Structural Analysis of Threshing Drum for Paddy Thresher

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Abstract- The objective of this paper is to design the threshing drum for paddy thresher and to analyse the structural behaviours on the threshing drum due to applied centrifugal force and toque on it. This paper discusses about the threshing drum of paddy thresher as axial flow type produced in Aung-Paddy Thresher Industrial Zone at Mandalay. The threshing drum consists of threshing discs, bars, teeth, hubs, disc supports and blades which are constructed with gray cast iron. The threshing drum diameter is 450mm and length of drum is 1050mm. The speed of threshing drum is 640rpm at power supplied 3.649kW. Weight of threshing drum, power and threshing torque are estimated in this paper. SolidWorks software is used for modeling and analysis of the threshing drum of paddy thresher. The stress distribution on threshing drum is expressed by theoretically and numerically approaches. The threshing drum was analyzed by using three different materials. Von-Mises stress and effective strain of Low Carbon Steel is lower than the other materials. So the suitable material is Low Carbon Steel. The simulation and theoretical results data of maximum von-Mises stress are 3.930 MPa and 4.741 MPa for Low Carbon Steel. The percent error is 17%. Von-Mises stress of Low carbon steel does not exceed yield strength value of 276MPa.So the design is satisfied.

Indexed Terms- Axial flow, Paddy thresher, Structural Analysis of Threshing Drum, Threshing Drum

I. INTRODUCTION

In world food production, rice is one of the most essential grains for people and the main staple food for our country. Myanmar is an agricultural country; the important bone of its economy is the agriculture field. In agriculture field, 34% of GDP, 15.4% of total export earnings and employs 61.2% of the labour force are contributed. Rice is an important crop in Myanmar not only because it is cereal crops but also because many farmers and labourers depend on it as their main source of livelihood. Accordingly, the demand for rice has been increased daily. For thousands of years, grain was separated by hand and was very laborious and time consuming. Therefore, the use of paddy threshers is becoming more and more popular and is the most suitable method for local farmers. In order to accomplish this process, there are two main threshing systems which are vertical flow and axial flow type of paddy thresher [3].

The main components of paddy thresher include threshing, separation and cleaning units. The threshing unit which consists of a rotating drum and concave jointly thresh the grains from the straws. The threshing teeth are bolted by screws axially. In the separation unit, threshed grains falls through the lower concave openings and then the screens are shaken with a crank which is powered from the main axle by belt. The circular motion of the main shaft is converted into oscillating motion of screen, which shakes it and separated the grain by performed screen from dust and small weed seeds from clean grains and also to deliver grains to the screw conveyor. The cleaning units which are removed other foreign materials and chaff from the grain. By passing the uncleanness grain over an oscillating screen through which a current air is blowed out by a fan, this unit is accomplished as shown in Figure-1 [10].

Agidi Gbabo, Lbrahim Mohammed Gana and Mattthew Suberu Amoto studied to thresh, separate and clean the seeds of millet where the threshing and cleaning efficiency are highest with 800rpm drum speed at 13% moisture content while the lowest efficiency was recorded when threshed with 600rpm drum speed at 17% moisture content. In this design, analysis was expressed with an observation to evaluate the necessary design size, strength and parameters of materials for the different kind of machine part in order to avoid failure by overload fatigue and yielding during the life time of the working machine [2].

II. METHODOLOGY

In this research, the design parameter is collected from paddy thresher with diesel engine (5.970kW), measuring the data of the threshing drum at Aung-Paddy Thresher Industrial Zone, (Mandalay), Myanmar. And then, calculated the weight of threshing drum, angular velocity, threshing power, threshing torque and centrifugal force for the threshing drum design. The theoretical and numerical analysis of threshing drum are expressed in this paper.

