

## Experimental Study on Active Vibration Control of Large Flexible Structures Based on Neural Network

Hongbin Yang<sup>1\*</sup>, Huixia Ding<sup>2</sup>

<sup>1</sup>School of Energy Engineering, Yulin University, Yulin, Shaanxi, 719000, China

<sup>2</sup>Yulin Shenhua Energy Company Limited Information Centre, Yulin, Shaanxi, 719000, China

\*Corresponding Author

**Keywords:** Flexible Structure, Vibration, Neural Network, Active Control

**Abstract:** with the Rapid Development of Aerospace Technology, Flexibility is an Important Development Trend of All Kinds of Aerospace Structures. Flexible Components Have Attracted More and More Attention, and the Problems of Elastic Deformation and Vibration Have Also Become the Focus of Research. Light Flexible Structure Can Increase the Weight of Payload and Improve the Efficiency of Vehicle. However, Reducing the Weight Often Increases the Flexibility of the Structure, Thus Causing Vibration of the Structure, Reducing the Operation Precision and the Service Life. the Traditional Vibration Control Method Has Been Seriously Challenged in This Field, Which Requires People to Carry out Active Vibration Control for Large Flexible Structures to Meet the Requirements of High-Tech Development Such as Aerospace Technology. Active Control Has Very Clear Feedback Loop, Excellent Adjustability and Adaptability. Based on the Neural Network, This Paper Studies the Vibration Suppression of Large Flexible Structures, Points out the Existing Problems of Active Control in Practical Systems, and Puts Forward the Improved Methods.

### 1. Introduction

Active Structural Vibration Control Technology, as a New Interdisciplinary Technology, Has Received Extensive Attention in Civil Engineering, Aerospace, Mechanical Engineering, Vehicle Transportation and Many Other Fields [1]. among Them, in the Field of Mechanical Engineering, There Are a Lot of Researches on Rotors, Gears, Machine Tools, Hydraulic Pipelines and Structural Parts. Active Control Technology of Structural Vibration Has Made Great Progress. One of the Key Research Topics At Present is to Use Active Control Technology to Suppress the Vibration of Flexible Space Structures [2]. Light Flexible Structure Can Increase the Weight of Payload and Improve the Efficiency of Vehicle. However, Reducing the Weight Will Often Increase the Flexibility of the Structure, Thus Causing Structural Vibration, Resulting in Reduced Operation Accuracy and Service Life [3]. in Structural Vibration Control, a Limited Number of Sensors and Actuators Are Usually Used to Suppress the Vibration of a Distributed Parameter System That is Actually Infinite-Dimensional. the Vibration Amplitude of the Flexible Structure is Large, Which Makes the Structural System Nonlinear. Due to the Installation of Sensors and Drivers, Their Characteristics Are Also Nonlinear. It is Difficult to Achieve Ideal Results by Using Classical Linear Control Methods to Actively Control the Flexible Structure [4]. in the Actual System, the Number and Position Optimization Problems Exist Simultaneously When Using Piezoelectric Patches to Realize Vibration Control. the Traditional Vibration Control Method Has Been Seriously Challenged in This Field, Which Requires People to Carry out Active Vibration Control on Large Flexible Structures to Meet the Requirements of High-Tech Development Such as Aerospace Technology [5].

Piezoelectric Ceramics Are Very Suitable as Sensors and Drivers in Active Vibration Control Systems Due to Their Good Electromechanical Coupling Performance and Insensitivity to Temperature. Vibration Control of Structures is Divided into Active Control, Passive Control and Hybrid Control According to Energy. Active Control Needs to Consume External Energy, While Passive Control Does Not Need to Consume External Energy. Hybrid Control is a Hybrid of Active

Control and Passive Control [7]. the Traditional Control Theory is Based on the Precise Mathematical Model of the Controlled Object, While There Are a Lot of Uncertain Factors in the Structural Control, Which Brings Difficulties to Establish the Precise Model of the Controller or Makes It Impossible to Obtain the Precise Mathematical Model At All. Active Control Has a Clear Feedback Loop with Excellent Adjustability and Adaptability [8]. in the Actual System, the Number and Position Optimization Problems Exist Simultaneously When Using Piezoelectric Patches to Realize Vibration Control. According to the Dynamic Characteristics of Controlled Objects, Piezoelectric Materials Are Usually Selected as Sensors and Actuators for Vibration Control of Intelligent Structures. the Process is to Use Sensors to Sense the Strain of Structures Due to Vibration [9]. Intelligent Algorithms Are Valued Because of Their Ability to Accurately Model and Approximate Nonlinear Systems. Neural Network Algorithm is One of the Most Potential Algorithms [10]. in This Paper, the Vibration Suppression of Large-Scale Flexible Structures is Studied Based on Neural Network, and the Problems Existing in the Application of Active Control in Actual Systems Are Pointed out, and the Improved Methods Are Proposed.

