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Optimization algorithms for composite beam as smart active control of structures using genetic algorithms

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Abstract. The principles of productive active and semi-active civil and infrastructure engineering structural control date back 40 years and significant progress has been recorded in those four decades. Smart structures typically have some control systems that enable them to deal with perturbations. The active vibration management techniques have been applied numerically and experimentally in order to reduce the vibrational levels of lightweight economic composite structures. Smart composite beams and plates have been produced and tested with surface-based piezoelectric sensors and actuators. It has been found that an effective model of smart composite plates can predict the dynamic characteristics. Utilizing Genetic Algorithm (GA) was designed and implemented. Two regression model as root mean square (RMSE) and determination coefficient (R^2) were used. The first and second bending modes are operated effectively by a beam, and simultaneous vibration levels are significantly reduced for the conductive plates by the simultaneous operation of the bending and twisting modes. Vibration management is realized by using efficient control. GA could show better performance for managing linear feedback laws under given assumptions.

Keywords: active control; optimization algorithms; composite beam; genetic algorithms

1. Introduction

Due to their high strength/weight relationship, the composite materials were added to various items made (Zhu *et al.* 2018, Abedini and Zhang 2020, Zhang and Mousavi 2020). In several special conditions, either under elastic or dynamic Reddy regime its streamlined layer with overlaying layers and various fiber orientations enables optimized construction (Alam *et al.* 2020c, Kordestani *et al.* 2020, Sun *et al.* 2020). Laminated composite materials are currently being developed with various state-of-the-art facilities, especially in the aerospace industry. The required tools for acquiring static or dynamic responses are a critical factor to remember (Alam *et al.* 2020a, b, Zhang *et al.* 2020, Abedini and Zhang 2021). It must be carried out with the aid of less invasive sensors and highly reliable actuators. In such matters, piezoelectrical materials can provide fascinating alternatives because they can either be connected to the surface or inserted within the structure (Repinaldo *et al.* 2020). The so-called smart systems include the combination of sensors and actuators, structures and control mechanisms (Sun *et al.* 2018, 2019a, Zhang *et al.* 2019, Li *et al.* 2020). The Finite Element Method (FEM) is one of the most appropriate approaches among various current methods of modelling clever composite structures (Yang *et al.* 2015, 2020, Abedini *et al.* 2020). The finite element process offers favorable modelling characteristics and relative ease for computational applications (Zheng *et al.* 2020, Zhang *et al.* 2021). Scientific literature has introduced a number of theories on the formulation of finite elements of smart composite systems, each one with its own beneficial and adverse characteristics of precision, implementation and computational effort (Zuo *et al.* 2015, 2017, Repinaldo *et al.* 2020). The Shear Deformation Theory in the third order, also known as High order shear Deformation Theory (HSDT) uses a polynomial equation to approximate the mechanical variables (Shariati *et al.* 2019a, 2020f, Afshar *et al.* 2020). In addition to the First Shear Deformation Theory (FSDT), another method used to model composite structures, the HSDT technique allows for improved approximations of numerical values achieved from the theory of 3D elasticity (Fanaie *et al.* 2015, 2019, Fanaie and Shamlou 2015, Afsar Dizaj *et al.* 2018). The FSDT as well as the HSDT are categorized in the literature as equivalent single layer theories. In addition

