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Theoretical Investigation of a Structure for Active Vibration Control with Fuzzy Logic Approach

Erdi GÜLBAHÇE[1,a], Mehmet ÇELİK[2,b],Mustafa TINKIR[3,c]

[1]Mechatronics Engineering Department, KTO Karatay University, Konya, TURKEY

[2]Mechanical Engineering Department, KTO Karatay University, Konya, TURKEY

[3]Mechanical Engineering Department, Necmettin Erbakan University, Konya, TURKEY

[a]erdi.gulbahce@karatay.edu.tr, [b]mehmet.celik@karatay.edu.tr, [c]mtinkir@konya.edu.tr

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Abstract. The main purpose of this study is to prepare mathematical model for active vibration control of a structure. This paper presents the numerical and experimental modal analysis of aluminum cantilever beam in order to investigate the dynamic characteristics of the structure. The results will be used for active vibration control of structure's experimental setup. Experimental natural frequencies are obtained and compared to verify the proposed numerical model by using modal analysis results. MATLAB System Identification Toolbox and ANSYS harmonic response function are used together to estimate beam's equations of motion which include its amplitude, frequency and phase angle values. Moreover, the mathematical model of beam is simulated in MATLAB/Simulink software to determine the dynamic behavior of the proposed system. Furthermore, another prediction model approach with multiple input and single output is used to find the realistic behavior of beam via an adaptive neural-network-based fuzzy logic inference system, in addition, impulse responses of the proposed models are compared and the control block diagram for active vibration control is implemented. As a first iteration, PID type controller is designed to suppress vibrations against the disturbance input. The results of modal analysis, the prediction models, controlled and uncontrolled system responses are presented in graphics and tables for obtaining a sample numerical active vibration control.

Introduction

Development of smart structures in engineering systems has seen a gradual increase during the last years. Mechanical vibration, one of the major problems in engineering applications, can be controlled using active or passive methods. As piezoelectric materials are mostly used in sensors and transducers to measure amplitudes and frequencies of vibrations, piezoelectric-based structures have gained significant importance in active vibration control [1-7].Therefore, significant studies are conducted on manufacturing, analyzing and modeling of piezoelectric materials and smart structures. Likewise, the importance of active vibration applications has improved due to the technological advances.

In this paper, numerical and experimental modal analyses of aluminum cantilever beam (250x20x1mm.) are obtained in order to investigate the dynamic characteristics of the structure for active vibration control. Natural frequencies of modal analysis methods are compared and MATLAB/System Identification Toolbox and harmonic response function of ANSYS are used together to estimate equations of motion of beam describing amplitude, frequency and phase angle values. Moreover, adaptive neural-network-based fuzzy logic prediction approach with multiple input and single output is used to find realistic behavior of the beam. Thus, impulse responses of uncontrolled system are calculated and a proportional-integral-derivative (PID) controller is designed for active vibration control of a sinusoidal disturbance input. The comparison results of modal analysis methods and controlled and uncontrolled active vibration responses are presented graphics and tables at the end of this table.

Modal Analysis and Prediction Model Approaches

Initially, a 3D CAD model of the proposed flexible aluminum cantilever beam is drawn using SolidWorks software. The mass of the accelerometer is taken into account in the analysis. Numerical modal analysis is applied in the ANSYS/Workbench software according to materials properties as listed in Table 1. Table 2 shows the approximate natural frequencies and mode shapes of resonance frequencies obtained from the numerical modal analysis.

