DEVELOPMENT AND TESTING OF A CONTINUOUS POWER OPERATED COCONUT HUSKER

by

ANU, S. CHANDRAN
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Thesis

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DECLARATION

I hereby declare that this thesis entitled **'Development and Testing of a Continuous Power Operated Coconut Husker'** is a *bonafide* record of the research work done by me during the course of the academic programme in the Kerala Agricultural University and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or society.

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Certified that this thesis entitled **'Development and Testing of a Power Operated Coconut Husker'** is a *bona-fide* record of the research work done independently by Ms. Anu S. Chandran (*Admission No:* 2010-18-103), under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship, or other similar title of any other University or Society to her.

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Anu S. Chandran

DEDICATED

TO

THE ALMIGHTY GOD

AND

MY LOVING PARENTS

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SYMBOLS AND ABBREVIATIONS

ANOVA	Analysis of variance
Avg.	Average
Dept.	Department
e.g.	For example
Er.	Engineer
et al.	and others
etc.	et cetera
Fig.	figure
Fig.s	figures
hp	horsepower
i.e.	that is
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering and Technology
Kg cm^{-2}	Kilogram per centimeter square
Kg_f	Kilogram force
kN	Kilo Newton
min.	minute(s)
mm	millimetre
M.S.	Mild steel
No.	Number
No.s	Numbers
Rpm	revolutions per minute
Rs	Rupees
s	second(s)
Sl. No.	Serial number
%	Per cent
∴	There fore

Introduction

Chapter 1

INTRODUCTION

Coconut is one of the most important crops in Kerala. Coconut palm is popularly known as '*Kalpa-vriksha*' or '*tree of heaven*' as it provides many necessities of life including food and shelter. The coconut palm (*Cocos nucifera*) is a member of the family Arecaceae, the only species in the genus *Cocos*. It grows to even 30 m tall, with pinnate leaves of 4 to 6 m long, and pinnae 60 to 90 cm long; old leaves breaking away leaving the trunk smooth. The coconut palm thrives in sandy soils and is highly tolerant to salinity. It resides in areas with abundant sunlight with annual rainfall of 150 cm to 250 cm, and relative humidity 70 to 80 per cent.

Botanically, a coconut is a simple dry nut. The husk or mesocarp is composed of fibers called coir. The inner stone or endocarp (outside shell), is the hardest part of the nut, has three germination pores that are clearly visible on the outside surface once the husk is removed. The radicle emerges through one of these germination pores when the embryo germinates. Adhering to the inside wall of the endocarp is the *testa*, with a thick albuminous endosperm (the coconut "meat"), the white and fleshy edible part of the seed. Hardness of the shell and husk increases with maturity. By the time the coconut naturally falls, the husk become brown, the coir become drier and softer, and the coconut is not damaged when it drops.

Coconut palms are mainly cultivated for its nuts from which two important commercial products, the copra and fibre are obtained. It can also be used for the production of by-products like oil, coir, coconut-shell powder, etc. Coconut palms are grown in more than 80 countries of the world, with a total production of 58 billion nuts. According to FAO statistics 2009, about 57.9 billion nuts were produced, which was equivalent to 7.3 million tonnes of oil. The coconut oil ranks sixth among the eight major vegetable oils of the world. India ranks third on world coconut map and in recent times became the largest producer of coconut with the production of 16.9 billion nuts from acreage under plantation of about 1.89 million hectares. Even though India is among the largest producers of coconut with a distinction of having the highest productivity of 7779 nuts per hectare as against 3630 nuts per hectare in Indonesia and 3859 nuts per hectare in Philippines, the per capita annual availability of coconut estimated to have been 10 nuts only which is quite low compared to 222 of Philippines, 145 of Sri Lanka and 55 nuts of Indonesia. India contributes about 19 per cent in area and 18 % in terms of production of coconut in the world. The States in India that are indulging in the production of this fruit; with their annual average production figures; are Kerala (6326 million nuts), Tamil Nadu (4867.1 million nuts), Karnataka (1209.8 million nuts), Andhra Pradesh (892 million nuts), West Bengal (323.5 million nuts), Orissa (274.6 million nuts), Maharashtra (273.4 million nuts), and Assam (204.9 million nuts). Kerala's contribution of coconut to India is 45.22%. Nearly all parts of the coconut palm are useful. The palms have a comparatively high yield; up to 75 fruits per year. Hence, Kerala is famous as the largest coconut growing State in India. Kerala is considered as the land of coconut and holds the key for the development of coconut production and marketing in the country.

A major problem concerned with coconut is its husking. The traditional tools used for husking include chopping knife or machete, crowbar (*paara*), etc. These tools make use of the principles of wedge and lever. The modern tools intended for small-scale husking are coconut husking machine, mini coconut-dehusker, KAU coconut husking tool (*Keramithra*), etc. Except for the crowbar, no other simple tool is beneficial in large-scale husking. A person skilled in husking husks about 2500-3000 coconuts in 6 hours using a crowbar. However, husking with a crowbar involves lot of drudgery. Copra and coir mills need the nuts and fibre in huge quantity for running the mills as a profitable unit. Thus it requires a husking machine suitable for large scale husking of coconut. In the mechanical husking of coconuts, the major components are husking and husk separating units. The design and development of such units are mainly based on the physical and mechanical properties of the coconut. The machine parameters also affect its performance. Hence, a study was conducted to develop a powered rotary husker and to assess and compare its performances with other available powered coconut husking machines.

The following are the objectives of the study.

i. To investigate the relevant physical and mechanical properties of coconut.
ii. Studies on different husking methods and design of major components.
iii. To fabricate a prototype of power operated coconut husker.
iv. To standardize the husking mechanism with respect to nut properties.
v. To work out the cost economics of the developed coconut husking machine.

Review of literature

Chapter 2
REVIEW OF LITERATURE

This chapter deals with brief reviews of the crop and its characteristics, structure and composition of coconut and physical properties. The reviews on the various types of coconut husking tools and machines, its structure and working principles mentioned.

2.1 Origin

The origin of this plant is the subject of debate. Most authorities claim that it is a native to South Asia (particularly the Ganges Delta); while others claim its origin is in north-western South America. Fossil records from New Zealand indicate that small, coconut-like plants grew there as long as 15 million years ago. Even older fossils have been uncovered in Kerala, Rajasthan, Tamil Nadu (at banks of River Palar, Then-pennai, Thamirabharani, Cauvery) and Mountain sides along Kerala borders, Konaseema-Andhrapradesh, and Maharashtra (India). Mention is made of coconuts in the 2^{nd}–1^{st} century BC in the Mahawamsa of Sri Lanka. The later Culawamasa states that King Aggabodhi I (575–608) planted a coconut garden of 3 yojanas length; possibly this could be the earliest recorded coconut plantation. (Chan, Edward and Craig R. Elevitch., 2006).

2.2 Climate and soil conditions

Coomans, 1975 found that fruit set is directly influenced by the monthly minimum temperatures below 23°C, over a period of four months, 18 months before harvest. He also observed a significant positive correlation between the annual yield and the mean annual minimum temperatures over a period of 18 months before harvesting, and a positive correlation between the number of female flowers per inflorescence and insolation and temperature of the 29th and 30th month before harvest. He suggested that the latter correlation was apparently influenced by the growing conditions during the stage of spadix differentiation.

It is generally accepted that the coconut palm requires at least 2,000 hours of sunshine per year to exploit its production potential fully (Ochs, 1977). Murry, 1977, cited by Rajagopal *et al*., 1990 estimated that 120 hours of sunshine per month would be favourable for coconut.

Due to low temperatures, coconuts may not only fail to produce nuts, but nut quality also may become seriously affected. Usually, damage caused to the nut by slight cold is not outwardly perceptible but can be seen in the abnormal or incomplete development of its meat, which is unevenly formed with many wrinkles. It was observed that nuts at their fastest development stage, i.e. 5-6 months after flowering, are most vulnerable to cold. Cold weather in such a period would cause the young nut to split or fall, after which it turns brown or black and dries up. Zushun (1986) observed that the lower limit for the palm and the leaf to survive the winter is 8°C, whereas that for the nut is 13°C. Besides withering of mature leaves, spear leaves may be killed and non-uniform development of the leaves in the crown may occur. It was stated that, even in the absence of any damage to the palms or nuts, the physiology of the palm is modified by low temperatures and production is non-existent during the winter period.

Coconut is a tropical crop; its growing area is confined between the tropics of Cancer and Capricorn. Latitude differences bring about day-length differences. The influence of day-length on coconut is unknown and is difficult to find out, as with the change of day-length there are also changes in the angles of the sun's rays as well as in temperatures. Long days may have a favorable influence on coconut growth, due to longer periods of sunshine. At these latitudes temperatures during daytime in summer are high and favorably influence fruit set and yield during this season. Lower sunshine intensity may not be a limiting factor as a leaf becomes light-saturated at values of less than 50% of direct solar radiation (Foale 1991).

The coconut palm thrives on sandy soils and is highly tolerant of salinity. It prefers areas with abundant sunlight and regular rainfall (150 cm to 250 cm annually), which makes colonizing shorelines of the tropics relatively straightforward. Coconuts also need high humidity (70 - 80%+) for optimum growth, which is why they are rarely seen in areas with low humidity, like the south eastern Mediterranean or Andalusia, even where temperatures are high enough (regularly above 24°C). Optimum growth is with a mean annual temperature of 27 °C, and growth is reduced below 21 °C (Chan, Edward and Craig R. Elevitch., 2006).

Coconut palms mainly grow in coastal areas of the tropics and subtropics. They require a hot moist climate with average annual temperatures between 20-28°C, average annual rainfall ranging from 1000 to 1500 mm and deep alluvial or loamy soils (Orwa *et al*., 2009).

The coconut palm can tolerate wide range of soil conditions. But the palm does show certain growth preferences. A variety of factors such as drainage, soil depth, soil fertility and layout of the land has great influence on the growth of the palm. The major soil types that support coconut in India are laterite, alluvial, red sandy loam, coastal sandy and reclaimed soils with a pH ranging from 5.2 to 8.0. (NABARD Coconut Cultivation Project, 2011)

2.3 Structure and composition

Botanically the coconut fruit is a drupe, not a true nut. Like other fruits it has three layers: exocarp, mesocarp, and endocarp. The exocarp and mesocarp make up the *husk* of the coconut. Coconuts sold in the shops of non-tropical countries often have had the exocarp (outermost layer) removed. The mesocarp is composed of fibers called coir which have many traditional and commercial uses. The shell has three germination pores (stoma) or *eyes*that are clearly visible on its outside surface once the husk is removed (Gibson, 1999).

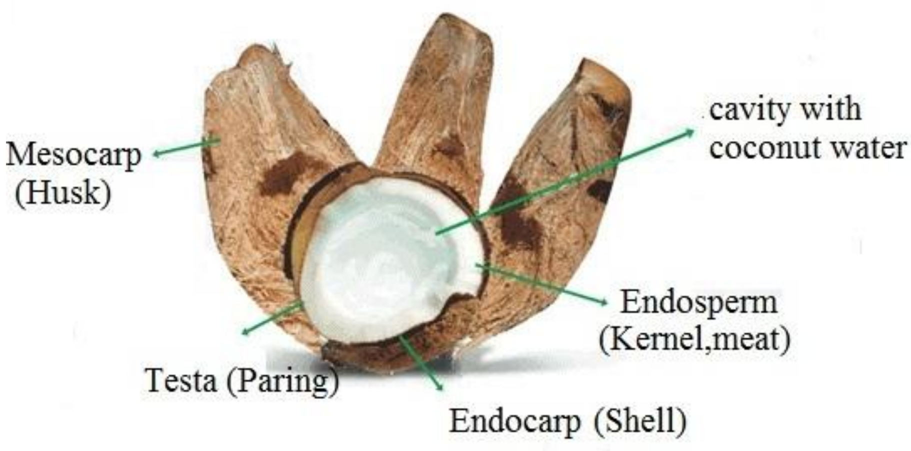


Plate 2.1 Structural details of coconut fruit

The coconut palm (*Cocos nucifera* L.) is one of the most useful tropical trees. A multipurpose tree, it is used for food, beverage, shelter, animal feed and is grown industrially for the edible oil contained in the flesh of its fruits. The tree can survive 50 years without needing much attention and the fruits drop all year long (Canapi *et al.*, 2005). The nut (structure) has a smooth epidermis over a fibrous mesocarp (husk) that covers the hard endocarp (shell). A thin brown layer (testa) separates the shell from the endosperm (kernel, flesh, meat), which is approximately 1-2 cm thick. A cavity within the kernel contains the coconut water (Canapi *et al.*, 2005). A full-sized coconut weighs about 1.44 kilograms (3.2 lb). It takes around 6000 full-grown coconuts to produce a tonne of copra. (Bourke and Tracy, 2009).

2.4 Varieties

The tall varieties are extensively grown throughout India while dwarf is grown mainly for parent material in hybrid seed production and for tender coconuts. The tall varieties generally grown along the west coast is called West Coast Tall and along the east coast is called East Coast Tall. Benaulim is the tall variety grown in Goa and coastal Maharashtra. Laccadive Ordinary, Laccadive Micro, Tiptur Tall, Kappadam, Komadan and Andaman Ordinary are some of the tall varieties. Chowghat Dwarf Orange, Chowghat Dwarf Yellow, Chowghat Dwarf Green, Malayan Yellow Dwarf and Malayan Orange Dwarf are some of the dwarf varieties grown in India. Gangabondam is a semi tall type grown in certain tracts of Andhra Pradesh. Details of some of the coconut varieties and hybrids released for cultivation in India are given in Table 2.1.

Table 2.1 Details of coconut varieties and hybrids grown in India

Sl. No.	Name	Area for which recommended	Annual nut yield/palm	Copra (g/nut)	Oil content (%)
Varieties					
1	Chandrakalpa	Kerala, Karnataka, TN	97	195	70.0
2	Kerachandra	AP, Maharashtra	110	198	66.0
3	Chowghat Orange Dwarf (Tender nut variety)	All coconut growing regions	–	–	–
4	Kalpa Pratibha	West Coast region and peninsular India	91	256	67.0
5	Kalpa Dhenu	West Coast region and Andaman and Nicobar Islands	86	242	65.5
6	Dalpa Mitra	West Coast region and West Bengal	80	241	66.5
7	Kalpatharu	Kerala, Karnataka, TN	116	176	68.0
8	Kalparaksha	West Coast region and root (wilt) diseases tracts of Kerala	65	215	65.5
9	Kalpasree	West Coast region and root (wilt) diseases tracts of	90	96.3	66.5

		Kerala			
10	Pratap	Konkan region	150	152	59.0
11	VPM-3	Tamil Nadu	77	191	66.0
12	ALR 1	Tamil Nadu	126	131	64.0
13	Kamrupa	Assam	101	162	64.0
14	Kera Sagara	Kerala	99	203	67.8
15	Kera Keralam	Kerala, Tamil Nadu and West Bengal	109	186	67.8
16	Kera Bastar	Andhra Pradesh, Konkan region in Maharashtra and Tamil Nadu	117	151	_
17	Kalyani Coconut-1	West Bengal	80	154	-
18	Gauthami Ganga	Andhra Pradesh	90	157	68.0
Hybrids					
1	Chandra Sankara	Kerala, Karnataka, Tamil Nadu	110	208	68.0
2	Kera Sankara	Kerala, Karnataka, Maharashtra, Andhra Pradesh	106	198	68.0
3	Chandra Laksha	Kerala, Karnataka	109	195	69.0
4	Kalpa Sankara	West Coast region and root (wilt) disease tracts of Kerala	84	170	67.5
5	Kalpa Samrudhi	Kerala and Assam	117	214	69.0
6	Laksha Ganga	Kerala, Tamil Nadu	108	195	70.0
7	Kera Ganga	Kerala	100	201	69.0
8	Kera Sree	Kerala	112	216	66.0
9	Kera Sowbhagya	Kerala	130	195	65.0
10	Ananda Ganga	Kerala	95	216	68.0
11	Godavari Ganga	Andhra Pradesh	140	150	68.0
12	VHC-1	Tamil Nadu	98	135	70
13	VHC-2	Tamil Nadu	107	152	69.0
14	VHC-3	Tamil Nadu	156	161	64.5
15	Konkan Bhatye Coconut Hybrid-1	Konkan Region, Maharashtra	122	180	67.1

Source : NABARD Coconut Cultivation Project, 2011

2.5 Physical Properties of coconut

Curray (1951) defined sphericity as the ratio of diameter of largest inscribed circle (d_i) to that of the diameter of smallest circumscribed circle (d_c) of any material.

$$\text{Sphericity} = \frac{\text{di}}{\text{dc}}$$

Harmond *et al*. (1965) defined size as the characteristic of an object which determines how much space it occupies. It can also be described within limits in terms of length, width and thickness. The shape was concerned with physical or spatial form of an object. Density was described as the compactness or concentration. Seed density can refer either to its quantity along with included void space or to a single seed, but in all cases it was expressed as mass per unit volume.

Keck and Goss (1965) found the frontal area of small grains using the formula $\pi d^2/4$, assuming them as sphere, in which d is the diameter of the sphere, determined by measuring the geometric mean of the three mutually perpendicular seed dimensions.

