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# THE IDENTIFICATION OF STOCHASTIC PARAMETERS IN LAMINATE STRUCTURES BY MEANS OF EVOLUTIONARY COMPUTATIONS

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## ABSTRACT

This paper is devoted to the application of evolutionary algorithm to the identification of the laminates' elastic constants treated as uncertain parameters. There exist many physical problems in which systems and processes have uncertainties of materials properties, boundary conditions, geometry etc. The granular type of information about these parameters results in the necessity of using various models of uncertainty in the form of interval, fuzzy and rough sets as well as the theory of probability.

The aim of the paper is to identify the elastic constants of the multi-layered, fibre reinforced laminates. They are the fibre-reinforced composites made up of a definite number of stacked, permanently joined plies (laminas). Laminas are typically built of one composite material but have different fibers directions. The main advantages of laminates, are the high strength-weight-ratio and the easiness of tailoring the material by manipulating parameters like components material, stacking sequence, fibres orientation or layer thicknesses [5]. As laminates are often produced individually, the non-destructive identification of the material properties is necessary. The identification procedure is usually performed for the measurements of state variables (e.g. displacements or strains) in sensor points for the structure subjected to the static load.

The multi-layered, fibre-reinforced laminates can be treated as the orthotropic materials [4]. As two dimensions of the laminate are typically significantly larger than the third one, laminates can be treated

as thin plates with four independent elastic constants: axial Young modulus $E_1$, transverse Young modulus $E_2$), axial-transverse shear modulus $G_{12}$) and axial-transverse and transverse-axial Poisson ratio $\nu_{12}$. The identified constants are treated as random variables with assumed distribution.

The evolutionary algorithms are the global optimization techniques [1],[6]. They are typically applied for deterministic optimization and identification problems, like presented in [3]. The idea of the interval/fuzzy evolutionary algorithm and its applications to the optimization and identification problems was considered in previous papers, e.g. [2]. Another form of granularity - the probability approach to the optimal design - is taken into account in the present paper. The parameters of systems and processes are modelled by random variables determined by a probability density function. The classical approach to solution of such problems is based on stochastic programming [7]. Proposed stochastic evolutionary algorithm (SEA) is based on the stochastic representation of the data. Each chromosome, being potential stochastic solutions of the identification task, is a multidimensional vector consisting of random variables (genes) with the Gaussian density probability function:

$$\mathbf{X}(\gamma) = [X_1(\gamma),\ X_2(\gamma), ..., X_i(\gamma), ...,\ X_n(\gamma)] \tag{1}$$

The aim of the identification is to find a vector $\mathbf{X}(\gamma)$ which minimizes the objective function $F(\gamma) = F(\mathbf{X}(\gamma))$ with constraints $P\left[g_j(\mathbf{X}) \geq 0\right] \geq p_j,\ j = 1, 2, ..., m$. A gene $X_i(\gamma)$ is represented by a random variable, which is a real function $X_i = X_i(\gamma),\ \gamma \in \mathbf{\Gamma}$ defined on a sample space $\mathbf{\Gamma}$ and measurable with respect to $P$.

In the present paper the random chromosome $\mathbf{X}(\gamma)$ has a *n*-dimensional Gaussian distribution of the probability density function and two moments are considered: the mean value *m* and standard deviation $\sigma$. As the result the stochastic identification problem can be transformed into the deterministic one by representing stochastic genes by mean values $m_i$ and standard deviations $\sigma_i$ of random variables:

$$\mathbf{X}(\gamma) = \ [(m_1, \sigma_1); (m_2, \sigma_2); ...; (m_i, \sigma_i); ...; (m_n, \sigma_n)] \tag{2}$$

Special evolutionary operators of mutation and crossover as well as the dedicated selection method are proposed for the SEA. Numerical examples presenting identification of the laminates' stochastic elastic constants by means of the SEA are enclosed.

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