Research Article

Formulation of Mathematical Model for Investigation of Parameters of Coconut De-Shelling Machine

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Abstract

Coconut fruit has many health benefits. Coconut oil is extracted from inner part of kernel after removing the outer hard shell. Coconut oil, coconut water and coconut husk are the most valued products of coconut. It is very difficult to remove the outer shell of coconut to get inner fruit without any damage. The procedure of removing copra from hard shell is very time consuming and labor intensive. In this paper mathematical modeling of coconut de-shelling machine has been discussed. The layout of the machine has been prepared after calculating hand torque, number of teeth on gears and shaft diameter is calculated based on combined bending moment and torsion moment.

Keywords: Coconut shell opener, design of shaft, Gear design

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Introduction

Coconut (*Cocos nucifera*) is one of the most versatile crops from which diversified products can be derived. India is the third largest producer of coconut in the world with an annual production of 23.90 MT in the year 2016-17 [1]. Leading Indian states in coconut production are Kerala, Tamil Nadu, Goa, Karnataka, Maharashtra, Orissa, West Bengal and Assam. Out of the total production, 50% of the crop is consumed for culinary and religious purpose, 35% used as copra, 2% for value addition, 11% for tender uses and 2% for seed purpose [2]. Raw coconut fruit has three layers 1) Exocarp-outer covering; 2) Husk- thick fibrous fruit; and 3) Endocarp-inner shell. Inside the hard shell, there is white albuminous endosperm or coconut meat which is filled with clear sweet liquid called coconut water [3]. Coconut is a nutritious source of meat, water, milk and oil. The value added products from coconut include edible products such as coconut water, coconut oil, coconut milk, coconut flour, dried copra, desiccated coconut, vinegar and jaggery. Apart from these, non edible parts of coconut such as coconut shell, leaf, husk are used as fuel in rural areas and in industries for boiler operations [3]. The most valued product from coconut is the coconut oil. Coconut oil is extensively used in food, toiletry and industrial segments due to its unique properties. It is widely used for cooking and frying, in soaps, cosmetics, hair oil and massage oil. Coconut oil is extracted from the kernel or meat of matured coconuts harvested from the coconut palm.

Farmers manually strike the outer hard shell of the coconut for getting the copra. This job is purely based on the skills of labour and is also very time consuming. Very little research work has been done in the field of extracting copra without damage from outer shell. A machine was developed having cutter driven by belt and motor [4]. Another machine was developed which had fully automatic de-shelling chamber driven by motor with manual loading and unloading system [5]. Removing of outer husk is also a tedious job. Prashant et al. [6] had designed a coconut fiber extraction machine for efficient de-husking of coconut and the authors used this husk for fiber extraction for making ropes [6]. A fully automatic machine was designed and developed which performed de-husking and crown removing of de-husked coconut simultaneously [7]. A hydraulic operated coconut de-husking machine was introduced with almost 97% efficiency [8]. Mechanization has led to the development of efficient machines for de-husking of coconut. The aim of this study was to develop a low cost manual coconut de-shelling machine. Coconut with husk and inner hard shell and the broken copra along with outer hard shell is depicted in the **Figure 1**.

Material and Methods

The layout of the machine is as such that as the handle rotates, the gears mounted on the driving shaft also rotates as shown in **Figure 2**. The driver shaft contains gear E, which meshes with gear C on the drive shaft. The driven shaft further contains a milling cutter D to transfer the torque on the shell of the coconut. It is assumed that the torque generated through the handle is transferred completely to the milling cutter D without any loss. The **Figure 3** depicts handle of the machine.

