Design and Structural Analysis of Shelling Shaft for Motorized Maize Shelling Machine

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Abstract – The objective of this paper is to design the shaft for maize sheller and to analyze the structural behaviors on the shaft due to applied fluctuating torque, bending moment and shearing force on it. This paper discusses about the calculation parameters of shaft design and bearings selection for maize shelling machine produced in Aung-Paddy Thresher Industrial Zone at Mandalay. Weight of threshing drum (shelling cylinder), fan blades, pulley and bearings are exerted on the shaft which is constructed with gray cast iron. The shaft diameter is 25mm and length is 942mm. The rotating speed of shaft is 302rpm at power supplied 1.1kW. SolidWorks software is used for modeling of shaft and analysis of the shaft is done by ANSYS software. The stress distribution on shaft is expressed by theoretically and numerically approaches. The theoretical and numerical results data of maximum von-Mises stresses are 92.699MPa and 87.659MPa for gray cast iron. The percentage error is 5%. The yield strength of gray cast iron is 276MPa. The theoretical and numerical results of maximum von-Mises stresses are not exceed the yield strength. Therefore, this design is satisfied.

Indexed Terms – Shaft Design, Bearing Selection, Structural Analysis of Shaft, Maize Sheller

I. INTRODUCTION

Maize is one of the most important cereal crops in the world agricultural economy and it has a source of a large number of industrial products besides its use as human food and animal feed. 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 earning and employs 61.2% of the labour force are contributed. Accordingly, the demand for maize has been increased daily. For thousand of years, most of farmers shell corn by mainly three methods; namely shelling cob grain by hand, hand operated corn sheller and beating by stick method were carried for removing corn kernel from the cob. Above these methods are very laborious and time consuming. Therefore, the use of maize sheller is becoming more and more popular and is the most suitable method for local farmers. The main components of motorized maize shelling machine include inlet hopper, main frame, outlet for corn cob, shaft and bearings, shelling cylinder, spikes or beater for maize seed, concave, blower fan, motor, pulley and belt assembly. The threshing unit which consists of a rotating drum and concave, jointly thresh the grains from the straws. The peg teeth are bolted by screws on the shelling cylinder axially. Before shelling the foliage is removed manually. From the inlet hopper, cobs are fed in between cylinder and concave. Kernels are removed by the action of shelling cylinder spikes which is powered by the shaft rotating from motor pulley and belt transmission. Blower fan blow off the lighter materials, shucks and small pieces of cobs. Clean grains are collected from the discharge chute. Concave clearance and cylinder speed can vary and adjusted as per recommendation.

Naveenkumar D.B states that maize shelling is difficult at a moisture level of above 25 percent. With this moisture content, grain stripping efficiency is very poor with high operational energy and causing mechanical damage to the kernels. A more efficient shelling is achieved when the grain has been suitably dried to 13 percent to 14 percent moisture content. When maize cobs with 13% moisture content were fed to sheller at cylinder rotating speed of 350 rpm, gave higher efficiency of shelling (98.51%) than other combinations. In this design, analysis was expressed with a 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.

Figure 1 . Motorized Maize Shelling Machine (Aung-Paddy Thresher Industrial Zone)

II. METHODOLOGY

In this research, the design parameter is collected from maize sheller with motor power of 1.1kW, measuring the data of the shelling cylinder at Aung-Paddy Thresher Industrial Zone, (Mandalay), Myanmar, and then, calculated the weight of shelling cylinder, angular velocity, shelling power, and shelling torque for the shelling cylinder design. The theoretical and numerical analysis of shelling cylinder are expressed in this paper.

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

A. Design Consideration of Shaft for Maize Shelling Machine

(1). Weight of shelling cylinder, pulley and fan blade:

Weight of shelling cylinder;

$$W_C = \rho\, g\, V_C \quad (1)$$

$$V_C = A_C \times L_C \quad (2)$$

$$A_C = \frac{\pi}{4} \times D_C{}^2 \quad (3)$$

where,
V_c - volume of shelling cylinder (m^3)
ρ - density of cast iron (kg/m^3)
g - acceleration due to gravity (m/s^2)
A_c - area of shelling cylinder (m^2)

