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First Steps Towards Structural Utilisation of the Lattice-Structured Cantilever Beam: System Identification, Modal and Static Structural Analysis

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Keywords:

Cantilever beam, System Identification, Modal analysis, Static Structural Analysis, Vibration Model, Lattice structures

Abstract

Materials with lattice structure have been used in many engineering fields. However, studies including dynamic and static analysis of lattice structured beams are not common in literature. In this study, three types of cantilever beams with lattice structure were designed as 3 Dimensionally in Topology software and analyzed in Ansys software. Square rotated, hexagonal and triangular type lattice structures were used in design of the beams. 10 Kilonewton force were applied to each beam and the displacements that were occurred at the free end side of the beams were recorded. Discrete time transfer function models, discrete time state space models and nonlinear Autoregressive with Extra Input models were obtained using input and output data set belongs to vibration of the beams. System Identification Toolbox of MATLAB was used to obtain the models. In addition, modal analysis and static analysis of the beams were realized. The results belong to system identification, modal analysis and static analysis were illustrated in figures, presented in tabular form and were discussed. After the non-lattice beam, the lowest specific deformation occurred in the triangular lattice beam. Therefore, the triangular lattice structure gave promising results for structural elements in pure bending state.

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1 INTRODUCTION

Long structural members with constant or variable cross-section geometry are called beams. Axially load, transversely load and moment applied elements along their length are called beam-columns [1]. Cantilever beams have a fixed end that generates reaction force and reaction moment, and a free end that undergoes translation, bending and twisting. In this way, cantilever beams are the main beam type used in vibration analysis studies in the literature [2]. Modeling of structures as cantilever beams is used in many areas such as measuring the deflection of cutting tools and the deflection of construction and machine structural elements [3]. In literature, there are many studies that involve obtaining vibration models of cantilever beams using analytical and finite element methods [4]. However, in engineering systems, there may be a difference between the actual system behavior and the model behavior for the same input. For this reason, success of system modeling approaches that is used to model the data obtained from the experimental set are important. In addition, success in modeling increases the success of the controllers designed for these systems [5].

Usage of experimental based modeling methods is increasing gradually in modeling of engineering systems. Input-output data sets of dynamic systems are used to obtain discrete-time or continuous-time models [6]. By applying various input signals to the created models, the system behavior can be observed and if necessary, these models are used in the design of the active controllers [7]. Today, due to the developments in microprocessor technology, modeling of engineering systems is also built in the form of discrete time dynamic model [8]. Unlike the continuous systems, the data of discrete-time systems is acquired at the sampling moment. If discrete time data was obtained from it, a dynamic system can be described as a discrete state space or transfer function model. If the system is nonlinear, ARX model should be used since state space and transfer function models can only be used to obtain linear models [9].

Representation of mathematical models in MATLAB environment can be done with MATLAB codes as well as in Simulink environment [10]. Simulink allows mathematical models to be expressed with block diagrams and reduces coding [11]. Expressing vibration models in Simulink environment provides convenience in terms of model analysis [12]. In the literature, there are several studies on vibration analysis and modeling made through commercial engineering programs [13, 14]. In the literature, finite element method-based analysis programs such as Ansys and LS-Dyna are used in many areas such as static, heat, flow, etc. analysis, machining, additive manufacturing, material strength determination, product verification [15, 16, 17, 18, 19].

In this study, an input of 10 Kilonewton 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.

With the advancement of manufacturing technology, products with complex geometry and internal structure that cannot be produced by traditional manufacturing can now be produced by additive manufacturing. Lattice structures are formed by the regular combination of repeating unit cells. Thanks to high precision and layered production, lattice structures can be produced by additive manufacturing. Owing to the lattice structure, the products increase the properties such as heat transfer, osteo-conductivity, flexibility, impact absorption, and lightness. Therefore, recently new products are produced using lattice-based designs [20, 21]. There is no comprehensive study on vibration analysis of lattice structures in the literature.

In this study, three types of cantilever beams with lattice structure were modeled in Ansys program as 3D. Square rotated, hexagonal and triangular type lattice structures were used in design of the beams. One of the objectives 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. 10 Kilonewton force were applied to each beam and the displacements that were occurred at the free end side of the beams were recorded. Using input and output data set belongs to vibration of the beams and System Identification Toolbox of MATLAB, discrete time transfer function models, discrete time state space models and nonlinear ARX models were obtained. In addition, modal analysis and static analysis of the beams were realized. The results belong to system identification, modal analysis and static analysis were illustrated were discussed.

2 MATERIALS AND METHODS

It is important to note that FEA, which is based on the Finite Element Method (FEM), is indeed a numerical technique used to approximate solutions to governing differential equations. FEA is commonly employed in engineering and design to analyze the behavior and performance of structures, mechanical systems, and devices. While FEA may not provide exact solutions, it offers valuable insights into the behavior and characteristics of a system. FEA is beneficial for the development of optimal designs and for validating experimental and analytical results. While FEA cannot completely replace experimental testing or analytical calculations, it can serve as a useful tool for design optimization and verifying approximate solutions.

Computer-aided simulations were carried out in Ansys Workbench Transient Analysis. Today FEA and Computational Fluid Dynamic (CFD) was used to solve processes such as metal turning, bone drilling, bone screwing, water jet process and erosion corrosion processes, fatigue behavior of implant materials, simulations of COVID-19 and other infections and optimal configuration of implant materials [16–19].

2.1 3D process of beams

The three-dimensional (3D) model of the beam was obtained using the lattice generation-based design software nTopology. The dimension of beams is 220x20x4 mm. After the modeling process of the beam, the meshing process was performed by converting the 3D model into voxel via nTopology 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 Fig. 1.

