

PREDICTION OF DEFORMATION OF A METAL MATRIX COMPOSITE AT HIGHER MODE BY ARTIFICIAL NEURAL NETWORK

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Abstract— Numerous advancement have been made in developing intelligent systems, some inspired by Biological Neural Network. In this paper this latest technique is used to predict the deformation with the use of natural frequency and mode of a selected Metal Matrix Composite (MMC). The modelling of this material is done using advanced analysis software ANSYS. The material matrix used in the design of the experimental model is Ti6Al4V. The ANN model is developed using non-linear autoregressive with external (exogenous) input (NARX) time series. The NARX network in this work is a feedforward network with the tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer. This network has two inputs. One is an external input, and the other is a feedback connection from the network output. To assign the network architecture for a NARX network, one needs to select the delays associated with each tapped delay line, and also the number of hidden layer neurons. In the following work, the input delays and the feedback delays to range from 1 to 4 and the number of hidden neurons to be 20. The created ANN model is run and the performance (P), gradient (g), coefficient of determination (R) and MSE are calculated by training and testing of the proposed network.

Keywords— Metal matrix composite (MMC), ANSYS, Artificial Neural Network (ANN), MatLab (Matrix Laboratories), Backpropagation, NARX.

INTRODUCTION

In modern time ANN has been a highly pursued research field. Due to its ability to replicate human brain, solve complex problems and even predict with high performance it is used to solve a wide variety of problems. The MMC used in this work is Ti6Al4V. Due to its varying application field like automotive, aerospace, rail engineering, electronics and marine it is being tested for many other uses, this MMC will has a wide area for use. Some work has been done this MMC to calculate the physical and mechanical the properties. ANN has also been used to calculate the damage test identification S. J. S. Hakim and H. Abdul Razak et al [18], prediction and deformation of steel plate with induction heating by Kang-Yul Bae and Sung-Nam Choi et al [6]. In this work NARX neural network is used to predict the maximum deformation of the selected MMC at higher modes with the help of mode shape and natural frequency. The use of NARX has been verified by Eugen Diaconescu et al [15] in predicting a chaotic time series. This work is slightly based on Truong-Thinh, Young-soo Yang et al [6] and some reference has also been made to Sergio Daniel Cardozo, Armando Muguel Awruch et al [10]. In the present work maximum deformation of the MMC at higher modes is predicted with the input parameters of mode shape and natural frequency. A total of 100 sample data set is created to train the created NARX neural network. The NARX network uses a tan-sigmoid transfer function.

Metal Matrix Composite

Metal matrix composites (MMCs) are composite materials that contain at least two constituent parts – a metal and another material or a different metal. The metal matrix is reinforced with the other material to improve strength and wear. They have also found applications to be resistant to radiation damage, and to not suffer from outgassing [12]. Most metals and alloys make good matrices for composite applications.

Material Properties

The Ti6Al4V MMC have the chemical composition of 90% Titanium, 6% Al, 4% Vanadium, and traces of oxygen and iron with 0.2% each. The physical properties [11] of the MMC are stated below.

Density	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
4430 kg/m ³	1.138e+011	0.342	1.2004e+011	4.2399e+010

Geometry and Design of Plate

The MMC plate used in the work is modelled on ANSYS. The dimensions of the plate is given in table below. The plate is fixed along y-axis at both ends. The analysis is performed for natural frequency and deformation at 100 modes. The values have been saved and used to train the NARX ANN.

