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Research Article

DESIGN AND DEVELOPMENT OF COLLECTION UNIT OF ROTARY CUTTING MECHANISM FOR HARVESTING SORGHUM

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Abstract- The rotary cutting mechanism was developed in Department of Farm Power and Machinery. The rotary cutting mechanism performs single operation i.e. collection of sorghum cobs with collection unit. Electric drive system is major source to operate electric motor, belt, pulleys etc. The laboratory test of rotary cutting mechanism held at Dr. PDKV, Akola for its performance. Rotary cutting mechanisms operated with seven different rpm of main shaft i.e. 290, 319, 363, 392, 435, 474 and 535 rpm. The cutting efficiency of rotary cutting mechanism ranges from 92 to 100 percent at 474 to 535 rpm of main shaft. The collection efficiency of mechanism increases from 290 rpm to 474 rpm and suddenly decreases at 535 rpm. The collection efficiency of collection unit was 76.47 to 97.20 per cent at 290 to 474 rpm of main shaft. Maximum collection efficiency was found to be 97.20 per cent at 474 rpm respectively.

Keywords- Rotary cutting mechanism, Collection unit

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Introduction

Grain sorghum (*Sorghum bicolor L. Mornch*) locally known as Jowar. Jowar (Sorghum) is the fifth most important cereal crop after wheat, rice, maize and barley. It is a major source of food grains for human beings also its plays as an important role of fodder and industrial raw material [2]. Major cultivation area of sorghum in central India is Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh (Bundelkhand) and Tamil Nadu. Other States grow sorghum in small areas primarily for fodder [5]. In India, sorghum production increased from 9 million t in the early 1970s to 12 million tons in the early 1980s and it was maintained at this level for over a decade, until the early 1990s, after that production was decrease to 7.2 million t. The production level decrease for the sorghum area over the years, 2006 was almost similar to that in early 1970s, which can be largely attributed to the adoption of improved varieties and hybrids. In 2006–07, India's sorghum was grown on 8.7 million ha (20 % of the world's sorghum area), with 3.9 million ha in the rainy season and 4.8 million ha in the post rainy season. Productivity in India is 1,345 Kg ha-1 in the rainy season and 480 Kg ha-1 in the post rainy season [1,6].

Agricultural mechanization implies the use of various farm machinery, tools and equipments to reduce the drudgery of the human beings and draught animals enhance the cropping intensity, precision and timelines of efficiency of utilization of various crop inputs and reduce the losses at different stages of crop production [3]. Due to the no. of labors and drudgery involved in the harvesting operation, there is a need to have mechanized means for harvesting sorghum [4].

Thus in view of the above, the study was undertaken with following objectives,

Objectives

To design and develop collection unit for rotary cutting mechanism.

Materials and Methods

The rotary cutting mechanism was design and developed at Department of Farm Power and Machinery (FPM), Dr. PDKV, Akola and lab trials were also conducted. Rotary cutting mechanism performs five major operations during the harvesting like cutting the Sorghum stalk at the bottom, conveying of the stalks, cutting of cobs from top, conveying and collection of cobs.

The rotary cutting mechanism is operated by small tractor linked with front side of tractor.

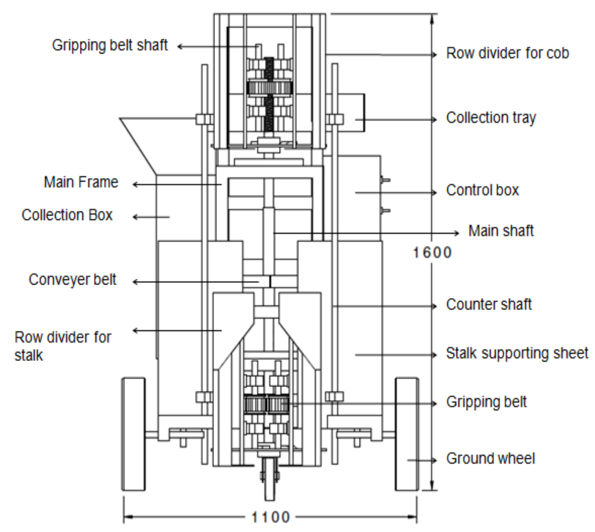


Fig-1 Modified frame of rotary cutting mechanism

Mechanical drive system 1

Mechanical drive system for rotary cutting mechanism has only one component i.e. cutting mechanism and proposes to have conveying and collection unit. Theoretical consideration regarding design and development of various components of collection unit of stalk and cob are described as follows.