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to this definition, there are also the hypotheses on the discrete equivalent layer in which the movements are continuous functions along the laminate thickness coordinating (Fanaie and Ezzatshoar 2014, Brandejsky 2018, Fanaie and Moghadam 2019). According to Reddy *et al.* (2003), the layer theories more suitable than that established with the Single Layers approach are better recommended for analyzes involving the world performance of compound laminates when focused on studying local effects on composites including delaminating mechanisms between adjacent layers, fiber rupture and edge effects (e.g., the determi-nation of natural frequencies, vibration modes and displacements). The techniques of vibration management, including passive, active and semi-active control systems can impede these vibrations (Xu *et al.* 2014b, Zhang and Wang 2019b). Through the use of piezoelectric and viscoelastic materials, passive monitoring in smart systems can be carried out (Repinaldo *et al.* 2020). So, its efficiency becomes subject to variances in device parameters. The research literature widely describes active control methods used for the control of vibration in smart systems (Xu *et al.* 2014a, Zhang and Wang 2019b). This technique uses a controller's secondary powers to mitigate vibrations of the structure (Younespour and Ghaffarzadeh 2015). The semi-active techniques include the combining the previous two techniques (Kasemi *et al.* 2012). A number of works have been devoted to active vibration regulation in smart systems based on the linear quadratic regulator (LQR) (Repinaldo *et al.* 2020). The optimum LQR control architecture is intended to minimize an arbitrary function or index of results. The successful vibration management in composite systems has been subjected to fluid control techniques (Alt *et al.* 2010). However, the optimum sets for fluctuating membership functions and fluid laws on the synthesis of fluid controls are difficult to describe. The description of these sets relies usually on the skill and trial and error processes of designers (Chen *et al.* 2019, Shariati *et al.* 2019c, Trung *et al.* 2019). The invention of new optimal controllers with advantages previously seen by fuzzy controllers is therefore important. A number of control engineering implementations successfully used smart device architectures built on furrowed logic and artifacts in neural networks (Kordestani and Zhang 2020, Mousavi *et al.* 2020, Ma *et al.* 2021, Ye *et al.* 2021). Artificial neural networks (ANNs) or neural networks (NNs) perform as computing systems, which are inspired by biological NN (Shariati 2013, Che-Ngoc *et al.* 2018, Toghroli *et al.* 2020). In fact, ANNs are a part of Artificial intelligence (AI) that are widely applied for the simulation process (Mohammadhassani *et al.* 2014b, Safa *et al.* 2020, Shariati *et al.* 2020c, e). AI provides many advantages compared to numerical and experimental methods. It is a cost-effective technique and is able to produce fast and accurate results (Shariati *et al.* 2019d, e, 2020d, Tran *et al.* 2019). Due to the ability of ANNs to model the nonlinear processes, they have been recognized as useful and popular approaches to address numerous problems such as data analysis, signal processing, structured prediction, clustering, regression, decision-making, dimension reduction (Sadeghipour Chahnasir *et al.* 2018, Sedghi *et al.* 2018, Katebi *et al.* 2019, Shariati *et al.* 2019g). A neuro-fuzzy system is a fuzzy system that applies a learning algorithm derived from NN theory to determine its parameters (fuzzy rules and fuzzy sets) by processing data samples (Mohammadhassani *et al.* 2013, Toghroli *et al.* 2014, 2016, Mansouri *et al.* 2019). An optimization algorithm is iteratively implemented to compare the different solutions for finding the best one (Dao *et al.* 2018, Shariati *et al.* 2019d, Naghipour *et al.* 2020b, Shariati *et al.* 2020a). One of the applicable and popular methods to solve the optimization problems is Genetic algorithm (GA) (Shariati 2008, Arabnejad Khanouki *et al.* 2010, 2011, Ismail *et al.* 2018). GAs optimize the search algorithms on the basis of evolution through random selection. Currently, GAs are the most used computational methods of evolution in artificial life applications (Daie *et al.* 2011, Mohammadhassani *et al.* 2014c, Safa *et al.* 2016, Nasrollahi *et al.* 2018). They are decentralized models, which can provide a background to understand other phenomena and systems around the world (Shariati 2020, Shariati *et al.* 2020b, g, Rajaei *et al.* 2021). Researchers have also utilized evolutionary computation methods such as genetic algorithm and particle swarm optimization to improve the accuracy and efficiency of the ANN-based algorithms (Arif *et al.* 2020, Naghipour *et al.* 2020a, Shariati *et al.* 2020h, Yazdani *et al.* 2020). The present study suggests an aggressive modal control of smart laminated composite materials by using a linear square regulation and Genetic Algorithm. The GA improves vibration diminishing performances of the structure through its learning and adaptive ability better than conventional controllers, for example linear quadratic regulators, nonlinear dynamics and uncertainties. In aerospace and weaponry, as well as robots, athletic gear and surgical prostheses, composite systems are commonly employed (Shariati *et al.* 2010, Shah *et al.* 2016b, Shahabi *et al.* 2016, Sun *et al.* 2019b). In enhancing protection and improvement of device functionality, active vibration management of these systems is of considerable significance as the occurrence of unintended vibrations can lead to volatility, lower efficiency and catastrophic failures (Worden *et al.* 2003, Hamidian *et al.* 2011, Shariati *et al.* 2018, 2019b). Conventional systems and sensors and actuators are used to shape so-called smart structures to eliminate vibrations during use. Smart architectures rely on control algorithms for their efficiency and functionality. In Alkhatib and Golnaraghi (2003), Fisco and Adeli (2011), a thorough review of the vibration-suppression control algorithm was submitted. Classic control algorithms such as direct proportional feedback and constant gain velocity (CGVF) feedback (Narayanan and Balamurugan 2003, Yang *et al.* 2005, Kumar and Narayanan 2007, 2008) are the most frequently used control algorithms. Optimal regulation (Linear-quadratic regulator (LQR) and Gaussian linear-quadratic (LQG) are used in Kapuria and Yasin (2010), Reis and Costa (2012), Zorić *et al.* (2013). In Qiu *et al.* (2007), we suggest a positive position feedback (PPF), proportional-derivative (PD) power and control technique that incorporates PPF and PD. The authors conducted in (Wang and Inman 2011) experimental and numerical comparisons

