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FINITE ELEMENT ANALYSIS AND OPTIMIZATION DESIGN OF ALUMINIUM AXIAL FAN BLADE

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ABSTRACT

The purpose of this work is to optimize the blade design of an axial-flow fan. Four different chord length and five twisting angle of their blades were studied. The fan was designed by using NACA 5505 series. The first investigation is conducted to the blade design in the variation of chord length. The base chord length is constant of 130 mm and the tip is vary from 84, 92, 102 and 110mm. The second study is in the variation of twisting angle from 0, 10, 20, 30 and 40^{o}. The performances of the fans were measured in a Von Mises stress criterion under pressure of 500Pa. From the variation of chord length, the shortest length of 84mm was delivered the the lowest stress. While the variation of twisting angle, the lowest stress is delivered by 40^{o} of twisting angle. The proposed blade design is presented by using combination of twisting angle 10, 20, 30 and 40^{o} in single blade model. The blade total length of 446.5mm is divided into four parts and every part have different twisting angle. From the stress result, the proposed model was delivered lower stress compared to the other models.

Keywords: axial fan, twist angle, chord length, stress analysis, finite element method.

INTRODUCTION

A revolution in the 19th century introduced a belt-driven fan in which wooden or metal blades were attached to the shaft. One of the first mechanical fans was built in 1832 and it was tested in coal mines. Further, developed fans have been utilized in diverse fields based on their application. These developments have been applied in various parts of the fan such as blades within which the twist angle and the shape of the cross section are of primary importance. The blades are generally characterized by the airfoil used, the chord length and the span of the blade. It have very complex three-dimensional geometries that can affect their performances (Kergourlay *et al*, 2006; Herald *et al,* 2010). The parameters that should affect the performances are the blade thickness, twisting angle and chord length.

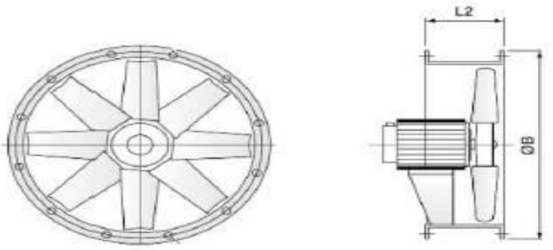

Figure-1. Axial-flow fan assembly.

An axial flow fan is a fan to create gas or air flow linearly along the axis of it. That will force air to move parallel to the shaft of blades. That are widely used in cooling, compression and ventilation. Axial fan are usually used by industrial in extreme condition such as large vibration, high temperature and high corrosion. For that reason the components and blades are made out of aluminium, which is lightweight, resistant to extreme environment. Therefore, the axial fan is very important in the ventilation system development in industries. Analysis and experiments have been carried out by several researchers to investigate the behavior both stress and fracture mechanics (Sarraf *et al*, 2011; Xuemin *et al*, 2015). Finite element methods (FEM) was used in the analysis of stress, strain, fatique and sheet metal forming as well (Chunxi *et al*, 2014; Leifur and Slawomir, 2015; Anggono *et al*, 2014).

Nowadays, the performance needs of fans are becoming increase due to the European regulation of the quest for higher energy-efficiency of fans. Here, a optimization design method for thinner axial-fan has been developed. The optimization is based on a stress analysis to find the optimum design of Aluminium blade both thinner and strength. The National Advisory Committee for Aeronautics (NACA) is one of the premiere institutes to develop airfoils. The airfoil developed by NACA are characterized into series (Anderson, 2001).NACA 5505 was selected in the design for thin and lightweight blade.

MECHANICAL ANALYSIS

In the axial-flow fan, the blades on the airflow to realise the energy transmission, therefore it can produce the pressure and make the air flow at the same time. Figure-1 gives illustration of axial-flow fan. The motor has diameter of *D*. Airflow enters into the blades at the absolute velocity of C_1 and leaves st that of C_2. Assuming tha C_1 is in the axial direction, $C_{1x} = 0$, we get:

$$\Delta C_x = C_{2x} - C_{1x} = C_{2x} \quad (1)$$

The inlet and outlet motion parameter of the airflow is:

$$W_m = \sqrt{C_u^2 + \left(u - \frac{C_{2u}}{2}\right)^2}$$
$$sin\beta_m = C_u / W_m$$
$$cos\beta_m = \left(u - \frac{C_{2u}}{2}\right) / W_m \quad (2)$$

