Mugla Journal of Science and Technology

NOISE AND VIBRATION DAMPING FOR YACHT INTERIOR

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Received: 23.11.2016, Accepted: 06.12.2016
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Abstract

Vibration damping and sound insulation are essential for all vehicles. Because moving parts and external factors such as wind, tracks, etc. can cause vibration and noise. Wave which is a dynamic force, drive system and HVAC (heating, ventilation and air conditioning) systems are the main vibration and noise generators in a vessel. These all can affect comfort level on board yachts. Different types of isolators and absorbers such as sylomer®, cork panels, etc. are used to reduce these effects. Comfort level on board yachts can be increased using these types of materials. Otherwise, discomfort of passenger and crew may increase. These materials not only reduce structure-borne and air-borne noise and vibrations from waves, air, engines, pumps, generators and HVAC systems but also protect vibration sensitive interior or fittings. Noise and vibration evaluation is an important issue for this reason. And, measurement tools must be used not only to minimize this problem but also fulfill the regulations such as "comfort class". Besides, providing quiet and low vibration increases the costs too. From this point of view, this study aims to explain clearly how noise and vibration damping can be done in a yacht.
Keywords: Sound insulation, Vibration damping, Yacht interior

YAT İÇMEKANI İÇİN GÜRÜLTÜ VE TİTREŞİM SÖNÜMLEMESİ

Özet

Titreşim sönümlemesi ve ses yalıtımı tüm taşıtlar için gereklidir. Çünkü hareketli parçalar ve rüzgâr, zemin, vd. gibi dış etkenler titreşime ve gürültüye neden olabilirler. Dinamik bir kuvvet olan dalga, tahrik ve iklimlendirme sistemleri deniz taşıtlarındaki temel titreşim ve gürültü üreteçleridir. Bunların hepsi yat üzerindeki konfor seviyesini etkileyebilir. Sylomer®, mantar panel, vd., değişik tipte izolasyon malzemeleri ve soğurucular, bu etkileri azaltmak için kullanılmaktadır. Aksi durumda yolcu ve mürettebat konforu azalabilir. Bu malzemeler sadece dalga, hava, motor, pompa, jeneratör ve iklimlendirme sistemlerinden kaynaklanan yapı ve hava kaynaklı gürültü ve titreşimleri düşürmez aynı zamanda titreşime duyarlı iç mekân ve donanımları da korur. Gürültü ve titreşim ölçümü bu sebeplerden dolayı önemli bir konudur. Ve ölçüm aletleri sadece bu sorunu en aza indirmek için değil aynı zamanda "Klas" gereksinimlerini karşılamalıdır. Bunun yanında, daha sessiz ve titreşimsiz bir ortam sağlamak maliyeti arttırır. Bu bakış açısıyla bu çalışma bir yatta gürültü ve titreşim sönümlemesinin nasıl yapıldığını anlaşılır şekilde açıklamayı amaçlamaktadır.
Anahtar Kelimeler: Ses izolasyonu, Titreşim sönümleme, Yat iç mekânı

1 Introduction

Noisy equipment such as power generators, engines, HVAC systems and etc. must be insulated to provide comfortable environments. Noisy equipment especially generates a loud, unpleasant or disturbing sound for perceivers by interfering with hearing. If this sound waves are around 20-20kHz than most of us can hear it [1]. This is related with amplitude and frequency of the sound and in general stated by using dB (decibel) abbreviation. This sound causes vibration while transmitted through medium such as air, liquids or structural members such as walls or floors. And vibration has its own sound waves that are generated by mechanical oscillation.

Vibration and noise are crucial facts for yachts (especially for superyachts). ISO 6954:2000 expresses the guidelines of vibration requirements for habitability on board but higher comfort requirements may provide lower specs. Higher comfort demands not only increases the building cost but may also affects the weight of yacht, delivery time, design activity, layouts and volume arrangement and thus complicate the building activity. According to Boote et al. [2] weight increase estimation is more than 100 tons to reduce vibration of a yacht between 90 to 100m. And this may mean additional fuel consumption.

Increase in performance and size lead to reduction necessity of vibration and noise especially for building comfortable yachts. And this can be achieved by designing new shapes and lay outs and using new construction materials to form a better structure [3]. Accordingly, Fricke and Bronsart [4] remark the importance of design as saying "*Vibration and noise are important design criteria*". But also according to them theoretical prediction of noise is not fully trusty.

