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Design and Development of Cutting Unit for the Banana Pseudo Stem by using Power Screw Mechanism

Shubham Pandey[1*], R. K. Naik[2] and Kishan Kumar Patel[1]
[1]Ph.D. Scholar, Farm Machinery and Power Engineering, IGKV, Raipur (C.G.) India.
[2]Professor, Farm Machinery and Power Engineering, IGKV, Raipur (C.G.) India.

(Corresponding author: Shubham Pandey)*
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ABSTRACT: The cutting action of banana pseudo stem by manual feeding is laborious, time consuming, un-economic as well as risky for the operators. Therefore, an attempt has been taken towards the automation of feeding action of banana pseudo stem to cut them by using rotary action of the blade. The experiment was conducted to design and development of cutting unit of banana pseudo stem in equal proportion on the basis of physical properties of banana pseudo stem. In this research, the feeding action of banana pseudo stem was done by power screw mechanism using mechanical arrangement and forward backward switch. This mechanism consists of lead screw, bearing, lead screw block and assembly, screw driving mechanism and supporting structure. The rotary cutting blade mounted on the rotor cuts the banana pseudo stem in two equal parts as it was feed by power screw mechanism.

Keywords: Cutting unit, banana pseudo stem, lead screw, bearing, forward-backward switch, rotary blade.

INTRODUCTION

Banana (*Musa* sp.) is most grown horticultural fruit in worldwide as well as in India. The share of banana production and average yield of banana in India is about 29% of the world and around 60 tons per hectare (FAO, 2021).

The banana plant contains leaves with bunches and fruits are used in religious purpose. After the fruit is obtained, the plant is thrown away giving rise to increase in waste. The proper disposal of this plant is another problem. By using a good cutting cum fiber extractor machine, a large amount of fiber can be obtained which will give rise to additional income.

Banana pseudo stem contain three major parts *viz.*, central core (10-15%), banana fiber (1.5-2%) and waste material after banana fiber extraction (80-85%) that includes Sap (35-40%) and scutcher (40-45%) (Jawale and Chaudhari 2018). The outer strands are coarse and can be used for basket weaving and making handbags (Vigneswaran *et al*., 2015).

The cutting of banana pseudo stem was done manually which was laborious and time consuming. The rotary cutter was also used to cut the pseudo stem but feeding of pseudo stem manually which is un-economic as well as risky for the operators. There is some automatic cutting and feeding machine is already developed for wood cutting (Mackerle, 2005), spiral grooved-wheel fertilizer feeders (Liping *et al.*, 2018), mechanical modeling on feeding control for pouring units (Gomanthi *et al.*, 2019) and automatic feeding and clamping mechanism for metal cutting (Phapale *et al.* 2020). At present, there are some research results on the automatic and mechanically feeding of stem to cut by rotary blade but it was costly and not desired for commercial purpose. Therefore, this research work was aimed to design and develop an automatic cutting and feeding unit of banana pseudo stem by using power screw mechanism and to carry out the performance evaluation of the developed machine.

MATERIAL AND METHODS

The cutting unit consists of Lead screw, Bearing, Lead screw block and assembly, Lead screw driving mechanism, cutting blade, power transmission system, feeding block and supporting structure.

A. Design of power screw

The feeding action of pseudo-stem was controlled by power screw mechanism. The objective of this project was to improve the traditional mechanical system of feeding by using power screw mechanism. The lead screw, also known as the power screw, was just a machine component that converts rotary motion into linear motion. The lead screw was small in size, simple in design, and has a high load carrying capacity. This mechanism consists of following parts *i.e.* Lead screw, Bearing, Lead screw nut and assembly, Lead screw driving mechanism and supporting structure. In lead screw selection process, following parameters were find out *i.e.* length of lead screw, material selection for screw and nut, outer or major diameter, minor diameter, pitch diameter, pitch, lead and type of thread.

Material selection. Material for screw shaft was taken as steel (C 40 to C 55) having 0.3 to 0.5 % C. EN8 is very common and cheap material for manufacturing lead screw due to availability and pricing. EN8 contains 0.36 to 0.44% of C which was in the range of requirement. Material available for block (nut) is bronze or cast iron. Bronze block was selected because of its high friction and wear resistance.

