International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.4., 2015
(July-Aug)

RESEARCH ARTICLE

ISSN: 2321-7758

STUDY AND ANALYSIS OF NATURAL FREQUENCY OF A MMC AT HIGHER MODE THROUGH ARTIFICIAL NEURAL NETWORK

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ABSTRACT

With the ongoing demand to simplify various lengthy and complex task researchers and scientist are looking into the field of Artificial Intelligence. In this work an artificial neural network is created based on NARX which predicts the natural frequency of the metal matrix composite, in this case titanium MMC with an orientation of 90^0. For higher efficiency of the neural network the number of hidden neuron is 20 which gives more accurate result and least error. For training the neural network Levenberg-Marquardt Backpropogation method is used. There are a total of 200 data sample set out of which 140 samples have been assigned for Training the neural network, 30 samples for Validation and 30 samples for Testing the Artificial neural Network. 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. (After the network has been trained, this feedback connection can be closed, as you will see at a later step.) For each of these inputs, there is a tapped delay line to store previous values. 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. Consequently the proposed ANN model using NARX is shown to be effective in predicting the natural frequency at higher modes.

Keywords— Metal matrix composite (MMC), Artificial Neural Network (ANN), MatLab (Matrix Laboratories), Supervised Learning, Advanced prediction techniques, ANSYS, Time series.

INTRODUCTION

In this era, 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 Titanium. 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. The previous works includes Prediction of natural frequency of laminated composite plates using artificial neural network by M.R.S. Reddy, B.S.Reddy et al [18]. Other work has been done using this method to calculate the physical and mechanical the properties of MMCs. 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 MMCat 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. In this work the NARX network uses a tan-sigmoid transfer functionfor high accuracy of prediction of natural frequency.

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.

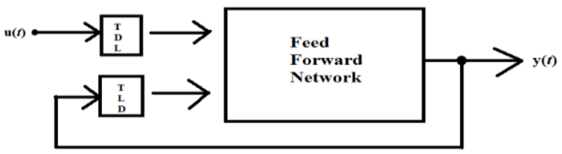

Figure: Basic ANN (NARX model)

Where aij is the input to the neuron, wij is the weight of the link, ∑ is the total input and a∫ is the activation function. Total weighted input is sum of inputs activation times their respective weights

$in_j = \sum j$ Wji.aj

Weight adjustment rule is given by

$$W_j \leftarrow W_j + \propto l_j + Err$$

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 jth input.

Metal Matrix Composite

A fiber-reinforced composite (FRC) is a high-performance composite material made up of three components - the fibers as the discontinuous or dispersed phase, the matrix acts as the continuous phase, and the fine interphase region or the interface. The matrix is basically **a homogeneous and monolithic** material in which a fiber system of a composite is embedded. It is **completely continuous**. The matrix provides a medium for binding and holding reinforcements together into a solid. It offers protection to the reinforcements from environmental damage, serves to transfer load, and provides finish, texture, color, durability and functionality. 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 Specifications

The Titanium MMC have the chemical composition of 90% Titanium, 6% Al, 4% Vanadium, and traces of oxygen and iron with 0.2% each the orientation is 90^o. 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 14.0. The dimensions of the plate is assumed to be a square plate with the length as 300mm and the width as 5 mm. 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)
Titanium MMC	300	300	5