Power transmission system 2

This section deals with the power transmission to various components of rotary cutting and conveying mechanism.

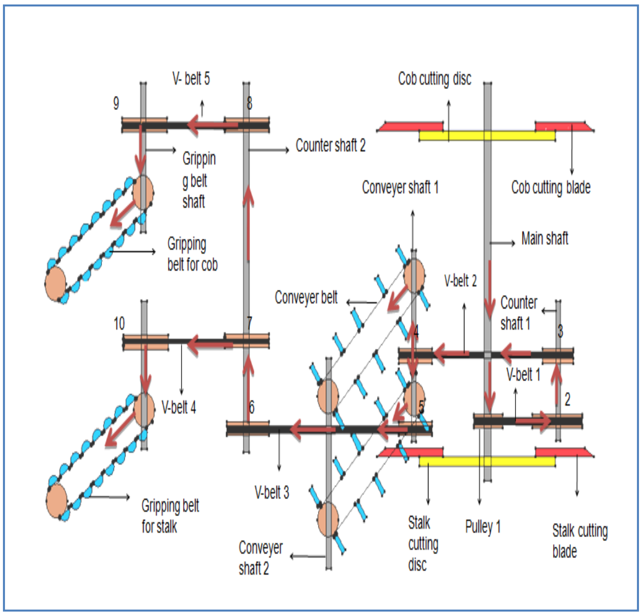


Fig-2 Power transmission for rotary cutting and conveying mechanism.

[Fig-2] shows the power transmission diagram of rotary cutting mechanism. The power is supplied by the generator to the electric motor. The electric motor operates at speed of 1420 rpm and transfer power to main shaft of rotary cutting mechanism with the help of v-belt and pulley. The main shaft rotates at the speed of 474 rpm and it transfers the power to counter shaft (1) by v-belt (1) and pulley (1 & 2) which rotates at the speed of 180 rpm. From the counter shaft power is transfer to conveying shaft (1) with the help of v-belt (2) and pulley (3 & 4), conveying shaft rotates two conveyer belts at same speed. The conveyer shaft (1) transfers the power to second counter shaft with the help of v-belt (3) and pulley (5 & 6). The second counter shaft transfer equal power to gripping belt use for holding and conveying of stalks and cobs.

Design of shaft 3 [7]

Shaft is a rotating machine element which is used to transmit power from one place to another. In order to transfer the power from one shaft to another, the members such as pulleys are mounted on it.

Torque at shaft (provided on conveying mechanism arrangement)

Torque at shaft is calculated by mathematical equation as follows,

$$Hp = \frac{2\pi N_m T_m}{4500} ------[Eq-1]$$

Therefore,

$$T_m = \frac{2.0\times 4500}{2\times 3.14\times 1420} — [Eq-2]$$

Where,
hp= Horse power, hp
N_m= Revolution of motor shaft, rpm
T_m= Torque develop by motor, Kg-cm

Tension in belt drive

Tension in belt is calculated by using following equation

$$T_m = (T_1 - T_2)\times r_1 --- [Eq-3]$$

Where,
T_m= Torque at motor, Kg-cm
T_1= Tension in tight side of the belt, Kg
T_2= Tension in slack side of the belt, Kg
r_1= Radius of motor shaft pulley, cm

$$\frac{T_1}{T_2} = e^{\mu_e \theta} ----- [Eq-4]$$

$$\mu_e = \frac{2\mu}{\sin\beta} ----[Eq-5]$$

Where,
e = Exponential
μ_e = Equivalent coefficient of friction
μ= Coefficient of friction (0.3 for rubber belt)
θ = Angle of contact, radians
β= Grove angle of pulley, 38°

$$\theta = \pi - 2\sin^{-1}\left(\frac{D_1 - D_2}{2C}\right) --[Eq-6]$$

Where,
D_1= Diameter of driving pulley, cm
D_2= Diameter of driven pulley, cm
C= Center to center distance between two pulleys, cm
Total vertical load acting on pulley is as follows,

