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Vibration analysis of fixed-fixed beam using particle swarm optimization

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Abstract: The significance of the beam and its industrial applications is obvious, and it undergoes dissimilar kinds of loading. Such loading might cause flaws in the beam .The presence of crack causes the change in the physical properties of a beam and thus reducing the stiffness of the beam with an invisible decline in natural frequencies. Crack depth and location are the key factors for the vibration scrutiny of a beam. In the present investigation, procedures have been developed for fault detection of a fixed-fixed beam with single crack using Finite Element Analysis (FEA) and Particle Swarm Optimization (PSO) technique. Diverse crack location effects are considered and the results are compared with different crack depth of the fixed beam. Then Particle swarm optimization algorithm has been developed using the first three relative natural frequencies taking from FE analysis. For comparative study both Standard PSO and APSO is used for crack diagnosis of fixed-fixed beam. The feasibility of proposed PSO techniques is compared through error analysis. The objective of the study is related to design Particle swarm optimization technique for prediction of crack location and crack depth in a uniform cracked fixed-fixed beam.

Keywords: Vibration Scrutiny, Beam, Flaw, Relative natural frequency, PSO.

I. Introduction

The AI methods have been premeditated with a purpose for quicker and precise estimation of fault present in the structures. This paper targets at exploring the use of AI methods such as Particle Swarm Optimization (PSO) for single crack identification in structures at an early stage by capturing the vibration factors. The fitness function for crack diagnosis is based on the vibration data, such as natural frequencies obtained from finite element analysis. The PSO and APSO were employed to predict the relative crack depth and relative crack location. The PSO and a fuzzy adaptive PSO (APSO) has been used which incorporates the dynamically varying inertia weight based on the variance of the population fitness. The feasibility of proposed PSO techniques is compared through error analysis.

The PSO is a bio-inspired evolutionary optimization algorithm, initially presented by Kennedy and Eberhart [1], which utilizes swarm intelligence to achieve the goal of optimization. Kishore et al. [2] have been studied that APSO gives the better performance than PSO and also APSO has been anticipated for solving the complex condition monitoring problem.Rane et al. [3] has studied the free vibration analysis of cracked structure. It has been observed that when the crack depth increases, the natural frequency of the beam decreases for a precise crack location. Nanda et al. [4] have made a comparison between the standard particle swarm optimization and the incremental particle swarm optimization for identifying flaw in mechanical member. They observed that I-PSO is more preferable for damage detecting then S-PSO. Qian et al. [5] have presented a hybrid optimization algorithm (HOA) combining particle swarm optimization (PSO) with simplex method (SM). This method helps to recognize delamination in laminated beams with good accuracy, reliability and efficiency.

II. Methodology

A. Standard PSO

The standard PSO model comprises of a swarm of M particles moving in a problem search space. Each particle is a potential solution of the global optimum over a given domain D. For a N-dimensional search space, the position of the i^{th} particle is represented as $X_i = (x_{i1}, x_{i2}. . . x_{iD})$ which represents the current position of the particle i $(1 \leq i \leq N)$ in a D – dimensional search space.

At each generation k, the new particle position is found by adding a displacement to the current position where the displacement is the particle velocity multiplied by a time step of one as shown in the Equation (1)

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (1)$$

Where, X_i^{k+1} and X_i^k represent the current and previous position of the i^{th} particle respectively
V_i^{k+1} is the current velocity of particle i and is represented as $V_i = (V_{i1}, V_{i2}, \ldots V_{iD})$

The velocity of each particle is also updated at each generation and it can be written as,

$$V_i^{k+1} = V_i^k + C_1 \times r_1 \times (x_{pb}{}^k - x_i{}^k) + C_2 \times r_2 \times (x_{gb}{}^k - x_i{}^k) \quad (2)$$

Where, V_i^{k+1} and V_i^k represent the current and previous position of the i^{th} particle respectively.

B. Fuzzy Adaptive PSO (APSO)

A methodology to transform the inertia weight is to use a dynamically adapted fuzzy system. The fuzzy system consist of three rules, with one input and one output. The input considered is change in standard deviation of global best fitness and the output is the change in inertia weight.

Here, the fitness function is represented as Equation (3).

$$F_i = \frac{1}{O_{th} + O_{bji}} \quad (3)$$

Where, O_{th} is the threshold value which ranges from 0 to 1.0. In the current work threshold value has been considered as 1 to avoid singularity in the solution domain. O_{bji} is the objective function taken from the selected data.

