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Active Vibration Isolation System Based on Artificial Neural Network

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Abstract: Effective isolation of high precision instruments from disturbances is commonly achieved via active vibration isolation systems (AVIS). However, there are a number of problems associated with the operation of AVIS. One such a problem is due to fluctuations of the AVIS plant characteristics. As a result, displacements of the object are observed, which makes the isolation incomplete. This work proposes an artificial neural network (ANN) based control system whereby training data for the ANN is obtained from an improved optimal algorithm for AVIS. The performance of the proposed ANN based control system is investigated and results are compared to those obtained from analytical models. The results show insensitivity of the proposed ANN to the variation in plant's time constant. Furthermore, the ANN procedure accomplished excellent vibration isolation compared with previous work. This work also shows that the use of a neural network does not require sophisticated adaptive methods.

Key words: Active vibration isolation, high precision instruments, optimal algorithm for AVIS, neural networks, back-propagation

INTRODUCTION

The majority of today's high precision instruments that are used for obtaining results in microns encounter measurement accuracy and calibration problems. The operational reliability and performance of high precision instruments are significantly affected by foundation disturbances. An effective method of reducing an oscillation is using an active vibration isolation system (AVIS), which allows the control of the dynamic rigidity of shock absorbers[1,2]. When optimised algorithms control such a system, the isolation quality is much higher. However, despite a great amount of research that has been carried out in this field, there are still a number of problems associated with the operation of these systems. On one hand, it is necessary to find out the optimal control algorithm for the AVIS. Although quality indices of the control system are well established in the automatic control theory and can be obtained using standard control techniques, it is more important for a vibration isolation system to evaluate the characteristics of disturbance compensation control. On the other hand, fluctuation of plant's time constant necessitates the use of the adaptive systems for maintaining quality indices. Although all standard control methods give good isolation performance in the required limits, they however, suffer from sensitivity to the object's time constant.

An actuator with a mass of vibration-isolated object can be an example of AVIS. Liquid, pneumatic, electromagnetic and other types of dampers are commonly used as actuating mechanisms. To define the majority of plants of isolation systems, the amplitude-frequency characteristics of these actuators can be approximated by a transfer function[1-4]. To design an adaptive AVIS that is capable of maintaining quality indices, three types of transfer functions have been considered[5]. One is based on Binomial Distribution, the second is based on Butterworth Distribution and the third is based on Quadratic Optimal Control, which obtains minimum integral from square error[5]. The transient response of these types to an impulse signal has been investigated and compared for different values of time constant

$$T^* = \frac{T_\mu}{T}$$

where T_μ is the fast time constant that restricts the signal bandwidth. The results of investigation have shown that the Quadratic Optimal Control provides minimum output (x_m) deviation (i.e. best quality index) for time constants $T^*>0.7$, whereas the best quality index is obtained with the Butterworth Distribution. Taking into account that in practical AVIS the time constant $T^* >0.7$, the Quadratic Optimal Control has been adopted as a base control technique. An Optimal algorithm for AVIS has been proposed[5]. Although the proposed AVIS suppress disturbances by approximately 20 times, however, it still suffers sensitivity to variation in the time constant of the isolated plant.

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In recent years, the application of artificial neural networks (ANNs) has attracted researchers working in the field of control systems. A vibration isolation control algorithm, based on an ANN, has been proposed[6,7]. Nevertheless, the application of ANNs in adaptive vibration isolation systems has not been addressed yet.

The study proposes an artificial neural network (ANN) based control system whereby training data for the ANN is obtained from an improved optimal algorithm for AVIS. The performance of the proposed ANN based control system is investigated and results are compared to those obtained from analytical models. Three sets of plant's time constant are chosen and the performance of the proposed control system is examined. The results show insensitivity of the proposed ANN to the variation in the time constant. Furthermore, the ANN procedure accomplished excellent vibration isolation compared with previous work.

Performance of optimised AVIS: The open-loop transfer function of the system, synthesised according to the Optimal Algorithm for AVIS[5] is represented as follows:

$$W_{base} = \frac{1}{T_\mu s(T_\mu s+1)(T^2s^2+2çTs+1)} \qquad (1)$$

Where ç is damping coefficient and T is plant's time constant.

