Design and Structural Analysis of Centrifugal Blower Blade

Nilar Win, Zin Ei Ei Win, Khaing Khaing Wai

Abstract— **The blowers are widely used in many industrial applications and farm machinery operation. The two main components of a centrifugal blower are the impeller and the casing. The stress pattern due to centrifugal force is highly complex in back sheet, shroud and blades of the impeller. The blower design is a single stage forward- curved centrifugal blower used in (40) tons Rice Mill in Pyay, Bago west region. The flow rate of this blower is 0.978 m^3/s and the blower speed is 2900 rpm. The required input power to blower is 6 kw and overall efficiency is 0.79% and to investigate the stress on centrifugal blower blade structural configuration with three locally materials namely mild steel, cast iron and aluminum. Autodesk Inventor Software is used for the design of blade model and the structural analysis of centrifugal blower blade.**

Index Terms— **forward-curved centrifugal blower, stress analysis, blade design, Autodesk Inventor Software.**

1. INTRODUCTION

Blowers are one of the types of turbo machinery which are used to move air continuously with in slight increase in static pressure. Blowers are widely used in industrial and commercial applications from shop ventilation to material handling, boiler applications to some of the vehicle cooling system [9]. Centrifugal blowers are mainly two main parts, namely, the casing and the impeller. Impeller is the most important parts of the blower components because of the fact that its performance inadvertently determines the blower's performance. The impeller is often considered an integral part of the suction motor since its housings and the motor are assembled as a unit. The impeller is always placed directly onto the shaft of the electric motor so that it spins at a very high speed. The effect of centrifugal force acting upon the spinning air within the impeller create the suction. As the impeller rotates, the spinning air moves away from the hub, creating a partial vacuum which causes more air to flow into the impeller . Air enters the impeller axially through the inlet nozzle which provide slight acceleration to the air before its entry to the impeller.

The action of the impeller swings the air from a smaller to the larger radius and delivers the air at a higher pressure and velocity. The centrifugal energy also contributes to the stage pressure rise. The flow from the impeller blades is collected by a spirally-shaped casing known as scroll or volute. It delivers the air to the exit of the blower. The scroll casing can further increase the static pressure of air. The outlet passage after the scroll can also take the form of a conical diffuser. The recent advances in steam turbine, electric motor, and high speed gearing design have greatly increased their use and application. Centrifugal blowers are fundamentally high speed machines (compared with the reciprocating, rotary, or displacement type).

1.1) Forward Curved Blade

The basic objective of a rice mill system is to remove the husk and the bran layers from paddy to produce whole white rice. The blower is the main component for milling because it removes the husk or outer layer from the paddy by using separation system. Forward-curved blade was selected because it is suitable for clean and dust laden air or gases. In addition, it is well suited for low tip speed and high airflow work as well as moving large volumes of air against relatively low pressures.

1.2) Velocity Diagram

A diagram called a velocity triangle helps in determining the flow geometry at the entry and exit of a blade. A minimum number of data are required to draw a velocity triangle at a point on blade. Some component of velocity varies at different point on the blade due to changes in the direction of flow. Hence an infinite number of velocity triangles are possible for a given blade. In order to describe the flow using only two velocity triangles, mean values of velocity and their direction are defined. Velocity triangle of any turbo machine has three components as shown in Fig. 1 [1].

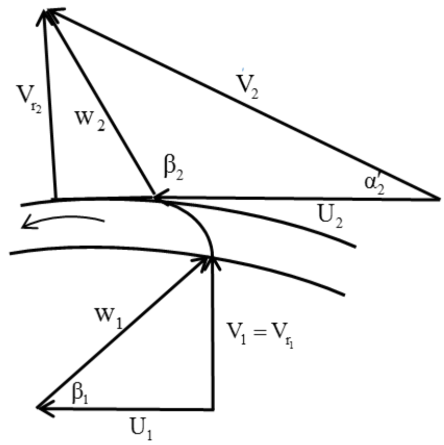

Figure 1. Velocity triangle for forward curved blade.

where, U = blade velocity

V = absolute velocity

W = relative velocity

Manuscript received October, 2018.

