IOP Conference Series: Materials Science and Engineering

Natural frequencies of twisted cantilever beam

To cite this article: J Malta *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **602** 012069

IOP Conf. Series: Materials Science and Engineering **602** (2019) 012069 doi:10.1088/1757-899X/602/1/012069

Natural frequencies of twisted cantilever beam

J Malta, Jefri, M Bur and E Satria

Department of Mechanical Engineering, Faculty of Engineering, Universitas Andalas

Abstract. This research is conducted to determine the natural frequencies of a twisted beam with different orientation of principal axes numerically using Autodesk Inventor. Further, the results are compared experimentally. To simplify in the analysis, the twisted cantilever beam is divided into two segments model. The orientation between two segments is simulated and tested variously. The natural frequencies obtained numerically and experimentally are selected only in transverse vibration based on the simulation of each mode shape of the cantilevered beam. In general, the natural frequencies of the simulated cantilever beam and experiment results tend to similar results.

1. Introduction

A twisted beam model can be found in a propeller blade as shown in figure 1. This propeller blade has a different orientation of the principal axis between cross section A-A and cross section B-B. The orientations in cross section A-A and B-B are θ_1 and θ_2, respectively. In static analysis, a beam with different orientation of cross-section has a characteristic of asymmetric bending. It means the deflection of the beam is not parallel to the line of action of the loading force [5]. Based on this term, it stands to reason the stiffness of the twisted beam is different comparing to the stiffness of the untwisted beam.

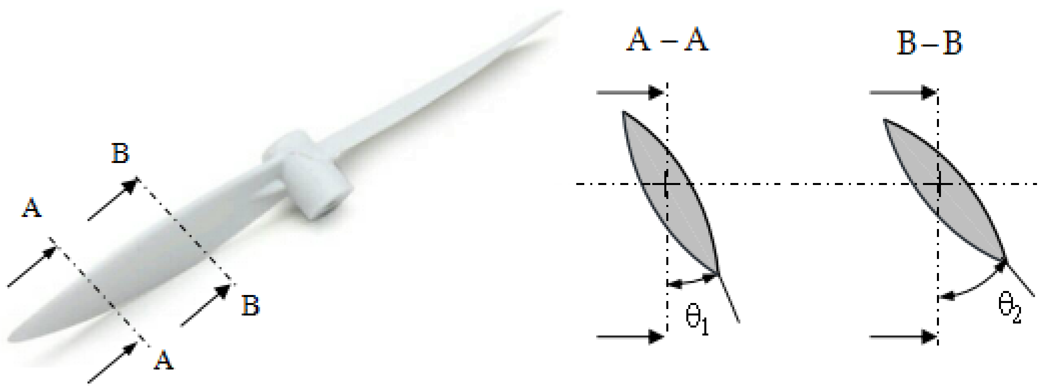


Figure 1. A propeller blade and its cross sections

To investigate the characteristic of a twisted beam, researchers have studied the shaft with different orientation along the shaft or beam. DiPrima and Handelman [1] have analyzed the twisted cantilever beam analytically. The twisted beam is described regarding a straight line, in which the locus of the centroids of the cross-sectional planes took normal to the line. They have also proposed the dynamic differential equations of the twisted beam for a rotating and a non-rotating twisted beam.

Furthermore, the researches of the twisted beam or anisotropic shaft especially in the dynamic analysis have been published. Malta in the references [3] and [4] has conducted an anisotropic rotor. In these researches, the shafts are modeled as the twisted anisotropic shaft. The natural frequencies of the model have also been determined numerically and experimentally.

Furthermore, several investigations of the twisted beam have been conducted using commercial software. King [2] simulated the twisted rectangular beam using the Abaqus software. Therefore, the deflections and stresses in beam have been shown. Malta et al. [5] presented the research about deflection of the twisted cantilever beam. In their research, the models of twisted cantilever beam are simplified into two segments beams with various orientations. In their research, the twisted cantilever beam is modeled by using a tool of the Autodesk Inventor.

However, the using of the Autodesk Inventor especially in the dynamic analysis is not familiar yet. Therefore, in this paper, a twisted beam is modeled as a minimal segment beam and analyzed using the Autodesk Inventor. These results will be compared to the experimental results. Besides, the natural frequencies of the twisted beam are also presented.

2. Model of the twisted cantilever beam

To determine the natural frequencies of the twisted cantilever beam, the stiffness of the beam must be analyzed. Based on the previous researches [3], and [5], it is known that the twisted beam has a characteristic of an asymmetric bending.