Weight of pulley,

$$W_P = \rho\, g\, V_P \quad (4)$$

Weight of fan blade,

$$W_F = \rho\, g\, V_F \quad (5)$$

$$V_F = A_F \times L_F \times n_F \quad (6)$$

where,
V_F - volume of fan blade (m^3)
n_F - number of blades

(2). Pulley drive system:
Angle of contact between the belt and pulley;

$$\theta = (180 - 2\alpha) \times \frac{\pi}{180} \quad (7)$$

$$\sin\alpha = \frac{D2 - D1}{2C} \quad (8)$$

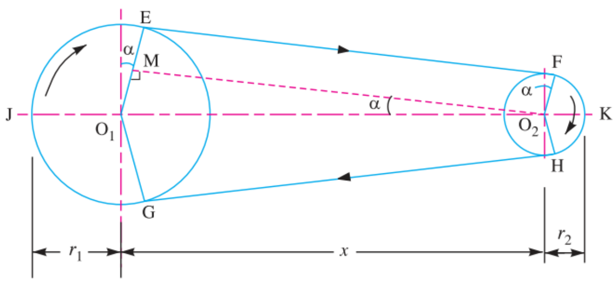

Figure 2. Pulley Drive System

where,
θ - angle of lap of pulley
D_2 - diameter of larger pulley (m)
D_1 - diameter of smaller pulley (m)
C - centre distance between two pulleys

Figure 2 illustrates pulley drive system.

Determination of tight sight and slack sight belt tension;

$$2.3 \log\left(\frac{T1}{T2}\right) = \mu\theta \quad (9)$$

$$P = (T_1 - T_2)\, v \quad (10)$$

$$v = \frac{\pi D1 N1}{60} \quad (11)$$

where;
T_1 - tension of tight sight (N)
T_2 - tension of slack sight (N)
μ - coefficient of friction for rubber (0.12)
P - transmitted power per belt (W)
v - belt speed (m/s)
N_1 - revolution of smaller pulley (r.p.m)

(3). Design consideration of shaft:
ASME Code equation for solid shaft is,

$$d = \left[\frac{16}{\pi\tau}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right]^{\frac{1}{3}} \quad (12)$$

where,
d - diameter of shaft (m)
M_b - maximum bending moment (Nm)
M_t - maximum torsional moment (Nm)
K_b - combined shock and fatigue factor applied to bending moment, K_b =1.5
K_t - combined shock and fatigue factor applied to torsional moment, K_b =1
τ - permissible shear stress (N/mm^2)

For shafts purchased under definite physical specifications the permissible shear stress (τ) may be taken as 30% of the elastic limit in tension (S_y) but no more than 18% of the ultimate tensile strength (S_{ut}). In other words, the permissible shear stress,

$$\tau = 0.3\ S_y \text{ or } 0.18\ S_{ut} \quad (13)$$
(choose smaller value)

The maximum torsional moment acting on the shaft,

$$M_t = \frac{P \times 60}{2\pi N} \quad (14)$$

(4). Bearing selection:
The equivalent bearing load P;

$$P = X\ V\ F_r + Y\ F_a \quad (15)$$

For pure radial load,
$F_a = 0$, $X = 1$, $V = 1$;
$\therefore P = F_r$

where,
P - equivalent bearing load
F_r - actual radial bearing load
F_a - actual axial bearing load
X - radial factor
Y - thrust factor
V - rotating factor

Nominal life in revolution;

$$L = \frac{60NL_h}{10^6} \quad (16)$$

where,
L_h - nominal life in working hour
L - speed in rev/min

Relationship between load and life;

$$L = \left(\frac{C_r}{P}\right)^P \quad (17)$$

where,
L - nominal life in revolution
C_r - basic dynamic capacity
P - equivalent bearing load
P - 3 for ball bearings / (10/3) for roller bearings

Calculation of bearing selection.
$P = F_r = 1465.36$
$L_h = 8000$ hr
N = 302 rpm
L = 144. 96
C_r = 7697.69 N = 7.697 kN

Therefore, bearing number 16005 Single-row Deep Groove Ball bearing is selected.
Inside diameter of bearing =25 mm
Outside diameter of bearing = 47 mm
Face width of bearing = 8 mm

Table 1: Result Data of Shelling Shaft

Parameters	Symbol	Value	Unit
Weight of shelling cylinder	Wc	864	N
Weight of pulley	W_p	652	N
Weight of fan blade	W_F	69.22	N
Speed of cylinder pulley	N_2	302	rpm
Angle of lap of smaller pulley	θ	2.15	rad
Tension in tight sight	T_1	182.335	N
Tension in slack sight	T_2	85.72	N
Maximum bending moment	M_b	140.771	N-m
Maximum torsional moment	M_t	23.187	N-m
Permissible shear stress	τ	82.8	MPa
Diameter of shaft	d	25	mm

Table I shows the calculated weight, diameter and bearing selection of the shelling shaft design used in maize sheller.