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These velocities are related by the triangle law of vector addition: $V = U + V_r$

2. Design of Centrifugal Blower

2.1) Design of Impeller

The design is analyzed by choosing single stage centrifugal blower. Input data for design calculations are taken from Aung Thiri Rice Mill in Pyay.

Air flow rate, Q = 0.978 m^3/s
Rotational speed, N=2900 rpm
Inlet air pressure, $P_i = 101325\ P_a$ (absolute)
Inlet air temperature, T_a = 303K
Discharge air pressure, P_d = 4.9113 kPa
Gravitational acceleration, g =9.81m/s^2
Air constant, R= 287 J/kg K
Overall pressure ratio:

$$\varepsilon_P = \frac{P_d}{P_a} \tag{1}$$

where P_d and P_a are discharge air pressure and inlet air pressure.

The design of blower is usually based upon either an adiabatic or an isothermal compression. The velocity head is negligible compared to the pressure head for blowers and compressors. The following expression for the head, based upon an adiabatic compression [1].

$$H_{ad} = \frac{RT_a}{\frac{K-1}{K}}\left(\varepsilon_P^{\frac{K-1}{K}} - 1\right) \tag{2}$$

Before the impeller dimensions can be fixed, the shaft size must first be approximated. It should be large enough to care for the torque and bending moment, to avoid excessive lateral deflection, and to keep the critical speed a safe distance from the operating speed. The shaft diameter based upon torque [1]

$$D_s = \sqrt[3]{\frac{16 \times T}{\pi S_s}} \tag{3}$$

The gas or air is initially at rest and is drawn into the eye of the impeller with velocity. The impeller on account of its rotation removes the gas or air from the eye. The gas in a receiver or the air in the atmosphere expands to fill this avoid. In so doing, the pressure drops and the velocity is attained. During this process the total head remains constant, so, by Bernoulli's theorem (neglecting elevation changes) [1]

$$H = \frac{V_0^{\ 2}}{2g} \tag{4}$$

By assuming a mean or average specific weight during the small pressure drop while the air is being expanded, the pressure of the gas in the impeller eye:

$$\varepsilon_P^{\ 0.283} - 1 = \frac{0.283H \times g}{RT_a} \tag{5}$$

The pressure ratio at the impeller eye:

$$P_0 = \frac{P_a}{\varepsilon_P} \tag{6}$$

The temperature at the impeller eye:

$$T_0 = \frac{T_a}{\varepsilon_P^{\ 0.283}} \tag{7}$$

The inlet velocity through the eye of the impeller is usually slightly higher than the velocity in the suction flange. Since the turbulence and friction losses are proportional to the velocity squared, the inlet velocity should be kept fairly low. On the other, very low values of eye velocity result in larger eye diameters and consequently poor impeller proportions. Assume value of eye velocity, the eye diameter may be found from the continuity equation [1]:

$$D_0 = \sqrt{\frac{4}{\pi} \times \frac{Q_0}{V_0}} \tag{8}$$

The vane inlet diameter may be made slightly greater than the eye diameter and then, the absolute velocity at the impeller inlet V_1 is assumed to be radial and V_1 is slightly greater than V_0 [1].

The inlet vane angle:

$$\tan \beta_1 = \frac{V_1}{U_1} \tag{9}$$

Which, may be increased somewhat to care for the contraction of the gas stream as it enters the vane passage.

The impeller areas, the flow must be increased because of the leakage past the impeller. This leakage may be assumed to be about 2.5 percent of the flow, found the equation is [1]:

$$A_1 = \frac{1.025Q_0}{V_1} \tag{10}$$

The impeller inlet width:

$$b_1 = \frac{A_1}{\pi D_1 \varepsilon_1} \tag{11}$$

where, the inlet vane thickness factor $\epsilon_1$assume 0.85 to 0.95.

