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Design & Performances of Coconut De-Shelling Machine

Mr. Ketan K.Tonpe [1], Mr. Vinod P. Sakhare [2], Dr. C. N. Sakhale[3]
[1] Research Scholar, Department of Mechanical Engg., Priyadarshini College of Engineering, Nagpur:19
[2]Assistant Professor, Department of Mechanical Engg. Datta Meghe Institute of Engineering, Technology & Research ,Wardha
[3]Associate Professor, Department of Mechanical Engg. Priyadarshini College of Engineering, Nagpur:19

ABSTRACT
The traditional method used in India, for the separation of copra and shell from partially-dried split coconuts, is labour intensive. To overcome this problem, a power operated coconut de-shelling machine was designed and developed. A coconut de-shelling machine comprising of cutter with belt drive. Performances test analysis conducted show that the machine de-shelled the fruits without nut breakage and also that its average de-shelling efficiency and capacity are 90% and 195 coconut per hour. All materials used in the fabrication of this machine are of standard specification and locally sourced. The estimated cost of producing one unit of the machine is twenty five thousand six hundred (Rs.25, 600). The machine also eliminated dependency on the epileptic public electric power supply in our rural areas which constitutes the major obstacle in the use of other mechanized coconut de-shelling equipment in the rural area.
***Keywords* -** Coconut De-shelling machine, de-shelling efficiency, capacity, small scale farmers

I. INTRODUCTION

Coconut (cocos nucifera) is one of the world most useful and important perennial plants [1].Coconut plays an important role in the economic, social and cultural activities of millions of people in our country. India is a major producer of coconut in the world. Coconut provides food, edible oil, industrial oil and health drink to humanity. All parts of coconut tree is useful in one way or other and the crop profoundly influences the socio-economic security of millions of farm families. Coconut oil, which comes under edible-industrial group, is used as a cooking oil, hair oil, massage oil and industrial oil. Coconut oil can be blended with diesel, straight in an adapted engine or turned into biodiesel

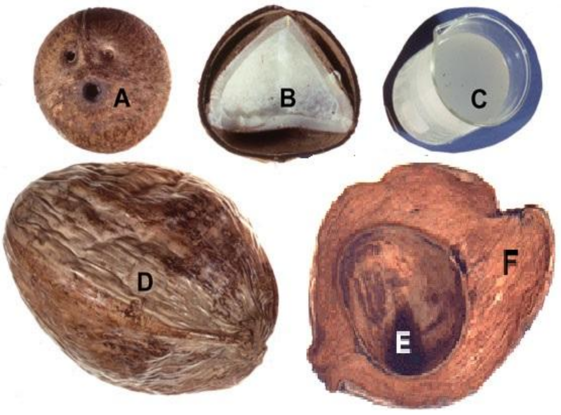

Fig. 1. Coconut Palm (Cocos nucifera)

The fruit of the coconut (Cocos nucifera) is technically a large, dry drupe (D) composed of a thin outer layer (exocarp), a thick, fibrous middle layer called a mesocarp (F), and a hard inner layer called an endocarp (E) that surrounds a large seed. The endocarp (A) contains three germination pores at one end, one of which the sprouting coconut palm grows through. The "meat" of the seed is endosperm tissue (B) and a small, cylindrical embryo is embedded in this nutritive tissue just opposite the functional germination pore. The seed is surrounded by an outer brown layer called the seed coat or testa. This is the brown material that adheres to the white "meat" or endosperm when it is removed from the endocarp shell. "Coconut water" (C) is multinucleate liquid endosperm that has not developed into solid tissue composed of cells. Copra comes from the meat of dried coconuts, while coir fibers are derived from the fibrousmesocarp.

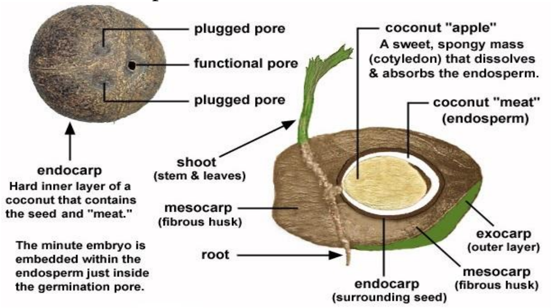

Fig. 2. Structure of a coconut fruit

Sprouting fruit of a coconut Cocos nucifera. The hard inner layer (endocarp) contains the actual seed composed of a minute embryo and food storage tissue (endosperm). The base of the embryo (cotyledon) swells into an absorbing organ that fills the entire cavity of the seed as it digests the endosperm. The endocarp has three germination pores, one functional pore and two plugged pores. [In "blind coconuts" all three pores are plugged.] The three pores represent three carpels, typical of the palm family (Arecaceae). Just inside the functional germination pore is a minute embryo embedded in the endosperm tissue. During germination, a spongy mass develops from the base of the embryo and fills the seed cavity. This mass of tissue is called the "coconut apple" and is essentially the functional cotyledon of the seed.