In this paper, it includes of three main parts, which are;
A: Design Consideration of Threshing Drum
B: Theoretical Analysis of Threshing Drum
C: Numerical Analysis of Threshing Drum

A. Design Consideration of Threshing Drum for Paddy Thresher

(1). Total weight of threshing drum:
Total weight of threshing drum,

$$W_{total} = W_{discs} + W_{supports} + W_{bars} + W_{teeth} + W_{blades} + W_{hub} \quad (1)$$

Where,
W_{disc} - weight of discs (N)
$W_{supports}$ - weight of supports (N)
W_{bars} - weight of bars (N)
W_{teeth} - weight of teeth (N)
W_{blades} - weight of blades (N)
W_{hub} - weight of hub (N)

Calculation of the weight of discs, supports, bars, teeth, blades and hub:
Weight of threshing discs:

$$W_{disc} = \rho v_{disc} g \quad (2)$$

$$v_{disc} = \frac{\pi(OD^2 - ID^2)_{disc}}{4} \times t \times n_d \quad (3)$$

Where,
V_{discs} - volume of discs (m^3)
ρ - Density of cast iron (kg/m^3)
g - Acceleration due to gravity (m/s^2)
A_{disc} - area of discs (m^2)
Weight of support:

$$W_{sup} = \rho v_{sup} g \quad (4)$$

$$V_{support} = [A \times l_{sup} \times n_{sup}] \quad (5)$$

Where,
$V_{support}$ - volume of supports (m^3)
A_{sup} - area of supports (m^2)

Weight of bars:

$$W_{bar} = \rho v_{bar} g \quad (6)$$

$$v_{bar} = A \times l \times n_b = lbh \times n_b \quad (7)$$

Where,
V_{bar} - volume of bars (m^3)
A_b - area of bars (m^2)
Weight of teeth:

$$W_{teeth} = \rho v_{teeth} g \quad (8)$$

$$v_{teeth} = A \times l \times n_t = \frac{\pi d^2}{4} \times l \times n_t \quad (9)$$

Where,
V_{teeth} - volume of teeth (m^3)
A_t - area of teeth (m^2)
Weight of blades:

$$W_{bl} = \rho v_{bl} \times g \quad (10)$$

$$V_{bl} = A \times l_{bl} \times n_{bl} = b_{bl} \times t_{bl} \times l_{bl} \times n_{bl} \quad (11)$$

Where,
V_{bl} - volume of blades (m^3)
A_{bl} - area of blades (m^2)
Weight of hub:

$$W_{hub} = \rho v_{hub} \times g \quad (12)$$

$$V_{hub} = \frac{\pi}{4}(OD_{hub}^2 - ID_{hub}^2) \times l_{hub} \times n_{hub} \quad (13)$$

Where,
V_{hub} - volume of hub (m^3)
A_{hub} - area of hub (m^2)
(2). Power of threshing drum:

Power = (work done)/time = Fωr (14)

Where,
F - Weight of threshing drum (N)
ω - Angular velocity (rad/sec)
r - Radius of threshing drum (m)

(3). Determination of Threshing Torque:
The threshing torque,
T = F×r (15)

Where,
F - Weight of threshing drum (N)
r - Radius of threshing drum (m)

(4). Required Force for Paddy Thresher:
The threshing bars, discs, teeth and other parts which are attached to the contained in the threshing drum, rotate with the shaft due to centrifugal force.
Centrifugal force at threshing drum:

$$F = m\times\omega^2\times r \quad (16)$$

Angular velocity of threshing drum:

$$\omega = \frac{2\pi \times N_{drum}}{60} \quad (17)$$

Where,
F - Centrifugal force (N)
m - Mass of threshing drum (kg)
ω - Angular velocity (rad/sec)
r - Radius of threshing drum (m)
N_{drum} - speed of the drum (rpm)

Table 1 Result Table of Threshing Drum

Parameters	Symbol	Value	Unit
Weight of threshing discs	W_{disc}	7.477	N
Weight of support	w_{sup}	31.784	N
Weight of threshing bars	W_{bars}	106.795	N
Weight of threshing teeth	W_{teeth}	79.883	N
Weight of threshing blades	W_{bl}	10.383	N
Weight of hub	W_{hub}	5.991	N
Total weight of threshing drum	W_{total}	242.284	N
Angular Velocity	ω	66.952	Rad/sec
Threshing Power	P	3.649	kW
Threshing Torque	T	54.514	N-m
Centrifugal force	F	24.909	kN

Table 1 shows the calculated weight, required power, torque and centrifugal force of the threshing drum design used in paddy thresher.