Specimen	Length (mm)	Breadth (mm)	Thickness (mm)
Ti6Al4V MMC	300	300	5

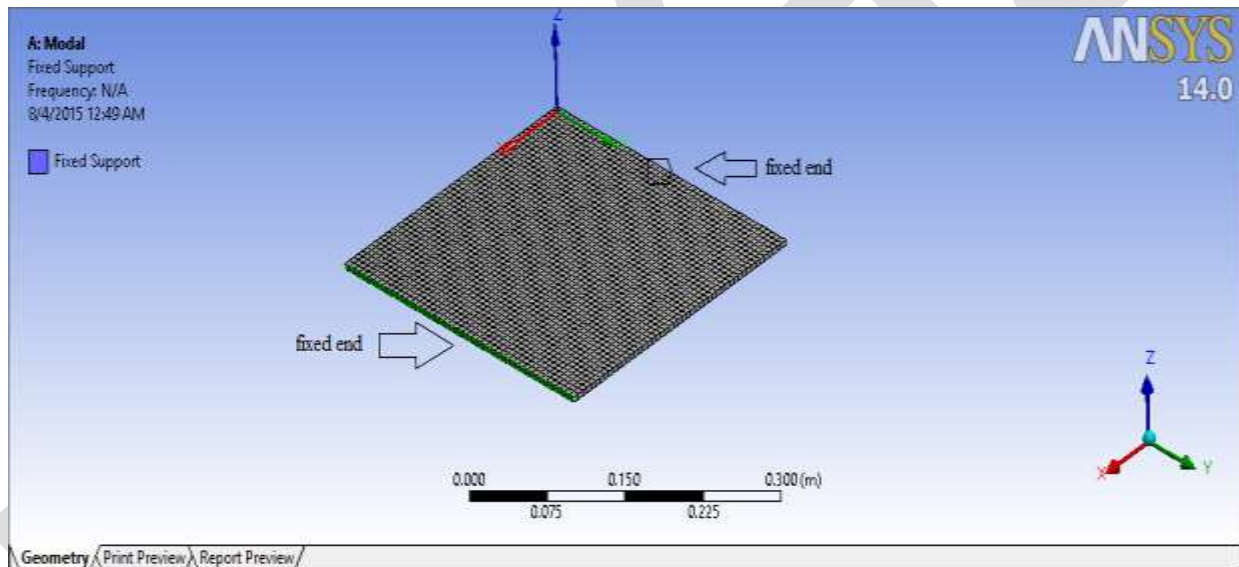


Figure: Geometry of the Ti6Al4V MMC plate created using ANSYS 14.0

Artificial Neural Network (ANN)

The neural network has a set of input links from other units, a set of output link to other units, a current activation function to compute the activation level in the next time step. The basic neural network is shown in figure below.

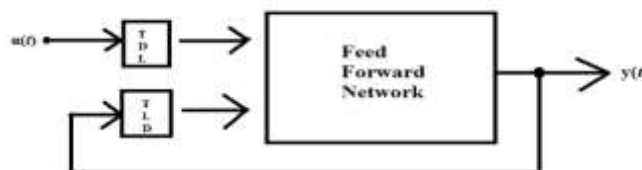


Figure: Basic ANN (NARX model)

Where a_{ij} is the input to the neuron, w_{ij} is the weight of the link, \sum is the total input and a_j^l is the activation function. Total weighted input is sum of inputs activation times their respective weights

$$in_j = \sum_j W_{ji}.a_j$$

Weight adjustment rule is given by

$$W_j \leftarrow W_j + \alpha l_j + Err$$

Where α is the learning rate. The computational model of a neuron is given using the formula

$$y = \theta \left(\sum_{j=1}^n w_j x_j - u \right)$$

Where θ is the unit step function at 0, w_j is the synapse weight associated with the j th input.

Nonlinear Autoregressive Network with Exogenous input (NARX)

The nonlinear autoregressive network with exogenous inputs (NARX) is a recurrent dynamic network, with feedback connections enclosing several layers of the network.

The defining equation for the NARX model is

$$y(t) = f(y(t-1), y(t-2), \dots, y(t-n_y), u(t-1), u(t-2), \dots, u(t-n_u))$$

where the next value of the dependent output signal $y(t)$ is regressed on previous values of the output signal and previous values of an independent (exogenous) input signal. A diagram of the NARX network is shown below, where a two-layer feedforward network is used for the approximation.