The outlet diameter of the impeller:

$$D_2 = \frac{60\sqrt{H_{ad} g}}{\pi N \sqrt{K'}} \tag{12}$$

where, K is the pressure coefficient which has a value between 0.5 and 0.65 depending on the type of impeller.

Taking outlet vane angle, β_2=96° (The vane outlet angle greater than 90°).

Blade number:

$$Z = 6.5 \times \frac{D_2 + D_1}{D_2 - D_1} \sin \frac{\beta_1 + \beta_2}{2} \tag{13}$$

But, the usual number of vanes varies between 15 and 30 in most blowers. A greater number of vanes will reduce the circulatory flow effect but will increase the friction [1].

The circulatory flow effect reduces the tangential component, by an amount equal W_z.

$$W_z = U_2 \frac{\pi \sin \beta_2}{Z} \tag{14}$$

Absolute outlet angle:

$$\tan\alpha_2' = \frac{V_{r_2}}{V'_{U_2}} \quad (15)$$

The total virtual head for an infinite number of vanes is the sum of heads due to centrifugal action, change in relative velocity and absolute velocity. The first two terms represent the pressure head which is developed in the impeller: the last term is the velocity head developed in the impeller and converted into pressure in the volute or diffuser. Hence, the virtual pressure head developed in the impeller [1]:

$$H_{vir,\infty} = \frac{1}{2g}(u_2^2 - u_1^2 + w_1^2 - w_2^2) \quad (16)$$

It may be assumed that, owing to the circulatory flow, friction and turbulence in the impeller, 10 percent of this head is lost. Hence the effective head is obtained in the following equation [1]:

$$H_{eff} = 0.9 \times H_{vir,\infty} \quad (17)$$

The impeller outlet pressure:

$$P_2 = \varepsilon_P \times P_0 \quad (18)$$

The friction and turbulence losses will be transformed into heat which raises the temperature of air. The outlet temperature may be upon the adiabatic head in the impeller neglecting losses [1]:

$$\varepsilon_P^{0.283} - 1 = \frac{0.283 \times H_{vir,\infty} \times g}{RT_0} \quad (19)$$

Assuming the 2.5 percent of leakage. The flow leaving the impeller:

$$Q_2 = \frac{1.025 m_a^{\circ}}{\rho_2} \quad (20)$$

Assuming the vane has constant thickness 3.175mm, the outlet vane thickness factor:

$$\varepsilon_2 = \frac{\pi D_2 - \frac{Zt}{\sin\beta_2}}{\pi D_2} \quad (21)$$

The impeller outlet width:

$$b_2 = \frac{A_2}{\pi D_2 \varepsilon_2} \quad (22)$$

TABLE I. RESULT DATA OF FORWARD CURVED BLADE CENTRIFUGAL IMPELLER DESIGN

No	Type	Actual data	Calculated data	Unit
1	Shaft diameter	83	83	mm
2	Impeller inlet diameter	254	260	mm
3	Impeller inlet width	89	81	mm
4	Inlet vane angle	-	26	degree
5	Number of blade	16	16	-
6	Impeller outlet diameter	533	530	mm
7	Impeller outlet width	63	61	mm
8	Outlet vane angle	-	96	degree

3. DESIGN OF BLADE SHAPE

There are two methods of constructing the vane shape from these curves. One is to construct it of tangent circular arcs, and the other is to calculate and plot the shape by polar coordinates. The design of blade shape is drawn by using polar coordinate method. In this method, the points on the vane surface are plotted by polar coordinates. For any radius R and angle θ measured in degrees from an assumed radial line passing through the intersection of the van surface with radius R_1 is given by the equation [1]:

$$\theta^{\circ} = \frac{180}{\pi}\int_{R_1}^{R}\frac{dR}{R\tan\beta} \quad (23)$$

