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Structural Analysis of Shafts and Bearings for Paddy Thresher

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Abstract – In this paper, an axial-flow type paddy thresher 5.97 kW with 450 mm cylinder diameter and 1028.7 mm cylinder length was designed. The main objective of this study is to analyze structural behaviors of threshing drum shaft, shaker shaft, fan shaft and to select the bearings. The major components of the machine are threshing, separating and cleaning units. The effects of threshing cylinder and concave, fan requirements and power transmission system which includes belt and pulley design, shafts design, and bearings design, were investigated. Shaft design consists mainly of the determination of the correct shaft diameter to ensure satisfactory strength when the shaft is transmitting power under various load conditions. The shaft is generally acted by torsional moment and force. The theoretical result of von-Mises stress is 62 MPa and effective strain is 4.032×10^{-4} for gray cast iron. Numerical result of von-Mises stress is 52.8 MPa and effective strain is 3.934×10-4. Percent deviation of von-Mises stress is 17% and effective strain is 2%. The structural analysis of threshing drum shaft is also accomplished in this paper and is analyzed by using ANSYS Workbench 17.0 on the basis of Finite Element Method.

Indexed Terms – **axial-flow, power transmission system, threshing drum, tensional moment, von-Mises stress**

I. INTRODUCTION

Rice is after wheat; the most widely cultivated in the world and is the most important food crops for almost half of the world's population. Paddy thresher is used to separate and is the most essential requirement for human's life. Many farmers grow paddy but could not afford the cost of the imported threshing machines because of their cost. Therefore, grain was threshed by hand with flails and is still being done by traditional methods like drum beating, bullock treading and tractor over harvested crop that results into low efficiency, was very laborious and time consuming. So, use of paddy thresher is becoming more and more popular and manual thresh is becoming discarded all over the country. Threshing is an integral part of the process, in which the rice that has been harvested is threshed to separate the grains from the rice straw. It is also capable of reducing time wastage, reduction in broken grains and separation of the stalk [5].

Myanmar is one of the agricultural countries. So utilization of modernization farm machine is needed to help agricultural production of the country. Many of additional jobs need to be created every year in rural area. Therefore, in the coming year, agricultural engineering has to play a major role in developing production and productivity appropriate mechanization inputs. In order to mechanize this process, paddy threshers have been developed hold-on or throw-in type of feeding the unthreshed paddy. In the hold-on type, paddy straws are held stationary while threshing is done by the impact on the particle from cylinder bars spikes or wire loops. In the throw-in type of machines, whole paddy straws are fed into the paddy thresher and a major portion of the grain is threshed by the initial impact of the bars or teeth on the cylinder. The initial impact also accelerates the straw and further threshing is accomplished as the moving particles hit the bar and the concave [5]. The objective of the study is to analyze structural behaviors of shafts and to select the bearings. Paddy thresher is comprised of threshing drum, shafts, bearings, fan, pulley, sieve, frame and the various components and is shown in Figure.1.

Figure.1 Automatic Paddy Thresher

Threshing mechanism is the main part of the paddy thresher. The basic operational functions of a thresher may be divided as follows.

- Threshing the grain from the stalk or stem
- Separating the grain from straw
- Cleaning the grain by removing chaff and other foreign matters

A. Shafts

Shaft is a rotating element which is used to transmit power from one place to another. This is the component that provides power to all the moving components in the threshing unit. In order to transfer the power, pulleys, gears, flywheels and sprockets are mounted on it. The following design consideration must be adhered to: the shaft should be strong enough to carry the weight of the threshing drum, teeth and the overall weight of this machine.

B. Fan

The fan blows a stream of air across the falling grain, removing dust and fines and blowing them away. It is made to rotate at a speed that is two times higher than the speed of the threshing cylinder. It is attached to the rear of the threshing machine and opposite the slope of the screen. Figure.2. shows a centrifugal fan and is comprised of four straight sheets attached to the shaft. This fan separates the straw particles and the grain.