A model of the twisted cantilever beam is designed based on the previous research by King [2], and further is modified by Malta et al. [5]. To simplify the twisted beam model, the beam is divided into two segments. In the Autodesk Inventor, the difference of orientation between two segments is set to 10^o, 20^o, 30^o, until 90^o. However, in the experimental setup, only the specimens with the difference of orientation 30^o, 60^o, and 90^o are available. An example of the specimen with the difference of orientation 30^o is shown in figure 2.

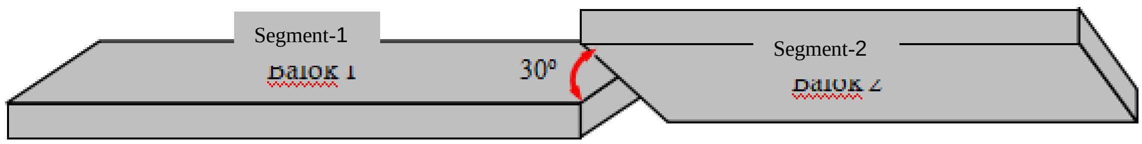


Figure 2. Model of the twisted beam with a difference of orientation 30^o

The material of beam is low carbon steel with the dimension per segment is 200 mm x 30 mm x 4 mm. After welded connections between two segments, the total length of the beam becomes 390 mm, because the end segments are overlapped connection of 10 mm. The specimen model beam can be shown in figure 3.

To determine the natural frequencies of the cantilever beam, the impact test is conducted to the beam to perform the Frequency Response Function (FRF). The FRF test uses the impact hammer which has a load cell. The dynamic responses are measured by using an accelerometer. The complete experimental setup is presented in figure 4.

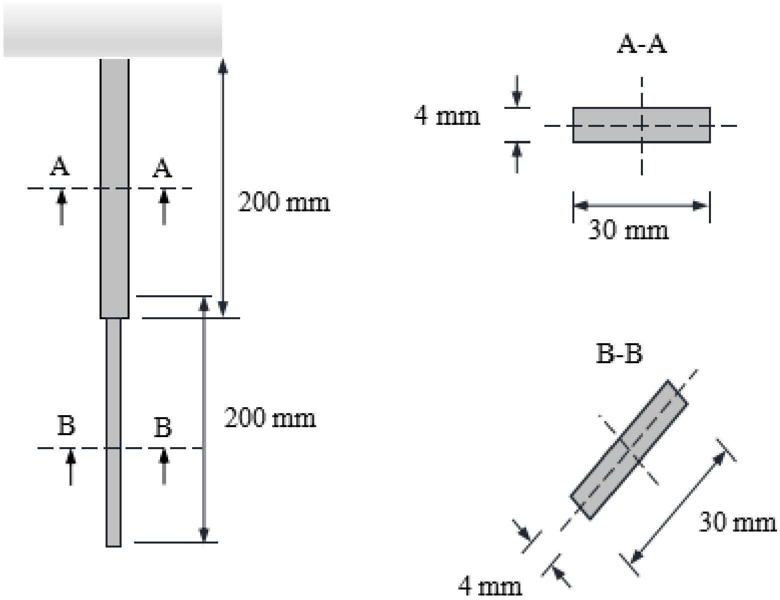


Figure 3. An experimental model of specimen beam

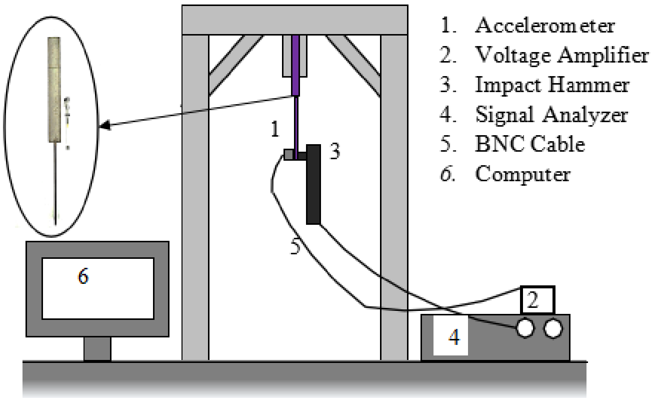


Figure 4. Experimental setup

3. Results and Discussion

The first model of the cantilever beam is a pure Euler's beam (i.e., a uniform cross-section along the beam). The differential equation of the Euler's beam is not discussed in this paper. The natural frequencies are obtained by solving the following equation [6]

$$\cos(\lambda_n L)\cosh(\lambda_n L) = -1 \tag{1}$$

Where λ_n is the characteristic value of the cantilevered beam, and L is the length of the beam. If we calculate the solution of the equation (1) for n = 1 until 3, we obtain