Mohsenin (1970) reported that ideally a greater number of measurements in various directions should be taken to determine the average diameter of an agricultural product. However, he concluded that three measurements namely major, intermediate, and minor diameters were sufficient to determine the size of material. He also concluded that the flowability of seeds mainly depend on sphericity. Sphericity is given by,

$$\text{Sphericity} = \frac{(lbt)^{\frac{1}{3}}}{l}$$

where,

l = Largest intercept, mm

b = Largect intercept normal to l, mm

t = Largest intercept normal to l and b, mm

Waziri and Mittal (1983) used an overhead projector to trace the outline of the projected boundary to determine the axial measurements. They placed the seeds in natural rest position and in vertical position to obtain minor, intermediate and major diameters. They concluded that sorghum and pearl millet kernels were spherical with average diameter of 2.72 ± 0.14 mm and 2.21 ± 0.19 mm respectively. They determined solid density of small objects using specific gravity bottles. It was 1370 and 1300 kgm^{-3} for sorghum and pearl millet respectively. They observed the thousand kernel weight of sorghum and pearl millet as 30.51 ± 1.18 and 8.51 ± 0.36 g respectively. The angle of repose of sorghum and pearl millet was 2.54 ± 0.9 and 22.4 ± 0.4 deg respectively.

Dutta *et al*. (1988) used shadow graph method to measure dimensions of three mutually perpendicular positions of gram. The shape of gram was found to be closest to prolate spheroid shape having

$$\text{Volume} = \frac{4}{3}\pi a^2 b$$

where,

a – semi major axis, mm

b – semi minor axis, mm

The surface area could be calculated by using the general geometrical equation of prolate spheroid.

Moisture content was determined by oven drying method as recommended by Association of Official Analytical Chemists (AOAC, 1995). This method is explained in section 3.1.5.

Keefe (1999) adopted digital image analysis technique for the measurement of length, width, area of linseed. Using a camera, the images were captured and analyzed using a software. The maximum length, width and area of the seed observed were 4.69 mm, 2.12 mm and 7.57 mm^2 respectively and the minimum values were 4.67 mm, 2.07 mm and 7.53 mm^2 respectively.

Mahadevan *et al*. (1999) used image analyzer (Leica Quantimet 500+) to measure the morphological characters of tree seeds. Four replications of 50 seeds each were selected randomly. The seeds of each replication were spread on a glass platform of a macro-viewer and images were captured by a digital camera. The captured images were analysed using the software called Quantimet 500+ or Qwin. The captured images were calibrated to actual scale. The seed characters like surface area, length, breadth, roundness, aspect ratio, equivalent diameter etc were accurately obtained using the digital image analysis.

Senthil (2002) determined the physical properties of cotton namely roundness, projected area, equivalent diameter and sphericity using an image analyser. The roundness, projected area, equivalent diameter and sphericity of cotton seed were observed as 1.27 ± 0.02, 26.70 ± 0.64 mm^2, 5.81 ± 0.07 mm and 0.504 ± 0.03 respectively. The thousand seed weight, true density and angle of repose of seed were determined as 80.42 ± 0.114 g, 1247.33 ± 2.353 kgm^{-3} and 23.0 deg respectively.

Bevington *et al*., (2003) reported that for measuring fruit size digital/dial vernier calipers are quick and easy to use. Digital vernier calipers do not operate in wet/damp conditions but dial type work in all conditions.

Sadrnia *et al.*, (2007) conducted studies on classification and analysis of fruit shapes in long watermelon using image processing technique. A standard colour camera, frame grabber, a PC and the ADOBE PHOTOSHOP^{TM} Program are used for image analysis to obtain digitized fruit shape. Images were taken from above fruits.

The x-coordinate defined the position of the fruits length and y-coordinate the position on width. The size and shape of coconut was determined by using image analysis to obtain digitized coconut shape.

Jahromi *et al*., (2008) conducted studied on mass modeling of date fruit with some physical characteristics. Linear dimensions, i.e. length, width and thickness and also projected areas, were determined by image processing method. In order to obtain dimensions and projected areas, WinArea_UT_06 system was used. This system consist of a sony photograph camera, a device for preparing media for taking picture, card capture and a computer software programmed with visual basic 6.0. From the digitized image, the length, width and the thickness of the fruit and first, second and third projected areas taken along the three mutual perpendicular axes are obtained.

2.6 Mechanical Properties

Sathyanarayana *et al.* in 1982 determine the modulus, strength and percentage elongation values of rachis, rachilla, leaf health and spathe by using Instron machine. The modulus, strength and percentage elongation values of rachis are found to be in the range of 2 to 6 GNm^{-2} , 48 – 104 MNm^{-2}, and 5.6 – 8.0 % respectively, while those of fibres from bark of the petiole and root are in the range of 6.0 – 24.7 GNm^{-2}, 157 – 191.81 MNm^{-2} and 3 – 3.85% respectively. For measuring tensile properties, a gauge length of 50mm of each of these fibres was mounted on a cardboard sample holder and pulled in an Instron machine at a strain rate of 2.5 cm min^{-1}.

Tensile and flexural strengths for the coconut spathe-fibre-reinforced composite laminates determined by using the INSTRON Material Test System ranged from 7.9 to 11.6 MPa and from 25.6 to 67.2 MPa respectively, implying that the tensile strength of coconut spathe-fibre is inferior to other natural fibres such as cotton, coconut coir and banana fibres (Sapuan *et. al.,* 2005).

Anupun *et al.*, 2009 reported that the rupture force of husk quickly decreases from 75.7 N to 53.3 N during the immature stage. After that, rupture force reduces slowly and linearly to 46.5 N at the end of the mature stage, then continues to decrease to 36.6 N at the end of the overmature stage. While the young coconut fruit is developing towards over-maturity, husk consisting of spongy tissue and embedded fibres (Jarimopas et al., 2007) gradually loses moisture leaving empty spaces in the tissue. Accordingly, when more mature and drier husk is compressed it deforms more easily and needs less force to rupture. The rupture force of shell (SF_R) uniformly and linearly increases in the days after pollination. SF_R increases from 58.6 N to 222.3 N for the first stage, continues to increase to 381.8 N at the end of the second stage, and reaches 443.2 N at the final stage of over-maturity.

2.7 Dehusking tools and machines

Agriculture is the backbone of Indian economy. The advancement of science and technology gave rise to the development of agriculture. Now a day, a major problem in the agricultural sector is the displacement of labourers and the resultant shortfall in the availability of labourers. This is seriously affecting the farming operations which are highly time-bound. The problem is becoming more acute because of the lack of machines to take the place of the displaced labourers. The situation is not any different in the coconut-husking sector as well.

As said earlier, lack of suitable machines for husking coconuts is one of the major problems concerned with coconut farmers. Though a number of simple tools have been developed, none has found sound application in large-scale husking. At the same time, at the domestic level, small tools like machete, crowbar (*paara*), KAU coconut husking tool named Keramithra, etc., have wide acceptability. The first two are the most traditional tools.

According to Jippu (1999), coconut husking might have started with single-blade instruments like wedge-shaped rock pieces, sharpened wooden-crowbars, etc. He classified the manually-operated coconut husking tools broadly as single-blade coconut-husking tool (*e.g*., machete, axe, crowbar, etc), Twin-blade coconut-husking tool (e.*g*., coconut spanner, keramithra, etc.) and Multi-blade coconut-husking tool (e.*g*. CPCRI coconut dehusker).

In the case of a single-blade coconut husking tool, its single blade acts as both the wedge and the lever. As the wedge enters the husk longitudinally and normal to its surface, the husk is little ripped open and divided and then pushed aside. Then, the blade, in the case of a coconut resting on a floor/ground, or the coconut, in the case of the tool resting on a floor/ground, is twisted in a peculiar orientation, as with a lever, to widen the slit, detach a sector of the husk from the kernel, and scoop it out. In this twisting, the wedge or blade acts as the lever and provides a mechanical advantage greater than one. In husking using single-blade tools, all unit operations are carried out manually. Since a very large force is to be applied as the effort, due to the small mechanical advantage, husking is tough and hard, and hence involves considerable drudgery.

In respect of twin-blade or multi-blade coconut husking tool, the juxtaposed blades act as the wedge at the time of impaling the coconut on them. Further ripping open, detachment of one or more sector(s) of husk from the kernel, and its scooping out are carried by the moving blade actuated by an extended lever. Though the extended lever provides more mechanical advantage than that of the single-blade tool, husking is still laborious and involves drudgery; of course lesser.

It is in this light that a device which allows manual feeding but separation of husk with mechanical means is considered. In order to select a tool which can be considered for modifying to this extent, the survey of literature was limited to the twin-blade tools.

The earliest known twin-blade husking tool developed was that of Waters (1946), which is a modified version of the smithy tongs. It had two lips sharpened like thin wedges. In the juxtaposed or closed position, it was swung and impaled on the coconut, and then separated to loosen the husk. The unit operations were repeated three or four times to finally take out the kernel. It is evident from its photograph and literature that it is not that much convenient to use. That could be the reason why it did not become popular at all.

Plate 2.2 Coconut husking tool

Brian, E. *et al*., 1976 reported that there was another twin-blade tool, which appeared to be better than that of Waters (1946) which was developed by Titmas and Hickish (1929). This was a tool mounted on a wooden platform, and standing upright when placed on the floor. Coconut is held by hand and impaled on the stationary tool. The depressing of its foot lever each time caused the separation of one sector of the husk. Repetition of these operations three or four times caused complete removal of the husk. Resetting of its movable blade on to the stationary blade, to keep them in the juxtaposed upright position, was achieved with the aid of a tension spring of high spring constant. Slipping of the foot from the pedal when depressing would be causing quick return of the pedal, and any part of the leg or body coming in the way of its path is bound to get an impact, which may sometimes be inflicting injury. Moreover, depressing of the pedal in the standing posture of the operator and with one foot, in coconut husking is not that advantageous, as this action destabilizes the operator. These disadvantages might have prevented the acceptance of this tool.

Ganesan and Gothandapani (1995) invented a mini coconut-dehusker. It consists of a tong-like tool mounted on a pillar. The coconut kept on its platform is impaled from the top with the sharp jaws of the tool swinging downwards about the pillar. After penetration, the handles of the tool are pulled outwardly to separate the jaws. This leads to ripping of the husk into one sector. The coconut is then turned and the tool made to impale on another portion of the remaining husk and the process of ripping open the husk is repeated. The operations are then repeated till complete husk is removed. It is understandable that husking using this tool involves more cumbersome unit operations. Each time, the operator has to bend for manipulating the coconut placed on the platform which could be at the ground level. Then, he has to rise and straighten up for lifting the tool and swinging it downwards against the coconut. This could be the reason for it not becoming popular. Besides, here too the blade actuation is manual. Based on the above, it was seen that it offered little scope for improvement to the level envisaged in this study.

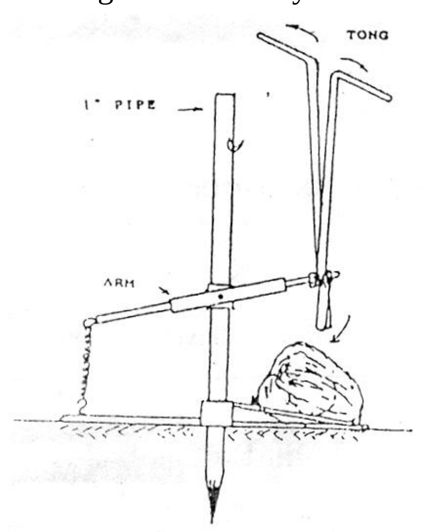


Fig. 2.1 Mini coconut dehusker

(*Ganesan and Gothandapani*, 1995)

The KAU Coconut Husking Tool (*Keramithra*) developed in the Kerala Agricultural University; as reported by Jippu and Joby (1998); is simple not only in construction but also in use. It consists of mainly a stationary wedge, a movable wedge, a hinge pin, a wedge seat, a lever and a pedestal with a base. The coconut is impaled with both the hands on to the two juxtaposed wedge-like blades oriented upwards. On pulling the lever upwards by one hand, the movable blade or wedge placed on the load arm of the lever swings away from the stationary blade loosening a sector of the husk from the nut. By repeating twice or thrice the husk can be separated completely from the coconut. It takes only about 8 to 20 seconds for husking a nut depending upon the variety, maturity of nut and skill of operator. It is light in weight (2.5 kg), and simple to use and handle. Though this tool is quite acceptable at the domestic level, it is not so in large-scale husking. In this case too, the actuation of movable blade is manual.

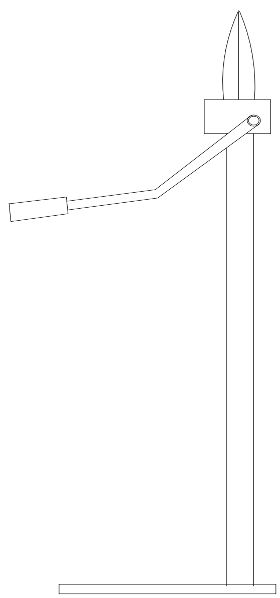


Fig. 2.2 KAU Coconut Husking Tool (*Keramithra*)

(*Jippu and Joby*, 1998)

Aboobekkar and Narayanan developed foot operated husking tools. Upon depressing the foot pedal downwards by one foot, the movable blade gets separated from the stationary blade, thus, ripping apart a sector of the husk of the coconut remaining impaled on the juxtaposed blades. Operations are repeated for completely removing the husk in three or four sectors. In these cases too, the blade/blades are actuated manually. On a comparison with the *Keramithra*, it was seen to be offering only lesser advantage. Hence, this too was not selected in this study (Muhammad, 2005).

In order to confirm the suitability of multi-blade tools for incorporating the modifications to satisfy the needs as contemplated, the survey was extended to the literature on them too.

In Central Plantation Crop Research Institute (CPCRI), Kasaragod, a manually-operated dehusker was developed and improved. It consists of three sharp separable blades, which initially faced upwards and in a juxtaposed position. In operation, the blades go up and outwardly by swinging about their pivots at the bottom. In the process, the husk of the coconut impaled upon the blades is torn apart and the nut is ejected. The impaling of coconut and actuation of the blades are carried out using a hand-lever and a foot-lever. This is however a cumbersome process and hence has not been accepted widely. Moreover, not only that the feeding is manual but also its movable blade actuation is again manual. The major impediment with this device was its large size. Hence, it was found to be unsuitable for the type of modifications preferred in this study (Gubash *et al.*, 2008).

A rotary coconut dehusker was developed in the Kelappaji College of Agricultural Engineering and Technology (KCAET), Tavanur (Muhammad, 2002 and 2005). It was intented for large-scale application. This powered-machine consists of a stationary concave, enveloping a rotating drum. The clearance space between the drum and the concave formed a converging volute to accept the whole coconut at the inlet and accommodate the husked smaller nut at the outlet. Numerous small blades are fixed on the outer surface of the drum and the inner surface of the concave. The coconut fed at the inlet and in the clearance between the inlet and the drum is compressed slightly by the system and forced to execute rolling or revolutions. In the process, the blade penetrates the husk and punctures it along different planes. The shear force exerted upon the coconut by the blades of the rotating drum and the concave cause to rip open the husk along different planes. In some cases, the coconuts are completely husked and the nut emerges out at the outlet. In some cases, full coconuts with punctured and softened husk emerge out. Such coconuts require secondary operations to remove the husk. Overall, the machine, as the first prototype, functioned satisfactorily. Also, it offered scope for further improvement. Based on the above, it was selected for the type of modifications preferred in this study.

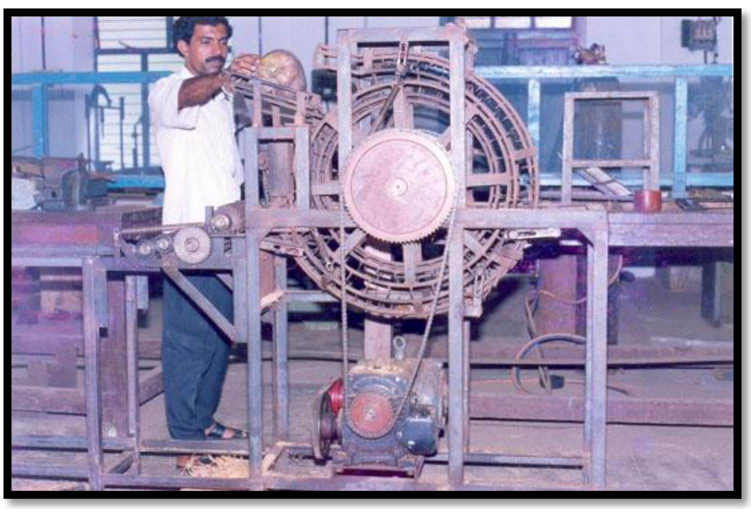


Plate 2.3 Rotary Coconut Dehusker

(*Muhammad*, 2002)

The mechanical coconut husker consists of 3 main components- an inlet throat, a husking mechanism and an outlet. The husking mechanism of the machine consists of 3 powered rollers powered by a 1.5 hp, 1440 rpm, single phase AC electrical motor with integral reduction mounted almost vertically at the top of the machine and a gear box. Power is transmitted to the roller through helical gears. The powered rollers mounted in the right row rotate at a speed of 50 rpm, the outermost one carrying a series of slightly curved sharp hook-like knives that engage with the husk when coconuts are fed from the mouth of the throat. The whole nut is fed through the feed chute holding it vertically by hand, towards the converging throat where it is caught between the two rollers. In the process, the sharp right roll consisting of slightly curved hook-like knives engage with the husk and left spring loaded knives press the coconut towards the right rollers. As the rollers rotate, the husk gets detached from the shell, effecting a complete dehusking of coconut. The dehusked coconuts fall through the slopping outlet towards the left and are collected (Santhi et al., 2006).

