Structural Analysis of Shafts and Performance Test of Paddy Thresher

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Abstract- The main objective of this study is to design the threshing drum shaft, shaker shaft, fan shaft and to analyze structural behaviors on these shafts and then to select the bearings. In this study, an axial-flow type paddy thresher (5.97kW) with 450mm cylinder diameter and 1028.7mm cylinder length was designed. This paper discusses about the shafts of axial-flow type paddy thresher produced in Aung Paddy Thresher Industrial Zone at Mandalay. The major components of the machine are threshing, separating and cleaning units. 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 models of these shafts are drawn by using Solid Works software. The stress distribution on these shafts is expressed by theoretical and numerical approaches. The theoretical and simulation results data of von-Mises stress for shaker shaft is 53.528 MPa and 48.048 MPa, for fan shaft is 43.077 MPa and 38.218 MPa. Percent deviation of shaker shaft and fan shaft is 8% and 10 % respectively. Von-Mises stresses of these shafts do not exceed yield strength value. In performance test, mean threshing capacity at different drum speed is also calculated. So, this design is satisfied.

Index Terms- Axial-flow paddy thresher, Structural analysis of shaker shaft and fan shaft, Performance test

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 three 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

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

Among them, threshing mechanism is the main part of the paddy thresher.

II. METHODOLOGY

In this research, design parameter is collected from paddy thresher (5.97 kW and measuring dates of threshing drum shaft, shaker shaft and fan shaft at Aung Paddy Thresher Industrial Zone, (Mandalay). The modeling of the shafts of threshing machine analyzed in the study was performed by using Solid works 2016 software. The whole work of designing and fabrication was done under following phases: design considerations, designing of shafts using Solid works software. Structural behaviors of shafts are analyzed by using ANSYS software. Theoretical and numerical analysis of these shafts are expressed in this paper.

A: Design Considerations for Shafts
B: Theoretical Analysis of Shafts
C: Numerical Analysis of Shafts
D: Performance Test of Paddy Thresher

A. Design Considerations for Shafts

Shaft is a rotating element which is used to transmit power from one place to another. 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. The function of the 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;

The ASME Code equation for a solid shaft,

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

Where;

S_s = Tensile strength of gray cast iron,
K_b = Combined shock and fatigue factor applied to bending moment
K_t = Combined shock and fatigue factor applied to tensional moment
M_t = Maximum tensional moment (Nm)
M_b = Maximum bending moment (Nm)

The Torsional Moment Acting on the Shaft

$$M_t = \frac{9550}{rpm} \times kW \qquad (2)$$

For rotating shafts, when load is suddenly applied; (Rob)
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).

TABLE I Calculation Results for Shaker Shaft

Parameters	Symbol	Value	Unit
Weight of Larger Pulley and Belt Tension for Vertical Component	W_{11}	86.205	N
Weight of Total Belt	W_{12}	253.23	N

Tension for Horizontal Component			
Weight of Eccentric Cam for Vertical Component	W_{21}	145	N
Weight of Eccentric Cam for Horizontal Component	W_{22}	540.918	N
Maximum Bending Moment	M_b	85.771	Nm
Maximum Torsional Moment	M_t	89.109	Nm
Diameter of Shaker Shaft	d	0.026	m

TABLE II Calculation Results for Fan Shaft

Parameters	Symbol	Value	Unit
Weight of Pulley and Total Belt Tension for Vertical Component	W_{11}	186.205	N
Total Belt Tension for Horizontal Component	W_{12}	258.235	N
Maximum Torsional Moment	M_t	33.47	Nm
Maximum Bending Moment	M_b	68.448	Nm
Diameter ff Fan Shaft	d	0.026	m

TABLE III Material Properties of ASTM40 Gray Cast Iron

Material Properties	Value	Unit
Young Modulus	124	GPa
Poisson Ratio	0.27	-
Yield Strength	276	MPa
Density	7200	kg/m^3

B. Theoretical Analysis of Shafts

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

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

Where;

M_b - Resultant bending moment on the shaft, N/m

d - Diameter of shaft, m

$$\tau_{xy} = \frac{16M_t}{\pi d^3} \quad (4)$$

Where;

M_t - torsional moment on the shaft,Nm

τ_{xy} - shear stress

Structural behavior (von-Mises stress, effective strain and deformation) of shafts are calculated by the theoretical approach. Shear stress also occurs due to friction as shown in Figure 2.

