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Obtaining Vibration Models of a Lattice Structured Cantilever Beam Constructed with Different Types of Materials

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Abstract

Lattice structures provide lightweight engineering components with optimal distribution. Lattice structures have been used in many engineering applications in recent years. In literature, studies including vibration models of lattice structured beams are not common. In this study, cantilever beams with lattice structures were modeled using three types of materials in the Ansys program. 20 kN force was applied to each beam and the displacements that occurred at the free end side of the beams were recorded. By using input and output data sets belonging to the vibration of the beams and the System Identification Toolbox of MATLAB, discrete-time transfer function models, discrete-time state space models, and nonlinear ARX models were obtained. The results for the success of the obtained vibration models of the cantilever beams were compared and discussed using tables and figures. It can be said that the lattice Ti6Al4V beam is superior to the measured and model output compared to other materials.

Keywords: Cantilever Beam, Lattice Structure, Vibration Model, 316L, MgAz91, Ti6Al4V

1. Introduction

Today, it is known that steel-constructed structures have been preferred for a long time, especially in the automotive and construction sectors. Steel-constructed structures, which are primarily used in the construction of industrial buildings and sports facilities, appear in the construction of medium-sized buildings day by day and their usage areas are increasing day by day. However, compared to other applications, it becomes significantly preferred due to the same structural rigidity, lightweight and low cost, earthquake resistance, and high construction speed [1,2]. In this respect, it is important to know the mechanical properties of the profiles to be used in steel construction structures and to determine how they will behave under a load. The behavior of a steel profile against the applied load can be easily determined by theoretical calculations or computer-aided structural analysis programs [3].

The use of experimental-based modeling methods in the modeling of engineering systems is increasing. To obtain discrete-time or continuous-time models, Input-output data sets are used in dynamic systems [4]. System behavior can be observed by applying various input signals to the generated models, and if necessary, these models are used in the design of active controllers [5]. Modeling of engineering systems is also built in the form of discrete-time dynamic models due to the developments in microprocessor technology today [6]. In this study, an input of 20 kN was applied to a cantilever that was beam modeled in Ansys, and the vibration occurring at the free end of the beam was recorded. By using the input-output data sets of the beam, discrete-time models representing the vibration of the beam were obtained. Out graphics of the vibration data obtained from Ansys, and the vibration data obtained from the discrete-time models were obtained in MATLAB/Simulink environment. The vibration models have been obtained using input and output data sets belonging to the vibration of the lattice-structured beams having different materials (316L, MgAz91, and Ti6Al4V) for only triangular lattice structures. By using the System Identification Toolbox (SIT) of MATLAB, discrete-time transfer function models, discrete-time state space models, and nonlinear ARX models were derived. The objective of this study is to determine which of the system identification methods used will obtain the dynamic model that most accurately represents the force input-vibration output data set. In the literature, system identification methods were not used in obtaining vibration models of lattice-structured beams.

1.1. Beam Materials For Analysis

Three materials were used and analyzed in the study. This product is 316L, AZ91, and Ti6Al4V alloys. Chemical analysis and mechanical properties are given in Table 1 and Table 2.

Weight%/ Beam Materials	Ti	Al	V	Mg	Zn	Cr	Fe	Si	N
316 L	-	-	-	-	-	21.29	71.55	0.08	7.09
MgAz91		8.84	-	90.50	0.66	-	-	-	-
Ti6Al4V	89.87	5.78	4.35	-	-	-	-	-	

Table 1: Chemical of Materials Beam

Properties/Materials	316 L	AZ91	Ti6Al4V
Density (kg/m^3)	8000	1740	4450
Modulus of Elasticity (Gpa)	193	44.8	113
Poisson Ratio	0.25	0.35	0.34

