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Development of lab model machine for optimization of operational parameters

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ABSTRACT

An experimental lab model machine was fabricated to optimize the parameters which affect the performance of the cotton stalk harvesting machine. A total of 26 runs (experiments) were conducted with lab model machine as set from Response surface methodology and mean chopped length, bulk density, fineness modulus (uniformity) and machine output were calculated for each run of the collected chopped cotton stalks. Based on optimization results, peripheral speed of 57.95 ms^{-1} and L type blade has been selected for fabrication of cotton stalk harvesting machine.

Key words : *Y blade, L blade, Belt shaft, Response surface methodology*

Introduction

Cotton (*Gossypium herbaceum*) is one of the most important commercial of India. The plant is a shrub native to tropical and subtropical regions around the world including the America, Africa and India. The biomass left in the field after picking seed cotton is called cotton stalks.In India the annual production of crop residue is approximately 500 Mt. The majority of it is used for fodder, raw material for energy production etc., still there is a huge surplus of 140 Mt out of which 92 Mt 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. A suitable tractor operated cotton shredder is a promising solution for the farming community. The labor-intensive operation of cotton stalk harvesting could be replaced with a cotton stalk harvesting machine.

Prior to development of cotton stalk harvesting machine, a simulation experiment (study) at lab level will assist in developing a better machine. In field conditions, cotton stalk are stationery and machine will move towards the stalks to cut (shred) them. In this lab study, cutting (shredding) unit is made stationary on a rigid L angle frame and cotton stalks are moved into cutting (shredding) unit at predetermined speed. The response surface methodology is an effective technique for optimizing complex process, since it reduces the number of experiments needed to evaluate multiple parameters and their interactions (Lee *et al.*, 2006). Considering the experimental need, the statistical technique response surface methodology (RSM) was employed for investigating the influence of three different forward speeds, three different rpm, two different blades, on chopped length bulk density fineness modulus (uniformity) and machine output. The design furnished 26 runs with different combinations of independent variables.

Materials and Methods

In this lab study, cutting (shredding) unit is made stationary on a rigid L angle frame and cotton stalks are moved into cutting (shredding) unit at predetermined speed. The cotton stalks are fixed on stalk holder which were riveted on endless belt. The cutting (shredding) unit consists of blades (flails) fitted on a shaft which is driven by a 5 hp electric motor, whose speed can be varied using V belt and pulley as per worked out peripheral blade (flail) speed. The cotton plants are harvested at the base from the field and are fixed in the cotton stalk holder of the belt which runs over two rollers. The drive roller is powered by a speed reducing gear box which driven by 3 hp electric motor through V belt drive. To avoid the sagging of the plant stalk carrying endless carrying belt, 3 number of idler rollers were provided at uniform distance (Fig. 1). The functional components incorporated in the developed machine are explained under the following sections.

Frame

The lab model machine is a 6000 x 600 mm rectangular frame which is at a height of 450 mm above ground level. At four corners of rectangular frame 4 pits of 305 mm depth are dug and four 755 x 50 x 6 mm L angles are erected by filling the pits with a mixture of RCC. The L angles of lengths 755 mm are erected in such a way that 305 mm length is in the pit and remaining 450 mm is above ground level.