$$W = T_1 + T_2 ----- [Eq-7]$$

The bending moment of shaft,

$$M = W\times L ----- [Eq-8]$$

Where,
M= Bending moment of shaft, Kg-cm
W= Total vertical load acting on pulleys, Kg-cm
L= Length of shaft, cm
Equivalent twisting moment of shaft

$$T_e = \sqrt{(M^2 + T^2)} --[Eq-9]$$

Where,
T_e= Equivalent twisting moment of shaft, Kg-cm
M= Bending moment of shaft, Kg-cm
T= Torque in shaft, Kg-cm
The equivalent twisting moment,

$$T_e = \frac{\pi}{16}\times\sigma_a\times d^3 - [Eq-10]$$

Hence,

$$d = \sqrt[3]{\frac{T_e\times 16}{\pi\times\sigma_a}} --- [Eq-11]$$

Where,
d= Diameter of the shaft, cm
σ_a= maximum allowable stress, Kg/cm^2
The equivalent bending moment (M_e) is given by,

$$M_e = \frac{1}{2}\left[M + \sqrt{(M^2 + T^2)}\right] --[Eq-12]$$

Where,
M_e= equivalent bending moment, Kg-cm
M= Bending moment of shaft, Kg-cm
T= Torque in shaft, Kg-cm
Now,

Equivalent bending moment

$$M_e = \frac{\pi}{32} \times \sigma_b \times d^3 ------ [Eq - 13]$$

Therefore,

$$d = \sqrt[3]{\frac{M_e \times 32}{\pi \times \sigma_b}} ------- [Eq - 14]$$

Where,
M_e= Equivalent bending moment, Kg-cm
σ_b= Allowable tensile stress, Kg/cm^2
d= Diameter of shaft, cm

Table-1 *Specification of shaft*

Sr. No	Specification	Counter shaft 1	Counter shaft 2
1	Type of belt	V- belt	V- belt
2	Speed ratio	2.53:1	1.74:1
3	Diameter (mm)	35	30
4	Torque (Kg-cm)	766.71	670
5	Pulley dimension (mm)	75, 75	75 75
6	Tension on tight side (Kg-cm)	214.60	187.47
7	Tension on slack side (Kg-cm)	10.08	8.81
8	Belt length (mm)	778	736
9	Max B.M. (Kg-cm)	898.73	392.56

Holding mechanism for cobs 4

Gripping belt was fabricated for the proper gripping of cobs. This mechanism consists of different parts i.e. gripping belt, pulley, shaft and bearing. The clearance between two belts was 40 mm provided for protecting cobs from damage and blockage. Gripping belt holds cobs for proper cutting and conveying [Fig-3]. In design of gripping belt tire gripper were used because uneven diameter of the cobs.

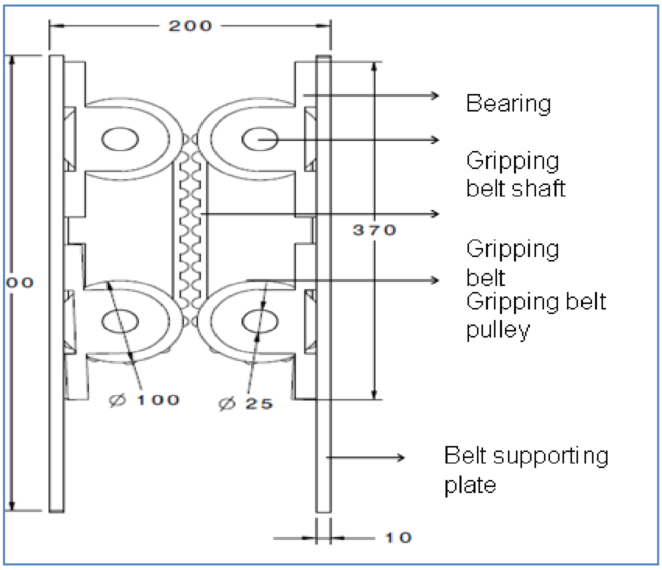
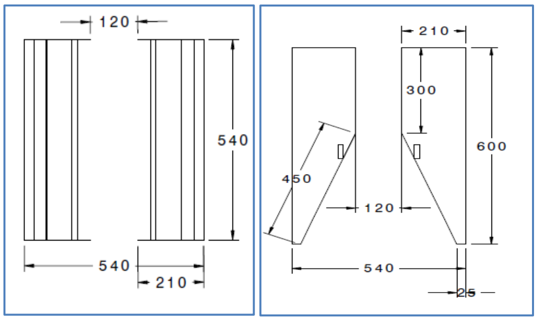


