Design Of A Throw-In Axial Flow Rice Thresher Fitted With Peg And Screw Threshing Mechanism

Gerald K. Ahorbo

Abstract: The research seeks to design a motorized rice thresher that can be manufactured by local artisans and accessed by all small-holder rice farmers. The concept of the thresher emanated from the working principles of a throw-in axial flow thresher, a peg type threshing mechanism and a screw type threshing mechanism. Components of the thresher were designed and a prototype was made.The power requirement of the thresher was evaluated and validated with the power thresher standards of the Institute of Agricultural Machinery, Japan which recommends an average power requirement of 3.5PS or less. The result was a rice thresher with threshing drum of diameter 400mm and length 1,120mm, a threshing drum shaft of diameter 36mm, a shaft bearing (SKF self-aligning) of designation 1406, a V-belt of number B66, an SKF wedge belt pulleys of designation PHP3SPB125TB and PHP3SPB280TB and a main assembly drawing. The power requirement was 1.4PS (1.03kW) for threshing long crops of length 1,282mm at feed rates up to 402kg/hr and 1.2PS (0.88kW) for threshing short crops of length 812mm at feed rates up to 429kg/hr.

Index Terms: design, power requirement, rice thresher, small-holder farmers, threshing mechanism

1. INTRODUCTION

In Ghana, rice (*Oryza sativa*) the third largest produced cereal after maize and sorghum is cultivated in each of the ten regions [1]. Majority of the producers are small-holder farmers who often use traditional manual threshing methods. These manual methods of threshing results into low production outputs ranging from 0.01 to 30kg of grain per man-hour [2] and low quality rice. This situation has compelled farmers to shift to the use of mechanical threshers which are sometimes difficult to access because of the limited number imported into the country and the absence of locally manufactured threshers. Others who have purchased such imported threshers encounter the problem of getting spare parts to replace certain worn out or broken parts. To help make threshers available to majority of small-holder rice farmers, this research aimed at designing an appropriate mechanically-powered rice thresher that could be manufactured locally by artisans for small-holder rice farmers. Even though there are several of such small mechanically-powered threshers on the Ghanaian market, those found are the small engine-operated types with designs based on mechanisms that have a rotating drum fitted with either peg-teeth or rasp-bars or wire loops for threshing. Common amongst them are threshers with the peg-teeth threshing mechanism which are found with most designs including designs of the popular International Rice Research Institute's (IRRI's) axial flow threshers. These threshers have peg-teeth cylinder and concave arrangements that generate mostly impact effects to thresh although some stripping effects are associated. Usually, the separation of rice grains from the panicle occurs as a result of rubbing, impact and stripping action [3].

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The other rice threshing mechanisms such as the screw type threshing which Ichikawa and Sugiyama [4] used to develop the Japanese screw type combine harvester, threshes mostly through friction created by a strong force conveying the crop between the spiral vane and concave along the direction of the cylinder axis. In this paper, a rice thresher that combines both peg and screw threshing mechanisms was designed, constructed and the power requirement ascertained and confirmed with the power thresher standards of the Institute of Agricultural Machinery (IAM), Bio-oriented Technology Research Advancement Institution (BRAIN), Japan.

2. MATERIALS AND METHODS

2.1. Main Parts of the Design and its Operation

The thresher consisted mainly of threshing drum, shaft, crimp wire mesh (or concave mesh), threshing blade (or auger) and peg-tooth, grain chute, feed tray, V-pulley and belt, bearing, baffle plate, straw chute (or straw outlet), straw thrower and electric motor. The threshing drum carried the auger, peg-teeth, and straw throwers by welds and it was fixed to the shaftby a flange (Fig. 1).

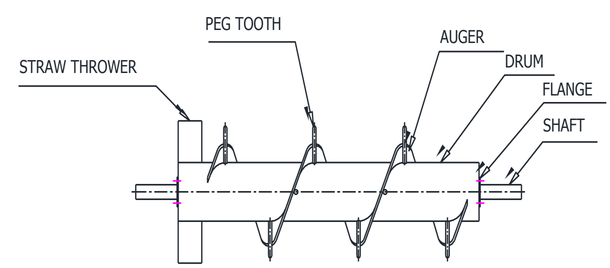

Fig. 1. *Peg-teeth and Screw Arrangement on Threshing Drum*

The drum was enclosed in a top cover and a bottom concave wire mesh and finally suspended on two sealed ball bearings bolted onto the rigid frame of the thresher. The top cover which had baffle plates, feed tray, straw outlet was attached to the rigid structural frame of the thresher with bolts and nuts (Fig.2).