$$\lambda_1 L = 1.875 \tag{2}$$

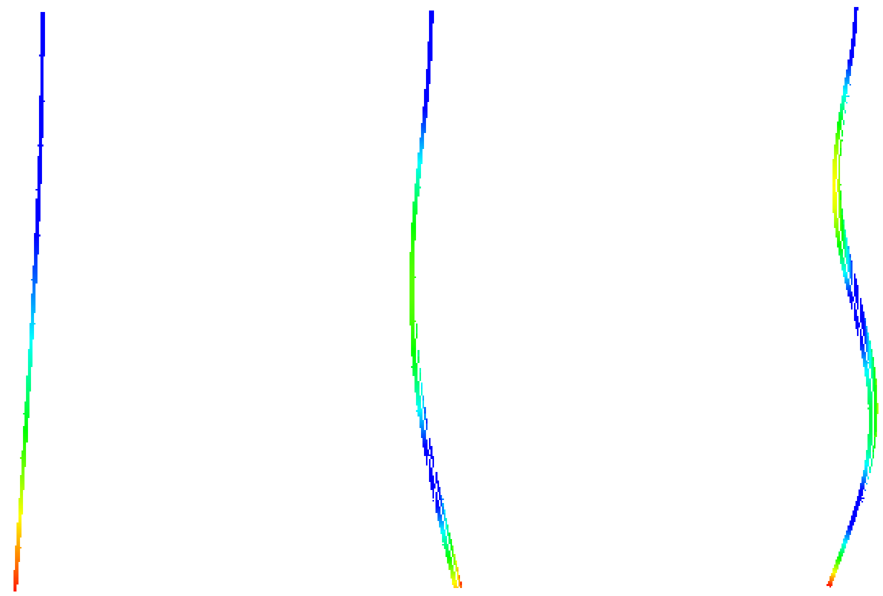
$$\lambda_2 L = 4.694 \tag{3}$$

$$\lambda_3 L = 7.855 \tag{4}$$

Therefore, the first natural frequency (f_1) can be calculated,

$$f_1 = \left(\frac{1.875}{L}\right)^2 \sqrt{\frac{EI}{\bar{m}}} \quad (5)$$

where L is the length of the beam, E is modulus elasticity of the beam material; I is a moment of inertia of beam cross-section, and $\bar{m}$ is the mass of beam per unit length. For the second and the third natural frequencies can be obtained with the same way. The solutions of the equation (2), (3), and (4) are noted in part of numerical in the first row on the table 1. The natural frequencies which are obtained from solving of the Euler's equation are in transverse vibration only. Therefore the torsion vibration cannot be achieved. The comparison of the numerical results of the Euler's equation and the experimental results, the natural frequencies in the experimental results are relative higher than the numerical results. These differences can be occurred due to the condition of cthe lamp of the specimens, while in the Euler's equation the cantilevered beam is assumed as perfectly clamped. However, in order to present how the mode shape in each natural frequency is, the Autodesk Inventor is used to simulate the cantilevered beam as shown in figure 5.



(a) (b) (c)

Figure 5. Mode shapes of the untwisted cantilever beam: (a) at the first natural frequency; (b) at the second natural frequency, and (c) at the third natural frequency

Furthermore, especially for the cantilevered beam models with the difference of orientation of 30^o, 60^o, and 90^o are performed using the Autodesk Inventor. By neglecting the torsion vibration, the natural frequencies are chosen in transverse vibration only. Therefore, the selected natural frequencies of the twisted cantilever beam are presented in table 1.

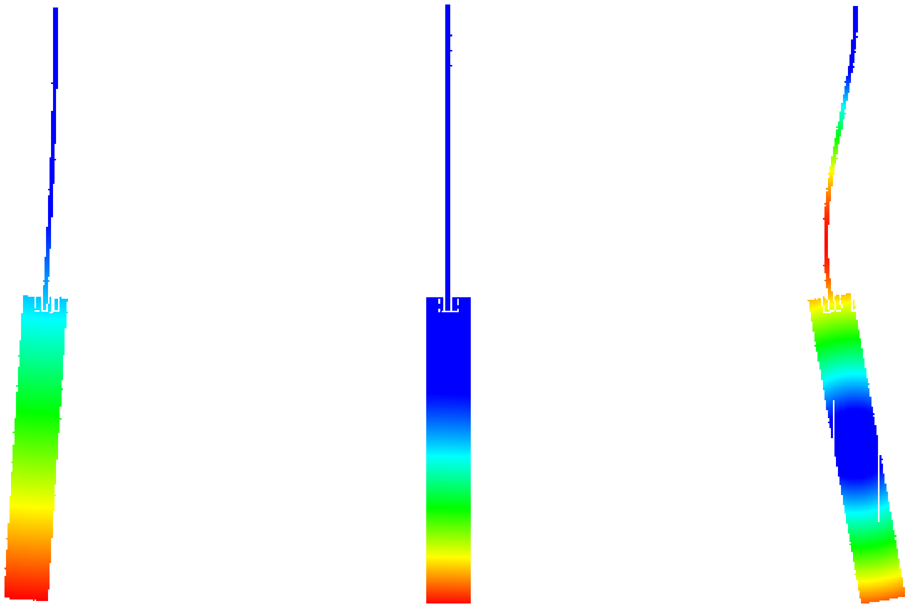
IOP Conf. Series: Materials Science and Engineering **602** (2019) 012069 doi:10.1088/1757-899X/602/1/012069