The inertia weight is updated by finding the variance "σ^2" of the population fitness as in Equation (4).

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{F_i - F_{avg}}{F_n} \right)^2 \quad (4)$$

Where, F_i is the fitness value of the i^{th} particle in the population,
F_{avg} is the average fitness value of the population of particles in a given generation and
Fn is the normalizing factor taken as shown in equation 5,

$$F_n = \{\max|F_i - F_{avg}|\}, \; i = 1, 2, 3 \ldots N. \quad (5)$$

By using the above formulation, the impact of the past velocity of a particle on the current velocity is selected to be random and the inertia weight is adapted randomly depending on the variance of the fitness value of a population. This consequences in an optional coordination of local and global searching abilities of the particles.

III. Objective Function

The cracked in a beam causes change in vibration natural frequencies. The objective function based on relative natural frequency can be expressed as in Equation (5.7).

$$\text{Minimize Obj} = K_0 + (K_1 \times RFNF) + (K_2 \times RSNF) + (K_3 \times RTNF) \quad (6)$$

Where, K_0, K_1, K_2, K_3 are the constants and
RFNF is the Relative First Natural frequency
RSNF is the Relative Second Natural frequency
RTNF is the Relative Third Natural frequency

IV. Error Calculation

The performance study of standard PSO and APSO are presented in terms of % error and performance plot for cracked fixed-fixed beams. The error for different PSO techniques used for fixed-fixed beam has been calculated between the predicted and actual value as shown in Equation (7),

$$\%\ \text{Error} = \left| \frac{\text{Predicated value} - \text{Actual value}}{\text{Actual value}} \right| \times 100 \quad (7)$$

V. Result and Discussion

In this current paper work swarm optimization technique is applied for recognition of crack depth and location in fixed-fixed beam. Reasonable variations in natural frequencies due to existence of crack are efficiently used to prediction structural damage recognition using anticipated adapted PSO. The result has been drawn from both standard PSO and APSO and analyses with the help of error analysis. A graphical representation has been shown in figure 1.1 and figure 1.2 for RCL and RCD respectively through error analysis.

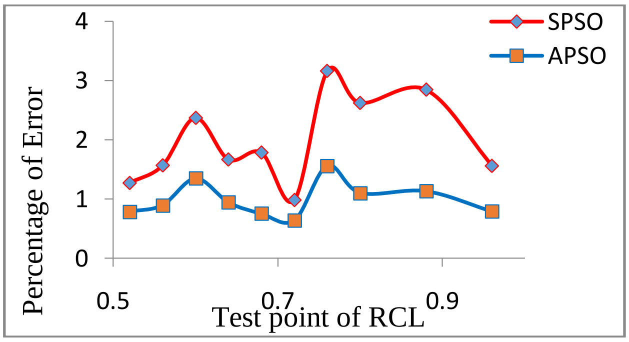

Fig. 1Error analysis of RCL for SPOS and APSO

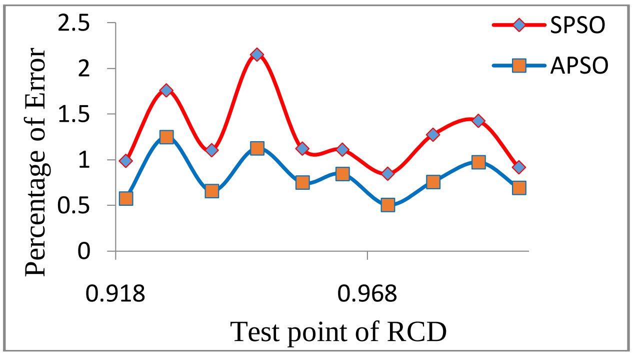

Fig. 2Error analysis of RCD for SPOS and APSO

Based on results obtained from finite element analysis, the APSO is found to be related with least error for prediction of crack location and crack depth from minimum 0.642% to maximum 0.505% compared to standard PSO from minimum 0.981% to maximum 0.845% in fixed-fixed beam respectively.

VI. Conclusion

A comparison is made for accessing the performance of standard PSO and APSO for identifying faults. The result reveals that the APSO technique is more appropriate than standard PSO with minimum percentage error.

Future Work

1- Hybrid PSO can be used to crack detection in fixed-fixed beam.
2- Artificial intelligence (AI) techniques like fuzzy logic, Genetic Algorithm, neural network optimization can be utilized for prediction of crack depth and location in fixed-fixed beam.
3-The vibration results obtained using finite element analysis can be verified by conducting experiments.

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