Design improvement of table fan blade in term of its vibration characteristic using finite element method

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Abstract. The main purpose of this paper is to improve vibration characteristic, which is natural frequency, of fan blade to get a good natural frequency. An existing table fan model TF1610 of three speeds with 16 inches blades was used for the study. To complete this study, finite element method has been used to perform the simulation and the analysis of the table fan blade. Components of the table fan are drawn using CATIA software. By using finite element software, the drawn table fan design was run for the analysis and the simulation to get the natural frequencies of the table fan blade and compared with the natural frequencies of the motor. The results show that, for Polycarbonate material, shape 4 is considered as the best shape. Shape 2 is considered as the best shape for Polyethylene Terephthalate and Polypropylene material.

1. Introduction
A poor design of fan blade can cause fatigue and a minor crack or fracture to the blade. Vibration characteristic, which is natural frequency, is one of the important parameters in designing fan blade to prevent resonance. The table fan produce sound as noise from the rotation of the fan blades and motor. Vibration or noise will be produced if the fan is not balanced properly that will further results in resonance. To avoid resonance, the fan blade natural frequency and motor frequency should in large difference. Therefore, it is important to design fan blade with good natural frequencies.

Tandon & Nakra [1] have investigated the high noise generated by table fan. The main sound produced by fan was analysed by grid layer. The highest level of sound intensity was produced at two regions, namely at motor and base of the table fan region. High level of noise was produced by both motor and base of the table fan.

Shinici Noda et.al. [2] have analyzed the spatial resonance frequency and its resonance mode of fan channel by FEM and experiments. They concluded that the resonance appears inside fan cover of the motor. The spatial resonance mode around a fan cover was Helmholtz resonance mode. N. S. Aher et al. [3] have carried out the analysis and extract the natural frequencies of cooling tower fan blades of different sizes, so that, the designer can ensure that the natural frequencies will not be close to the frequency of the main excitation forces in order to avoid resonance. The Rayleigh method has been applied to find the fundamental frequency of blades by considering blade as a Stepped, Taper, continuous cantilever beam. A MATLAB program has been developed to predict the fundamental
frequencies. Also, three dimensional models of blades have been developed in Unigraphics NX 5 and modal analysis is carried out by ANSYS 14.5. M. NagaKiran et al. [4] have investigated the effect of various number of fan blades and various of materials to the efficiency of the fan. By observing the analysis results, for all materials, the analyzed stress values are less than their respective yield stress values, so using all the three materials is safe under given load conditions. The strength of the composite material E Glass is more than that of other 2 materials Mild Steel and Aluminium Alloy. By observing the analysis results, the displacement and stress values are less when 8 blades are used. Therefore, they concluded that composite material E Glass and using 8 blades are recommended as the best design because of its high efficiency.

This research aims to simulate various design/model of blades of table fan in order to get the best design that have good characteristic in vibration. The best model of blade should have natural frequencies that far enough from the natural frequency of motor, therefore the possibility of resonance can be reduced. The result of this research can improve the level of health of human being since the noise from fan very disturb to the human being earnest.

The marking system is a new system that is used for this analysis based from the similar research done by Gasporani et al. [5]. Gasporani et al find the differences between 53 Hz and 55 Hz with 10 different modes by using TCSLDV method. The differences of the frequencies are then converted to percentage (%) form, while in this research we have given marks based on the differences of the frequencies. The reason for giving marks for this study is, three speed of table fan motor is considered and from those three speeds, the difference for lowest and highest frequency for each speed is calculated. The increase of the blade thickness leads to decrease in the stresses and deformations and that is due to the higher reduction in structural stiffness. Therefore, thin blades give greater stresses and deformations than the thick blades [6].

2. Finite Element Simulation

2.1. Model of fan

CATIA V5 (Computer Aided Three-dimensional Interactive Application) works as the developing tool of the table fan design. CATIA software is popular among the 3D model software’s. The model created based on existing model which is from TF1610 of three speeds with 16 inches blades. The blade of the model has a length of 399 mm. The hub of the fan blade is created by using a circular shape with the thickness of 40 mm and width of 36 mm.

Five different shape with different thickness were proposed to replace the old design. Each shape of the blade will be analyzed with 2mm, 3 mm and 4 mm thickness. For this analysis, 3 different thicknesses were chosen. In previous research, five different thickness of the curvature blade was selected by Abdullah and Schlattmann [6]. The increase of the blade thickness leads to decrease in the stresses and deformations. Therefore, thin blades give greater stresses and deformations than the thick blades. Figure 1 showed the proposed model to replace the existing model.

