UDK: 539.421:515.122:658.512/.514=20
COSATI: 14-07, 20-03, 11-04

Multi-Objective Fuzzy Optimization of Sizing and Location of Piezoelectric Actuators and Sensors for Vibration Control Based on the Particle Swarm Optimization Technique (Part 1: Theoretical Model)

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Sizing and location of the piezoelectric actuators and sensors for vibration control of flexible structures is usually based on maximum control effectiveness and achieving the maximum output for the vibration in the modes of interests. Integration of piezoelectric patches affects the mass and the original dynamic properties of the parent structure. This is the first part of the two-paper research which presents the theoretical development of the multi-objective fuzzy optimization technique of sizing and location of the collocated piezoelectric actuators and sensors on the thin-walled composite beam. The optimization criteria for the optimal size and location of piezoelectric A/Ss are based on the degree of controllability (DC) for controlled modes. The optimization procedure implies the constraining of the original dynamic properties change and the limitation of the mass increase. A pseudogoal function, derived based on the fuzzy set theory, gives an expression for global objective functions eliminating the use of weighting coefficients and penalty functions. the particle swarm optimization technique is used to find the optimal configuration..

Key words: **piezoelectric element, actuator, vibration measurement, composite materials, beam, fuzzy logic, multi-objective optimization, theoretical model.**

Introduction

THE optimization of sizing and location of actuators and sensors for active vibration control of flexible structures has been shown as the one of the most important issues in design of active structures since these parameters have a major influence on the performance of the control system [1, 2]. In these optimization problems, two approaches are dominant. The first approach combines optimal location/size of actuators/sensors and controller parameters where some studies [3-5] propose a quadratic cost function to present the measurement error and control energy. The second common approach considers optimal location/size of actuators/sensors independently of controller definition with the maximization of controllability/observability using the grammian matrices [6, 7], the H2 norm [8, 9] or the modal controllability index [10, 11].

It can be seen that the main focus of these investigations is sizing/location of piezoelectric actuators/sensors for maximum control effectiveness. The natural frequency spectrum of the parent structure is affected by the integration of piezoelectric patches. In the case of the failure of an active system, this change of dynamic properties might become significant [11]. Also, the increase of the mass of structure cannot be ignored, especially for aerospace structures. Some previous Dhuri [11] works considered the change of natural frequencies through the objective function in multi-objective optimization.

For the vibration analysis and control, an active structure can be discretized into a finite number of elements. During practical implementation, this model needs to be truncated, where only the first few modes are taken into account. However, the state feedback control law, based on a reduced model, may excite the residual modes resulting in spillover instability for even a simple beam problem [12]. Considering that fact, some authors have introduced residual modes in the optimization problem [7, 9].

Due to the complexity of the problem, classical optimization methods which apply gradient-based search techniques are not convenient for use. A good solution for such optimization problems relies on heuristic optimization algorithms. Many studies have used the genetic algorithm (GA) for finding out the optimal sizing and location of sensors and actuators and other parameters related to the control performances. Few papers have used an integer-real-encoded GA [5,7,13] and the zero-one optimization technique [4,11] for solving optimization problems. The simulated annealing (SA) algorithm can be used to determine the location of piezoelectric patches in order to

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maximize actuators efficiency in the feedback control.[14] Montazeri, Poshtan, and Yousefi-Koma [17] consider the particle swarm technique to optimize the control system in a smart laminated plate.

This is the first part of the two-paper research which presents a theoretical development of the multi-objective fuzzy optimization technique of placement and sizing of collocated piezoelectric actuators and sensors on a composite beam for maximum active vibration control effectiveness. The main idea of the presented optimization algorithm is a transformation of both objective functions and constraints into pseudogoal functions through the process of fuzzification, converting a multi-objective optimization problem into a single-objective one, using the fuzzy decision principle proposed by Bellman and Zadeh [16] and finding an optimal configuration with a help of the PSO algorithm. To the best of our knowledge, this optimization algorithm will present an innovative approach for solving a problem of sizing and location of piezoelectric actuators and sensors. The optimization problem is formulated independently of the controller definition using DCs to measure control effectiveness for the vibration in the controlled modes. The optimization criterion is used ensuring a good DC for the controlled modes. The optimization process is performed constraining the original dynamic properties change including the limitation of the increase of the mass, using or neglecting limitation in DCs for residual modes for spillover effect reduction. Also, the distribution of DCs among actuators is discussed to ensure its uniform distribution.