Table 2: Properties of Materials Beam

MgAz91 and Titanium are in the light material group compared to stainless steel. Their densities are 1.74, 4.5, and 7.9 gr/cm3 respectively. Titanium and its alloys are known to have excellent tensile stress and corrosion. Table 1 and Table 2 show the mechanical properties of the alloys used in the study. In addition, it shows the chemical composition of the alloy, which is the determining factor in the formation of microstructure and phases, and therefore its properties, that is, its mechanical properties. For example, the mechanical properties of pure titanium are enhanced by the addition of Al and V. The metallurgical state of the metals as well as the composition and the synthesis process change their mechanical properties, i.e. the annealed state has better ductility than the cold worked, and cast metal implants generally have lower strength than those made by forging. Unlike failure in the tensile test, in which the sample is subjected to progressively increasing loading until fractures, failure of a component practically occurs after a long repeated cycle of stress or strain. This phenomenon is called fatigue and is the cause of many failures in machine parts in practice. Also, the solution of complex vibration problems, especially in the industrial sector, requires engineering applications for detailed analysis as well as the right material selection [7].

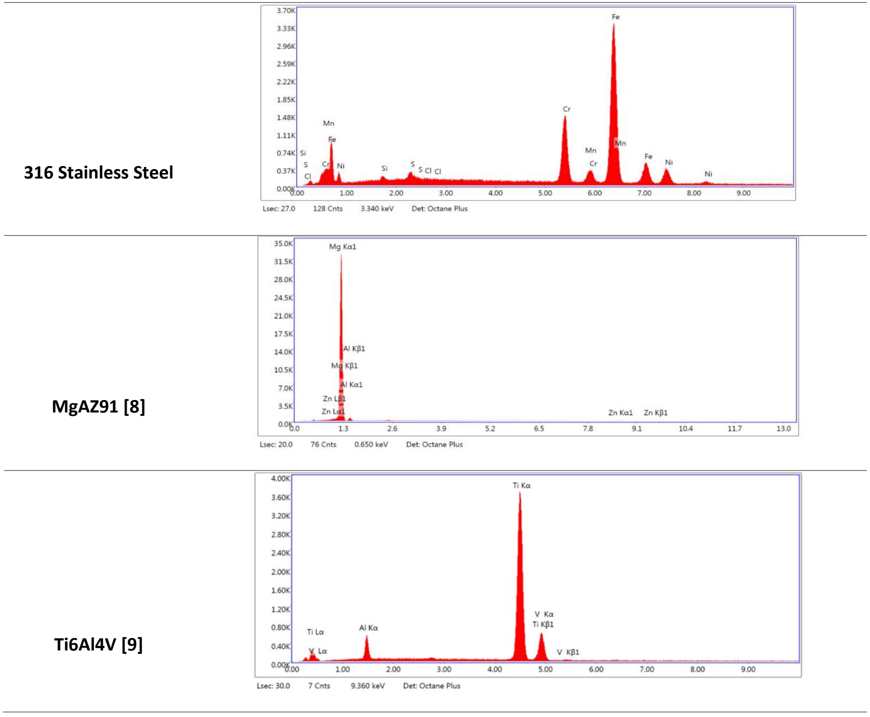


Figure 1: EDS Analysis for Materials

1.2. Computer-Aided Simulation

Finite Element Analysis (FEA) is very important for the development of optimum designs of mechanics and devices. It is desirable as an important method for validating experimental and analytical results. Computer-aided simulations were carried out in Ansys Workbench Transient Analysis. Today, FEA and computational fluid dynamics (CFD) are used to solve many engineering and health problems [10-15].

1.3. Three-Dimensional Modelling Process of Beams

The three-dimensional (3D) model of the beam with a triangular lattice structure was obtained using the lattice generation-based design software nTopology. The dimension of the beams is 220x20x4 mm. After the modeling process of the beam, meshing from the voxel method process. After the modeling process of the beam with a triangular lattice structure, the meshing process was performed by converting the 3D model into a voxel via topology software. The mesh file has been exported by converting it to Ansys mechanical input file type (.cdb) to be compatible with Ansys. The mesh file has been transferred to the Ansys Workbench Transient Analysis module as an external model as seen in Figure 2.