Airflow exerts on the blade in two components, the lift P_{y1} normal to the W_m and the drag P'_{x1} parallel to the W_m respectively

$$P_{y1} = \frac{1}{2}\rho C_{y1} b_1 \Delta r W_m^2 \quad (3)$$

$$P'_{x1} = \frac{1}{2}\rho C'_{x1} b_1 \Delta r W_m^2 \quad (4)$$

where,
Δr = particular of radius

$$C_{y1} = C_{y1}(\alpha)$$
$$C'_{x1} = C_x(\alpha) + 0.018 C_{y1}^2 + \frac{0.08\pi r}{Z_1 D(1-d)}$$

The reactive force R_{x1} subjected on the blade is$R_{x1} = -P'_{x1}$

From the Figure-2, if the blade moves uniformly, the driving force to let the blades rotate is

$$F_u = P_u = P_1 sin(\varepsilon + \beta_m) = \frac{1}{2}\rho C_{y1} b_1 \Delta r W_m^2 \frac{sin(\varepsilon+\beta_m)}{cos\varepsilon} \quad (5)$$

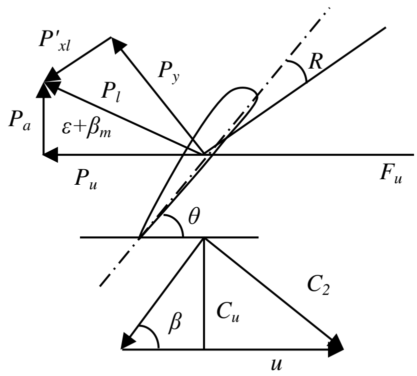

Figure-2. Force diagram of blade element.

MATERIALS AND METHODS

In this study, a blade of NACA 5505 airfoil is analyzed for the Von Mises stress distribution and how it varies as a function chord length and twist degree. The blade is made of aluminium. It has a length of 446.5mm and has a cross sectional profile of NACA 5505 airfoil. The primary chord length before variation was 130mm. Later, it was varied till 84mm. The twist angle was gradually changed in increments from 0 deg to 40 deg.

The blade is made of Aluminium6061-T91with the Young's modulus of 6.9E9 Pa and Poisson ratio of 0.33.The pressure load is applied to the lower surface of the blade

DESIGN METHODOLOGY

INFLUENCE OF CHORD LENGTH

In this analysis, the investigation is conducted in changing the chord length changes the Von Mises stress over the wing. The base chord length is constant of 130mm. The tip chord length was chosen to be 110mm. Then the tip chord length is changed gradually to a value of 102, 92 and 84 mm. Figure-3. gives illustration of different tip chord length that will be used in the analysis.

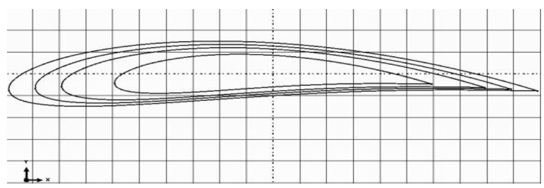

Figure-3. Various chord lengths of NACA5505.

INFLUENCE OF TWISTING ANGLE

Blade angle is defined as the angle between the chord of a propeller or rotor blade and a plane normal to the axis of rotation. Its amount changes along the span and it declines from root to tip because of the blade twist angle.

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In order to promote the efficiency, the airflow of an axial flow fan should be consistently spread over the working face of the fan wheel. In other words, the axial air velocity should be the same from hub to tip. On the other hand, the velocity of rotating blade is not evenly distributed. Its velocity is low near the centre and escalates towards the tip. This variation of velocity should be compensated by a twist angle of the blade, which is a larger blade angle near the centre and smaller blade angle toward the tip. In the analysis, the variation of twist angle are 0°, 10°, 20°, 30° and 40° as illustrated in the Figure 4.

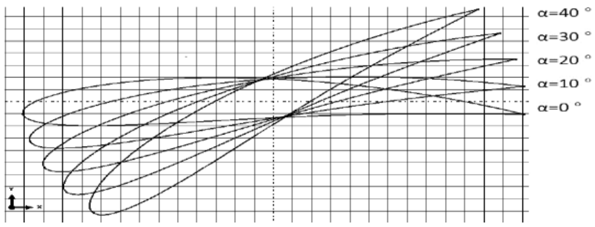

Figure-4. Airfoil shape of cross section with diverse Twist angles.

From the variation of tip chord length and twisting angle, there are 4 types models of different tip chord length. Then every models have variation 5 types of different twisting angle. So, in the analysis there are 20 different models.

