International Journal of Robotics and Control Systems
Vol. 5, No. 1, 2025, pp. 570-584
ISSN 2775-2658
http://pubs2.ascee.org/index.php/ijrcs

Modeling the Structural Dynamics of Carbon Fiber Composites for Robotic Systems Under Sinusoidal Load

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ARTICLE INFO

Article history
Received October 31, 2024
Revised December 21, 2024
Accepted January 24, 2025

Keywords
Modeling;
Free Vibration Modeling;
Composite Shells;
Bending Analysis;
PPS Composite;
Robotic System

ABSTRACT

The demand for robotic systems employing composite materials is steadily improving due to their high bending stiffness, favorable strength-to-weight ratio, and durability under dynamic loading. It is still challenging to guarantee dynamic stability and precise frequency response in composite robotic components. This study addresses these issues by conducting a simulation-based 3D bending analysis and frequency response modeling of carbon/epoxy and carbon/PPS composites under sinusoidal loading. The remarkable mechanical and thermal properties of carbon/epoxy and carbon/PPS composites, such as their high specific strength, stiffness, and excellent fatigue resistance, align well with the requirements of robotic systems. The model comparison involved analyzing three-dimensional bending stresses, displacements, and free vibration dynamics for both materials under a sinusoidal load applied to their inner surfaces. The sinusoidal load was selected to simulate periodic dynamic forces commonly encountered in robotic applications, such as oscillating arms, vibrating components, and cyclic loading during operation. The thick shell (S=4) of axial length (L=4S) and circumferential span (α=45°) comprises cross-ply laminate [90°/0°/90°] with supported boundary conditions. The transverse displacement of the carbon PPS composite cylindrical shell was 0.719 nm, which was lower than that of the carbon epoxy composite (0.746 nm). The same behavior was observed for the stress values. Conversely, the PPS composite cylindrical shell yielded a higher natural frequency. The obtained eigenvalues indicated a similar behavior when comparing the shape modes with a relative increase in their values in the carbon PPS composite.