Stress calculation. Stress was calculated by given formula (Bhandari, 2017):

$$\sigma = \frac{S_{yt}}{fos} \qquad \text{... (1)}$$

It was assumed that the factor of safety to be 3 due to less force is applied and material is made of homogeneous ductile yield strength.

$$\sigma = \frac{S_{yt}}{fos} = \frac{385}{3}$$

$= 128.33$ MPa

Selection of thread type. The trapezoidal type of thread was selected due to more economical thickness in the core diameter, stronger and large load carrying capacity.

Diameter calculation. Lead screw length required was 1600 mm because optimum length of pseudo-stem was considered as 1000 mm. It was also calculated that the load required to pushing the pseudo-stem which was 500 N. The combined load of screw was calculated for getting proper diameter.

Hence, combine loading (Axial + Bending) (Bhandari, 2017).

$$\sigma_t = \sigma_a + \sigma_b = \frac{P}{A} + \frac{M` y.}{I} \qquad \text{... (2)}$$

$$\sigma_t = \frac{P}{\frac{\pi}{4} \times d_3{}^2} + \frac{P \times e \times \frac{d_3}{2}}{\frac{\pi}{64} \times d_3{}^4}$$

Where,

P = Push force, N;

D_c = Nominal diameter, mm; and

e = Eccentricity, mm;

The eccentricity was assumed as 230mm (by taking samples of 100 plants the diameter was found to be 200 mm on average and adding additional block height as 30 mm).

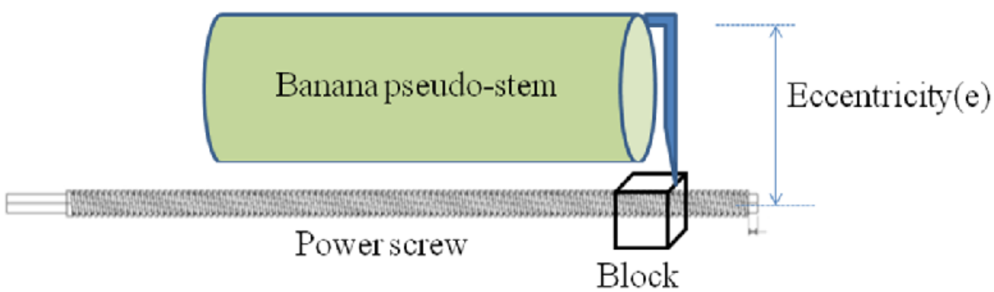

Fig. 1. Eccentric push force required to feed the banana pseudo-stem.

$$\sigma_t = \frac{4P}{\pi d_3{}^2} + \frac{32 \times P \times e.}{\pi \times d_3{}^3} \qquad \text{... (3)}$$

Since, $\sigma = \frac{S_{yt}}{fos} = \frac{385}{3}$

$= 128.33$ MPa

Using equation (3)

$$192.5 = \frac{4 \times 500}{\pi d_c{}^2} + \frac{32 \times 500 \times 230}{\pi \times d_c{}^3}$$

$d_3 = 22$mm

So, for the safety purpose taking factor of safety as 1.33 times, it was considered as 30 mm.

The nominal diameter was required for design lead screw and was calculated by formulae:

$$d_3 = d - p \qquad \text{... (4)}$$

According to standard table for dc=30 mm, 'p' should be 6

$d = d_3 + p = 30 + 6 = 36$ mm

Similarly, $d_2 = d - 0.5p = 36 - (0.5 \times 6) = 33$ mm

Lead calculation (l). It was based on the pith and number of start (n). The numbers of start (n) selected as 2 due to less time requirement, high speed of operation, less torque and reduce the difficulties in manufacturing. Hence, Lead was calculated as

$$I = n \times p \qquad \text{... (5)}$$

Where,

I = Lead, mm;

n = Number of start = 2; and

p = Pitch, mm.

I=2×6=12 mm, $2\theta = 30^0$ or $\theta = 15^0$

Helix angle of thread

$$\text{Tan } \alpha = \frac{l}{\pi d_m} \qquad \text{... (6)}$$

$$\text{Tan } \alpha = \frac{12}{\pi \times 33}$$

Tan α = 0.1157 , α = 6.602°

Now, for safety purpose and better failure free results, increasing load by 50%.

Hence, W= 500 N to 1000 N.