2.2 Loading and boundary conditions

The parameters of the material used for analysis were used from the Material library in the Ansys Program. The Structural Steel material with the stress strain curve in the material library was selected. Hex dominant FEA mesh method was used for the 3 cantilever beams. In the FEA, meshing is performed by transforming the model into a more regular hexahedron structure, voxel unit, as shown in Fig. 2. Mesh element size is adjusted between 1 and 1.2 mm. For square rotated lattice structured beam, 40211 element number, 80236 joint points, for hexagonal lattice structured beam 52816 element number, 104482 joint points, for triangular lattice structured beam 55265 element number and 19997 joint points were created. The beam is fixed at one end and a force of 10 kN was applied to the free end of the beam in Fig. 3. The displacements occurring at the free end of the beam are analyzed using the FEA and recorded for use in obtaining vibration models. The mechanical properties of the beam were given in Table 1.

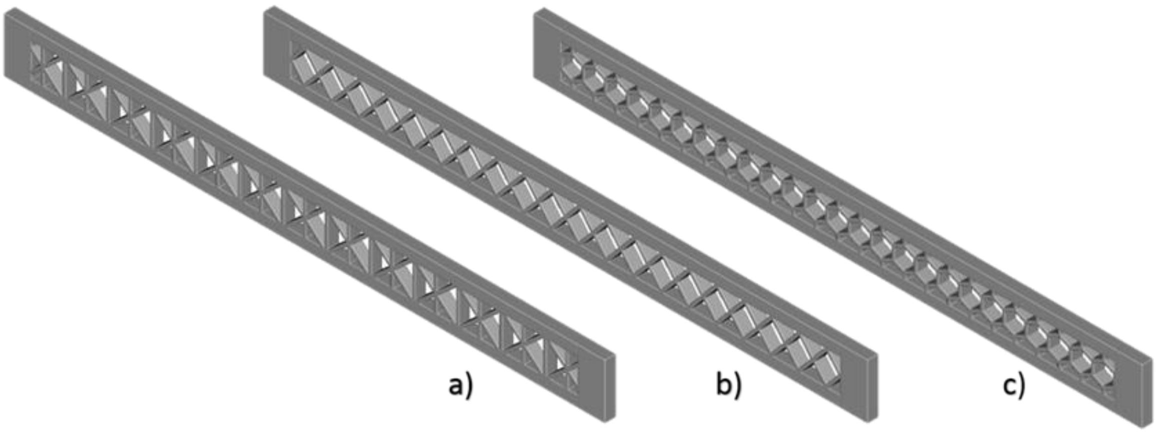


Figure 1. Cantilever beams with Various Lattice modelled in nTopology: a) Triangular b) Square rotated c) Hexagonal

