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PREDICTION OF NOISE LEVELS WITHIN A SUBMERGED VESSEL BY STATISTICAL ENERGY ANALYSIS

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The aim of this study is to develop a sound transmission model that can be used to predict the vibration and noise levels of a submerged vessel. The interior noise transmitted from mechanical vibrations of the hull of a submarine and the turbulent boundary layer excitation on the submarine are investigated. A simplified physical model of the submarine hull, which includes effects of bulkheads, end enclosures, ring stiffeners and fluid loading due to the interaction of the surrounding medium, is presented in the study. An energy approach, i.e., Statistical Energy Analysis (SEA) is used for the analysis because the characterization of the hull of the structure can be done by a very large number of modes over the frequency range of interest as deterministic analysis methods such as finite element and boundary element formulations are limited to low frequency problems. The SEA model application consists of the determination of SEA subsystems and parameters and the utilization of power balance equations to estimate energy ratio levels of each subsystem to that of the directly excited subsystem. Through the implementation of SEA method, sound pressure levels within the hull of the structure are obtained. In terms of military purposes, sound levels within the submarine compartments are vital in the aspects of preserving of submarine stealth.

1. Introduction

It is crucial that submarines or submerged bodies in the sea run as quietly as possible to reduce the probability of detection. Significant vibration levels stemming from the submarines' machinery and the flow are transmitted through the hull of the structure, which is unwanted for quiet operation[1]. Many noise sources such as auxiliary machines of the submarines are not in direct contact with the fluid. However, vibrations generated by these sources when not absorbed by special mountings or techniques in-situ are transmitted to radiating surfaces. The noise levels both for the near-field and far-field are important at the sides of noise exposure of the submarine crew as well as survivability of sensitive equipment mounted in submarine and detectability of the structure, successively. Reduction of this structure-borne radiated noise is necessary for the structure in order to provide comfortable and quiet working space for the crew and the interior equipment and preserve its stealth in operational conditions against the enemy vessels around the structure. Due to the fact that structure-borne noise modelling of an underwater structure is an important issue, a careful assessment and analysis should be conducted.

The focus of this work is to investigate the noise levels inside a submerged structure under two different configurations using Statistical Energy Analysis (SEA). The methods such as finite element and boundary element are insufficient or impractical when the system is characterized by a very large number of modes over a high frequency range of interest. Moreover, the higher order mode analysis is sensitive to small changes in structure geometry and material properties. For such complex problems, Statistical Energy Analysis (SEA) is the inevitable methodology that takes the irregularities of the system into account[2]. On the other hand, the moderate detail requirements make SEA less exhausting and expensive than finite element methods.

2. Model Development

In this study, the submarine model used in the study of Caresta and Kessissoglou on low frequency vibration of a submerged hull is utilized. The submarine is composed of a 45 m length and 40 mm thick cylindrical shell stiffened with 90 stiffeners, 2 bulkheads and 2 end caps. The stiffeners have a rectangular cross section 0.08 m x 0.15 m and their spacing is 0.5 m along the cylinder shell[3]. In order to predict noise transmission in an underwater structure using SEA method, VA One software product is used. The physical system elements used in the model are the regularly framed underwater structure, fluid around the structure and the machinery sources (Figure 1).

