

Equalization of Natural Frequency Spacing in Panel Design

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When designing structures such as automobiles, isolating the natural frequencies of each component is common practice to avoid unexpected frequency variations caused by coupling between parts after assembly. However, in simple-shaped subsystems like rectangular plates, the natural frequencies are often closely spaced, making sufficient separation difficult. On the other hand, in the field of quantum mechanics, it is known that energy levels repel each other in chaotic systems, such as stadium-shaped plates, which prevents them from clustering together. Inspired by this phenomenon, this study investigates a practical method to equalize the natural frequency spacings of a structure modeling a vehicle roof panel by adjusting the arrangement of spot welds.

In the field of quantum mechanics, the phenomenon known as level repulsion has been observed in the quantum problem of a free particle within a chaotic system. Level repulsion refers to the phenomenon where energy levels repel each other, preventing them from being close to each other. Experiments by Schaadt et al. have confirmed that results similar to those found in chaotic quantum systems are obtained even in plate vibration problems where wave trajectories exhibit chaotic behavior.

When conducting eigenvalue analysis on a stadium-shaped plate, the resulting distribution of natural frequency spacings closely resembles a Poisson distribution, similar to that of plates with simple shapes like rectangles. This occurs because the shape possesses point-group symmetry, allowing the eigenvalue problem to be decomposed into a block-diagonal form corresponding to distinct symmetry classes. While interactions within a block give rise to level repulsion, the absence of interactions between different blocks prevents such repulsion, leading to the degeneracy of natural frequencies. Consequently, to induce level repulsion, it is necessary to break the symmetry and adopt a shape that does not allow the eigenvalue problem to be decomposed into multiple symmetry classes.

Based on the theory, it can be predicted that even for a rectangular plate, it is possible to reduce the proximity of natural frequencies by controlling the shape to alter wave reflection. To demonstrate the application of this theory to vehicle body structures, an analysis was conducted using a model simulating a vehicle roof panel. We conducted an analysis using two models: one in which 10 points per edge were fully constrained parallel to the edges, and another in which the constraint positions were randomly varied with small changes, perpendicular to the edges and outward from the constraint points of the first model. Hereafter, these models will be referred to as straight welding and random welding respectively.

Figure 1 shows the probability density (y-axis) of the normalized natural frequency spacings (x-axis) for both models. Compared to the straight welding, the distribution of natural frequency spacings in random welding approaches the Wigner distribution. The maximum difference in welding position between the straight welding and random welding patterns is 3 mm, representing only a minor alteration relative to the plate's size. However, the spacing of the natural frequencies changes significantly, demonstrating that even slight structural modifications can yield effective results.

In conclusion, we incorporated insights from quantum mechanics into vibration design, proposing a new strategy to reduce the probability of natural frequencies clustering together, and demonstrated its application using a panel model. Specifically, by randomly varying the positions of spot welding, we were able to shift the distribution of natural frequency spacings closer to the Wigner distribution compared to straight welding arrangements.

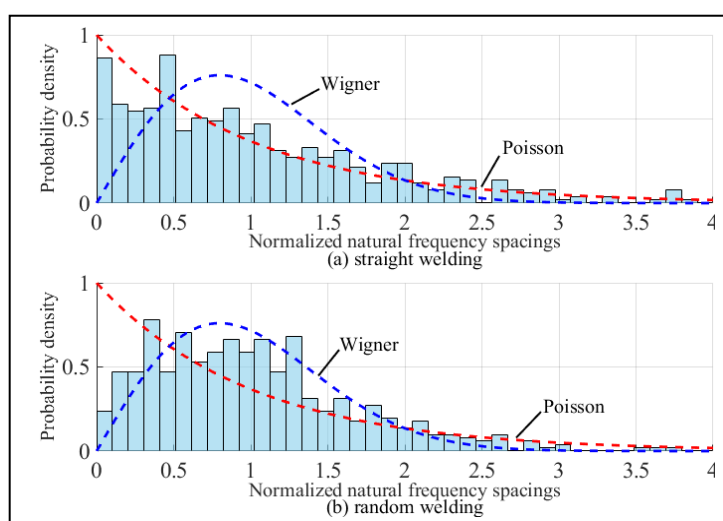


Fig. 1 Probability distributions of natural frequency spacings