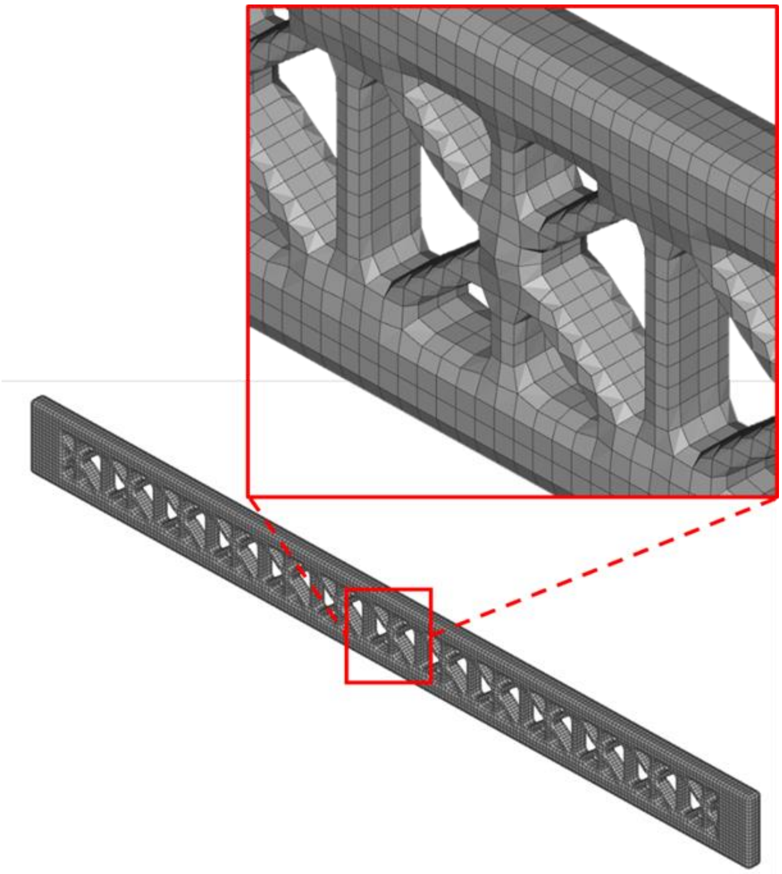


Figure 2. The voxel type mesh structure of the beam

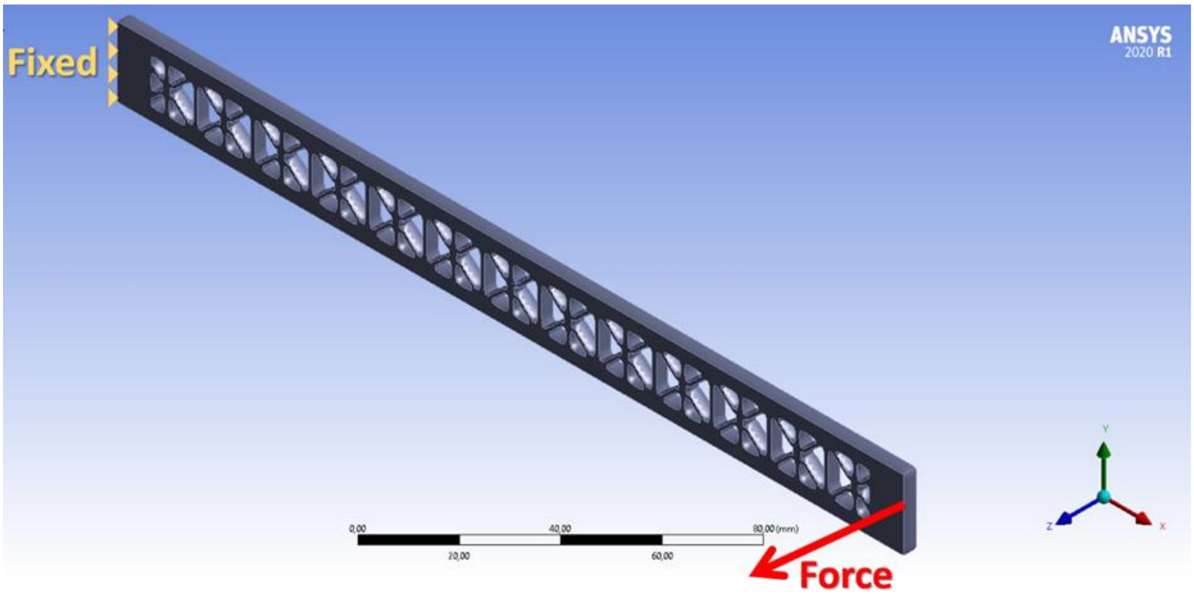


Figure 3. The loading and boundary conditions

Table 1. The mechanical properties of beam

Parameters	Value
Density (kg/m^3)	7850
Modulus of elasticity (GPa)	200
Poisson ratio	0,3

An input force of 10 Kilonewton was applied for 2 seconds to the free end of the 3D modeled fixed beam in the Ansys environment. The vibration data on the beams 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 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 as shown in Fig. 4.

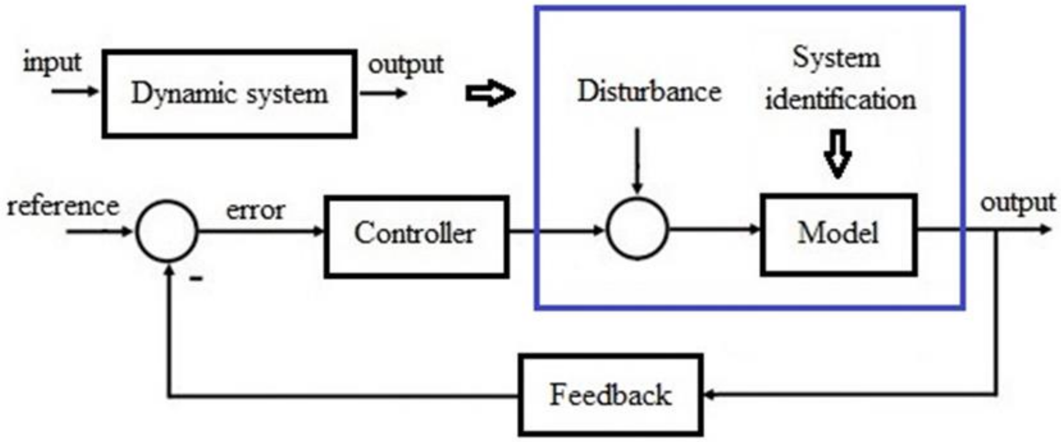


Figure 4. System identification step in a closed loop control system

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 the models such as discrete-time and continuous-time transfer functions, state-space models, process models. In this study, discrete time transfer function, discrete time state space model and nonlinear ARX model were used to obtain the dynamic models. Application interface of SIT of MATLAB is as illustrated in Fig. 5.

