Design, Fabrication and Testing of Hammer Thresher

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ABSTRACT

Mini combine harvester needs a thresher that paddy and straw inserted into thresher room. We desing Hammer thresher as a part of the mini combine harvester. The research seeks to make a motorized rice thresher that paddy and straw inserted into thresher room. The concept of the thresher emanated from the working principles of the hammer mill mechanism, but the operating system is continuous. The result shows a rice thresher with threshing hammer of diameter 350 mm and length 500 mm, a threshing hammer shaft of diameter 25.4 mm. we design Components of the machine, and it make a prototype. The power requirement of the machine was 1 HP. When shaft thresher rotates, it will produce a beating, friction and shaking. This process can separate grain from rice straw and panicles respectively. The capacity of this machine is 132.1-168.0 kg rice per hour. Therefore, the speed of shaft rotation and area of straw chute affected threshing efficiency and rice quality.

Key Words: hammer thresher, paddy, straw, efficiency

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INTRODUCTION

The process of removing grains from the panicles of crops like rice, sorghums, wheat, beans, guinea corn is known as threshing. This step requires machine to make more efficient that called thresher. Commonly, the traditional farmers in Indonesia do not have the financial ability and large land size into large plantations business. In fact, modern mechanization commonly use in Europe, America and big Asian farms. Ajavi et al. (2014). There are two types of thresher based on the driving tool that are (a) manually using the pedal (pedal thresher) and (b) Driven with the engine (power thresher).

The use of thresher in harvesting cannot be separated with the development of new varieties of short-lived and easy to fall out. Thresher machine is also known as Power Thresher is a type of thresher machine that has proven reliable and very compatible with various kinds of paddy fields in Indonesia. This thresher machine has been widely used by farmers throughout the archipelago because of its practical advantages and easily transferred from the other one land it operated with diesel-powered engines. In Indonesia thresher became known among the farmers in the 70's. At the start of IRRI (International Research Rice Institute) introduced thresher in Indonesia. Previously paddy threshing was done manually, that is old paddy plant, at the bottom cut. Paddy is cut using a sickle. Then the paddy stalk is held by hand, and the panicle of paddy is struck against the hard object/bamboo, so that the grain removes from the panicle. This traditional method produces a high loss/inefective, because it will bounce the grain everywhere. Singh and Vinay (2014) mentioned that in India, threshing of paddy is manual. It was beating out the grains with a stick or rubbing out under the feet, both of which need time and labor intensive. Beside paddy threshing can use an animal. Animal trampling is treading a layer of 15 to 20 cm thick of paddy Amare *et. al*. (2015).

The thresher design in Indonesia in general/homogen, is almost the same that there is a cylinder that rotates and given serrations on the surface of the cylinder. The cylinder rotates with a rotational speed of 100-400 rpm. The rate of cylinder 100 rpm is a cylinder driven by humans, while the cylinder with 400 rpm rotation is driven with 5 HP engine. This type of thresher is operated using a paddy stem cut 10 cm above the ground with a sickle or mower. Then the base of the paddy stem is held by hand, and the end of the rice stalk is placed over the rotating cylinder. Separating the grain from panicle was with the mechanism hit and rubbed.

Thresher design in Indonesia as above cannot be used with the way the panicle and stalks are inserted into the thresher. Thresher by inserting the panicle and stalk into the thresher chamber will lighten the workload of the labor, besides of this design is required to for designing the mini combine harvester that stalks and paddy panicle into the thresher room. The mini combine harvester is needed by farmers in Indonesia now, because a farmer in Indonesia posses the average farm size is less than 0.4 ha. Singh *et. al*. (2008) mentioned that this limits rice production to around 400 kg per household. Due to the low result and income, farmers cannot afford costly, and high-capacity paddy combine harvester. Large-capacity threshers are inappropriate and even sophisticated, but Indonesia farmer can not adopt the small-sized Japanese harvesting equipment immediatly Quick (1998). In Indonesia, The goverment introduce a big combine harvester in 90's, but farmers can not accept the machine. Rice is grown in less than 1 ha, considering efficiency and cost is not suitable for mechanical harvesting and threshing, particularly in small fragmented land holdings Hussain (1982). Hammer thresher operates to release the grain from it is panicle like a hammer mill mechanism. Ajaka and Adesina (2014) reported that the general design hammer mill was based on the process of allowing a strong and durable metallic object inform of hammers to beat any material that obstructs its way during operation, thereby resulting into breakage of the material which can also be referred to as size reduction in comminution. But the hammer thresher uses a rubber material on the tip instead of metal. It is intended that the impact on rice will be reduced. Harbi et al. (2012) reported that the hammer thresher added a curve plate at the top of the wall and drove rice straw out to a rice straw discharge hole above the wall surface with a size of 15 x 19 cm. The result is easier straw out. The aim of the research is to design, fabricate and test the performance of thresher that has operated like a hammer mill.