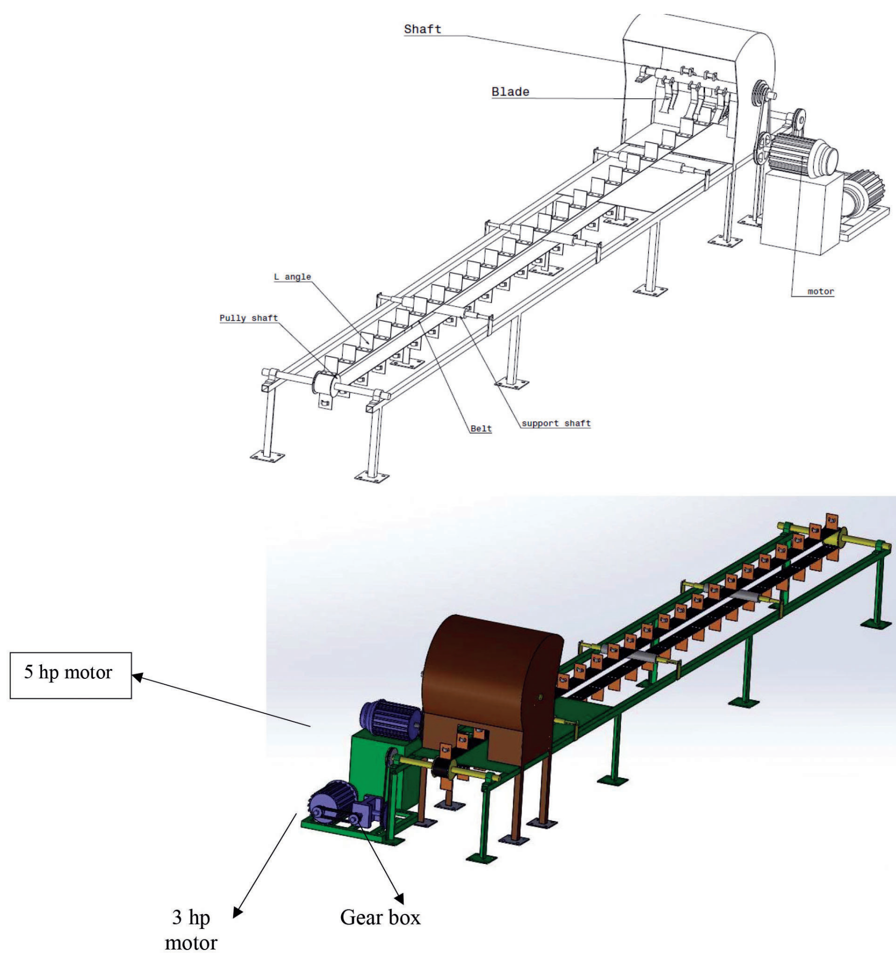

Fig. 1. Lab model assembly

Along the 6000 mm sides of rectangular frame and at equal distances two intermediate support L angle are provided.

At 450 mm height and along 6000 mm side of rectangular frame L angles are joined by welding with hollow square pipe of 6000 x 40 x 2 mm size. The opposite side of rectangular frame is also welded with similar size hollow square pipe. At the four corners of the hollow square pipes 4 pedestal bearings of 40 mm size are screwed on hollow square pipes.

Belt Pulley shaft

MS sheet of 100 x 100 x 2 mm is bent into a shape of hollow cylinder. Both the ends of the cylinder are welded with a circularly cut MS sheet of 140 mm diameter with centres aligned collinearly. This provision is made to prevent side slippage of the belt. At the centre of circular MS sheet two hole are punched on either side to pass a 40mm diameter 780 mm length shaft. This shaft is welded to the circular MS sheet and the entire unit rotates as a single unit. Two such shafts are made for both the ends of rectangular frame. The two ends of this shaft are fixed in the pedestal bearings mentioned in the (para I) as show in Plate 1 on either side of rectangular frame. At one end of rectangular frame and at one side of this shaft a key way of 4 mm is cut to mount a pulley and key. This pulley is connected to a gearbox (gear ratio 1:25) output shaft by V belt drive and the gear box input shaft is connected to a 3 HP electric motor by V belt drive. The speed of the belt is changed by changing the different diameter size pulleys on this shaft.

Belt

Rubber belt of 100 mm width and 3 mm thickness is used for this experiment and the length of the belt is arrived from the formula (Khurmi and Gupta, 2006).

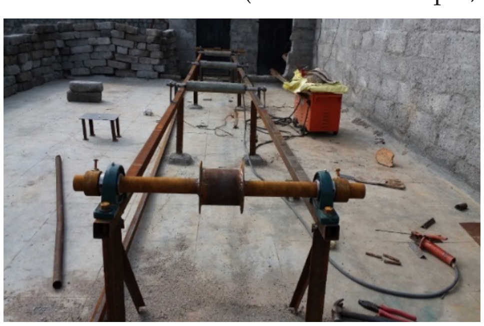

Plate 1. Belt pulley shaft arrangement in the lab model machine

$$L = \pi(r_1 + r_2) + 2x + \frac{(r_1 - r_2)^2}{x} \quad \ldots(3.10)$$

Where,

L = Total length of belt

r_1 and r_2 = radii of pulley (Both pulleys are of same diameter)

x = Distance between two centres of pulley

Cotton stalk holders

MS sheet of 135 x 80 x 2 size is used for making cotton stalk holders. Along 135 mm side of the MS sheet the sheet is bent at a distance of 35 mm to form a L shape. 35mm side of the L shape is riveted to the belt and remaining 100 mm side is drilled with holes to accommodate C clamps. At every 300 mm distance of belt, L shaped stalk holders are riveted along the length of the belt. With C clamps cotton stalk stalks are held firmly against L shaped MS sheet as shown in Plate 2.