The nut varies from 147 to196mm in diameter and 245to 294mm long. Three sunken holes of softer tissue called “eyes” are at one end of the nut. Inside the shell is a thin, white, fleshy layer, about 12.25mm thick at maturity, known as the “coconut meat”. The interior of the nut is hollow and partially filled with a watery liquid called “coconut milk”. The meat is soft and jelly-like when immature and becomes firm at maturity. The coconut milk is abundant in unripe fruits but it is gradually absorbed as ripening proceeds [3]. According to [4], the meat of immature coconut fruit can be made in to ice cream while that of a mature coconut fruit can be eaten fresh or used for making shredded coconut and livestock feed. Coconut milk is a refreshing and nutritious drink while its oil is use for cooking and making margarine.

Coconut is commercially cultivated in 93 countries especially on the small and marginal holdings over an area of 11.8 million hectares and about 10.26 million tons of copra equivalent were produced in the year, India contributes to 15.28% of the global area and 19.44% of global production, and is the largest single market for coconut, consuming almost its entire production of 12.6 billon nuts. Indonesia is the next largest market for coconut, consuming nearly 11.2 billion nuts accounting for about 74% of its production. As much as 50.8% of the total coconut area in India is concentrated in Kerala and the state account for 43.6% of the total production of the country. Kerala is a small state along the west coast of India, which accounts for only 1.18% of the total land area of the country.

Rey (1955) reported a knife-shaped shallow spoon, which moved back and forth upon the rotation of a cam, and in the process, the coconut meat was scooped in fragments. Mix (1957) designed a shelling machine for removing the shell from the fresh coconut meat, while Blandis and Glaser (1973) used water under pressure to separate the coconut meat from the shell. Even in large processing units, about 15-20 labours are used for de-shelling 20,000 to 30,000 nuts (Singh,2004). This is a labour-intensive operation and takes several hours to separate shell and copra. However, no attempt has been made so far to develop a mechanical de-shelling machine, With this objective, an attempt has been made in the present study to develop a de-shelling machine.

II. MATERIAL AND METHOD

A. *Machine Description:*

The major components of the developed coconut de-shelling machine shown in Figure 3 are frame, Cross cutter, conveying unit, driven and driver pulleys, rubber belt and motor and bearing housing.

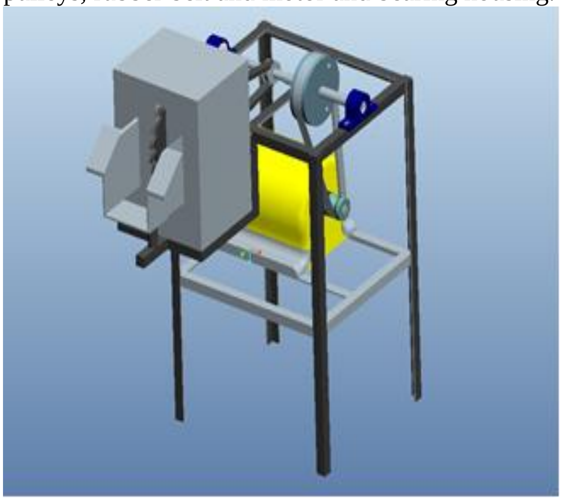

Fig.3. Diagram of the developed coconut de-shelling machine

The frame is the main supporting structure upon which other components of this machine were mounted. The frame is a welded structure construction from 50x50x5 mm angle iron with dimensions of 650 mm length, 740 mm width and 1000 mm height. The de-shelling unit comprises of two shaft one is intermediate shaft and other is cutter shaft. Intermediate shaft is a mild steel rod of 25mm diameter and 610 mm long and also mounted cutter shaft 25 mm diameter and 250 mm long supported at both ends by ball bearing. A 1 H.P (0.745 KW) induction motor, which is attached to the base of stand transmits power from motor shaft to intermediate shaft No. 1 through single groove pulley P1 (2.5”) and pulley P2 (11”) which are attached to motor shaft, intermediate shaft respectively and is connected by V-belt drive 680 mm. Motor shaft is rotated at 1440 RPM and intermediate shaft is rotated at 388 RPM. In intermediate shaft located the pulley P3 (2.5”) which transmitted the power to cutter shaft at which rotate speed 388 RPM, Since coconut shell contain low strength, hence it requires low speed for cutting, The de-shelling rod attached to frame structure which is near to disc cutter. The coconut eye of the coconut fruit and locate it to the de-shelling rod, without touching the disc cutter and rotate smoothly to de-shelled the coconut.