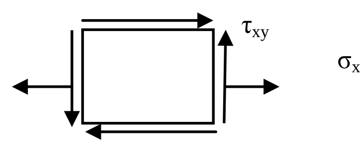

Figure.2.Stress in x-y Plane

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

$$\sigma_1, \sigma_2 = \frac{1}{2}\left[\left(\sigma_x + \sigma_y\right) \pm \sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}{}^2}\right] \quad (5)$$

Where;σ_1 - maximum principal stress, N/m^2

σ_2 - minimum principal stress, N/m^2

Von-Mises stress or effective strain,

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2} \quad (6)$$

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

$$\varepsilon_1 = \frac{1}{E}\left[\sigma_1 - \upsilon\left(\sigma_2 + \sigma_3\right)\right] \quad (7)$$

$$\varepsilon_2 = \frac{1}{E}\left[\sigma_2 - \upsilon(\sigma_1 + \sigma_3)\right] \qquad (8)$$

$$\varepsilon_3 = \frac{1}{E}\left[\sigma_3 - \upsilon(\sigma_1 + \sigma_2)\right] \qquad (9)$$

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

$$\bar{\varepsilon} = \left[\frac{2}{3}\left(\varepsilon_1^{\ 2} + \varepsilon_2^{\ 2} + \varepsilon_3^{\ 2}\right)\right] \qquad (10)$$

TABLE IV Theoretical Result for Shafts

Shaft	Diameter(m)	Effective Strain	von-Mises Stress (MPa)
Shaker Shaft	0.026	0.000371	53.528
Fan Shaft	0.026	0.000302	43.077

C. Numerical Analysis of Shafts

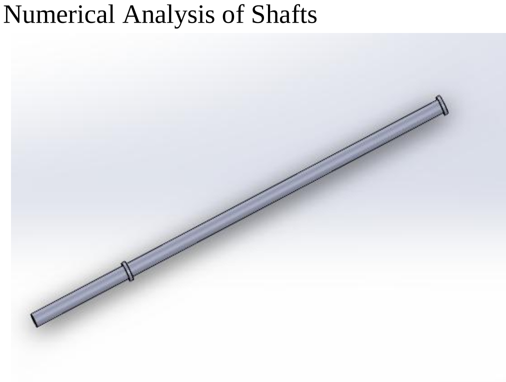

Figure.3. 3D Model of Shaker Shaft

Figure.3. shows the model of threshing drum shaft for paddy thresher. This shaft is drawn by Solidworks software.

Figure.4. shows the mesh of shaker shaft. This mesh model has 1323 nodes and 1522 elements.

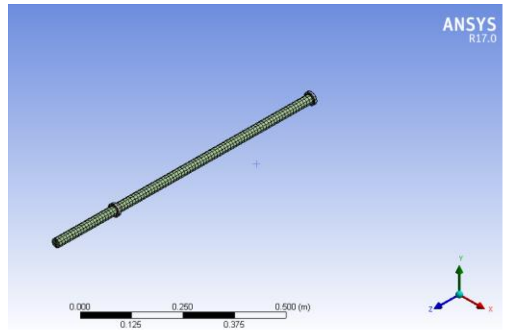

Figure.4. Meshing of Shaker Shaft

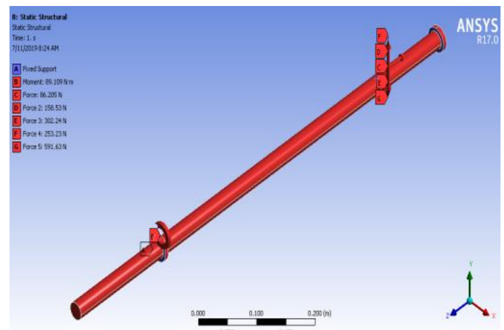

Figure.5. Boundary Condition of Shaker Shaft

In the static structural analysis, the boundary condition is regarded. The locations of fixed support are the surface of bearing and the tip.

Figure.7. shows the analysis of the effective strain affected on the drum shaft for gray cast iron. The maximum elastic strain is 3.41×10^{-4} and the minimum effective strain is 3.23×10^{-7}.