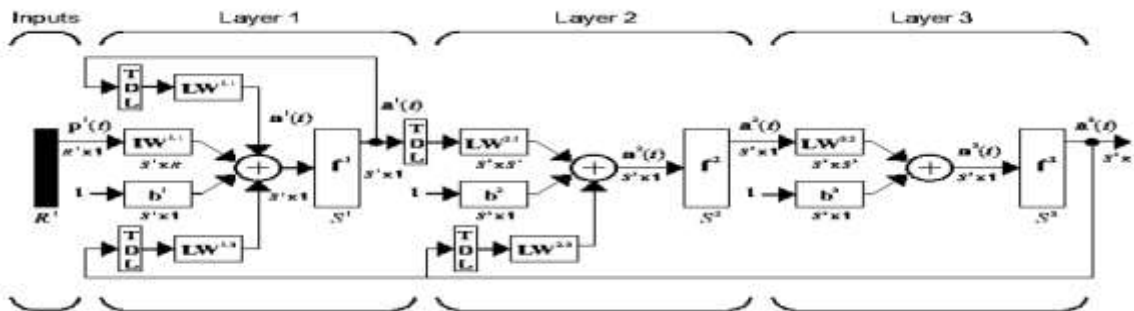


Figure: A two-layer feedforward NARX network

Levenberg Backpropagation

This method is similar to the Quasi-Newton method. NARX algorithm was designed to approach second order training speed without having to compute the Hessian matrix. The Hessian matrix can be approximated by

$$H = J^t J$$

And the gradient can be calculated using

$$g = J^t e$$

Where J is the Jacobian Matrix that contains first derivatives of the network error w.r.t the weight and biases and e is the vector of network error. The Levenberg-Marquardt Backpropagation algorithm can be represented as

$$x_{k=1} = x_k - [J^t J + \mu I]^{-1} J^t e$$

Training

The artificial neural network created to predict the deformation of the Ti6Al4V MMC is developed using NARX. A total of 100 data samples is used as input. The input used is the natural frequency and mode shape of the MMC. For maximum performance 70 target time steps have been taken and the remaining 30-30 time steps have been allotted to for validation and testing. The training automatically stops when the generalization stops improving as indicated by increase in MSE of the validation sample. The selected training method (NARX) is run on an Intel(r) CoreTM i3 processor P.C.