Comfort on board means low levels of vibration and noise and these two are closely related to hull structures [3]. Noise and vibration may cause discomfort to passengers and crew [5] and onboard comfort of passenger and crew depends on exposure duration to vibration [6]. Also they can cause damage to sensitive tools or equipment, structural parts and interior fittings too [7].

From this point of view, this study aims to explain how noise and vibration damping are done for yachts in terms of used equipment.

2 Noise and Vibration

There are lots of vibration and noise sources in a vessel and these may include [8];

- Driving mechanisms such as engines
- Shaft-line dynamics
- Pressure radiated from propeller and forces
- HVAC installations
- Maneuvering devices
- Cargo handling and mooring machinery
- Vortex shedding
- Intakes and exhausts
- Slamming phenomena

And according to Fricke and Bronsart [9] waves, vortex induced vibration, ice, internal flow, machinery, propellers, and blast are some of the exciting mechanisms or sources. These mechanisms must be in depth evaluated to provide lower specs.

Distance between source and perceiver must be well arranged to provide a cheaper sound reduction. Using noise barriers, damping structures or active antinose equipment is technical and expensive but better way to achieve this. In yacht interior distance between source and perceiver arrangement maybe not enough to provide comfortable environment due to both internal and external factors such as wind waves especially in rough water.

2.1 Wave-Induced Vibrations

Wave-induced vibration of hull has an important impact on interior construction with regards to structural design. According to Fricke and Bronsart [10] wave is a critical feature in design and re-assessment that may reason crucial impacts on many offshore structures.

These types of vibration is divided into two; springing and whipping. These two can be assumed as transient oscillations which occur from the environmental effects. According to Storhaug *et al*. [11; 12; 13] considering of wave-induced vibration in design stage was recommended to minimize negative effects.

2.2 Machinery or Propeller-Induced Vibrations

Machinery such as marine generators generates vibrations as known. These vibrations is being damped by using different mounting materials such as rubber core mounts or else.

Propulsion and its systematic design have significant impact on damping the oscillation. If counter-rotating propellers is used for propulsion then decrease of oscillations magnitude is conceivable. That's why sound and vibration damping is a more than issue to provide comfortable structures.

Irregularity of water inflow through the propeller can induce different pressure on blades. So, non-uniform wake generates propeller induced vibrations. And, these vibrations are transmitted through shaft to surrounding structure [14]. It's noted that coupling between structure and shafting should be designed well to minimize the vibration level. According to Lee et al [6] propeller can cause extreme stern vibration. That's why Cao et al [14] stated that proper rear bearings must be used to achieve minimum vibration transfer from the propeller excitation. Considering that an accurate estimation of noise and vibration is essential.

2.3 Noise

It's important to minimize noise as much as it gets for comfort of crew and passengers on board because noise has a negative impact on human psychology as well as performance. Especially interior noise is much more important than air- and underwater-radiated noise for habitability on a yacht.

Juras [15] stated that wooden vessels have better characteristic than steel, aluminum and FRP yachts for noise up to 125 Hz. Also noise level of large ships is generally higher than smaller ones [3]. Similarly, Metin [16] stated that faster and bigger yachts mean increasing noise.

3 Literature Review

Zhou and Croker [17], Cha and Chun [18] and Song et al [19] studied performance of acoustic insulation components to determine the loss on values of sound transmission.

According to Anon [20] designers generally decide to use absorption (fibrous or cellular such as mineral wool, fiberglass, ceramic, melamine, polyamide and urethane), barrier (existing structures such as walls, cabinets, enclosures and etc. and supplemental ones), dampers (viscoelastic forms in homogeneous or free-layer and constrained layer) and gasketing (sealable and conformable to the irregular surfaces) materials.

According to Fricke and Bronsart [10] passive mountings are the one of the approaches to cut off conduction of vibration occurs from machineries. Moon et al. [21] applied a hybrid dampener, rubber and piezo-stack actuator combined, to provide a damping mount that has fast responding, small displacement and low power consumption features.

A complete analysis of vibration and noise requirement of American Bureau of Shipping (ABS) is presented by Baker and McSweeney [22]. Out of ABS, followings regulate the comfort level of yachts; Bureau Veritas, Det Norske Veritas, Germanischer Lloyd, Lloyd's Register and RINA.

And, in table 1, 2 and 3 some requirements are summarized by [3] in terms of yacht length and location according to some of these Classification Societies.

Table 1. Whole body vibration limits according to length.