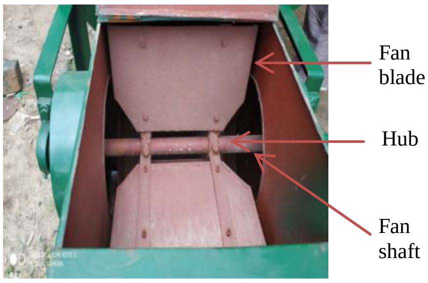

Figure.2 Arrangement of Fan Sheet

C. Bearings

Bearing is a mechanical element that constrains relative motion and reduces friction between moving parts. Single-row deep-groove ball bearings were employed for the shaft because of their advantages: they compact in size, easy to mount and maintenance cost.

There are two types of bearing. They are;

1) Mechanical contact bearing: Sliding, Rolling and Flexural bearings
2) Non-contacting bearing: Fluid film and Magnetic bearings

II. METHODOLOGY

The threshing machine used in the study takes power from the engine and cleans out the grains by removing straw particles . The modeling of the shafts of threshing machine analyzed in the study was performed by using Solidworks 2016 software.The whole work of designing and fabrication was done under following phases: design considerations, designing of shaft and fan using Solidworks software. Structural behaviors of shafts are analyzed by using ANSYS software.

III. DESIGN OF SHAFTS AND SELECT BEARINGS

In paddy thresher, threshing drum shaft is the most important part of the whole machine because it takes power from the used engine and performs threshing process and transmits power to the other shaft. Shaker shaft is to give oscillating action to the sieve and screen by means of an eccentric plate cam action. Fan shaft is for grain cleaning process by means of a fan.

Design of shafts of material based on strength is controlled by maximum shear theory. For solid shafts, the ASME code equation is;

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (1)$$

where;

S_s - tensile strength of gray cast iron for shaft
K_b - combined shock and fatigue factor applied to bending moment
K_t - combined shock and fatigue factor applied to torsional moment
M_t - maximum torsional moment (N-m)
M_b - maximum bending moment (N-m)
d - diameter of shaft (m)

Maximum bending moment on the shaft

$$M_{b(max)} = \sqrt{{M_V}^2 + {M_H}^2} \qquad (2)$$

The torsional moment acting on the shaft

$$M_t = \frac{9550 \times kW}{rpm} \qquad (3)$$

For rotating shafts, when load is suddenly applied;

K_b = 1.5 to 2.0;
K_t = 1.0 to 1.5.

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 not more than 18% of the ultimate tensile strength (S_{ut}). In other words, the permissible shear stress,

$\tau = 0.3\, S_y$ or $0.18\, S_u$ (Choose smaller value).

To calculate shaft design of the machine, it is required to estimate load applied on the shafts. In this machine, the load exerted on it are pulleys and other components. Figure.3. illustrates the bending moment diagram of threshing drum shaft.

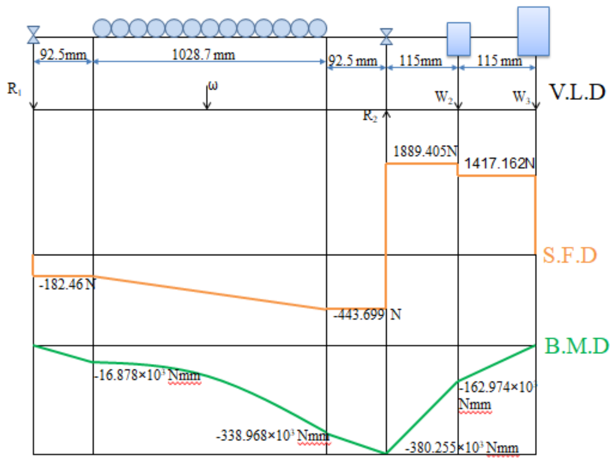

Figure.3 Bending Moment Diagram of Threshing Drum Shaft

TABLE I CALCULATION RESULTS FOR DIAMETER OF SHAFTS

Shafts	Value	Unit
Threshing Drum Shaft	38	mm
Shaker Shaft	26	mm
Fan Shaft	25	mm

Table I shows the calculation results for the diameter of threshing drum shaft, diameter of shaker shaft and diameter of fan shaft.