Calculation of coefficient of friction (μ). The coefficient of friction steel screw and bronze nut was in the range of 0.1- 0.18. Friction occur maximum on account of poor lubrication; consider the worst condition where the operator is careless about the lubrication of the screw (Patil *et al.*, 2018).

$\mu = 0.18, \quad \theta = 15^{\circ}, \quad \varphi = 10.20^{\circ},$

$$\mu \operatorname{Sec}\theta = \frac{\mu}{\cos\theta} = \frac{0.18}{\cos 15} = 0.18635$$

$\varphi > \theta$, Screw is self- locking

Torque calculation

$$M_t = P \times \frac{d_m}{2} \quad \text{... (7)}$$

$$p = \frac{W \times (\mu \operatorname{Sec}\theta + \tan\alpha)}{1 + \mu \operatorname{Sec}\theta \tan\alpha} \quad \text{... (8)}$$

Where,

W= 800 N

$\mu = 0.18$

$\theta = 15^0$

$$p = \frac{800 \times (0.18365 + 0.1157)}{1 + (0.18365 \times 0.1157)}$$

$$p = 234.49 \approx 234.5 \text{ N}$$

$$M_t = P \times \frac{d_m}{2} = 234.5 \times \frac{33}{2} = 3869.25 \text{ N} - \text{mm}$$

Total torque required to push the pseudo-stem using the threats bearing with coefficient is in the range of 0.01 to 0.02. The higher coefficient of friction (i.e. 0.02) and newly manufactured bearing on shaft was considered. So, uniform pressure theory is applicable (Bhandari, 2017).

$$(M_t)_c = \frac{\mu_c \times w}{3} \; \frac{{D_0}^3 - {D_i}^3}{{D_0}^2 - {D_i}^2} \quad \text{... (9)}$$

$$(M_t)_c = \frac{0.02 \times 800}{3} \times \frac{40^3 - 30^3}{40^2 - 30^2} = 281.90 \text{ N} - \text{mm}$$

Both bearing considered same amount of load during pushing of the banana pseudo-stem. Hence, total load of bearings = 2 x $(M_t)_c$ = 281.90 N-mm

So, Total torque required to push the stem of the plant,

$$M_t = (M_t)_t + (M_t)_c = 3869.25 + 563.80 = 4433.3 \text{ N} - \text{mm}$$

Stress calculations for checking design are safe or not. Shear stress was calculated by using formula given by Bhandari, (2017)

$$\tau = \frac{16\, M_t}{\pi {d_c}^3} = \frac{16 \times 4433.3}{\pi \times 33^3} = \frac{0.628\text{N}}{\text{mm}^2} \quad \text{... (10)}$$

Compressive stress calculation

$$\sigma_c = \frac{W}{(\frac{\pi}{4} \times {d_c}^2)} = \frac{800}{\frac{\pi}{4} \times 33^2} = 0.935 \frac{\text{N}}{\text{mm}^2} \quad \text{... (11)}$$

Bending stress calculation was done using following formula as given below (Bhandari, 2017)

$$\sigma_b = \frac{32 \times M_b.}{\pi \times {d_c}^3} = \frac{32 \times (800 \times 230)}{\pi \times 33^3} = 52.15 \frac{\text{N}}{\text{mm}^2} \quad \text{... (12)}$$

It was observed from Fig. 1 that load was eccentric which implies failure occurs due to bending. Therefore, neglecting compressive stress and considering the effect of combination of torsion shear stress and bending stress determined by following equations:

$$\tau_{max} = \sqrt{(\frac{\sigma_b}{2})^2 + \tau^2} \quad \text{... (13)}$$

$$\tau_{max} = \sqrt{(\frac{52.15}{2})^2 + 0.628^2} = 26.08 \text{ N/mm}^2$$

Factor of safety is given by,

$$\text{fos} = \frac{S_{sy}}{\tau_{max}} = \frac{0.5\, S_{yt}}{\tau_{max}} \quad \text{... (14)}$$

$$\text{fos} = \frac{0.5 \times 385}{26.08} = 7.38$$

Since, fos = 7.38 > 2, which was match to design.

So, double start trapezoidal thread of 36 mm diameter and 6 mm pitch was suitable for design and manufactured by a specialist screw manufacture for this machine.