III. DESIGN ANALYSIS OF THE MACHINE

A. ***Design consideration:***

The coconut de-shelling machine was developed based on the following consideration:

1. The availability of materials locally to reduce cost of production and maintenance of the machine.
2. The de-shelling rod was introduced in between and near to disc cutter without touching the disc cutter and smoothly conducts the operation.
3. It is desired that the coconut fruits should be well de-shelled without nut breakage and also that cobra extracted should not be distorted, thus pulleys were carefully designed/selected to meet the required synchronized speeds of the de-shelling units.

B. ***Selection of pulley and determination of their speeds and belt tensions:***

The machine requires four pulleys and a belt for its drives. Standard pulley were selected due to simplicity in design, availability/economy of maintenance, absence of end thrust on bearing and suitability for heavy loads. Due to its availability, durability, cost and performance, mild steel pulleys with grooves angle of 38^0 each were selected. The driving pulley was mounted on the motor shaft and the driven on the intermediate shaft. In motor shaft the pulley diameter 88.9 mm and intermediate shaft 279 mm diameter, thus the of motor shaft has transmitted power to intermediate shaft with belt drive run at the less speed and this speed was determined as 458 rpm using the relation;

$$N_1D_1 = N_2D_2 \tag{1}$$

Where:

N_1 is the speed of the driving pulley = 1440

N_2 is the speed of the driven pulley = 45

D_1 is diameter of smaller pulley (P_1)

D_2 is diameter of lager pulley (P_2)

The centre distance, C between the adjacent pulleys was computed as 680mm.

Thus, length of the belt, *l* was computed as 1501.62 mm from expression given by ;

$$L = \frac{\pi}{4}(D_3 + D_4) + 2C + \frac{(D_4 - D_3)^2}{4C} \tag{2}$$

Where, D_1 is the diameter of the pulley on the driven motor shaft. Type "A" V-belt is suitable for this drive since the drive transmitted less than 0.81 kW. Based on a v-belt with standard nominal width, nominal thickness, minimum diameter, no. of strands and bending stress factor, centrifugal tension factor of 13 mm, 8 mm, 75 mm, 6, 17.6 x 10^3, 2.52 was selected for drive. Consequently, determine as , 2.74 rad and 6.70 m/s using Equation (2), (3) and (4) respectively in accordance [11].

$$\theta = \pi - \frac{D_3 + D_4}{C} \tag{3}$$

$$Vp = \frac{\pi D_3 N_3}{1000} \tag{4}$$

Where: θ= Angle of lap of the drive, rad.

Vp= Perperial velocity (Belt speed),m/s

N_1 = Speed of the driven pulley, rpm

In addition, Maximum, centrifugal tension, working load and life of belt were sequentially computed as 4.52 N, 169 N, 34.10 N respectively from the following relation by [11];

$$Fc = Kc\left(\frac{Vp}{5}\right)^2 \tag{5}$$

$$Fw = w^2 \tag{6}$$

$$F = \frac{F_1 + F_c + F_{bmax}}{9.8} \tag{7}$$

Where: F_c = Centrifugal tension of the belt, N

F_w= working load of the belt,N

F= Fatigue of the belt,N

F_b= Bending load of the belt, N

α = Cone angle

μ= Coefficient of friction between pulley and belt Now, design of pulley for cutter shaft .The driving pulley was mounted on the intermediate shaft and the driven on the cutter shaft. In motor shaft the pulley diameter 63.5 mm and cutter shaft 152 mm diameter, thus the of intermediate shaft has transmitted power to cutter shaft with belt drive run at the less speed and this speed was determined as 190 rpm . In addition, Maximum, centrifugal tension, working load and life of belt were sequentially computed as 8.41 N, 169 N, 127 N respectively from the following relation by [11];

C. ***Determination shaft diameter:***

The diameter, *d* for each of the two shaft of this machine was determine using maximum stress relation given by [11] as;

$$\tau_{max} = \frac{16 \times 10^3}{\pi D^3}\sqrt{(Kt \times T)^2 + (Kb + M)^2} \tag{8}$$

Where :

τ= Allowable shear stress for steel shaft with provision for key ways = 88.8 N/mm^2

T = Torque transmitted by the shaft , N-mm

M = Maximum bending moment on the shaft, N-mm

K_t = Combined shock and fatigue factor for twisting.