THE PROPOSED MODEL

According to the variation of twisting angle and tip chord length, the new model of blade is then proposed. The model will use all twisting angle of 0°, 10°, 20°, 30° and 40° in a blade design as described in Figure-5. Then the model is varied into different tip chord length. The other properties of
Aluminium 6 series.

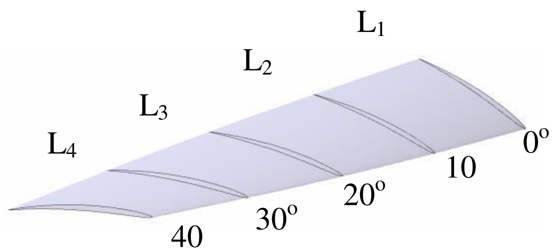

Figure-5. The proposed model use different twisting angle in four span.

RESULTS AND DISCUSSIONS

Figure-6. shows the maximum stress in every tip of chord length. From the figure, it can be said that increasing tip of chord length will increase the maximum stress on blade. The analysis is conducted by using the blade model without twisting angle or the twisting angle is zero. The highest stress of 1.68 x 10^7 Pa is delivered from the tip of chord length 110 mm as shown in the Figure-7. While the shortest tip of chord length 84 mm was delivered the the lowest stress 1.19 x 10^7 Pa. The phenomenon can be happen due to the acting force is higher in the higher surface area. From the definition, pressure is force per unit area. When the pressure is constant, the force is proportional to the area. Based on the investigation of the influence of chord length, the best model is the lowest stress. That is the blade model with the tip of chord length 84 mm.

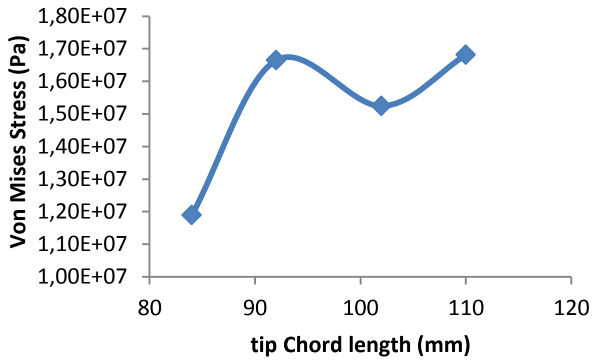

Figure-6. Influenced of tip chord length in the stress generation.

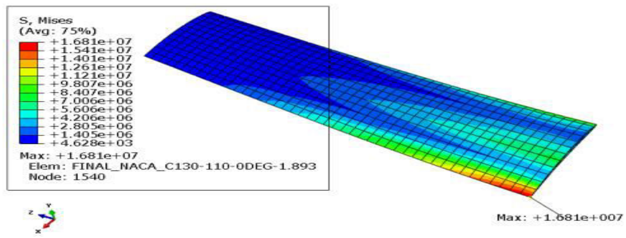

Figure-7. Stress distribution of NACA 5505, tip chord length 110 mm.

The investigation of the blade is continued to the influence of twisting angle in every variation of chord length. Starting from the tip of chord length 84 mm, the result is described in the Figure-8. The highest stress is 1.19 x 10^7 Pa resulting from the twisting angle of 0°. The stress is then decrease related to the increasing of twisting angle 10°, 20°, 30° and 40° . The stresses are 1.17 x 10^7, 1.0^9 x 10^7, 1.05 x 10^7 and 1.02 x 10^7 Pa respectively.

The lowest stress is 1.02 x 10^7 Pa delivered from the twisting angle 40° as seen in the Figure-8. It was seen that the overall stress results of chord length 84 mm is lower then the others model of longer chord length in

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every twisting angle of 0°, 10°, 20°, 30° and 40°. The chord length 92 and 110 mm were delivered stress in a same trend as shown in the Figure-8.

The investigation is then continued to plot the maximum stress in every twisting angle of the different chord length model as described in the Figure-9. From the figure, it is clearly seen that the highest stress was delivered by twisting angle 0° with 110 mm chord length. While the lowest stress was delivered by 40° twisting angle with 84 chord length. According to the analysis of the influence of twisting angle, the suggested model is 40° of twisting angle.

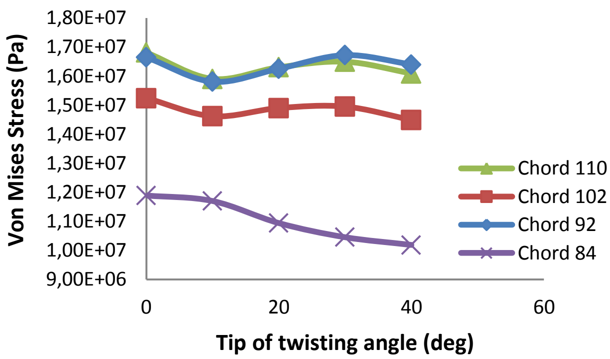

Figure-8. Influenced of twisting angle of stress generation in the variation of tip chord length.