Plate 2.4 Mechanical coconut husking machine

A project on the development of a rotary mechanism with manual feeding for husking coconut was also undertaken at the KCAET, Tavanur (Gubash *et al.*, 2008). It was intended for large-scale application. The rotary mechanism comprised a segmented ring attached through three spokes to a main shaft and a spear-like curved blade. The blade carried a slotted radial spoke to enable its mounting on the segmented ring. In operation, the blade rotated downwards on the husking side to enable the blade to husk the coconut during its downward travel. However, this tool did not become a perfect solution for the present crisis in this sector. Since this machine was found unsuitable for the type of modifications suggested in this study, this too was not selected as the tool for improvement in this study.

A project on the development of a power operated coconut husking machine was also undertaken at KCAET, Tavanur (Aneesh *et al*., 2009). It consists of a mechanized opening of blades with manual feeding of coconut one at a time. It consist of a cage like follower actuated by a half-way cam which was driven by a 2 Hp motor by means of V-belt and pulley. When the cam acts on follower, it moves backward causing the movable blade to open. The cam is designed in such a way that the closing time of blade is 2 s, so that we can utilize that time for impaling the coconut into the juxtaposed blades and the opening time of blade is one second. Though this machine requires 12-14 s for husking a nut depending on the skill of operator, it is not an efficient machine for large scale husking of coconut. Hence it not selected for further improvement.

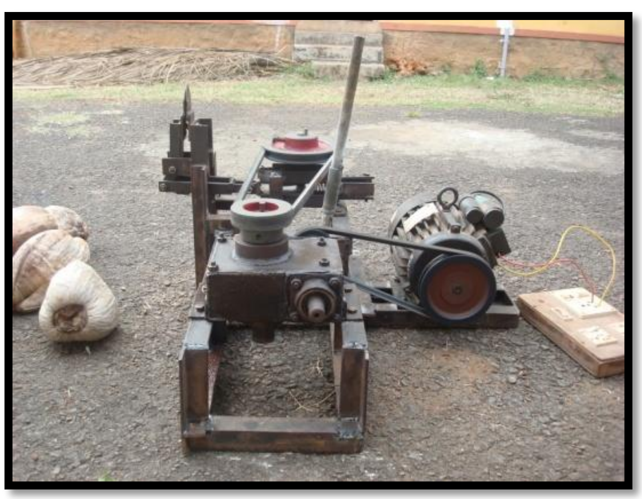


Plate 2.5 Power operated coconut husking machine

(*Aneesh et al, 2009*)

In spite of the efforts taken at different places, an efficient tool for large-scale husking of coconut, in which continuous feeding of coconut is possible, is yet to be developed. Consequently, the development of the one closest to the powered rotary coconut husking machine has been taken as a research study in this programme. Hence, this machine was selected for modification.

Material and Methods

Chapter 3

MATERIALS AND METHODS

In this chapter, the methods followed to determine the physical and mechanical properties of coconut are detailed. Selection and optimization methods of various machine parameters and the fabrication details for the development of the prototype are described. Also its performance evaluation is briefly summarized.

3.1 Physical properties

The design of the feeding chute, husking and husk separating units, the shapes of the rotating drum and the concave and the clearance between the concave and the rotating drum are mainly based on the physical properties of coconut. The important physical properties under consideration are size, shape, weight, shell diameter, and moisture content. The coconuts are graded based on its size as small, medium and large among both green (182 to 195 days after pollination) and dried (195 to 206 days after pollination) coconuts (Siripanich, 1995). Twenty coconuts from west coast variety were randomly selected for the study.

3.1.1. Size and shape

The size and shape of the coconut is important in deciding the shape and size of the feeding chute and the husking unit. A sample of twenty coconuts, each from dry and green were selected for determining the size and shape. A standard digital color camera, a personal computer and the Auto CAD software were used for image analysis to obtain digitized coconut shape.

An experimental set up was made to take the images of sample coconuts. It consists of a stand with a camera fixed to it and a base. The positions of camera can be adjusted to get appropriate focal length. The samples should be fixed at the base and the images are taken at two perpendicular positions of the coconut. Images should be taken at fixed position and with fixed camera focal length. The distance between the camera and the specimen is set as 45 cm. The abscissa defined the position of its diameter and the position on length is represented on the ordinate.

Measurements on three mutually perpendicular principal axes viz; major, intermediate and minor diameters were determined. The parameters namely length, breadth and equivalent diameter were obtained using the image analysis technique.

Plate 3.1 Experimental setup for taking photograph for image analysis

Dry and green mature coconuts were used for experiments. These were segregated into three categories as small, medium and large depending on the size as measured along the longitudinal natural rest position i.e. the length as major axis and diameter as the minor axis. The size classifications are given in the Table 3.1.

Table 3.1 Classification of the coconuts based on size

Category	Size (diameter), mm	Length, mm
Small	< 150	< 220
Medium	150 – 170	220 – 250
Large	> 170	> 250

3.1.2 Sphericity

Sphericity is a yardstick to measure the roundness or spherical nature of an object. This parameter is responsible for movement of coconut between the husking drum and the concave. Sphericity was determined using the following expression (Mohsenin, 1970). Lengths of the intercepts taken were those obtained under Art. 3.1.1 above as major, intermediate and minor diameters respectively.

$$\text{Sphericity} = \frac{(lbt)^{\frac{1}{3}}}{l} \qquad \text{------ } 3.1$$

where, *l* = the largest intercept, mm

b = the largest intercept normal to *l*, mm

t = the largest intercept normal to *l* and b, mm

3.1.3 Weight of coconut

A random sample of about 20 coconuts were selected and weighed on an electronic balance having sensitivity of 0.01g and the observations were averaged. The observations were recorded and the average weight was calculated.

3.1.4 Shell diameter

Shell diameter is determined by using measuring tape. On wrapping the tape along the circumference of the coconut, the diameter is calculated by using the equation 3.2. Random samples of 20 husked nuts were selected.

$$d = \frac{C}{\pi} \qquad \text{---------}3.2$$

where, d = diameter of the shell

C = circumference of nut

π = 3.14

3.1.5 Moisture content

Moisture content of the coconut husk is an important parameter as it influences the husking force. It was determined by oven dry method. Hundred grams of coconut husk is placed in a hot air oven. The temperature of the oven is set at 106 ^{0}C and the sample is kept in oven for 24 hours. The samples were taken out and were placed in desiccators to cool down. The reduction in the weight of sample is observed and recorded.

$$\text{Moisture content} = \frac{Wi - Wf}{Wi} \times 100 \qquad \text{-------} \; 3.3$$

where W_i = initial weight of the sample

W_f = final weight of the sample after drying

3.1.6 Husk thickness

Husk thickness refers to the thickness of the mesocarp (husk) from the epidermis to the endocarp (shell). It is another parameter for the design of blades and clearance adjustment between the knurling rollers. Husk thickness is measured using vernier calipers of least count 0.05 mm at various positions of coconut with respect to the pedicel end, viz, at the pedicel end, at 1/4th distance from pedicel end, at 1/2th distance from pedicel end, at 3/4th distance from pedicel end and finally at the apex. Samples include two lots of green and dry coconuts of 15 numbers each.

3.2 Mechanical properties

The force required to open a rip of husk from the coconut depends on the piercing and shear forces. The important mechanical properties under consideration are husk separating force and shell breaking force.

3.2.1 Husk separating force

The husk separating force of both green and dry coconut was determined with the help of Universal Testing Machine (UTM) of 20 T capacity. Approximate load range was calculated by assuming an ultimate stress of 5000 kg cm^{-2} and setting the pendulum and scale accordingly. The specimen between the wedge grips was secured and the pointer of UTM was adjusted to zero. The pumping was started and the movable cross rail was raised by hydraulic pressure. The deflection and corresponding load was noted at regular intervals. The load pointer moved up until the yield point, and it remained constantly. The load at deflection corresponding to the yield point was also noted.

Plate 3.2 Experimental set up for determining husk separating force

3.2.2 Shell Breaking force

The shell breaking force was found out in a UTM. This force is one of the major mechanical properties affecting the breakage of shell due to blade impact in operation. The scale and pendulum load was selected by assuming the crushing load as 50 kg cm^{-2}. The specimen was placed over the cross rail with flat faces of the sample as horizontal. The specimen between the platforms of the testing machine was carefully centered. Load was applied axially at a uniform rate of 140 kg $cm^{-2}min^{-1}$, till failure. The maximum load at failure was also recorded.

Plate 3.3 Experimental set up for determining shell breaking force

3.3 Machine parameters

The machine parameters viz. the length, shape and angle of the blade influence the husking of coconut. These parameters were optimized under laboratory test conditions. The speed of rotation of the husking drum was also optimized.

3.3.1 Length of blade

The length of the blade is an important parameter as both the piercing and shear forces are responsible for husking of coconut. In order to fix the length of blade, the husk thickness was measured along the longitudinal cross section of the coconut with respect to various positions of the pedicel end, i.e. at the pedicel end, at $1/4^{th}$ distance from the pedicel end, at $1/2^{th}$ distance from the pedicel end, at $3/4^{th}$ distance from pedicel end and finally at the apex. Samples include two lots of green and dry coconuts of 15 numbers each. Accordingly, the blade was made and was tested for the penetrating length at the three position of the coconut both at the ridge and the face. Hence depending upon the husk thickness and for easy penetration, the levels of blade length selected were 20, 30 and 40 mm respectively.

3.3.2 Shape of the blade

The shape of the blade affects the piercing force in husking of coconuts. The easy penetration and separation of husk from the nut depends on the shape of blades. Three shapes namely bevel, round and pointed type blades were selected for the study. These were individually fitted on the Universal Testing Machine and piercing strength for each blade were observed and recorded.

3.3.3 Blade angle

The blade angle is another parameter affecting the efficiency of husking of coconuts. The blade angle is optimized by conducting trial run with test specimen. Three blade angles were selected respectively as 70, 80 and 90 degs.

3.3.4 Speed of rotation

The speed of rotation of the husking drum influences the husking efficiency. The speeds of rotation selected were 50 rpm and 100 rpm. Tests were conducted with speed reduction gear box of 30 : 1 for obtaining 50 rpm and 15 : 1 for obtaining 100 rpm.

(a) (b) (c)

Plate 3.4 Different shape of blades used for testing (a. bevel edged b. pointed edged c. round edged)

3.3.5 Levels of machine parameters

The levels of independent parameters affecting the husking are furnished in Table 3.2. The various parameters of the blade viz. length, shape and angle of the blade were replicated three times and the speed of rotation was replicated two times.

Table 3.2 Levels of machine parameters

Sl No	Parameters	Levels
1	Length (L), mm	L_1 = 20
		L_2 = 30
		L_3 = 40
2	Shape (S)	S_1 = Bevel edge
		S_2 = Round edge
		S_3 = Pointed edge
3	Angle (A), deg	A_1 = 90
		A_2 = 80
		A_3 = 70
4	Speed of rotation, rpm	N_1 = 100
		N_2 = 50

Number of replications - 3

Total number of experiments - $3 \times 3 \times 3 \times 2 \times 3 = 162$

An experimental set up was made for optimizing the machine parameters. Three lengths of blades such as 20, 30 and 40 mm; three shapes viz. bevel, round and pointed; and three angles of 70, 80 and 90 deg were selected for the experiment. Each combination was tested and the husking rate and husking efficiency were found out. The blades of each shape and length was made and tested. The speed of rotation levels selected was 50 rpm and 100 rpm. From the literature, it was found that a speed of rotation of about 30 rpm was found to be the best for husking of coconut (Gubash *et. al.*, 2008). The speed of rotation of a machine similar to the continuous power operated coconut husking machine was found to be 144 rpm (Muhammad, 2002). As these lower and higher speeds are not sufficient to give the requisite output such as less husking time per nut, more husking efficiency and reduced nut breaking, speeds of 50 rpm and 100 rpm were set in experimental test rig.

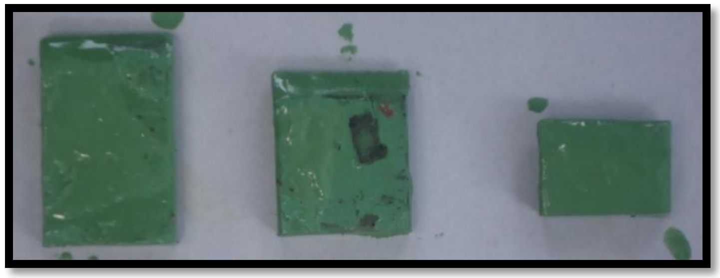


Plate 3.5 Bevel shaped blades

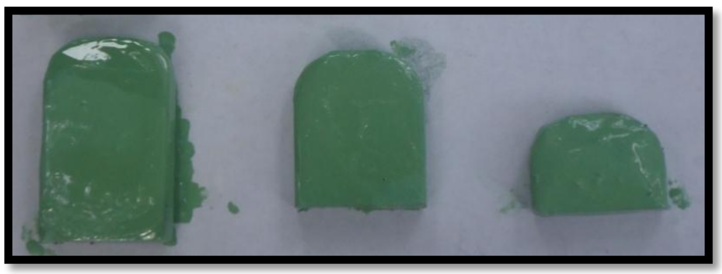


Plate 3.6 Round edged blades

Plate 3.7 Pointed edge blades

3.3.6 Optimization of machine parameters

The design parameters of the coconut husking machine were optimized based on the length, shape, angle and speed of rotation of the blades. Four factor completely randomized design was used to analyze the data thus obtain and find out the interaction between the factor combinations. MSTAT statistical software was used to do analysis of variance and mean comparison table was obtained. The mean comparison table was analyzed to observe the treatment which yields the desired husking rate and husking efficiency.

3.4 Development of prototype

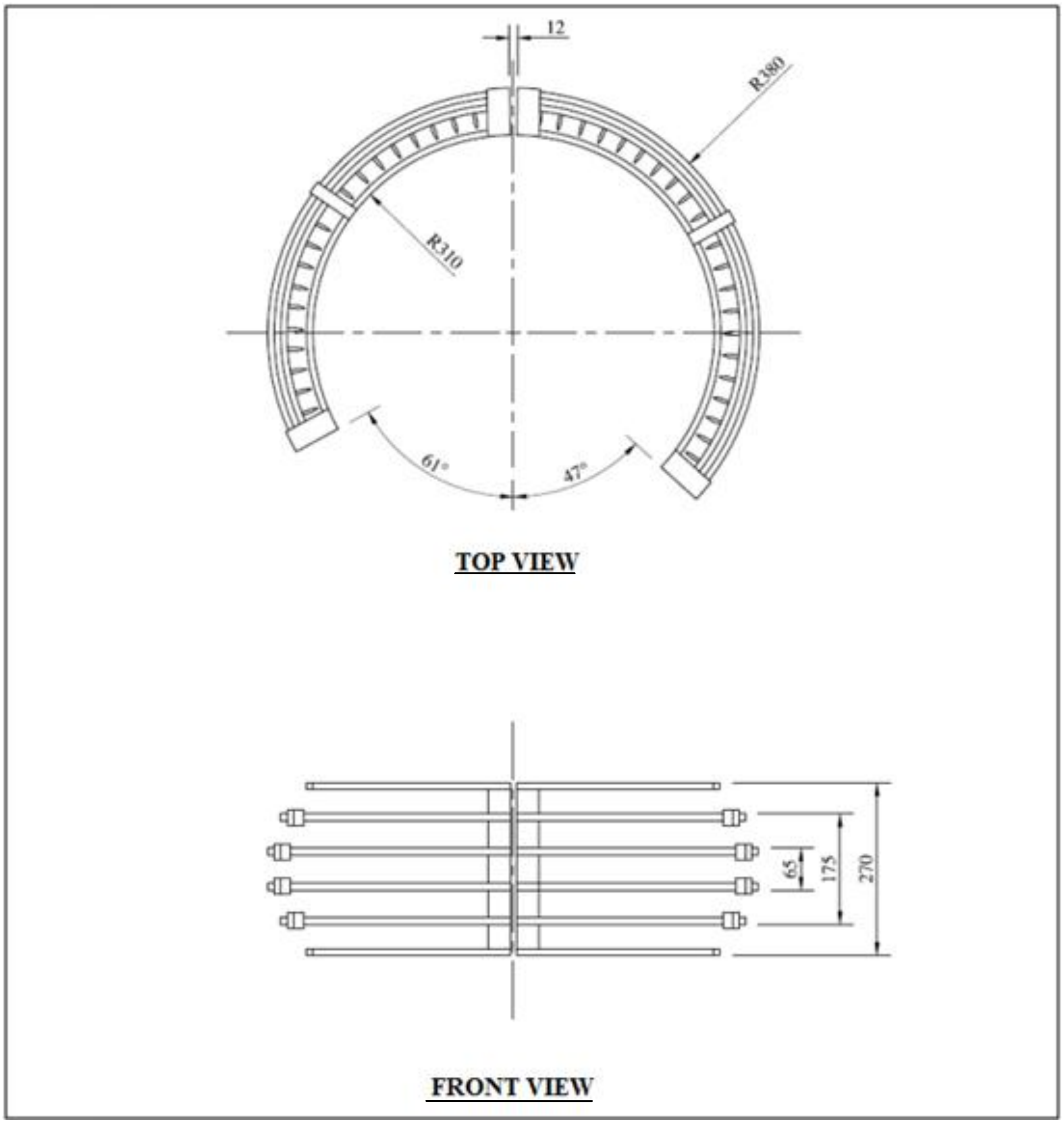
The prototype of the power operated coconut husking machine was developed based on the optimized physical and mechanical parameters of the coconut and the machine parameters such as length, shape, thickness of the blade and speed of rotation of the husking drum. The design of the major components of the continuous power operated coconut husking machine was given in Appendix V. The main components of the machine are respectively as feeding chute, husking unit, husk separating unit and power transmission unit.