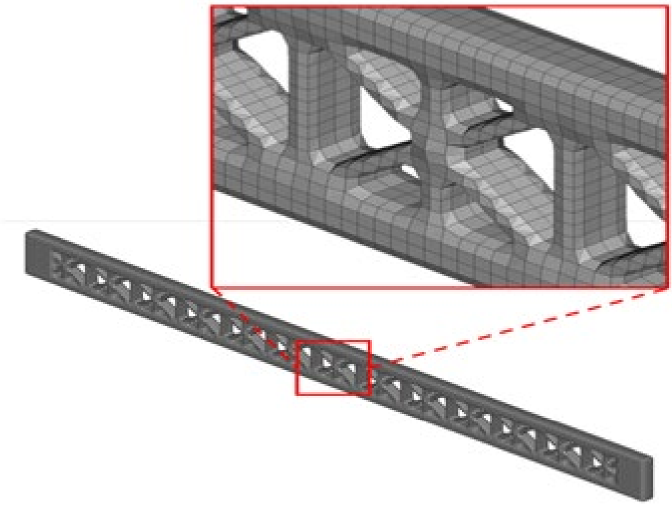


Figure 2: The Voxel Type Mesh Structure of the Beam

1.4. Loading and Boundary Conditions

In the FEA, meshing is performed by transforming the model into a more regular hexahedron structure, voxel unit, as shown in Figure 3. Mesh element size is adjusted between 1 and 1.2 mm. For beam with a triangular lattice structure, 55265 element numbers and 19997 joint points were created. The beam is fixed at one end and a force of 20 kN was applied to the free end of the beam in Figure 4. The displacements occurring at the free end of the beam are analyzed using the FEA and recorded for use in obtaining vibration models. curve peaks of HA doped and TCP doped mixtures located 2θ near 26° and 32° are the same as biological apatites' peaks in the literature (Ref 31, 50). The curve of undoped resin has no peaks at both 0 and 2. weeks kept in SBF. Therefore, it concludes that even if any particle appears in the undoped resin parts' images, it does not chemically confirm that it is an apatite mineral.

