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Development of Cotton stalk harvesting machine for ex-situ application

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ABSTRACT

Cotton *(Gossypium hirsutum*) is an important commercial crop in India. Annually 30.79 million tons of cotton stalk residue is being generated in India. In India, after harvesting cotton lint, cotton stalks are removed by either manual uprooting or cutting them using sickle above the ground level, which is a laborious operation and contributes to increase in crop production. After removing cotton stalks from field, farmers are burning cotton stalks in their fields. Burning of stalks increases CO_2, CO, N_2O and NO_x in the atmosphere which leads to increase in air pollution. Instead of burning the stalks in fields, cotton stalks have the potential to be used for *ex-situ* application such as, raw material for briquettes due to its high lignocellulosic nature. *Ex-situ* utilization cotton stalk aids in generating additional income to farmers. In order to utilize the cotton stalk for *ex-situ* application a cotton stalk harvester was developed and evaluated in the field conditions which gave the following results; mean chopped length 122.7 mm, bulk density 197.86 kgm^{-3}, fineness modulus 1.828, machine output of 1259.85 kgh^{-1}, chopping height 118.6 mm field capacity 0.17 ha h^{-1}, and fuel consumption of 7.54lh^{-1}

Key words : *Fineness modulus, Bulk density, Machine output, Cchopping height*

Introduction

Cotton (*Gossypium Herbaceum*) commonly is the import cash crop in India. In India the annual production of crop residue is approximately 500Mt. The majority of it is used for fodder, raw material for energy production etc., still there is a huge surplus of 140Mt out of which 92Mt is burnt every year (Bhuvaneshwari *et al*., 2019). Especially small-scale farmers resort to burning of crop residues,as it is an inexpensive alternative due to the lack of technological awareness and lack of proper disposal opportunities. Burning of crop residues in large scale increases CO_2, CO, N_2O and NO_x in the atmosphere and has led to shocking increase in air pollution (Bhuvaneshwari *et al*., 2019). In India, crop residues are removed by manual uprooting or cutting the stalks which is high labour intensive and contributes towards high cost of crop production. The biomass left in the field after picking seed cotton is called cotton stalks. On an average about 3 tons of stalks per hectare are being produced and available for thermal applications. One of the approaches that is being actively pursued worldwide towards improved and efficient utilization of agricultural and other biomass residues is their densification in order to produce pellets or briquettes. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of applications. Cotton stalks contains about 46 % of alpha cellulose and 26 % lignin (Jha *et al*., 2008). If cotton stalks are left in the field, it serves as an overwintering site for insects such as the pink bollworm. The pink bollworm is major threat to sustainable cotton production. The manual removal of cotton stalks is a laborious and time-consuming activity; therefore, an attempt has been made to develop cotton stalk harvesting machine for ex-situ application

Materials and Methods

Selection of power source

The selection of suitable power source is very important while developing any type of agricultural machine. The power required for rotary shredder is 22.06 kW per 1.5 m operating width (Bosoi *et al*., 1990). It is proposed to cover 2 rows spacing's of the crop in the same operation accommodating 75 or 90 cm row spacing's so, overall effective working width is fixed as 1.8 m for development. Hence, the power requirement for cotton stalk harvesting under consideration was estimated as 42.50 kW (57 hp). A 42.50 kW (57 hp) tractor) was used as a power source for the present study.

Components of cotton stalk harvesting machine

The prototype tractor operated cotton stalk harvesting machine consists of a heavy-duty main frame, hitch system, side support plates, gear box housing, power transmission system, rotor shaft assembly with blades and metal cover for rotor assembly

1. Main frame
2. Power transmission system
3. Cutting (shredding) unit
4. Discharge spout
5. Hitch frame
6. Frame and rotor shaft joint side support plates
7. Guard cover
8. Height adjustment device
9. Collecting unit

Main Frame

Four hollow square bars of length 2050 mm and 1050 mm (two each) are fabricated from a 60 x 60 x 6 mm M.S. angle Iron. These four bars are welded at the corners to form a rectangular frame of size 2050 x 1050 mm. Along the side of 1050 mm and at a distance of 250 mm from one end of frame, a L angle (50 x5 mm) of length 2050 is welded. Similar at along 1050 mm side another L angle (50 x 50 mm) of length at a distance of 250 mm from another end of frame is welded, inside the main rectangular frame another rectangular frame (2050 x 500 mm) as shown in (Fig. 1). This arrangement was made to weld a delivery discharge spout.