Bearings selection,

Single-row deep-groove ball bearings were employed for the shaft because they are low maintence cost and do not require starting torque.The following relations were used in designing the bearings:

$$P = XVF_r + YF_a \quad (4)$$

where;
P - equivalent load or design load (N)
V - rotation factor (1 for inner race rotating)
F_r - applied radial load (N)
F_a - applied thrust (N)
X - radial factor
Y - thrust factor

Bending radial force,

$$F_r = \sqrt{R_V{}^2 + R_H{}^2} \quad (5)$$

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

where;
L - norminal life in million of revolution
L_h - norminal life in working hours
n - speed in rpm

Relation between load and life,

$$L = \left(\frac{C_r}{P}\right)^p \quad (7)$$

where;
p - 3 for ball bearing
C_r - basic dynamic capacity

TABLE II SINGLE-ROW DEEP-GROOVE BALL BEARING SELECTION FACTOR[12]

Bearing	Dynamic Load, kN	Inner Dia:m	Outer Dia: mm	Width, mm	Max: Speed, rpm
Drum Shaft Bearings	14	38	66	15	639
Shaker Shaft Bearing	3.8	26	37	7	639
Fan Shaft Bearing	6.6	25	42	9	1702

In this thresher, single row deep grove ball bearings are used. Table II shows the selection of single-row deep-groove ball bearings.

IV. EVALUATING OF WEIGHT OF FAN

Fan is located frame bottom just below the cylinder and is mounted on shaft. This fan separates the shells and the grains. The section of fan blade is shown in Figure.4.

For blade,
Number of blade = 4
Length of fan blade = 10.2 m

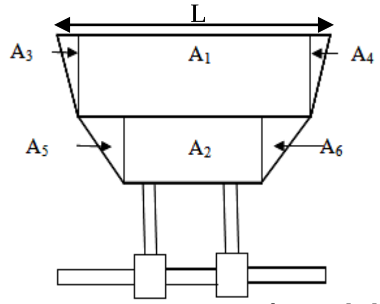

Figure.4 Section of Fan Blade

TABLE III SPECIFICATION DATA OF FAN

Parameters	Symbol	Value	Unit
Density of Fan for Gray Cast Iron	ρ	7200	kg/m^3
Inner Diameter of Hub	D_i	25	mm
Outer Diameter of Hub	D_o	42.7	mm
Length of Hub	L_h	31.75	mm
Number of Hub	n_{hub}	2	-

Table III shows the specification data of fan blade and the hub. Table IV illustrates the calculation results for fan.

Weight of fan,

$$W = \rho g V \quad (8)$$

where;
ρ - density of fan blade (kg/m^3)
V - volume of the material used for fan (m^3)
g - acceleration due to gravity (m/s^2)

$$\text{Mass of fan blade, } m = \frac{W}{g} \quad (9)$$

TABLE IV CALCULATION RESULTS FOR FAN

Parameters	Value	Unit
Weight of Fan Blade	129.68	N
Weight of Hub	3.25	N
Total Weight of Fan and Hub	132.93	N
Total Mass of Fan and Hub	13.55	kg

V. STRUCTURAL ANALYSIS OF DRUM SHAFT

Stress can be defined as the internal resistance offered by a unit area of a material to an externally applied load. The basic types of stress analysis are torsional shear stresses, bending stresses, and stresses due to combined torsional and bending loads.

Bending stress

$$\sigma_x = \sigma_b = \frac{32M_b}{\pi d^3} \quad (10)$$

where;
M_b - Resultant bending moment on the shaft (N-m)
d - Diameter of shaft (m)

$$\tau_{xy} = \frac{16M_t}{\pi d^3} \qquad (11)$$

where;
M_t - torsional moment on the shaft (N-m)
τ_{xy} - shear stress (N/mm^2)

Structural behaviour (von-Mises stress, effective strain and deformation) of shafts are calculated by the theoretical approach. Threshing drum shaft is made of gray cast iron. Shear stress also occur due to friction as shown in Figure 5.