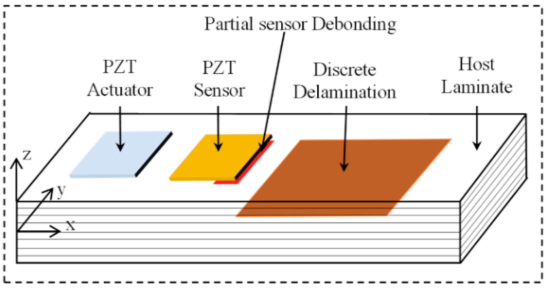


Fig. 1 Bonded laminated composites

on the basis of energy consumption between four control systems (PPF, PID, nonlinear control and LQR) Fuzzy controls were employed in Sharma *et al*. (2007), Wei *et al*. (2010), Nasser *et al*. (2012), the active monitoring of the vibration of flexible structures.

The review of available publications on the active vibration regulation of smart structures leads to the inference that no work on PID controller is used to actively suppress smart structures (Wen *et al*. 2011, Habibi *et al*. 2018, 2019, Pul 2020). This document introduces an experimental examination of a smart cantilever beam's active vibration control using a PID controller. The first-order low-pass Filter is used in a derivative action and in the feedback of Integrated Action to avoid negative derivative and integrative events within a PID controller. The gains are tuned using the Ziegler–Nichols system in the first iteration (Åström and Hägglund 1995).