3.4.1 Feeding chute

Feeding chute is a component of the coconut husking machine for feeding the coconut into husking unit. It is made of mild steel square rods of 5 mm size. An inverted conical shape feeding chute was fabricated based on size and shape of the coconut. The opening of the feeding chute can be adjusted by means of tension spring attached to a handle. On pulling the handle, the spring loaded chute wide opens and on releasing, the chute converges and holds the coconut firmly. The well holded coconut is then pushed into the clearance between the concave and rotating drum of the husking unit.

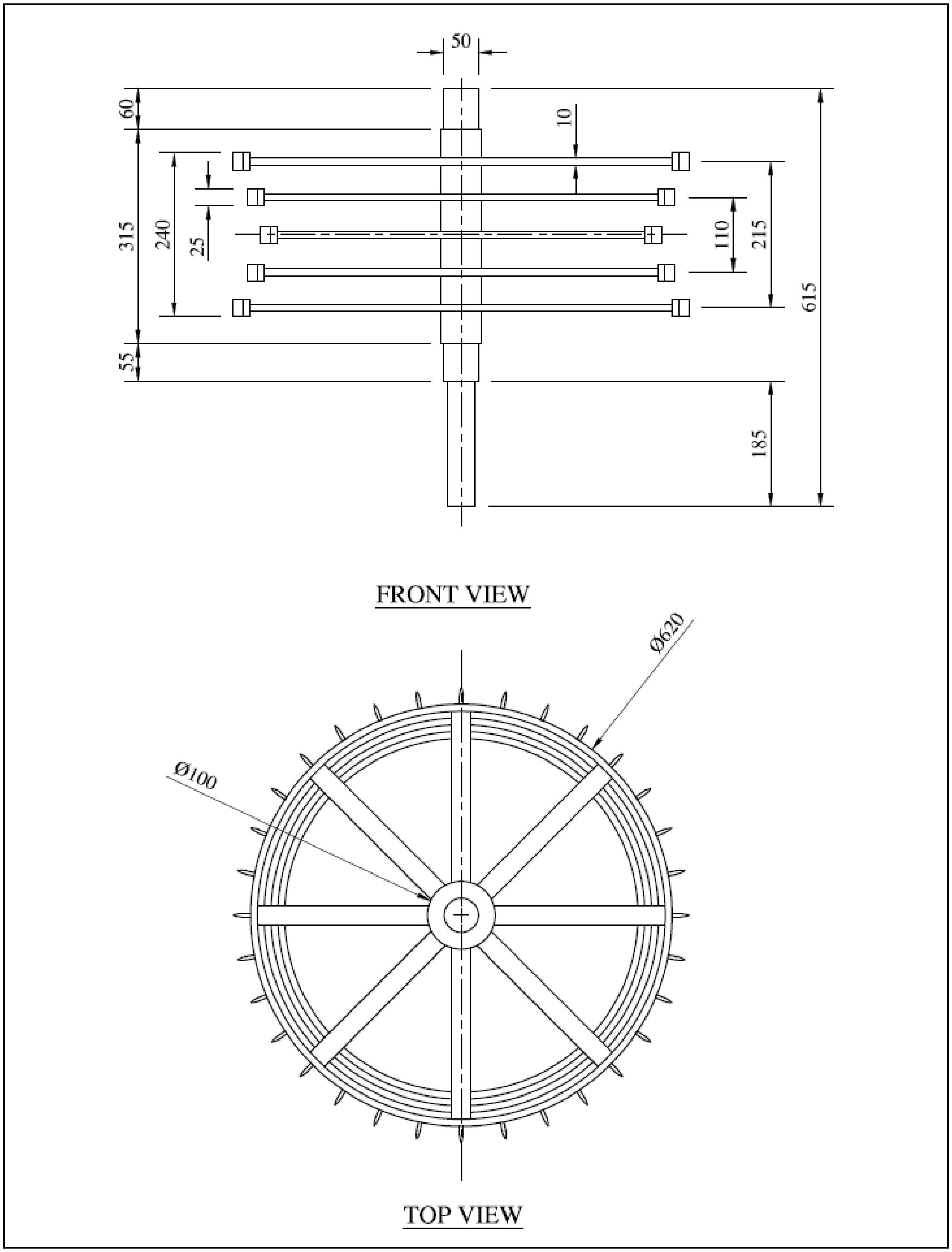
3.4.2 Husking unit

This is the main functional unit of the machine. It is fabricated based on the size and shape of the coconut. It consists of a rotating drum and a stationary concave (Fig 3.1 and 3.2). The rotating drum consists of five rims whose diameters were selected depending on the shape and length of travel of the coconut. As suggested by Muhammad (2002), the length of travel of coconut has to be set for 2 m for effective separation of husk. Accordingly the maximum diameter of the rim was fixed as 620 mm. Based on the length of travel of the coconut inside the husking unit the diameter of the rim was fixed as 620 mm for the first rim, 570 mm for the second rim, 530 mm for middle rim, 570 mm and 620 mm for the next two rims. This involute shape of the husking drum favours almost all the shapes of coconut to enter into the husking unit. The stationary concave is fabricated according to the size and shape of coconut. In order to pierce and rip the husk from the nut, 32 blades of 30 x 23 x 5 mm were welded on the rims of both rotating drum and stationary concave with a spacing of 60 mm. The ripped coconut ejected from the husking unit is fed into the husk separating unit where the husk is separated from the nut.



All dimensions are in mm

Fig. 3.1 Views of concave envelope

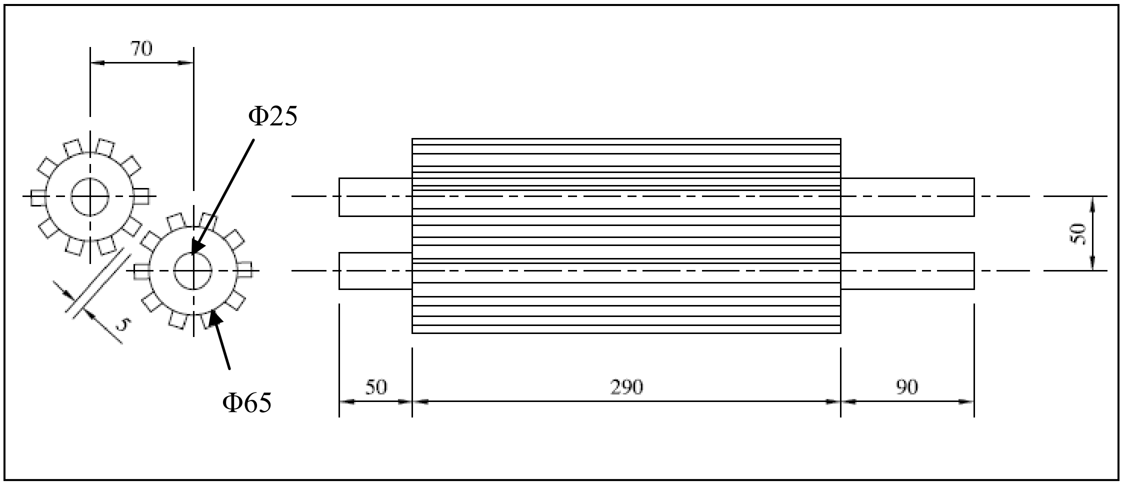


All dimensions are in mm

Fig 3.2 Views of rotating drum

3.4.3 Husk separating unit

The husk separating unit (Fig 3.3) consists of a set of knurling rollers made of mild steel of diameter 65 mm and length of 430 mm. These rollers rotate in opposite direction at a speed of 160 rpm. The rollers receive the power from the motor through chain drive. A clearance of about 5 mm was provided between the rollers to get a firm grip on the husk. A speed reduction of 9:1 is provided through chain and sprocket arrangement.

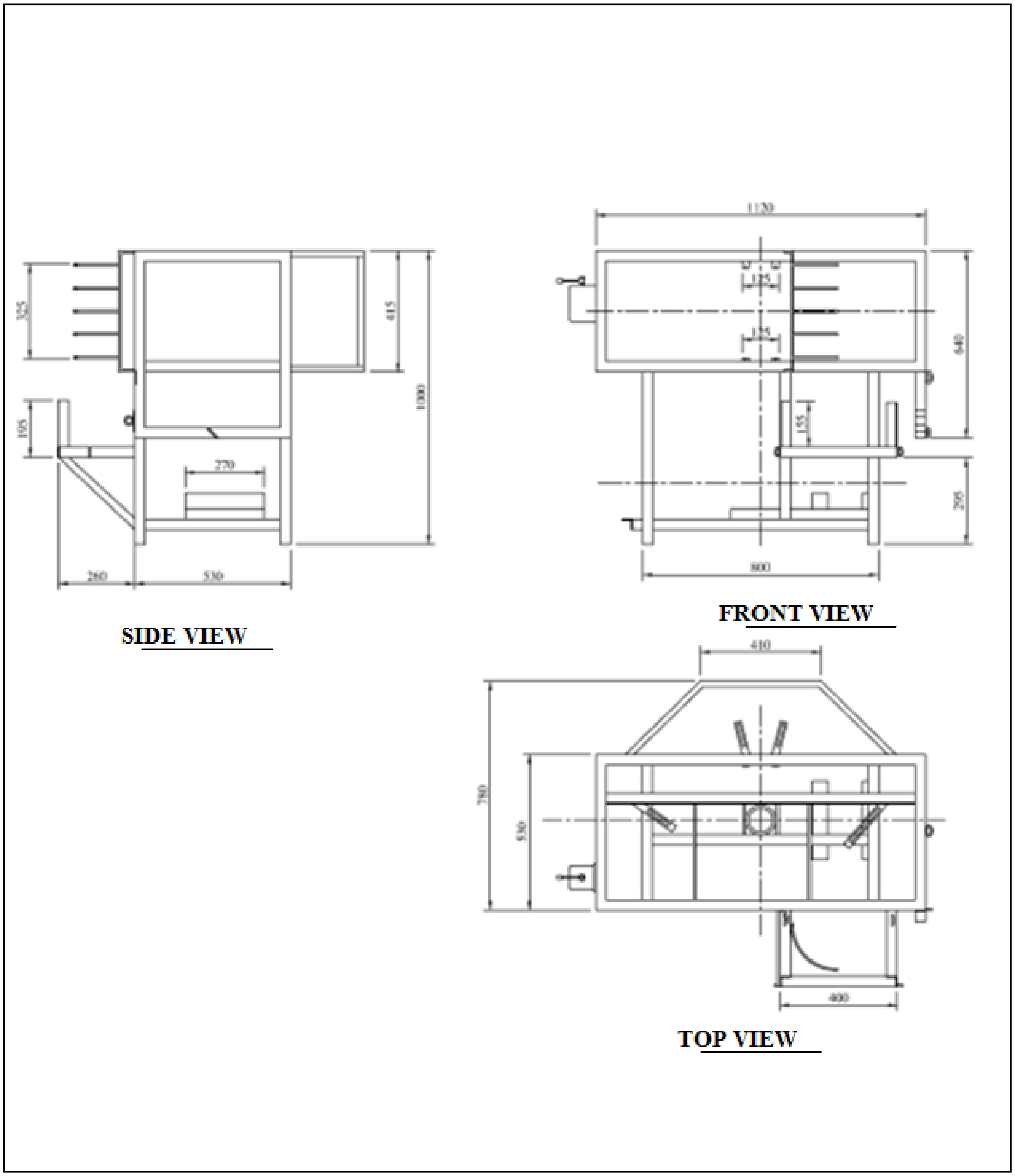


All dimensions are in mm

Fig 3.3 Knurling roller of husk separating unit

3.4.4 Power transmission unit

The prime mover used is a 3 φ squirrel cage induction motor of 2.2 kW. The drive is taken out to rotate the husking and husk separating unit. A speed reduction unit with a speed ratio of 30:1 is used to reduce the motor speed from 1440 rpm to 48 rpm to give power to husking unit. Also the drive of the motor taken to the husk separation unit by means of chain drive where the speed is reduced from 1440 to 160 rpm through chain and sprocket drive.



All dimensions are in mm

Fig 3.4 Views of machine frame

3.5 Working

For effective husking of the coconut, grading is essential. If large coconuts are fed into the machine, the outer concave gets expanded to accommodate the larger diameter and remains in that position along the entire length of travel of the coconut. So, in continuous feeding, if smaller coconuts are fed immediately after a larger coconut, the blades cannot get penetrate into its husk as the outer concave is in expanded position. So it will simply pass into the separating unit without husking. So it is recommended to grade the coconut depending on its size before fed into the machine.

Such graded coconuts are to be fed to the inverted conical shaped feeding chute. The opening of the feeding chute can be adjusted by means of tension spring attached to a handle. On pulling the handle, the spring loaded chute wide opens and on releasing the chute converges and holds the coconut firmly. The firmly holded coconut is then pushed into the clearance between the concave and rotating drum of the husking unit. As the drum rotates, the blades on the periphery of the rotating drum and the concave penetrates the husk and punctures it along different planes. Due to the piercing force of the blades and the shear force excerted on rotation, cause to rip opens the husk along different planes. The entire husk of the coconut will get loosened and softened as it emerges out from the husking unit. This coconut then falls to the husk separating unit. As this punctured coconut with softened and loosened husk fall into the knurling rollers, it grabs the husk into it on rotation. Thus the entire husk gets separated from the nut.

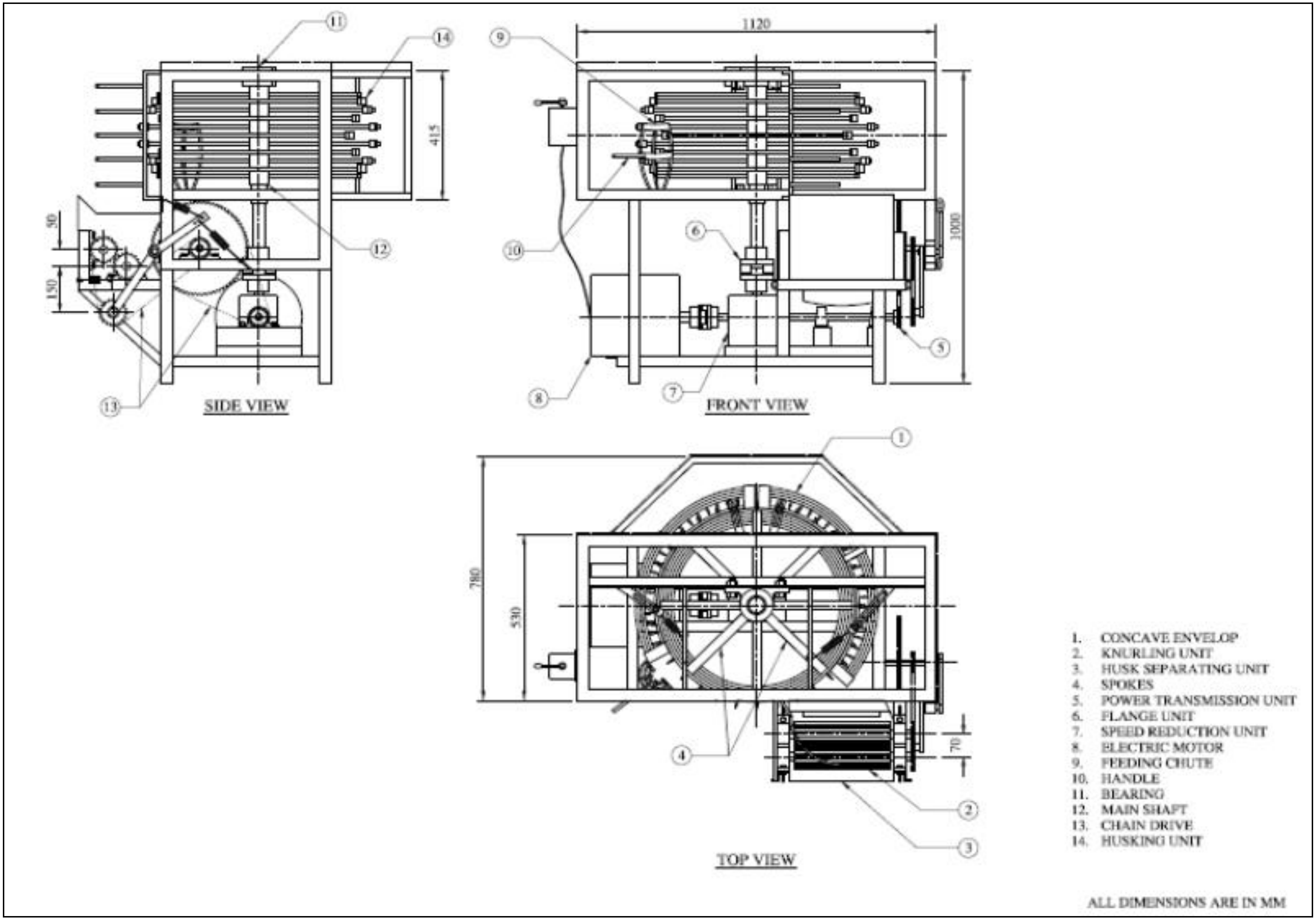


Fig 3.5 Continuous power operated coconut husking machine

3.6 Performance analysis

The performance of the coconut husking machine was evaluated in terms of husking rate, energy requirement, percentage of nut breaking, and capacity of the machine. Dry and green mature coconuts were used for conducting trial runs with the machine. Coconuts were fed continuously and the time taken for husking was noted. The number of husked, unhusked and broken coconuts was recorded from which the capacity, efficiency and percentage broken were found out. The power requirement for the operation was also noted. Fifty coconuts were used for each set of experiments in three replications. The average of these performance parameters were calculated and recorded.

