Genetic Algorithm Based Objective Functions Comparative Study for Damage Detection and Localization in Beam Structures

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Abstract. The detection techniques based on non-destructive testing (NDT) defects are preferable because of their low cost and operational aspects related to the use of the analyzed structure. In this study, we used the genetic algorithm (GA) for detecting and locating damage. The finite element was used for diagnostic beams. Different structures considered may incur damage to be modelled by a loss of rigidity supposed to represent a defect in the structure element. Identification of damage is formulated as an optimization problem using three objective functions (change of natural frequencies, Modal Assurance Criterion MAC and MAC natural frequency). The results show that the best objective function is based on the natural frequency and MAC while the method of the genetic algorithm present its efficiencies in indicating and quantifying multiple damage with great accuracy . Three defects have been created to enhance damage depending on the elements 2, 5 and 8 with a percentage allocation of 50% in the beam structure which has been discretized into 10 elements. Finally the defect with noise was introduced to test the stability of the method against uncertainty.

1. Introduction

In recent years, genetic algorithms have been recognized as promising techniques for intelligent search difficult optimization problems. A method of the genetic algorithm is very attractive compared to conventional methods because it does not require a search of solution within the entire space of solution. Iturrioz et al [1] used a separate index: COMAC criterion (Coordinate Modal Assurance Criterion). Numerical and experimental vibration modes were determined the index position and the magnitude of the damage.

Messina et al. [2] proposed an approach to uncertainty for the detection of damage that was later extended in [3] to identify the extent of damage in several sites. Data validation was performed by free digital noise tests. This approach, however, may involve significant computational effort when it comes to large structures.

For structures with higher degree of freedom, MI Friswell et al. (1998) [4] had developed a technique which is based on the combined use of the sensitivity of eigenvalues and genetic algorithms to identify the location and extent of damage from the measured vibration data. They used a genetic algorithm to minimize a square value of the frequency error.

J. H. Chou and J. Ghaboussi (2001) [5] used a GA to solve an optimization problem formulated for the detection and identification of structural damage. The "Output error" indicating the difference between the measured and calculated responses under static loads and the equation error indicating the residual force in the equilibrium equations were used to formulate the objective function to be optimized. The proposed method can successfully detect the location and magnitude of damage and determine the correct unmeasured nodal displacement, while avoiding the complete finite element analyzes. Cawley and Adams [6] used the variations in the natural frequency finite element models to find the damage. H. M. Gomes and N.R.S. Silva [7] used two methods, one based on the frequency sensitivity to damage and the second is based on optimization and parametric finite element modelling techniques. [8] have Used a substructure FE-based approach to identify and localize damages in a complex mechanical systems using the subspace fitting method.

1.1 Aim and scope

In this paper the damage identification problem is addressed by means of a Genetic Algorithm (GA) approach. It has utilized in order to achieve the optimal results in the damage detection problem. The objective functions used in the optimization process are based on the dynamic analysis data in the structure (frequencies and mode shape). Various numerical finite element methods will be performed on clamped free beams discretized into 10 elements.

2. Modeling and Applied stresses identification

We consider a clamped free beam of pure unidirectional composite of AS4/3501-6 graphite-epoxy materials with symmetrical order of layers flexion. The finite element model is discretized in 10 elements as shown in Figure 1. Each node of the finite element has three degrees of freedom, normal displacement w along the z axis, a rotation γ around the y axis and longitudinal displacement u. since the beam is macroscopically considered homogeneous, i.e. there is only one layer, the shear correction coefficient is the same as for isotropic beam ,i.e. K Correction =5/6 [9].

