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Vibration suppression of printed circuit boards using an external particle damper

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ABSTRACT

Particle damping is an effective method of passive vibration control, of recent research interest. The novel use of particle damper capsule on a Printed Circuit Board (PCB) and the development of Radial Basis Function neural network to accurately predict the acceleration response is presented here. The prediction of particle damping using this neural network is studied in comparison with the Back Propagation Neural network. Extensive experiments are carried out on a PCB for different combinations of particle damper parameters such as particle size, particle density, packing ratio, and the input force during the primary modes of vibration and the obtained results are used for training and testing of neural networks. Based on the prediction from the better trained network, useful design guidelines for the particle damper suitable for PCB are arrived at. The effectiveness of particle dampers for vibration suppression of PCB under random vibration environment is demonstrated based on these design guidelines.

1. Introduction

The particle damping technique is relatively a new method in passive damping. Here, the damping is achieved by either filling metal or ceramic particles within the cavities of the primary vibrating structure, or the particles are enclosed in an external capsule and then attached to the vibrating structure. The vibration energy is absorbed by the particles and dissipated into heat energy through collisions, friction between the particles and cavity walls and also between the particles.

Panossian [1,2] pioneered the particle damping method and applied to various cases including launch vehicle structures for vibration suppression. Particle damping was applied on an aluminum alloy beam and the experiments were carried out both in air and water medium for the various combinations of particle damper parameters such as particle size and volumetric packing ratio. Significant damping was achieved for certain combinations of particle damper parameters. It is observed that the performance of particle dampers is significantly dependent on the particle size, the packing ratio, the particle density, and the amplitude of vibration.

There are some important studies in the application of particle damping technology using experimental [3,4] and numerical [5–10] techniques. One of the main advantages of this technique is that it provides very significant vibration

Abbreviations: AA, Aluminum alloy; ANNs, Artificial neural networks; BPN, Back propagation neural networks; DEM, Discrete element method; FEM, Finite element method; MSE, Mean squared error; PCB, Printed circuit board; PD, Particle density; PR, Packing ratio; PS, Particle size; PSD, Power spectral density; RBF, Radial basis function; RML, Response measurement location; RPD, Relative percent deviation; SS, Stainless steel; WC, Tungsten carbide

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control over a wide range of frequencies [11]. It can also be used under different operating environment such as different temperature and radiation field. The empirical method based design guidelines were proposed for particle damper designs from extensive experiments carried out on three structural specimens namely beam, bond arm and bond head stand by Xu et al. [12]. The bond head stand and bond arm are the two important parts in the ultra-fine pitch electronics packaging machines. The vibration that occurs during the operation was suppressed with the addition of particle damper. The relationship between the damping ratio and the particle damper parameters such as particle size, and packing ratio for various modes were studied. The experimental investigation on a mild steel beam and plate with particle damping treatment was conducted by Xu et al. [13]. It was observed that the damping was significantly effective and strong attenuations were achieved within a broad frequency range. The particle damping technology was applied on a bond arm structure to suppress vibration by Chan et al. [14].

An analytical method for predicting the behavior of particle damper was developed based on the modeling of instantaneous dynamics of all particles-the Discrete Element Method (DEM). Cundall and Strack [15] pioneered the DEM technique in the particle damping application and the details of DEM was given by Hart et al. [16]. Wong et al. [9] presented an improved DEM simulation to predict the energy dissipation in a particle damper. Individual particles were modeled as elements with mass and rotational inertia, whereas contact between particles and walls were represented using appropriate springs and dampers. The DEM is a useful tool in particle damping simulations. However the main limitation of the method is the high computational effort required to model the instantaneous interactions between all particles. The method also has other drawbacks such as the requirement of various assumptions and detailed material information. The damping performances of particle dampers were predicted using non-DEM methods in very few studies. Olson et al. [5] developed a mathematical model for particle dampers based on particle dynamics method. The damping effect of a single particle vertical impact damper for a wide range of excitation frequencies and amplitude was developed by Duncan et al. [7] using a computer simulation.

The above review summarizes the application of particle damping method to various types of structures and the effect of damping behavior with respect to particle damper parameters using experimental methods, DEM technique and other methods from the reported studies in the literature. As seen from the literature, the design of particle damper depends on various system parameters which are characterized using various methods such as Discrete Element Method (DEM), analytical method, etc, However, very high computational effort (as in DEM) is needed to model particle damping. In addition, particle dampers have numerous modeling limitations. Hence there are no well-defined design guidelines for the optimal particle damper design because of its nature and inherent complexity. Researchers are exploring methods to define a mathematical model of the complicated process using input–output data. Artificial Neural Network (ANN) is considered as an accurate and faster method to model real world complex problems in comparison to polynomial and empirical models [17]. It is known for the ability to model highly complicated input–output relationships where the conventional interpolation techniques [18] would fail. The conventional interpolation techniques (such as Kriging, Inverse Distance Weighting, Polynomial Interpolation, etc) are based on the idea that a definite relationship exists between the inputs and the outputs. On the other hand, ANNs were observed as universal functional approximators that can approximate any function with greater accuracy [19,20]. Hill et al. [21] and Papanastasiou et al. [22] concluded that the performance of ANN in prediction was better compared to statistical regression methods along with various advantages. ANN does not require dependency assumptions among independent variables and solves multivariate problems involving independent variables with nonlinear relationships. The method is also known for its ability to generalize well on a wide variety of problems and is well suited for prediction applications. It has been applied in various disciplines [23–25] for a wide range of problems and has been effective in predicting accurate results in all the applications within the bounds of the training data. However, its performance beyond the training data is not encouraging.

It is known that the particle damper design depends on the number of particle damping parameters and many correlations between them would be readily addressed in ANN. In a conventional interpolation scheme, a lot of manual effort would be required which may become tedious. Even the system identification method such as Restoring Force Surface method is useful mainly for simple systems with few variables. Considering the complexities of the problem, it is proposed to use ANN for the particle damped system. Multi-layered feed forward and back propagation neural network, commonly called as Back Propagation Neural (BPN) network and the other one, Radial Basis Function (RBF) neural network are found to be effective ANNs in modeling and predicting the various real-world function approximation problems from the reported literatures. The prediction capability of both BPN and RBF neural networks and their details and comparison are further discussed in the next section.

In spacecraft application, PCBs are widely used for mounting various types of electronic components. During launch of spacecraft, the PCBs will undergo severe vibration loads. One of the main causes of failure of electronic components attached on PCBs is the severe vibration loads. The PCBs with electronic components are in turn mounted on to spacecraft through appropriate mechanical structure which is referred as electronics package. The suppression of acceleration response on the PCB to avoid the failure of electronic components is highly important in the design of electronics packages for spacecraft applications, which is vital for successful spacecraft operation. The electronics package is mainly susceptible to random vibration which occurs during various launch ascent phases. Hence the electronics package is mainly designed and qualified for random vibration loads based on the launch loads in the frequency range between 20 Hz and 2000 Hz.

Though the particle damper literature covers many applications, its suitability to the PCB type of structure with external damper capsule specific to spacecraft application is very limited [26]. In this work, a circular shaped particle damper attached to the PCB and the novel application of both BPN and RBF neural network in modeling and predicting the particle damping parameters using experimental tests are addressed. Based on the predictions, the relationship between the acceleration responses and the applied forces for the various combinations of system parameters such as Particle Size (PS),