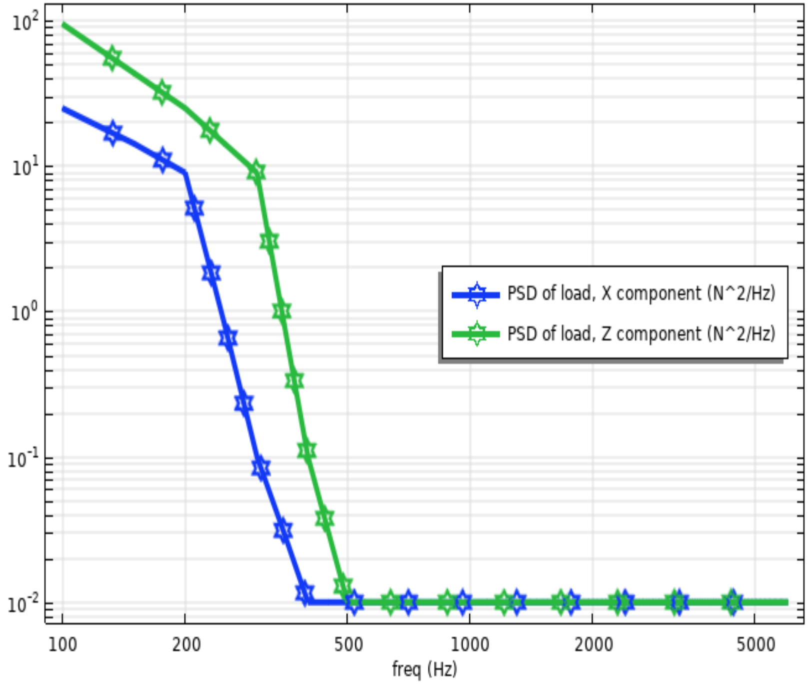

Figure 15. PSD of loads applied (N^2/Hz) (x- & y-axis in log scale).

Input Random Excitations PSDs

5. Propeller vibration source case

- More specifically, when considering the primary source of vibrations from the propulsion system, it's notable that they typically operate in the range of 600-2400 rpm, corresponding to frequencies within 10 to 40 Hz.
- To investigate these vibrations in detail, we have employed the input PSD as depicted in Figure 16.

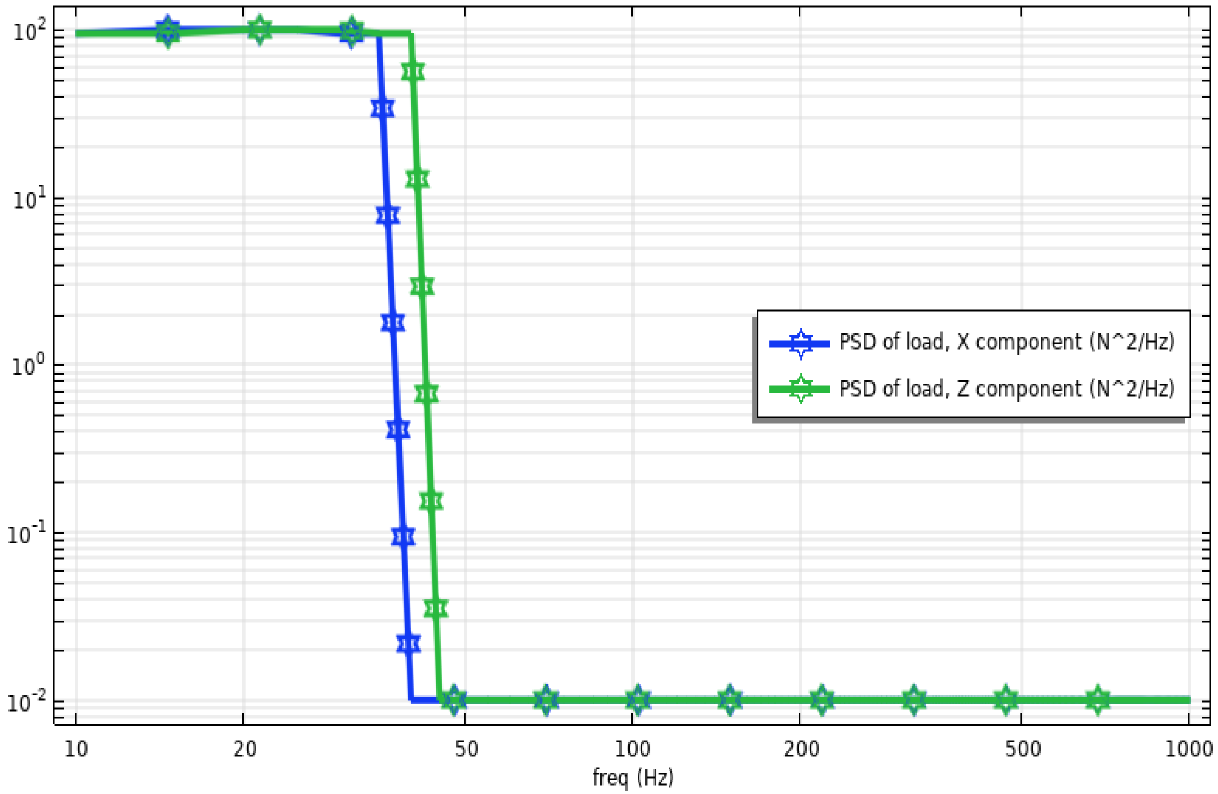

Figure 16. PSD of loads applied (N^2/Hz) for case of the vibration due to propulsion system (x- & y-axis in log scale).

Structural vibration analysis: Simulation Result

- For each of these input scenarios, we update the ROM solution obtained from the Eigen frequency analysis and analyze the displacement response at a specific point.
- This point is characterized by coordinates: X = -0.035 m, Y = 0 m, Z = 0 m, and it holds significance as a representative location on the outer casing of the AVS.
- As the obtained computed PSD of V and W displacement responses, expressed in (m^2/Hz), consistently indicate no displacement magnitude across various input PSDs of various structural vibration sources.
- This outcome is expected accordingly to the sets of Eigen frequencies obtained.
- Thus it can be inferred that these structural vibration sources do not interfere with the operational frequency range of the designed AVS when mounted on platforms such as AUVs.

Conclusion

- It is concluded that these structural vibration sources do not disrupt the operational frequency range of the designed AVS when mounted on platforms like AUVs using suspending structure, here it is the rod of length 50 cm with flange connector.
- However, it's worth noting that in the future, exploring different suspending structures is valuable.
- Moreover, the study presented here can be extended up to 5 kHz, considering that changes in interference become more pronounced according to the Eigen frequency sets obtained in the Eigen analysis.
- The inferences will allow us to design appropriate isolation mechanisms to reduce mechanical coupling between the AUV platform and the AVS resulting in more accurate AVS measurements.

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