Equations of active vibration control

A laminated composite beam with integrated piezoelectric sensors and actuators is considered. From a finite element model based on the third-order shear deformation theory [17], the equations of motions of the system in the modal coordinates [18] can be written as follows:

$$\{\ddot{\eta}\}+\left[\omega^2\right]_{\mathrm{C}}\{\eta\}=[\Psi]_{\mathrm{C}}^{\mathrm{T}}\{F_{\mathrm{m}}\}+[\Psi]_{\mathrm{C}}^{\mathrm{T}}[K_{\mathrm{me}}]_{\mathrm{A}}\{\varphi\}_{\mathrm{AA}} \tag{1a}$$

$$\{\ddot{\eta}\}+\left[\omega^2\right]_{\mathrm{R}}\{\eta\}=[\Psi]_{\mathrm{R}}^{\mathrm{T}}\{F_{\mathrm{m}}\}+[\Psi]_{\mathrm{R}}^{\mathrm{T}}[K_{\mathrm{me}}]_{\mathrm{A}}\{\varphi\}_{\mathrm{AA}} \tag{1b}$$

where $[\Psi]_{\mathrm{C}}$ and $[\Psi]_{\mathrm{R}}$ present the modal matrix of the controlled and residual modes respectively, $\{\eta\}$ is the vector of the modal coordinates, $\left[\omega^2\right]_{\mathrm{C}}$ and $\left[\omega^2\right]_{\mathrm{R}}$ is the diagonal matrix of the squares of the natural frequencies of controlled and residual modes respectively, $[K_{\mathrm{me}}]_{\mathrm{A}}$ is the piezoelectric stiffness matrix of the actuator, and $\{\varphi\}_{\mathrm{AA}}$ is the vector of the applied electric potentials on the actuators. Lower ordered modes are most easily excitable because they have lower energy associated. A controller has been therefore designed for active control for only the first few modes. Eq. (1) can be presented in the state-space form as

$$\{\dot{X}\}=[A]\{X\}+[B]\{\varphi\}_{\mathrm{AA}}+\{d\} \tag{2}$$

where

$$\{X\}=\begin{Bmatrix}\{\eta\}\\ \{\dot{\eta}\}\end{Bmatrix},\quad [A]=\begin{bmatrix}[0] & [0] & [\mathrm{I}] & [0]\\ [0] & [0] & [0] & [\mathrm{I}]\\ -\left[\omega^2\right]_{\mathrm{C}} & [0] & [0] & [0]\\ [0] & -\left[\omega^2\right]_{\mathrm{R}} & [0] & [0]\end{bmatrix}, \tag{3}$$

$$[B]=\begin{bmatrix}[0]\\ [0]\\ [B]_{\mathrm{C}}\\ [B]_{\mathrm{R}}\end{bmatrix}=\begin{bmatrix}[0]\\ [0]\\ [\psi]_{\mathrm{C}}^{\mathrm{T}}[K_{\mathrm{me}}]_{\mathrm{A}}\\ [\psi]_{\mathrm{R}}^{\mathrm{T}}[K_{\mathrm{me}}]_{\mathrm{A}}\end{bmatrix},\quad \{d\}=\begin{Bmatrix}\{0\}\\ \{0\}\\ [\psi]_{\mathrm{C}}^{\mathrm{T}}\{F_{\mathrm{m}}\}\\ [\psi]_{\mathrm{R}}^{\mathrm{T}}\{F_{\mathrm{m}}\}\end{Bmatrix},$$

present the state vector, the system matrix, the control matrix and the disturbance vector respectively, where [I] and [0] are the appropriately dimensioned identity and zero matrix.

Optimization criteria for collocated piezoelectric actuators and sensors sizing and location

Multi-objective optimization problem statement

Wang and Wang [10] proposed a controllability index for the actuator, obtained by maximizing global control force. The modal control force applied to the system can be written as

$$\{f_{\mathrm{C}}\}=[B]\{\varphi\}_{\mathrm{AA}} \tag{4}$$

It follows from Equation (4) that

$$\{f_{\mathrm{C}}\}^{\mathrm{T}}\{f_{\mathrm{C}}\}=\{\varphi\}_{\mathrm{AA}}^{\mathrm{T}}[B]^{\mathrm{T}}[B]\{\varphi\}_{\mathrm{AA}} \tag{5}$$

