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Analysis Of The Use Of Fiber-Metal Laminates Material To Reduce Vibrations In L-Extension Type Pedestals Using Finite Element Method

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Abstract

Engine vibration transmitted through supporting pedestals can reduce the durability of ship structures and affect onboard comfort. Fibre-Metal Laminates (FMLs) may improve vibration isolation through impedance mismatch between their metal and composite layers. This study aims to determine the effect of FML material type, layer arrangement, and placement location on the vibration and structural responses of an L-extension pedestal. Finite Element Analysis was performed in Abaqus. GFRP, CFRP, and unidirectional carbon-fibre prepreg (UD-CFP) were modelled in three- and five-layer arrangements. Four material placement configurations were evaluated in the simulations. The dynamic response was analysed at 24 frequency points from 10 to 250 Hz using the Total Vibration Level Drop, while structural performance was assessed using maximum von Mises stress. The steel baseline produced 21.187 dB and 28.62 MPa. Applying FMLs to the entire structure gave the best vibration isolation. Five-layer AL/GFRP/AL/GFRP/AL produced the highest vibration level drop of 32.064 dB but increased stress to 42.65 MPa. Three-layer AL/UD-CFP/AL was selected as the optimum configuration, producing 30.122 dB and 33.71 MPa.

Keywords: Ship Structure Vibration, Fibre-Metal Laminates, L-extension Pedestal, Finite Element Analysis, Total Vibration Level Drop

1. Introduction

Mechanical vibrations generated by marine engines are transmitted through supporting pedestals, which can significantly degrade component durability and onboard comfort if not properly isolated (Zhao et al., 2021). To address this issue, structural design approaches utilizing the impedance mismatch principle have been developed to attenuate elastic waves by altering material properties, cross-sections, or structural shapes. For instance, L-extension pedestal designs employ L-shaped geometries to generate multi-reflection and wave conversion along the vibration path, demonstrating superior total vibration attenuation compared to conventional designs (Zhao et al., 2021).

In addition to structural modifications, material selection plays a pivotal role in optimizing vibration isolation. Fibre-Metal Laminates (FMLs), which combine the high stiffness of metals with the exceptional viscoelastic damping of composites, offer a highly stable and lightweight alternative for marine pedestals (Chen et al., 2025; Merzuki et al., 2021). Furthermore, the multi-layered hybrid architecture of FMLs facilitates directional control of wave propagation, which can significantly amplify the impedance mismatch effect on structures like the L-extension (Wang et al., 2025).

Previous studies have generally examined L-extension geometry and Fibre-Metal Laminates as separate approaches to vibration control. Zhao et al. (2021) demonstrated that the impedance mismatch generated by an L-extension geometry could improve vibration attenuation. However, the study was limited to a homogeneous metallic pedestal and did not consider hybrid laminate materials. Meanwhile, Merzuki et al. (2021) investigated the vibration characteristics of FMLs but did not examine their integration into an L-extension ship-engine pedestal or the effects of laminate arrangement and placement location. Therefore, systematic evidence remains limited regarding how different FML constituents, layer configurations, and placement locations affect both vibration isolation and structural stress in an L-extension pedestal. This study addresses this gap by comparing GFRP-, CFRP-, and UD-CFP-based FMLs in three- and five-layer arrangements across four placement configurations using finite element analysis. The novelty lies in combining the impedance-based L-extension geometry with spatially varied FML configurations and identifying the optimum design based on both the Total Vibration Level Drop and maximum von Mises stress.