## 2. Active Vibration Control Principle for Large Flexible Structures

The Nonlinear Connection of Large Complex Flexible Structures and the Large Deformation of Flexible Structures Make It Necessary to Consider the Nonlinear Vibration Problem. Moreover, the Active Control of Linear Control Law Based on Traditional Control Theory Has Poor Control Effect on Transient Vibration and Nonlinear Vibration. Before the System Design, the Initial Conditions Are Difficult to Determine, and the Actuator Configuration is Not Affected by the Initial Conditions and Control Laws of the System, But by the Inherent Characteristics of the System. the Model is Weak in Dependence and Has Been Widely Used and Trusted in the Field of Industrial Control, Especially for Low-Order Linear Systems. However, It Has Poor Control Performance for High-Order Nonlinear Systems. What is More Regrettable is That It is Difficult to Incorporate the Experience of Control Experts into the Control System [11]. When Deformation Occurs Due to External Force in a Certain Direction, the Dielectric Will Generate Polarization and Positive and Negative Charges on Its Two Opposite Surfaces. When the External Force Disappears, the Dielectric Will Return to an Uncharged State. the Purpose of Vibration Fuzzy Control Method and Other Conventional Control Methods is to Control the Response of Structural Vibration. the Conventional Control Method Relies on the Precise Mathematical Model of the System Structure, While the Fuzzy Control Method Changes the Controlled System Model from Clear and Precise to Fuzzy and Uncertain. When the Contraposition Sensor Signal is Used as the Feedback Signal to Design the Control Law, It is Easy to Cause False Suppression Phenomenon, That is, the Output of the Sensor is Suppressed But the Vibration is Not Suppressed.

According to the Dynamic Characteristics of Controlled Objects, Piezoelectric Materials Are Usually Selected as Sensors and Actuators for Vibration Control of Intelligent Structures. the Process is to Use Sensors to Sense the Strain of Structures Due to Vibration. the Piezoelectric Material Converts the Vibration Signal into a Corresponding Electrical Signal, Passes through the Controller, Generates a Control Signal, and Then the Control Signal is Applied to the Structure by the Actuator to Complete the Control. Figure 1 is the Working Principle of Piezoelectric Intelligent Structure Control System.

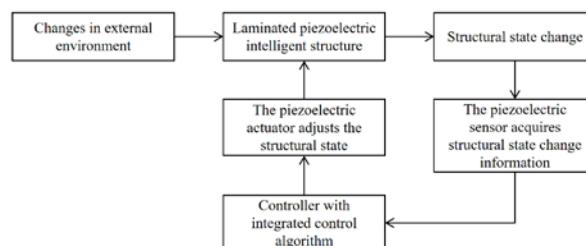


Fig.1 Working Principle of Piezoelectric Intelligent Structure Control System

The positive piezoelectric effect of piezoelectric materials represents their ability to convert

mechanical energy into electrical energy. After measuring the change in the amount of positive and negative charges, we can calculate the amount of deformation at the paste. Since the large-value frequency components that need to be controlled in the mechanical vibration structure generally come from the frequency conversion of the rotating structure and its frequency multiplication, the frequency domain peak control method can simplify the control and reduce the noise influence. Large flexible structures are characterized by large flexibility, dense low-frequency modes, and complex structures, so it is difficult to establish accurate mathematical models. When using heuristic rules to implement fuzzy control, it has been implicitly assumed that the process does not produce significant changes beyond the operator's experience [12]. Especially for large and complex flexible structures, it is difficult to get fuzzy rules and their corresponding parameters based on experience. In order to overcome the limitation of general fuzzy control, it is necessary to make the fuzzy controller have the ability of self-adaptive and self-learning. If the electric field is applied in the polarization direction of the dielectric, the dielectric will produce deformation. When the electric field is removed, the deformation will disappear. Accordingly, this phenomenon is called reverse piezoelectric effect. In order to make the sensor measure the vibration of the board to the greatest extent, the sensor should be pasted close to the root of the board. Based on the previous analysis, the actuator should also be pasted as close to the root of the plate as possible.