B. Theoretical Analysis of Threshing Drum
Structural behaviour (von-Mises stress, effective strain) of threshing drum are calculated by theoretical approach. The threshing drum is made of gray cast iron ASTM40.

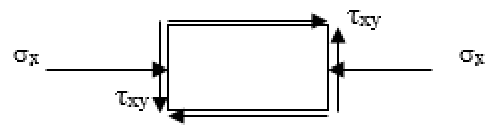

Figure 1. Stress in the x-y plane

Figure 1. Illustrates theoretical stress model in x-y plane.

(1) Bending stress for threshing drum:

$$\sigma_x = \sigma_b = \frac{F}{A_{drum}} = \frac{m\omega^2 r}{\pi D t} \quad (18)$$

(2)Shear stress for threshing drum:

$$\tau_{xy} = \frac{T \times R}{J} \quad (19)$$

The Principle stresses for threshing drum can be calculated in von-Mises criteria.

$$\sigma_{1,2} = \frac{1}{2}\left(\sigma_x + \sigma_y\right) \pm \frac{1}{2}\left[\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2\right]^{\frac{1}{2}} \quad (20)$$

The von-Mises stress,

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{\frac{1}{2}} \quad (21)$$

The constitutive equations are called the relation between stress and strain. Hooke's law would be show that;
Principle strains:

$$\varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \upsilon(\sigma_2 + \sigma_3)\right] \quad (22)$$

$$\varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \upsilon(\sigma_1 + \sigma_3)\right] \quad (23)$$

$$\varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \upsilon\left(\sigma_1 + \sigma_2\right)\right] \qquad (24)$$

The effective strain for threshing drum:

$$\bar{\varepsilon} = \left[\frac{2}{3}\left(\varepsilon_1^{\,2} + \varepsilon_2^{\,2} + \varepsilon_3^{\,2}\right)\right]^{\frac{1}{2}} \qquad (25)$$

Table 2 Material Properties of Astm40 Gray Cast Iron [1]

Material Properties	Values	Units
Young Modulus, E	124	GPa
Poisson Ratio, υ	0.27	-
Yield Strength, S_y	276	MPa
Density, ρ	7200	kg/m^3

Table 2shows the materials properties of ASTM40 gray cast iron for design calculation of the threshing drum.

Table 3 Theoretical Results of Threshing Drum

Von-Mises Stresses, $\bar{\sigma}$ (MPa)	Effective Strain, $\bar{\varepsilon}$ ($\times 10^{-5}$)	Shear Stress, τ (MPa)	Centrifugal Force, F (kN)	Bending Stress, σ_b (MPa)
3.720	2.485	0.069	24.909	3.524

Table 3 shows the theoretical results of the threshing drum design. The von-Mises stress, the effective strain, shear stress, centrifugal force and bending stress are calculated by theoretically in the threshing drum design.

C. Numerical Analysis of Threshing Drum

To estimate the following stresses and strains distribution of the threshing drum, SolidWorks software has been used. The design of the threshing drum was analysed with gray cast iron ASTM40.

(1). Model of Threshing Drum for Paddy Thresher:

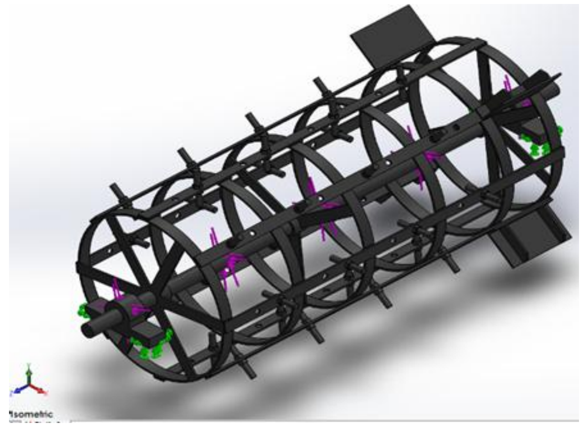

Figure 2. 3D Modeling of Threshing Drum

Figure 2 shows the model of threshing drum for paddy thresher which is drawn by SolidWorks Software 2016.