Yacht length (m)	Notation	Freq. Range (Hz)	Acceleration Measurement	Maximum level	
				Underway ($mm/s^{2)}$	Anchor mm/s^2
L≤45	Comf(Y)	1-80	α_w (v)	89,4 (2,5)	53,5 (1,5)
	Comf+(Y)	1-80	α_w (v)	53,5 (1,5)	45 (1,25)
L≥45	Comf(Y)	1-80	α_w (v)	71,5 (2)	45 (1,25)
	Comf+(Y)	1-80	α_w (v)	53,5 (1,5)	35,75 (1)

αw = multi axis acceleration value calculated. v = spectral peak of structural velocity.

Table 2. Whole body vibration limits according to locations.

Locations	Bureau Veritas		Lloyd's Register		RINA	
	Freq. *(Hz)*	*v (mm/s)*	Freq. *(Hz)*	v_{rms} *(mm/s)*	Freq. *(Hz)*	*v (mm/s)*
Cabin and Lounges	1-80	1-3	1-80	1,8-2,5	0-100	1-3
Public spaces	1-80	1-3	1-80	2,5-3,3	0-100	1-3
Open recreation decks	1-80	2-4,5	1-80	2,5-3,8	0-100	2,-4

v_{rms} = overall frequency weighted r.m.s. value of vibration. v = spectral peak of structural velocity.

Table 3. Maximum noise levels for superyachts both for harbored and sailing conditions. Values in dB (A).

Spaces	Lalangas [23]		ABS Comf (Y)		BV		GL (Cruise Ship)		LR	RINA
	Harb	Sail	Harb	Sail	Harb	Sail	Harb	Sail	Harb Sail	Harb Sail
Owner Cab.	35	73	40	45	40	50	44	52	50	45
Guest Cab.	35	73	45	50	40	50	46	54	53	45
Lounge	40	77	50	50	45	55	52	60	55	55
Ext. decks	50	89	60	65	55	75	64	72	63	55

Juras [15] studied noise assessment of a small vessel and tried to figure out to reduce intensity of the noise sources.

According to Bronsart and Fricke [9] light, slender, and flexible structures are inherently prone to dynamic responses.

4 Application Examples

As mentioned before there are different materials that are used for noise and vibration damping. These materials are applied to different part of the yacht as seen in figures in this chapter.

Insulation of engine room is different and much more detailed than living spaces such as cabins due to intensive vibration occurs from machinery installation and fire insulation [24].

Figure 1. Rubber mount for engine fixing [1].

As seen in Figure 1, mounting tools, also pulse plates for all surfaces, must be used to prevent vibration transfer to the hull. Rock-wool (as seen in Figure 4) and lead plates used to provide fire insulation in engine room.

In galley, differently from other living spaces, walls consist of steel plates and high density rock-wool and doors have fire proof features to provide fire insulation [24].

Figure 2. Sylomer application to the floor [25].

As seen in Figure 2, sylomer®, green one, is an elastic material that commonly used for isolate noise and vibrations occur from engines, pumps and drive systems of yachts. These materials decouple the main inner structures such as cabin or floor wall from hull or main structure. Thus, all interior members such as screwed or bonded parts can be protected while airborne noise minimized and comfort level increased. Effect of Sylomers' on structural behavior of lightweight wooden construction has been investigated by Bolmsvik and Brandt [26].

Figure 3. Rubber cantilevered Z rots application.

Installation of rough wall panels to the yacht hull can be done differ ways but as seen in Figure 3, Z rots are the one of the easiest way to do this. Z rots screwed to stud bolts that are welded to yacht hull and then balsa wooden frames screwed to damping rots. As seen, honeycomb core rough wall panels screwed to this substructure to minimize the vibration and noise. These panels are hollowed due to not weight of yacht overall. Also decorative wall panels will provide noise damping addition to installed rock-wool (seen as shiny material in Figure 3).

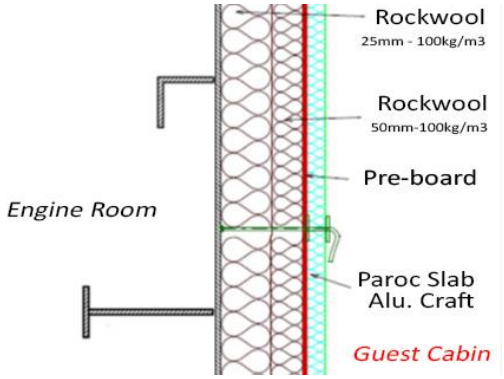

Figure 4. Separation and insulation of engine room and cabin of MY Africa [27].