Using the singular value analysis, $[B]$ can be written as $[B]=[M][S][N]^{\mathrm{T}}$, where $[M]^{\mathrm{T}}[M]=[\mathrm{I}]$, $[N]^{\mathrm{T}}[N]=[\mathrm{I}]$ and

$$[S]=\begin{bmatrix}\sigma_1 & 0 & \cdots & 0\\ 0 & \sigma_2 & & 0\\ \vdots & & \ddots & \vdots\\ 0 & 0 & \cdots & \sigma_{N_{\mathrm{A}}}\\ \vdots & \vdots & & \vdots\\ 0 & 0 & \cdots & 0\end{bmatrix} \tag{6}$$

where N_{A} presents the number of actuators. Equation (5) can be written as

$$\{f_{\mathrm{C}}\}^{\mathrm{T}}\{f_{\mathrm{C}}\}=\{\varphi\}_{\mathrm{AA}}^{\mathrm{T}}[N][S]^{\mathrm{T}}[S][N]^{\mathrm{T}}\{\varphi\}_{\mathrm{AA}}\ \text{or}$$

$$\|f_{\mathrm{C}}\|^2=\|\varphi\|_{\mathrm{AA}}^2\|S\|^2 \tag{7}$$

Thus, maximizing this norm independently of the applied voltage $\{\varphi\}_{\mathrm{AA}}$ induces maximizing $\|S\|^2$. The magnitude of σ_i is a function of the location and size of the piezoelectric actuator. Wang and Wang [10] proposed a controllability index which is defined by

$$\Omega_{\mathrm{C}}=\prod_{i=1}^{N_{\mathrm{A}}}\sigma_i \tag{8}$$

The higher controllability index, the smaller electrical potential will be required for control. This index represents controllability for all the modes globally, and its magnitude is a function of the location and size of piezoelectric actuators. The drawback of this definition of the controllability index is the fact that it gives only information about controllability for all modes of all actuators, i.e. controllability for a certain mode of a certain actuator cannot be seen. The controllability index can be obtained in a more suitable form for models based on the finite element, where, instead of maximizing the norm $\|S\|^2$, the applied force for each mode has been maximized independently of $\{\varphi\}_{AA}$. According to the control matrix, presented in Equation (3), the controllability indices for controlled and residual modes can be written in the following way

$$\bar{\sigma}_{Ci}^2 = (B_i)_C (B_i)_C^T, \quad \left(\bar{\sigma}_{Ci}^R\right)^2 = (B_i)_R (B_i)_R^T \tag{9}$$

$(B_i)_C$ and $(B_i)_R$ present the i-th row of matrices $[B]_C$ and $[B]_R$, respectively. The i-th row of matrix $[B]$ consists of sub-rows which correspond to the particular actuator and sensor, so the controllability index for the i-th mode of the j-th actuator can be defined as

$$\bar{\sigma}_{Cij}^2 = \left(B_{i(j)}\right)_C \left(B_{i(j)}\right)_C^T \tag{10}$$

Implementing Equation (9) in Equation (10)gives

$$\bar{\sigma}_{Ci}^2 = \sum_{j=1}^{N_A} \bar{\sigma}_{Cij}^2 \tag{11}$$

As mentioned earlier, the piezoelectric patches sizing and location should be such that those should give good controllability for controlled modes, so objective functions can be written as

$$\text{maximize} \quad DC_{Ci} = \frac{\bar{\sigma}_{Ci}^2}{\bar{\sigma}_{Ci\max}^2} \cdot 100 \quad i = 1,..,N_C \tag{12}$$

where DC_{Ci} present the degree of controllability (DC) for controlled modes, $\bar{\sigma}_{Ci\max}$ denotes the maximum controllability index for controlled modes and N_C presents the number of controlled modes. It is shown that misplaced sensors and actuators lead to control system instability[19]. Due to that, in this work, only collocated sensors and actuators will be considered. The actuator and its corresponding sensor have the equal length and they are set symmetrically: the sensor at the bottom surface, and the actuator on the top surface of the beam. According to Equations (10) and (12), the DC becomes

$$DC_{Ci} = \sum_{j=1}^{N_A} DC_{\text{Cont}ij} \quad \text{where} \quad DC_{Cij} = \frac{\bar{\sigma}_{Cij}^2}{\bar{\sigma}_{Ci\max}^2} \cdot 100 \tag{13}$$

Presents the DC for the i-th mode of the j-th actuator.