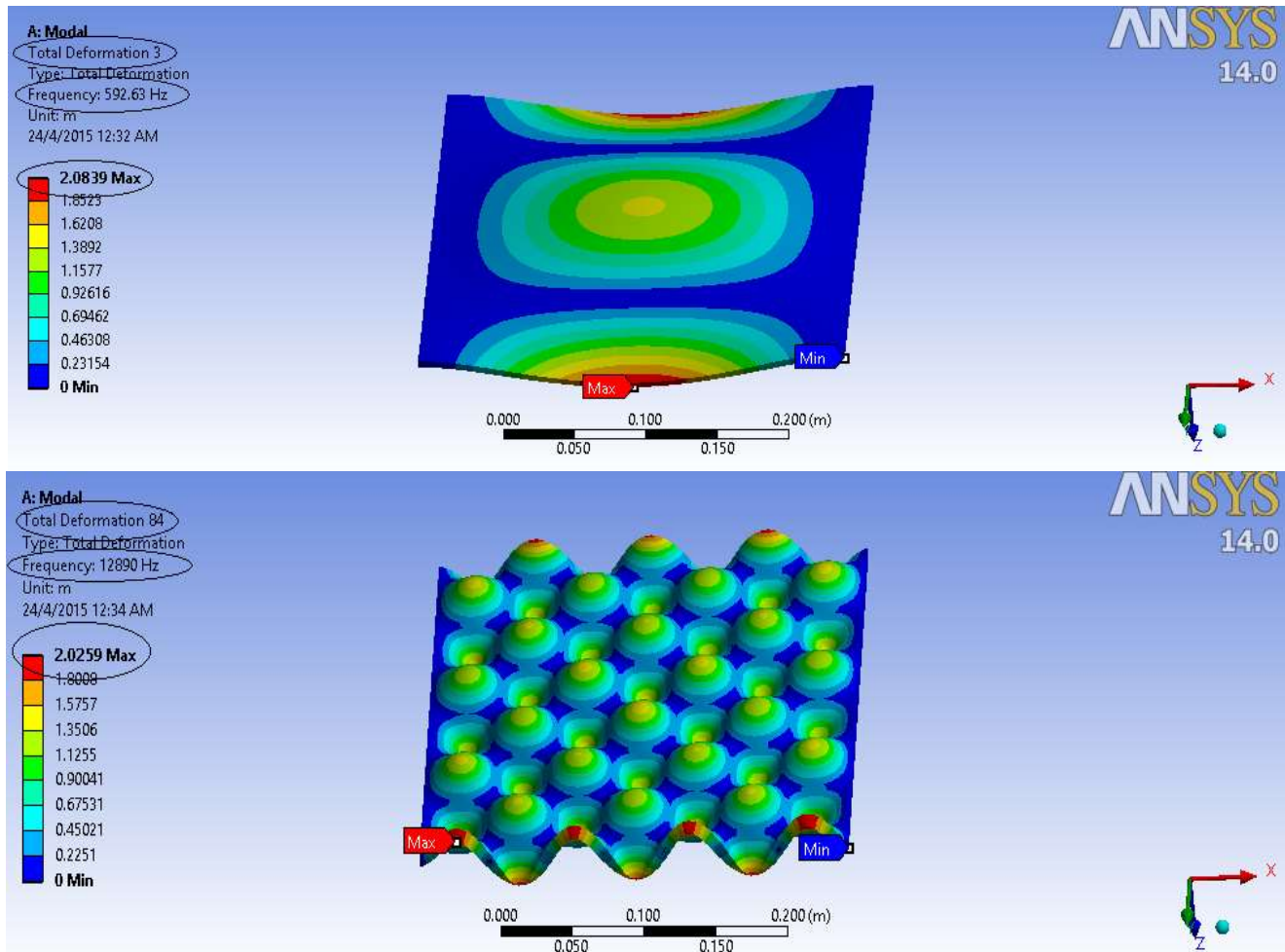


Figure: Data (highlighted) used to train the ANN

Learning

The precise definition of learning of an ANN is the processing of input data and updating the network architecture and connection weights so that a network can efficiently perform a specific task as in this work to predict the deformation of Ti6Al4V MMC. The NARX is a recurrent (feedback) network in which loops occurs because of feedback connections. The network learns the connections weights from available training data given as external input.

Testing

The neural network test itself using the given data set and creates a simple NARX Simulink model upon successful completion of the MatLab program. The figure below shows the output of the ANN program created using MatLab.

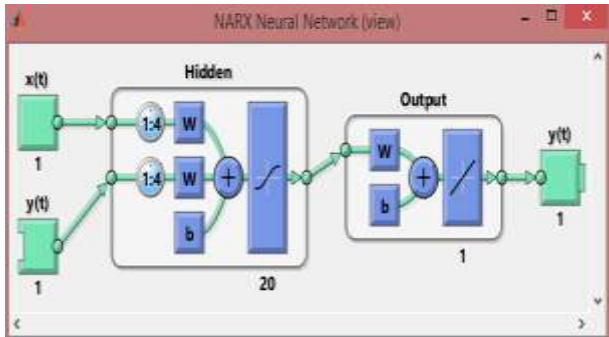


Figure: Created NARX Network

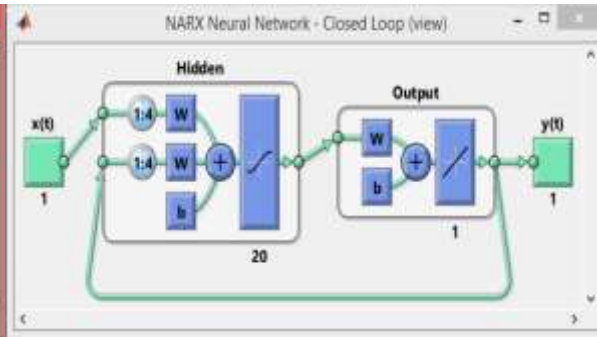


Figure: NARX during Training

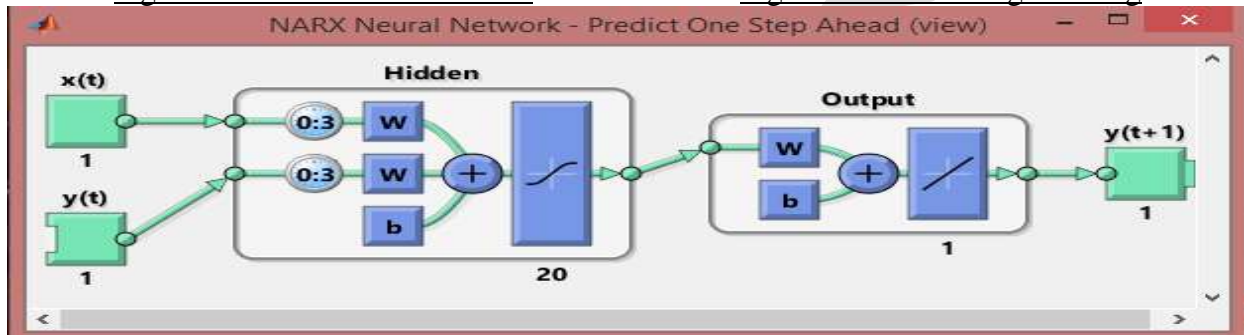


Figure: NARX One-Step Ahead View

Regression

Regression states the best fit line showing a linear relationship between natural frequency and deformation. The values of regression (R) for training is 0.91665, for validation the value is -0.33262 and the value of R for testing is -0.13865 as shown in figures below.