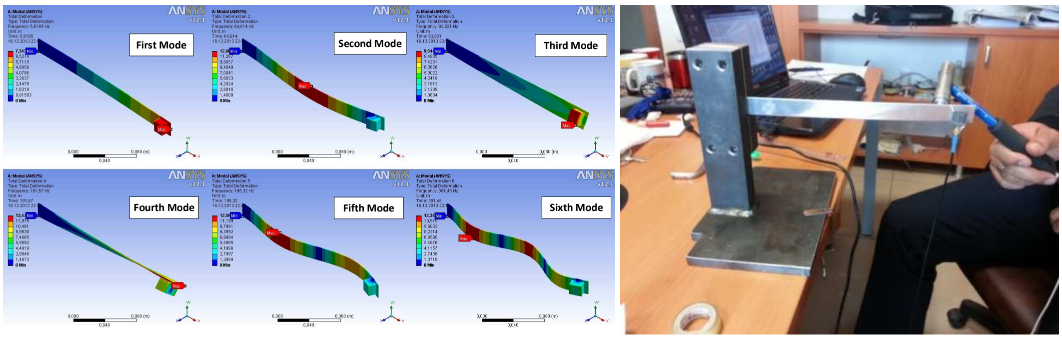
Table 1.Data from Ansys

	Accelerometer	Aluminum Beam
Properties		
Volume	2,25e-006 m³	5,e-006 m³
Mass	0,094e-002 kg	1,38e-002 kg
Mass Moment of Inertia Ip1	4,72e-007 kg·m²	4,62e-007 kg·m²
Mass Moment of Inertia Ip2	4,72e-007 kg·m²	7,21e-005 kg·m²
Mass Moment of Inertia Ip3	6,54e-007 kg·m²	7,26e-005 kg·m²
Nodes	492	3276
Elements	75	414

Table 2. Natural frequencies

Mode	Frequency [Hz]	Mode Shapes
1	5,6185	Bending
2	64,814	Bending
3	93,821	Torsion
4	191,67	Torsion
5	195,32	Bending
6	381,45	Bending

The mode shapes results of the modal analysis are shown in Figure 1a.The third and fourth modes are torsional and other modes are in bending. After these analyses, a physical prototype is produced and experimental modal analysis is performed on the structure. A modal hammer is used for applying disturbance to the beam in the experimental set up. In addition, a three-axis accelerometer mounted to obtain the frequency response function (FRF) matrix and consequently response of the system. Figure 1b shows the experimental setup for the modal analysis.



a) b)

Figure 1.Numerical and experimental modal analysis

a) Mode shapes of aluminium beam b) Modal analyses experimental setup

For the experimental modal analysis, five points are determined on cantilever beam with equal intervals and the accelerometer is placed on the tip of beam for rowing hammer application. Data from the each point are processed and displayed by DeweSoft software. Experimental modal analysis results are obtained and shown in Figure 2. FRF graphic of aluminum beam in experimental modal analysis is processed to find natural frequencies

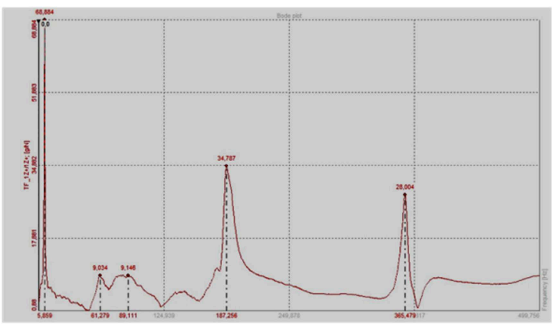


Figure 2.FRF graphic of aluminum beam in experimental modal analysis

The natural frequencies obtained from both modal analyses are compared in Table 3. From this table it is understood that the modal analysis results are close to each other. The experimental results are used to verify the numerical modal analysis from ANSYS Software. With the validated numerical model, harmonic response analysis is obtained through the proper mathematical model of the beam developed considering the accuracy of numerical modal analysis. In Ansys Software, a disturbance of 1-N force is applied to tip of the cantilever beam and response of the structure is analyzed. Figure 3 shows the bode plots for the frequency response of this-so called-smart beam.

Table 3.Experimental and numerical natural frequencies.