2. Fundamental Theory

To evaluate the effectiveness of a structure in isolating or dampening vibrations, a parameter known as the vibration level drop is utilized. The calculation of this vibration isolation performance is based on the comparison of the average acceleration values at the vibration source (excitation points) and the points receiving the residual vibration waves (evaluation points). This average acceleration value is calculated using the Root-Mean-Square (RMS) method from a total of $\boldsymbol{n}$ observation points, formulated as follows:

$$a^{ave} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} a_i^2} \tag{1}$$

where $\boldsymbol{a_i}$ represents the acceleration response at a specific excitation or evaluation point. Once the RMS acceleration values at the upper plate or excitation points ($\boldsymbol{a_{up}^{ave}}$) and the evaluation points at the bottom ($\boldsymbol{a_{down}^{ave}}$) are obtained at the same frequency, the average vibration level drop ($\boldsymbol{L_a}$) can be calculated using the following equation:

$$L_a = 20\log\left(\frac{a_{up}^{ave}}{a_{down}^{ave}}\right) \tag{2}$$

Furthermore, in the analysis of the sweep frequency range from external loads, the overall structural damping performance across $\boldsymbol{m}$ evaluated frequency points is expressed as the total vibration level drop ($\boldsymbol{L_a^{all}}$). This total attenuation is determined through the following equation:

$$L_a^{all} = 10\log\left(\sum_{j=1}^{m} 10^{0.1L_a^j}\right) \tag{3}$$

In addition to structural design parameters, the use of advanced materials such as Fibre-Metal Laminates (FMLs) plays a crucial role in vibration control. FMLs are hybrid materials consisting of thin metal layers, typically aluminum alloys, combined with composite fiber layers and bonded using a polymer matrix. The primary concept behind FMLs is to combine the high stiffness and strength of metals with the lightweight, fatigue-resistant, and design flexibility properties of composite materials. From a vibration damping perspective, FMLs offer significant advantages over conventional monolithic metals due to the energy absorption mechanisms occurring between the metal and composite layers. The presence of materials with varying acoustic impedances within a single laminate induces an impedance mismatch phenomenon, which impedes the propagation of vsibration energy and effectively reduces the dynamic vibration response of the pedestal structure.

3. Methodology

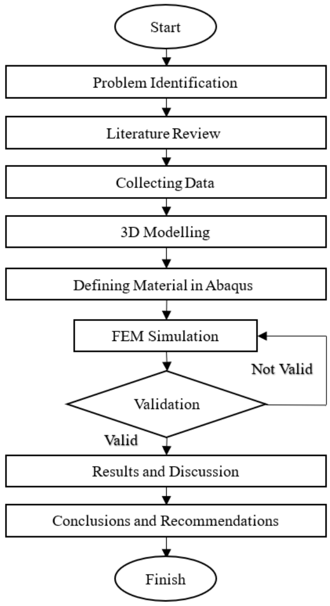

Figure 1. Flow Chart

This research was conducted through a series of systematic stages, starting from problem identification to the achievement of analytical results. The entire research process employed Finite Element Analysis (FEA) simulations; therefore, a proper understanding of the FEA software operation, specifically Abaqus, is essential to ensure accurate and reliable simulation outcomes.

The initial stage of the study involved problem identification and formulation, including the determination of research background, objectives, problem limitations, and the applied methodology. This stage was intended to ensure that the research has a clear direction and well-defined scope in addressing the investigated problem.

Subsequently, a literature review and data collection were carried out as the theoretical foundation of the study. These data were then used as the basis for 3D modeling and performing FEA simulations to analyze the vibration damping characteristics on the pedestal.

3.1 Pedestal Dimensions and Model

Based on the reference journal, the L-extension pedestal model data used in this study were obtained. Table 3.1 presents the main dimensions, and Table 3.2 presents the component thicknesses of the pedestal.

Table 1. Dimension of Pedestal

Dimension	Value (mm)
Length	8.300
Width	2.000
Height	210

Table 2. Thickness of Each Pedestal Components

Components	Symbol	Thickness
Top plate	t_1	**20 mm**
Bottom plate	t_2	**10 mm**
Upper and lower internal webs	t_3	**5 mm**
Horizontal internal plate	t_4	**5 mm**
Middle internal web	t_5	**5 mm**

Based on the obtained dimension data, the pedestal was subsequently modeled according to the given specifications. This modeling process aims to accurately represent the geometric shape and characteristics of the pedestal, which serves as the basis for the subsequent FEA simulation.