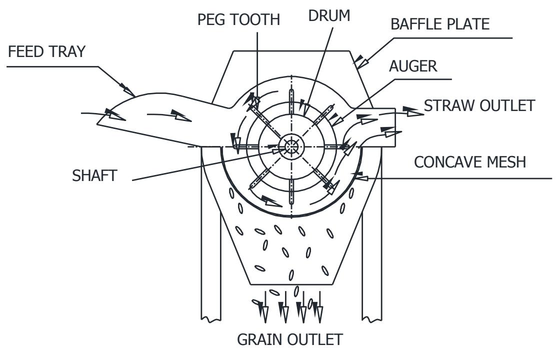

Fig. 2. *Threshing Unit Arrangement*

The concave wire mesh was firmly attached to the rigid structural frame by welds. An electric motor and V-belts were used to connect the shaft carrying the threshing drum to the drive shaft via pulleys. The electric motor (or petrol engine) provided the primary motion that transmits torque via the pulleys, V-belt and bearings to the shaft carrying the threshing drum and sets it into rotation. A whole harvested rice with the straw introduced into the thresher through the feed tray reaches the rotating threshing drum and by the threshing blades and tooth pegs arrangement, the rotation of the drum produces impact, stripping and rubbing effects on the rice straw against the baffle plates and the crimp wire mesh, thereby removing and separating the grains from the panicles and straws respectively. The spiral nature of the blade and tooth pegs wraps 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 (rice) are removed from the panicle and straw.

2.2. Calculations and Formulae of the Design

2.2.1. Threshing Drum and Flange Bolt

A cylindrical shaped threshing drum was designed using St.34 (ultimate tensile strength 330N/mm^2 and yield tensile strength 200N/mm^2) thin plate. The formulae used for the design were:

i. 2πr (where r = radius of drum) to determine the appropriate diameter of the drum that fully or partly (about 65%) wrap rice straws of 800mm to 1300mm length.
ii. Permissible torque = $[0.5(\sigma_{yt})/fs] \geq$ applied torque = $4F/[n(\pi d^2)]$ to select either the size or the number of bolts that will secure the power transmission shaft flange to the cylinder (where fs = factor of safety, F = tangential force on the flange bolt, n = number of bolts, d = diameter of bolt, and σ_{yt} = yield tensile strength of St.34 used for bolt).

2.2.2. Threshing Drum Shaft

Asteel material (St.42) of 410N/mm^2 ultimate tensile strength and 250N/mm^2 yield tensile strength was used to design the threshing drum shaft. The shaft was considered to be subjected to combined loads and considerable minor shocks during feeding and threshing. The ASME shaft design code was used for the design and the formulae employed were:

i. Torque (M_t) = $60(10^3)$ (Power in hp)/[2π(speed in rpm)].
ii. Weight (W) acting on the shaft = mg = ρVg (where ρ is density of steel, V is the volume, and g is the acceleration due to gravity). The weight (W) on the shaft was due to the weights of pegs, spiral blade, straw throwers, cylinder together with its side plates, flanges, rice straws and other weights due to the welds and other fittings. The weight of the welds and other fittings was considered to be about 25% of the sum of the other calculated weights.
iii. The permissible torque (τ_{max}) for the shaft with pulley keyed to it, was computed as $\tau_{max} = 0.75(0.18\sigma_{ut})$.
iv. Shaft diameter (d) = $\{16\sqrt{[(k_b.M_b)^2 + (k_t.M_t)^2]}/(\pi\tau_{max})\}^{⅓}$, (where M_b = maximum value of bending moment, M_t = torque produced by prime mover, τ_{max} = permissible torque and values of k_b and k_t chosen as 2.0 and 1.5 respectively for minor shock loads) as stated by Spotts [5].
v. The standard size of shaft was selected from GTZ [6] and the suitable size of set screw used to key the flange to the shaft was also selected from Design Data [7].

2.2.3. Bearing

A 5 years life-span of 10 hours daily operation bearing was designed using catalogue data from SKF [8] together with the following formulae from Bhandari [9]:

i. $P = XF_r + YF_a$, where P = equivalent dynamic load (N),F_r = radial load (N),F_a = axial or thrust load (N), X = radial factor, and Y = thrust factor.
ii. $L = (60nL_h)/10^6$, where L_h = bearing life (hours) and n = speed of rotation (rpm)
iii. $C = PL^{1/\rho}$, where C = dynamic load capacity (N), ρ = 3 (for ball bearing), and L = bearing life (in million revolutions).