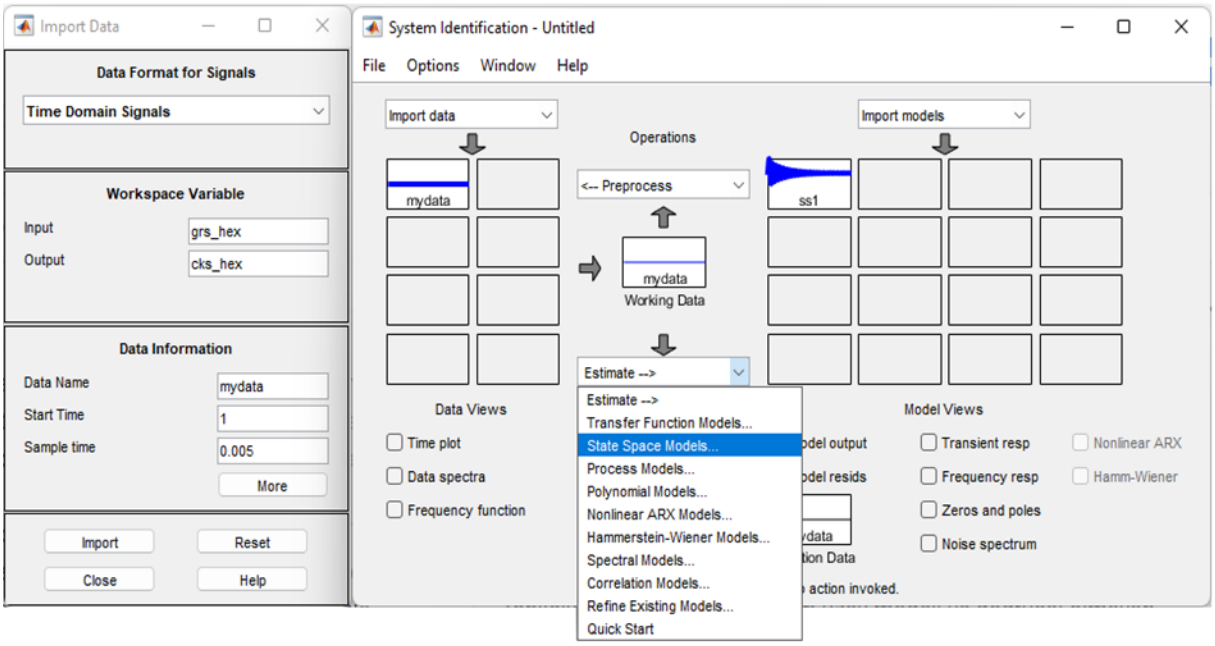


Figure 5. Application interface of SIT of MATLAB

3 RESULTS AND DISCUSSION

In application interface of SIT, there are several options to derive models. In discrete time transfer function section, the model structure with 4 poles and 4 zeros was selected and Levenberg-Marquardt algorithm was selected as search method. In discrete time state space model section, model order and form were respectively selected as 4 and free. In nonlinear ARX model section, linear regressor was selected as regressor type. Goodness of fit value which is calculated using Normalized Root Mean Square (NRMSE) was used as statistical criteria that gives the success of the obtained models. Goodness of fit value belong to derived dynamic models were given in Table 2, Table 3 and Table 4. Value of model parameters were given in Table 5.

Table 2. Goodness of fit value for the model of Hexagonal Lattice beam

Model	Goodness of fit(%)
Discrete time transfer function	99.17
Discrete time state space model	98.70
Nonlinear ARX model	94.90

Table 3. Goodness of fit value for the model of Square Rotated Lattice beam

Model	Goodness of fit(%)
Discrete Time Transfer Function	99.35
Discrete Time State Space Model	99.00
Nonlinear ARX Model	93.59

Table 4. Goodness of fit value for the model of Triangular Lattice beam

Model	Goodness of fit(%)
Discrete Time Transfer Function	99.57
Discrete Time State Space Model	99.38
Nonlinear ARX Model	98.51

Table 5. Value of system identification parameters of all models

Lattice type	Model	Parameters
Hexagonal	Discrete Time Transfer Function	Numerator= [0, 0.0904766251029139, 0.185056449878711, 0.0536719213237366, 0.00615236428912092], Denominator= [1, -0.935455762702205, 1.27748833580247, -0.644043503773166, 0.157214053348753]
Hexagonal	Discrete Time State Space Model	A= [0.404823090293822, -0.774368414781938, 0.0694761536507045, 0.0131067855388888; 0.776195409994955, 0.159301917599051, -0.519025519568719, -0.00923312519221001; 0.239817646155380, 0.600189534931174, 0.0752308912498092, -0.0785915517908121; 0.467982073013681, 0.125681631390398, 0.903642794988491, -0.0657702497951871] B= [0.00126645067732293; 0.0268753622515615; -0.0736073980878595; 0.135688094309606] C= [-5.56620695418249, 3.02663084028265, -0.342920922513473, -0.0522932619012701] D= [0]
Hexagonal	Nonlinear ARX Model	Scaling coefficients= [-1.839752324241154], Wavelet coefficients=[-2.26593902772712; -1598.68228305947; -0.154464780950676] Input projection= [0.0343164077693348, -0.877913368672479, 0.662380355513033, -4.04581259424427; 0.0341149786133724, -1.19400136365400, 2.17339685260722, 2.19314644034452; 0.0876567390914707,

		.55406923770863, 1.02292589444033, -0.169005375724656; 0.0876578988629650, -0.745676983099736, -2.12807119702622, 0.899326495176906]
Square Rotated	Discrete Time Transfer Function	Numerator= [0, 0.0479335359178158, 0.100948830926682, 0.0488384347491802, 0.00201991677320827] Denominator= [1, -0.854255248700986, 1.20734975415781, -0.496700489331231, 0.0883998393058679]
Square Rotated	Discrete Time State Space Model	A=[0.380604896371044, -0.808456468610023, 0.115266796348355, -0.00792179446037114; 0.820728828884215, 0.193300918135823, -0.485311983859011, 0.0224536624180409; 0.176124702022747, 0.535961941346048, 0.129518223047383, 0.0824622209790245; -0.304916619377965, -0.0860568382388065, -0.703988926969191, -0.580884432319160] B= [0.000628711356531962; 0.0159303268649632; -0.0726480096937738; -0.122345139328663] C= [-3.24654719603607, 1.89925632956570, -0.319921632259821, 0.0246573838416490] D= [0]
Square Rotated	Nonlinear ARX model	Scaling coefficients= [ ], Wavelet coefficients= [-0.718547020006978], Input projection= [0.0203830379056464, -0.483158338074194, 2.25816177647337, -6.12137717352685; 0.0202526131575575, -0.529211917903646, 3.78793832152375, 3.86564292126629; 0.0967536673940079, 1.84400343368239, 0.294458222501900, -0.0365994761600244; 0.0967040815267257, -1.63227790836547, -1.56388186632051, 0.517289705114017]
Triangular	Discrete Time Transfer Function	Numerator= [0, 0.0774744252403287, 0.158854460305913, 0.0788121135149408, 0.00107947233150786] Denominator= [1, -0.598918014622067, 1.06589591626440, -0.490532721408610, 0.106332117718748]
Triangular	Discrete Time State Space Model	A= [0.357057344403864, -0.776095011543794, 0.137659930053724, -0.0157792670462949; 0.636887233542369, 0.0443318065854254, 0.551548843899324, -0.00506677253145375; -0.482757271910880, -0.616486389506154, 0.00675835047447727, -0.0885646844278300; -0.481420690442067, 0.107795300517975, 0.817951897194151, -0.0557551227846749] B= [-0.000267883649210521; -0.0494269464321914; -0.0675757579127017; 0.110978646560239] C= [3.90413684576926, -2.17055586132356, 0.337190869153980, -0.0507221633207369] D= []
Triangular	Nonlinear ARX Model	Scaling coefficients= [ ], Wavelet coefficients= [-1.040420832196304], Input projection= [0.0271253216123059, -0.627831280160581, .44833383931904, 5.82844670046420; 0.0269573915746181, -0.748491547005804, 3.43766255607542, -2.96802024708732; 0.0931640395500408, 1.80819366606018, 0.461706987874709, 0.0796108481491919; 0.0931356307830215, -1.40924713774894, -1.87867332219571, -0.918072650980721]