3.6.1 Husking rate

Husking rate is the number of coconuts husked per unit time. Green and dry coconuts of 20 numbers each were selected randomly and fed to the machine. The time required for husking each coconut was noted. The minimum and maximum times required for husking green and dry coconuts were separately noted.

3.6.2 Energy requirement

It is the electric power required for the machine to husk coconuts for a period of time. A 3-phase 3 wire energymeter is connected to the motor of the machine to find out the energy requirement. The power required in kilowatts (kW) per hour of husking coconut was observed and recorded.

3.6.3 Percentage of nut breaking

It refers to the number of broken nuts expressed in percentage during continuous husking in one hour. The percentage of nut breaking was determined by

$$\text{Nut breaking (\%)} = \frac{Number\ of\ nuts\ broken}{Total\ number\ of\ coconut\ husked} \times 100$$

3.6.4 Capacity of the machine

The capacity of the machine refers to the number of coconuts husked in one hour. The husking efficiency of the machine is the ratio of total number of nuts husked to the total number of coconuts fed to the machine and depends on the total number of husked, damaged, and broken nuts. The capacity and efficiency of the machine in husking are separately calculated and recorded.

3.7 Comparative performance

A comparative performance analysis was conducted with the conventional method and a commercial model coconut husking machine. The detail of the commercial model of the husking machine is given in the Appendix VI.

Plate 3.8 Coconut husking by conventional method

The conventional method of large scale dehusking is done by a stationary sharp wedge mounted upright on the earth. The height of the tool above the ground level varies from 45 to 60 cm depending upon the ergonomic considerations of the worker. Holding the coconut by both hands, it is pressed on to the sharp wedge parallel to its longitudinal axis. Also, the coconut is pressed away from the tool. On doing so, the wedge inside the husk swirls slightly and separates a sector of the husk from the nut. This operation is repeated two or three times to loosen the remaining sectors and the nut are finally separated out from the husk through manual pulling. In this method one labour can husk 2500 - 3000 coconuts in 6 hours.

In the commercially available coconut husking machine, the coconut is fed through the feeding chute by holding it vertically and pushing through the converging throat between the two rotating rollers. The sharp hook shaped blades of the right hand roller engage into husk while the blades of the spring loaded left hand roller press the coconut towards the other roller. As the rollers rotate, the husk gets detached from the shell, effecting a complete husking of coconut. The husked coconuts fall through the slopping outlet towards the left and are collected. The experiment was conducted with the same independent variables as employed for the continuous powered coconut husking machine. These two methods were compared with that of the continuous power operated coconut husking machine. In this machine, 500 numbers of coconut husked in one hour.

Plate 3.9 Coconut husking by commercial husking machine

The capacity, husking efficiency, percentage of nut breaking and the energy requirement is compared among the three methods. A three phase three wire energymeter is connected in series with the machine and the energy requirement is observed and recorded.

3.8 Cost economics

The cost of operation of the developed machine was calculated following standard procedures. The required data for husking of coconut and the labour charges were collected from the nearby farmers. The saving in cost in the operation with continuous power operated coconut husking machine was worked out in comparison with the manual method of husking and husking with commercial model.

Results and Discussions

Chapter 4
RESULTS AND DISCUSSION

The physical and mechanical properties of coconut required for the design and fabrication of continuous power operated coconut husking machine were determined and are summarized. The machine parameters viz., length, shape and angle of the blade and speed of rotation of the husking drum were optimized. A prototype of the continuous power operated coconut husking machine was developed based on optimized physical and mechanical properties of the coconut and machine parameters. The performance of the machine in comparison with conventional method and a commercial model were conducted and the results were discussed. Cost economics of the continuous power operated coconut husking machine were carried out and compare with the conventional and commercial model.

4.1 Physical properties of coconut

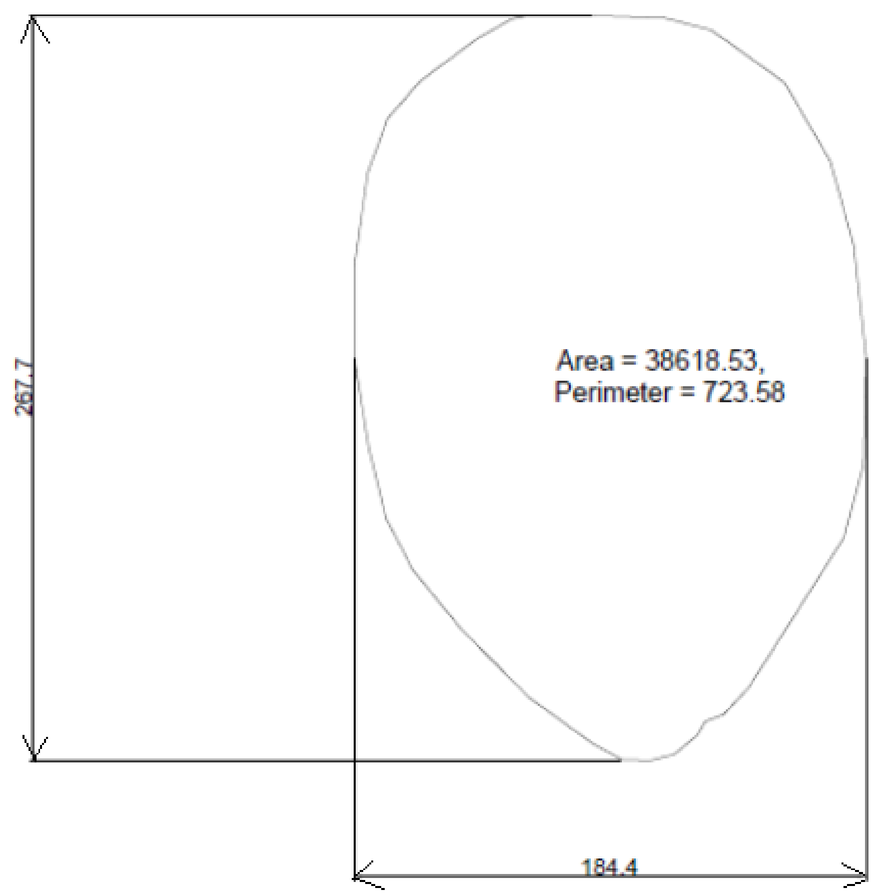
The physical properties of the coconut such as the size, shape, sphericity, weight, moisture content, shell diameter and husk thickness influenced the performance of the husking machine and are given in Appendix I.

4.1.1 Size and shape

The size and shape of the coconut were determined by using image analysis technique (Fig 4.1). The minimum length and diameter of dry coconut were found out as 220.73 mm and 172.05 mm and maximum length and diameter were 263.51 mm and 206.1 mm respectively; and for green coconut, the minimum values of length and diameter were 230.29 mm, 174.48 mm and maximum values were 257.64 mm, 201.03 mm respectively. The feeding chute and the husking unit were developed based on the average values of the size and shape of the selected coconuts.

4.1.2 Sphericity

Sphericity was determined by recording the lengths of the intercepts along major, intermediate and minor diameters and was calculated using the equation suggested by Mohsenin, 1970. The average sphericity of dry and green coconut were found out as 0.808 and 0.786. This factor decided the shape of the feeding chute, movement of the coconut through the clearance between the husking drum and the concave.



All dimensions are in mm

Fig. 4.1 Size and shape of coconut

4.1.3 Weight

The weight of the coconut was determined by using an electronic balance. The minimum and maximum weight was found out as 0.70 kg and 1.23 kg for dry coconut and 0.75 kg and 1.89 kg for green coconut. The momentum due to the weight of the moving coconut through the husking drum indirectly affects the speed and piercing force of blades attached to the drum.

4.1.4 Shell diameter

The shell diameter was determined by a measuring tape as explained under Art. 3.1.4. Twenty husked nuts were selected randomly. The average diameter of the nut was found to be 96.216 mm. This parameter is responsible for the piercing depth and force of the blades attached to the husking drum.

4.1.5 Moisture content

Moisture content was determined as in Art. 3.1.5. The average moisture contents of the husks of the green and dry coconuts were separately found out as 10.056 and 1.295 % (wet basis). This factor affected the husking rate and time as it influences the inter fibral strength.

4.1.6 Husk thickness

The husk thickness was measured along the longitudinal cross section of husk. The average husk thickness of the green coconut was found out as 5.52 cm at pedicel end, 2.826 cm at the apex, 3.413 cm at $1/4^{th}$ distance from pedicel end, 2.18 cm at $1/2^{th}$ distance from the pedicel end and 2.11 cm at $3/4^{th}$ distance from the pedicel end. The average husk thickness of the dry coconut was found out as 6.39 cm at pedicel end, 3.42 cm at apex, 2.95 cm at $1/4^{th}$ distance from the pedicel end, 2.264 cm at $1/2^{th}$ distance from the pedicel end and 1.777 cm at $3/4^{th}$ distance from the pedicel end. Husk thickness is an important parameter affecting the size and shape of the blades of the husking unit and the clearance adjustment between the knurling rollers of the husk separating unit.

4.2 Mechanical properties

The mechanical properties such as the husk separating and shell breaking forces and toughness were found out and are presented in Appendix II. These properties were used for designing the husking and husk separating units of the power operated coconut husking machine.

4.2.1 Husk separating force

The minimum husk separating forces for green and dry coconuts were found out as 0.513 kg cm^{-2} and 0.067 kg cm^{-2}. The maximum values of husk separating force for green and dry coconuts were found out as 1.757 kg cm^{-2} and 1.072 kg cm^{-2} using UTM of 20 T capacity. This property decided the speed of rotation of husk separating units of the machine.

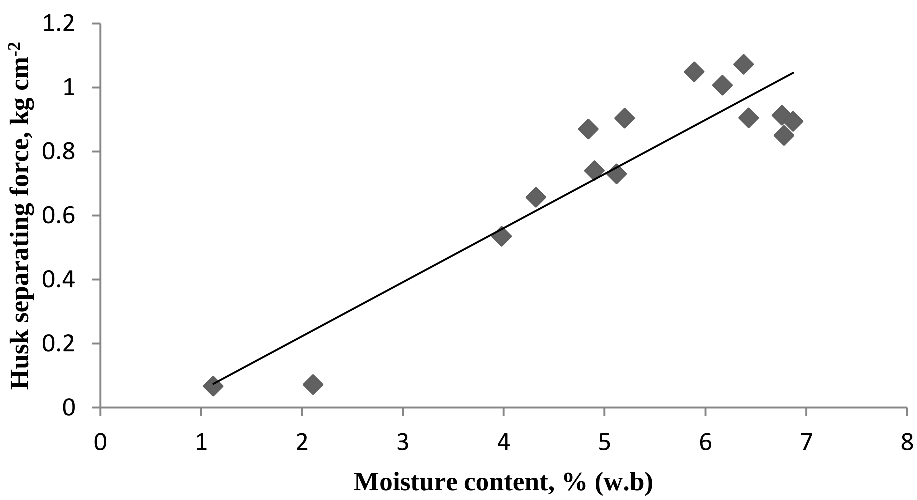


Fig. 4.2 Effect of moisture content on husk separating force

The effect of moisture content on husk separating force is shown in Fig 4.2. It shows that the force required for separating the husk from the nut increases gradually as the moisture content increases. This may be due to the high adhering force due to moisture content between the fibres. It was also experienced that a higher bonding force between the fibres of the husk than between husk and the nut.

4.2.2 Shell breaking force

This force was determined using Universal Testing Machine by applying the load along the vertical axis. The maximum shell breaking force was found out as 920 kg_f. The design of the husking blade is given in Appendix V.

4.3 Optimization of blade parameters

The selected blade parameters were optimized for the development of the major components of the husking machine. The major parameters optimized are the length, shape and angle of the blade and speed of rotation of the husking drum. The various lengths of blade tested were L_1, L_2 and L_3 are respectively as 20, 30 and 40 mm and shapes such as S_1, S_2 and S_3 are respectively as bevel edged, round edged and pointed edged. The blade angle selected were A_1, A_2, and A_3 were 90, 80 and 70 degs respectively. The speed of rotation selected were N_1 and N_2 as 100 and 50 rpm. The average values of the measured parameters were found out and are presented in Appendix IV.

4.3.1 Analysis of variance for blade parameters

The analysis of variance for the length of the blade with respect to different shape and angle of the blade and speed of rotation is given in Table 4.1. From the table, it is inferred that the effect of treatment combinations of length and shape of the blade, length and angle of the blade and also length and speed of rotation of the husking drum are significant. The interaction A x B x C x D (length x shape x angle x speed of rotation) is significant, indicating that length, shape and angle of the blade and speed of rotation of the blade affect the husking time.

Table 4.1 Optimization of blade parameters based on speed of 100 rpm

Sl. No.	Treatment	Length of the blade (mm)	Shape of the blade	Blade angle (deg)	Speed of rotation (rpm)	Average husking time (s/nut)	Husking efficiency (%)
1	$L_1S_1A_1N_1$	20	Bevel	90	100	22.33	33.3
2	$L_1S_2A_1N_1$	20	Round	90	100	26.57	33.3
3	$L_1S_3A_1N_1$	20	Pointed	90	100	28.43	33.3
4	$L_1S_1A_2N_1$	20	Bevel	80	100	22.27	33.3
5	$L_1S_1A_3N_1$	20	Bevel	70	100	17.47	33.3
6	$L_1S_2A_3N_1$	20	Round	70	100	20.53	33.3
7	$L_1S_2A_2N_1$	20	Round	80	100	27.3	33.3
8	$L_1S_3A_3N_1$	20	Pointed	70	100	26.77	33.3
9	$L_1S_3A_2N_1$	20	Pointed	80	100	28.53	33.3
10	$L_2S_1A_1N_1$	30	Bevel	90	100	22.9	33.3
11	$L_2S_2A_1N_1$	30	Round	90	100	26.23	33.3
12	$L_2S_3A_1N_1$	30	Pointed	90	100	29.8	33.3
13	$L_2S_1A_2N_1$	30	Bevel	80	100	23.17	33.3
14	$L_2S_1A_3N_1$	30	Bevel	70	100	23.37	33.3
15	$L_2S_2A_3N_1$	30	Round	70	100	27.17	33.3
16	$L_2S_2A_2N_1$	30	Round	80	100	25.5	33.3
17	$L_2S_3A_3N_1$	30	Pointed	70	100	27.5	33.3
18	$L_2S_3A_2N_1$	30	Pointed	80	100	24	33.3
19	$L_3S_1A_1N_1$	40	Bevel	90	100	27.03	33.3
20	$L_3S_2A_1N_1$	40	Round	90	100	24.63	33.3
21	$L_3S_3A_1N_1$	40	Pointed	90	100	28.77	33.3
22	$L_3S_1A_2N_1$	40	Bevel	80	100	29.5	33.3
23	$L_3S_1A_3N_1$	40	Bevel	70	100	31.67	33.3
24	$L_3S_2A_3N_1$	40	Round	70	100	26.87	33.3
25	$L_3S_2A_2N_1$	40	Round	80	100	27.47	33.3
26	$L_3S_3A_3N_1$	40	Pointed	70	100	29.33	33.3
27	$L_3S_3A_2N_1$	40	Pointed	80	100	26.7	33.3