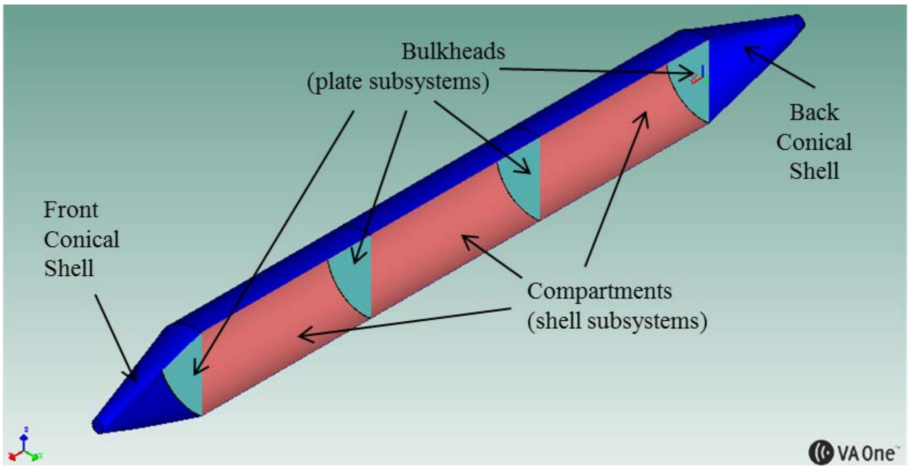

Figure 1. The submarine model developed in VA One

In the analysis, all compartments are presented as cylindrical shell subsystems whereas the bulkheads of the structure are plate subsystems. For shell and plate subsystems, the wave propagates in two dimensions. The ring stiffeners are defined in the software product, which enables the users characterize the subsystem as ribbed plate in the property selection. The fluid medium (air) in the compartments is modelled as acoustic cavities of the system. The acoustic cavities are then used to represent wave propagation in three dimensions. The external section of the structure is subjected to turbulent flow by sea water. In the model, there are 11 subsystems, 5 acoustic cavity subsystems, 11 area junctions and 4 line junctions. The plate and shell subsystems are coupled with each other through line junctions, the coupling of the acoustic cavities and shell and plate subsystems is provided by area junctions. The construction of these subsystems and junctions is achieved through SEA method.

3. Analysis & Results

With the creation of the subsystems and junctions of the submarine model, the analysis to get the sound level predictions within the submarine compartments can be performed.

3.1 Evaluation of Modal Density Parameter

The modal density of a subsystem gives the number of modes per unit frequency. This parameter for a subsystem can be evaluated with the developed model in VA One. In Figure 2, modal densities of conical shell and compartment subsystems are given.

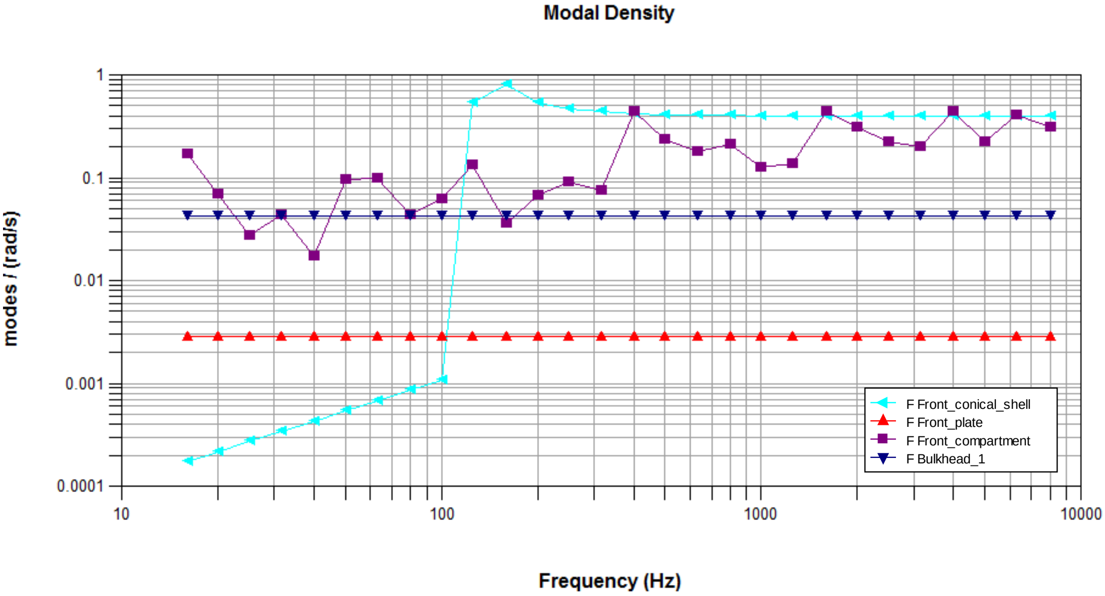

Figure 2. Modal Density of the Compartment Subsystem

The modal density concept is highly dependent on the geometry, material and frequency of the structure. For flat plates, the modal density is independent of frequency and the values for the bulkheads are constant for all the frequencies. At high frequencies, the subsystems' modal densities reach to constant values except the compartments. This is because the modal density of the shell approaches the modal density of a flat plate[4]. The acoustic cavity subsystems, filled with air inside the compartments, display high modal density characteristics.