Experimental results have shown that foundation displacement can be in the range of 25-30 μm (5). Hence, the performance of Optimal Algorithm for AVIS has been investigated applying a randomly generated signal that represents the reported range of foundation vibration. Fig. 1 demonstrates the displacement of a vibration-isolated object in response to foundation oscillation when the Optimal Algorithm for AVIS is used. Three cases with different values of plant time constant are represented. One case corresponds to a base plant time constant T_{base}, which is assumed equal to one representing the absence of fluctuation of the plant time constant. The other two cases correspond to the maximum possible deviation of the T_{base} by ±100%, respectively. Oscillation of the vibration-isolated plant is reduced to a range between -1 to 1.5 μm. However, it can be observed that the above control method suffer from sensitivity to variation in the time constant of the isolated pant (Fig. 1).

ANN based active vibration isolation system: An ANN based AVIS has been designed for the control of adaptive

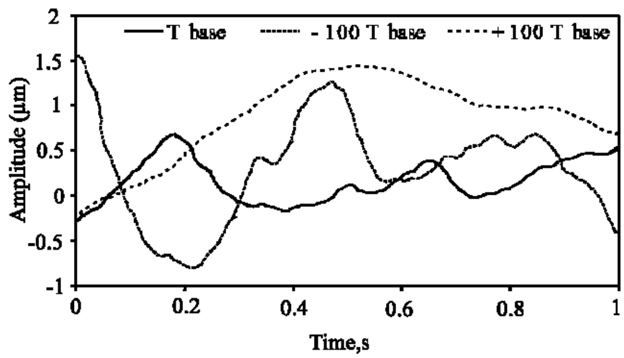

Fig. 1: The performance of the sample AVIS output for different plant's time constant

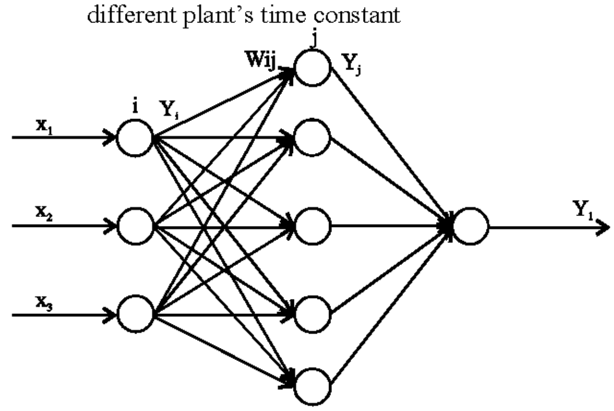

Fig. 2: Multilayer Neural Network used for the design of ANN based AVIS

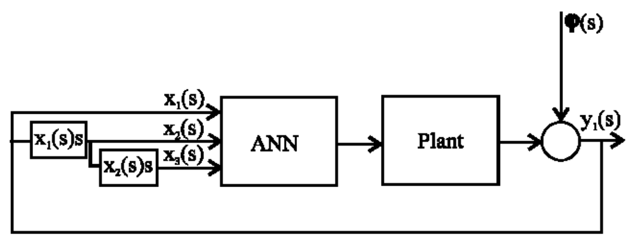

Fig. 3: Schematic diagram of the proposed ANN based control of an AVIS

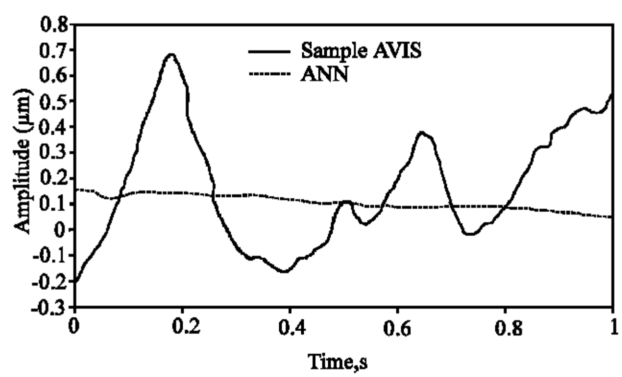

Fig. 4: Performance of ANN based AVIS compared to that of sample AVIS when a randomly generated signal in the range of 25-30 μm is applied