2.2. Material properties

The modelling procedure also requires the specification of material properties. These properties may include: Modulus of Elasticity, Poisson's Ratio, Coefficient of Thermal Expansion, Modulus of Rigidity, Density and similar. The specific material properties required will depend upon the type of analysis being performed. Three different types of materials are used for the table fan model analysis. All the materials and its properties are stated in Table 1.
Figure 1: Five different shapes of table fan blade

Table 1. Properties of table fan blade material

| Types of Materials           | Density (tonne/mm$^3$) | Young Modulus (MPa) | Poisson Ratio | Tensile Strength (MPa) |
|-----------------------------|------------------------|---------------------|---------------|------------------------|
| Polycarbonate               | $1.2 \times 10^{-9}$   | $2.0 \times 10^3$   | $0.37$        | $70$                   |
| Polyethylene Terephthalate  | $1.38 \times 10^{-9}$  | $2.8 \times 10^3$   | $0.30$        | $55$                   |
| Polypropylene               | $8.55 \times 10^{-10}$ | $1.3 \times 10^3$   | $0.45$        | $40$                   |

2.3. Boundary condition

Boundary conditions define constraints on the model. These typically are limitations on displacement in the analysis of mechanical parts. There are no boundary conditions for this analysis since the real condition of blade fan is free free.

3. Result and discussion

Five different shape of fan blade is designed with different thickness of the fan blade. Each shape of the blade will be analyzed with 2mm, 3 mm and 4 mm table fan blade thickness. Polycarbonate, Polyethylene Terephthalate and Polypropylene are the three different materials being used for analysis.

Results that are obtained is then tabulated according to the frequency produced by the table fan motor, which is 13.67 Hz at low speed, 16.45 Hz at medium speed and 19.20 Hz at high speed. The lowest and highest value of the frequency will be taken to find the difference between the frequency produced by table fan blade and the frequency produced by the table fan motor. After the differences being calculated, the marks of range 1 to 5 will be given according the highest differences. Total marks for each shape is 30 marks. So, the shape that gain the highest mark will be consider as the best design for each material according to its blade thickness.

3.1. Polycarbonate material

Figure 2 shows the result of marks of 2 mm blade’s thickness made of Polycarbonate material. The best shapes for this 2mm blade thickness of Polycarbonate material are shape 2, shape 4 and shape 5. From the graph it can be observed that the highest mark obtained which are 20. For shape 2, the differences of frequency at low speed are 13.367 Hz and 13.367 Hz, at medium speed are 16.45 Hz, and 1.534 Hz
while at high speed are 1.152 Hz and 75.173 Hz. For shape 4, the differences of frequency at low speed are 0.208 Hz and 64.855 Hz, at medium speed are 2.988 Hz, and 62.075 Hz while at high speed are 5.738 Hz and 59.325 Hz. For shape 5, the differences of frequency at low speed are 13.67 Hz, 13.67 Hz, at medium speed are 16.45 Hz, and 1.042 Hz while at high speed is 1.168 Hz and 74.884 Hz.

3.2. Polyethylene Terephthalate material
The best shape for this 2mm blade thickness of Polyethylene Terephthalate material is shape 2. From the graph, it can be observed that the highest mark obtained is 22. For shape 2, the differences of frequency at low speed are 13.67 Hz, 5.8 Hz, at medium speed are 16.45 Hz, and 3.02 Hz while at high speed are 19.20 Hz and 0.27 Hz. The data for marks of 2 mm blade’s thickness made of Polyethylene Terephthalate material was stated in Figure 3.

3.3. Polypropylene material
The best shape for this 2mm blade thickness of Polypropylene material is shape 2. From the graph it can be seen that it has, the highest mark obtained which are 23. For shape 2, the differences of frequency at low speed are 13.67 Hz, 5.253 Hz, at medium speed are 16.45 Hz, and 2.473 Hz while at high speed are 0.263 Hz and 74.413 Hz. Figure 4 shows the result of marks of 2 mm blade’s thickness made of Polypropylene material.
Figure 4. Mark of 2 mm blade’s thickness made of Polypropylene material.

From the table above, it is shown that the existing model is not at optimum or best level of performance. Some other shapes and improved models are having better natural frequencies result compare to the existing model. It need to replace the existing design with the model/shape that has the highest mark. It gives the lowest probability for resonance phenomena occurred in the fan system.

4. Conclusions
After an observation and analysis have been made, it is proven that the study on the natural frequencies of a table fan blade by using finite element method is accomplished and the objective is achieved successfully. The aim of analysis programmed is to provide information of the important of designing a table fan impeller model that have a huge different in its natural frequencies compared to the natural frequencies of the table fan motor.

The natural frequency of the table fan blade is also have been redesigned so that the best natural frequency can be achieved as an improvement. Based on the research and development planning, a better natural frequency from the output result by simulation of the table fan impeller which varies from the frequencies of the motor is achieved as expected. Once a better natural frequency is achieved, resonances also have been avoided. For Polycarbonate material, shape 4 is considered as the best shape. Shape 2 is considered as the best shape for Polyethylene Terephthalate and Polypropylene material.

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