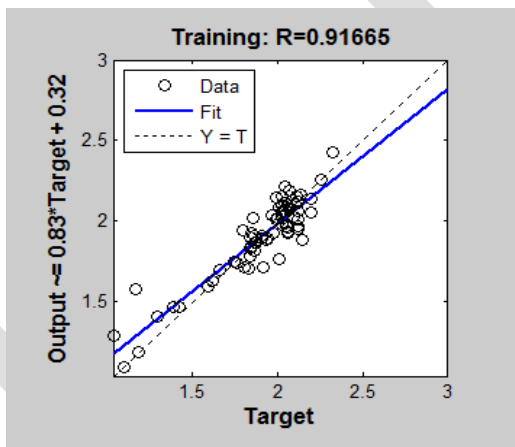


Figure: Regression for Training

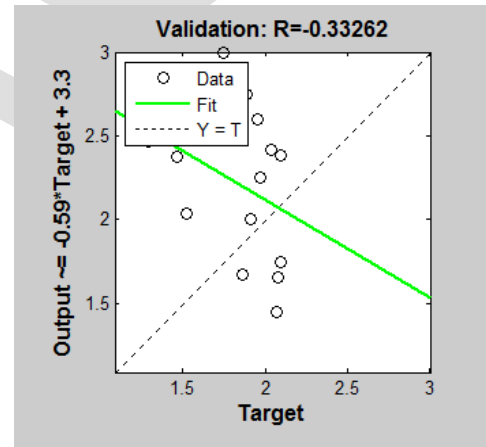


Figure: Regression for Validation

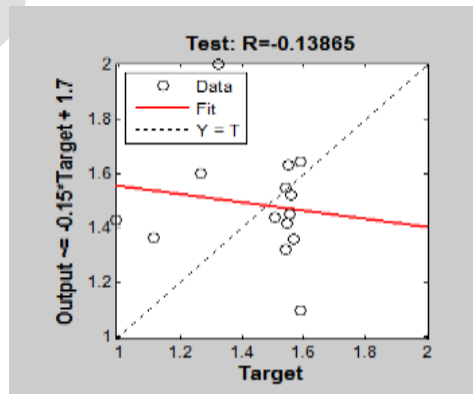


Figure: Regression for Testing

Performance of Neural Network

The NARX created gives the values of epoch, performance, gradient and validation check is shown in figure below.

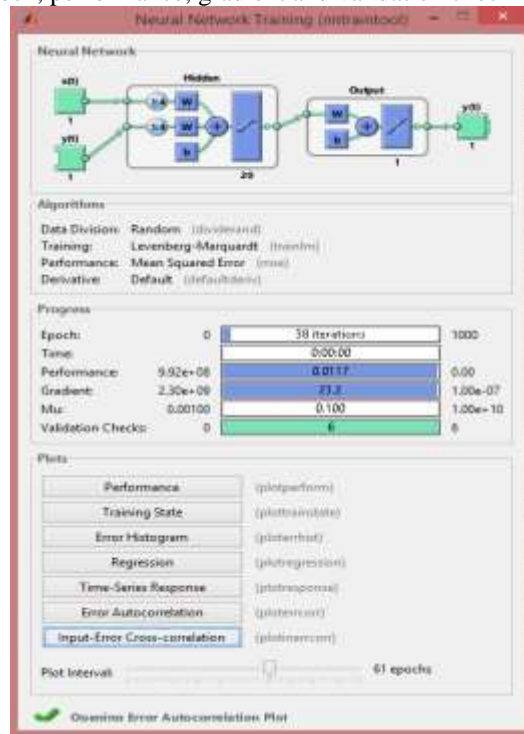


Figure: nntoolbox after testing completes

Conclusion

The designed NARX network predicts the deformation at the next higher mode with a performance of 0.0117 and a gradient of 23.2. The response graph of the created neural network shown in graph below plots all the parameters of the NARX neural network with full details of training validation, output and error.