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

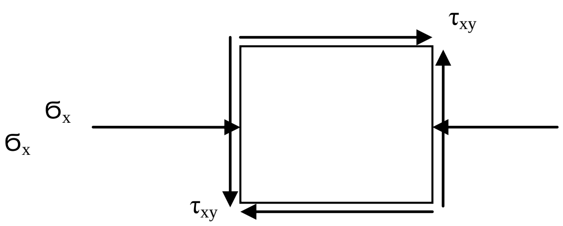

Figure 3. Stress in the x-y plane

Figure 3. illustrates theoretical stress model in x-y plane.

(1) Bending stress for shelling shaft:

$$\sigma_x = \sigma_b = \frac{32M_b}{\pi d^3} \quad (18)$$

(2) Shear stress for shelling shaft:

$$\tau_{xy} = \frac{16M_t}{\pi d^3} \quad (19)$$

The Principle stresses for shelling shaft can be calculated in von-Mises criteria.

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

The von-Mises stress,

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

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

Principle strains:

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

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

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

The effective strain for threshing drum:

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

Table 2: Material Properties of ASTM 40 Gray Cast Iron [1]

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

Table 2 shows the materials properties of ASTM40 gray cast iron for design calculation of the shelling shaft.

Table 3: Theoretical Result of Shelling Shaft

Von-Mises Stresses, σ (MPa)	Effective Strain, $\bar{\varepsilon}$ ($\times10^{-4}$)	Shear Stress, τ (MPa)	Bending Stress, σ_b (MPa)
92.699	6.529	7.56	91.769

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

C. Numerical Analysis of Shaft

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

(1). Model of Shelling Shaft for Maize Sheller:

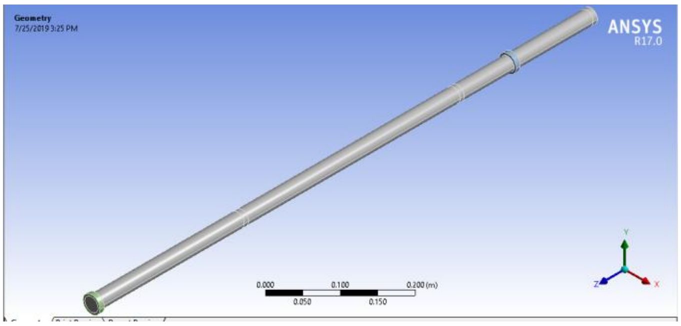

Figure 4. 3D Modeling of Shelling Shaft

Figure 4 shows the model of shelling shaft for maize sheller which is drawn by SolidWorks Software and import to the ANSYS Software.

(2). Meshing of Shelling Shaft:

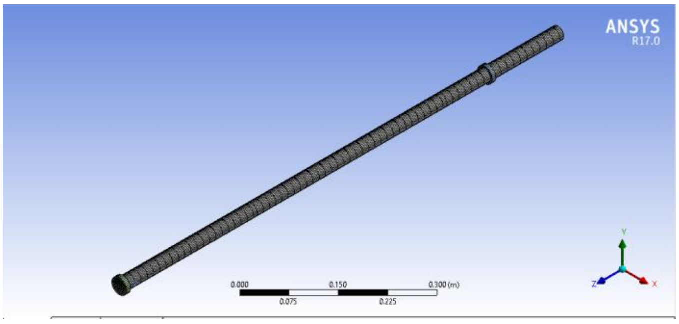

Figure 5. Meshing of Shelling Shaft

Figure 5 shows meshing of shaft by using ANSYS software. The generated mesh is done by fine position to obtain the good quality of mesh. Number of nodes are 27997 and Elements are 5964.

(3). Boundary Condition of Shelling Shaft;

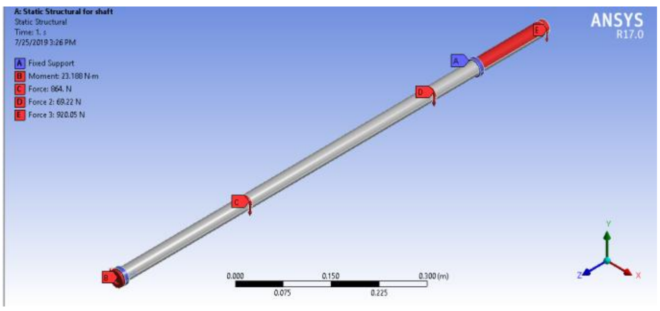

Figure 6. Boundary Condition of Shelling Shaft

Figure 6 shows the boundary condition of shelling shaft. Fixed supports are provided at the bearings on the t shaft. The simulation is carried out by choosing the static condition. The weight of shelling cylinder, pulley, fan blade and torsional moment are acting on the shaft.