Mode	Experimental[Hz]	Numerical [Hz]
1	5,86	5,61
2	61,28	64,81
3	89,11	93,82
4	187,25	191,67
5	190,58	195,32
6	365,48	381,45

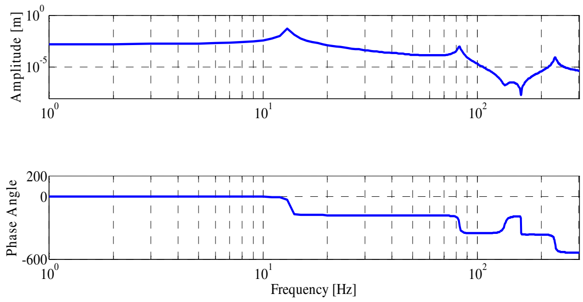


Figure 3.Bode plots of proposed beam

The estimate (mathematical) model is formed in MATLAB/ System Identification Toolbox and it is compared with ANSYS model and a 0.7% prediction error is obtained as shown in Figure 4.

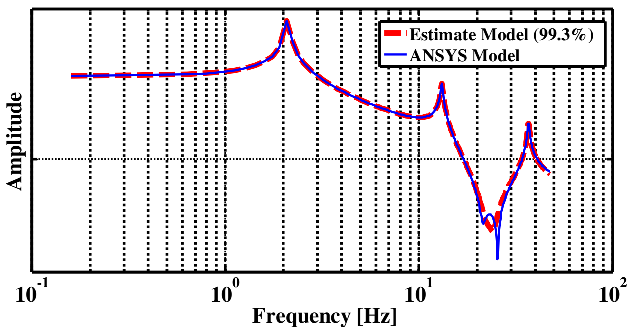


Figure 4.Estimate model of system

The initial ANSYS model is a SISO (single input, and single output) model. An adaptive neural network-based fuzzy logic prediction model is created to find the actual dynamic characteristics of the system. The training and test data from the ANSYS model are chosen for neural network of the fuzzy model and three gaussian type membership functions are used for two inputs to obtain better estimation results. Membership functions and linguistic variables are shown in Figure 5. In these figures, linguistic variables of membership functions are described as Negative, Medium and Positive for displacement error input and Small, Zero and Big for disturbance input respectively. Moreover nine rules are used in rule table which is determined by artificial neural network of fuzzy logic prediction model. Also nine constant values are used as tip displacement for output membership functions of fuzzy logic model. The comparison of two prediction approaches is given in Figure 6. From these results, it is inferred that fuzzy logic model can be used as actual beam system according to displacement-time responses.

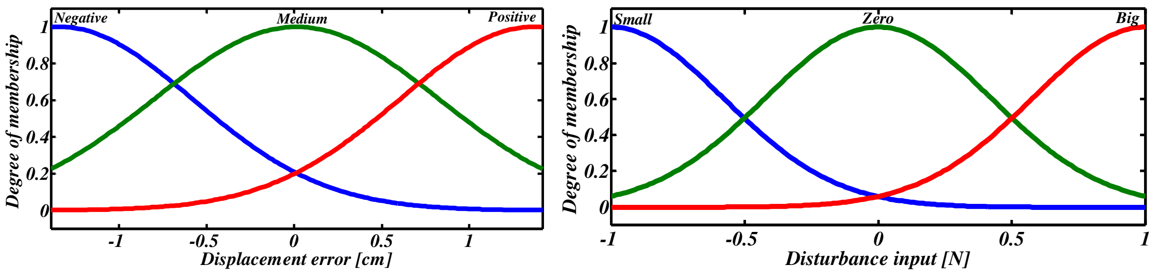


Figure 5.Membership functions of fuzzy logic model for two input variables

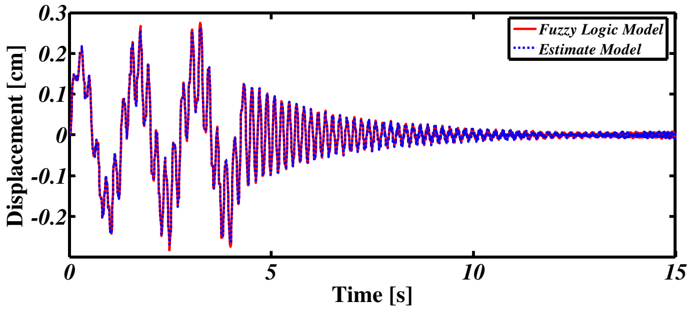


Figure 6.Comparison of proposed prediction model

Controller Design

As seen in Figure 7 block diagram of proposed system is created and a PID controller is designed for active vibration control in MATLAB/Simulink. According to Ziegler Nicholas Methodgain parameters of PID controller are optimized such as Kp= 50, Ki= 2 and Kd= 0.1.