K_b = Combined shock and fatigue for bending.

Shaft material consider as SAE 1030 steel Sut = Ultimate tensile strength=527 MPa and Syt = Yield strength in compression =296 MPa Therefore , design shear stress (τ_{max}) should be τ_{max}< 0.30

Syt or τ_{max}< 0.18 Sut. τ_{max} < 0.30 x 296 = 88.8 MPa or τ_{max}<0.18 x 527 =94.86 MPa. Selecting minimum value i.e. τ_{max} = 88.8 MPa.
Now, because there is a keyway at critical section τ_{max} should be reduced by 25 precent. Therefore τ_{max}=0.75 x 88.8 = 66.6 MPa.

D. *Electric motor Specifications:*

A three phase 1hp electric motor with a rated speed of 1440 rpm was chosen for the de-shelling machine. It is because it is the range of electric motor available in the market with a specification close to the estimated minimum power requirement of 0.745 kW and by virtue of the coconut mass and density the high shelling speed like 190 rpm is needed to give the coconut adequate momentum to let the coconut be shelled by impaction.

E. *Determination of shaft Load and Reactions:*

- Figure 5 and 6 shows a schematic representation of the cutter shaft in the vertical and horizontal planes respectively.

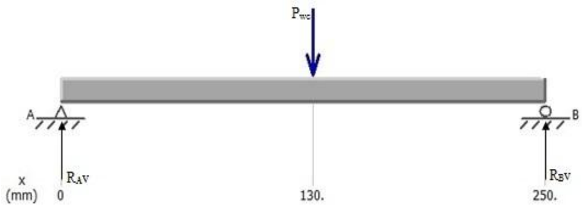

Fig. 5. Cutter shaft loading in the vertical plane

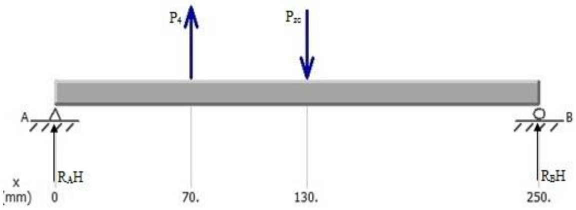

Fig. 6. Cutter shaft loading in the horizontal plane

With reference to figure 5, the summation of forces in the vertical direction is given as

$$\sum Fr\uparrow = R_AV + R_BV - P_{wc} = 0 \quad (9)$$

With reference to figure 6, the summation of forces on the horizontal direction is given as

$$\sum Fr\uparrow = R_AH + R_BH + P_4H - P_{ZC} = 0 \quad (10)$$

Using the Shelled strength of coconut to be 230N/m,the valves obtained using equations (14) and (15) are R_AV = 22.32 N, R_BV = 24.19 N, R_BH = 142.5 N and R_AH = -104.5 N.
Therefore, the maximum bending moment on this shaft is 101668 N-mm. The de-shelling of the coconut fruit by the driven shaft is partially sudden with minor shock at the start of each operation and gradual as the process progresses, hence, *Kb* =1.5 and *Kt* =1.5 [11]. Hence, the minimum diameter of this shaft was determined as 22.14 mm using Equation (8). Thus, a standard solid mild steel shaft of 25mm in diameter was selected for this machine's driven cutter shaft.

- Figure 7 and 8 shows a schematic representation of the intermediate shaft in the vertical and horizontal planes respectively.

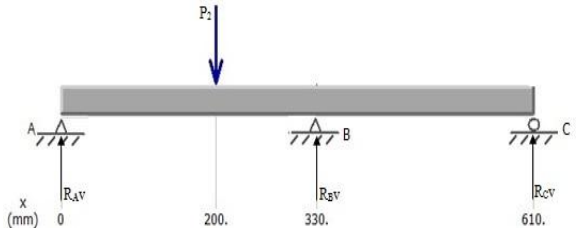

Fig. 7. Intermediated shaft loading in the vertical plane

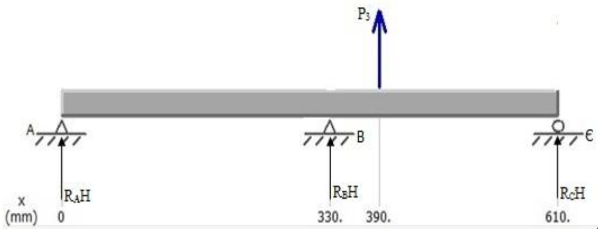

Fig. 8. Intermediated shaft loading in the horizontal plane

With reference to figure 7,the summation of forces in the vertical direction is given as