The SEA method is applied when the modal density values of the subsystems are high enough. Thus, above 100 Hz the developed model has reliable results and the frequency range of this problem can be noted as between 100 Hz and 8 kHz.

3.2 Prediction of Sound Level inside the Compartments

After model development, energy balance equations are formed. In the analysis, the damping loss factors of the subsystems are chosen as 1%. Responses predicted by SEA method are proportional to the power input. The input excitations are engine air-borne noise (ABN) and turbulent boundary layer noise (TBL). The analyses for the two excitations are conducted for each operating conditions. The configurations used in the analyses are given in Table 1.

Table 1. Analysis Configurations

First Condition TBL noise	Depth	5 m
	Speed	5 m/s
		10 m/s

Second Condition Engine noise (ABN) TBL noise	Depth	5 m
	Speed	5 m/s
		10 m/s

In order to discern the effects of the noise sources separately for the noise levels within the compartments of the submarine model, the analysis is conducted for different conditions for the input loadings and speed of the submerged vessel considering the submerged condition of a submarine.

A-weighted sound levels are presented between 31.5 Hz and 8000 Hz, which is the frequency band for the given input, in 1/1 octave band centre frequencies.

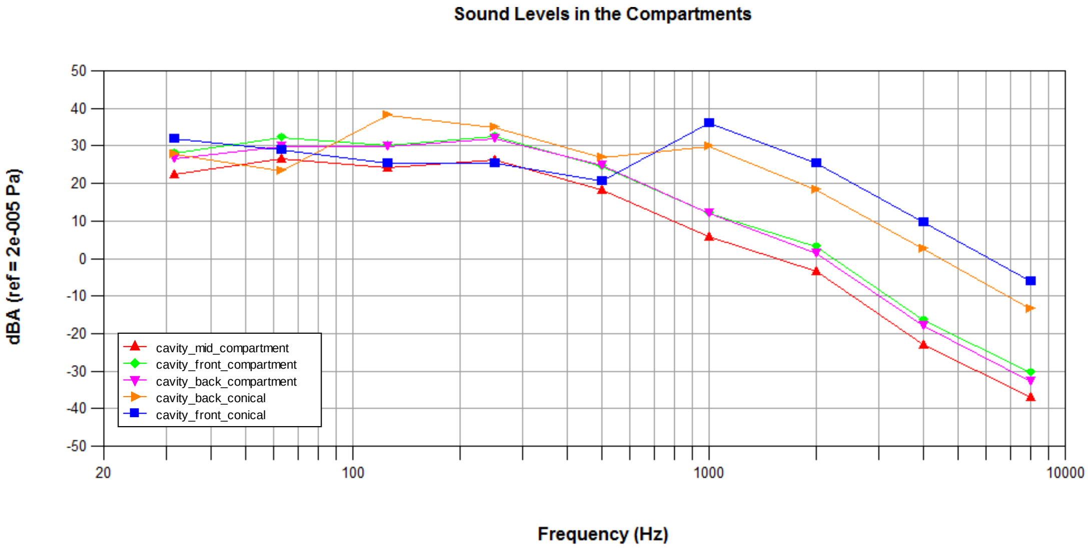

Figure 3. SEA Estimation for the Sound Levels within the Compartments (1st Condition - 5 m/s)