Constraints

Constraints are related to the change of natural frequencies and the mass of the parent structure and the DC of residual modes. They can be written as follows

$$\left|\omega_i^{\text{new}} - \omega_i^{\text{old}}\right| / \omega_i^{\text{old}} < \varepsilon_{fi} \quad i = 1,..,N_{\text{fmods}} \tag{14}$$

$$\left|m^{\text{new}} - m^{\text{old}}\right| / m^{\text{old}} < \varepsilon_m \tag{15}$$

$$DC_{Ri} < DC_{Ri}^{\max} \quad i = 1,..,N_R \tag{16}$$

where ω_i^{new} denotes the natural frequency of the i-th mode of the beam with piezoelectric patches, ω_i^{Old} denotes the natural frequency of the i-th mode of the beam without piezoelectric patches, and ε_{fi} is the tolerance of change of the i-th natural frequency. N_{fmods} presents the number of constrained modes, m^{new} denotes the mass of the beam with piezoelectric patches, m^{old} denotes the mass of the parent beam and ε_m is the tolerance of the mass change. $DC_{Ri}^{\max}$ is the maximum allowable DC for the i-th residual mode and N_R is the number of residual modes.

Mathematical model of multi-objective fuzzy optimization

In this section, a fuzzy optimization approach based on a pseudogoal function for a multi-objective problem is proposed. The objective function, given in Equation (12), which has to be maximized, can be written as a pseudogoal function in the form of the fuzzy number

$$\mu_{Ci}(\mathbf{p}) = \frac{DC_{Ci}(\mathbf{p}) - DC_{Ci\min}}{DC_{Ci\max} - DC_{Ci\min}} \tag{17}$$

where $DC_{Ci\min}$ and $DC_{Ci\max}$ denote the minimum and maximum DC for controlled modes, respectively, $\mu_{Ci}(\mathbf{p})$ presents the membership function of the i-th objective function and $\mathbf{p}$ presents the design variables set. According to the formulation of the DC ($DC_{Ci\min} = 0$ and $DC_{Ci\max} = 100$), the previous expression becomes

$$\mu_{Ci}(\mathbf{p}) = \frac{DC_{Ci}(\mathbf{p})}{100} \tag{18}$$

The membership function of the i-th objective function is presented in Fig.1. Constraints may also receive the same fuzzification process as the objective functions. In this process, the amplification method is used by Zhao and Wang [20], where the amplification coefficient $\bar{\beta}$ is used in order to determine the tolerance of the upper limit of the constraints. So, the membership functions of the constraints become

$$\mu_{fi}(\mathbf{p}) = \begin{cases} 1, & \left|\omega_i^{\text{new}} - \omega_i^{\text{old}}\right| / \omega_i^{\text{old}} < \varepsilon_{fi} \\ \dfrac{\bar{\beta}_{fi}\varepsilon_{fi} - \left|\omega_i^{\text{new}} - \omega_i^{\text{old}}\right| / \omega_i^{\text{old}}}{\bar{\beta}_{fi}\varepsilon_{fi} - \varepsilon_{fi}}, & \varepsilon_{fi} \le \left|\omega_i^{\text{new}} - \omega_i^{\text{old}}\right| / \omega_i^{\text{old}} < \bar{\beta}_{fi}\varepsilon_{fi} \\ 0, & \left|\omega_i^{\text{new}} - \omega_i^{\text{old}}\right| / \omega_i^{\text{old}} \ge \bar{\beta}_{fi}\varepsilon_{fi} \end{cases} \tag{19}$$

$$\mu_m(\mathbf{p}) = \begin{cases} 1, & \left|m^{\text{new}} - m^{\text{old}}\right| / m^{\text{old}} < \varepsilon_m \\ \dfrac{\bar{\beta}_m\varepsilon_m - \left|m^{\text{new}} - m^{\text{old}}\right| / m^{\text{old}}}{\bar{\beta}_m\varepsilon_m - \varepsilon_m}, & \varepsilon_m \le \left|m^{\text{new}} - m^{\text{old}}\right| / m^{\text{old}} < \bar{\beta}_m\varepsilon_m \\ 0, & \left|m^{\text{new}} - m^{\text{old}}\right| / m^{\text{old}} \ge \bar{\beta}_m\varepsilon_m \end{cases} \tag{20}$$