2.2.4. V-belt

The following systematic steps were followed and tables, formulae and design expressions from Sakai [10] and Bhandari [11] were used to design the V-belt:

i. The design power was calculated using a V-belt service factor that was selected based on medium duty service at daily maximum operation of 10 hours as stated in Sakai [10].
ii. The standard diameter of pulley and center distance between the two pulleys was determined from tables compiled by Sakai [10] and Bhandari [11].
iii. The pitch length (L) of the belt was calculated from the formula $2C + \pi(D+d)/2 + (D-d)^2/4C$, where D is the diameter of big pulley, d is the diameter of small pulley and C is the center distance between the pulleys.
iv. The specification and number of V-belts required to transmit the power was determined using the tables compiled by Sakai [10] and Bhandari [11].

2.2.5. V-pulley

The V-pulley was designed with formulae from Bhandari [11] that was based on Fig. 3 and the steps listed:

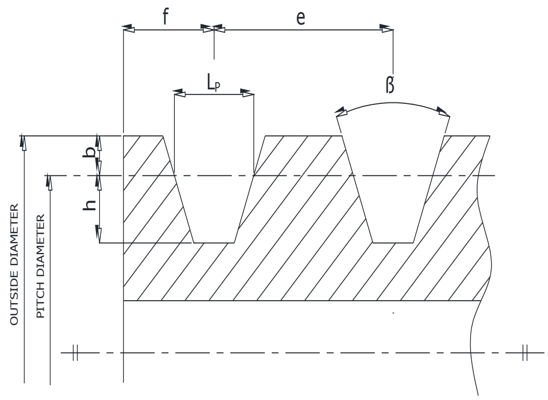

Fig. 3. *Pulley Diagram*

i. A recommended pitch width (L_p) and groove angle (β) were selected from tables compiled by Bhandari [11].
ii. The minimum distance from the tip of pulley to the pitch line (b), was computed from $0.3L_p$.
iii. The distance between the centers of two grooves (e), was calculated from $1.35L_p$.
iv. The edge of pulley to first groove center (f), was computed using $0.9L_p$ and the minimum depth below the pitch line (h), was computed from $0.7L_p + 1$.

2.3. Main assembly of the design

The main assembly was generated from the thresher components and sub-assemblies developed from the design calculations. The drawing was made with AutoCAD software.

2.4. Evaluation and Validation of Power Requirement

2.4.1. Development of prototype

A prototype of the designed thresher was made from the drawings using basic manufacturing tools and equipment such as engineers try square, steel rule, clamps, scriber, vernier caliper, micrometer screw guage, dot punch, lathe machine, pedestal drill and grinder, bending and rolling machines, gas and arc welding machines, hand drill and grinder, power hacksaw, vertical band saw, milling machine and spraying gun. The steel materials used were crimp wire mesh,angle irons, plates, bars and rodsmade out of St.34 and St.42 as specified in Maitra and Prasad [12]. The standard machine components used comprised of bolts and nuts, set screw, SKF bearing, V-belt, SKF pulley and an electric motor.

2.4.2. Power Requirement

A variety of rice crop was selected for the test and the moisture content of the grain and straw measured. Two types of lengths of the crop were used for the test. The baffle angle and concave clearance of the thresher was maintained fixed at 10^o and 10mm respectively. The rotational speed of the threshing drum shaft was kept at 650rpm with the help of a tachometer and the motor with regulating speed shown in Fig.4.The torque was measured in N-m using the torque transducer shown in Fig.5.

Fig. 4. *Motor with Regulating Speed*

Fig. 5. *Torque Transducer*

The feeding of the thresher was done manually and uniformly in small amounts of 1.2kg at rates of 3.4kg/min, 3.5kg/min, 4.9kg/min and 7.2kg/min for the short crop, and 3.3kg/min, 4.2kg/min, and 6.7kg/min for the long crop. The various amounts (in kg) of the crop fed into the thresher were measured using a spring balance. The feeding time for each test was longer than 2 minutes and it was the time interval between the start and the end of threshing. Finally, the power requirement (in PS) was computed using the formula: Power = [Torque (Nm) x Speed (rpm)] x 1.43 x 10^{-4}. The results were validated with the IAM power thresher standards which requires that an average power requirement of a power thresher with 400mm width threshing drum shall be less than 3.5PS when fed 1.2kg bundle of rice crop, and less than 2.5PS when fed 0.8kg bundle.