TABLE II. RESULT DATA FOR BLADE SHAPE

Ring	R	β	ΔR	$\frac{\Delta R}{R\tan\beta}$	Δθ°	θ°
1	0.13	26				0
			0.027	0.3154	18.07	
R_b	0.157	40				18.07
			0.027	0.1558	8.93	
R_c	0.184	54				27
			0.027	0.0791	4.53	
R_d	0.211	68				31.53
			0.027	0.0338	1.94	
R_e	0.238	82				33.47
			0.027	0.0027	0.15	
2	0.265	96				33.62

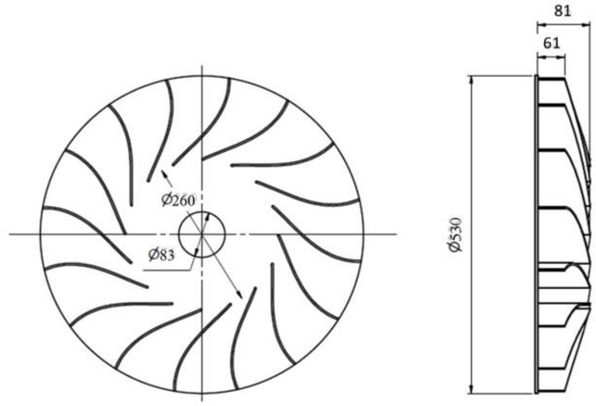

Figure 2. 2D Impeller Drawing.

4. NUMERICAL SIMULATION OF CENTRIFUGAL BLOWER BLADE

The designed centrifugal blower blade was analyzed with static structural by using Autodesk Inventor Software. The blade was analyzed with flow rate 0.978 m^3/s, rotational speed 2900rpm and three locally available materials, namely mild steel, cast iron and aluminum were used for the blade materials. The input geometry was drawn in Inventor Software with result parameters.

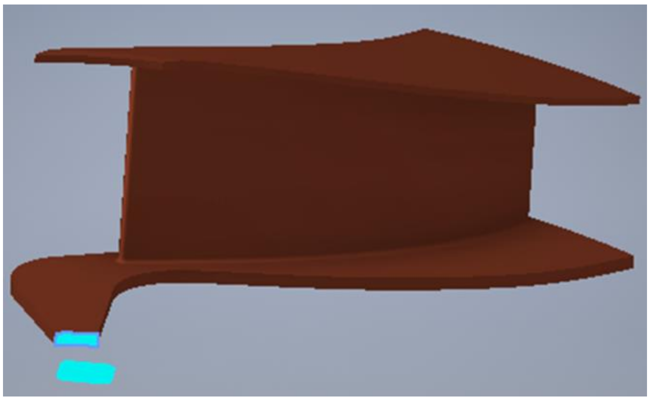

Figure 3. 3D Split Model of Centrifugal Blade

TABLE III. MATERIAL PROPERTIES

Material	Mild steel	Casr iron (Ductile)	Aluminum (6061)
Young's Modulus	207GPa	168GPa	68.9GPa
Poisson's ratio	0.3	0.31	0.33
Density	7850kg/m3	7100kg/m3	2700kg/m3
Yield strength	210MPa	379MPa	275MPa

4.1) Static structural analysis of the centrifugal blower blade by using mild steel

The Von mises stress and deformation using mild steel are illustrated in Figure 4 and 5. The equivalent Von mises stress on the blade is 80.33 MPa while the yield strength of the blade material is 210 MPa. The blade will work safely at this stress.