A composite cantilever with a reinforced fiber piezoelectric actuator and tensile gage sensors are provided for the device. The application is proposed. The beam is modeled based on the third-order shear deformation principle using a finite element system. The control algorithm is set up with an embedded PIC32MX440F256H micro-controller on a PIC32-PINGUINO- OTG frame. The test examines vibration modulation under regular arousal and initial static distortion. The experimental findings corresponding to the PID controller are contrasted with the relevant results using proportional (P) power, PI control (proportional–integral) and PD control. The benefit of mixing composites with intelligent materials can be achieved by creating "intelligent composites" or "intelligent composites" (Liu *et al*. 2017, Galyshev *et al*. 2019, Huang *et al*. 2021a, b). One explanation for this work is that some types of mechanisms and processes should be created to adjust to correct operating environments (Toghroli *et al*. 2017, Milovancevic *et al*. 2019, Sajedi and Shariati 2019, Qi *et al*. 2020b). The added benefit of using this particular form of material into the structure is that the mechanism for sensing and actuating is specifically sensed and driven into the structure. In recent years, research and development have grown enormously on the topic of "smart composites" (Mohammadhassani *et al*. 2014a, Li *et al*. 2019, Luo *et al*. 2019, Majedi *et al*. 2020). The objective is to study how powerful a lightweight composite beam can be with intelligent sensors and actuators. As sensors and actuators for this study, piezoelectric materials will be used because they have the benefits of high rigidity, light mass, low energy consumption and fast deployment. Piezoelectric structures are the prime contenders for applications with dynamic stabilization, such as resonant vibration, active vibration reduction and bumping (Shariati *et al*. 2012, 2017, Wei *et al*. 2018, Qi *et al*. 2020a). PZT is a widely used piezoelectric ceramic (PiZT). PZT is a type of ceramic. An E-glass composite laminated beam is manufactured using the vacuum bagging method in this research for the purpose of successful vibration suppression. The composite beam is configured in a lifting configuration. Finite element simulation is carried out in order to show the fundamental modal frequencies and modal forms of the laminated composite beam (Jalali *et al*. 2012, Davoodnabi *et al*. 2019, Xie *et al*. 2019, Majedi *et al*. 2021). The FEM findings are then correlated with the experimental modal test results. Two PZT-patches are bundled at all parties of the beam near its clamping end as a sensor and an actuator in order to ensure successful vibration suppression of the versatile composite beam (Shariati *et al*. 2011, Shah *et al*. 2015, Ziaei-Nia *et al*. 2018). An automated data acquisition and in real time control system, Voltage Vulnerator and composite beam with PZT sensor and actuator are part of the total vibration removal system (Shah *et al*. 2016a, Nosrati *et al*. 2018, Shariati *et al*. 2019f). Two active vibration management methods are developed and applied, stress rate feedback (SRF) and positive position feedback (PPF). Feeding structural location co-ordinate to the compensator and the performance of a compensation and a positive scalar gain in structure is used to give positive feedbacks (PPF) (Chau *et al*. 2004). In a specific mode, PPF provides simple damping if the modal properties are known. The implementation of PPF is also simple. Song *et al*. (1998) showed PPF to be resilient to uncertain modal frequencies experimentally. String Feedback Rate (SRF) regulation is used for active space configuration damping (Newman 1992). The SRF is used to feed back to the compensator the structural velocity coordinate and the compensator location coordinate is fed back to the structure compounded by a negative profit. SRF has a broader active damping zone and with a reasonable bandwidth will stabilize more than one mode. The SRF is built in this research to regulate the 1st mode vibration. The vibration in both 1st and 2nd modes is controlled using two PPF controllers simultaneously. Experimental findings show that both methods SRF and PPF are successful in the active increase in the damping by PZT sensors and actuators of the versatile composition beam.

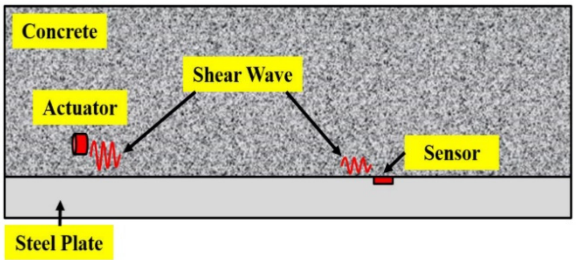


Fig. 2 The principle of concrete-encased composite structure bond-slip monitoring using shear wave based active sensing approach

2. Methodology

2.1 Statistical data

150 data were originally extracted. The current study has investigated composite beam as smart active control of structure management using GA model. The model was built and the outcomes were analyzed by regression indicators.

2.2 Genetic Algorithm development

Genetic Algorithm (GA) is one of the tree-based methods for function approximation (Azamathulla and Ghani 2010, Sarıdemir 2014). The most considerable advantage of GP is its capability in generating closed form formulations in the *D* dimensional space of the problem, where *D* is the number of variables. In GP, mathematical operators such as +, -, /, √, *log*, *sin*, *cos*, *tanh* are randomly distributed on the branches or nodes of the tree, then, the three main operations of genetic algorithm (GA), i.e., selection, crossover, and mutation, are applied for fitting to the input data. Crossover, and selection operators of GP are a little different than those of GA. Crossover is accomplished by changing or replacing a bunch of operators on branches of the tree with other branches, which has been randomly selected (Faradonbeh *et al*. 2016, 2018). Mutation is conducted by changing only an operator randomly with another operator. Similar to GA, a cost function (fitness function) is defined for GP (Babanajad *et al*. 2013). The cost function herein can be in the term of root mean squared error (*RMSE*). Accordingly, if the value of *RMSE* in the training phase reduces, the operators have been selected better and a more precise result or closed form formulation can be obtained (Guven and Gunal 2008). In GP, every gen represents a bunch of branches and operators and for every individual (string of chromosome) and every iteration, these branches are combined and closed-form formulation is presented (Koza 1992). Fig. 3 shows a trained GP model with obtained formula.