3. RESULTS

3.1. Threshing drum and flange bolt

The threshing drum designed was of diameter (Ø400mm) and length (1,120mm). The spiral blade was of width 50mmand the peg tooth was of size Ø10 x 50mm.Three bolts were considered to secure the flange to the threshing drum as shown in Fig.6 and the force they contained was $F = M_t/r$ = 143,312Nmm/50mm = 2,866 N.

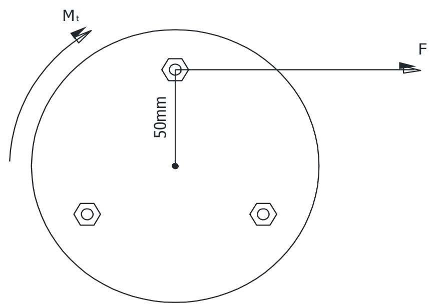

Fig.6. *Flange Bolt Design Diagram*

Consequently, the standard size of bolt suitable for the computed 6.07mm bolt was M8 and the selected suitable set screw for the flange was M10.

3.2. Drum Shaft

A 500N total weight acted on the shaft and as a result the bending moment (M_b) effect on the shaft was 153,750Nmm as shown in Fig.7.

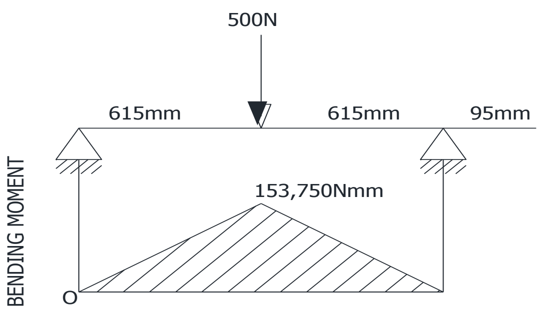

Fig.7. *Bending Moment Diagram*

The torque (M_t) required for turning the threshing drum was 77,168Nmm for the shaft rotating at high speed of 650rpm, and 143,312Nmm for the shaft rotating at low speed of 350rpm. The permissible torque (τ_{max}) is 55.5 N/mm^2 ≈ 56 N/mm^2 and the shaft diameter calculated for the 650rpm and 350rpm speeds were 33.4mm and 34.9mm respectively. Hence the selected standard shaft size was 36mm.

3.3. Drum Shaft Bearing

The calculated dynamic load capacity was 32,266N for the 650rpm speed and 48,758N for the 350rpm speed. Hence, the designated SKF bearing computed for 5 years life-spanof a 10 hours daily operation at high speed of 650rpm and low speed of 350rpm threshing wasan SKF self-aligning bearing of number 1406.

3.4. V-Belt

The design power (drive power) calculated was 5.78kW for a considered service factor of 1.1. The selected cross section of the belt was B and the standard diameters of pulleys selected were 125mm and 275mm. The selected center distance was 540mm and the pitch length of the belt was 1,718.74mm. The actual belt power rating computed was 2.09kW and the number and type of V-belts required to transmit the design power was 3 pieces of B66 conventional V-belt.

3.5. V-Pulley

The selected pulley groove cross section and angle based on the V-belt designed for the 125mm pulley pitch diameter was B and 340 ± 0.50 respectively. Distance between two adjacent centers of grooves was 19mm and the distance from the edge of pulley to the first groove center was 12.6mm. The top width of groove was 14mm and the groove depth below the outside diameter was 15mm. Hence for 3 groove standard pulley, the selected suitable SKF wedge belt pulleys from SKF Pulley Catalogue [13] were of designation PHP 3SPB125TB and PHP 3SPB280TB.

3.6. Main Assembly Drawing

Fig.8 shows the main assembly drawing of the designed thresher.