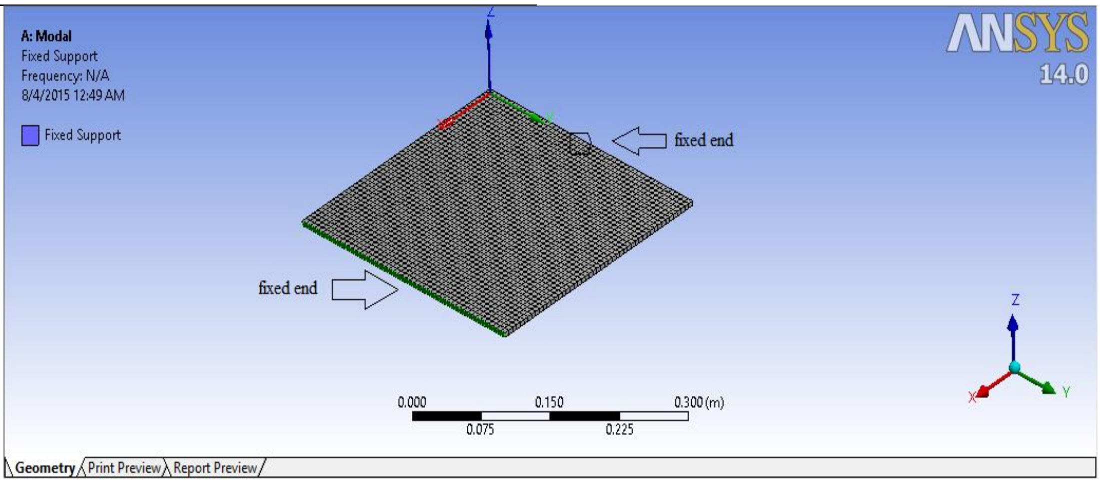

Figure: Geometry of the Titanium MMC plate modelled using ANSYS

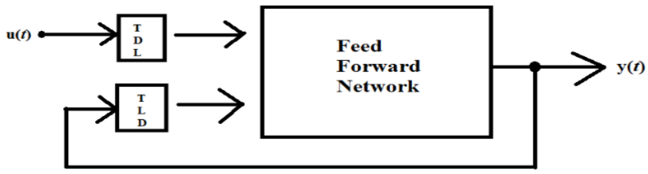

Figure: NARX model

Where aij is the input to the neuron, w_{ij} is the weight of the link, ∑ is the total input and aʃ is the activation function. Total weighted input is sum of inputs activation times their respective weights

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

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

$y(t)=f(y(t-1),y(t-2),\dots,y(t-ny),u(t-1),u(t-2),\dots,u(t-nu))$

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 feed forward network is used for the approximation.

Deformation Analysis

The deformation of the Tiitanium MMC is done using ANSYS. The data obtained is then used to train and test the NARX artificial neural network which thrn predicts the natural frequency at the next higher modes. The NARX network created here works on two input and single output.

The figures of the deformation analysis are shown below with the corresponding values of Natural frequency.