Table 4.2 Optimization of blade parameters based on speed of 50 rpm

Sl. No.	Treatment	Length of the blade (mm)	Shape of the blade	Blade angle (deg)	Speed of rotation (rpm)	Average husking time (s/nut)	Husking efficiency (%)
1	$L_1S_1A_1N_2$	20	Bevel	90	50	9.53	66.6
2	$L_1S_2A_3N_2$	20	Round	70	50	11.6	66.6
3	$L_1S_3A_1N_2$	20	Pointed	90	50	14.53	66.6
4	$L_1S_1A_2N_2$	20	Bevel	80	50	8.96	66.6
5	$L_1S_1A_3N_2$	20	Bevel	70	50	18.33	66.6
6	$L_1S_3A_3N_2$	20	Pointed	70	50	22.67	66.6
7	$L_1S_2A_2N_2$	20	Round	80	50	12.46	66.6
8	$L_1S_2A1N_2$	20	Pointed	70	50	18.76	66.6
9	$L_1S_3A_2N_2$	20	Pointed	80	50	18.1	66.6
10	$L_2S_1A_1N_2$	30	Bevel	90	50	7.23	100
11	$L_2S_2A_1N_2$	30	Round	90	50	14.9	100
12	$L_2S_3A_1N_2$	30	Pointed	90	50	25.9	66.6
13	$L_2S_1A_2N_2$	30	Bevel	80	50	7.73	100
14	$L_2S_1A_3N_2$	30	Bevel	70	50	18.56	66.6
15	$L_2S_3A_3N_2$	30	Pointed	70	50	21.7	33.3
16	$L_2S_2A_2N_2$	30	Round	80	50	14.56	66.6
17	$L_2S_2A_3N_2$	30	Round	70	50	20.9	33.3
18	$L_2S_3A_2N_2$	30	Pointed	80	50	18.7	66.6
19	$L_3S_1A_1N_2$	40	Bevel	90	50	12.93	100
20	$L_3S_2A_1N_2$	40	Round	90	50	17.77	66.6
21	$L_3S_3A_1N_2$	40	Pointed	90	50	14.83	66.6
22	$L_3S_1A_2N_2$	40	Bevel	80	50	11	100
23	$L_3S_1A_3N_2$	40	Bevel	70	50	23.6	66.6
24	$L_3S_3A_3N_2$	40	Pointed	70	50	21.5	66.6
25	$L_3S_2A_3N_2$	40	Round	70	50	11.8	66.6
26	$L_3S_2A_2N_2$	40	Round	80	50	14.23	66.6
27	$L_3S_3A_2N_2$	40	Pointed	80	50	16.67	66.6

L_1, L_2, L_3 = 20, 30 and 40 mm

S_1, S_2, S_3 = Bevel, Round and Pointed edge

A_1, A_2, A_3 = 90, 80 and 70 deg

N_1, N_2 = 100 and 50 rpm

Analysis of variance (ANOVA) revealed that all the factors namely length (L), shape (S) and angle of the blade (A) and the speed of rotation of the husking drum (N) and also their combinational effects are significant. It was observed that in the combination with L_2 = 30 mm, S_1 = bevel edged, A_1 = 90 degrees and N_2 = 50 rpm, i.e. $L_2S_1A_1N_2$, the husking time was 7.233 s and the husking time for the combination with L_1 = 20 mm, S_1 = bevel edged, A_2 = 80 degrees and N_2 = 50 rpm, i.e. $L_1S_1A_2N_2$ was 8.967 s which was on par with first combination. Individually when the effects were considered, the effect of length L_1 was the best, as regard shape it was bevel edged, angle of 80 degrees and speed of rotation of 50 rpm was better. In total, if the combinational effects and the individual effects are put together, the combination $L_1S_1A_2N_2$ is found to be the best. Since the blade length of 20 mm was found to be significantly superior, but when the combinational effect was taken, the blade length of 30 mm was found to be more suitable. Further experimentation with blade length ranging from 20 to 30 mm is necessary to determine the exact blade length. As regard as other parameters especially blade shape and speed of rotation, the most suitable one are bevel edged blade and a speed of 50 rpm. Regarding angle, since slanting orientation will do the least damage to coconut, 80 degree angle is found to be more acceptable. Hence it is concluded that for a minimum husking time, the length, shape and angle of the blade were fixed respectively as 20 mm, bevel edged and 80 deg. The speed of rotation was fixed at 50 rpm.

4.4 Development of the prototype

The prototype (Fig. 4.3) of the power operated coconut husking machine was developed based on the optimized physical and mechanical parameters of the coconut and the machine parameters. The main components of the machine are respectively as feeding chute, husking unit, husk separating unit and power transmission unit (Plate 4.1). The specification of each component is given in Appendix V.

Plate 4.1 The continuous power operated coconut husking machine

4.5 Performance analysis

The performance analysis was done as explained in section 3.6. Data of the experiments on husking rate and electrical power consumption (energy requirement) for green and dry coconuts are separately presented in Table 4.3 and 4.4. Samples include two lots of green and dry coconuts of 20 numbers each.

4.5.1 Husking rate

Data of the experiments on husking rate for green and dry coconuts are presented in Tables 4.3.

Table 4.3 Husking rate of green and dry coconut

Sl. No.	Green coconut		Dry coconut	
	Diameter (mm)	Husking time (s)	Diameter (mm)	Husking time (s)
1	146.49	8	149.68	8
2	159.23	**6**	154.45	12
3	139.81	11	152.87	15
4	143.93	8	149.61	11
5	142.96	14	136.62	**3**
6	157.00	7	148.24	11
7	152.83	12	146.87	8
8	136.62	9	149.24	9
9	136.68	10	153.68	**15**
10	150.94	19	143.76	7
11	174.56	18	145.13	10
12	192.47	22	147.91	5
13	200.30	**22**	150.90	8
14	156.33	7	146.94	7
15	151.58	12	143.65	11
16	146.51	8	152.06	13
17	161.48	13	148.56	8
18	148.73	8	153.89	12
19	153.08	8	148.73	9
20	147.17	10	145.89	8
Avg	**154.935**	**11.6**	**148.434**	**9.5**

It is seen from the Table 4.3 that the minimum and maximum time required for complete husking of a green coconut were 6 s and 22 s and that for a dry coconut was 3 s and 15 s respectively. Thus the mean time required for complete husking of green coconut is 11.6 s and that of dry coconut is 9.5 s. This may be due to the fact that as the moisture content increases, the interfibral strength increases. Hence more time is required for husking of green coconut than the dry coconut.

4.5.2 Energy requirement

Energy requirement was determined by using a 3 φ 3 wire energymeter and is given in Table 4.3. The average energy requirement for husking green coconut was 0.734 kW and for dry coconut was 0.739 kW. It is revealed that the average energy requirement for husking of both dry and green coconuts was somewhat the same. The maximum energy required for husking green coconut was found out as 0.762 kW which was for large category and that of dry coconut was 0.770 kW which was also for large category. Also the minimum energy requirement was found out as 0.713 kW for small category of green coconut and 0.720 kW for small category of dry coconut.

4.5.3 Percentage of nut breaking

Major problem of commercially available large scale coconut husking machines is the chance of breaking of nuts while husking. The test was conducted by feeding 100 coconuts after grading as large, medium and small. The average percentage of nut breaking for green coconut was calculated as 4.67 % and for dry coconut was 2.97 per cent. The Table 4.4 shows the percentage of nut breaking for large, medium and small coconuts of both dry and green coconuts.

4.5.4 Capacity

Data of the experiment conducted for determining the capacity of the machine was presented in the Table 4.4. Samples of three grades of coconuts as large, medium and small fed separately and continuously to the machine. The total number of coconuts husked per hour was found out as 387 for dry and 325 for green types. The efficiency of the machine in husking was found out as 82.79 per cent.

Table 4.4 Performance analysis of the machine

No load power: 0.6 kW

Type of coconut	Category	Capacity (nuts/h)	Husking efficiency (%)	Nut breaking (%)	Energy (kW)
Green	Large	249.58	79.76	8	0.762
	Medium	355.87	84.09	4	0.726
	Small	369.46	76.84	2	0.713
Average (Green)		324.97	80.23	4.67	0.734
Dry	Large	262.69	81.57	6	0.770
	Medium	445.10	88.41	2	0.728
	Small	452.49	86.12	1	0.720
Average (Dry)		386.76	85.37	3	0.739
Average		**355.86**	**82.79**	**3.83**	**0.7365**

4.6 Comparative performance analysis

The developed prototype was compared with manual method and a commercial model. The technical details of the commercial model are given in Appendix VII. Samples of 100 coconuts fed continuously to the machine and the number of husked coconuts in 30 minutes was recorded. The performances such as capacity, efficiency, percentage of nut breaking and the energy requirement were found out separately for dry and green coconuts. The manual husking was also conducted with a crowbar and the results are given in Table 4.5 and that of commercial model is given in Table 4.6.

Table 4.5 Husking by manual method

Type	Category	Capacity (nuts/h)
Green	Large	111
	Medium	126
	Small	103
Average (Green)		113.33
Dry	Large	105
	Medium	76
	Small	90
Average (Dry)		90.33
Average (Total)		**101.833**

Table 4.6 Performance analysis of husking by commercial model

No load power: 0.6 kW

Type of coconut	Category	Capacity (nuts/h)	Efficiency (%)	Nut breaking (%)	Energy (kW)
Green	Large	318.9	79.8	10	0.730
	Medium	309.3	85.9	8	0.762
	Small	334.3	77.8	9	0.710
Average (Green)		320.83	81.17	9	0.734
Dry	Large	348.2	74.9	17	0.783
	Medium	345.7	79.6	11	0.780
	Small	354.9	74.0	12	0.773
Average (Dry)		349.6	76.17	13.33	0.778
Average (Total)		**335.21**	**78.67**	**11.16**	**0.756**

From the Tables 4.4, 4.5 and 4.6, it is inferred that the average capacity of continuous power operated coconut husking machine is much better and is found out as 355.86 nuts per hour compared to the manual method and by husking by commercial model. The efficiency in husking of continuous power operated coconut husking machine was found out as 82.79 % which is more than the commercial model. The energy requirement is only 0.7365 kW compared to the commercial model for which it was 0.756 kW. The percentage of nut breaking was only 3.81 % compared to the commercial model having 11.16 per cent.

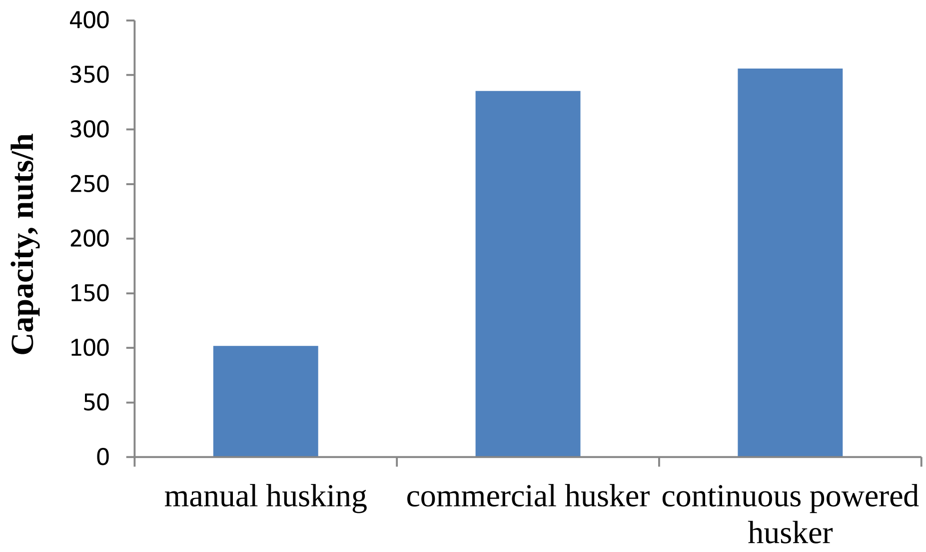


Fig 4.3 Performance comparison with commercial model and conventional method in terms of capacity

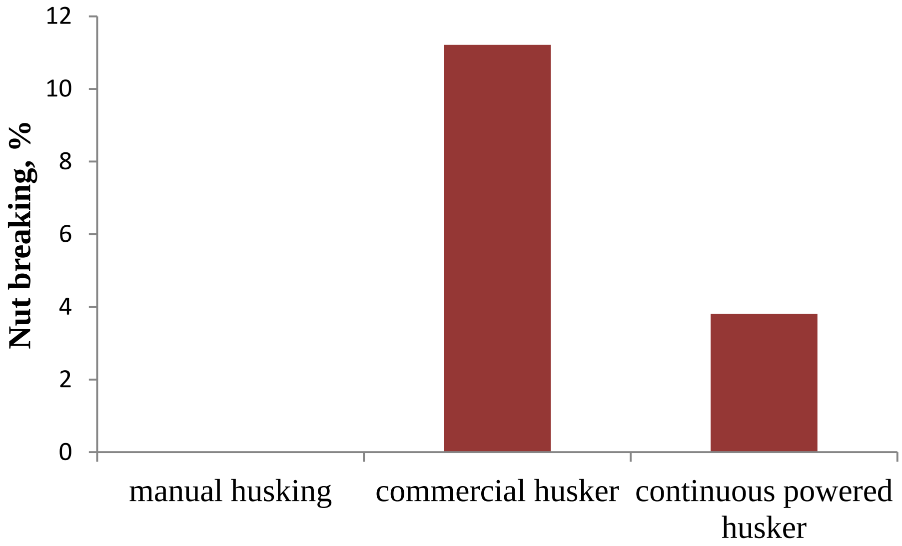


Fig 4.4 Performance comparison with commercial model and conventional method in terms of nut breaking

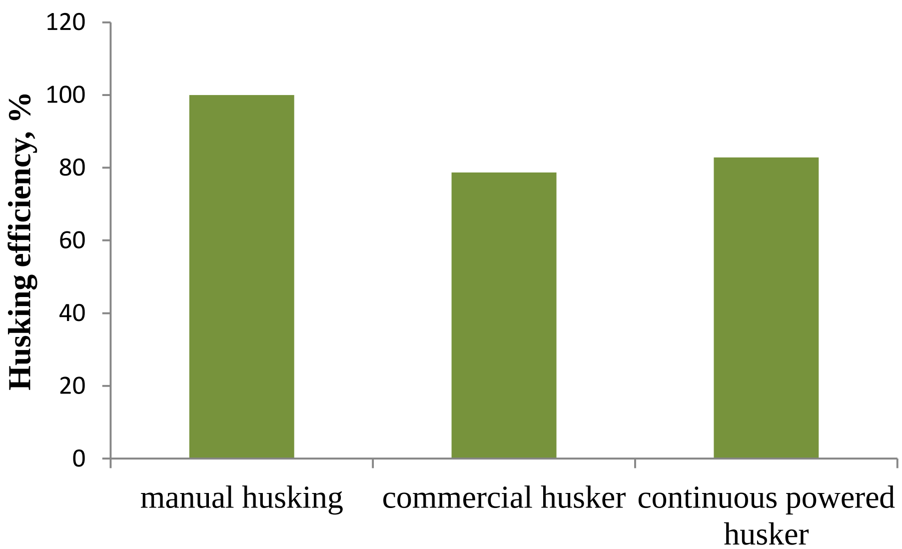


Fig 4.5 Performance comparison with commercial model and conventional method in terms of husking efficiency

4.7 Cost economics and its comparison

The operating cost of the continuous power operated coconut husking machine is Rs. 95.374 per hour and the cost of husking per nut is Rs. 0.267. The operating cost of commercial model is Rs. 98.269 per hour and the cost of husking is Rs. 0.293 per nut. In the case of manual husking using a KAU coconut husking tool (keramithra), the cost of husking is Rs. 0.75 per nut. The calculation of cost was presented in Appendix VI.

The performance of the developed prototype and commercial model is almost on par in terms of cost of husking per nut, capacity and husking efficiency. The major problem of commercially available mechanical huskers is the breaking of nuts during husking. Hence, the coconut farmers are reluctant to accept such machines. It was observed that the nut breaking percentage of the newly developed coconut husker is only 3.81 per cent compared to the commercial models. Hence the developed prototype has a potential for adoption by coconut farmers.

Summary and Conclusions

Chapter 5

SUMMARY AND CONCLUSION

Coconut is one of the major crops in Kerala. The major post-harvest operation performed on a coconut is its husking. The traditional tools used for husking include chopping knife or machete, crowbar (*paara*), etc. These tools make use of the principle of wedge and the principle of lever. The modern tools that are used for small-scale husking are coconut husking machine, mini coconut-husking machine, KAU coconut husking tool (*Keramithra*), etc. Except for the crowbar, no other simple tool is beneficial in large-scale husking. A person skilled in husking using a crowbar husks 2500-3000 coconuts in about 6 hours. However, husking with a crowbar involves lot of drudgery. Copra and coir mills need the nuts and fibre in huge quantity for running the mills as a profitable unit. Thus it requires husking machine suitable for large scale husking of coconut. Hence, a study was conducted to develop a continuous power operated coconut husking machine and to assess and compare its performances with other available powered coconut husking machines.

It was in this consideration that the present study was undertaken with the following objectives.

i. To investigate the relevant physical and mechanical properties of coconut.
ii. Studies on different husking methods and design of major components.
iii. To fabricate a prototype power operated coconut husker.
iv. To standardize the husking mechanism with respect to nut properties.
v. To work out the cost economics of the developed coconut husking machine.

To get the first hand information, experiments were conducted to determine the physical and mechanical properties of coconuts. The physical properties include size and shape, sphericity, weight, shell diameter, moisture content and husk thickness. Based on these data, the design of feeding chute, the shape of the rotating drum and concave and the clearance between the concave and the rotating drum was done. Also the mechanical properties such as husk separating and shell breaking forces of coconut were determined with the help of Universal Testing Machine (UTM). It was found that the husk separating force and the husking time varies with moisture content. The force required for separating the husk from the nut increases gradually as the moisture content increases. This may be due to the high adhering force due to moisture content between the fibres. It was also experienced that a higher bonding force between the fibres of the husk than between husk and the nut. The machine parameters such as length and shape of the blade and speed of rotation of the husking drum were optimized following ANOVA test for the development of the major components of the husking machine.