### 3. Active Vibration Control of Large Flexible Structures Based on Neural Networks

Optimal control is the core of modern control theory. It is mainly to select an appropriate control law according to the existing mathematical model of the controlled object so that the controlled object can reach the maximum value of the selected performance index under the specified requirements. Modal analysis is to transform the physical coordinates in the vibration differential equations of a linear time-invariant system into modal coordinates and decouple the equations into a set of independent equations described by modal coordinates and modal parameters so as to obtain the modal parameters of the system. Fuzzy identification includes structure identification and parameter identification. It uses fuzzy implicit and composite operators to identify the parameters of the front and back parts of the rule to establish the relationship between language variables. The key of the fuzzy control method for piezoelectric materials to actively control the vibration of complex flexible structures lies in the selection and determination of the membership functions of the controller's input variables, output variables and fuzzy rules, i.e. fuzzy identification [13]. Due to the unique self-learning ability of neural networks, neural networks are used in the rule generation part of fuzzy systems, which is an adaptive fuzzy system based on neural networks. The system model of linear quadratic optimal control is a system expressed in the form of state space. The objective function is a quadratic function that integrates the state of the object and the control input. Linear optimal control usually includes an optimal problem with feedback.

The neural network consists of an input layer, a nonlinear hidden layer and a linear output layer. The goal of vibration control is to minimize the following error function:

$$E(k) = \sum_{i=1}^{N_e} e_i^2(k) = \sum_{i=1}^{N_e} (p_i(k) + c_i(k))^2 \quad (1)$$

Here  $N_e$  is the number of error sensors in the system, and  $p_i(k)$  and  $c_i(k)$  are the disturbance and control quantities at time  $k$  at the  $i$ -th sensor respectively. The goal can be achieved by adjusting the weight of the neural network through the following gradient descent algorithm:

$$w(k+1) = w(k) - \frac{\partial E(k)}{\partial w(k)} \quad (2)$$

Where  $\mu$  is the convergence coefficient. The control quantity  $c_i(k)$  at the  $i$ -th error sensor is:

$$c_i(k) = \sum_{j=1}^{N_o} x_{oj}(k) * TF_{ij} = \sum_{j=1}^{N_o} \left( \sum_{l=1}^{N_h} (x_{lh}(k) w_{jl}) * TF_{ij} \right) \quad (3)$$

Where  $N_o$  is the number of drivers,  $N_h$  is the number of hidden layer nodes,  $*$  is the convolution operator, and  $TF_{ij}$  is the transfer function between the  $j$ -th driver and the  $i$ -th sensor.

Vibration control algorithm includes training algorithm of output layer and hidden layer.

The training algorithm for the output layer is:

$$w_{jl}(k+1) = w_{jl}(k) - 2 \sum_{i=1}^{N_e} e_i(k) g_{ijl}(k) \quad (4)$$

Where  $g_{ijl}(k)$  is the filtered hidden layer output signal:

$$g_{ijl}(k) = x_{lh}(k) * TF_{ij} = TF_{ij} * f \left( \sum_{q=1}^{N_d} x_{qd}(k) w_{lq} \right) \quad (5)$$

The input variables of fuzzy controller are usually three, namely error, error change and error change. The input variables in structural vibration control can be displacement, velocity and acceleration of structural vibration. Neural network is also called artificial neural network. Its inspiration comes from the thinking of human brain and can be said to be based on modern brain science. According to the output membership function obtained by fuzzy reasoning, different methods are used to find a representative accurate value as the control quantity. This step is called fuzzy output deblurring decision. The most commonly used membership functions of input variables are triangles and trapezoids. The result of fuzzification is that the membership degree of different membership functions can be obtained for any precise input value. Similar to the brain is made up of biological neurons, artificial neural network is also made up of a large number of units connected with each other, people can complete many complex things with the cooperation of many biological neurons. Membership function is the basis of applying fuzzy set to practical problems. The key to make good use of fuzzy set is to construct membership function correctly. Biological neurons are composed of cell bodies, axons, dendrites and synapses. The learning process of human brain is the process of making self-regulation. In order to simulate its characteristics, the similarity between neural network and neural network lies in that the information obtained from external learning is transferred to internal storage.

#### 4. Conclusions

This paper focuses on the vibration suppression of flexible plates from the experimental point of view, points out the problems existing in the practical application of active control, and verifies the phenomenon in the experiment. In the construction of active vibration control platform, the position of sensors and actuators is set at the root of cantilever beam by default, and there is no optimization of the position and number of actuators and sensors, which is very important for vibration control. It is helpful to find out some specific stability design criteria of fuzzy control and determine the control parameters of fuzzy controller by studying the stability conditions with simulation experiments. When piezoelectric materials are used to actively control the vibration of flexible structures, the placement of sensors/actuators is a key issue, which directly affects the effect of vibration control and the engineering implementation of the controller. The problem can be avoided by slightly modifying the scheme of collocated configuration. The improved control results verify the effectiveness of the proposed method. Further work is to use multiple piezoelectric sensors and actuators to obtain the transfer functions between sensors and actuators for more complex flexible structures. The stability, anti-interference and multi-objective control of different measuring points of the algorithm in practical application still need to be further studied and solved.

## Acknowledgement

This work is financially supported by Industry-University-Research Cooperation Project of Yulin (2016CXY-04)

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