Plate 2 Cotton stalk holder of lab model machine

Lab model blade (flail) shaft

A hollow shaft of thickness 10 mm, outer diameter 60 mm and length 500 mm is used and flail (blade) shaft. Through this hollow shaft a solid shaft of 40 mm diameter and 720 mm length is passed and welded in such way 110 mm of solid shaft is protruded on either side. Eight number of 60mm length brackets (30 x 5mm size) are welded on periphery of hallow rotor shaft at an angular space of 120^0(as shown in Plate 3). The blades are fasted to this hollow shaft through nut and bolt system. This shaft is mounted on the frame discussed in (para I) through pedestal bearings. The blade (flail) tip speed of the blade was 21 ms^{-1}, 38.5 ms^{-1} and 58 ms^{-1} respectively.

Plate 3. Lab model flail shaft

Rectangular frame for mounting lab flail shaft

Two L angles of size 1660 mm x 50 x 6 mm and 450 x 50 x 6mm are welded at the corners to make a rectangular frame of 1660 x 450 mm size. Two such frames is made to erect on either side of Main rectangular frame (as discussed in I). Two pits of size 760 × 500 × 400 mm and at a distance of 450 mm from one belt pulley shaft (as discussed in II) are dug on either side of main rectangular frame. The two L angle rectangular frames 1660 × 450 mm size are erected in the two pits on either side of the main rectangular frame and filled with RCC. The L angle rectangular frames are erected in such a way that, the length 1660 mm side of frame is inserted into pit upto a depth of 760 mm and remaining 900 mm is above ground level. To this L angular frames, dome shape bent MS sheet of size 1270 × 550 × 2 mm is welded to simulate the conditions of tractor operated cotton stalk harvesting machine. This provision of two rectangular frames on either side of the main frame is made to mount the flail(blade) shaft (as discussed in II). On these rectangular frames two pedestal bearings of size 40 mm are screwed. In these pedestal bearings flail shaft is fixed. The lab model flail shaft is driven by a V belt drive coupled to a 5 hp electric motor. The speed of the lab model flail shaft is changed by changing the different diameter size pulleys on the shaft and on output shaft of 5 hp electric motor.

Shredding blades

(a) Y-type Blade

To fabricate the shredding blades, 40 mm width and 10 mm thick flat EN8 material was selected and cut into 220 mm length pieces. Berensten, (1973) found that bevel angle of 35^{o} was most efficient during impact harvesting. Therefore, in all cut piece's edge was sharpened to obtain 35^{o} bevel angles and a marking carried at 75 mm distance from one end. The prepared cut pieces were bent at the marked position using a 5-ton capacity hydraulic press to achieve 120^{o} included angle with the help of fixtures. Two bent pieces were placed back-to-back on a level metal sheet surface and welded together to obtain the required Y – shapewith an overall length of 200 mm blade as shown in Fig. 2.

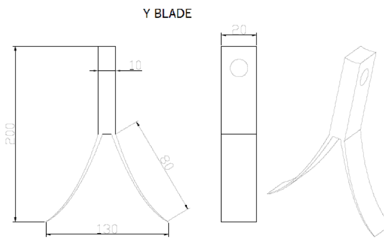

Fig. 2. Y blade

(b) L – type Blade

To fabricate the L- shape blade also EN8 metal flat of 40 x 5 mm size was used and 35^{o} bevel angle provided on cutting edge side. The flat was cut in to 280 mm length pieces and marked at 80 mm distance from on end. These prepared pieces were bent at the marking to obtain 130^{o} included angle with a hydraulic press to obtain L – shape. The total length of blade was 200 mm as shown in Fig. 3.

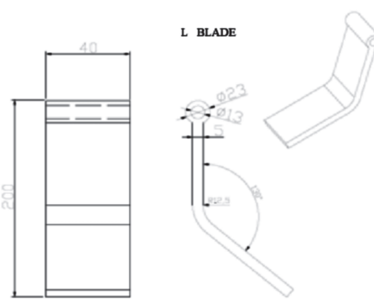

Fig. 3. L blade

Results and Discussion

A total of 26 runs (experiments) were conducted with lab model machine as set from Response surface methodology and mean chopped length, bulk density, fineness modulus (uniformity) and machine output were calculated for each run of the collected chopped cotton stalks. The experimental data values were analysed using Response surface methodology design and the dependent parameters were optimized based on the given boundary conditions to response parameters. The optimized parameters for laboratory machine are peripheral speed of 57.95

ms^{-1}, L type blade and forward speed of 2.21 km h^{-1}. The predicted values of the response under optimized conditions were mean chopped length of 109.3 mm, fineness modulus of 1.56, bulk density of 255.265 kgm-3 machine output of 573.67 kg h^{-1}.

Conclusion

A laboratory model was developed to optimize the machine parameters which affect the performance of the cotton stalk harvesting machine. The optimized parameters were used to develop the cotton stalk harvesting machinery. Based on optimization results, peripheral speed of 57.95 ms^{-1} and L type blade has been selected for fabrication of cotton stalk harvesting machine.

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