According to Table 2, Table 3 and Table 4, the highest modeling success belongs to discrete time transfer function model obtained for Triangular Lattice structured beam. Fig. 6 shows and proves the similarity between the measured output and model output for Triangular Lattice beam. It was also given transient structural analysis deformation for triangular, square rotated, and hexagonal type lattice structures in Z direction in Fig. 7a, 7b, 7c, respectively.

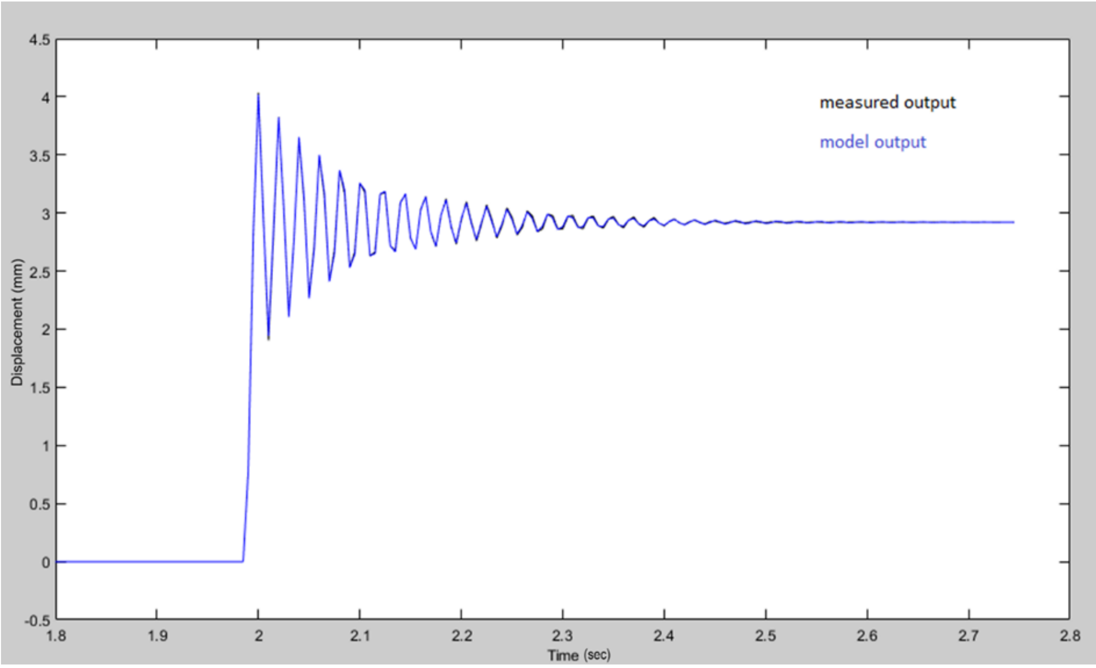
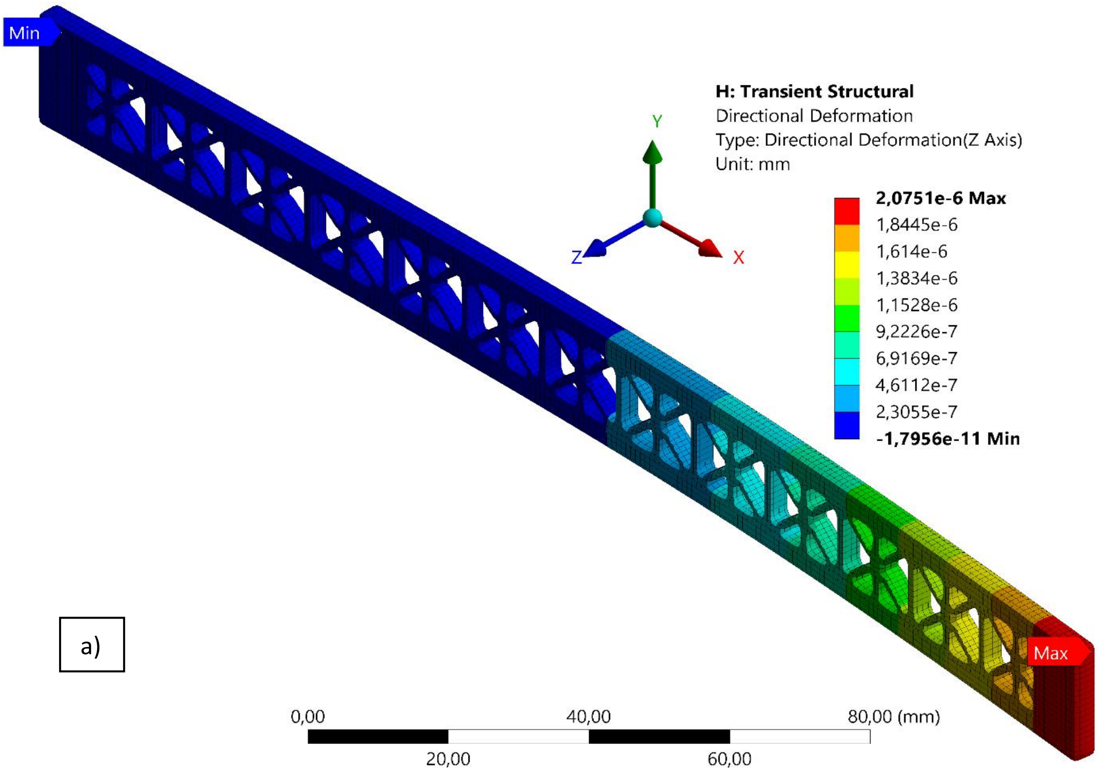