$$\mu_{\mathrm{R}i}(\mathbf{p}) = \begin{cases} 1, & DC_{\mathrm{R}i} < DC_{\mathrm{R}i}^{\max} \\ \dfrac{\bar{\beta}_{\mathrm{R}} DC_{\mathrm{R}i}^{\max} - DC_{\mathrm{R}i}}{\bar{\beta}_{\mathrm{R}} DC_{\mathrm{R}i}^{\max} - DC_{\mathrm{R}i}^{\max}}, & DC_{\mathrm{R}i}^{\max} \le DC_{\mathrm{R}i} < \bar{\beta}_{\mathrm{R}} DC_{\mathrm{R}i}^{\max} \\ 0, & DC_{\mathrm{R}i} \ge \bar{\beta}_{\mathrm{R}} DC_{\mathrm{R}i}^{\max} \end{cases} \tag{21}$$

The membership functions of the constraints are presented in Figs. 2(a), 2(b) and 2(c). According to the fuzzy decision principle [16], the fuzzy decision is defined as the intersection of fuzzy objectives and fuzzy constraints. Thus, the optimum solution $\mathbf{p}^*$ can be selected by maximizing the smallest membership function

$$\mu_{\mathrm{D}}\left(\mathbf{p}^*\right) = \max \mu_{\mathrm{D}}(\mathbf{p}) \tag{22}$$

where

$$\mu_{\mathrm{D}} = \min\left\{ \min_{i=1,N_{\mathrm{C}}} \mu_{\mathrm{C}\,i}\,,\ \min_{j=1,N_{\mathrm{fmods}}} \mu_{\mathrm{f}\,j}\,,\ \mu_{\mathrm{m}},\ \min_{k=1,N_{\mathrm{R}}} \mu_{\mathrm{R}\,k} \right\} \tag{23}$$

presents the membership function of the optimal decision function.

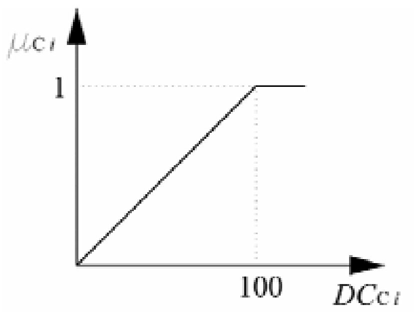

Figure 1. Membership functions of the objective functions.

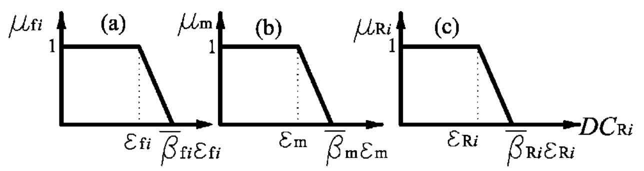

Figure 2. Membership functions of the constraints: (a) change of the natural frequencies, (b) change of the mass, (b) DC for the residual modes.

Optimization implementation using the particle swarm optimization

The particle swarm optimization (PSO) has been inspired by the social behavior of animals such as fish schooling, insect swarming and birds flocking. It was introduced by Kennedy and Everhart [21]. The system is initialized with a population of random solutions (called particle position in PSO). Every particle is affected by three factors: its own velocity, the best position it has achieved (best local position) which is determined by the highest value of the objective function encountered by this particle in all previous iteration and the overall best position achieved by all particles (best global position) which is determined by the highest value of the objective function encountered in all previous iterations. A particle changes its velocity (v) and position (p)in the following way

$$\begin{aligned} v_{id}^{k+1} &= w v_{id}^{k} + c_1 r_1 \left(l_{id} - p_{id}^{k} \right) + c_2 r_2 \left(g_d - p_{id}^{k} \right) \\ p_{id}^{k+1} &= p_{id}^{k} + v_{id}^{k+1} \\ i &= 1, n \quad d = 1, m \end{aligned} \tag{24}$$

where w is the inertia weight, c_1 is the cognition factor, c_2 is the social learning factor, r_1 and r_2 are random numbers between 0 and 1, the superscript k denotes iterative generation, n is the population size, m is the particle dimension, l_{id} and g_d are the best local and global positions. Perez and Behdinan [22] give the upper and lower limits of inertia weight for structural design.