Partitioning and positioning of the volumes in a yacht projects depends on length, yacht type, deck number, owner request and etc. In general, positioning a guest cabin nearby engine room (as seen in Figure 4) is not a preferred application due to aforementioned reasons.

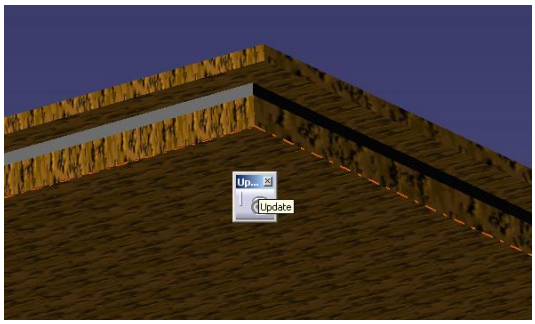

Figure 5. CATIA drawing of insulated floor panel [28].

Carpets or parquets are generally applied on a rough floor panel. These panels also consist of noise insulation or absorbing materials such as baryfol. A rough floor panel that is consists of 15mm marine plywood, 6mm baryfol as core material and 8mm marine plywood as surface is seen in Figure 5. This panel bonded with expoy resin to make it run-proof and resistant to humid conditions. Also, flexible bonding materials such as SikaFlex are used for deck or seam applications for vibration damping.

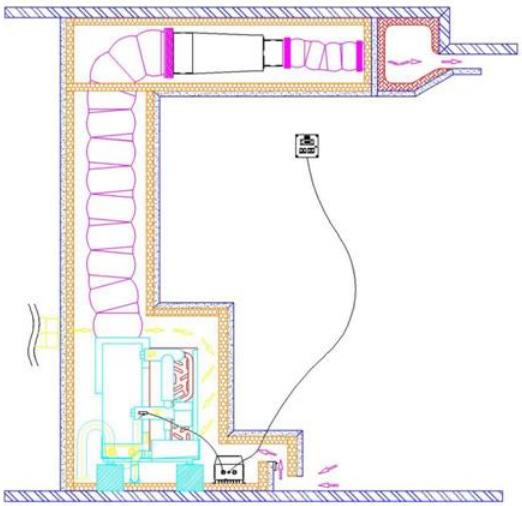

Figure 6. Hidden HVAC system of a cabin [29].

HVAC installation is a complex activity due to its location inside the living spaces as seen in Figure 6. These systems are essential for comfort onboard but generate noise and vibration as well as heat while in use. Proper materials (such as rubber mount equipment as seen in fig 1 to fix it to floor) must be used for fixing and covering the tools to prevent these negativeness. But, having said that lots of materials are heat sensitive and have a lifespan depends on running conditions.

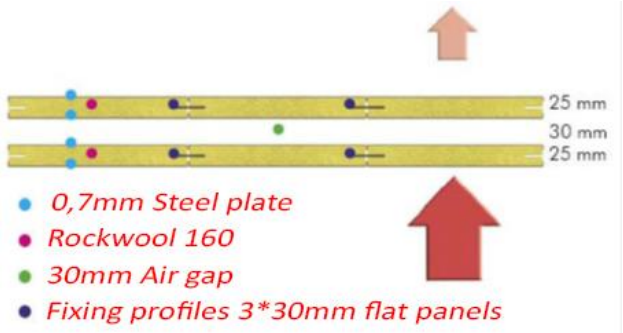

Figure 7. Double wall with air pocket [27].

Double wall is a favorable application when lower noise level deserved. In Figure 7, double wall application consists of rock-wool, air gap and rock-wool but it may differs both thickness and materials with regard to limitations, requirements, budget, and etc.

5 Conclusion

Privacy is an important indicator of yacht quality due to confined living areas especially when yacht is underway. And, either guest or owners do not want someone hear their conversations or other noises or vibrations inside the cabins. That's why noise and vibration damping and monitoring is an important issue.

In short, you have to interrupt the transmission of sound and this is the key to provide a silent environment [30]. Using aforementioned materials or tools is effective way to achieve this goal up to some extent. But it may be said that it's not possible to zeroize these negativeness by using existing materials or tools.

Yacht type and length, owner demands, class requirements and design parameters must be taken into consideration while evaluating or calculating noise and vibration features at the beginning project.

6 Acknowledgment

This study was presented as an oral presentation at the II. International Furniture Congress (IFC 2016), 13-15 October 2016, Muğla, Turkey.

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