Figure 6. Measured and model output for Triangular Lattice beam



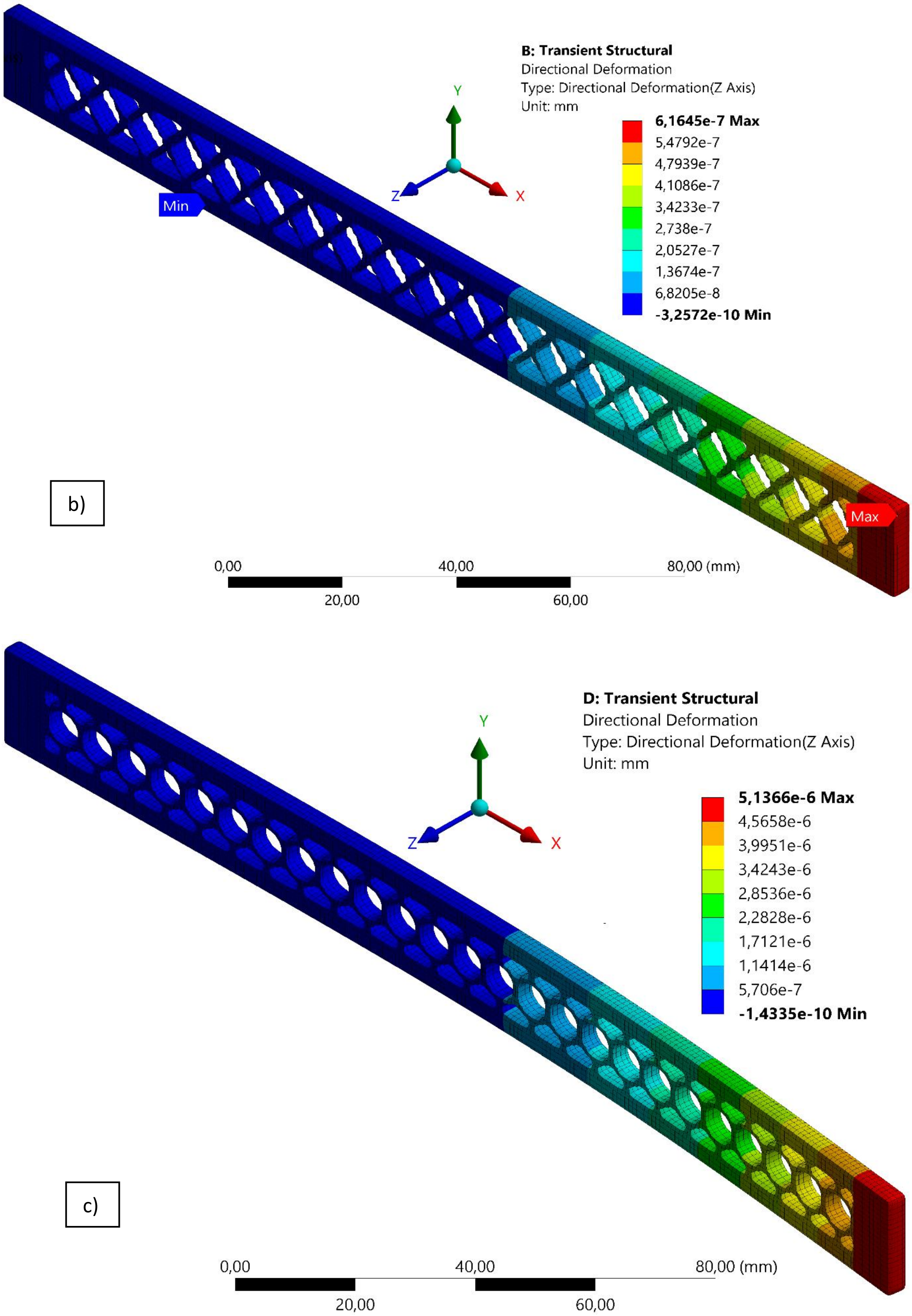


Figure 7. Deformation in Z direction, triangular (a), square rotated (b), hexagonal type (c) lattice structures

First natural frequencies and the deformation values of beams resulting from pure bending in static structural analysis are given in Table 6 and Table 7 respectively.

Table 6. Modes of the beams

Specimen	1. Natural Frequency [Hz]
No Lattice Form	7.877 E-2
Triangular Form	5.545 E-2
Square Rotated Form	5.458 E-2
Hexagonal Form	5.646 E-2

Table 7. Deformations of the beams in Static Structural analysis

Lattice Type	Volume (mm^3)	Deformation (mm)	Specific Deformation (mm/mm^3)
No lattice	17357,9	1,2376	0,0000712989475
Triangular	10888,2	3,8612	0,0003546224353
Square rotated	10186,1	4,2289	0,0004151638017
Hexagonal	10267,0	3,923	0,0003820979838