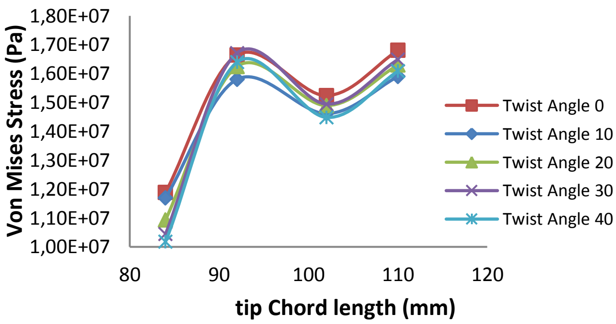

Figure-9. Maximum stress in every twisting angle.

RESULTS OF PROPOSED MODEL

The proposed model of fan blade is design based on the investigation of the influence of chord length and twisting angle related to generate stress in the blade. The model is then analyzed by using finite element method of Abaqus Student Edition. The analysis condition is same as the previous analysis, therefore the result is able to compare each others.

The proposed model is varied in chord length to make sure the lowest stress is delivered by the lower chord length as mention before. Figure-10 described the maximm stress in different model of chord length. From the figure, it is clearly seen that the lowest stress of 7.78 x 10^6 Pa was delivered by the model with 84 mm chord length as seen in the Figure-11. The figure is illustrated the stress distribution of blade model.

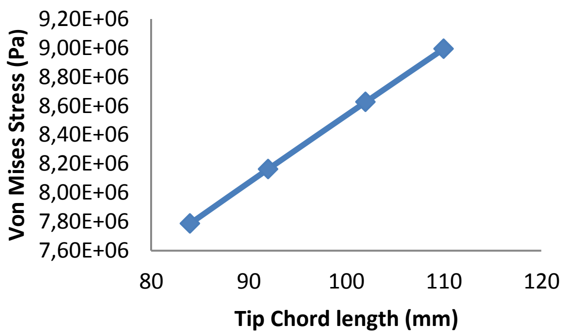

Figure-10. Maximum stress of proposed model in variation of tip chord length.

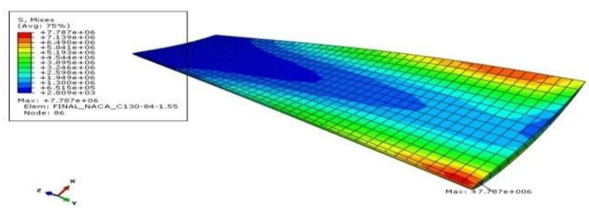

Figure-11. Stress distribution of proposed model of NACA 5505, tip chord length 84 mm.

While the highest stress of 8.99 x 10^6 Pa as plotted in Figure10 and illustrated in Figure-12 is delivered by model with 110 mm chord length. Figure-12 shows the stress distribution of the model and give the location of highest stress in the blade model. All maximum stress location is in the area of the base because that area is near to the location of constraint or clamp position. The stress concentration will be rise on the area of clamp but for the proposed model, the maximum stress is lower than the yield stress of the material.

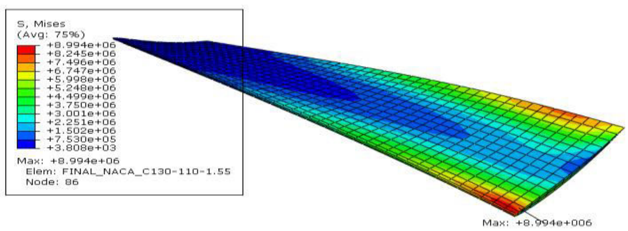

Figure-12. Stress distribution of proposed model of NACA 5505, tipchord length 110 mm.

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CONCLUSIONS

The stress analysis of the Aluminium fan blade has successfully conducted by using finite element method. The lower chord length of the fan blade has given lower stress in every condition of twisting angle. While the twisting angle of 40^o has also shown the lowest stress.

The proposed model has successfully developed using 84 mm chord length and distributed twisting angle from 0^o, 10^o, 20^o, 30^o and 40^o in one blade. The stress analysis of the proposed model has successfully shown that the maximum stress is lower than the other models. Based on the stress analysis, the proposed model has delivered the best results and able to implement for axial fan blade.

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