MATERIALS AND METHOD

Main parts of the design and its operation

The thresher is equiped by shaft, crimp wire mesh (or concave mesh), threshing hammer, grain chute, feed tray, V-pulley and belt, bearing, straw chute (or straw outlet), straw thrower and electric motor. The threshing hammer rotates to hit and to rub paddy panicle and straw throwers by flow air in the threshing room, and it was fixed to the shaft (Figure 1).

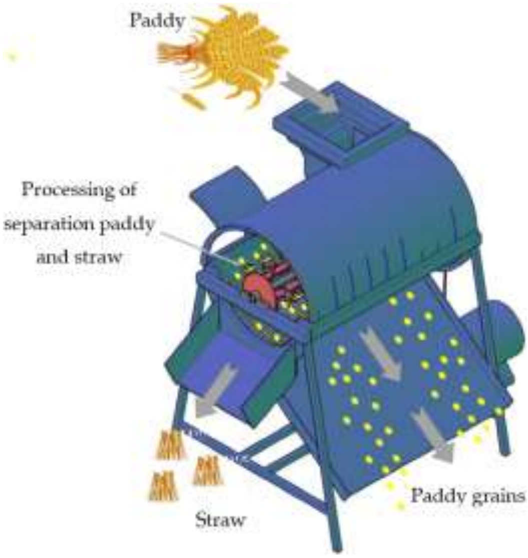

Figure 1: Sketch of power thresher

Design theories and calculations

Determination of shaft speed

The shaft speed the following parameters are calculated by equation 1

$$\frac{D_1}{D_2} = \frac{N_1}{N_2} \quad (1)$$

Where N_1 is a revolution of the smaller pulley, rpm; N_2 is a revolution of the larger pulley, rpm; D_1 is the diameter of the smaller pulley, mm; D_2 is the diameter of a larger pulley, mm.

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value shaft speed is reduced by 4% (Spolt, 1988).

Determination of nominal length of the belt (L)

The following parameters L are calculated by equation 2.

$$L = 2x + \pi(r_2 + r_1) + \frac{(r_2 - r_1)^2}{x} \quad (2)$$

Where

x: Distance between pulley1 wjth pulley2
r_1: Radius of pulley1
r_2: Radius pulley2

Where, L is the length of the belt, mm; C is the center distance between the larger pulley and the smaller pulley, mm; r_1 is the radius of the smaller pulley, mm; r_2 is the radius of the larger pulley, mm Khurmi and Gupta (2005).

Determination of linear speed of hammer

The following equation can calculate the peripheral speed of the hammer rotation (V).

$$V = \frac{2\ \pi r N}{60}\left({}^{m}/_{s}\right) \qquad (3)$$

Where N is rotation per minute, rpm.

Position of rotating hammer.

Hammer spins with a center rotation. If the hammer's rotational speed is low, the hammer's position will form an angle with the hammer's radius, and if the hammer's rotational speed is high (400 rpm) the hammer position is parallel to the radius r. Then the angle between r and the hammer can be determined by the following equation:

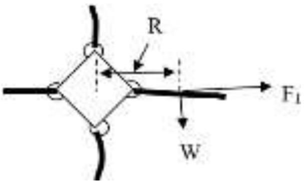

Figure 2: Force distribution of hammer

Centrifugal force of hammer

When the hammer spins, it produces a centrifugal force (F1)

$$F_1 = m\frac{V^2}{R}(N) \qquad (4)$$

Weigh of hammer

The weight of the hammer is calculated as follows,
$W = mg$

Where m: the mass of hammer, kg
g : gravity force, m/s^2

Angle of θ

Angle of position of hammer againts radius is θ:

$$\theta = \tan^{-1}\left[\frac{mg}{m\frac{V^2}{R}}\right] = \theta = \tan^{-1}\left[\frac{gR}{V^2}\right] \qquad (5)$$