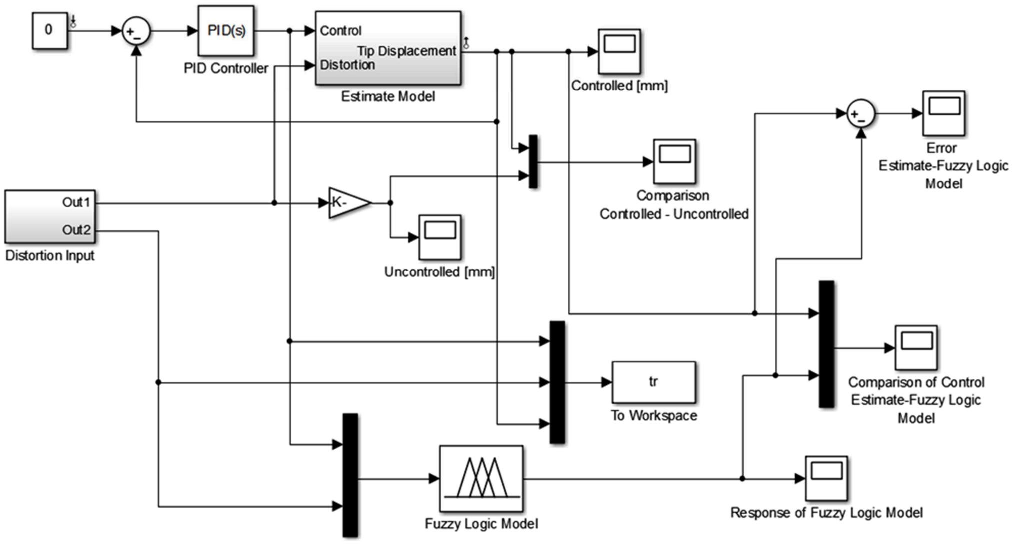


Figure7.Block diagram of system

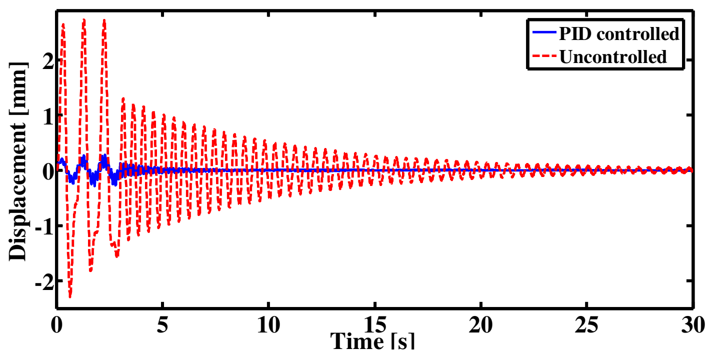


Figure 8. Comparison of controlled and uncontrolled system

Displacement responses of PID controlled and uncontrolled proposed system are plotted in Figure 8. These results show that maximum displacements of uncontrolled and controlled beam are calculated as 0.3 mm and 2.7 mm respectively. Moreover, the PID controller suppresses beam deflection in 5 seconds and decreases deflections by 89% against the same disturbance input.

Conclusion

The aim of this study was to find the mathematical model for active vibration control of aluminum cantilever beam. Two modal analyses methods and two prediction models are used to investigate the dynamic characteristics of the flexible structure. Modal analyses and modeling results show that fuzzy logic model was successfully implemented and valuable information has been obtained before active vibration control of experimental setup. A sample controller (PID) is used to find the differences between controlled and uncontrolled system. The effectiveness of this controller is verified using simulations. In the future study an effective controller (Resonance Control (RC), Positive Position Feedback Feed Through (PPFFT), etc.) will be used and implemented for experimental vibration control of the structure.

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