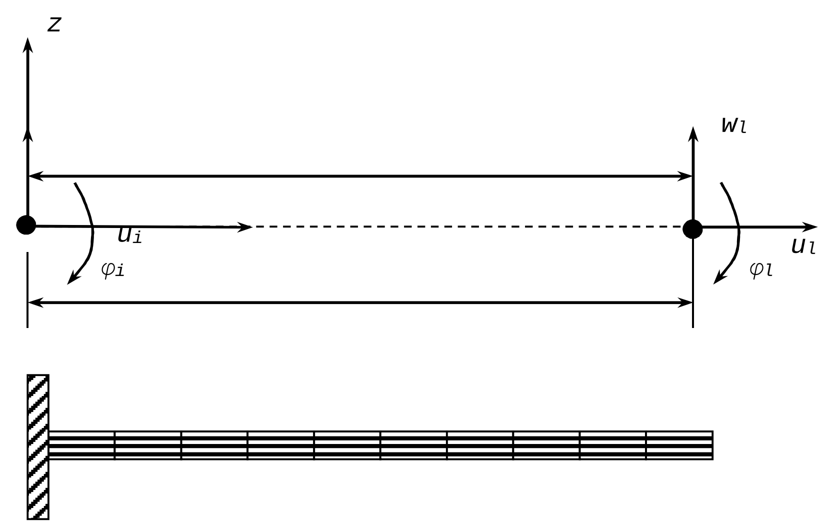

Figure.1 beam structure of unidirectionally reinforced graphite-epoxy beam

The material properties and beam dimensions of AS4/3501-6 graphite epoxy [10] are given in Table 1.

Table 1. Dimension and material of beam

Ply property	Mean value
Length (m)	0.75
Width (m)	0.03
Thickness (m)	0.005
Longitudinal modulus (GPa)	141.96
Transverse Shear modulus (GPa)	6
Density (kg.m-3)	1600
Poisson's ratio v	0.42

3. Modal Assurance Criterion (MAC)

The Modal Assurance Criterion (MAC) value indicates the degree of correlation between the two modes and ranges from 0 to 1, with 1 for any correlation and 0 for no correlation. The deviation from 1 can be interpreted as a damage indicator of in structures. This is based on comparison between the changes in the mode shapes obtained from both tests and calculations, the MAC is defined by Ostachowicz WM et al. 1996 [11]:

$$\mathrm{MAC}\ (\varphi_i, \varphi_j) = \frac{(\varphi_i^T \varphi_j)^2}{\varphi_i^T \varphi_i \varphi_j^T \varphi_j} \tag{1}$$

Where: φ_i is the tested Eigen vector and $\varphi_j$the calculated eigen vector.

The objective function to be minimized is defined as follows:

$$\mathrm{Fitness} = \Sigma\ (1 - \mathrm{MAC})^2 \tag{2}$$

4. Natural frequencies variations

The natural frequency is used as a diagnostic parameter in the procedures for structural assessment using vibration monitoring. A great advantage to use only specific to the damage assessment structures values that can easily obtained and cheaply acquired that make the approach provide an assessment of the economic structure technique. The objective function to be minimized is defined as follows according to MTV Baghmisheh et al 2008 [12]:

$$\Delta\omega = \sum_i^n ((\omega_i^m - \omega_i^a)^2 / (\omega_i^m)^2) \tag{3}$$

i = mode number (i=1, 2, 3,….,n), ω_i^m = tested natural frequencies and ω_i^a = Calculated natural frequencies.

5. Application of the Genetic Algorithm

The Genetic Algorithm (GA) is an evolutionary optimization method, used efficiently for different kinds of optimization problems in last decades [13]. In our study 10 individual, also called chromosomes, represent the two damage parameters of position and rate, are converted to binary encoding. The population evolves toward better solution iteratively in a process inspired from the natural evolution, where they are allowed to cross among themselves in order to obtain favorable solutions. The fitness is the objective function value, calculated in Eqs (2-3). The best feasible solutions have higher probability to be chosen as parent of new individuals, where the properties of the parents are combined by exchanging chromosomes parts, to produce two new designs. After, the mutation is performed by randomly replacing the digits inside of a randomly selected chromosome.
These basic operators are repeated to create the next generations until the maximum number of iterations is reached [14].the methodological approach to the damage detection and localization problems using FEM and GA according to the following:

1- Modeling beam structures using FEM
2- Expressing the damage by stiffness reduction at a global level by identification of dynamic measure (frequencies and eigenvector).
3- Calculation the frequencies and eigenvectors proposed by GA
4- Solving the inverse problem after the providing given frequencies and eigenvector to objective function of optimization algorithm in order to calculate a local damage using GA.

5.1 *optimization parameter*

In GA method, each of the 100 individuals contains two chromosomes representing the wanted damage parameters using a total number of iterations of 200.After several applications, a crossover coefficient of 0.8 and mutation of 0.1 were used in the GA parameters.