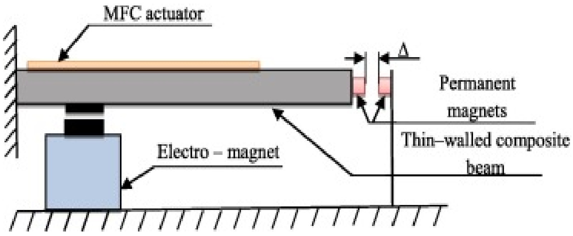


Fig. 3 Active –passive vibration control

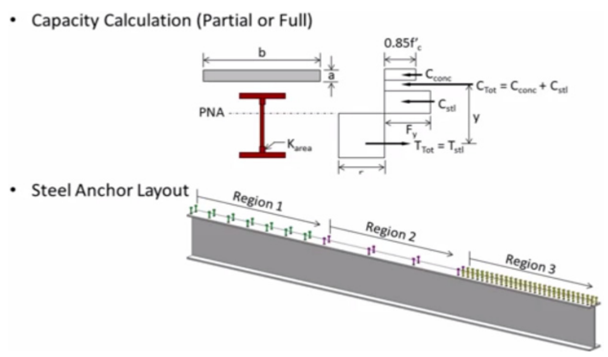


Fig. 4 Composite beam design

3. Result and discussion

3.1 Model performance indicators

Based on the data obtained from the literature, 30% of data is used in testing phase, while 70% is randomly used for training part. To compare the results of GA in both phases, statistical model performance indicators of root mean square (*RMSE*) and determination coefficient (R^2) were used.

$$R^2=\frac{\left[\sum_{i=1}^{N}(O_i-\bar{O}).(P_i-\bar{P})\right]^2}{\sum_{i=1}^{N}(O_i-\bar{O}).\sum_{i=1}^{N}(P_i-\bar{P})} \tag{1}$$

$$RMSE=\sqrt{\sum_{i=1}^{N}\frac{1}{N}(O_i-P_i)^2} \tag{2}$$

$P =$ *predicted values*
$\bar{P}$ = *predicted values*
O = *observed values*
O_i = *observed values in sample* i
$\bar{O}$ = *mean of observed variables*
N = *number of training or testing samples*
P_i = *predicted values in sample* i