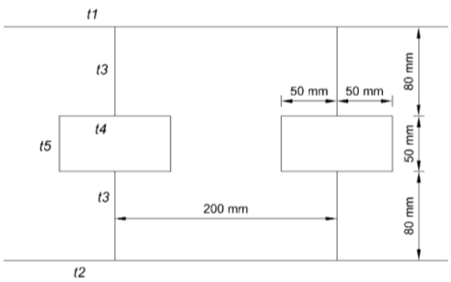

Figure 2. Model Geometry

3.2 Finite Element Method Simulation

The numerical analysis was conducted using the Finite Element Method in Abaqus. The simulation procedure included geometry discretization, material definition, boundary condition assignment, load application, and solver setup. Steady-State Dynamics analysis was used to evaluate the vibration response over a frequency range of 10–250 Hz. Acceleration responses were obtained from 12 excitation points representing the engine mounts and 20 evaluation points located at the intersections of the longitudinal girders and cross beams of the deck grillage. Before the material variations were analysed, a mesh convergence study was conducted to determine a sufficiently mesh-independent solution.

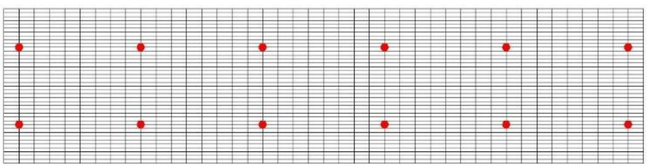

Figure 3. Exitation Points

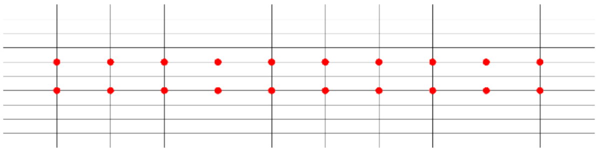

Figure 4. Evaluation Points

3.3 Mesh Convergence Study

A mesh convergence study was conducted using the conventional steel pedestal with 5,280, 6,720, and 7,560 elements. The corresponding maximum von Mises stresses were 25.88, 28.32, and 28.62 MPa. The difference between the two finest meshes was only 1.06%, indicating that the numerical solution approached mesh independence. The 7,560-element model also produced deviations of 3.5% for maximum von Mises stress and approximately 4.4% for Total Vibration Level Drop compared with the published numerical results of Zhao et al. (2021). Therefore, the 7,560-element mesh was selected for all subsequent simulations.

Table 3. Mesh Convergence Results

Element Number	**Von Mises Stress (Simulation)**	**Von Mises Stress (Reference)**	**Deviation**
5280	25,88	29,63	-14,5%
6720	28,32	29,63	-4,6%
7560	28,62	29,63	-3,5%

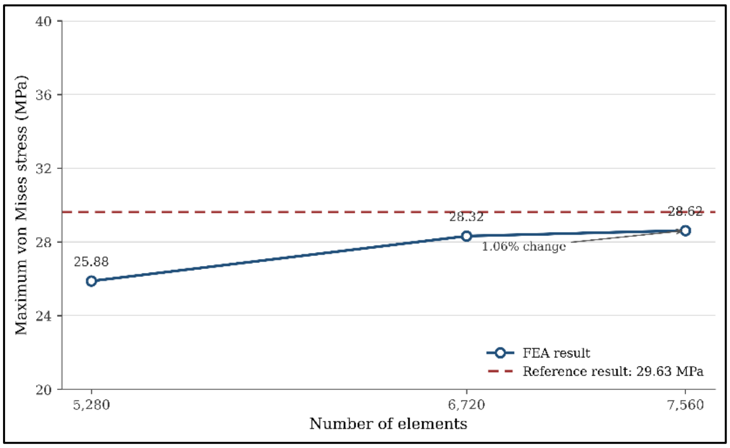

Figure 5. Mesh Convergence Graph

3.4 Material and Location Variations

After establishing the baseline model, variations in materials and their placement locations were applied to analyze the vibration characteristics and changes in the damping efficiency. The materials used included conventional steel as the baseline and Fibre-Metal Laminates (FMLs) utilizing glass fiber (GFRP), carbon fiber (CFRP), and Unidirectional Carbon Fiber Prepreg (UD-CFP).