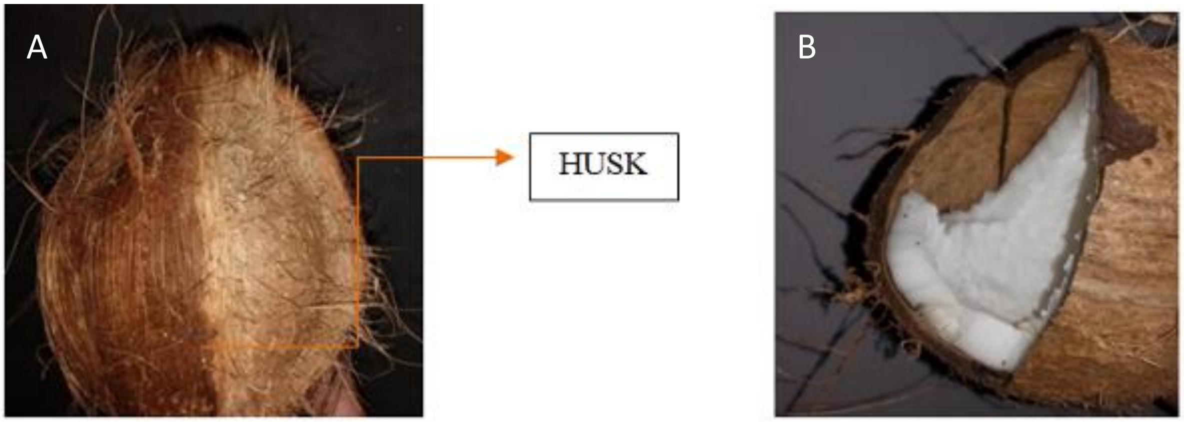

Figure1 (A) The husk and the hard shell, (B) The inner copra and the outer hard shell

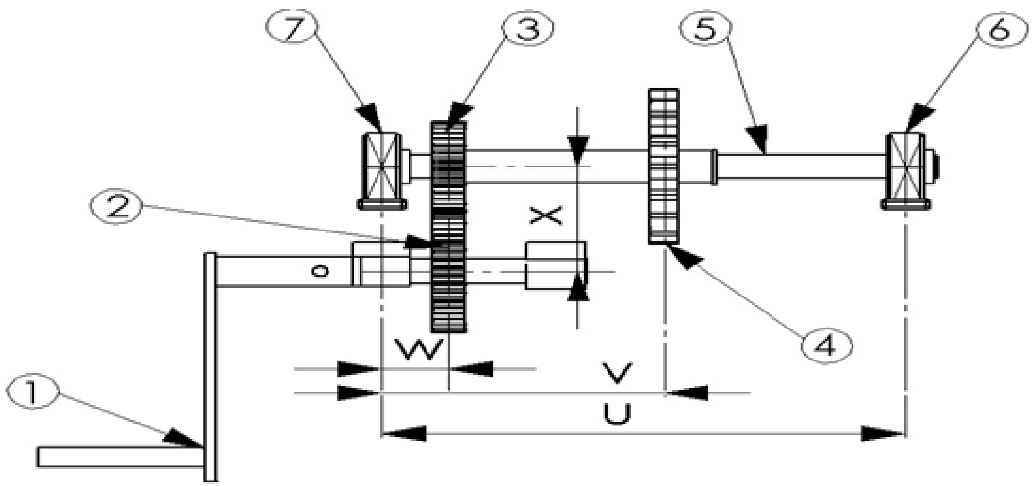

Figure 2 Layout of Machine

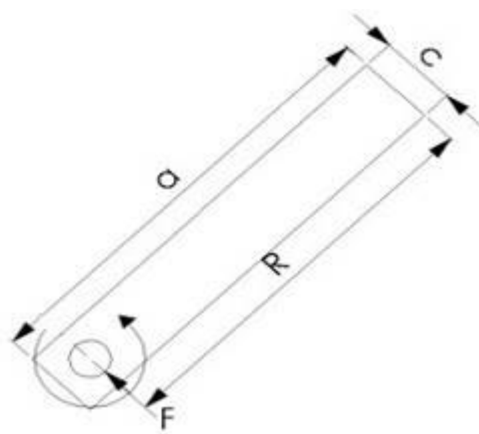

Figure 3 Handle

The lists of components are described in the bill of materials in **Table 1**.The shaft length, centre distance between the shafts and milling cutter distance from bearing 7 is taken as 365 mm, 97 mm, and 182 mm respectively as given in **Table 2**.