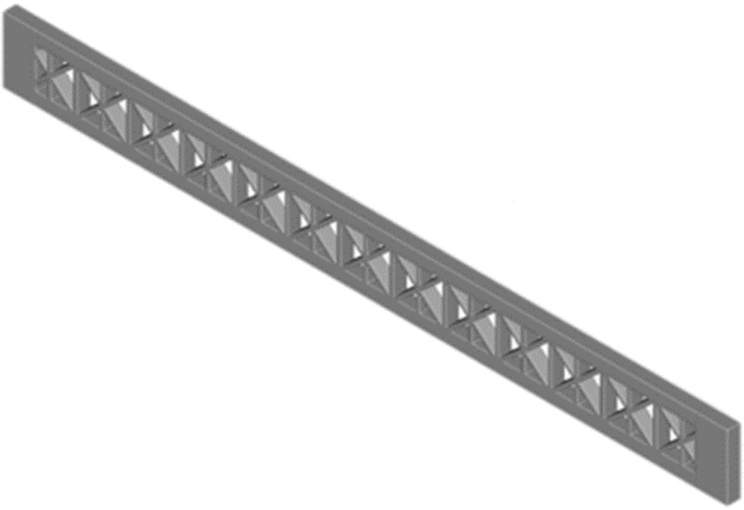


Figure 3: The Cantilever Beams with Triangular Lattice Structure

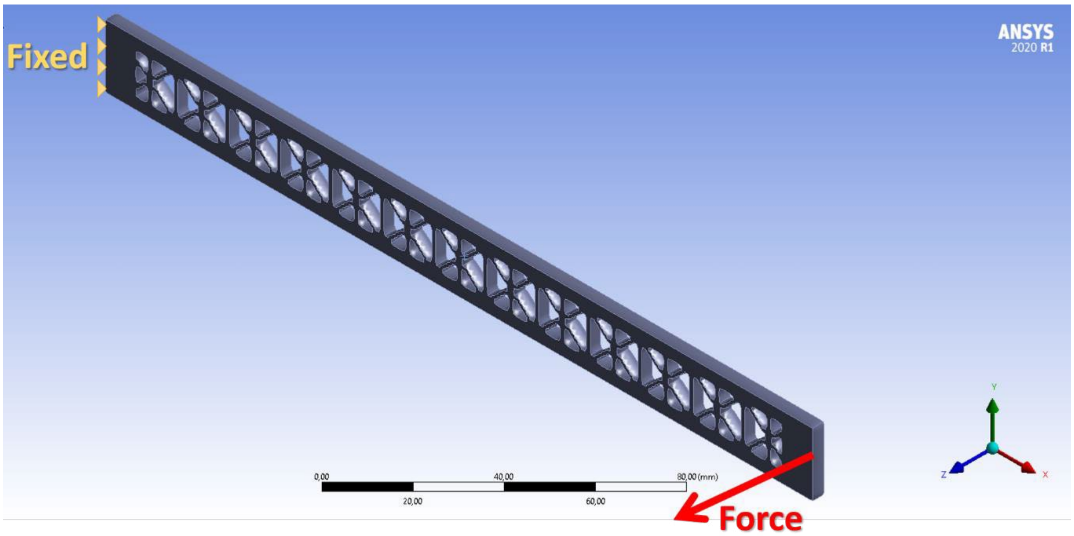


Figure 4: The Loading and Boundary Conditions

1.5. Vibration Modeling

An input force of 20 Kilonewton was applied for 2 seconds to the free end of the beam with triangular lattice structure fixed beam in the Ansys environment. The vibration data on the beam with a triangular lattice structure were recorded as 400 data in total, including 200 data per second. Discrete-time transfer function and state space models and nonlinear ARX models were obtained in MATLAB program by using the output data set of the input force applied to the fixed beam with triangular lattice structure and the displacement corresponding to the input. System modeling plays a key role in control system design. If the model is well defined, controller design can be better, and optimum system output can be obtained. The place of system identification in control system design is shown in Figure 5.

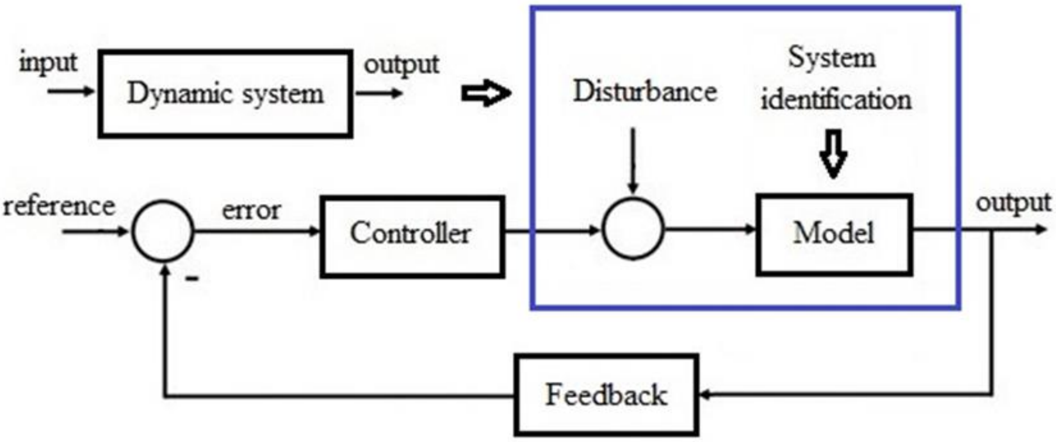
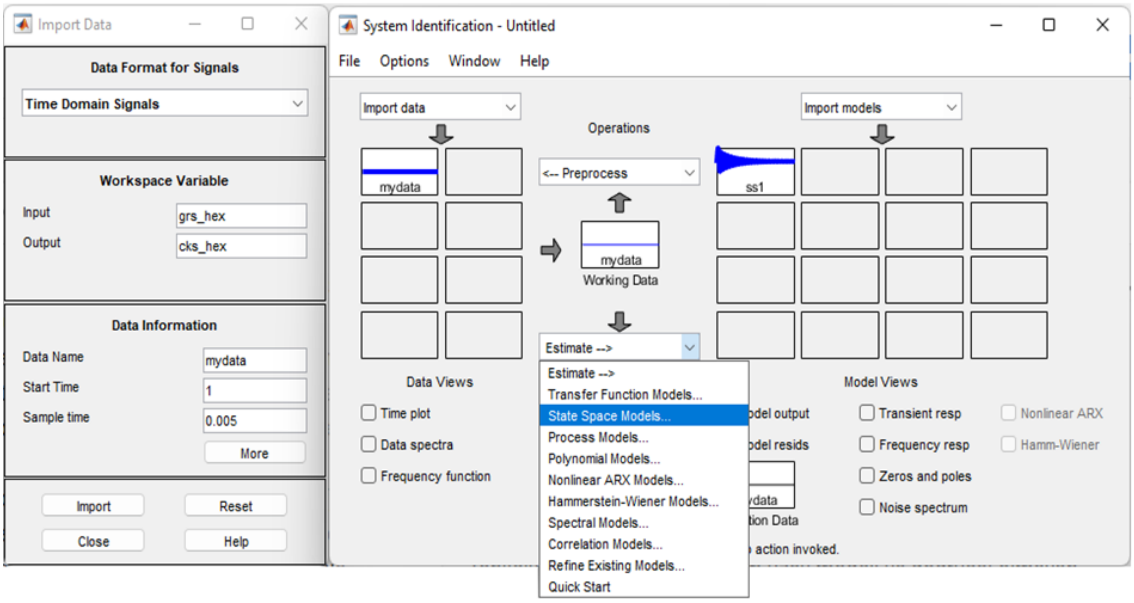


