Determination of Coupling Factors for Bolted Plates using Finite Element Analysis

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1. INTRODUCTION & OBJECTIVE

Statistical Energy Analysis (SEA) is one of the widely used energy methods, developed in the early 1960s to predict the vibration response of structures at high frequencies [1].SEA parameters can be computed by analytical wave approach, power injection method [2], experimental approach, finite element method or the receptance method [3].SEA involves predicting the vibration response of a complex structure by dividing it into a number of subsystems, and is characterized by mean energy per mode. The change in energy level between subsystems is characterized by internal and coupling loss factors. Internal loss factor corresponds to damping factor ($\acute{\eta}_i$) in the subsystem itself and CLF ($\acute{\eta}_{ij}$) corresponds to the energy dissipation during flow across the subsystems. Coupling loss and internal loss/damping factors constitute a matrix of energy balance equations, which is used to compute the energies by the power balance approach, once the power inputs are known. The CLFs can be obtained using analytical wave approaches from coefficients of energy propagation, via junctions of subsystems, known for several types of junctions. Alternatively, the values can also be found by the power injection approach after computing the energies (E_i) and power inputs (P_{ij}) through experiments or finite element analysis by using equation(1) for a particular frequency (ω) of excitation [4].

$$\omega\begin{bmatrix} \left(\eta_1+\sum_{i\neq 1}^{N}\eta_{1i}\right)n_1 & -\eta_{12}n_1 & \cdots & -\eta_{1N}n_1 \\ -\eta_{21}n_2 & \left(\eta_2+\sum_{i\neq 2}^{N}\eta_{2i}\right)n_2 & \cdots & -\eta_{2N}n_2 \\ \vdots & \vdots & \ddots & \vdots \\ -\eta_{N1}n_N & \cdots & \cdots & \left(\eta_N+\sum_{i\neq N}^{N-1}\eta_{Ni}\right)n_N \end{bmatrix}\times\begin{bmatrix} \frac{\langle\bar{E}_1\rangle}{n_1} \\ \frac{\langle\bar{E}_2\rangle}{n_2} \\ \vdots \\ \frac{\langle\bar{E}_N\rangle}{n_N} \end{bmatrix}=\begin{bmatrix} \bar{P}_{i,1} \\ \bar{P}_{i,2} \\ \vdots \\ \bar{P}_{i,N} \end{bmatrix}, \quad (1)$$

In this paper, a finite element model of a structure, consisting of two steel plates(500mm×500mm×1.6mm) jointed by three bolted lap joints with an overlap of 50 mm has been modeled using ANSYS software. The upper and lower plates are modeled using SHELL 63 elements. A coupled bolt model approach has been used in the present case [5], with the bolts modelled using BEAM 188 elements. RBE 3 element has been used as the constraint equations. The initial strain due to applied preload has been applied to the FE beam elements representing bolts. Three bolts with one of the bolts, centrally located and the others 50 mm away from the edge of the plate have been modelled as case-1. In case-2, the central bolt is removed. The internal loss factors estimated by the experimental power injection method on a single plate for different excitation frequencies has been used for the finite element simulation at the respective frequencies. The damping factor for the bolt element has been adjusted to get similar values of velocity responses as obtained from experiments as case-1.

A harmonic force with unit load intensity has been applied in the range of frequencies of 0-3500 Hz. The load has been applied on one plate and the velocity responses on both the plates have been computed. Macros have been developed in Ansys Parametric Design Language (APDL) for automating the computation of energy of each subsystem with mass and maximum subsystem velocity. Coupling factors have been computed from the velocity responses for the bolted joint plates using finite element method and compared with the values obtained from the experimental approach for both the cases.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

The apparent coupling factors ($\eta_{12} = \eta_{21}$) for the two cases of the bolted plates obtained from Finite element analysis and experiments has been computed and the velocity responses obtained by both the methods have been compared in figures 1 and 2. The results obtained from the studies signify the importance of modeling of discrete joints like the bolted joints in computation of the coupling factors and its further use in computation of energies and velocity responses using statistical energy approach as compared to the values obtained using analytical wave approaches

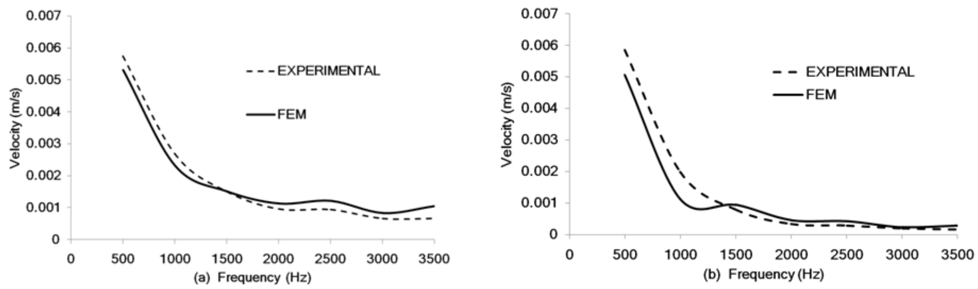

Fig. 1. Velocity Responses for Plate 1 and Plate 2 (Case -1)

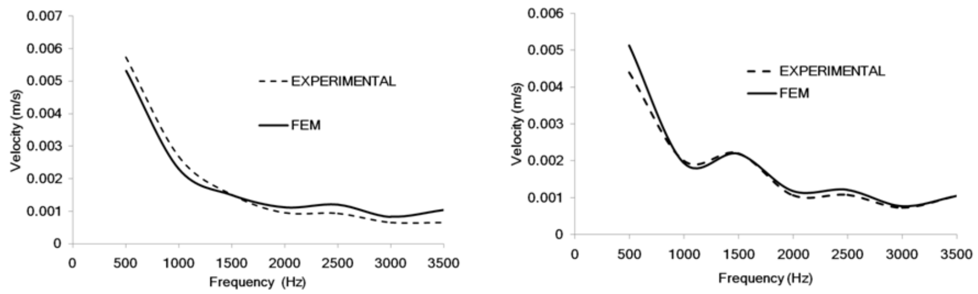

Fig. 2. Velocity Responses for Plate 1 and Plate 2 (Case -2)

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