Each S/A pair is determined with two parameters: position which represents a distance from the root of the beam (x) and its length (l) (Fig.3(a)). In this work, the beam is discretized in finite elements, so, the position of an S/A pair is defined by the position of the left node and the length is defined by the number of elements covered by this pair (Fig.3(b)). Consequently, $p_{i(2j-1)}$ presents the position of the j-th S/A pair, and $p_{i(2j)}$ presents its length (Fig.3(b)).

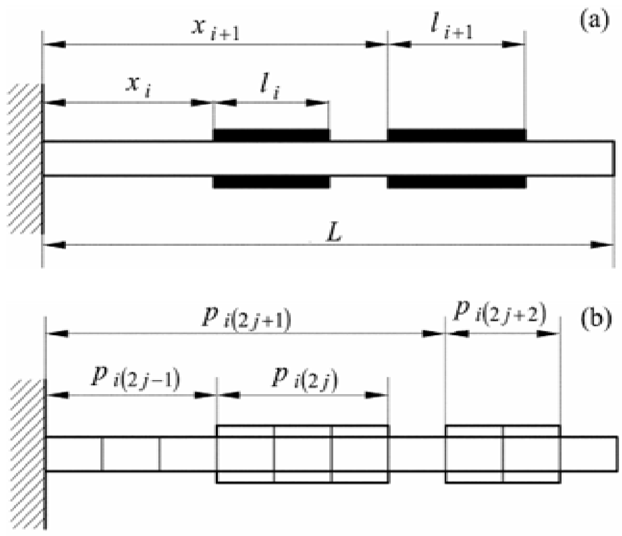

Figure 3. a) Position and length of an arbitrary S/A pair on the beam, b) Position and length of an arbitrary S/A pair after discretization.

It is obvious that the coordinates of a particle and the corresponding velocity are integer numbers. Because of that, the discrete method must be used. Velocity is updated by the following equation for each iteration [24]

$$v_{id}^{k+1} = \mathrm{int}\left(w v_{id}^{k} + c_1 r_1 \left(l_{id} - p_{id}^{k} \right) + c_2 r_2 \left(g_d - p_{id}^{k} \right) \right) \tag{25}$$

in which $\mathrm{int}(f)$ is getting the integer part of f. Due to the formulation of the particle coordinates, other constraints appear – the geometric constraints. These constraints are

1. the coordinates of the particle must not be non-positive number
2. minimum distance between two patches is one element (there is no overlapping)
1. last piezoelect ic patch must not be outside of the beam.

The membership function of this constraint can be represented in the following way

$$\mu_{\mathrm{G}} = \begin{cases} 1, & \textit{if geometric constrains are not violated} \\ 0, & \textit{if geometric constrains are violated} \end{cases} \tag{26}$$

and the optimization problem can be transformed in the following way

$$\mu_{\mathrm{D}}\left(\mathbf{p}^{*}\right)=\max \mu_{\mathrm{D}}(\mathbf{p}) \tag{27}$$

where

$$\mu_{\mathrm{D}}=\min\left\{\min_{i=1,N_{\mathrm{C}}} \mu_{\mathrm{C}\,i}\,,\ \min_{j=1,N_{\mathrm{fmods}}} \mu_{\mathrm{f}\,j}\,,\ \mu_{\mathrm{m}},\ \min_{k=1,N_{\mathrm{R}}} \mu_{\mathrm{R}\,k}\,,\ \mu_{\mathrm{G}}\right\} \tag{28}$$

Conclusion

In the first part of the paper, the problem of sensors and actuators sizing and location on the cantilever laminated beam is considered. The optimization algorithm based on the multi-objective fuzzy optimization and the particle swarm optimization technique for optimal sizing and location of piezoelectric actuators and sensors is developed. The main idea of the presented optimization algorithm is a transformation of both objective functions and constraints into pseudogoal functions through the process of fuzzification, converting a multi-objective optimization problem into a single-objective one, using the fuzzy decision principle. The optimization procedure implies the constraint on the original dynamic properties change and the limitation of the mass increase. The degree of controllability (DC), used to represent control effectiveness, is defined in a such way that it possesses computational simplicity, independence of the applied control law and easy handling in the case of finite element discretization. The fuzzy set theory implementation enables easy computation, expression simplicity of constraints and objective functions, and avoiding the use of weighing coefficients and penalty functions.

Further conclusions will be given in Part 2 of this paper, where the numerical simulation of the presented optimization technique will be presented.

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Received: 27.04.2014.