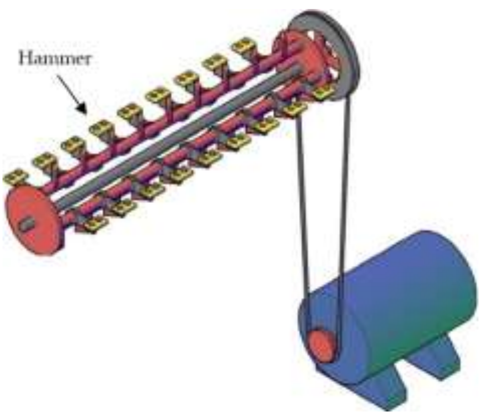

Figure 3: Part of hammer thresher

Determination of V belt contact angle

$$\mathrm{Sin}^{-1}\alpha = \frac{R - r}{x} \qquad (6)$$

$\theta = 180 - \alpha$

Where, R is the radius of the large pulley, mm; r is the radius of the smaller pulley, mm; θ is the angle of wrap of drive and the driven pulley, rad (Khurmi and Gupta, 2005).

Determination of the belt tension

$$2{,}3 \log \frac{T_1}{T_2} = \mu\, \theta\, \mathrm{cosec}\, (\beta) \qquad (7)$$

$T_1 = \sigma A$ (N)

Where T_1 is tensioned in the tight side of the belt, Nm; T_2 tensions in the slack side of the belt, Nm; μ is coefficient of friction; β is the groove angle of V-belt, S is the maximum permissible belt stress, MN/m^2; A is area of belt (Khurmi and Gupta, 2005).

Determination of the torque and power transmitted for the shaft

Power (Tr) = $(T_1 - T_2)$ V

= $(T_1 - T_2)$ R N (W) .... (8)

Where Tr is resultant torque, Nm; T_1 & T_2 are tension in the belt, Nm; and R is the radius of the bigger pulley, mm.

Determination of the shaft diameter

The diameter of the shaft (d), neglecting the bending moment on the shaft is:

$$d^3 = \frac{16\,T}{\pi\tau} \qquad (9)$$

Testing procedures

An electric motor and V-belts were used to connect the shaft carrying the threshing hammer to the drive shaft via pulleys. The electric motor provided the primary motion that transmits torque via the pulleys, V-belt, and bearings to the shaft carrying the hammer and sets it into the rotation. Paddy with the straw 4 kg/min (cut 10 cm length under panicle) sample was fed continuously into rotating hammer of the machine through the feed hopper. It will continue steps by beatting, friction, and shaking. Some of hammer wrap the whole paddy on the drum and moves along the length of the threshing drum in the forward direction until they reached the straw chute and then expelled by the straw thrower at which time almost all the grains (paddy) is clean from the panicle and straw. Thresher has two holes of the straw chute. One of straw chute laid at beside thresher drum and the other at the surface of thresher drum. The material used for testing of the machine is paddy that is cut paddy stem10 cm bellow of the panicle. The testing apparatus is the stopwatch, and weighing balance. 4 kg/min of rice sample was fed continuously into the thresh chamber of the machine through the feed hopper. The thresher tested with the rotation of hammer three levels and area of straw chute four levels. Every the experiment use 50 kg rice that is cut about 10 cm bellow penicle.

Results and Discussion

The rotation of the driving motor is 1440 rpm. The diameter of the pulley is 3 inches and on the thresher pulleys diameter 6, 9, or 12 inches. Then it got the pulley diameter on thresher as in Table 1.

Table 1: Effective transmission with use V-belt pulley

No	Rotation shaft theory (rpm)	Rotation shaft actual (rpm)	Effective transmission (%)
1	360	350	97.2
2	480	465	96.9
3	720	692	96.1

There is a slip on the transmission system. According to Spolt (1988), the axial speed of the thresher shaft will be reduced by 4%. Pulley rotation on the motor thresher on the measurement results showed about 96%.

The peripheral speed of a hammer with 465 rpm and radius 17.5 cm by using equation 4 is 8.52 m/s. In the 90° hammer position there is a deviation of the hammer position with angle θ. The angle value θ can be calculated using equation 6. The gravity value of 9.81 m/s2 then the angle of hammer position deviation is 0.024°. This means that hammer deviations when it is rotating, can be ignored or the position of the hammer angle corresponds to the position of the radius of hammer like figure 2.