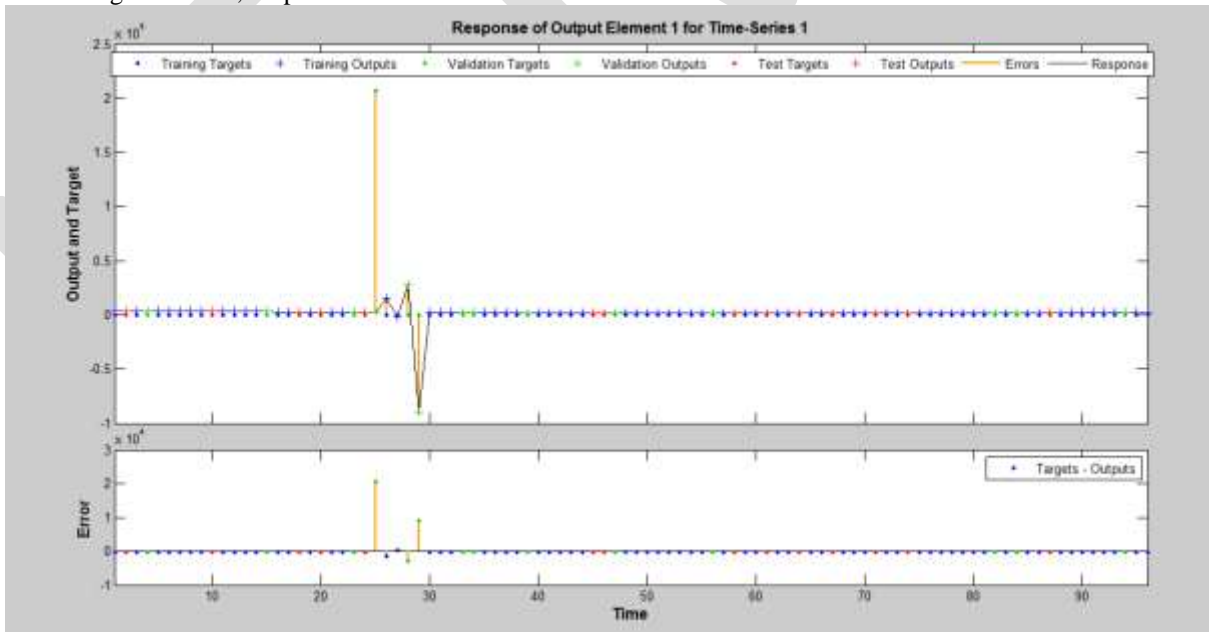


Figure: Response of the NARX ANN output

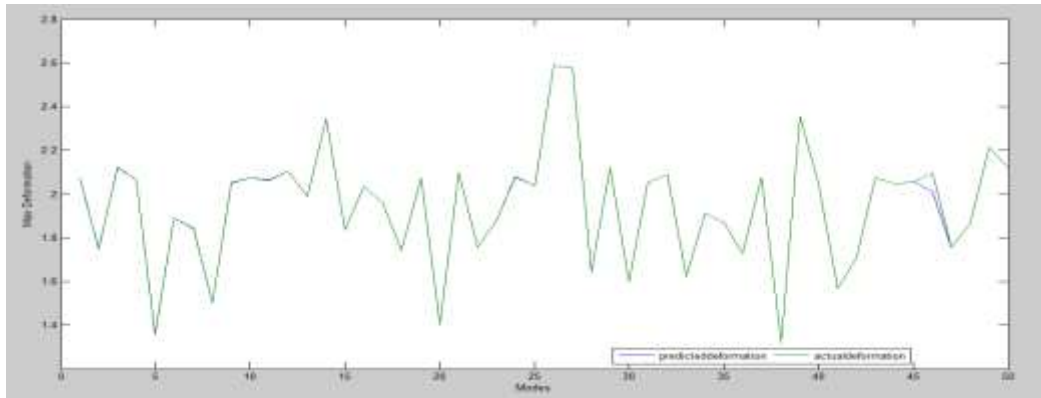


Figure: Actual vs Predicted Deformation

The graph between the actual and predicted natural frequencies of next 50 mode given in figure below with next 50 modes on x-axis and Max. Deformation on y-axis shows the high efficiency of the NARX ANN in prediction of the deformation at higher modes.

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