Note: *$R^2$of 1, and RMSE of 0 are the ideal form in a predictive model.*

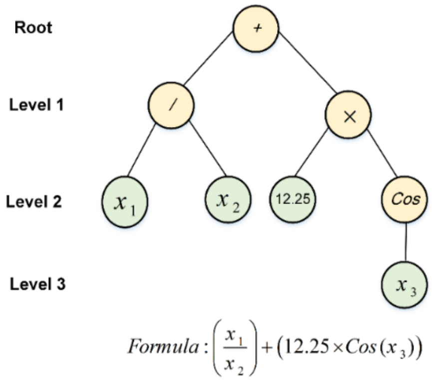


Fig. 5 A trained GP model with four operators

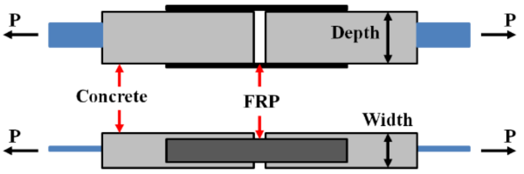


Fig. 6 The double shear tests in literature

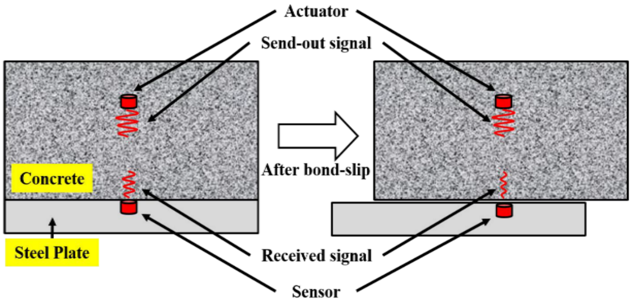
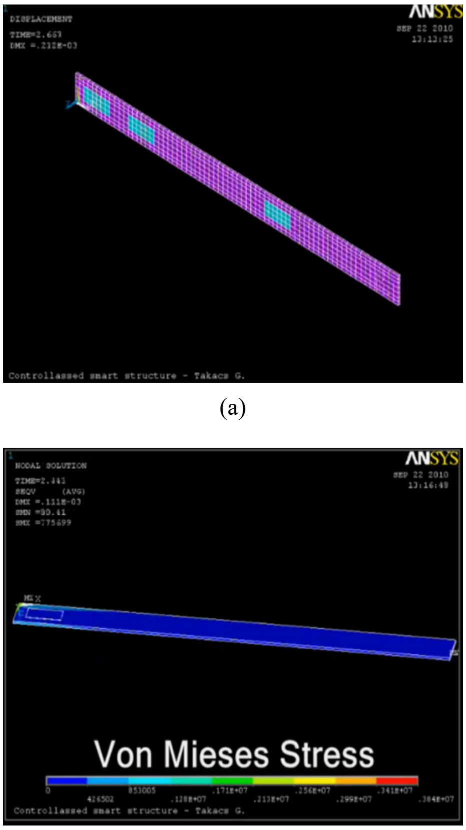


Fig. 7 The principle of guided stress wave based active sensing approach



(a)

(b)

Fig. 8 Controlling the active vibration beam

3.2 Data preparation

3.2.1 Data distribution pattern

In this study, GA was used to accurately measure the composite beam as smart active control of structures. Figs 9, 10, 11, and12 showed the developing of the model and its diagrams. Fig. 9 shows the results of GA for the observed date (horizental axix) and predicted data (vertical) in determining the composite beam as smart active control of structures in test phase. Accordingly, in Fig. 9, the observed data distribution is between -1 to 1, also the distribution of predicted values is from -1 to 1. The blue dots are almost over the black bold line, meaning that there is a good correlation between the predicted and observed values, showing the accuracy of GA model in determining the composite beam as smart active control of structures.

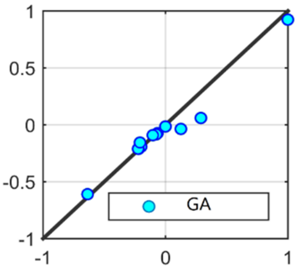


Fig. 9 AI results for composite beam as smart active control of structures values in GA (test data)

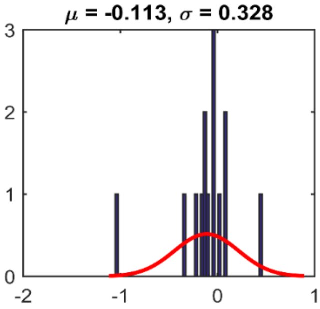


Fig. 10 Error distribution for GA in test phase

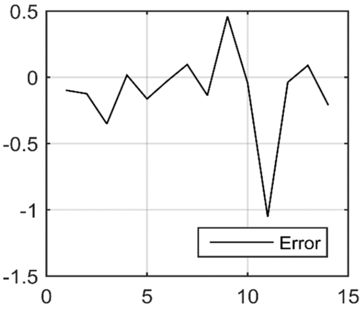


Fig. 11 Observed error values for GA (test phase)

H axis = observed values
V axis = predicted values

Fig. 10 shows the error distribution in GA model in test phase. The horizontal axis is the error distance from -2 to 1 and the vertical axis is the number of data distance. Also, the variance of value (σ) is 0.328 while the mean of value (μ) is -0.113 in test phase. According to this diagram, the highest error was seen in 0.01 with 3 data and the lowest error was occurred in -1 and 1 with roughly 1 data.

In Fig. 11 (Observed Error Values), the horizontal axis is the number of data from 0 to 15 for GA. The vertical axis is the errors value for this model.