Table 4. Mechanical Properties of Steel

Material	E	ν	ρ
Baja	210.00	0.30	7 850

Table 5. Mechanical Properties of FMLs Material

Material	E_1	E_2	ν	G_{12}	G_{13}	ρ
GFRP	7.00	7.00	0.22	1.00	2.50	1720.00
CFRP	17.50	17.50	0.24	2.00	10.50	1430.00
UD-CFP	107.00	10.00	0.27	4.00	4.00	1384.00
Aluminium 2024-T0	70.60	70.60	0.30	28.00	28.00	2780.00

The variations in the placement of the composite materials were evaluated across four configurations to observe the influence of structural stiffness distribution on the damping effectiveness: on the upper plate, on the lower plate, on both the upper and lower plates, and across the entire structure.

Table 6. Variations of Material Location

Variation Model	Placement Configuration
1	Top Plate
2	Bottom Plate
3	Top and Bottom Plate
4	Overall Strucuture

4. Results and Discussion

After performing the Finite Element Analysis (FEA) simulations, the vibration isolation performance and structural integrity of the L-extension pedestal were evaluated by comparing various Fibre-Metal Laminate (FML) configurations against a conventional steel baseline. Under dynamic loading, the baseline steel pedestal generated a total vibration level drop of 21.187 dB and a maximum von Mises stress of 28.62 MPa. The simulation results indicate that the placement of the composite materials significantly affects both damping efficiency and mechanical load distribution. Across all material types (GFRP, CFRP, and UD-CFP), applying the FMLs to the entire structure (Variation 4) consistently maximized vibration energy dissipation, achieving total vibration level drops ranging from approximately 29 dB to 32 dB. In contrast, applying the composite solely to the upper plate (Variation 1) or both the upper and lower plates (Variation 3) led to higher stress concentrations, while modifications isolated to the lower plate (Variation 2) yielded the lowest damping improvements and had negligible effects on stress distribution.

Regarding material selection, the glass fiber (GFRP) configurations provided the highest damping efficiency, peaking at 32.064 dB for the 5-layer structure; however, this configuration induced the highest local bending stresses, reaching up to 42.65 MPa. The carbon fiber (CFRP) variants offered a balanced performance, providing better structural strength than GFRP but with slightly lower vibration attenuation. Ultimately, the Unidirectional Carbon Fiber Prepreg (UD-CFP) demonstrated the most optimal structural rigidity. Although its extreme unidirectional stiffness slightly limited multi-directional energy dissipation compared to GFRP, the 3-layer AL/UD-CFP/AL configuration applied to the entire structure successfully balanced excellent vibration isolation (30.122 dB) with the safest structural stress limit (33.71 MPa) among the modified structures. The comprehensive results comparing the total vibration level drop and maximum von Mises stress for all variations are presented in Table 1 and Table 2 below.