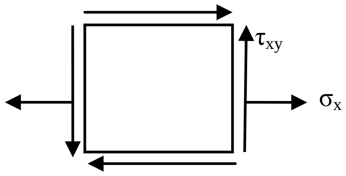

Figure.5 Stress in x-y Plane

Maximum principal stress for the shafts can be calculated in von-Mises critea.

$$\sigma_1, \sigma_2 = \frac{1}{2}\left[(\sigma_x + \sigma_y) \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^{\ 2}}\right] \qquad (12)$$

Where;σ_1 - maximum principal stress (N/m^2)
σ_2 - minimum principal stress (N/m^2)

Von-Mises stress or effective strain,

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \qquad (13)$$

The relation between stress and strain is called a constitutive equation. Hooke's law would be show that;
Principal strains

$$\varepsilon_1 = \frac{1}{E}[\sigma_1 - \upsilon(\sigma_2 + \sigma_3)] \qquad (14)$$

$$\varepsilon_2 = \frac{1}{E}[\sigma_2 - \upsilon(\sigma_1 + \sigma_3)] \qquad (15)$$

$$\varepsilon_3 = \frac{1}{E}[\sigma_3 - \upsilon(\sigma_1 + \sigma_2)] \qquad (16)$$

For the von-Mises criterion, the effective strain of threshing drum shaft is;

$$\bar{\varepsilon} = \left[\frac{2}{3}\left(\varepsilon_1^{\ 2} + \varepsilon_2^{\ 2} + \varepsilon_3^{\ 2}\right)\right] \qquad (17)$$

Table.V illustrates the material properties of ASTM40 gray cast iron.

TABLE V MATERIAL PROPERTIES OF ASTM40 GRAY CAST IRON

Material properties	Value	Unit
Young Modulus, E	124	GPa
Poisson Ratio, υ	0.27	-
Yield Strength, S_y	276	MPa
Density, ρ	7200	Kg/m^3

Table VI illustrates theoretical result of stress and strain calculationn of threshing drum shaft for gray cast iron.

TABLE VI RESULT FOR STRESS AND STRAIN FOR DRUM SHAFT

Material	Von-Mises stress(MPa)	Effective strain
Gray cast iron	63	4.032×10^{-4}

VI. NUMERICAL ANALYSIS OF THRESHING DRUM SHAFT

Threshing drum shaft is a solid cylindrical shaft which is fixed at one end and on the other end which a torsional moment of 89 Nm is applied. The drum shaft is modelled in Solidworks software. The material for drum shaft is gray cast iron.

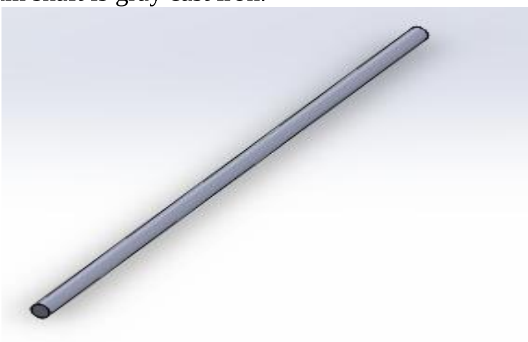

Figure.6 3D Model of Threshing Drum Shaft

Figure.6 shows the model of threshing drum shaft for paddy thresher. This shaft is drawn by Solidworks software.

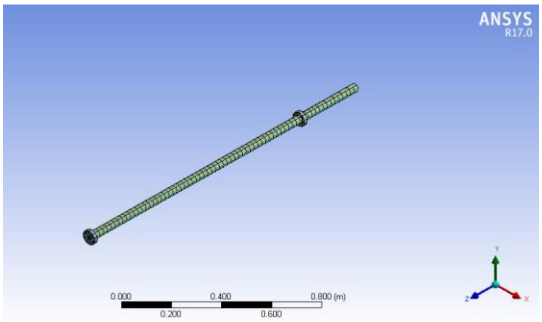

Figure.7 Mesh of Threshing Drum Shaft

Figure.7 shows the mesh of threshing drum shaft. To generate the mesh model of drum shaft, the relevance center is fine, element size is default and smoothing is fine This mesh model has 1223 nodes and 1002 elements.

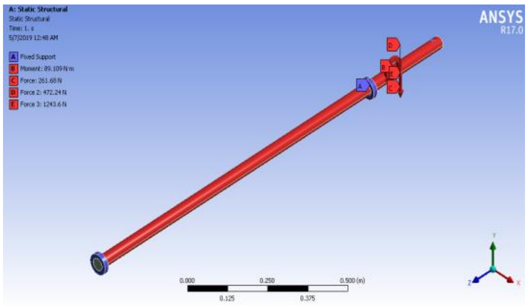

Figure.8 Boundary Condition of Threshing Drum Shaft

In the static structural analysis, the boundary condition is regarded. The locations of fixed support are the surface of bearing and the tip. Applying the force to the surface of the shaft and torsional moment at the outer surface of the shaft .The boundary condition and fixed support of the shaft are shown in Figure.8.