In Fig. 12, the horizontal axis indicates the observed values of testing samples and the vertical line shows the predicted values. In this diagram, the blue line shows 100% overlap between the observed and predicted values (Ideal form), but in this study, the radial lines have 15% differential from the black line (Fig. 12). Any compatible

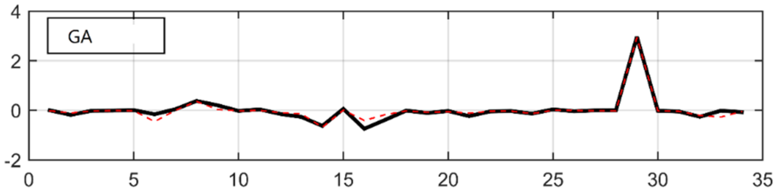


Fig. 12 The composite beam as smart active control of structures in GA (test data)

Table 1 The training and testing phase results GA

	Training phase		Testing phase	
AI Model	*RMSE*	R^2	*RMSE*	R^2
GA	0.8754	0.9809	0.7689	0.9965

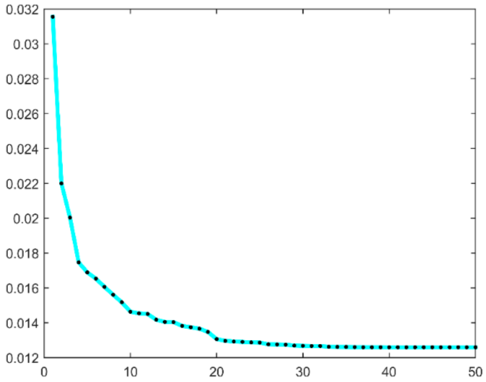


Fig. 13 The cost diagram

between these two lines means that our model reaches its ideal form with the least error percentages and high accuracy, however, it's not the case in our research (very less discrepancy). Then, GA could show better performance in the analysis of the objective of this study. Comparing the R^2 of GA as 0.9867, the results have shown that the R^2 value in GA is nearer to 1 than, showing the best performance of GA (Table 1) in this study. On the whole, because of the less difference between the observed and predicted values, GA has shown its best performance in predicting the composite beam as smart active control of structures.

Going through Table 1, the corresponding values of *RMSE* and R^2 could define the properness of the model. Obviously, the best *RMSE* value is the lowest one near to 0. In this research, the *RMSE* of GA in train phase is 0.8754, and the R^2 value in GA is 0.9809. The RMSE value in test phase is 0.7689 and RSQR is 0.9965. Comparing the R^2 values in both phases, the nearest value to 1 is considered as the best performance. Therefore, GA could show better performance in terms of the objective of this study and proved itself as a satisfactory method to analyze the composite beam as smart active control of structures in test phase. Fig. 12 shows the best cost diagram. Regarding GA, the weight of each neuron is changed to develop the model. In diagram 13, the vertical axis is cost and the horizontal axis is the number or iterations that was ordered to develop itself (90 times) to find its better performance. So, when the decreasing of cost reached to a stable case, it was stopped. It means that in our diagram, the cost was reduced at 10 iterations and was kept on up to 90 iterations to find its stability. After 90 iterations, the running is stopped due to adequate stability of cost line. This diagram showed the drastically decline of cost while using the composite beam as smart active control of structures.

4. Conclusions

An integrated technique is used to study the successful vibration regulation reaction in hybrid composite shells. The ideal LQR controller would be stronger than the traditional CGVF controller because vibration suppression can be achieved early. The spherical shell is simpler and takes less time than the cylindrical shell to check the vibrations with the same excitement. This is due to the doubly curved circular casing. As the shell gets smaller, the vibration regulation time increases. The gain (G) value for thick shells is more necessary to stabilize the vibration. The limits have a significant impact on vibration amplitude, voltage control and time of adjustment. In related cases, the overall control voltage amplitude rises and the control time declines as the boundary state changes from the clamped-clamped to the cantilever. The normal frequencies are higher for higher modes of vibration as free vibrations occur in any extreme condition. The normal frequencies are tightening up when the shell is thinner with a certain shell structure and boundary conditions. This research has used GA as a smart active control of structures that proves its success in this study to provide a correct analysis of the composite beam.

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