6. Results and discussions

The approach presented in this study where the natural frequency is used as a diagnostic parameter in the procedures for structural assessment using vibration monitoring allows drawing the following interpretation:

6.1 Objective function based on the changes in the natural frequency – Figure 2

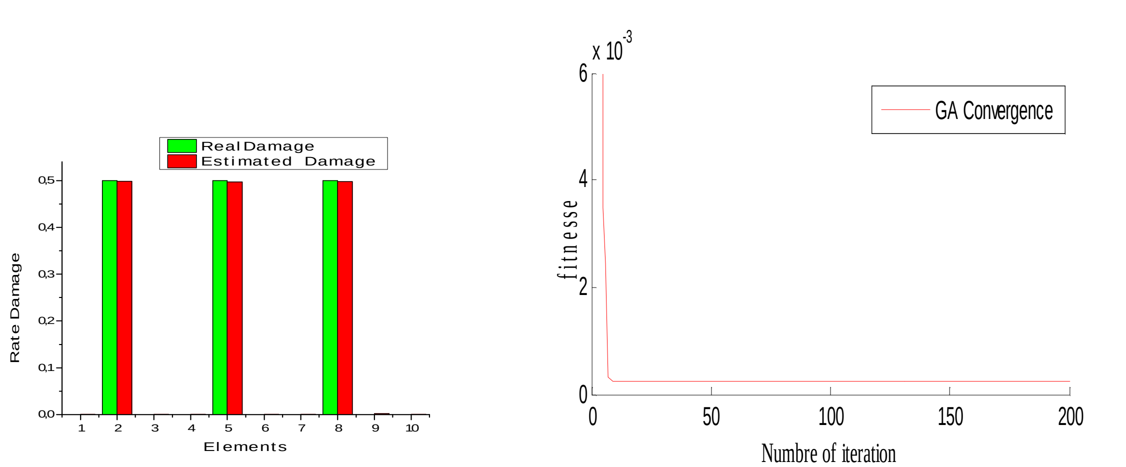

Figure 2. Objective function based on the change of the natural frequency.

The objective function based on the change of the natural frequency gives good results because the reduction in rigidity has a relatively large effect on the natural frequency in relation to the eigenmodes.

6.2 Objective function based on Modal Assurance Criterion (MAC) – Figure 3

From the results it can be observed that the objective function based on Modal Assurance Criterion (MAC) provides good results of the damage position in the beam elements. However, errors are estimated between actual and estimated damage with disturbances in other elements.