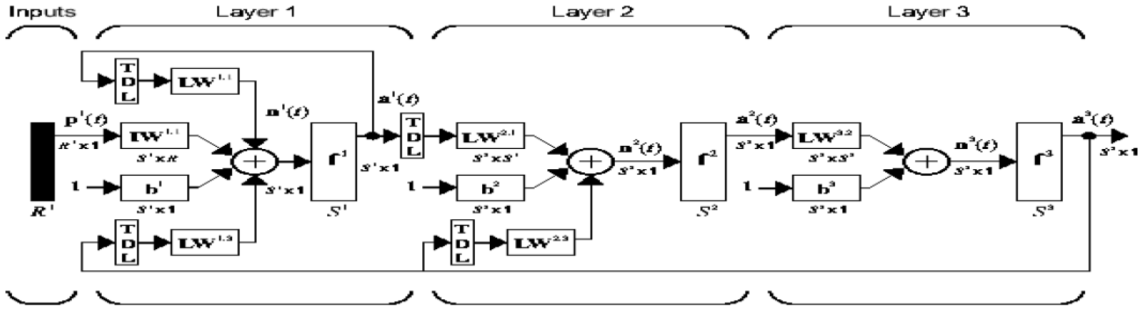


Figure: A two-layer feed forward NARX network

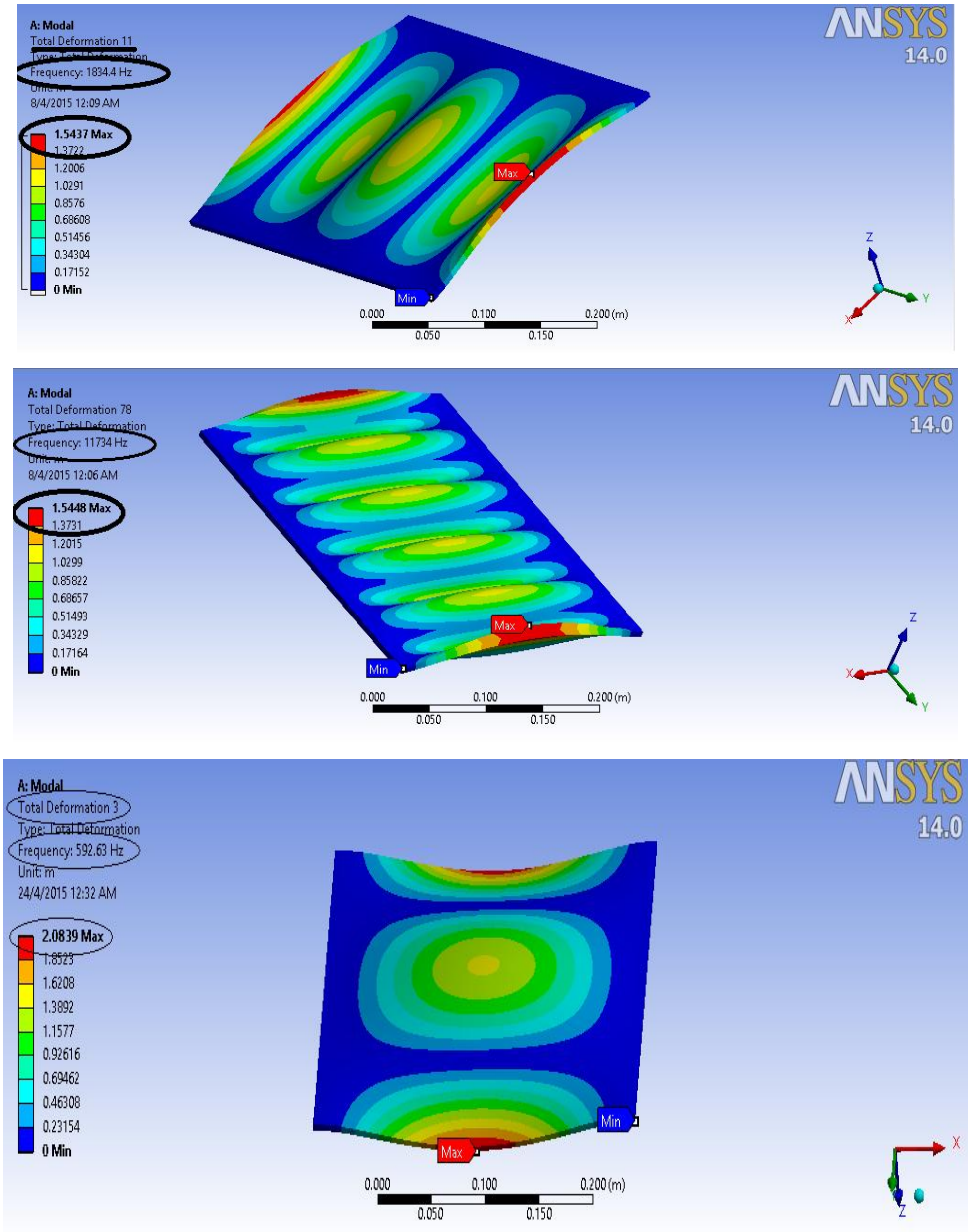


Fig: The input data and deformation for the neural network(highlighted)

Training

The artificial neural network created to predict the deformation of the Titanium MMC is developed using NARX. A total of 200 data samples is used as input. The input used is the natural frequency and mode shape of the MMC. For maximum performance 140 target time steps have been taken and the remaining 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 i7 processor P.C.