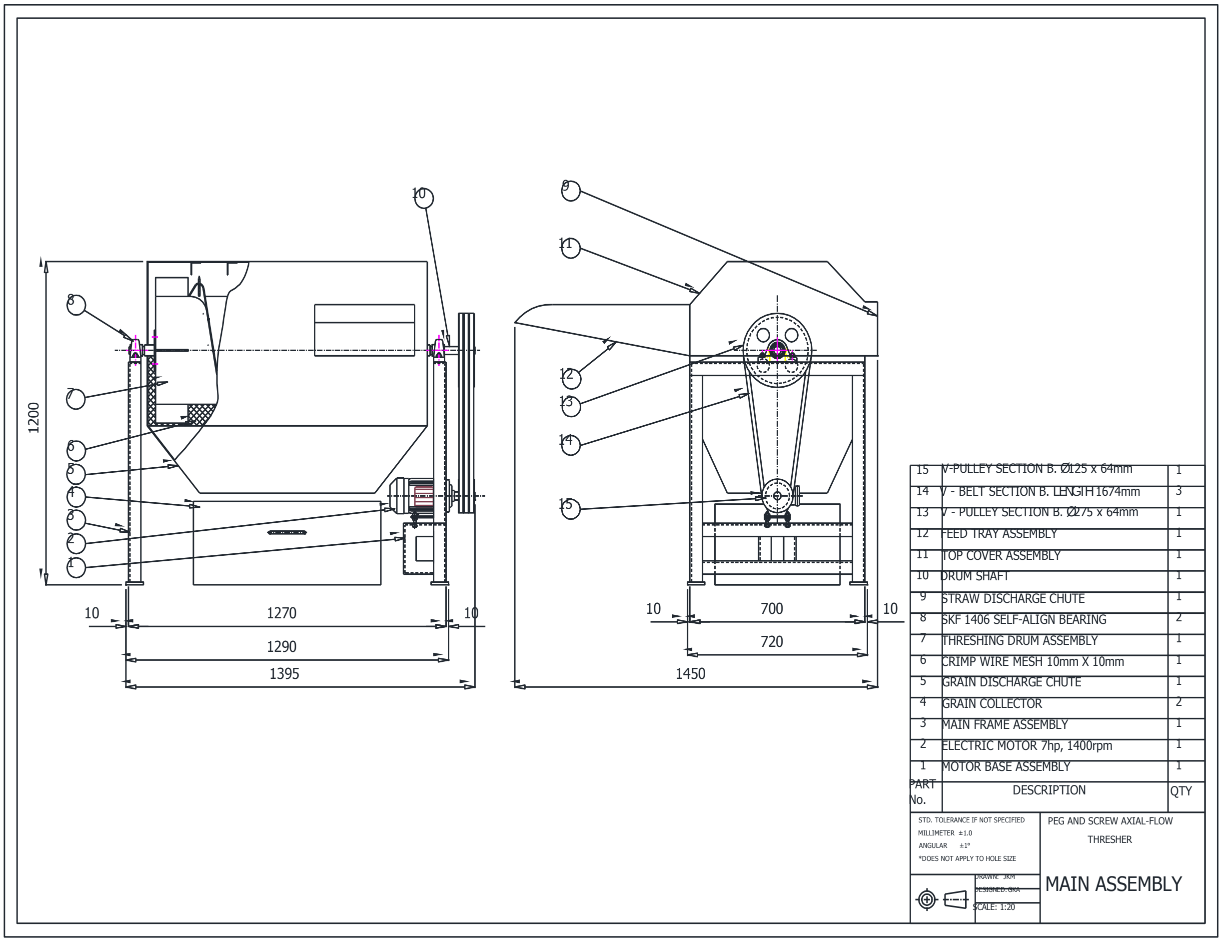

Fig.8. *Main Assembly Drawing*

3.7. Power Requirement

Fig.9 showed the prototype that was developed from the designed thresher components and the assembly drawing that was further used to conduct test to evaluate the threshing power requirement.

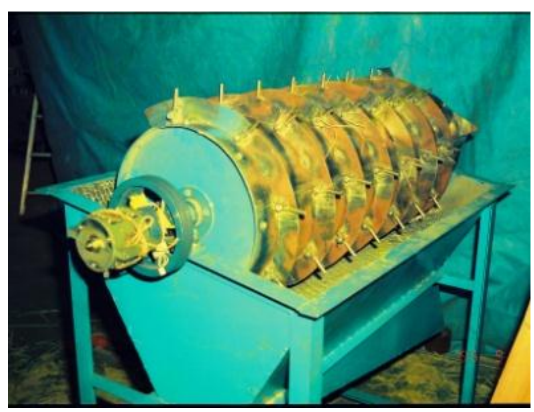

Fig.9. *Fabricated Thresher*

Table 1 showed the condition of the threshed crop and Tables 2 and 3 showed the measured torques and its computed power requirement (in PS) for the respective long and short lengths of rice crop.