$$\sum Fr\uparrow = R_AV + R_BV + R_cV - P_2V = 0 \quad (11)$$

With reference to figure 8, the summation of forces on the horizontal direction is given as

$$\sum Fr\uparrow = R_AH + R_BH + R_cH + P_3H = 0 \quad (12)$$

Using the Shelled strength of coconut to be 230N/m,the valves obtained using equations (11) and (22) are R_AV = 360.41 N, R_BV = -224 N and R_cV=232 N , R_BH = 1256 N and R_AH = --1066 N and R_cH= 1012N.

Thus, the maximum bending moment on the conveyor shaft is 251877.89Nmm. The twisting and conveying of coconut fruit by the auger during as the fruit is been de-shelled is sudden with minor shocks, hence, *Kb* = 2 and *Kt* =1.5 [11]. The minimum diameter of this intermediated shaft was determined from Equation (8) as 23.13mm. Therefore, a standard 25mm diameter solid mild steel shaft was selected for the intermediated shaft.

IV. ENGINEERING ECONOMICS

The estimated cost of the shelling machine was about Rs25,600, which included material Disc cutter ,bearings, pulleys, rubber v- belt, construction cost, 1-hp motor and profit of the machine for producer

(about 30%, 15%,and 10% respectively). The cost of cutting per fruit could be evaluated from the fixed cost (depreciation and interest) and variable cost (electricity, labour and maintenance). Sink fund method was used to calculate the fixed cost. Details of assumption for calculating the variable cost are given in Table 1

Machine life	10	year
Salvage Value	10	%
Electricity	0.105	Rs. /Unit
1 – Labor cost	250	Rs./day
Working hour	8	Hours/day
Working day	210	Days/year
Machine capacity	200	Fruits/hour
Interest	8	%/year

Table 1

V. PERFORMANCE EVALUATION PROCEDURE:

In order to actualize the aims of this project, the deshelling capacity and efficiency of the coconut deshelling machine were evaluated using ten experimental runs after its fabrication. Each test involved operating the machine by a different operator and recording of the total number of fruits, NT each of the twenty operators deshelled in a given time. The deshelling process as per each operator was timed with a stop-watch. Also determined in each test are number of well deshelled nuts without distortion on the length of the Shell extract, Ndf and number of well deshelled nuts with distorted husk extract, Ndw. Thereafter, the efficiency, η and capacity, C of the machine were computed in each case using the following relations:

$$\eta(\%) = \frac{N_{df}}{N_T} \times 100 \tag{14}$$

$$C(Coconut/h) = \frac{N_T}{t} \tag{15}$$

VI. RESULT AND DISCUSSION

The results of the performance test (Table 2) show that the machine performed above 86% efficiency in all the tests cases as expected. It is also obvious from this table that the capacity of the developed machine ranges between 191 and 206 nuts per hour depending on the operator, however, on average an operator deshelled 195 nuts per hour with this machine. This machine was fabricated with standard and locally sourced materials and its estimated cost Twenty five thousand six hundred (Rs.25,600.00) thus, the machine is affordable to small scale farmers and maintainable.

S/No.	Number of fruits Deshelled	Number of well deshelled fruits	Number of fruits not deshelled well	Time (Second)	Efficiency (%)	Capacity (Coconut/h)
1	16	14	2	292.58	87.50	196
2	15	13	2	282.68	86.66	191
3	17	16	1	308.78	94.11	198
4	16	15	1	297.56	93.75	193
5	15	13	2	272.78	86.66	197
6	17	15	2	321.89	88.23	190
7	17	15	2	319.85	88.23	191
8	15	14	1	275.90	93.33	195
9	16	14	2	289.91	87.50	199
10	17	16	1	295.71	94.11	206
Average					**90**	**195**

Table 2: Result of Performance Evaluation of Coconut Deshelling Machine

VII. CONCLUSIONS

A power operated coconut deshelling machine was designed and developed. Coconut deshelling machine which deshelled coconuts without nut breakage and machine is easy to operate and perform with an average deshelling efficiency and capacity of 90% and 195 nuts per hour. Introduction of this machine eliminates the problem of extracted shell length distortion associated with the use of some risks involved in the use of cut and hold the coconut de-shelling.

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