

Title of Thesis: **Design and Development of Novel Acoustic Metamaterials for Application in Industrial Noise Control**

Abstract

Noise-induced hearing loss (NIHL) is a major occupational health hazard in mechanised industries, where workers are exposed to noise levels often exceeding permissible limits. Among industrial workers, the 4 kHz frequency band is most susceptible to NIHL, and the human ear is more sensitive in the 0.5–6 kHz range. This research focuses on developing novel acoustic metamaterials (AMMs) capable of attenuating industrial noise in the 0.5–6 kHz range, with a specific emphasis on maximising sound absorption at 4 kHz. Two types of subwavelength resonator structures, Inline Spherical Cavity (ISC) and Inline Cylindrical Cavity (ICC) were considered as the internal structure of AMM. The geometrical parameters influencing the acoustic performance were varied, including port diameter, cavity diameter, and port length. For the ISC structure, an additional parameter, cavity length, is considered. The experimental runs were structured using Box Behnken Design (BBD). Response Surface Methodology (RSM) was used to model and optimise the relationship between the geometric parameters of the acoustic metamaterial structures and the acoustic responses (peak sound absorption coefficient (SAC) and peak absorption frequency). AMM samples were fabricated using 3D printing and tested in an Impedance Tube Apparatus to measure SAC and sound transmission loss (STL). The ICC-based AMM (13.6 mm thick) performed better as compared to the ISC-based AMM (13.3 mm thick), achieved a peak SAC of 0.99 at 4 kHz and STL ranging from 8.5 to 42 dB across the 0.5–6 kHz band. Due to its superior SAC and STL characteristics, the ICC-based AMM was deemed suitable for application in operator cabin design, where both high SAC and STL are essential. As SAC reduces internal reflections and reverberation, while STL attenuates external industrial noise, ensuring comprehensive noise protection. A case study of a mineral processing plant was considered, in which a noise survey was conducted at eleven operator locations. Equivalent SPLs of up to 98.6 dB(A) were recorded near the primary crusher. Based on these findings, an operator cabin ($2 \times 2 \times 3 \text{ m}^3$) was designed using ICC-based AMM panels. Finite Element Analysis, following ISO 11957:1996, showed that the cabin could reduce equivalent SPL by 14.8 dB(A), bringing operator exposure within safe limits. This research demonstrates a validated AMM-based solution that offers both sound absorption and insulation, enabling effective localised protection against industrial noise and contributing to safer work environments.

Keywords: Noise-induced hearing loss, Acoustic metamaterial, Sound absorption, Sound transmission loss, Operator cabin