Robust optimization approach for mixed numerical/experimental identification of elastic properties of orthotropic composite plates

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ABSTRACT

The vibration method for the identification of elastic parameters of plate-type structural elements consists of finding parameter values that minimize the difference between physically measured and numerically calculated (mostly using the finite element method (FEM)) natural frequencies. The main problem here is the estimation of the accuracy of results and minimizing the effects of different sources of uncertainty.

The influence of plate thickness and material density variance can be reduced using the first L nondimensional frequencies $\Psi_i = f_i/\bar{f}$ (i=1, 2,…, L), where f_i is the i-th natural frequency and $\bar{f} = \sum_{j=1}^{L} f_j/L$. This scaling can be done with measured frequencies $f_i^{measured}$ as well as with frequencies f_i^{num} calculated by FEM. The classical nondimensionalization approach uses coefficients that depend on unknown elastic parameters, thereby leading to an iterative minimization process.

Thus the identification of component values of the elastic constants vector $\boldsymbol{E^*}$ (in the simplest case containing three elastic moduli E_x, E_y, G_{xy}, and Poisson's ratio ν_x) using the robust optimization requires simultaneous minimization of the discrepancy function

$$\boldsymbol{E}^* = \underset{\boldsymbol{E},\boldsymbol{w}}{\arg\min} \sum_{i=1}^{L} w_i^2 \left(\widehat{\Psi}_i(E) - \Psi_i^{\text{measured}}\right)^2 \tag{1}$$

and standard deviations $Var\left(E_j^*\right),\ j = 1,2,3,4$ of identified parameters subject to constraint

$$\sum_{i=1}^{L} w_i^2 = 1. \tag{2}$$

Here $\widehat{\Psi}_i(E)$ denotes the surrogate model for the dependency of natural frequencies on the elastic parameters and w_i is the weighting coefficient for the i-th frequency. A surrogate model with high accuracy can be created using third-order polynomial approximations of planned numerical experiments with FEM software. Making some assumptions about the variance and covariance of geometrical parameters of plate specimens and frequency measurements, exact expressions for the variance of identified parameter values [1] can be obtained and used in optimization. Using the weighting coefficients as additional optimization variables gives the possibility of best choice of the set of frequencies for each identified parameter. Experiments with orthotropic composite plates showed a major decrease of identification error compared to the standard least square minimization method.

REFERENCES

[1] J. Auzins, E. Skukis, K. Kalnins, P. Lefort, B. Laure, W. Trümper, "Identification of Climate Cycle Influence on Mechanical Properties for Knitted Gf/Pp Textile Composites", 11th International Conference on Vibration Problems, Z. Dimitrovová et al. (eds.), Lisbon, Portugal, 9-12 September 2013, CD-Edition, (2013).