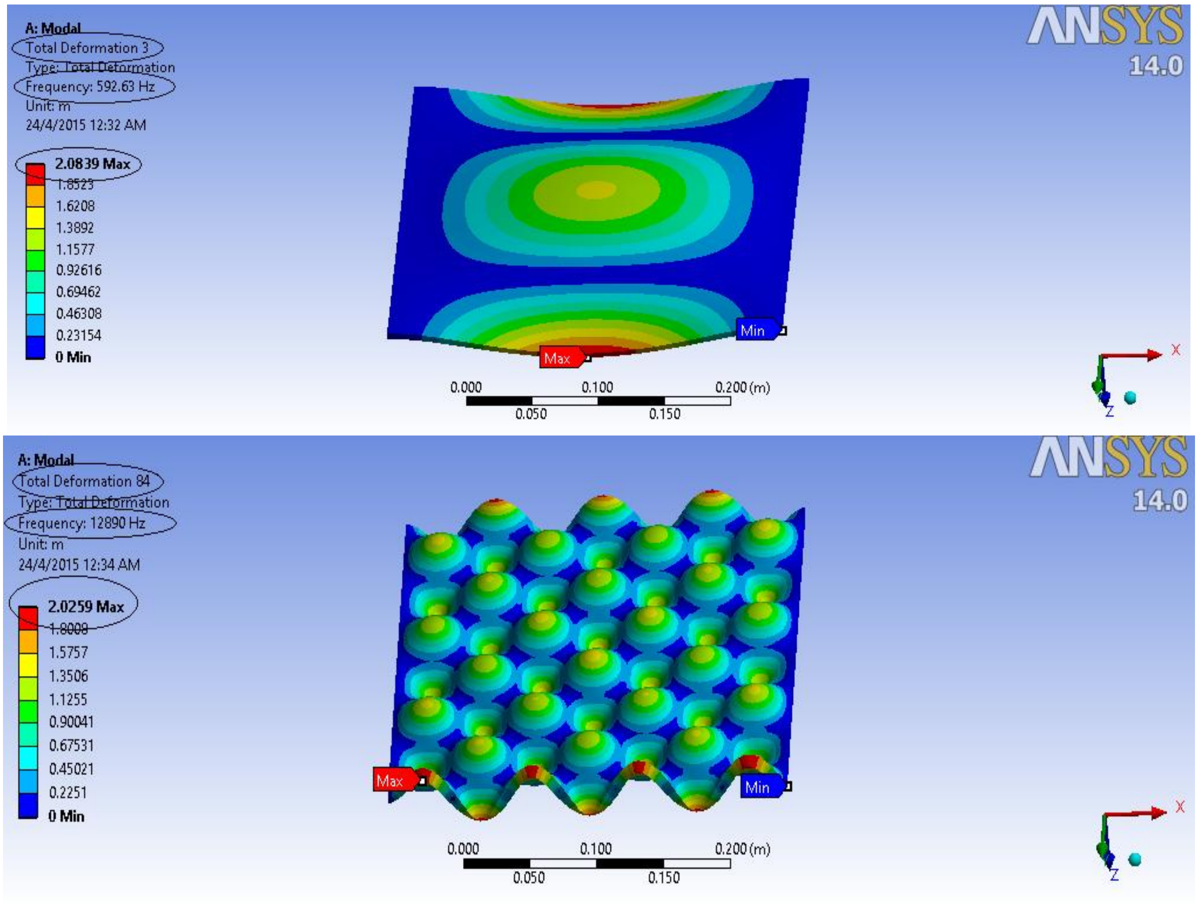


Figure: Data(highlighted) used to train the ANN

Learning

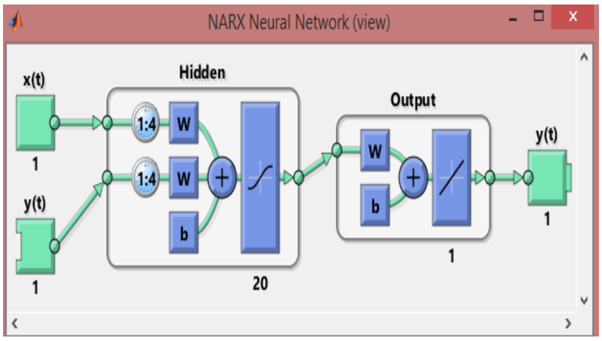
Learning algorithms search through the solution space to find a function that has the smallest possible cost. For applications where the solution is dependent on some data, the cost must necessarily be a *function of the observations*, otherwise we would not be modelling anything related to the data. It is frequently defined as a statistic to which only approximations can be made. In this work the learning is Supervised Learning.

As a simple example, consider the problem of finding the model, which minimizes, for data pairs drawn from some distribution. In practical situations we would only have samples from and thus, for the above example, we would only minimize. Thus, the cost is minimized over a sample of the data rather than the entire data set.

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 Titanium 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

Validation is a check to see if the neural network is working within the defined parameters. After which the Train trains a network net according to “net.trainFcn” and “net.trainParam”. 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.