Table 1. Natural frequencies of the twisted cantilever beam

Orientation [degree]	1st natural frequency [Hz]		2nd natural frequency [Hz]		3rd natural frequency [Hz]	
	Num.	Exp.	Num.	Exp.	Num.	Exp.
0	(21.81)*	18.01	(138.14)*	114.04	(382.73)*	321.10
30	22.63	17.67	114.80	121.37	375.75	310.77
60	22.76	18.01	90.77	89.03	354.36	333.44
90	22.74	16.34	82.40	81.36	343.68	312.10

Num. = numerical result using Autodesk Inventor
Exp. = experimental result
( )* = the natural frequencies are obtained by solving the Euler's equation

As reported in section 2, the twisted cantilever beam is simulated in the Autodesk Inventor. In table 1, the results are presented only for the twisted beam with a difference of orientation of 30°, 60°, and 90°. The numerical results of the natural frequencies are compared to the experimental results for the same orientation. In general, both the numerical and experimental results have the same tendency. In the first natural frequency, the beam with the orientation of 60° has the highest frequency. The similar tendency occurs in the third natural frequency. The different tendency occurs only in the second natural frequency, whereas the frequency tends to decrease significantly. Especially for the twisted beam with the orientation of 90°, its mode shapes are shown in figure 6. These mode shapes are obtained through the simulation in the Autodesk Inventor.



(a) (b) (c)

Figure 6. Mode shapes of the twisted cantilever beam with the orientation of 90°: (a) at the first natural frequency; (b) at the second natural frequency, and (c) at the third natural frequency

Figure 6 shows that the mode shapes of the twisted cantilever beam with the difference of orientation of 90° are similar to the mode shapes of the untwisted cantilever beam as shown in figure 5. In figure 6, these similar mode shapes occur in the segment-1 of the beam, while the segment-2 follows the movement of the end of the segment-1. This phenomenon seems like an untwisted beam with the additional mass at the end of the segment-1 of the beam. Therefore, the natural frequencies of the twisted beam with the orientation of 90^o are lower than the untwisted beam.

4. Conclusions

Based on the data after analyzing the natural frequencies of twisted cantilever beam numerically and experimentally, some important points can be concluded:

- The Autodesk Inventor as a tool can be used to analyze the natural frequencies of a twisted cantilever beam.
- In general, the existence of difference of orientation in the cantilevered beam influences the natural frequencies.
- Based on the mode shape at the first natural frequency for the transverse vibration, the highest stiffness of the dynamic system occurs in the twisted cantilever beam with the difference of orientation of 60^o.

Acknowledgments

Authors gratefully thank the Dean of Faculty of Engineering, Universitas Andalas, who has funded this research with the contract No. 067/UN.16.09.D/PL/2017.

References

[1] DiPrima R C and Handelman G H 1954 Vibrations of twisted beam *Jour. of App. Math.* pp 241-59.
[2] King M S 2012 *Applying Classical Beams Theory to Twisted Cantilever Beams and Comparing to the Results of FEA* Thesis, Rensselaer Polytechnic Institute.
[3] Malta J 2009 *Investigation of Anisotropic Rotor with Different Shaft Orientation* Dissertation Technische Universitaet Darmstadt, Germany
[4] Malta J 2013 A modified rotor model to approach the dynamic responses of the anisotropic rotor with different shaft orientation *Proc. of Int. Conf. of Qual. in Res.* Yogyakarta pp 91-6
[5] Malta J, Bukhari A and Bur M 2017 Numerical and experimental analysis of cantilever beam with various shaft orientation *Proc. of Ann. Nat. Conf. of Mec. Eng. (SNTTM) XVI* Surabaya pp 129-32
[6] McConnell K G 1995 *Vibration Testing, Theory and Practice* (New York: John Wiley & Sons, Inc.) p 145