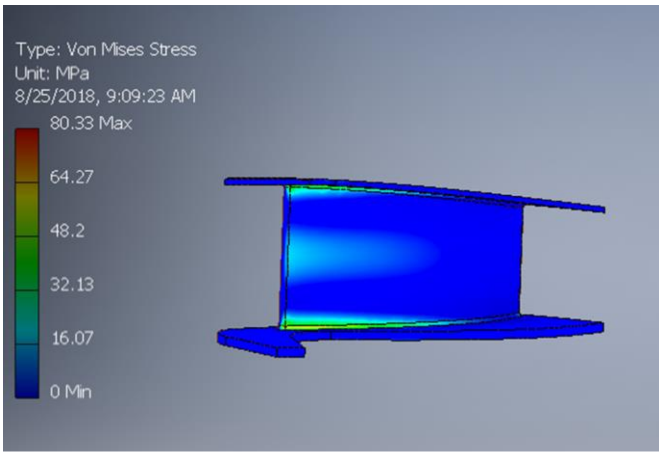

Figure 4. Von mises stress for mild steel impeller blade

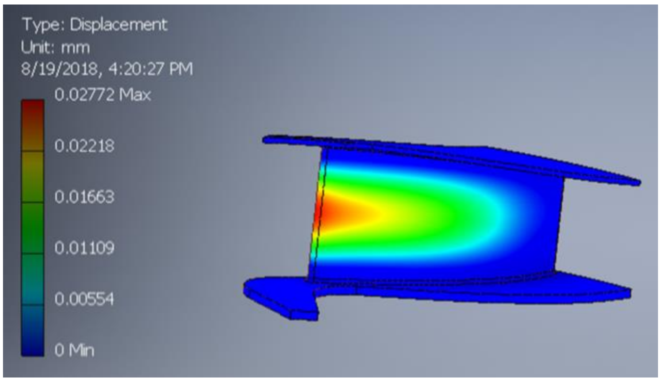

Figure 5. Deformation for mild steel impeller blade

4.2) Static structural analysis of the centrifugal blower blade by using cast iron

The Von mises stress and deformation using cast iron are illustrated in Figure 6 and 7. The equivalent Von mises stress on the blade is 71.09 MPa while the yield strength of the blade material is 379 MPa. The blade will work safely at this stress.

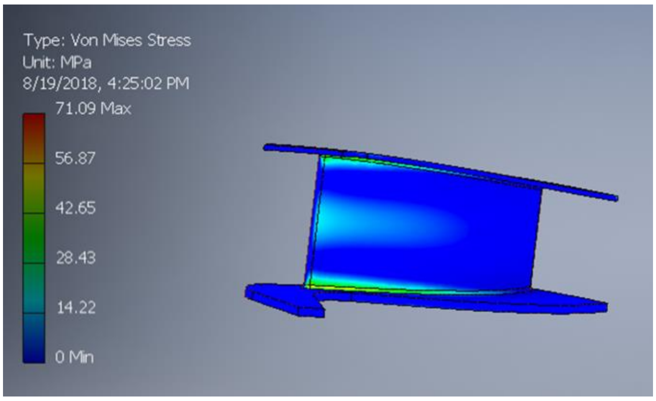

Figure 6. Von mises stress for casr iron impeller blade

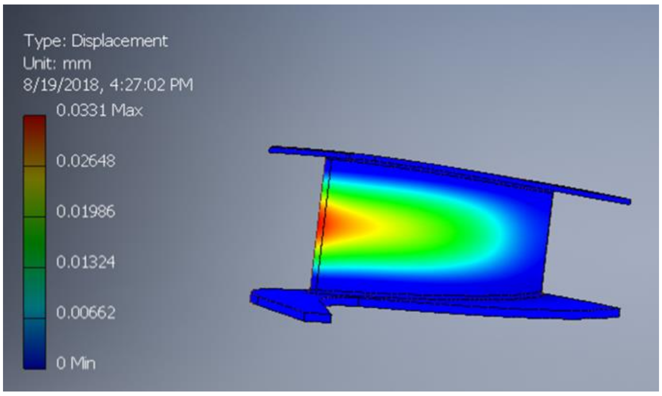

Figure 7. Deformation for casr iron impeller blade

4.3) Static structural analysis of the centrifugal blower blade by using aluminum

The Von mises stress and deformation using aluminum are illustrated in Figure 8 and 9. The equivalent Von mises stress on the blade is 26.72 MPa while the yield strength of the blade material is 275 MPa. The blade will work safely at this stress.