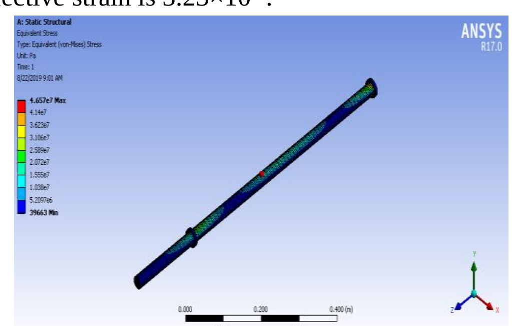

Figure.6. Von-Mises Stress of Shaker Shaft

Figure.6. shows the von-Mises stress affected on shaker shaft for gray cast iron. It can be noticed that the maximum stress is generated at the root of the section is 46.57×10^{6}Pa and the minium stress is 39.66×10^{3}.

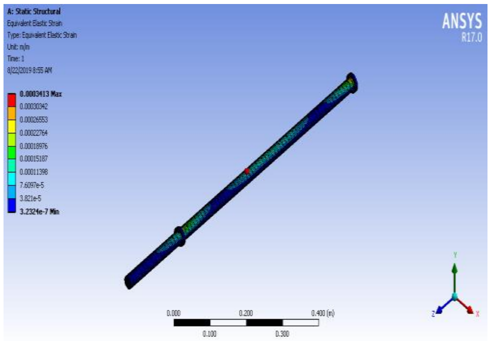

Figure.7. Effective Strain of Shaker Shaft

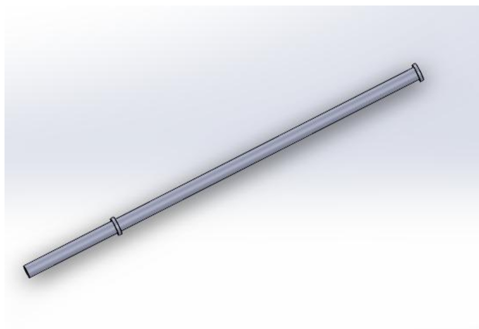

Figure.8. 3D Model of Fan Shaft

Figure.8. shows the model of fan shaft for paddy thresher. This shaft is drawn by Solid works software.

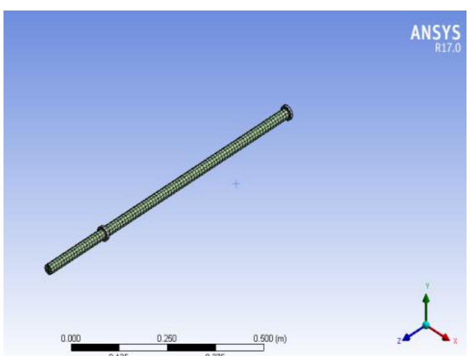

Figure.9. Meshing of Shaker Shaft

Figure.9. shows the mesh of shaker shaft. This mesh model has 1245 nodes and 1433 elements.

In the static structural analysis, the boundary condition is regarded. The locations of fixed support are the surface of bearing and the tip.

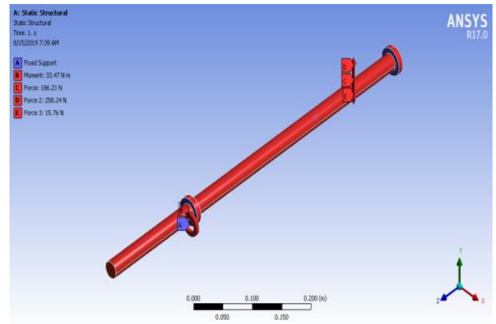

Figure.10. Boundary Condition of Fan Shaft

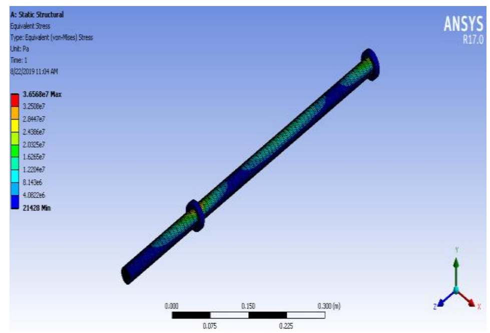

Figure.11. Von-Mises Stress of Fan Shaft

Figure.11. shows the von-Mises stress affected on shaker shaft for gray cast iron. It can be noticed that the maximum stress is generated at the root of the section is 46.57×10^{6}Pa and the minium stress is 39.66×10^{3}.