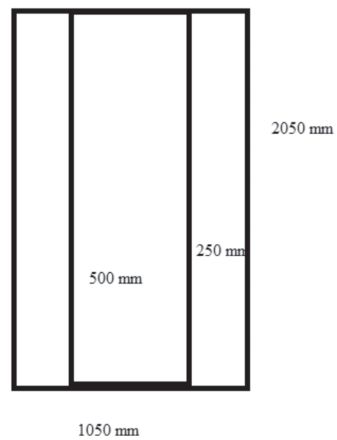

Fig. 1. Top view of Main frame

Power transmission system

A standard propeller shaft with both side universal joint were used to connect tractor P.T.O to the gear box input shaft. Power from tractor P.T.O is transmitted to gear box (mounted on the frame of machine) shaft through propeller shaft. The speed reduction from gear box input put shaft to gear box output shaft is 1.2:1. Power from gear box output shaft to rotary unit was provided with the help of double sheave V belt drive.

The speed of gear box output shaft in transmission system is calculated by using the formula (Khurmi and Gupta, 2006). The speed of rotary shaft in power train from transmission system is calculated by using the formula)

$$N_1T_1 = N_2T_2 \quad ....(3.11)$$

Where,

N_1= speed of input shaft (rpm)

N_2 = Speed of auxiliary shaft (rpm)

T_1= No. of teeth on bevel gear which is mounted on input shaft

T_2= No. of teeth on bevel gear which is mounted on auxiliary shaft

N_1 = 540 rpm, T_1 = 9 teeth, & T_2 = 11 teeth

$$N_2 = \frac{N_1 \times T_1}{T_2}$$

$$N_2 = \frac{540 \times 9}{11}$$

The rpm of output shaft of gear box is 441.8

Speed of rotor shaft

The speed of rotary shaft in power train from transmission system is calculated by using the formula

$$N_3 D_1 = N_4 D_2 \quad \ldots(3.12)$$

Where,

N_3 = Speed of gear box output shaft (rpm)

N_4 = Speed of rotor shaft (rpm)

D_1= Diameter of pulley which is mounted on gearbox output shaft

D_2= Diameter of pulley which is mounted on rotor shaft

N_3 = 441.8, D_1= 50 cm D_2= 11 cm

$$N_4 = \frac{N_3 D_1}{D_2} \quad \ldots(3.13)$$

$$N_4 = \frac{N3 \text{ x } D1}{D2}$$

$$N_4 = \frac{441.8 \text{ x } 50}{11}$$

N_4= 2008.18

Diameter of rotor shaft = 150 mm

Length of blade = 200 mm

rpm of rotor shaft = 2008

Diameter of rotation = 550 mm

Peripheral speed of blade =

$$= \frac{2000 \times 1 \times \pi \times 0.55}{60} = 57.8 \text{ ms}^{-1}$$

$\cong 58 \text{ ms}^{-1}$

Therefore, the rpm of rotor shaft on which flail type blades are mounted is 2008 which produced a flail(blade) tip speed of 58 ms^{-1}. This shaft is driven by V belt drive.

Gearbox housing

The gear box housing is in rectangular shape made of cast steel material with provision for various drive shafts, gears, proper capacity housing for bevel gears and gear oil and other fitments. The gear box is mounted on two L angles of length 230 mm and thickness 6 mm. These two L angles are welded to main frame. The power train in the gear box consists of 50 mm input shaft with 10 splines at the front end. The front end of input shaft is connected to the P.T.O shaft with the help of two universal joints to draw the power from the tractor.