In this study, goodness of fit value was used as statistical criteria that gives the dynamic modelling success of the obtained models. It has been seen from Table 2 belongs to hexagonal lattice beam that discrete time transfer function model has the highest goodness of fit value with 99.17 while nonlinear ARX model has the lowest goodness of fit value with 94.90. Table 3 that belongs to square lattice beam shows that discrete time transfer function model has the highest goodness of fit value with 99.35 while nonlinear ARX model has the lowest goodness of fit value with 93.59. Table 4 belongs to triangular lattice beam shows that discrete time transfer function model has the highest goodness of fit value with 99.57 while nonlinear ARX model has the lowest goodness of fit value with 98.51. Results prove that the best model type to obtain vibration models of hexagonal, square rotated and triangular lattice structured beams is discrete time transfer function model. Goodness of fit values are very close to each other, and the highest goodness of fit value belongs to discrete time transfer function model obtained for Triangular Lattice beam. Fig. 6 shows measured and model output for Triangular Lattice beam and proves the modeling success of discrete time transfer function model. In addition, the results of Table 2, 3 and 4 are very similar and the support element arrangements have little impact on the success of vibration models of the beams.

A comparison of the modal analysis for the beams was given in Table 6. Structure of the beam becomes more flexible and susceptible to vibration, as its natural frequency decreases. As a result of Table 6, the natural frequencies of all lattice forms are similar but a little lower than no lattice form. It is obvious that the support element arrangements have little impact on the stability of the beams. However, the fundamental (initial) natural frequency of no lattice form is highest one and this indicates that the beam with no lattice form is the most stable beam used in this investigation.

The static structural analysis results for different beams are shown in Table 7. Three beams with different lattice structures and one beam with no lattice structure were subjected to a uniaxial 10 kN force. The force-induced deformation values in the force axis (z axis) were investigated. The beam with no lattice structure had the lowest deformation value. The lowest deformation values followed, respectively, in the beam with triangular, hexagonal, square rotated lattice structure. Specific deformation values were calculated considering the weight of the beams. The ranking based on these values remains unchanged. As a result, the beam without lattice structure showed the most rigid behavior due to the absence of sharp mesh elements, regular meshing, and smooth geometry. When the lattice structures were compared among each other, it was seen that the triangular lattice had the lowest deformation value. Therefore, for a beam subject to pure bending, the triangular lattice structure offers hope for future studies due to its rigid behavior.

4 CONCLUSION

In this study, vibration models of lattice structured beams modeled on Ansys were obtained in MATLAB environment. In simulation, it is possible to apply an input signal at the desired amplitude and time and to observe the output with the data at the desired frequency. In addition, it is not necessary to place actuators and sensors on the beams in simulation environment. When it is desired to obtain a vibration model of a cantilever beam that will be placed on a real experiment set, actuators and sensors should be placed on the beam. Under these conditions, the vibration behavior of the beam will change. The sampling frequency of vibration data obtained from a vibration sensor is very important for modeling success. In addition, it is possible that the data read from a sensor on the real experiment set contains electrical noise, which will reduce the modeling success. As a future study, the authors plan to investigate the modeling success of the methods in SIT of MATLAB and to investigate vibration of the beams when a real experimental setup is used. In this study, static analysis was performed using three types of lattice structures and one type of mesh in finite element analysis. Different types of mesh and lattice structures can be used to support the results of this paper.

Although there are many studies using lattice cells in the literature, these studies include only one of the static, flow and heat transfer analyses. There are no comprehensive studies on dynamic loading or vibration of the part after loading. Thanks to this study, the vibration response of lattice structures, which are frequently used in recent years and called meta materials, was tried to be discovered. Thus, the first step was taken towards measuring the dynamic response of lattice structures and a contribution was made to the literature. Lattice have great potential use in many engineering designs. This study will be a contribution to engineering fields which vibration is a significant role on its dynamic behaviour [23].

Author Contributions

Muhammed Enes DOKUZ: Software, Validation, Beam design, modelling, and structural analysis, Investigation, Resources, Data curation, Writing - Review & Editing, Visualization
Kadir GÖK: Conceptualization, Methodology, Software, Beam design, modelling, and structural analysis, Investigation, Resources, Writing - Review & Editing, Visualization, Supervision, Project administration
Serkan ÇAŞKA: Conceptualization, Methodology, Software, Validation, System identification analsys, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration

All authors read and approved the final manuscript.

Conflict of interest

No conflict of interest was declared by the authors.

References

[1] N. S. Trahair, “Beam-columns,” in Flexural-Torsional Buckling of Structures, CRC Press, 2017, pp. 205–218. doi: 10.1201/9780203755938-11.

[2] S. Orhan, “Analysis of free and forced vibration of a cracked cantilever beam,” *NDT & E International*, vol. 40, no. 6, pp. 443–450, Sep. 2007, doi: 10.1016/J.NDTEINT.2007.01.010.

[3] A. Gök, C. Gologlu, and H. I. Demirci,"Determination of form defects depending on tool deflection in ball end milling of convex and concavesurfaces", *Journal of the Faculty of Engineering and Architecture of Gazi University*, Vol. 29, Issue 2, pp. 365-374, 2014.

[4] Z. A. Jassim, N. N. Ali, F. Mustapha, and N. A. Abdul Jalil, “A review on the vibration analysis for a damage occurrence of a cantilever beam,” *Eng Fail Anal*, vol. 31, pp. 442–461, 2013, doi: https://doi.org/10.1016/j.engfailanal.2013.02.016.

[5] A. Ayyad, M. Chehadeh, M. I. Awad, and Y. Zweiri, “Real-Time System Identification Using Deep Learning for Linear Processes with Application to Unmanned Aerial Vehicles,” *IEEE Access*, vol. 8, pp. 122539–122553, 2020, doi: 10.1109/ACCESS.2020.3006277.