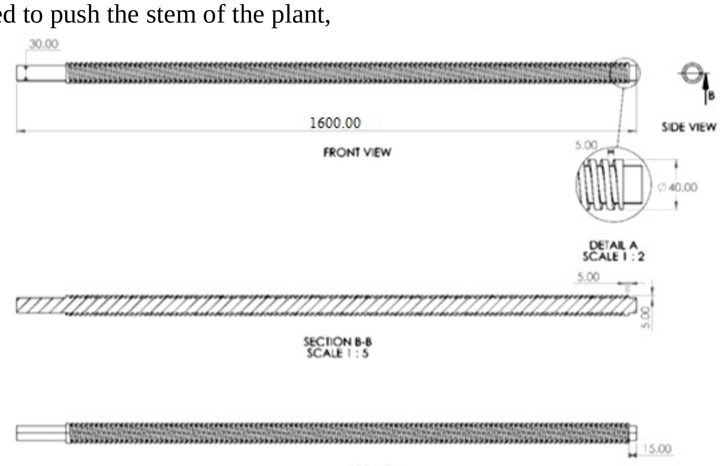

Fig. 2. Sectional view of power screw.

Design of circular cutting blade. The cutting operation was conducted by a sharp circular serrated blade. The pseudo stem was feed through external applied force (square block of power screw) during cutting operation. The reciprocal relations between pseudo-stem and the cutting edge generated when pseudo-stem was penetrated by the tooth of a circular saw (Kováč and Mikleš 2010). The cutting edge pressed on the resisting pseudo-stem which causes loads on the frontal, rounded, and back surfaces of the cutting edge. The cutting resistance was created as the chip and was separated by the wedge. The cutting resistance was a reaction to the cutting force which was same size but was observed in the opposite direction of motion. The resistances acting against the cutting edge of a circular saw tooth could be summed as one resultant force 'F' consists of the following:

(i) Forces necessary for cutting a pseudo-stem using a cutting wedge via deformation of the piece surrounding the cutting edge,

(ii) Forces necessary for the deflection of chips and the overcoming of the chip's friction against the leading edge of the tooth, and

(iii) Forces necessary for suppression of friction on the back and leading surfaces in contact with the machined surface.

The component of the force 'F' in the direction of cutting feed is called the cutting force and was used for practical calculations of energy expenditure during the cutting process. The cutting force F on a tooth of a circular saw acts on chips of width b and thickness h regarding to the cutting resistance for disintegrated material K using the formula given by Krilek *et al.* (2014).

$$F = \frac{K.b.h.v_f}{60.v_c} \quad \text{... (15)}$$

Where,

F= Cutting force, N;

K = Cutting resistance for soft wood, N/mm^2;

b = Width of chip, mm;

h = thickness of the chip, mm;

v_f = Feed velocity of pseudo-stem, m/min; and

v_c = Cutting velocity of blade, m/s;

The optimal performance of a circular saw blade was achieved by choosing cutting conditions based on the material to be cut. The recommended cutting speed for circular saw blade material depends on the requirements of cutting surface quality, the technological state of the machine etc (Schajer, 1986). The diameter of circular saw blade was depending up on maximum diameter of feeding pseudo-stem and it was calculated as 190 mm. Since, diameter of cutting blade is 2 times the diameter of feeding pseudo-stem.

Therefore,

$$D_b = 2 \times D_s = 2 \times 190 = 380 \text{ mm} \quad \text{... (16)}$$

The recommended diameter and speed of circular saw blade was 400 mm and 510 rpm which were equal to the speed of decorticator.

Therefore,

$$v_c = \omega r = \frac{\pi d N}{60} \quad \text{... (17)}$$

$$v_c = \frac{\pi \times 0.4 \times 510}{60} = 10.68 \text{ m/s}$$

Since, the speed of screw was 510 rpm and pitch of lead was calculated as 6 mm. So, 6 mm pitch covered by one revolution of screw. Hence the feed velocity was calculated as

$$v_f = 6 \times 510 = 3060 \text{ mm/min} = 3.06 \text{ m/min}$$

Width and thickness of chip was considered as 200 mm and 6 mm. The specific cutting resistance for soft wood (i.e. banana pseudo stem) was considered as 19.01 N/mm^2 (Karpuschewski *et al.*, 2018).