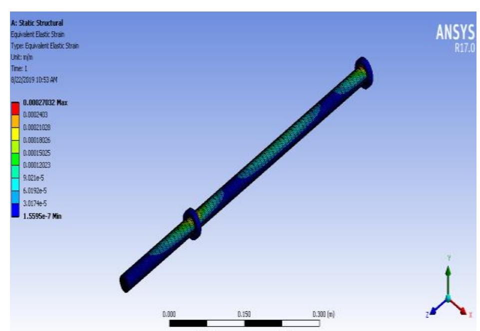

Figure.12. Effective Strain of Fan Shaft

Figure.12. shows the analysis of the effective strain affected on fan shaft. The maximum effective strain is 2.7×10^{-4} and the minimum effective strain is 1.559×10^{-7}.

D. Performance Test of Paddy Thresher

Threshing Capacity (T_c)

$$T_c = \frac{W_t}{T}$$

Where;

T_c = Threshing capacity (kg/min)

W_t = Weight of grains at the grain outlet (kg)

T = Time Taken to thresh

TABLE V Results Data of Performance Test

Feed Rate of Paddy (kg)	Time Taken (s)	Speed (rpm)	Threshing Capacity(kg/hr)
50	300	600	300
50	180	800	500
50	120	1000	750
50	110	1200	660

Figure.13. could be seen that drum speed of 600rpm recorded the least threshing capacity of 300kg/hr whilst the highest threshing capacity 750 kg/hr was recorded at 1000 rpm drum speed.

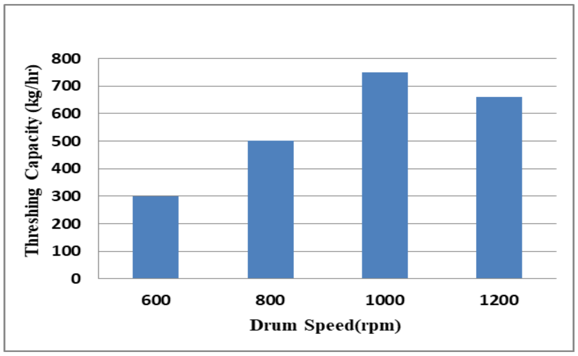

Figure.13. Mean Threshing Capacity at Different Drum Speed

III. 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 shaker shaft gives 10% and 8%. Structural analysis (von-Mises stress, effective strain) of fan shaft gives 11% and 10% respectively. ASTM 40 gray cast iron material design is safe and von-Mises stress are within the yield stress of material. According to the performance test result, the highest threshing capacity of 750kg/hr was recorded at 1000rpm drum speed. Threshing capacity depends on crop conditions and machine operational parameters and the feeding rate of materials into the grain inlet. Threshing capacity generally increased with increasing drum speed.

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 provides economic support by preventing the use of unnecessary material.

TABLE VI Comparison of Theoretical and Numerical Results for Shafts

Shafts	Theoretical Result of von-Mises stress(MPa)	Simulation Result of von-Mises stress(MPa)	deviation (%)
Shaker Shaft	53.528	48.048	10
Fan Shaft	43.077	38.218	11

TABLE VII Comparison of Theoretical and Numerical Results for Shafts

Shafts	Theoretical Result of Effective Strain($\times 10^{-4}$)	Simulation Result of Effective Strain($\times 10^{-4}$)	deviation (%)
Shaker Shaft	3.716	3.426	8
Fan Shaft	3.024	2.694	10

IV. CONCLUSION

In conclusion, this paddy thresher reduces human labor involved in threshing at an affordable cost and reduces the time used for threshing operation. Total power required by the machine was 8hp operating at 1500 rpm. The shaft and fan are drawn by Solid works software and is analyzed by ANSYS 2017 software. The design for drum shaft, shaker shaft and fan shaft is calculated by using ASME code equation .In this study, structural behaviors (von-Mises stress, effective strain) of these shafts give close results by theoretical and numerical approaches. This design paddy thresher is electric motor powered 2man/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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