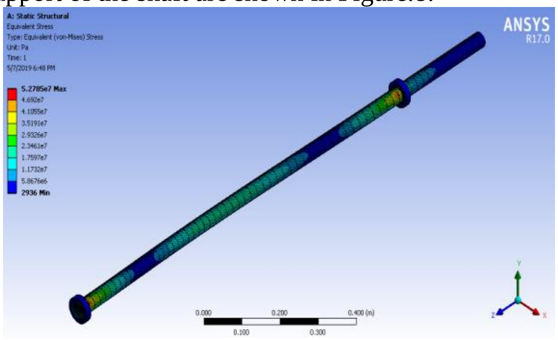

Figure.9 Von-Mises Stress for Gray Cast Iron

Figure.9 shows the von-Mises stress affected on the drum shaft for gray cast iron. It can be noticed that the maximum stress is generated at the root of the section is 52.8×10^{6}Pa and the minium stress is 2.936×10^{3}.

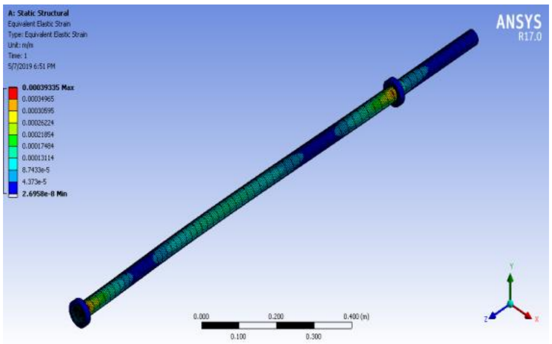

Figure.10 Effective Strain of Threshing Drum Shaft

Figure.10 shows the analysis of the effective strain affected on the drum shaft for gray cast iron. The maximum elastic strain is 3.934×10^{-4}. and the minimum effective strain is 2.695×10^{-8}.

VII. Results and Discussion

Material characteristics of the system model and the analysis depends on time were performed the stress application. The comparison of theoretical and simulation results of threshing drum shaft are shown in Table V. Structural analysis (von-Mises stress, effective strain) of drum shaft gives close results by theoretical and numerical approach. In this table, percent deviation of von-Mises stress is 17% and effective strain is 2%. Gray cast iron material design is safe and von-Mises stress is within the yield stress of material. Finally, the results that will be obtained by using these types of software in agricultural machinery production will increase the production quality and the same time provide economic support by preventing the use of unnecessary material.

TABLE VII Simulation Result of Drum Shaft

Material	Theoretical Result of Von-Mises stress(MPa)	Simulation Result of Von-Mises stress(MPa)	deviation (%)
Gray Cast Iron	62	52.8	17

Table VII shows the results data of von-Mises stress for gray cast iron and compared the results data of theoretical and simulation.The percentage error is 17%..

TABLE VIII Simulation Results of Drum Shaft

Material	Theoretical Result of Effective Strain($\times10^{-4}$)	Simulation Result of Effective Strain($\times10^{-4}$)	deviation (%)
Gray Cast Iron	4.032	3.934	2

Table VIII shows the comparison of effective strain for theoretical and simulation results for gray cast iron. The percent error is 2%.

VIII. Conclusion

In this paper total power required by the machine was 8 hp operating at 1500 rpm. This paddy thresher reduces human labour involved in threshing at an affordable cost and reduces the time used for threshing operation. The shaft and fan are drawn by Solidworks software and is analyzed by ANSYS 2017 software.The design for drum shaft is calculated by using ASME code equation. In this paper, structural behaviours (von-Mises stress, effective strain) of drum shaft gives close results by theoretical and numerical approaches. This design paddy thresher is electric motor powered, 2 man/machine and increase threshing efficiency and productivity. It is easily reparable and can be used for both commercial and domestic purposes. This machine is capable of threshing, separation of stalk from the grains, thereby, giving a better method of threshing than the traditional methods.

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