(2) Boundary Conditions of Threshing Drum:

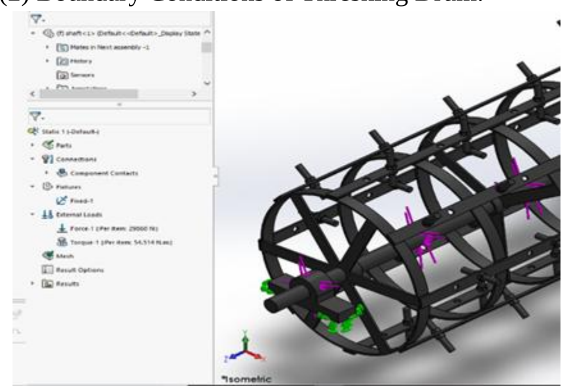

Figure 3. Boundry Condition of Threshing Drum

Figure 3 shows the boundry condition of threshing drum. Fixed supports are provided at the bearings on the threshing drum shaft. The simulation is carried out by choosing the static condition. The centrifugal force and torque are acting on the shaft of threshing drum. The centrifugal force acting on this shaft is the direction of threshing drum rotation. So, the angular velocity is presented the shaft.

(3). Meshing of Threshing Drum:

Figure 4 shows meshing of threshing drum by using SolidWorks software 2016. To generate the mesh model of the threshing drum, with curvature-based mesh, element size is default and smoothing is fine in the mesh program.

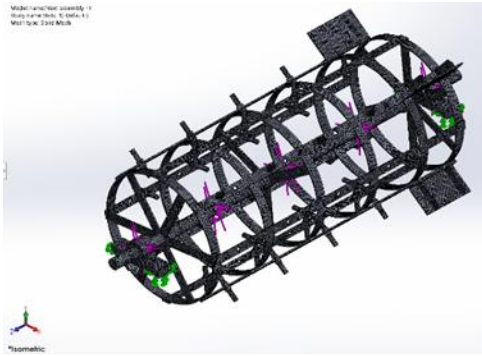

Figure 4. Meshing of Threshing Drum

(4). Stresses and Strains Analysis of Threshing Drum:

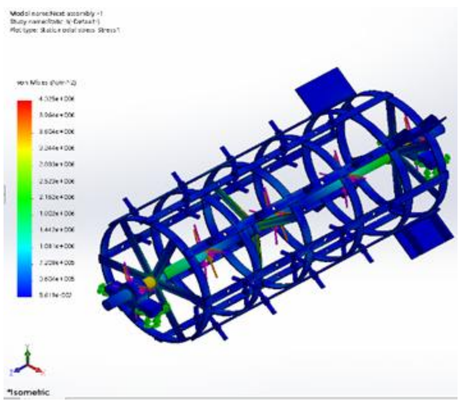

Figure 5. von-Mises Stress for ASTM40 Gray Cast Iron

Figure 5 shows the von-Mises stress affected on the threshing drum for ASTM40 Gray Cast Iron. It can be noticed that the maximum stress is generated at the discs supports of the drum is 4.741 MPa, which is below the yielding stress of the ASTM40 Gray Cast Iron.