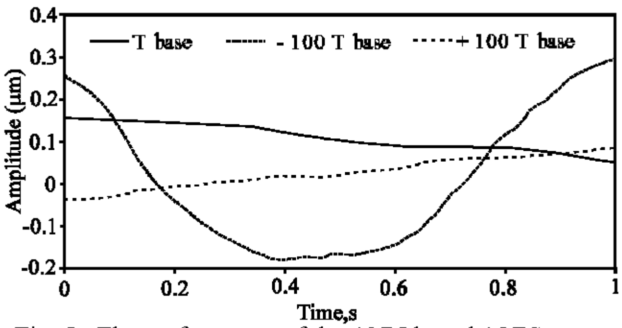

Fig. 5: The performance of the ANN based AVIS output for different object's time constant

systems, i.e. it takes into account changes of the plant characteristics. A Multilayer Neural Network (MLNN)[8] is used in this design. An MLNN comprises a number of interconnected processing elements (PE), known as artificial neurons[8]. The neurons are arranged in layers, including an input layer, followed by a hidden layer(s) and an output layer. The ANN used in this study comprises an input layer with three PEs, one hidden layer with five PEs and an output layer with one PE (Fig. 2). The inputs $x_1(s)$, $x_2(s)$ and $x_3(s)$ are the deviation, velocity and acceleration of the sample system input, respectively. The output $y_1(s)$ is the AVIS controlling signal.

The supervised Back-Propagation algorithm was used for off-line training of the ANN. A training data file that is required for the training process was prepared by simulating the response of the investigated AVIS when randomly generated input signals were applied. The data file included several cases with different characteristics that account for the possible fluctuation of the plant time constant. An optimal template (sample) AVIS was used in each case. After training, the proposed ANN was included in the investigated system to supersede the sample AVIS (Fig. 3). The performance of the proposed model (Fig. 3), was investigated by simulating several cases with different plant time constants.

Figure 4 shows a comparison between the outputs of an ANN based AVIS and the outputs of the Optimised AVIS at T_{base}.

The response of the ANN based AVIS provides deviation of the vibration isolated object in the range of 0.1-0.2 μm compared to a range of –0.2 to 0.8 μm provided by the Optimised AVIS that is equivalent to about four times improvement in performance (Fig. 4).

Figure 5 depicts the effect of changing the time constant of vibration-isolated object on the performance of the ANN based AVIS. Fig. 5 shows three cases similar to those considered for the Optimised AVIS. One of these cases corresponds to base plant time constant, T_{base}, without deviation and the other two cases correspond to maximum deviation of T_{base} by ±100 %, respectively.

Comparing Fig. 1 with Fig. 5, it is obvious that the deviation of the plant time constant has significantly affected the performance of the Optimised AVIS (e.g. oscillation of the vibration-isolated plant can be in the range between -1 to 1.5 μm), whereas it has a negligible effect on the performance of the ANN based AVIS (e.g. oscillation of the vibration-isolated plant is in the range between -0.3 to 0.3 μm only). Therefore, using an ANN based AVIS reduces the effect of fluctuation of the plant time constant as it improves of the optimal AVIS quality indices.

The study proposes an optimal control algorithm to protect high precision objects from foundation disturbances using an ANN based AVIS. The maximum deviation of output in response to a transient input (randomly generated signal that represent foundation displacement signal) is considered. It has been shown that an optimal algorithm for AVIS (i.e. template AVIS) may provide smallest maximum deviation of isolated plants, however, fluctuations of the plant time constant significantly influence the quality indices of the template AVIS. It has been shown that the proposed ANN based AVIS overcomes this shortcoming and facilitates obtaining improved quality indices of the isolation system. It has also been shown that using the ANN allows one to supersede sophisticated vibration-isolation adaptive systems by a simplified AVIS. As a result the proposed ANN based AVIS operation is far more efficient.

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