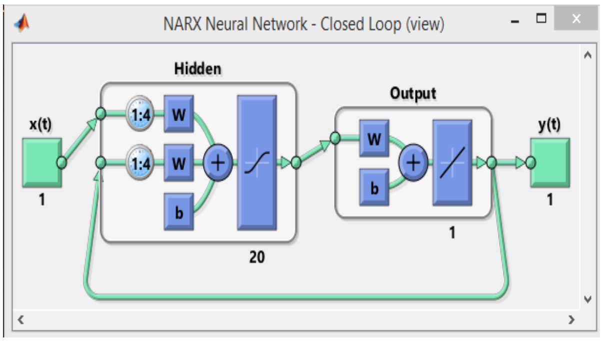


Figure: Created NARX NetworkFigure: NARX during Training

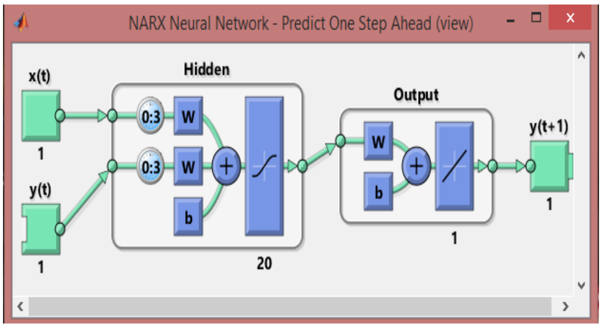


Figure: NARX One-Step Ahead View

Regression

Regression states the best fit line showing a linear relationship between natural frequency and deformation. The values of regression (R) for training is 0.99968, for validation the value is 0.93278 and the value of R for testing is 0.99958 as shown in figures below.

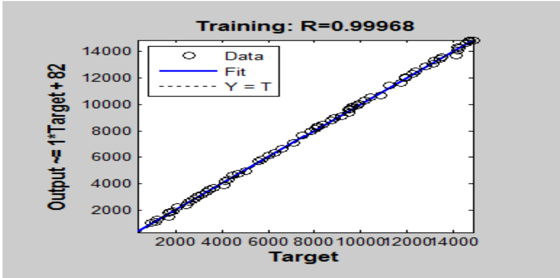


Figure: Regression graph Training

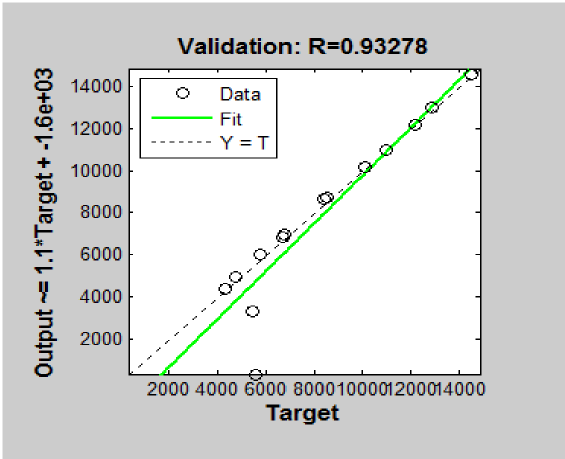


Figure: Regression graph Validation

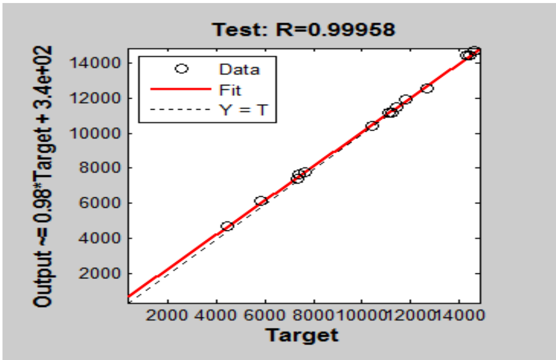


Figure: Regression graph Testing

Input error correlation

The input error correlation graph generated shows the high performance of the created NARX artificial neural network.