Višeciljna fazi optimizacija veličine i položaja piezoelektričnih aktuatora i senzora za upravljanje vibracijama bazirana na optimizaciji rojem čestica (deo 1: teorijski model)

Određivanje veličine i položaja piezoelektričnih aktuatora i senzora za aktivno upravljanje vibracijama savitljivih struktura obično je bazirano na maksimalnoj efikasnosti upravljanja i postizanja maksimalnog izlaza za modove vibracija od interesa. Integracija piezoelektričnih delova utiče na masu i dinamičke performanse bazične strukutre. Ovo je prvi deo istraživanja koje predstavlja teorijski razvoj višeciljne fazi optimizacione tehnike za određivanje položaja i

veličine piezoelektričnih aktuatora i senzora na tankozidnoj kompozitnoj gredi. Kriterijumi optimizacije za određivanje optimalne veličine i položaja piezoelektričnih aktuatora i senzora zasnivaju se na stepenu upravljivosti upravljanih modova. Procedura optimizacije obuhvata ograničenje promene prvobitnih dinamičkih karakteristika i ograničenje u porastu mase. Pseudociljna funkcija, zasnovana na teoriji fazi skupova, daje izraz za globalnu ciljnu funkciju eliminišući upotrebu težinskih koeficijenata i kaznenih funkcija. Optimizacija rojem čestica je upotrebljena za nalaženje optimalne konfiguracije.

Ključne reči: **piezoelektrični element, aktuator, merenje vibracija, kompozitni materijali, greda, fazi logika, višekriterijumska optimizacija, teorijsko razmatranje.**

Мультицелевая фаза оптимизации размера и расположения пьезоэлектрических приводов и датчиков для управления вибрациями на основе оптимизации роя частиц (часть 1: теоретическая модель)

Определение размера и расположения пьезоэлектрических приводов и датчиков для активного контроля вибрациями гибких структур, как правило, происходит на основе максимальной эффективности управления и максимизации выходов из рассматриваемых режимов вибрации. Интеграция пьезоэлектрических компонентов влияет на массу и динамические характеристики основной структуры. Эта первая часть исследования представляет теоретическую разработку методов мультицелевых фаз оптимизационной техники для определения положения и размеров пьезоэлектрических приводов и датчиков на тонкостенном композитном вале. Критерии оптимизации для определения оптимального размера и расположения пьезоэлектрических приводов и датчиков основываются на степени управляемости контролируемых режимов. Процедура оптимизации включает в себя ограничение изменения исходных динамических характеристик и ограничение роста массы. Псевдоцельная функция, основанная на теории фазных множеств, даёт выражение для глобальной целевой функции, исключив использование весовых коэффициентов и штрафных функций. Оптимизация роем частиц используется, чтобы найти оптимальную конфигурацию.

Ключевые слова: **пьезоэлектрический элемент, привод, измерения вибраций, композиционные материалы, вал, фази логики, оптимизация по множеству критериев, теоретическое рассмотрение.**

Optimisation "fuzzy" multi objective de la taille et de la location des actuaires piézoélectriques et des capteurs pour le contrôle des vibrations basée sur l'optimisation par essaim des particules (première partie: modèle théorétique)

La détermination de la taille et de la location des actuaires piézoélectriques pour le contrôle actif des vibrations des structures flexibles est basée généralement sur l'efficacité maximale de contrôle et sur la réalisation de la sortie maximale pour les modes des vibrations d'intérêt. L'intégration des pièces piézoélectriques influe sur la masse et sur les performances basiques de la structure. C'est la première partie de la recherche qui représente le développement théorique de la technique d'optimisation "fuzzy" multi objective pour la détermination de la location et de la taille des actuaires piézoélectriques et des capteurs sur la poutre composite aux parois minces. Les critères d'optimisation pour la détermination de la taille optimale et de la location des actuaires piézoélectriques et des capteurs sont basés sur le degré de la contrôlabilité des modes contrôlés. La procédure d'optimisation implique la limitation du changement des caractéristiques dynamiques originales ainsi que la limitation de la croissance de masse. La formation pseudo visée basée sur la théorie des ensembles "fuzzy" donne expression pour la fonction globale visée en éliminant l'emploi des coefficients de poids et des fonctions de pénalité. L'optimisation par un essaim de particules a été utilisée pour trouver la configuration optimale.

Mots clés: **élément piézoélectrique, actuaire, mesurage des vibrations, matériaux composites, poutre, logique fuzzy,optimisation multi critère, considération théorique.**