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An improved PSO algorithm for parameter identification of nonlinear dynamic hysteretic models

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A B S T R A C T

The nonlinear dynamic hysteretic models used in nonlinear dynamic analysis contain generally lots of model parameters which need to be identified accurately and effectively. The accuracy and effectiveness of identification depend generally on the complexity of model, number of model parameters and proximity of initial values of the parameters. The particle swarm optimization (PSO) algorithm has the random searching ability and has been widely applied to the parameter identification in the nonlinear dynamic hysteretic models. However, the PSO algorithm may get trapped in the local optimum and appear the premature convergence not to obtain the real optimum results. In this paper, an improved PSO algorithm for identifying parameters of nonlinear dynamic hysteretic models has been presented by defining a fitness function for hysteretic model. The improved PSO algorithm can enhance the global searching ability and avoid to appear the premature convergence of the conventional PSO algorithm, and has been applied to identify the parameters of two nonlinear dynamic hysteretic models which are the Leishman-Beddoes (LB) dynamic stall model of rotor blade and the anelastic displacement fields (ADF) model of elastomeric damper which can be used as the lead-lag damper in rotor. The accuracy and effectiveness of the improved PSO algorithm for identifying parameters of the LB model and the ADF model are validated by comparing the identified results with test results. The investigations have indicated that in order to reduce the influence of randomness caused by using the PSO algorithm on the accuracy of identified parameters, it is an effective method to increase the number of repeated identifications.

1. Introduction

The nonlinear dynamic hysteretic models are commonly used in the dynamic analysis of nonlinear structures, but contain lots of model parameters to be identified accurately and effectively. Among the existing methods for identifying the parameters of nonlinear hysteretic models, a two-stage least square algorithm was developed by Yar and Hammond [1] to identify parameters of the Bouc-Wen hysteretic model. As the convergence time of the least square algorithm dramatically increases with the number of parameters and depends on the proximity of initial values, some parameters were fixed according to the characteristic of Bouc-Wen model to decide the initial values of other parameters. Then, all model parameters were identified by using the iterative method. As it needs to manually fix some model parameters in the first stage of the identification, this algorithm is not suitable for nonlinear model including some coupling parameters. Another

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identification method based on genetic algorithm was presented by Petrone et al. [2] to decide the parameters of an elastomeric rheological hysteretic model. However, the operations of coding, crossover and mutation in genetic algorithm may make the identification process to be complicated and reduce the convergence speed. Do et al. [3] used the genetic algorithm and the Nelder-Mead simplex method to identify the nonlinear model parameters of tension-sheath mechanism. In their research, the Nelder-Mead simplex method was used to refine the initial results calculated by the genetic algorithm. Talatahari and Rahbari [4] proposed the enriched imperialist competitive algorithm for the parameter identification of magneto-rheological dampers.

As a random searching algorithm, the Particle Swarm Optimization (PSO) algorithm [5] iteratively updates the positions of particles which have the ability to remember and share the information to obtain the optimal solution. Due to its excellent characteristics of simple principle and fast convergence, the PSO algorithm has been widely applied to some domains: multi objective optimization [6], mode identification [7], signal processing [8], damage identification [9], etc. However, the PSO algorithm may get trapped in the local optimum and appear the premature convergence not to obtain the real optimum results. In order to improve the performance of PSO algorithm, some investigations had been made by combining PSO algorithm with other intelligent algorithm [10,11], introducing some mechanism into standard PSO algorithm [12–14] and modifying the inertia weights [15]. In this paper, an improved PSO algorithm by defining a fitness function for hysteretic model has been presented.

Two nonlinear dynamic hysteretic models are crucial to analyze the rotor aeroelastic problems and strengthen the rotor aeroelastic stability [16]. One is the unsteady dynamic stall model for blade airfoil, and the other is the nonlinear dynamic model for elastomeric damper which can be used as the lead-lag damper in rotor.

The dynamic stall is caused by the harmonic pitch oscillation of the airfoil. The shed vortex formed at the leading edge of the airfoil leads an abrupt change in the aerodynamic properties of the airfoil. The variation of airfoil's normal force with angle of attack shows the phenomenon of nonlinear hysteresis. Leishman and Beddoes (LB) [17] simulated the unsteady aerodynamic forces of the airfoil under dynamic stall by using indicial response functions, and divided the aerodynamic forces into three parts: attached flow, separated flow and dynamic stall. The LB dynamic stall model has good accuracy and has a wide application in comprehensive aeroelastic analysis of rotor and wind turbine [18–20]. However, the complicated LB dynamic stall model makes it difficult to accurately identify the parameters containing in the model.

The elastomeric damper installed in rotor can provide the stiffness and damping of blade lag motion to ensure the aeroelastic stability of rotor system. But the dynamic characteristic of elastomeric damper has strong nonlinearity and varies with the amplitude and frequency of excitation. The variation of restoring force with material deformation shows the phenomenon of nonlinear hysteresis. Comparing with the model in frequency domain developed by Felker et al. [21] and the model in time domain developed by Gandhi and Chopra [22], the anelastic displacement field (ADF) model proposed by Smith et al. [23] can accurately capture both the complex modulus properties and the stress-strain hysteretic properties of elastomeric damper, and has been used for the aeroelastic stability analysis of rotor [24].

The parameters of LB dynamic stall model and ADF model vary with the shape of airfoil and the material property of elastomeric damper respectively, and are identified by using the improved PSO algorithm presented in this paper. The accuracy and effectiveness of the improved PSO algorithm for the parameter identification in the models are validated by comparing the normal force-angle of attack hysteretic curves of two airfoils and the stress-strain hysteretic curves of the elastomeric damper with test results [17,23,25]. Also, the influence of randomness by using the PSO algorithm on the accuracy of identified parameters and the method for reducing the influence are investigated.

2. Improved PSO algorithm for hysteretic model identification

2.1. A fitness function for hysteretic model identification

As an emerging evolutionary algorithm, the PSO algorithm origins from the simulation of bird foraging, has simple principle and is easy to implement. For the optimal identification of N parameters, the PSO algorithm randomly arranges D particles to form the swarm in which every particle contains N parameters in the searching range. The position of every particle corresponds to a set of values of N parameters to be identified and can be used to calculate the fitness value which can evaluate the quality of identified parameters.

Every particle has the ability to remember information to judge if the position of particle is the best according to the fitness value and save the parameters corresponding to the best position as $\vec{p}_d^{\,j} = (p_{d1}^j,\ p_{d2}^j,\ \cdots,\ p_{dN}^j)$, and has the ability to share information to get the best position of the swarm and save the parameters corresponding to the best position as $\vec{q}^{\,j} = (q_1^j,\ q_2^j,\ \cdots,\ q_N^j)$. The nth parameter c_{dn}^j containing in the dth particle at the jth iteration step is iteratively updated by using the following equations:

$$c_{dn}^{j+1} = c_{dn}^j + v_{dn}^{j+1} w \tag{1}$$

$$v_{dn}^{j+1} = v_{dn}^j + a_1 r_1 (p_{dn}^j - c_{dn}^j) + a_2 r_2 (q_n^j - c_{dn}^j) \tag{2}$$

where, $n = 1, 2, \ldots, N$, $d = 1, 2, \ldots, D$, a_1 and a_2 are the accelerated constants between 0 and 2, r_1 and r_2 are the random