Putting all the values in Equation 15, the value of cutting force (F) was found as:

$$F = \frac{19.01 \times 200 \times 6 \times 3.06}{60 \times 10.68} = 108.93 \text{ N}$$

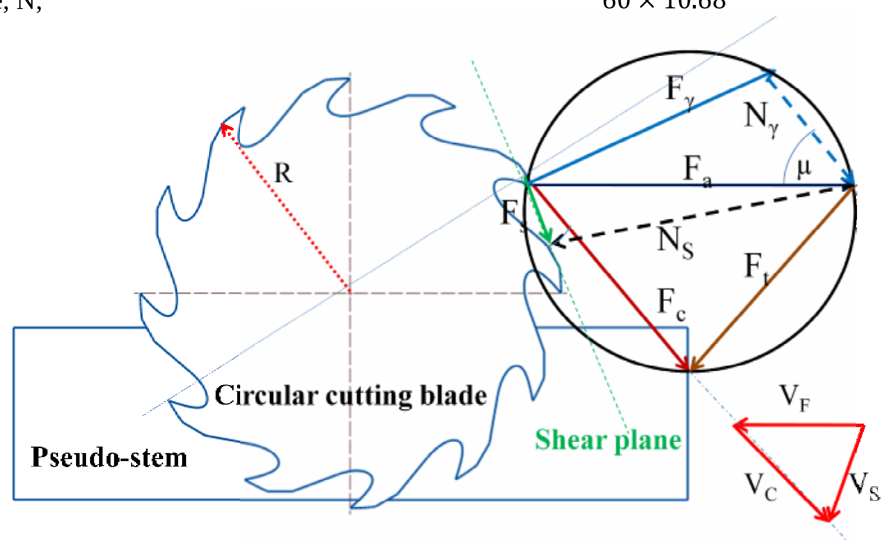

Fig. 3. Different forces acting on the circular blade.

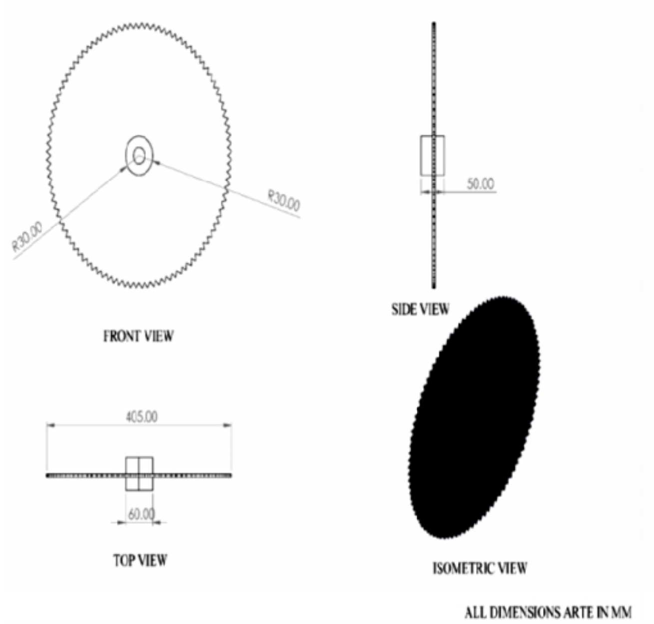

Fig. 4. Sectional and isometric view of cutting blade.

Fig. 5. Developed power lead screw.

The cutting power required to cut the banana pseudo-stem was calculated by formula given by Schajer, 1986.

$$P = F \times v_c = 108.93 \times 10.68 = 1163.4 \text{ Watt}$$

The cutting power was also calculated by using torque M_t, and diameter of cutting blade D_b. So, the formula used to calculate power was given by

$$P = \frac{2 \times M_t \times v_c}{D_b} \qquad \text{... (18)}$$

$$1163.4 = \frac{2 \times M_t \times 10.68}{0.40}$$

M_t = 21.78 N-m

Hence, the cutting force, cutting power and cutting torque of saw cutting blade was calculated as 108.93 N, 1163.4 Watt and 21.78 N-m respectively.

C. Transmission system of cutting unit

The power transmission in cutting unit was from motor having rated rpm as 1425. Cutting unit consists of different pair of gears and belt pulley arrangement. The labelled and systematic diagram of cutting unit of banana pseudo-stem was given in Fig. 6.