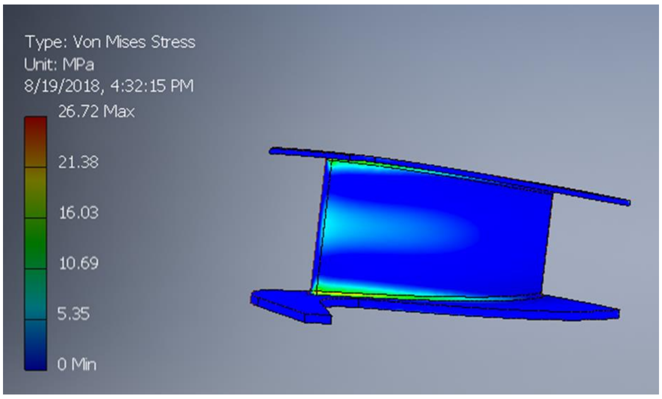

Figure 8. Von mises stress for aluminum impeller blade

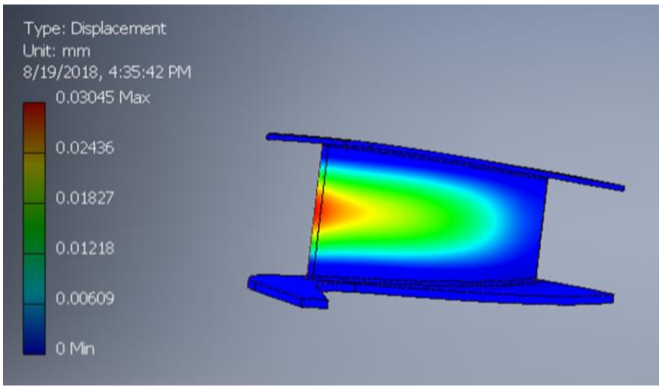

Figure 9. Deformation for aluminum impeller blade

TABLE IV. VON MISES STRESS AND DEFORMATION FOR THREE TYPES OF MATERIALS

No	Material	Stress (MPa)	Deformation (mm)
1	Mild steel	80.33	0.02772
2	Cast iron	71.09	0.03310
3	Aluminum	26.72	0.03045

5. Conclusion

In this research, detailed calculation of a centrifugal blower used in (40) tons rice mill was done and structural analysis are made by Autodesk Inventor Software. The comparison of existing and calculated data was also performed. And then, the stress analysis was carried out by three different materials such as mild steel, cast iron (Ductile iron) and aluminum (6061). Static analysis reveals that max stress on blade are 80.33 MPa, 71.09 MPa and 26.72 MPa, respectively and maximum displacement on blades are 0.02772 mm, 0.03310 mm and 0.03045 mm. The maximum von mises stress location for all three types of materials is at the fixed end of the blade. The existing blower made by mild steel is more in weight. By replacing Aluminum and Cast Iron instead of it, the weight is reduced. But, the use of Mild Steel materials costs more effective than the other two materials. And then, mild steel material having minimum deformation therefore there are less chances of failure of the blower blade as compare to other two materials. The greatest benefit of it is that it can be fabricated easily, available commercially and so relatively cheap in price.

Acknowledgment

The author is deeply gratitude to supervisor Dr. Zin Ei Ei Win, Professor and head of Department of Mechanical Engineering, Pyay Technological University for her valuable suggestions and guidance. The author is very thankful to U Saw Ba Tin, Lecturer, Department of Mechanical Engineering Department, for his guidances and advices. The author would like to express greatful thanks to co-supervisor Daw Khaing Khaing Wai, Lecturer, Department of Mechanical Engineering, member U Soe Kyaw, Lecturer, Department of Mechanical Engineering and to all the teachers from Mechanical Department of Pyay Technological University.

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