Khurmi and Gupta (2005) mentioned of rubber V-belt material have μ (coefficient friction) = 0.3 if contact with dry iron, The density of rubber V-Belt material is 1140 kg/m3. Motor pulley diameter is 7.62 cm, and thresher pulleys diameter is 22.86 cm. The distance between the centers of two pulleys (x) is 84 cm. Value of the α is calculated by equation 7. We get the α value is 0,184 rad. The angle of the lap on the motor pulley is calculated with θ= 180 – 2 α or θ = 0.77 rad. Area V-belt is 375 10^{-6} m^2. Mass per m of V-belt is 0.4275 kg. The speed of V-Belt is 11.48 m/s. Centrifugal tension of V-belt (Tc) is calculated with TC = mV^2. The centrifugal tension value is 56.48 N. An allowable tensile stress V-belt is 2.5 MPa. The Tension in the tight side of the belt (T) is calculated by σ A. Then T is 937.5 N. Tension T_1 is 937.5 N – 56.48 N = 881.02 N. Tension in the slack side of the belt (T_2) is calculated by equation 8. The groove angle is 17,5°. Tension T_2 is 57.7 N. Power transmitted for the shaft (P) is calculated by equation 9. The Power transmitted for the shaft is 2161 Watt. We use motor Power 1 HP (749 Watt). The V-Belt is feasible to power transmitted for the shaft.

We use motor power 749 Watt. Rotation of shaft is 465 rpm. The Shaft gets on torque is 15.39 Nm (15,390 Nm). The diameter of the shaft, neglecting the bending moment on the shaft is calculated by equation 9. The shaft is made of mild steel with an allowable shear stress of 42 MPa. Determine the diameter of the shaft, neglecting the bending moment on the shaft. We get the shaft diameter is 12.31 mm. We use the shaft diameter of 25,4 mm. The shaft is feasible for rotation hammer thresher.

Osueke (2013) mentioned that the threshing process affected the quality and availability of cereals in the global market highly. A wrong selection of threshing conditions which in this case are the machine and crop parameters leads to low threshing performance and grain loss. Grain/threshing loss is measured regarding grain damage while threshing performance is measured regarding threshing efficiency, thresher capacity and threshing loss.

Table 2: Effect speed of rotating drum thresher for threshing efficiency and rice quality

Treatment	Threshing efficiency (%)		Paddy quality (%)	
(rpm)	no paddy leftover	Paddy left over	good	damage
350	95.18	4.82	99.41	0.59
465	98.52	1.48	98.96	1.04
692	99.11	0.89	96.90	3.10

The ratio of the total weight of grain threshed to the total weight of grains fed into the threshing that expressed in percentage is thresher efficiency (Sujanarko et.al., 2016). Thresher efficiency and rice quality are affected by the peripheral velocity of the hammer (Agrawal et al., 2013). High rotation of hammer will be impacted by beating force for rice. The High beating will be easy to remove rice from panicles and can mechanically damage to rice. Tabel 2 is shown that high rotation of hammer gets on paddy left over was low, but it is was high percentage damage. At shaft rotation 465 rpm resulted in paddy leftover 1.48% dan mechanical damage 1.04 %. This condition is also reported by the researcher. Speed for drum thresher can mechanically damage rice. Speed 400, 500, 600 and 700 rpm damaged for 0%, 0%, 1% and 1.5% rice respectively after threshing (Ajavi et al., 2014). While Alizadeh and Khodabakhshipour (2010) mentioned that the drum speed increased from 450 to 850 rpm and .the broken and cracked grains increased from 0.00 to 0.592 % and from 9.50 to 25.20 %, respectively.

The area of straw chutes has affects thresher efficiency. The wider the expenditure hole, the lower the thresher efficiency. This indicates that the larger the expenditure hole then the paddy duration is not long in the thresher chamber. The area of the discharge hole 160 cm2 resulted in the value of small grain damage and high threshing efficiency (Table 3).

Table 3: Effect of area straw chute for threshing efficiency and rice quality

Treatment	Thresher efficiency (%)		Paddy quality (%)		Time	Capacity
(cm^2)	No paddy leftover	Paddy left over	good	damage	(minute)	(kg/h)
200	96.34	3.66	99.70	0.30	12.5	168.0
180	97.41	2.59	99.24	0.76	13.4	156.7
160	99.04	0.96	98.96	1.04	13.7	153.3
140	99.33	0.67	97.90	2.10	15.9	132.1

International Rice Research Institute (1986) mentioned that this performance parameter is not different from the performance of the threshering paddy unit in the market which is usually between 92-98%.

Figure 4: Hammer thresher prototype

CONCLUSIONS

Operational hammer thresher can be done by inserting the rice with the stalk into the threshing room. The operation of hammer trasher is easier compared to conventional thresher operation in Indonesia. Equipment capacity of 132.1 to 168.8 kg of rice per hour is quite feasible for small-scale paddy farmers. The motor drive 1 Hp (746 Watt). The effective rotation of this equipment uses 465 rpm, with the straw expenditure opening being 180 cm^2.

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