The results of the ANOVA test revealed that individually when the effects were considered, the best features of the blade were respectively as effect of length L_1 = 20 mm was the best, as regard shape was bevel edged (S_1), angle of 80 degrees (A_2) and speed of rotation of 50 rpm (N_2). In total, if the combinational effects and the individual effects are put together, the combination $L_1S_1A_2N_2$ is found to be the best. Since the blade length of 20 mm was found to be significantly superior, but when the combinational effect was taken, the blade length of 30 mm was found to be more suitable. Further experimentation with blade length ranging from 20 – 30 mm is necessary to determine the exact blade length. As regard as other parameters especially blade shape and speed of rotation, the most suitable one are bevel edged blade and a speed of 50 rpm. Regarding angle, since slanting orientation will do least damage to coconut, 80 degree angle is found to be more acceptable.

Considering these factors a new model of coconut husking machine was developed. It generally consisted of a feeding chute, husking and husk separating units, and a power transmission unit. An inverted conical shape feeding chute was fabricated based on size and shape of the coconut. The opening of the feeding chute can be adjusted by means of tension spring attached to a handle. On pulling the handle, the spring loaded chute wide opens and on releasing, the chute converges and holds the coconut firmly. The firmly holded coconut is then pushed into the clearance between the concave and rotating drum of the husking unit. The husking unit consists of a stationary concave and a rotating drum. The inner side of the concave and the outer side of the rotating drum is provided with numerous blades. The coconut fed at the feeding chute gradually enters into the clearance between the inlet and the drum and forced to execute rolling motion. In the process, the blade penetrates the husk and punctures it along different planes. The shear force exerted upon the coconut by the blades of the rotating drum and the concave cause to rip open the husk along different planes. The full coconuts with punctured and softened husk fall into the husk separating unit which consists of two knurling rollers. There the softened and punctured husk is separated and the nut emerges through the outlet. The prime mover used is a 3 φ squirrel cage induction motor of 2.2 kW. This rotation is bifurcated to rotate the husking unit and to the separating unit. A speed reduction unit with gear ratio of 30:1 is used to reduce the motor speed from 1440 rpm to 48 rpm. The speed of the motor is also bypassed to the knurling rollers by means of chain drive. Here the speed is reduced from 1440 to 160 rpm through chain and sprockets units. All components are fixed on the frame.

The coconut samples were collected from the KCAET instructional farm and used for testing. The husking rate, energy requirement, percentage of nut breaking and capacity of the machine were observed and recorded. The results of performance evaluation indicated that the minimum and maximum time required for complete husking of a green coconut were 6 s and 22 s and that for a dry coconut was 3 s and 15 s respectively. Thus the mean time required for complete husking of green coconut is 11.6 s and that of dry coconut is 9.5 s. It is revealed that the average energy requirement for husking of both dry and green coconuts was the same and found out as 3.97 kW.

The performance comparison of husking with manual and commercial husking machine was also conducted separately. It was found out that the average capacity of continuous power operated coconut husking machine is somewhat similar to that of commercial model. The efficiency of continuous power operated coconut husking machine was found out as 82.79 %. The energy requirement is only 0.7365 kW compared to the commercial model for which it was 0.756 kW. The percentage of nut breaking was only 3.81 % compared to the commercial model having 11.21 per cent.

The operating cost of the continuous power operated coconut husking machine is Rs. 95.374 per hour and the cost of husking per nut is Rs. 0.267. The operating cost of commercial model is Rs. 98.269 per hour and the cost of husking is Rs. 0.293 per nut. In the case of manual husking using a KAU coconut husking tool (keramithra), the cost of husking is Rs. 0.75 per nut. The performance of the developed prototype and commercial model is almost on par in terms of cost of husking per nut, capacity and husking efficiency. The performance of the developed prototype and commercial model is almost on par in terms of cost of husking per nut, capacity and husking efficiency. The major problem of commercially available mechanical huskers is the breaking of nuts during husking. Hence, the coconut farmers are reluctant to accept such machines. It was observed that the nut breaking percentage of the newly developed coconut husker is only 3.81 per cent compared to the commercial models.

Therefore, the study and the results indicated that the husking machine developed under the study has a potential for large-scale adoption of course with further refinement.

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Appendices

APPENDIX I

Physical properties of coconut

a. Size and shape of dry coconut

Sl. No	Length (mm)	Diameter (mm)	Perimeter (mm)	Cross sectional area (mm^2)	Thickness (mm)	Sphericity
1	254.07	188.4	719.93	38074.26	180.7	0.787
2	**220.73**	186.38	656.18	32304.76	196.53	0.898
3	245.28	205.64	805.99	46852.63	202.96	0.772
4	252.99	**206.1**	770.37	44791.17	201.47	0.803
5	236.1	175.98	700.79	35240.95	176.65	0.760
6	234.97	187.17	670.70	34119.18	192.06	0.867
7	248.42	188.94	687.67	35520.92	187.17	0.831
8	234.18	181.72	705.39	39183.15	189.9	0.811
9	233.08	198.42	676.87	34635.27	185.47	0.878
10	238.48	203.88	738.46	44636.23	200.96	0.789
11	242.8	193.66	680.63	35389.23	189.42	0.854
12	256.49	185.43	687.63	35469.87	188.28	0.809
13	241.66	**172.05**	680.42	33180.73	174.38	0.759
14	**263.51**	175.34	706.25	35683.84	178.21	0.766
15	252.48	184.12	761.48	41980.67	186.72	0.738

Size and shape of green coconut

Sl. No	**Length (mm)**	**Diameter (mm)**	**Perimeter (mm)**	**Cross sectional area**	**Thickness (mm)**	**Sphericity**
1	241.13	192.71	759.84	42501.69	189.36	0.755
2	252.63	**174.48**	734.54	38495.74	179.82	0.732
3	254.53	**201.03**	733.89	40100.92	192.13	0.842
4	**230.29**	191.36	669.18	34537.58	185.5	0.875
5	242.68	185.21	761.46	41999.67	188.69	0.742
6	**257.64**	193.56	719.81	38319.18	191.67	0.803
7	248.56	175.54	687.89	34902.81	172.05	0.767
8	255.8	188.36	731.38	39008.87	175.34	0.757
9	253.51	175.36	706.25	35683.83	190.43	0.783
10	239.22	187.48	763.92	42501.69	190.17	0.753
11	249.95	177.28	738.87	39264.45	170.21	0.727
12	246.18	190.31	717.03	38500.79	205.38	0.864
13	230.82	186.89	654.09	32480.08	190.47	0.874
14	244.27	190.79	775.59	43670.36	187.10	0.744
15	241.89	188.58	732.81	39363.07	195.68	0.774

Diameter of coconut at different positions of coconut

Sl no	**Dia at 1/4th position (mm)**	**Dia at 1/2th position (mm)**	**Dia at 3/4th position (mm)**
1	140.4	153.0	129.6
2	147.7	171.9	159.2
3	138.2	157.0	131.2
4	124.2	139.8	122.6
5	118.5	146.5	118.1
6	153.8	177.4	164.9
7	176.1	184.4	158.6
8	151.9	174.5	139.2
9	136.6	158.5	136.6
10	157.0	143.9	121.9
11	122.9	136.6	116.9
12	139.2	147.1	121.3
13	127.3	150.1	122.6
14	133.1	152.8	131.8
15	109.2	142.9	118.4
16	112.4	148.7	123.6
17	137.6	161.4	136.9
18	133.4	151.5	127.7
19	126.8	156.3	141.7
20	183.7	200.3	169.1
Avg	**138.5**	**157.7**	**134.6**

b. Moisture Content of green coconut husk

Sl. No	Initial weight (g)	weight after 24 hrs (g)	weight after 48 hrs (g)	**Moisture Content (wb),%**
1	55.81	46.12	46.12	17.36
2	50.77	45.70	45.68	10.03
3	47.04	43.90	43.86	6.76
4	54.19	51.67	51.62	4.74
5	51.93	46.67	46.60	10.26
6	57.15	53.85	53.81	5.84
7	52.67	46.25	46.25	12.19
8	51.02	47.51	47.45	6.99
9	48.42	44.86	44.82	7.43
10	52.86	46.12	46.12	12.75
11	51.47	46.20	46.20	10.24
12	68.32	55.67	55.67	18.52
13	58.18	52.50	52.48	9.79
14	59.99	53.64	53.64	10.58
15	50.77	47.03	47.02	7.36
Avg	52.18	49.04	48.18	**10.056**

Moisture content of dry coconut husk

Sl. No	Initial weight (g)	weight after 24 hrs (g)	weight after 48 hrs (g)	Moisture Content (wb),%
1	55.72	55.63	55.60	0.22
2	52.89	52.37	52.30	1.12
3	55.12	54.80	54.75	0.67
4	50.77	50.50	50.49	0.55
5	46.96	46.36	46.36	1.09
6	54.26	53.92	53.62	1.18
7	49.93	49.40	49.40	1.06
8	51.38	50.93	50.90	0.93
9	51.88	50.67	50.67	2.33
10	49.97	49.40	49.39	1.16
11	56.77	56.37	56.30	0.83
12	54.91	53.31	53.29	2.95
13	48.27	47.86	47.84	0.89
14	52.62	51.53	51.53	2.07
15	51.42	50.20	50.20	2.37
Avg	52.19	51.55	51.51	**1.29**

b. Husk thickness for green coconuts (*From a longitudinal cross-section of husk*)

	Husk thickness at the location from pedicel end, *cm*				
Sl. No	**At pedicel end**	**At apex**	**At ¼ th distance**	**At ½ th distance**	**At ¾ th distance**
1	7.0	3.0	3.7	3.3	2.1
2	4.0	2.8	3.3	2.5	2.8
3	7.8	3.2	4.1	1.4	0.9
4	8.1	3.1	3.8	2.6	3.7
5	3.9	2.9	2.1	0.8	1.9
6	5.5	2.5	3.6	2.2	1.8
7	3.5	3.1	3.8	2.3	2.6
8	5.0	2.6	3.0	2.5	1.5
9	5.0	2.5	3.0	1.5	2.5
10	6.0	1.9	5.2	3.0	1.7
11	7.6	3.2	2.9	1.8	2.4
12	5.9	3.3	3.1	2.1	1.8
13	4.1	2.9	3.5	0.9	2.1
14	3.5	2.4	2.4	3.2	2.3
15	5.9	3.0	3.7	2.6	1.5
Avg	**5.52**	**2.83**	**3.41**	**2.18**	**2.11**

Husk thickness for dry coconuts (*From a longitudinal cross-section of husk*)

	Husk thickness at the location from pedicel end, *cm*				
Sl. No	**At pedicel end**	**At apex**	**At ¼ th distance**	**At ½ th distance**	**At ¾ th distance**
1	7.5	3.5	2.8	2.0	1.5
2	6.5	4.0	2.5	2.0	1.5
3	5.0	3.5	3.5	2.5	1.5
4	6.0	4.0	3.0	2.5	2.5
5	5.0	3.0	3.0	2.0	1.5
6	6.0	4.0	2.0	2.0	1.5
7	6.0	4.0	3.0	2.0	1.5
8	6.0	3.0	3.0	2.0	1.5
9	6.0	2.5	3.0	3.0	3.0
10	7.5	3.0	3.0	2.5	2.0
11	6.9	3.7	2.9	2.2	1.4
12	6.1	3.1	3.2	2.1	1.6
13	6.8	3.6	3.6	2.4	2.1
14	7.4	2.9	2.8	2.5	1.4
15	7.1	3.5	3.3	2.9	1.5
Avg	**6.39**	**3.42**	**2.97**	**2..31**	**1.73**

c. Weight of Coconut

Weight of dry coconut (kg)	Weight of green coconut (kg)
0.80	1.10
0.88	1.10
0.83	1.20
1.23	1.15
0.90	0.95
0.80	1.30
0.94	1.20
0.84	1.55
1.05	0.75
1.00	1.80
1.15	1.54
0.92	1.89
0.96	1.78
1.11	1.54
1.07	1.02
1.01	1.10
1.09	1.23
1.08	0.86
1.02	1.54
0.70	1.12

APPENDIX II

Mechanical properties of coconut

a. Husk separating force for green and dry coconut (Hf)

Sl. No.	Hf_d (kg/cm^2)	Moisture content of green coconut, wb, (%)	Hf_g (kg/cm^2)	Moisture content of dry coconut, wb, (%)
1	0.067	1.12	0.513	0.26
2	0.072	2.11	0.675	0.53
3	0.535	3.98	0.824	0.83
4	0.657	4.32	1.002	0.93
5	0.87	4.84	1.015	0.98
6	0.74	4.9	0.911	0.98
7	0.73	5.12	0.759	1.02
8	0.904	5.2	0.652	1.06
9	1.0487	5.89	0.609	1.06
10	1.0069	6.17	0.91	1.16
11	1.072	6.38	0.714	1.16
12	0.905	6.43	0.835	1.18
13	0.913	6.76	0.977	1.31
14	0.85	6.78	1.522	1.94
15	0.894	6.87	1.496	2.33
16	0.076	4.38	1.584	2.87
17	0.172	2.91	1.622	2.95
18	0.735	2.98	1.67	2.98
19	0.657	4.32	1.721	2.98
20	0.89	4.47	1.757	3.98
Avg	**0.69**	**4.79**	**1.08**	**1.62**

b. Shell breaking force and energy required in shell breaking

Sl. No.	Diameter (mm)	Shell breaking force (kgf)	Thickness (mm)
1	97.59	150	3.0
2	92.07	210	2.5
3	92.13	320	3.1
4	96.46	430	3.0
5	93.54	**920**	2.8
6	97.89	530	3.0
7	99.14	590	3.1
8	95.73	420	3.1
9	95.98	390	3.2
10	95.16	400	2.8
11	99.62	440	2.9
12	97.96	320	2.9
13	94.24	400	3.0
14	98.63	530	3.2
15	94.87	410	3.2
16	96.78	430	3.1
17	95.34	900	3.0
18	96.12	450	3.0
19	98.07	380	3.1
20	97.01	420	3.0

APPENDIX III

Piercing strength of blades of different shapes

Shape of blade	No. of replications	Piercing force at different positions, kgf		
		At 1/4th distance from pedicel end	At 1/2th distance from pedicel end	At 3/4th distance from pedicel end
Round edge	1	30	15	10
	2	30	35	30
	3	25	30	45
Bevel edge	1	25	20	15
	2	20	20	15
	3	35	50	30
Pointed edge	1	30	15	25
	2	15	10	15
	3	30	40	55

Piercing distance of husking blade on coconut

Sl. No	Piercing distance		
	at pedicel end	at 1/2th from pedicel end	at 3/4 th from pedicel end
1	3.5	1.6	1.1
2	3	1	0.8
3	2.9	1.8	1.2
4	2.1	1.7	1.1
5	2.9	1.5	1.1
6	3.8	2.9	1.4
7	3.7	2.3	1.5
8	3.2	1.3	0.9
9	4.1	2.6	1.2
10	2.3	2.1	1.1
Avg	**3.15**	**1.88**	**1.14**

APPENDIX IV

Optimization of machine parameters

Observations:-

Sl. No.	Treatment	Length of the blade	Shape of the blade	Blade angle	Speed of rotation	Husking time	Average husking time	Husking efficiency
		(mm)		(deg)	(rpm)	(s/nut)	(s/nut)	(%)
1	$L_1S_1A_1N_1$	20	Bevel edge	90	100	22.6	22.33	33.3
						21.4		
						23		
2	$L_1S_2A_1N_1$	20	Round edge	90	100	26.4	26.57	33.3
						27.2		
						26.1		
3	$L_1S_3A_1N_1$	20	Pointed edge	90	100	30.6	28.43	33.3
						28.4		
						26.3		
4	$L_1S_1A_2N_1$	20	Bevel edge	80	100	23.2	22.27	33.3
						20.9		
						22.7		
5	$L_1S_1A_3N_1$	20	Bevel edge	70	100	17.3	17.47	33.3
						15.4		
						19.7		
6	$L_1S_2A_3N_1$	20	Round edge	70	100	20.4	20.53	33.3
						22.8		
						18.4		
7	$L_1S_2A_2N_1$	20	Round edge	80	100	27.8	27.3	33.3
						26.3		
						27.8		
8	$L_1S_3A_3N_1$	20	Pointed edge	70	100	26.9	26.77	33.3
						28.1		
						25.3		
9	$L_1S_3A_2N_1$	20	Pointed edge	80	100	29.1	28.53	33.3
						28.9		
						27.6		
10	$L_1S_1A_1N_2$	20	Bevel edge	90	50	9.2	9.53	66.6
						9.4		
						10		