Figure 5: System Identification Step in a Closed-Loop Control System

The parameters of the models were obtained using methods in SIT of MATLAB. The toolbox includes functions and blocks, and an application that is used to derive models of the dynamic systems using measured input-output data of the system. Time-domain and frequency-domain input-output data can be used to estimate models such as discrete-time and continuous-time transfer functions, state-space models, and process models [16]. In this study, discrete time transfer function, discrete time state space model and nonlinear ARX model were used to obtain the dynamic models. The application interface of SIT of MATLAB is illustrated in Figure 6.



Import Data

Data Format for Signals: Time Domain Signals

Workspace Variable

Input: grs_hex

Output: cks_hex

Data Information

Data Name: mydata

Start Time: 1

Sample time: 0.005

Figure 6: Application Interface of SIT of MATLAB

2. Results

In the application interface of SIT, there are several options to derive models. In the discrete time transfer function section, the model structure with 4 poles and 4 zeros was selected and the Levenberg-Marquardt algorithm was selected as the search method. In the discrete-time state space model section, model order, and form were respectively selected as 4 and free. In the nonlinear ARX model section, the 4th-order polynomial regressor was selected as the regressor type. The goodness of fit value which is calculated using Normalized Root Mean Square (NRMSE) was used as a statistical criteria that gives the success of the obtained models. The goodness of fit values belonging to derived dynamic models are given in Table 3-5.

Model	Goodness of Fit(%)
Discrete-time transfer function	99.19
Discrete-time state space model	98.89
Nonlinear ARX model	97.40

Table 3: Goodness of Fit Value for the Model of 316L Beam

Model	Goodness of Fit(%)
Discrete-time transfer function	99.16
Discrete-time state space model	98.92
Nonlinear ARX model	97.53

Table 4: Goodness of Fit Value for the Model of the MgAz91 Beam

Model	Goodness of fit(%)
Discrete-time transfer function	99.24
Discrete-time state space model	98.92
Nonlinear ARX model	96.92

Table 5: Goodness of Fit Value for the Model of Ti6Al4V Beam

According to Table 3, Table 4, and Table 5, the highest modeling success belongs to the discrete-time transfer function model obtained for the Ti6Al4V beam. Figure 7 shows and proves the similarity between the measured output and model output for the Ti6Al4V beam.