The force F is applied by the human hand on the lever. The handle is rotated along the radius R. The parameters of the gears are depicted in **Table 3**. The handle may be rotated at high speed or low speed depending upon the expertise of the user.

Table 1 Bill of material of machine components

Part No.	Name	Material	Quantity
1	Handle	MS	1
2	Gear E	20MnCr5	1
3	Gear C	20MnCr5	1
4	Milling cutter D	HSS	1
5	Shaft	MS	1
6 & 7	Bearing A and B	Std.	2

Table 2 Layout of the machine

Part No.	Length in mm
U	365
V	182
W	44
x	97

Table 3 Layout of machine handle

Sr.No.	Item described
I	a
II	R
II	c

D_c denotes the pitch circle diameter of the gear C and D_E denotes the pitch circle diameter of the gear E as shown in **Figure 4**.

On the basis of center distance, the parameters of spur gears are calculated as per **Table 4**. Milling cutter is having sharper and harder teeth than an ordinary gear as shown in **Figure 5**.

Milling cutter has good penetrating and cutting action on the hard surfaces, so it breaks the outer shell of coconut very easily. The human hand can apply force up to 450 N on levers [9].The torque transmitted is given by:

Torque = Force x Radial distance = 450 x 228 = 102600 N-mm

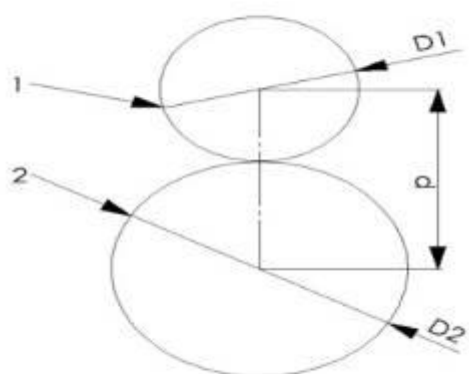

Figure 4 Meshing of Gears

Table 4 Gear data for gear selection

Sr. no.	Item described	Driver E	Driven C
	P.C.D.	116	78
	Module	2.6	2.6
	Pressure angle	20^0	20^0
	No. of teeth	45	30

Shaft subjected to combined loading

Since the shaft is subjected to combined bending and torsion moment, the shaft diameter is calculated on the basis of either equivalent twisting moment or equivalent bending moment. Assuming torque acting on gears C and cutter D is same as that of the shaft ,therefore the tangential force acting at gear C:-

$$R_c = \frac{T}{D_C} R_c = \frac{102600}{78} = 1316 \text{ N}$$

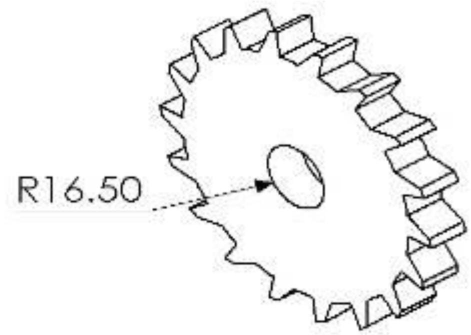

Figure 5 Isometric view of milling cutter

Total load acting downward at shaft at C:-
W_c = weight of gear C = 4 N

$$R_c + W_c = 1316 + 4 = 1320 \text{ N}$$

Tangential force acting at gear D:-

$$R_d = \frac{T}{D_D}$$

$$R_d = \frac{102600}{130} = 790 \text{ N}$$

Total load acting downward at shaft at D:-
W_d = Weight of Milling cutter D =10N

$$R_d + W_d = 790 + 10 = 800 \text{ N}$$

Taking Moment along A,

$$R_b \times 365 = R_c \times 44 + R_d \times 182$$

$$R_b = \frac{1320 \times 44 + 800 \times 182}{365} = 558 \text{ N}$$

Upward force is equal to downward force,

$$Ra = R_c + R_d - R_b = 1320+800-558 = 1562 \text{ N}$$

Bending Moment at C:-

$$Mc = Ra \times 44 = 1562 \times 44 = 68728 \text{ N-mm}$$

Bending Moment at D:-

$$M_d = R_b \times 184 = 558 \times 184 = 102672 \text{ N} - \text{mm}$$

The bending moment diagram depicts maximum moment at gear C and milling cutter D as shown in **Figure 6**. It is clear that maximum moment acts on gear D.