Fig-3 Crop holding mechanism

Row divider for Cobs 8

The dividers for cobs were fabricated from material 0.5 mm size of M.S. sheet and 25 x 25 x 3 mm M.S. angle with 600 x 210 x 540 mm dimensions [Fig-4.]. Two row dividers were fabricated with 120 mm spacing. It is mounted on front side of mechanism.



a) Front view b) Top view

Fig-4 Row divider for cob

Collection unit of the mechanism 5

Collection unit of the rotary cutting mechanism mainly consists of the gripping belt, collection tray and collection box. Gripping belt hold cobs and convey to collection tray and finally move to collection box by gravity.

Collection tray 6

Collection tray was fabricated from M.S. sheet having dimensions 690 mm length, 690 mm width and 150 mm height with slope of angle 30° [Fig-5]. All dimensions of this tray are selected on trial and error basis. It was mounted at the end of gripping belt to collect the sorghum cobs.

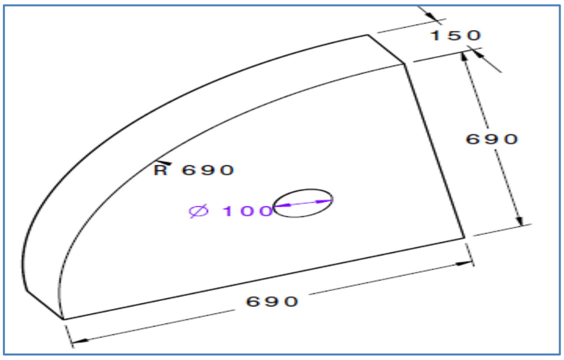


Fig-5 Collection tray

Collection box 7

Collection box was fabricated rectangular in size made of MS sheet having dimensions are 370 mm length, 250 mm width, 730 mm height, which was mounted on right side of the mechanism. Outlet was given at the bottom of the box for removing the cobs manually. The dimension of outlet flap is 250 x370 mm Capacity of collection box is 450 cobs [Fig-6].

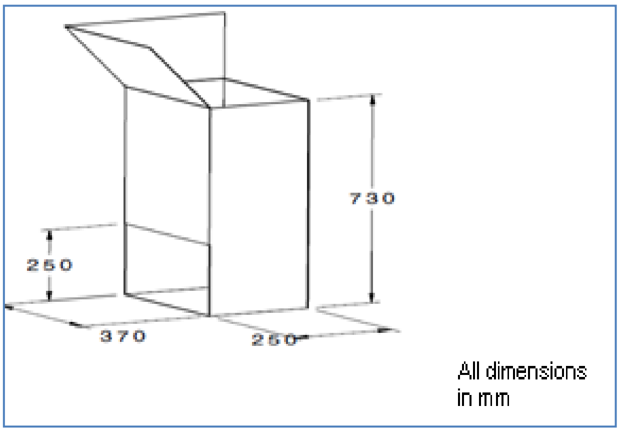


Fig-6 Isometric view of cob collection box

Collection efficiency of collection unit 9

Conveying efficiency of the collection unit was calculated by this equation.

$$\text{Collection Efficiency} = \frac{(W_1 - W_2)}{W_1} \times 100$$

Where,
W_1 =Total number of plants
W_2 = Number of cobs not collected in the collection box of the collection unit after harvesting

Results and Discussion

The rotary cutting mechanism was tested in the laboratory evaluate its overall performance. It was tested in laboratory to assess the performance of various parts of mechanism in respect of extent of mechanical and internal damage and also its overall working and mainly cob collection efficiency of mechanism. The results pertaining to the design and development collection unit of rotary cutting mechanism for harvesting sorghum are presented. The results obtained were tabulated in a manner to evaluate proper functioning of various component of rotary cutting mechanism. Harvesting of sorghum requires two stage operations first to cut the stalk from bottom and second at cob height with the help of manual labour. These operations are tedious and time consuming due to shortage of labour and their increasing wages and thus harvesting of sorghum is becoming a difficult task. To overcome this problem, the rotary cutting mechanism was design and developed in the department of Farm Power and Machinery, Dr. PDKV, Akola. The result obtained in test are presented and discussed in this chapter as below,

Performance of rotary cutting mechanism 1

Performance of rotary cutting mechanism was carried out in laboratory. In which the lab trial were conducted to observe the working and breakdown of whole mechanism of collection efficiency were also calculated.