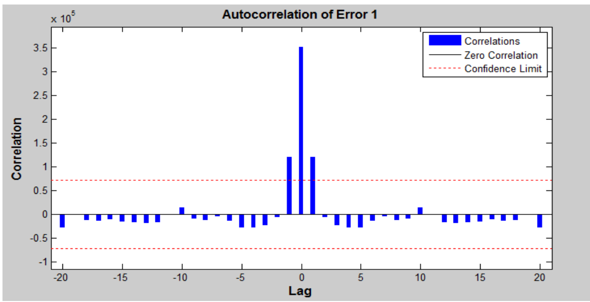


Fig: Autocorrelation for Error

Performance of Neural Network

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

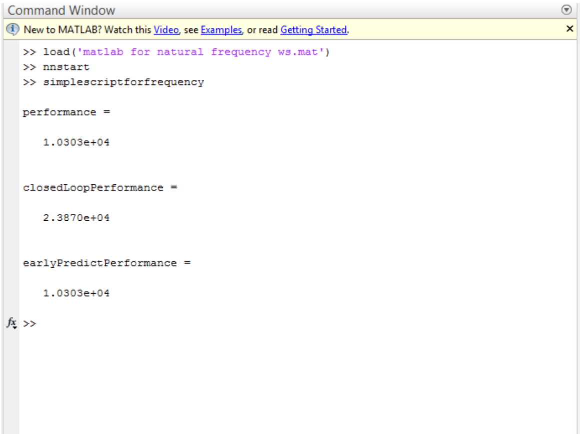


Fig: Matlab Result for all performance

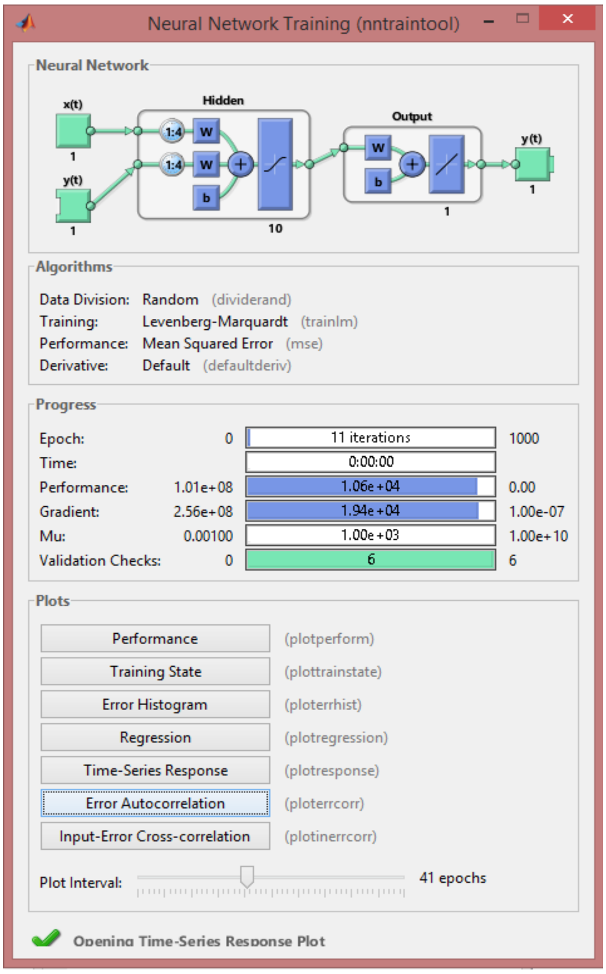


Figure: nntraintool after testing completes

Conclusion

The designed NARX network predicts the natural frequency at the next higher mode with a performance of 1.06e+04the closed loop performance of 2.3870e+4 and the early predict performance 1.0303e+4.The gradient of 1.94e+4. 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.

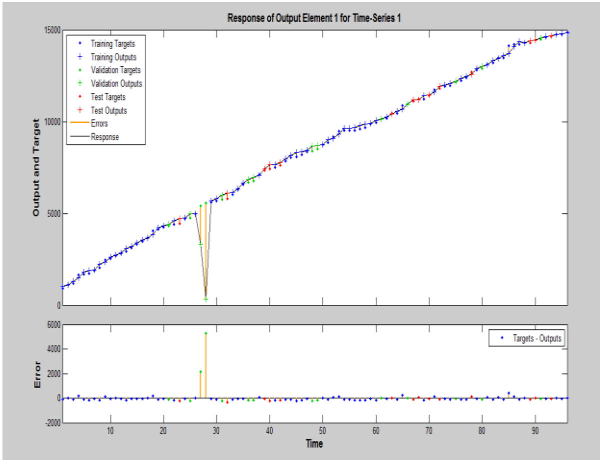


Figure: Response of the NARX network output

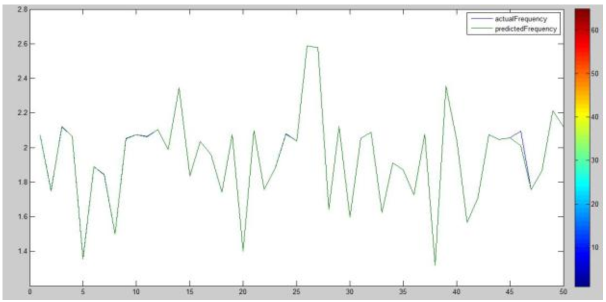


Figure: Predicted vs Actual Natural frequency

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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