Maximum bending moment transmitted by shaft,

$$M_d = M = 102672 \text{ N} - \text{mm}$$

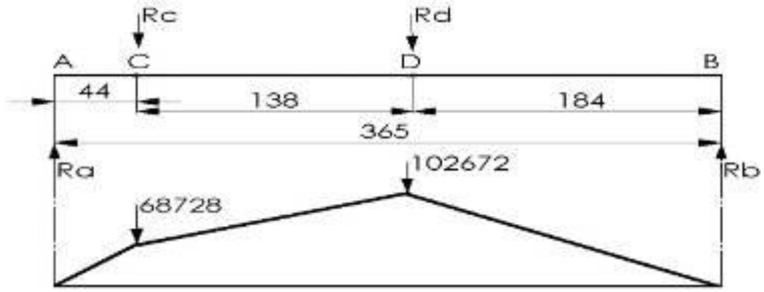

Figure 6 Bending moment diagram of the shaft.

We know that equivalent twisting moment,

$$T_{eq} = \sqrt{F_b M^2 + F_t T^2}$$

$$T_{eq} = \sqrt{(1.5 \times 102672)^2 + (1.2 \times 102600)^2} = 197151 \text{ N-mm}$$

We know that equivalent twisting moment (T_{eq}),

$$T_{eq} = \frac{\pi}{16} \times \tau \times d^3 \qquad 197151 = \frac{\pi}{16} \times 40 \times d^3 \qquad d = 30\text{mm}$$

We know that equivalent bending moment,

$$M_{eq} = ½ (F_b M + \sqrt{F_b M^2 + F_t T^2})$$

$$M_{eq} = \frac{1}{2}(1.5 \times 102672) + \sqrt{(1.5 \times 102672)^2 + (1.2 \times 102600)^2}$$

$$M_{eq} = 175580 \text{ N} - \text{mm}$$

We know that equivalent bending moment (M_e)

$$M_{eq} = \frac{\pi}{32} \times \sigma_b \times d^3$$

$$175580 = \frac{\pi}{32} \times 60 \times d^3 \text{ ; d = 32 mm}$$

The machine has to be designed by taking shaft diameter as 32 mm

Results and Discussion

Based on the empirical relationship, the number of teeth on driving gear, driven gear and diameter of the shaft are calculated as shown in **Table 5**. The number of teeth on the driving gear is 45, on driven gear 30 and the diameter of the shaft is calculated as 32 taking the pressure angle as 20°. The actual machine is designed as per the calculated parameters of the machine by taking into consideration combined effect of torsion and bending moment.

Table 5 Based on the empirical relationships, gear and shaft data

Item no.	Description	No. of Teeth(Z)		P.C.D. of Gear		Diameter of Shaft
1	Gear C	Z_C	30	D_C	78	32 mm
2	Gear E	Z_E	45	D_E	116	
p	Center Distance	97 mm				

Conclusion

Considering combined effect of torsion and bending moment, we have calculated the diameter of the shaft, the number of teeth on driving and driven gear by fixing the center distance of the shafts to 97 mm. The module is taken as 2.6 with pressure angle of 20^0. Fatigue factors of combined torsion and bending moment are also taken into consideration while designing the shaft diameter. The diameter of shaft is calculated by equivalent bending moment and equivalent twisting moment. Taking the larger value out of the two cases, the diameter of the shaft is taken as 32 mm. The number of teeth on gears is calculated as 30 and 45. Based on the above calculation, the design and development of the machine has to be carried out. A mathematical model has been formulated to design a low cost manually operated machine for opening the coconut fruit without damaging it. These calculated parameters serve as basis for further lay outing and design of the machine.

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