[6] S. Çaşka and M. E. Dokuz, “Ankastre Bir Kirişin Ayrık Zamanlı Titreşim Modelinin Meta- sezgisel Optimizasyon Yöntemler i Kullanılarak Elde Edilmesi Obtaining a Discrete Time Vibration Model of a Cantilever Beam by Using Meta-heuristic Optimization Methods,” *Bilecik Seyh Edebali University Journal of Science*, vol. 9, no. 1, pp. 32–41, 2022.

[7] A. A. Ali, R. A. R. Lateef, and M. W. Saeed, “Intelligent tuning of vibration mitigation process for single link manipulator using fuzzy logic,” *Engineering Science and Technology, an International Journal*, vol. 20, no. 4, pp. 1233–1241, 2017, doi: 10.1016/j.jestch.2017.08.001.

[8] R. De Keyser, C. Copot, A. Hernandez, and C. Ionescu, “Discrete-time internal model control with disturbance and vibration rejection,” *Journal of Vibration and Control*, vol. 23, no. 1, pp. 3–15, Aug. 2015, doi: 10.1177/1077546315601935.

[9] W. Liu, “Appendix A: System Identification: State and Parameter Estimation Techniques,” in Introduction to Hybrid Vehicle System Modeling and Control, John Wiley & Sons, Ltd, 2013, pp. 325–363. doi: 10.1002/9781118407400.APP1.

[10] S. M. Khot and N. P. Yelve, "Modeling and response analysis of dynamic systems by using ANSYS© and MATLAB©," *Journal of Vibration and Control*, vol. 17, no. 6, pp. 953–958, Oct. 2010, doi: 10.1177/1077546310377913.

[11] S. Alegre, J. V Míguez, and J. Carpio, "Modelling of electric and parallel-hybrid electric vehicle using Matlab/Simulink environment and planning of charging stations through a geographic information system and genetic algorithms," *Renewable and Sustainable Energy Reviews*, vol. 74, pp. 1020–1027, 2017, doi: https://doi.org/10.1016/j.rser.2017.03.041.

[12] R. Sharma, V. Vashisht, and U. Singh, "Modelling and simulation frameworks for wireless sensor networks: a comparative study," *IET Wireless Sensor Systems*, vol. 10, no. 5, pp. 181–197, 2020, doi: https://doi.org/10.1049/iet-wss.2020.0046.

[13] M. Imran, S. Badshah, and R. Khan, "Vibration Analysis of Cracked Composite Laminated Plate: A Review," *Mehran University Research Journal of Engineering and Technology*; Vol 38 No 3 (2019): July IssueDO - 10.22581/muet1982.1903.14 , Jul. 2019, [Online]. Available: https://publications.muet.edu.pk/index.php/muetrj/article/view/1140

[14] E. J. Sapountzakis and I. N. Tsiptsis, "Generalized vibration analysis of beams including warping effects by isogeometric methods," *Journal of Vibration and Control*, vol. 24, no. 6, pp. 1032–1050, Jan. 2017, doi: 10.1177/1077546316685679.

[15] A. Gök, H. Demirci, K. Gök, "Determination of experimental, analytical, and numerical values of tool deflection at ball end milling of inclined surfaces", *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, vol. 230, Issue 2, pp. 111-119, Jun. 2016, doi:10.1177/0954408914540633.

[16] S. Korucu, K. Gök, M. Tümsek, G. Soy, ve A. Gök, "Farklı Profillere Sahip Kirişlerde Meydana Gelen Eğilme Gerilmesi ve Sehim Miktarının Teorik ve Nümerik Yöntemler ile Analizi", *DEUFMD*, vol. 21, Issue 62, pp. 469–482, 2019, doi: 10.21205/deufmd.2019216213.

[17] K. Gok, S. Inal, L. Urtekin, and A. Gok, "Biomechanical performance using finite element analysis of different screw materials in the parallel screw fixation of Salter–Harris Type 4 fractures," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 41, no. 3, p. 143, 2019, doi: 10.1007/s40430-019-1640-z.

[18] K. Gök, A. B. Selçuk, and A. Gök, "Computer-Aided Simulation Using Finite Element Analysis of Protect Against to Coronavirus (COVID-19) of Custom-Made New Mask Design," *Transactions of the Indian Institute of Metals*, vol. 74, no. 5, pp. 1029–1033, 2021, doi: 10.1007/s12666-021-02227-4.

[19] Y. Pirhan, K. Gök, and A. Gök, "Comparison of two different bowel anastomosis types using finite volume method," *Comput Methods Biomech Biomed Engin*, vol. 23, no. 8, pp. 323–331, Jun. 2020, doi: 10.1080/10255842.2020.1722809.

[20] M. E. Dokuz, M. Aydın, and M. Uyaner, "Production of Bioactive Various Lattices as an Artificial Bone Tissue by Digital Light Processing 3D Printing," *J Mater Eng Perform*, 2021, doi: 10.1007/s11665-021-06067-7.

[21] B. K. Nagesha, V. Dhinakaran, M. Varsha Shree, K. P. Manoj Kumar, D. Chalawadi, and T. Sathish, "Review on characterization and impacts of the lattice structure in additive manufacturing," *Mater Today Proc*, vol. 21, pp. 916–919, Jan. 2020, doi: 10.1016/J.MATPR.2019.08.158.

[22] H. Deniz Ada, M. Erdem, and K. Gok, "Computational fluid dynamics simulation of erosion-corrosion in abrasive water jet machining," *Surface Review and Letters*, vol. 28, no. 05, p. 2150031, Jan. 2021, doi: 10.1142/S0218625X21500311.

[23] S. Çaşka, K. Gök., M. Aydın and İ. Özdemir, "Finite element method based structural analysis of quadcopter UAV chassis produced with 3D printer." *Journal Of Science And Technology Of Dumlupınar University*, Issue 44, pp. 24-32, June 2020