Table 1. *Condition of the Threshed Crop*

Crop	Variety	Average length of short crop	Average length of long crop	Average moisture content of grain	Average moisture content of straw
Indica	Belle Patna	812mm	1282mm	19.6%	64.2%

Table 2.*Measured Torque for Long Crop*

Feed rate (Kg/hr)	198	254	402
Torque (Nm)	10.3	14.4	14.6
Power (PS)	1.0	1.3	1.4

Table 3. *Measured Torque for Short Crop*

Feed rate (Kg/hr)	205	210	295	429
Torque (Nm)	6.0	11.7	13.2	12.4
Power (PS)	0.6	1.1	1.2	1.2

4. DISCUSSIONS

The designed threshing drum of size Ø400mm provided a circumference of 1,256mm to wrap the rice crops to be threshed.

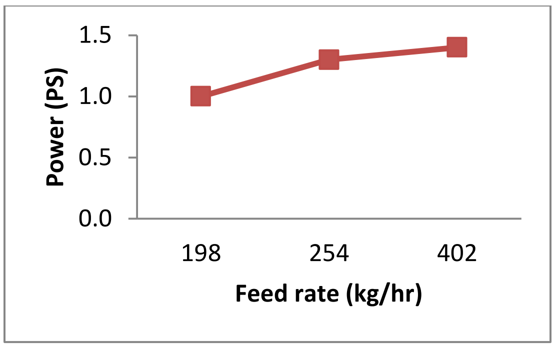

Fig. 10. *Power Requirement for Long Crop*

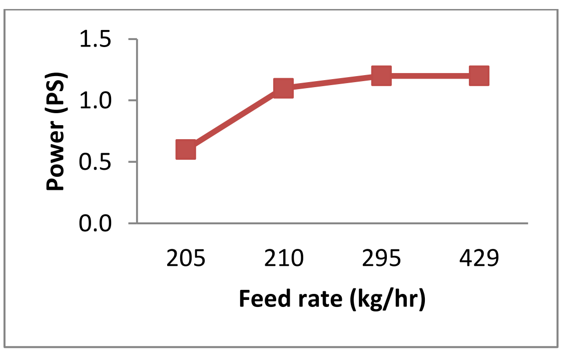

Fig. 11. *Power Requirement for Short Crop*

For the long crops of average length 1,282mm, the wrap was 98% and a power requirement of 1.0 to 1.4PS (0.74 to 1.03kW) was realized for feed rates from 198 to 402kg/hr (Fig.10). In the case of the short crops of lengths 812mm, the power requirement was from 0.6 to 1.2PS (0.44 to 0.88kW) for feed rates from 205 to 429kg/hr (Fig. 11). It was observed that the power requirement of the thresher increased with increase in feed rate. Also, the length of crop fed to the thresher influenced the power requirement; that is, the long crops required higher power at same rates of feeding the short crops.These increases in power were due to more compressed crop material as a result of more crops wrapped on the drum which increases friction between the crop material during conveyance and the components in the threshing compartment. Therefore, the maximum power required to thresh long (1,282mm) crops with grain moisture content of 19.6% and straw moisture content of 64.2% at drum speed of 650rpm for 402kg/hr feed rates was 1.4PS (1.03kW) whiles that for the short (812mm) crops at feed rates of 429kg/hr was 1.2PS (0.88kW).These powers conform to the Japanese national standard, which recommendsan average power requirement less than 3.5PS for the 1.2kg bundles fed.Throughout the test it was observed that the thresher was able to separate the rice straws from the grains during the threshing and clogging did not occur with feeds at rates up to 402kg/hr for the long crop lengths and 429kg/hr for the short crop lengths.

5. CONCLUSIONS

i. A compact motorized throw-in axial flow rice thresher that uses combined peg and screw threshing mechanism was designed and successfully constructed.

ii. The prototype threshed up to 1,282mm length of whole harvested rice cropsof 19.6% moisture content grain and 64% moisture content straw at threshing drum speed of 650rpm and feed rates from 198 to 402kg/hr inclusive with maximum threshing power of 1.4PS (1.03kW) and also threshed 812mm length of crop with maximum threshing power for feed rates from 205 to 429kg/hr.

iii. The evaluated power requirement of the thresher validatedthe Japan national standardwhich states that the average power requirement should be less than 3.5PS (2.6kW) for 1.2kg bundle of feeds.

Acknowledgement

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