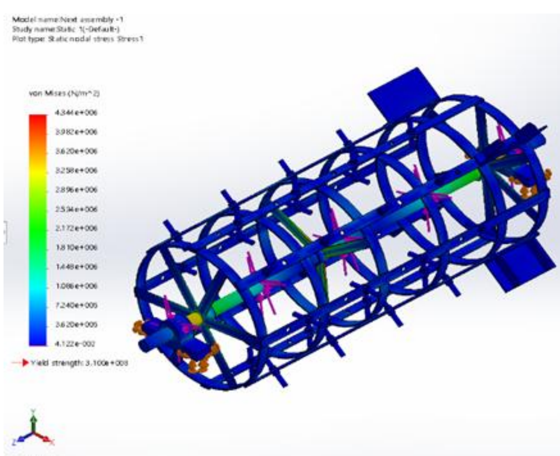

Figure 6. von-Mises stress of Ductile Cast Iron

Figure 6 shows the von-Mises stress affected on the threshing drum for Ductile Cast Iron. It can be noticed that the maximum stress is generated at the discs support of the drum is 4.344 MPa, which is below the yielding stress of the Ductile Cast Iron.

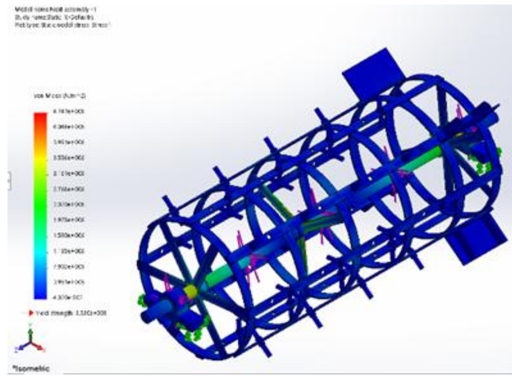

Figure 7. von-Mises stress of Low Carbon Steel

Figure 7 shows the analysis of the von-Mises stress affected on the threshing drum for Low Carbon Steel. It can be noticed that the maximum stress is generated at the discs supports of the drum is 4.325 MPa, which is below the yielding stress of the Low Carbon Steel.

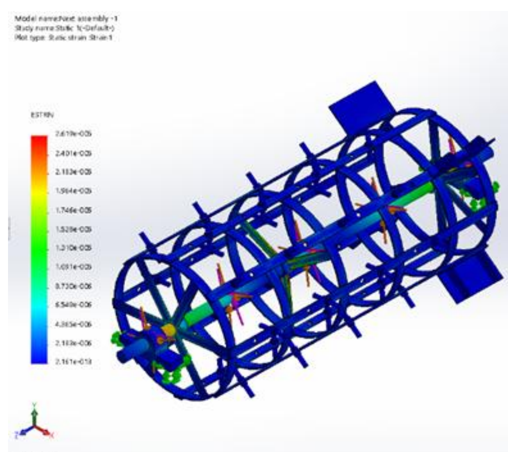

Figure 8. Equivalent Elastic Strain for ASTM40 Gray Cast Iron

Figure 8 shows the analysis of the equivalent elastic strain for ASTM40 Gray Cast Iron. The selected maximum elastic strain is 2.619×10^{-5}.

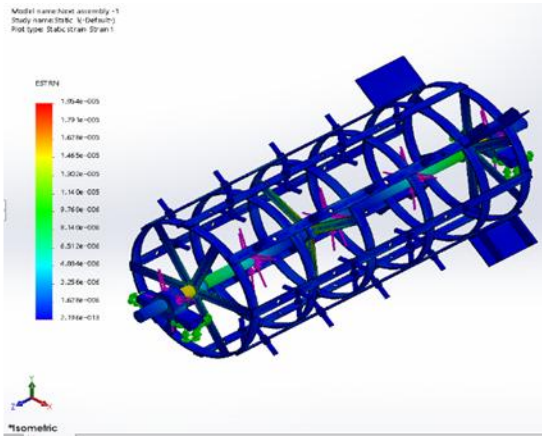

Figure 9. Equivalent Elastic Strain for Ductile Cast Iron

Figure 9 shows the analysis of the equivalent elastic strain for Ductile Cast Iron. The selected maximum elastic strain is 1.954×10^{-5}.