Design of shaft

The design was based on torsion strength considered by calculating the drive torque of rotating shaft which was subjected to twisting moment only.

a. Design of Input Shaft to gear box

The torque transmitted by the shaft was calculated by using formula suggested by Khurmi and Gupta (2006).

$$T = \frac{P \times 60}{2 \times \pi \times N} \quad \ldots (3.14)$$

Where,

T = torque transmitted by the shaft, N-m

P = power, kW

N = rpm of shaft

T = 639.8 N-m

T = 639.8 x 10^3N-mm

The torque transmitted by the shaft (T), ...(3.15)

Where,

τ = torsional shear stress, MPa

d = diameter of the shaft, mm

d^3 = 77606.98

d = 42.6 mm

The shaft diameter was selected as 45 mm.

b. Design of Gear box output Shaft

The torque transmitted by the shaft was calculated by using formula Khurmi and Gupta (2006).

$$T = \frac{P \times 60}{2 \times \pi \times N} \quad .. (3.16)$$

Where,

T = torque transmitted by the shaft, N-m

P = power, W

N = rpm of shaft

T = 783.43 N-m

T = 783.43 x 10^3 N-mm

The torque transmitted by the shaft (T),

d^3= 94999.68d = 45.62

The shaft diameter was selected as 50 mm.

On this shaft 500 mm double pulley is mounted as discussed in section 3.9.2.2

Cutting blade

The cutting blades fitted on the of rotary shaft need to exert sufficient impact force at higher speeds to shred the Cotton stalk into multiple pieces in a shorter period. Therefore, EN8 material was used for fabricating the blade.

Thickness of blade affects the specific cutting energy and shredding efficiency of shredder (Bosoi *et al.,* 1990). Hence, 10 mm thickness of blade was used for this study based on review of previous studies.

The blade effective cutting width is selected on the basis of the maximum diameter of the stalk of the crop to be shredded (Bosoi *et al.*, 1990).

Blade cutting width (b) = d_{max}+ (30 to 50) mm (3.17)

It was observed that, under the field conditions the mean girth of the Cotton stalk is 21 ± 3.5 mm (dmax). Hence, considering other practical application the blade cutting length were taken as 80 mm for L blade.

Types of blade	=L blade
Total No. of cutting blades on Rotor shaft	= 32
Length of cutting blades	=200 mm
Width of cutting blades	= 80 mm
Thickness of cutting blades	=10 mm

The inner cutting edge has been bevelled at 35° for easy cutting. The cutting blade rotating direction is selected anti-clock direction to obtain the cut at tangential angle to the imaginary rotational circle of the blade tip. The total length of length is 200 mm. (Fig. 2).

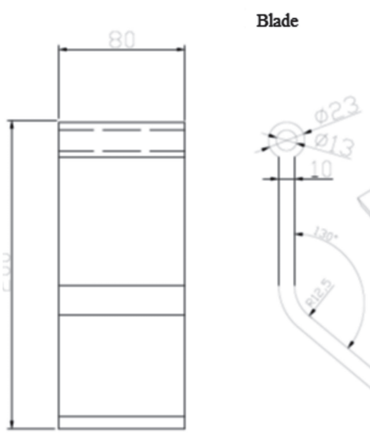

Fig. 2. L type Blade

Rotor shaft

A hallow cylindrical pipe of 150 mm outer diameter with 10 mm wall thickness and 1800 mm length was selected for rotor shaft. A ten mm thick M.S plain sheet was taken and 155 mm diameter circular disc portions (two numbers) marked and separated through gas cutting.

To fit the shredding blades on the rotor, 60 mm length brackets (30 x 5 mm size) are welded on rotary shaft. The blades are fixed in the bracket through nut and bolts. The brackets were welded on rotary shaft in such a that, the blades (flails) were staggered on the planes perpendicular to the rotational axis with an angular spacing of 90^0. The rotational speed of the rotor shaft was 2008 rpm which produced flail tip speed of 58 ms^{-1}.

Determination of Byte length

Byte length is the forward distance travelled in between successive cuts of stalk by the blades. The byte length of a blade is determined by considering the process of stalk cutting by two adjacent blades in one vertical plane and mounted on the same side of the rotor shaft. The byte length is calculated using the formula (Ananthakrishnan and Jayashree, 2012).

$$L_b = \frac{S \times \pi \times D}{Vm} \quad .. (3.18)$$

Where,

L_b= Byte Length, mm

S = forward speed of the tractor, ms^{-1}(2 km h^{-1} = 0.55 ms^{-1})

D = Outer diameter of the rotating blade = 550 mm

V_m= Speed of rotary unit (ms^{-1}) = 58 ms^{-1}

$$L_b = \frac{0.55 \times \pi \times 550}{58} \quad .. (3.18)$$

L_b = 16.3 mm

The byte length worked out is lower than the intra row spacing recommended for cotton which ranges from 300 to 450 mm in the rainfed regions of the country.