Laboratory testing of rotary cutting mechanism 2

For as their performance and working condition was concerned. The performance of different components of rotary cutting mechanism and collection system in the laboratory test [Table-2].

Table-2 *working of rotary cutting mechanism*

Units	Components	Working
Cutting mechanism	Electric motor	Good
	Cutter bar	Satisfactory
Collection	Gripping belt	Good
	Cutter bar	Satisfactory

The performance evaluation of rotary cutting mechanism was conducted in laboratory for stalk holding mechanism. During trials, the stalks with cobs were feed manually to the gripping belt to observe the performance of gripping belt, feeding stalk to rotary cutting mechanism and after cutting of cob at top the collection of cobs in the collection box. The test was conducted at different rpm of the rotary cutting mechanism

Collection efficiency of collection unit 3

Cobs were conveyed towards the collection box through a conveying tray. The collection efficiency was calculated as 15 numbers of plants before harvesting and number of cobs collected in the collection box. From the [Table-3] it was observe that the cutting efficiency increases with increase in rpm of rotary cutting mechanism from 290 to 474 rpm and further it goes on decrees at 535 rpm. The minimum efficiency observed at 290 rpm whereas maximum was observed at 474 rpm.

The collection efficiency of cobs was observing minimum at 290 rpm of conveyer shaft whereas maximum was obtained at 474 rpm of conveyer shaft. The minimum values observe was 76.47 per cent at 290 rpm and maximum was 97.20 percent observing at 474 rpm of conveyer shaft.

Table-3 *Collection efficiency of rotary cutting mechanism*

Sr. No.	Main shaft rpm	Cutting efficiency	Collection efficiency (%)
1	290	95	76.47
2	319	97	79.42
3	363	96	82.37
4	392	98	88.13
5	435	99	92.26
6	474	99	97.20
7	535	92	92.26

Summary and Conclusions

An attempt was made to design and develop tractor front mounted rotary cutting mechanism in the Department of Farm Power and Machinery, College of Agricultural Engineering and Technology, Dr. PDKV, Akola and test trails were taken for sorghum. Performance of rotary cutting mechanism was tested in the laboratory with different parameters. Cutting of plant consist of rotary cutter, row divider, conveying unit and collection unit and for the separation of cobs, which consisted of cutter bar, gripping belt, conveying belt, collection tray and collection box for collecting the cobs. Above mentioned mechanism was powered by electrically to achieve maximum energy. The performance of harvesting the sorghum crop was evaluated according to two methods i.e. Mechanical. On the basis of the experiment conducted on lab following conclusions could be drawn,

1. Gripping belt and collection tray of collection unit work satisfactory
2. Selected power source 2.0 hp electric motor is suitable for operation of rotary cutting mechanism.
3. Maximum cutting, and collection efficiency of collection unit of rotary cutting mechanism was found to be 99and 97.20 per cent at 474 rpm of main shaft.

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Author’s contributions

Concept and designed: R.R. Gajbhiye, Dr. Mrudulata M. Deshmukh and Dr. S K Thakre. Conceptualized Paper: R R Gajbhiye,Dr. Mrudulata M. Deshmukh and Dr. S K Thakre. Contributed Material/testing machine: R R Gajbhiye, Dr. Mrudulata M. Deshmukh and Dr. S K Thakre. Wrote the paper: R R Gajbhiye and M M Deshmukh

Abbreviations

cm- Centimeter, ha- Hector, kg-cm- Kilogram Centimeter, kg-ha^{-1}-kilogram per Hector, mm- Millimeter, M.S.- Mild Steel, rpm- Revolution per Minute, t- Tones

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of Interest: None declared

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