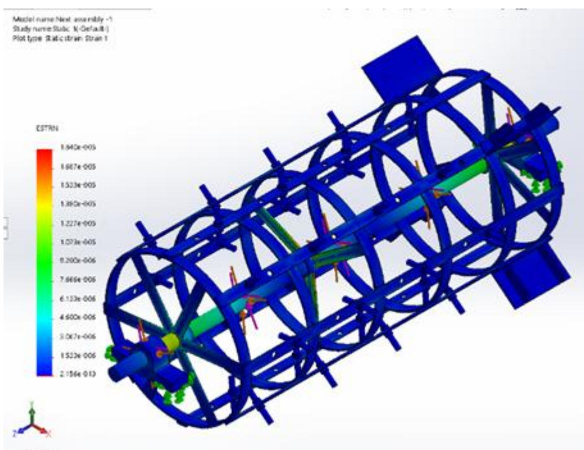

Figure 10. Equivalent Elastic Strain for Low Carbon Steel

Figure 10 shows the analysis of the equivalent elastic strain for Low Carbon Steel. The selected maximum elastic strain is 1.840×10^{-5}.

III. RESULTS AND DISCUSSION

- Comparison Of The Result Of Theoretical And Simulation

In this paper, the von-Mises stress of threshing drum is computed by theoretically and numerically with three different materials. And then, compared stress simulation analysis using SolidWorks software.

Table 4 Simulation Results of Threshing Drum (von-Mises)

Material	Theoretical results of von-Mises stress	Simulation results of von-Mises stress	Error
ASTM40 Gray Cast Iron	3.720 (MPa)	4.325 (MPa)	14%
Ductile Cast Iron	3. 878 (MPa)	4.344 (MPa)	11%
Low Carbon Steel	3.930 (MPa)	4.741 (MPa)	17%

Table 4 shows the results data of von-Mises stress for three different materials and compared the results data of theoretical and simulation. The percentage error is 14% for ASTM40 Gray Cast Iron, 11% for Ductile Cast Iron and 17% for Low Carbon Steel.

Table 5 shows the comparison of theoretical and simulation results of equivalent strain for three different materials. The percent error for ASTM40 Gray Cast Iron, Ductile Cast Iron, Low Carbon Steel are 5%, 9% and 8% respectively.

Table 5 Simulation Results of Threshing Drum (Equivalent Strain)

Material	Theoretical results of equivalent elastic strain	Simulation results of equivalent elastic strain	Error
ASTM40 Gray Cast Iron	2.485×10^{-5}	2.619×10^{-5}	5%
Ductile Cast Iron	1.781×10^{-5}	1.954×10^{-5}	9%
Low Carbon Steel	1.695×10^{-5}	1.840×10^{-5}	8%

Table 5 shows the comparison of theoretical and simulation results of equivalent strain for three different materials. The percent error for ASTM40 Gray Cast Iron, Ductile Cast Iron, Low Carbon Steel are 5%, 9% and 8% respectively.

IV. CONCLUSION AND RECOMMENDATION

The threshing drum is drawn and analysed by SolidWorks software. The maximum von-Mises stress is affected in Low Carbon Steel, when compared to the ASTM40 Gray Cast Iron and Ductile Cast Iron where a maximum von-Mises stress of 4.741 MPa was noticed. While the minimum value of von-Mises stress is 3.720 MPa was noticed in ASTM40 Gray Cast Iron. The minimum equivalent elastic strain is Low Carbon Steel than two materials. The values of deformations are 5.846×10-2 for ASTM40 Gray Cast Iron, 4.244×10-2 for Ductile Cast Iron and 3.685×10-2 for Low Carbon Steel. From the above results, the maximum stress was found in Low Carbon Steel but the Low Carbon Steel has the less deformation than other two materials. Finally, Low Carbon Steel is the best suitable than other materials. But for out project, we chose ASTM40 Gray Cast Iron because it is easily available in the market and it is very cheap.

The other components such as concave and shaker should be designed and analysed for the future study. The threshing drum design should be modified because it influences in turbine performance.

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