Discharge spout

A hollow rectangular frame of size 1900 x 500 x 2 mm is made MS sheet. This hollow frame is bent into an arc as show in Fig. 3.

Hitch frame

A standard three-point hitch arrangement was fabricated with mild steel flats (40 mm x 7 mm size) and fitted to the main frame assembly. Two 730 mm length flats of 40mm width and 7 mm thick were taken and markings were made at 90 mm and 340 mm distance from one end of flat. The flat thus marked was bent to obtain 150^0 external angle at first

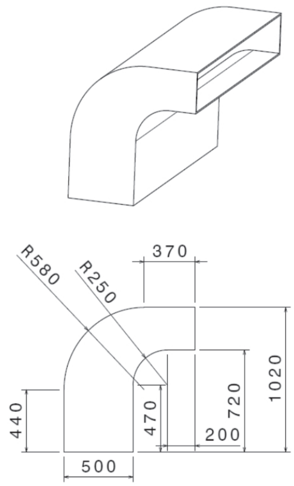

Fig. 3. Discharge spout

marking and 120^0 internal angle at the second marking position using heavy duty hydraulic press.

Frame and rotor shaft joint side support plates

Two 10 mm thickness M.S plates of overall size of 1000 x 530 mm were taken and marked to required dimensions. After markings are made carefully, the plates were cut using gas cutting torch and followed by grinding work using a portable power operated hand grinding machine to remove unevenness of the cut profiles and obtain smooth surface. Thereafter holes are drilled and the plates are joined to the either side of main frame with bolt and nut joints. A rectangular slot of 200 x 70 mm is provided on bottom portion of the plates to facilitate rotor shaft with the help of heavy duty 50 mm size flange bearing and weld joints.

Guard cover

To avoid spillover or throwing off initial cut stalks beyond the cutting width by swinging blades mounted on rotor shaft a guard cover was provided on back and side portions of rotor shaft using a 3 mm thick mild steel sheet.

Height adjustment device

To adjust the height of cut, a height adjusting telescopic wheels were provided at the rear of the cotton stalk harvester.

Collection unit

Datta *et al.* (1975) studied dynamic load carriage operation and reported that the maximum load should not exceed 30 kg while participants walking at a speed of 5 kmh^{-1}

Since two persons are needed for unloading and carrying the collecting bag the minimum capacity for collecting unit was considered as 60 kg. The collecting bag was fastened to the discharge spout. Therefore, a larger capacity bag of 120 kg was made so that the bag can be easily fastened to the discharge spout with minimum storage capacity of 60 kg. Assuming bulk density of cotton stalk is 240.0 kgm^{-3}. For collecting 240.0 kg of shredded cotton the volume need is 1 m^3.

For collecting 120 kg shredded cotton stalk the volume required is

$$= \frac{120 \times 1}{240.0}$$

$$\cong 0.5 \text{ m}^3$$

The length of discharge spout is 1900 mm, width of discharge spout is 30 mm. Therefore, a collecting bag of size 2000 x 350 x 700 mm (Fig. 4) is made which has a volume of 0.5 m^3 and minimum collecting capacity of 60 kg of shredded cotton stalks.

Fig. 4. Cotton stalk harvesting machine with collecting unit

Long run test of cotton stalk harvester

Long run test was conducted for 1 ha based on the performance of cotton stalk harvester at different forwards. The observations *viz.*, mean chopped length, bulk density, fineness modulus (uniformity), machine output, chopping height, field capacity, fuel consumption was recorded.

Results and Discussion

The developed machine was evaluated for long run test. The test yielded mean chopped length 122.7 mm, bulk density 197.86 kgm^{-3}, fineness modulus 1.828, machine output of 1259.85 kgh^{-1}, chopping height 118.6 mm field capacity 0.17 ha h^{-1}, and fuel consumption of 7.54lh^{-1}

Conclusion

In order to utilize the cotton stalk for ex-situ application a cotton stalk harvester was developed and evaluated in the field conditions. The evaluation gave the following results mean chopped length 122.7 mm, bulk density 197.86 kgm^{-3}, fineness modulus 1.828, machine output of 1259.85 kgh^{-1}, chopping height 118.6 mm field capacity 0.17 ha h^{-1}, and fuel consumption of 7.54lh^{-1}

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