Table 7. Total Vibration Level Drop Results

Material	Variation	Total Vibration Level Drop (dB)
AL/GFRP/AL	Model 1	24.985
	Model 2	20.545
	Model 3	24.228
	Model 4	31.513
AL/CFRP/AL	Model 1	24.040
	Model 2	20.434
	Model 3	23.222
	Model 4	30.205
AL/UD-CFP/AL	Model 1	24.456
	Model 2	20.107
	Model 3	23.272
	Model 4	30.122
AL/GFRP/AL/GFRP/AL	Model 1	24.988
	Model 2	20.541
	Model 3	24.271
	Model 4	32.064
AL/CFRP/AL/CFRP/AL	Model 1	24.162
	Model 2	20.445
	Model 3	23.331
	Model 4	30.761
AL/UD-CFP/AL/UD-CFP/AL	Model 1	24.333
	Model 2	20.353
	Model 3	23.493
	Model 4	29.847

Table 8. Maximum Von Mises Stress Results

Material	Variation	Maximum Von Mises (Mpa)
AL/GFRP/AL	Model 1	39.75
	Model 2	28.62
	Model 3	39.75
	Model 4	36.76
AL/CFRP/AL	Model 1	38.97
	Model 2	28.62
	Model 3	38.97
	Model 4	36.59

Material	Variation	Maximum Von Mises (Mpa)
AL/UD-CFP/AL	Model 1	38.65
	Model 2	28.62
	Model 3	38.65
	Model 4	33.71
AL/GFRP/AL/GFRP/AL	Model 1	40.40
	Model 2	28.62
	Model 3	40.40
	Model 4	42.65
AL/CFRP/AL/CFRP/AL	Model 1	39.63
	Model 2	28.62
	Model 3	39.63
	Model 4	41.08
AL/UD-CFP/AL/UD-CFP/AL	Model 1	38.22
	Model 2	28.62
	Model 3	38.22
	Model 4	35.25

5. Conclusion

The results show that the material type, layer arrangement, and placement location of Fibre-Metal Laminates significantly affect the vibration and structural responses of the L-extension pedestal. The conventional steel model produced a Total Vibration Level Drop of 21.187 dB and a maximum von Mises stress of 28.62 MPa. Among the placement configurations, applying FMLs to the entire structure consistently produced the highest vibration isolation for all investigated materials. In contrast, placement on the lower plate produced the lowest vibration reduction and did not change the maximum stress from the steel baseline. Material type and layer arrangement also created a trade-off between vibration reduction and structural stress. The five-layer AL/GFRP/AL/GFRP/AL configuration produced the highest Total Vibration Level Drop of 32.064 dB but also generated the highest maximum stress of 42.65 MPa. The three-layer AL/UD-CFP/AL configuration applied to the entire structure produced a Total Vibration Level Drop of 30.122 dB and a maximum stress of 33.71 MPa, which was the lowest among the modified FML configurations. Therefore, this configuration was selected as the optimum design because it provided effective vibration isolation while maintaining comparatively low structural stress.

References

Chen, W., Li, Q., Zhang, Y., Xu, L., Li, P. & Li, X. (2025) 'Integrated optimization of vibration isolation and impact resistance of ship pedestal with 3D negative Poisson's ratio honeycomb structure', *Ocean Engineering*, 341. Available at: https://doi.org/10.1016/j.oceaneng.2025.122772[cite: 1].

Merzuki, M.N.M., Ma, Q., Rejab, M.R.M., Sani, M.S.M. & Zhang, B. (2021) 'Experimental and numerical investigation of fibre-metal-laminates (FMLs) under free vibration analysis', *Materials Today: Proceedings*, 48, pp. 854-860. Available at: https://doi.org/10.1016/j.matpr.2021.02.409[cite: 1].

Wang, Y., Wu, H., Jia, P., Li, X., Peng, W., Zhang, D., Yang, T. & Sun, J. (2025) 'The application prospects of metamaterials in the rolling process', *International Journal of Advanced Manufacturing Technology*. Springer Science and Business Media Deutschland GmbH. Available at: https://doi.org/10.1007/s00170-025-16741-y[cite: 1].

Zhao, X., Li, Y., Yuan, Y., Tang, W. & Xue, H. (2021) 'Study of L-extension type ship vibration isolation pedestal based on impedance mismatch principle', *Chinese Journal of Ship Research*, 16(3), pp. 144-151. Available at: https://doi.org/10.19693/j.issn.1673-3185.01983[cite: 1].