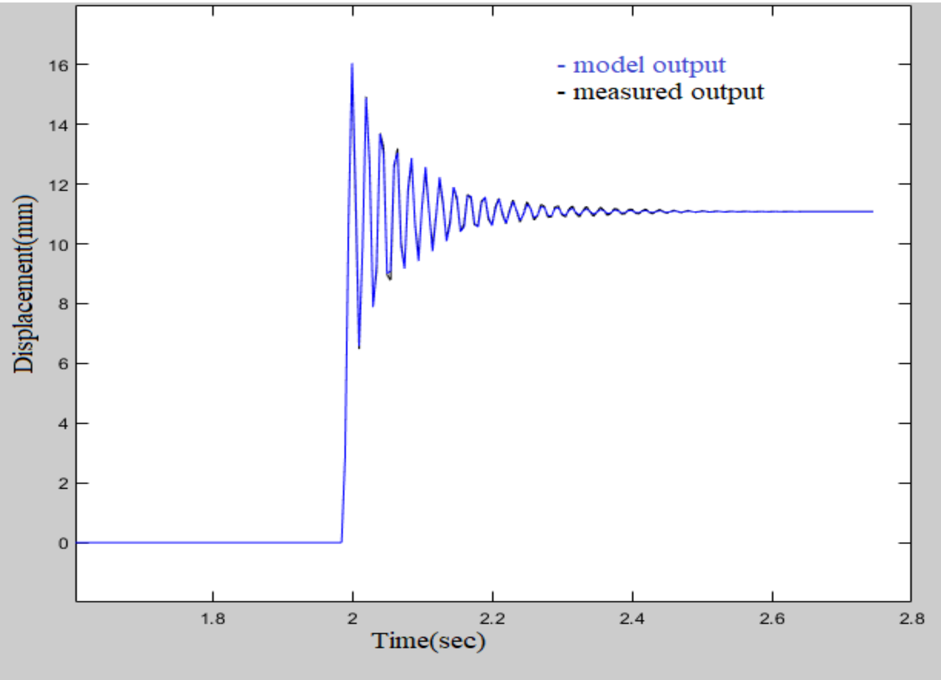


Figure 7: Measured and Model Output for Ti6Al4V

3. Discussion

In this study, goodness of fit value was used as a statistical criteria that gives the success of the obtained models for beams selected from 316L, MgAz91, and Ti6Al4V materials. It has been seen from Table 3 belongs to 316L beam that the discrete-time transfer function model has the highest goodness of fit value of 99.19 while the nonlinear ARX model has the lowest goodness of fit value of 97.40. Table 4 which belongs to the MgAz91 beam shows that the discrete-time transfer function model has the highest goodness of fit value at 99.16 while the nonlinear ARX model has the lowest goodness of fit value at 97.53. Table 5 belongs to the Ti6Al4V beam and shows that the discrete-time transfer function model has the highest goodness of fit value at 99.24 while the nonlinear ARX model has the lowest goodness of fit value at 96.92. Results prove that the best model type to obtain vibration models of the tested lattice structured beams is the discrete-time transfer function model.

4. Conclusion

In this study, vibration models have been obtained using input and output data sets belonging to the vibration of the beams selected from 316L, MgAz91, and Ti6Al4V materials. The displacements occurring at the free end of the beam are analyzed using the FEA and recorded to use for obtaining vibration models. Considering Table 3, Table 4, and Table 5, it can be said that good of fit values are very close to each other and the highest goodness of fit value belongs to the discrete-time transfer function model obtained for beam Ti6Al4V with lattice structure. Figure. 7 shows the measured and model output for beam Ti6Al4V with lattice structure proving the modeling success of the discrete-time transfer function model. When the results of Ti6Al4V, Mg AZ91, and 316 stainless steel are examined, it is clear that the MgAZ91 alloy undergoes high deformation. However, 316 stainless steel has undergone less deformation than Ti6Al4V due to the Cr and Ni contribution it contains and the high modulus of elasticity.

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