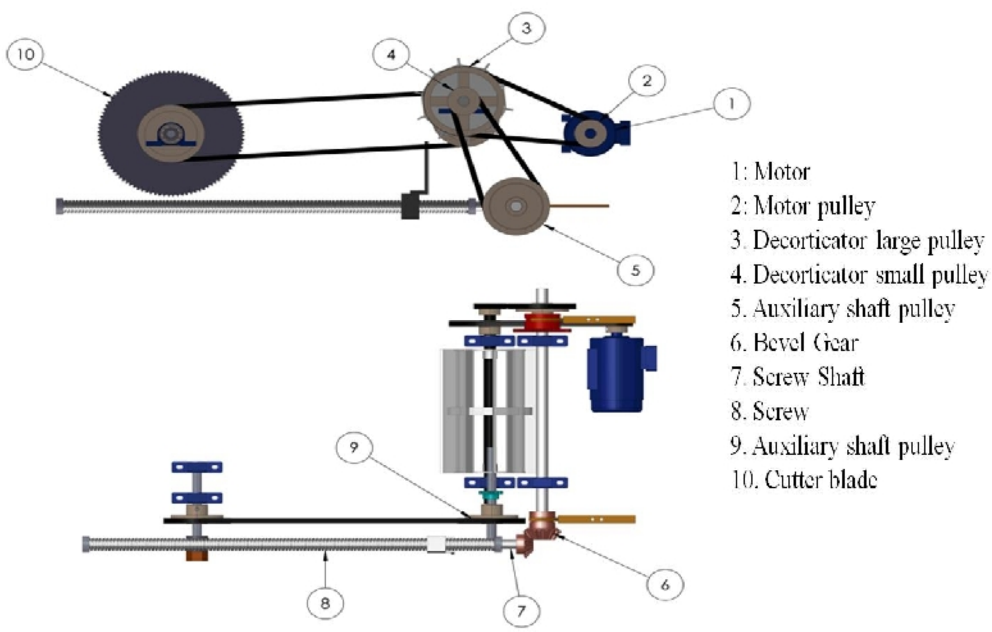

Fig. 6. The labelled diagram of power transmission system for cutting unit.

A pair of pulley was used to transmit power from lay shaft to the rotor shaft where cutting blade was mounted. The size of pulley on both lay and rotor shaft was same *i.e.* 127 mm.

A bevel gear arrangement was used to transmit power from first auxiliary shaft to the power screw shaft. The speed of auxiliary and lead screw shaft was calculated as 255 rpm and 510 rpm respectively. Therefore, the larger bevel gear size was considered as 127 mm with 20 numbers of teeth as easily available in the market. So, Number of teeth of smaller gear was calculated using following formula given by Khurmi and Gupta (2005).

$$\frac{N_S}{N_A} = \frac{T_A}{T_S} \quad \ldots (19)$$

Where,

N_A = Speed of auxiliary shaft, rpm;
N_S = Speed of lead screw shaft, rpm;
T_A = Number of teeth of larger gear; and
T_S = Number of teeth of smaller gear.

$$\frac{510}{255} = \frac{20}{T_S}$$

$T_s = 10$

Hence, the number of teeth in smaller gear attached to lead screw shaft was calculated as 10.

RESULT AND DISCUSSION

The developed cutting unit of banana pseudo stem consist of different component i.e. power lead screw, cutting blade, feeding tray and bevel gear. The detail description, material of construction and specification of all the components cutting unit is discussed below:

Power lead screw. The power lead screw is used to feed the pseudo-stem for the cutting action. The diameter and length of power screw are selected as 30 mm and 1600 mm respectively. The power screw is made up of steel (C40 to C55) *i.e.* EN8 material due to easily available in market and having high hardness and tensile strength.

Circular cutting blade. The circular cutting blade is made up of high speed steel (HSS) with 400 mm diameter and 5 mm thickness. The diameter of cutting blade decides the size of pseudo-stem to be cut. The speed of cutting blade was decided as 510 rpm.

CONCLUSION

The cutting unit of banana pseudo stem were designed and developed successfully at Dept. of Farm Machinery and Power Engineering, SVCAET and RS, IGKV, Raipur. The design and development of power screw mechanism for feeding of pseudo stem to the rotary cutter was completed and it is safe to be implementing in machine for feeding of pseudo stem. It saves the time of cutting and also money for the cutting of banana pseudo stem.

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