(4). Stresses and Strains Analysis of Shelling Shaft:

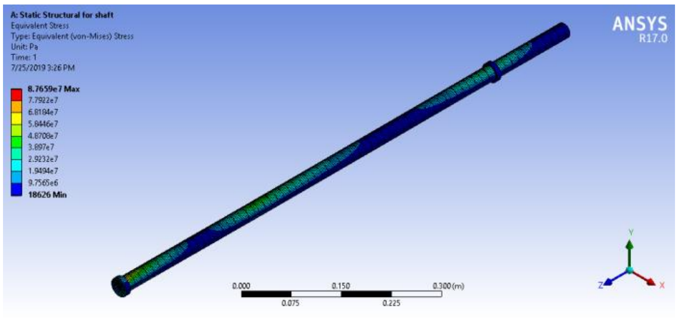

Figure 7. von-Mises Stress Distribution of Shelling Shaft

Figure 7. shows the shelling shaft is applied by force and moment. It can be seen that the von-Mises stress is generated at the support of the shaft is 87.659MPa. And the minimum von-Mises stress is 18626Pa.

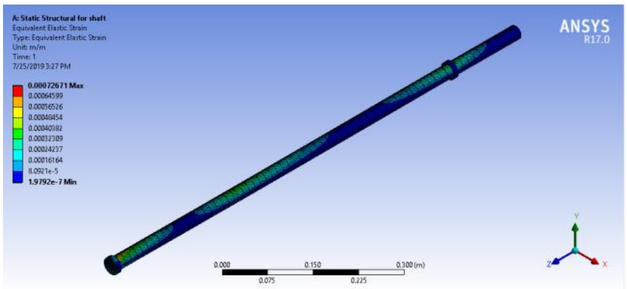

Figure 8. Effective Strain Distribution of Shelling Shaft

Figure 8 shows the effective strain distribution of shelling shaft. The maximum and minimum effective strains are 7.2671×10^{-4} and 1.9792×10^{-7} which occur due to Von-Mises stresses on the shelling shaft.

Table 4. Comparison of Theoretical and Numerical Result of Threshing Drum

Results	Theoretical	Numerical	(%) Deviation
Von-Mises Stress, ϭ (MPa)	92.699	87.659	5
Effective Strain, $\bar{\varepsilon}$ ($\times10^{-4}$)	6.529	7.2671	10

Table 4 shows the comparison of theoretical and simulation results for gray cast iron ASTM40. The error percent of Von-Mises stresses and effective strains are 5% and 10% respectively.

III. RESULT AND DISCUSSION

In this paper, weight of shelling cylinder, pulley, fan blade, speed of cylinder pulley, angle of lap of smaller pulley, tension in the tight sight and slack sight, shaft diameter and bearing selection, maximum bending moment and torsional moment and permissible shear stress were calculated. The maximum bending moment, maximum torsional moment, permissible shear stress and weight of shelling cylinder, pulley and fan blade are 140.771N-m, 23.187N-m, 82.8MPa and 864N, 652N, 69.22N design used in maize sheller. The von-Mises stress, the effective strain, shear stress and bending stress are calculated by theoretically in the shelling shaft design. The theoretical result of maximum von-Mises stress is 92.699 MPa, the numerical result of maximum von-Mises is 87.659MPa. If the stress distribution from numerical analysis is larger than the theoretical, the shelling shaft can be used for longer life time. After checking the results, the theory and simulation results are nearly the same. Therefore, these values are not exceeded the yield strength of gray cast iron 276MPa. So, this design is satisfied. The model of shelling shaft design is drawn by SolidWorks software and structural analysis is simulated by ANSYS software.

IV. CONCLUSION

In this paper, the shelling shaft is designed with 25mm diameter and 942mm length of maize sheller and collected the specification data from Aung Paddy Thresher Industrial Zone at Mandalay. The model of shelling shaft design is drawn by SolidWorks software and structural analysis is simulated by ANSYS software. The shelling shaft is rotating with 302rpm and it can apply of weights and moments which are calculated. The maximum von-Mises stress occurred at the threshing supports and the minimum value of von-Mises stress was found at the others. While the maximum von-Mises stress is 87.659MPa, the maximum effective strain value is 7.2671×10^{-4}. The theoretical result is included between the ranges of the numerical result which are not exceed the yield strength of gray cast iron 276MPa. So, this design is satisfactory.

V. ACKNOWLEDGEMENT

The first author wishes to acknowledge her deepest gratitude to her parents, to her first batch CoE student Maung San Mya Tun and her relatives and friends to carry out this research. And then, the author expresses his heartfelt gratitude to U Nyi Hla Nge Foundation, for his finances to construct this machine.

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