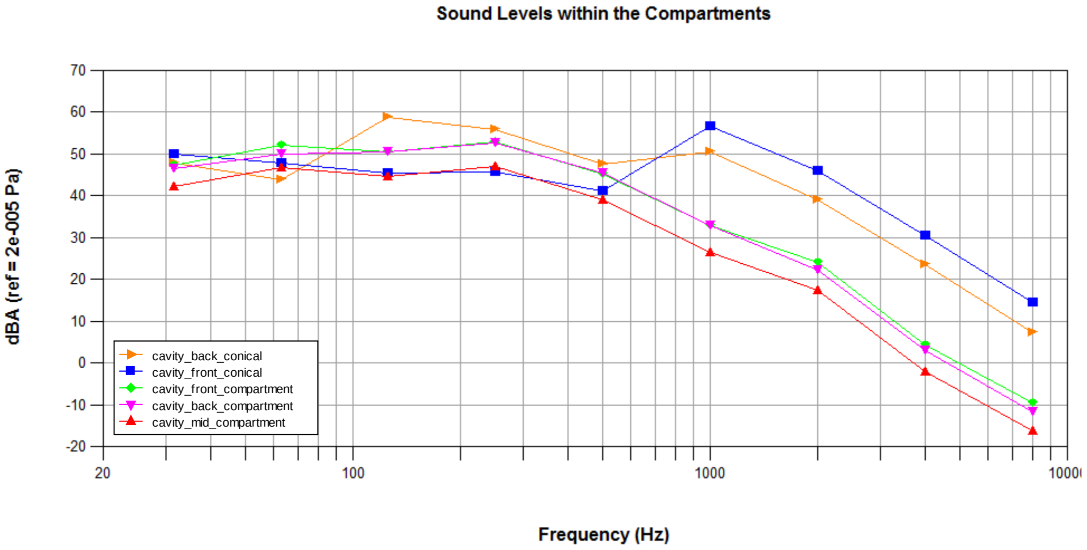

Figure 4. SEA Estimation for the Sound Levels within the Compartments (1st Condition - 10 m/s)

For the first configuration, TBL noise contribution is analysed. In terms of the magnitude, the TBL noise results in low noise levels within the compartments. When the results of the sound levels within the compartments are examined, at low frequencies the values are close to each other. For mid and high frequencies the values within the conical compartments are getting higher compared to cylindrical shell compartments. At some frequencies distinct peak values can be observed for the compartments with conical shapes. In addition, above 1000 Hz, the front conical compartment is the noisiest region due to higher values of the vibration velocity for the submarine model. This can be better explained by the flow direction.

As the submarine moves faster, the sound levels are getting observably higher owing to increases in the velocity levels. It can be noted that the sound levels increase nearly 15 dB at the speed of 10 m/s for all the frequency range.

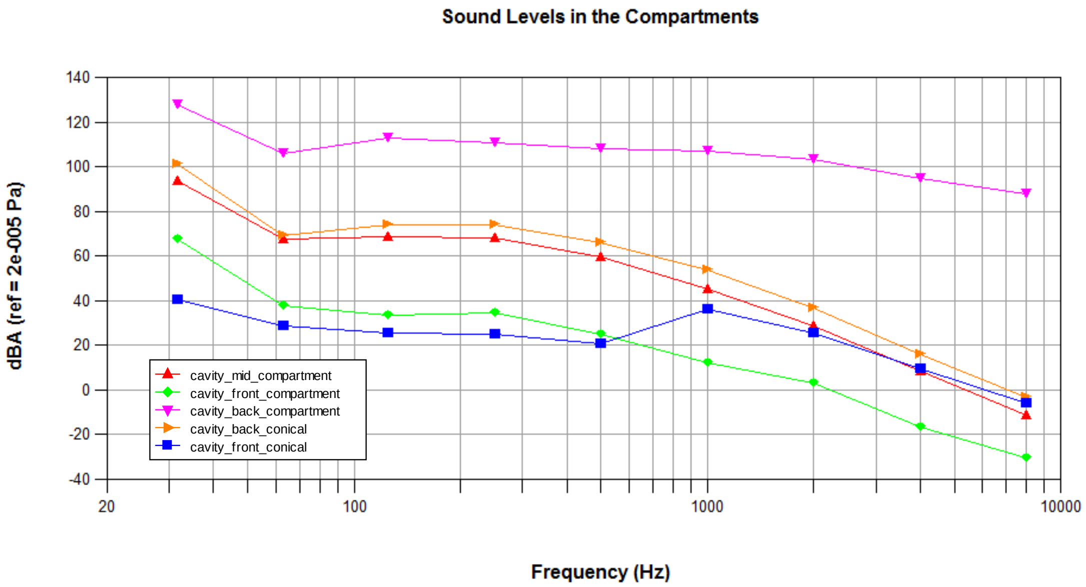

Figure 5. SEA Estimation for the Sound Levels within the Compartments (2nd Condition - 5 m/s)