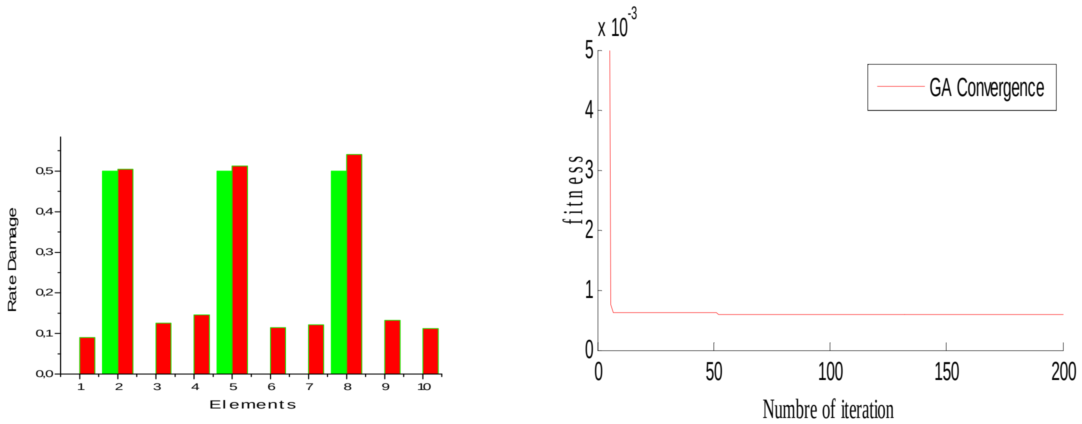

Figure 3. Objective function based based on MAC

6.3 Objective function based on Modal Assurance Criterion (MAC) and natural frequency – Figure 4.

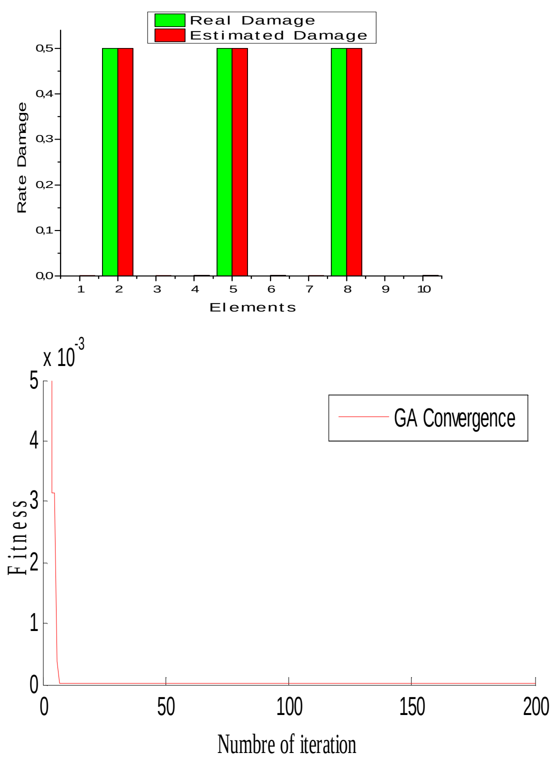

Figure 4. Objective function based on the change on MAC and natural frequency

The objective function based on the change of the natural frequency and Modal Assurance Criterion (MAC) is the best objective function, because the reduction in stiffness has a relatively large effect on the natural frequencies and the Modal Assurance Criterion (MAC).

6.4 Defect detection with noise 5 % Level – Figure 5

A white Gaussian noise was introduced using MATLAB code to the input data to test the precision of the method with presence of uncertainty, the figure Fig.5 shows that the algorithm could estimate the damaged element precisely, the damage rate was successfully guessed for a high noise level of 5%, it is noted that other damaged element with a weak damage rate was proposed.

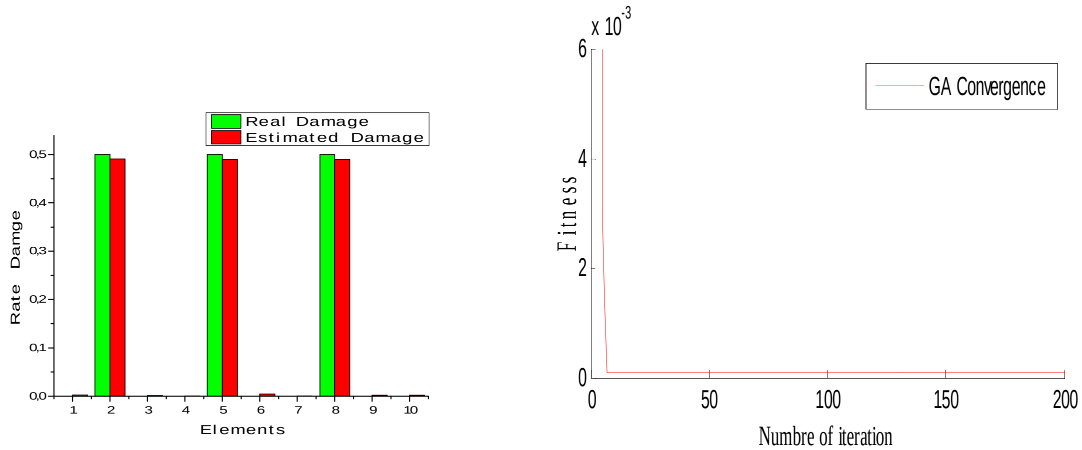

Figure 4. Objective function based on the change on MAC and natural frequency with noise 5% level

7. Conclusion

In this work an optimization approach has been developed and used for vibration analysis of beam structure to detect and locate multi damages using genetic algorithm. Three objective functions were considered. The main conclusions of this work can be formulated as follows:

- The study shows that the genetic algorithm is effective to identify the positions and assignment of multiple degree of damage. The objective function based on the change of the natural frequency gives good results because the reduction in rigidity has a relatively large effect on the natural frequency in relation to the eigen modes.

- The objective function based on the change of the natural frequency and Modal Assurance Criterion (MAC) is the best objective function since the reduction in stiffness has a relatively large effect on the natural frequencies and Modal Assurance Criterion (MAC) compared to own modes and eigenvectors.

- The noise level was introduced to test the stability of the approach. The algorithm proved its accuracy even after a high level of perturbation was imposed.

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