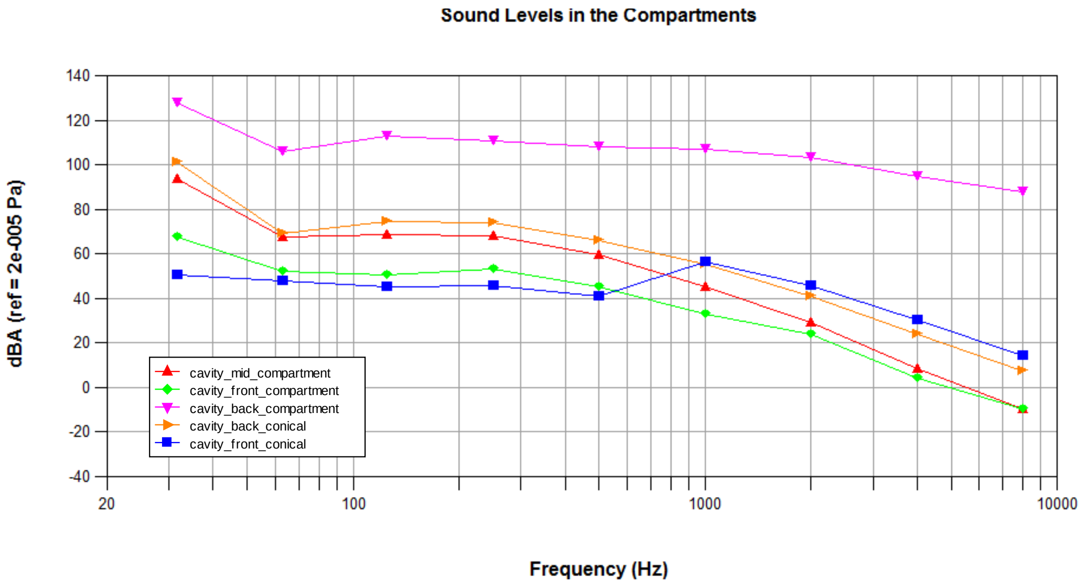

Figure 6. SEA Estimation for the Sound Levels within the Compartments (2nd Condition - 10 m/s)

When the air-borne noise levels of the machine are added to the system, it is obvious that the sound levels of the compartments increase remarkably, especially the sound levels inside the rear compartment increase appreciably. The curves of the sound levels within the compartments are parallel to each other and are arranged in descending order, from the back compartment to the front compartment.

For high frequencies, the values of sound levels of the compartments are getting closer. For mid and high frequencies, the compartments except the back compartment at the speed of 10 m/s have nearly 2 dB higher values than the values related with the speed of 5 m/s. When the engine ABN is introduced to the submarine, the effects of the change in the speed due to TBL excitation are not noticeable.

4. Conclusions

This study presents a model to describe the acoustical behaviour of a submarine under different loading conditions. The sound levels within the compartments due to turbulent boundary layer and engine excitations are predicted. Results show that effect of TBL excitation on interior noise levels of the submerged structure depends on the speed of the submerged structure, as anticipated. When only TBL noise excitation on the structure is applied, lower sound pressure levels within the compartments are obtained. The effect of TBL originated noise can be seen notably for mid and high frequencies as the submerged structure is analysed under TBL and engine noise excitations. The extent of contributions of these two excitations into overall noise within the compartments has been demonstrated through the study. High sound and vibration levels are obtained in this study due to the fact that low damping and low absorption values are used in the analyses. Another reason can be attributed to the direct introduction of sound and vibrational power levels into the structure. The damping and absorption factors are important parameters in aspects of noise and vibration transmission.

REFERENCES

[1] Ross D., *Mechanics of Underwater Noise*, Pergamon Press, Oxford, (1976).

[2] Lyon R. and DeJong R., *Theory and Application of Statistical Energy Analysis*, Butterworth-Heinemann, Second Edition, (1995).

[3] Caresta M., Kessissoglou N.,“Acoustic signature of a submarine hull under harmonic excitation”, *Applied Acoustics,* 71, pp. 17-31, (2010).

[4] Langley R. S. and Bercin A. N., “Wave intensity analysis of high frequency vibrations”, from the collection “Statistical Energy Analysis, An Overview, With Applications in Structural Dynamics” by A. J. Keane and W. G. Price, Cambridge University Press, (1994).

[5] ESI Group, VA One 2010.5 User’s Guide, (April 2011).

[6] Cavcar Yayladere B., *Prediction of Noise Transmission in a Submerged Structure By Statistical Energy Analysis,* Master Thesis, Middle East Technical University, (2012).