11	$L_1S_2A_3N_2$	20	Round edge	70	50	11.8 10.8 12.3	11.6	66.6
12	$L_1S_3A_1N_2$	20	Pointed edge	90	50	12.8 13.4 17.4	14.53	66.6
13	$L_1S_1A_2N_2$	20	Bevel edge	80	50	9.4 8.2 9.3	8.96	66.6
14	$L_1S_1A_3N_2$	20	Bevel edge	70	50	17.2 18.5 19.3	18.33	66.6
15	$L_1S_3A_3N_2$	20	Pointed edge	70	50	22.6 20.8 24.6	22.67	66.6
16	$L_1S_2A_2N_2$	20	Round edge	80	50	12.4 14.2 10.8	12.46	66.6
17	$L_1S_2A1N_2$	20	Pointed edge	70	50	17.8 18.2 20.3	18.76	66.6
18	$L_1S_3A_2N_2$	20	Pointed edge	80	50	18.1 19.8 16.4	18.1	66.6
19	$L_2S_1A_1N_1$	30	Bevel edge	90	100	20.6 22.7 25.4	22.9	33.3
20	$L_2S_2A_1N_1$	30	Round edge	90	100	24.6 26.2 27.9	26.23	33.3
21	$L_2S_3A_1N_1$	30	Pointed edge	90	100	29 27.6 32.8	29.8	33.3
22	$L_2S_1A_2N_1$	30	Bevel edge	80	100	23.4 21.8 24.3	23.17	33.3
23	$L_2S_1A_3N_1$	30	Bevel edge	70	100	22.9 19.8 27.4	23.37	33.3
24	$L_2S_2A_3N_1$	30	Round	70	100	27.8	27.17	33.3

			edge			25.3 28.4		
25	$L_2S_2A_2N_1$	30	Round edge	80	100	25.4 23.2 27.9	25.5	33.3
26	$L_2S_3A_3N_1$	30	Pointed edge	70	100	28.1 27.9 26.5	27.5	33.3
27	$L_2S_3A_2N_1$	30	Pointed edge	80	100	23.9 21.6 26.5	24	33.3
28	$L_2S_1A_1N_2$	30	Bevel edge	90	50	7.2 7.3 7.2	7.23	100
29	$L_2S_2A_1N_2$	30	Round edge	90	50	15.2 14.3 15.2	14.9	100
30	$L_2S_3A_1N_2$	30	Pointed edge	90	50	24.2 28.4 25.1	25.9	66.6
31	$L_2S_1A_2N_2$	30	Bevel edge	80	50	7.6 8.4 7.2	7.73	100
32	$L_2S_1A_3N_2$	30	Bevel edge	70	50	18.5 16.8 20.4	18.56	66.6
33	$L_2S_3A_3N_2$	30	Pointed edge	70	50	21.1 24.1 19.9	21.7	33.3
34	$L_2S_2A_2N_2$	30	Round edge	80	50	14.3 12.1 17.3	14.56	66.6
35	$L_2S_2A_3N_2$	30	Round edge	70	50	20.2 18.9 23.6	20.9	33.3
36	$L_2S_3A_2N_2$	30	Pointed edge	80	50	17.6 18.1 20.4	18.7	66.6
37	$L_3S_1A_1N_1$	40	Bevel edge	90	100	27.2 28.2	27.03	33.3

						25.7		
38	$L_3S_2A_1N_1$	40	Round edge	90	100	23.9	24.63	33.3
						26.3		
						23.7		
39	$L_3S_3A_1N_1$	40	Pointed edge	90	100	29.4	28.77	33.3
						26.8		
						30.1		
40	$L_3S_1A_2N_1$	40	Bevel edge	80	100	29.7	29.5	33.3
						31.4		
						27.4		
41	$L_3S_1A_3N_1$	40	Bevel edge	70	100	34.2	31.67	33.3
						29.2		
						31.6		
42	$L_3S_2A_3N_1$	40	Round edge	70	100	26.5	26.87	33.3
						28.2		
						25.9		
43	$L_3S_2A_2N_1$	40	Round edge	80	100	28.1	27.47	33.3
						27.4		
						26.9		
44	$L_3S_3A_3N_1$	40	Pointed edge	70	100	29.9	29.33	33.3
						30.7		
						27.4		
45	$L_3S_3A_2N_1$	40	Pointed edge	80	100	26.4	26.7	33.3
						26.3		
						27.4		
46	$L_3S_1A_1N_2$	40	Bevel edge	90	50	12.6	12.93	100
						11.9		
						14.3		
47	$L_3S_2A_1N_2$	40	Round edge	90	50	18.7	17.77	66.6
						17.3		
						17.3		
48	$L_3S_3A_1N_2$	40	Pointed edge	90	50	15.2	14.83	66.6
						14.3		
						15		
49	$L_3S_1A_2N_2$	40	Bevel edge	80	50	11	11	100
						12.8		
						9.2		
50	$L_3S_1A_3N_2$	40	Bevel edge	70	50	23.4	23.6	66.6
						22.8		
						24.6		

51	$L_3S_3A_3N_2$	40	Pointed edge	70	50	21.9 19.6 23	21.5	66.6
52	$L_3S_2A_3N_2$	40	Round edge	70	50	12.7 11.9 10.8	11.8	66.6
53	$L_3S_2A_2N_2$	40	Round edge	80	50	14.5 14.3 13.9	14.23	66.6
54	$L_3S_3A_2N_2$	40	Pointed edge	80	50	16.2 15.6 18.2	16.67	66.6

$L_{1,}$ $L_{2,}$ L_3 = 20, 30 and 40 mm

$S_{1,}$ $S_{2,}$ S_3 = Bevel, Round and Pointed edge

$A_{1,}$ $A_{2,}$ A_3 = 90, 80 and 70 deg

$N_{1,}$ N_2 = 100 and 50 rpm

Results of statistical analysis conducted for optimizing the tool parameters

Function: FACTOR

Experiment Model Number 6: Four Factor Completely Randomized Design

Data case no. 1 to 162.

Factorial ANOVA for the factors:

Replication (Var 5:) with values from 1 to 3

Factor A (Var 1:) with values from 1 to 3

Factor B (Var 2:) with values from 1 to 3

Factor C (Var 3:) with values from 1 to 3

Factor D (Var 4:) with values from 1 to 2

Variable 6:

Grand Mean = 20.951   Grand Sum = 3394.000   Total Count = 162

Coefficient of Variation: 7.94%

s_ for means group 2:   0.2265   Number of Observations: 54

y

s_ for means group 4:   0.2265   Number of Observations: 54

y

s_ for means group 6:   0.3923   Number of Observations: 18

y

s_ for means group 8:   0.2265   Number of Observations: 54

y

s_ for means group 10:   0.3923   Number of Observations: 18

y

s_ for means group 12:   0.3923   Number of Observations: 18

y

s_ for means group 14:   0.6794   Number of Observations: 6

y

s_ for means group 16:   0.1849   Number of Observations: 81

y

s_ for means group 18:   0.3203   Number of Observations: 27

y

s_ for means group 20:   0.3203   Number of Observations: 27

y

s_ for means group 22:   0.5548   Number of Observations: 9

y

s_ for means group 24:   0.3203   Number of Observations: 27

y

s_ for means group 26: 0.5548 Number of Observations: 9

y

s_ for means group 28: 0.5548 Number of Observations: 9

y

s_ for means group 30: 0.9609 Number of Observations: 3

y

Analysis of variance for machine parameters

K Value	Source	DF	SS	MS	F value	CD	Prob
2	Length of the blade (A)	2	142.62	71.31	25.7454	0.6278	**
4	Shape of the blade (B)	2	643.589	321.795	116.1791	0.6278	**
6	A x B	4	329.769	82.442	29.7646	1.087	**
8	Angle of the blade (C)	2	169.043	84.522	30.5152	0.6278	**
10	A x C	4	116.767	29.192	10.5393	1.087	**
12	B x C	4	242.653	60.663	21.9015	1.087	**
14	A x B x C	8	258.733	32.342	11.6765	1.88	**
16	Speed of rotation (D)	1	4118.285	4118.285	1486.845	0.512	**
18	A x D	2	73.986	36.993	13.3558	0.8878	**
20	B x D	2	63.828	31.914	11.5221	0.8878	**
22	A x B x D	4	78.5	19.625	7.0853	1.537	**
24	C x D	2	248.396	124.198	44.8399	0.8878	**
26	A x C x D	4	53.495	13.374	4.8284	1.5278	**
28	B x C x D	4	211.17	52.792	19.0599	1.5378	**
30	A x B x C x D	9	106.648	13.331	4.813	2.6634	**
-31	Error	108	299.14	2.77			
	Total	161	7156.625				

Coefficient of variation: 7.94 %, DF – Degrees of freedom, SS – Sum of Squares, MS – Mean squares, CD – Critical difference value, ** Significant at 1 % level

APPENDIX V

Design of main components of continuous power operated coconut husking machine

a. Blade

Maximum load acting on the blade during husking is taken as 10 kN to 15 kN.

Therefore, the maximum load,

$$P = 1.650 \times S \times l \times \tau\, max$$

Where,

P = maximum load = 15000 N

S = size of weld or thickness of plate, mm = 5 mm

l = length of weld or width of blade, mm = l

$\tau\, max$ = maximum permissible shear stress, Mpa = 80 Mpa (for fillet weld)

So, 15000 = 1.650 x 5 x l x 80

∴ $l = 22.7 \approx 23$ mm

i.e the width of the blade = 23 mm

The length is taken as 24 – 30 mm as it provide better strength. ∴ ∵

Maximum permissible shear stress intensity in the weld material,

$$\tau\, max = \frac{4.242\, T}{Sl^2}$$

i.e, $80 = \frac{4.242 \times T}{5 \times 23^2}$

T = 49.882 kN-m ≈ 50 kN-m

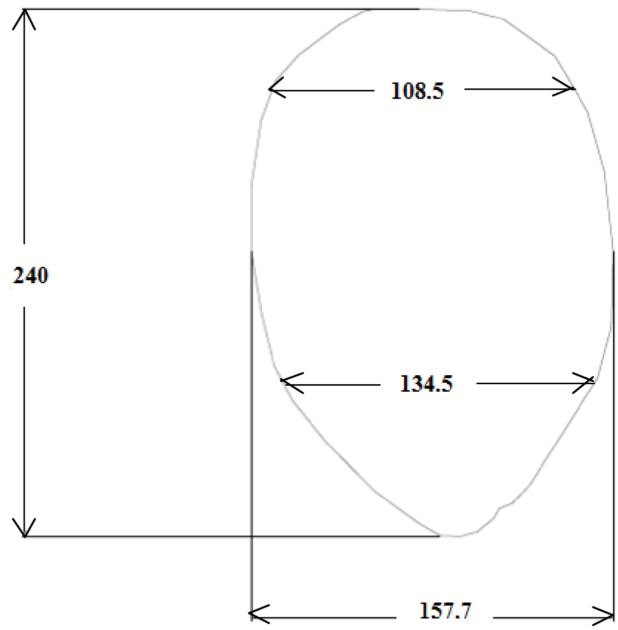
As welding strength is considered, the width of blade is important.

Dimensions of the blade:-

- Thickness of blade – 5 mm
- Width of the blade – 23 mm
- Length of blade – 24-30 mm
- Welding thickness – 5 mm
- Material of construction – Mild steel

b. Husking unit

Husking unit consist of two parts. The rotating drum and a concave envelop. The rotating drum is a single unit with five rims whose diameter varies depending on the shape of coconut.



All dimensions are in mm

Fig. 7.1 Shape of coconut showing average diameter at various positions and average length

The average length of coconut is approximately taken as 240 mm and so the length of the husking drum is 240 mm. For effective husking, the length of travel of coconut inside the husking unit should be at least 2m (Muhammad, 2002). So the maximum diameter of the drum is taken as 620mm.

i.e ,

$$2 \text{ m} = \pi \times D$$

Where D – diameter

Therefore, $D = 2/\pi = 0.6366 \approx 620$ mm

From Fig. 7.1, it was found that the average length of coconut was 240 mm and the average diameter at various positions viz. at 1/4th , 1/2th and 3/4th position was 108.5 mm, 157.7 mm and 134.5 mm respectively.

The clearance between the rims = 240 ÷ 4 = 60 mm

The mean diameter difference = 157.7 - 108.5 = 49.2 ≈ 50 mm

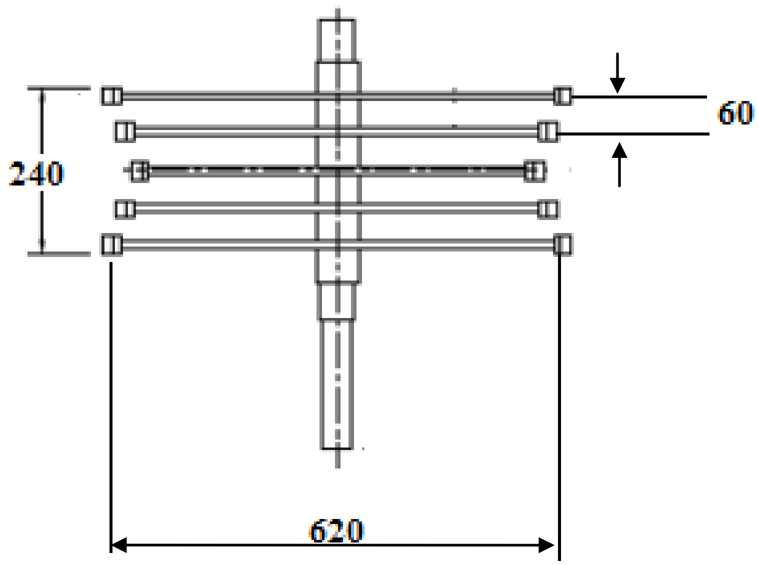
So the diameter of second rim = 620 – 50 = 570 mm

The mean diameter difference between the 1/2th and 3/4th positions = 157.7 – 134.5

= 23.2 mm

So the diameter of the third rim = 570 – 20 = 530 mm

The details and the dimensions of the rim are given in Fig. 7.2.



All dimensions are in mm

Fig 7.2 Design of husking drum

- Diameter of the first rim – 620 mm
- Diameter of the second rim – 570 mm
- Diameter of the third rim – 530 mm
- Diameter of the fourth rim – 570 mm
- Diameter of the fifth rim – 620 mm

Similarly the concave is also designed depending on the shape of coconut. The number of blades is assumed as 32 – 35 with 60 mm spacing depending on the diameter on each rim.

c. Main shaft

The prime mover selected was a 3 phase induction motor of 2.2 kW and 1440 rpm. So the power transmitted in Watt by the shaft is,

$$P = \frac{2\pi NT}{60}$$

$$2.2 \times 10^3 = \frac{2\pi \times N \times T}{60}$$

T = Force x radial distance

For the force, we have the maximum husk separating force of 0.702 kg cm^{-2} and radial distance of 620 mm (maximum diameter of the husking drum)

$\therefore$, T = 0.702 x 9.8 x 62

= 426.5 ≈ 430 N-m

So, As $P = \frac{2\pi NT}{60}$

$$2.2 \times 10^3 = \frac{2\pi \times N \times 430}{60}$$

$\therefore$, N = 48.8 rpm ≈ 50 rpm

Twisting moment, $T = \frac{\pi}{16} \times \tau \times d^3$

where,

τ – torsional shear stress

d – diameter of shaft

According to American Society of Mechanical Engineers (ASME) code for the design of transmission shafts, the maximum permissible working stress in tension or compression may be taken as 112 Mpa for shaft without allowance for keyways and 84 Mpa for shaft with allowance for keyways. Also, σ_t = 0.6 $\sigma_{elastic}$ or 0.36 $\sigma_{ultimate}$ whichever is maximum, permissible tensile stress, σ_t = 56 Mpa (without keyway) and 42 Mpa (with keyway); Permissible shear stress, τ = 0.3 $\tau_{elastic}$ or 0.18 $\tau_{ultimate}$ whichever is less.

σ_t = 0.6 $\sigma_{elastic}$

42 = 0.6 $\sigma_{elastic}$

∴ $\sigma_{elastic} = \frac{42}{0.6}$ = 70 Mpa

σ_t = 0.36 $\sigma_{ultimate}$

$\sigma_{ultimate}$ = 116.67 Mpa

So, Permissible shear stress, τ = 21 Mpa

∴ T = $\frac{\pi}{16} \times \tau \times d^3$

430 × 10^3 = $\frac{\pi}{16} \times 21 \times d^3$

d = 47.07 mm ≈ 50 mm

So, the diameter of the shaft = 50 mm

Factor of safety = $\frac{\sigma_{ultimate}}{\sigma_t}$ = 116.67 ÷ 42 = 2.77 ≈ 3

Dimension of shaft are:-

- Diameter of the shaft, d – 50 mm
- Speed of rotation of shaft, N – 50 rpm
- Length of the shaft is taken as 620 mm
- Material of construction – mild steel

d. Power transmission unit

The prime mover selected was a 3 phase induction motor of 2.2 kW and 1440 rpm. The husking efficiency was found to be more, when the rotating drum operates at a speed of 50 rpm. In order to obtain 48 rpm at the shaft, a speed reduction box is used. The gear reduction unit derives its power from the electric motor through a gear ratio of 30 : 1. The speed of the machine is reduced from 1440 rpm to 48 rpm by speed reduction unit and thus the desired rpm is obtained at the main shaft.

In the case of power transmission to knurling rollers, the final power required at the shaft of knurling rollers should be 160 rpm for effective removal of husk. So the 1440 rpm of the motor should be reduced to 160 rpm by using chain and sprockets.

Rated power = 2.2 kW with 1440 rpm

i.e N_1 = 1440 rpm

Velocity ratio = $\frac{N_1}{N_2}$

Also, $\frac{N_1}{N_2} = \frac{T_2}{T_1}$ [$\because$ T_2 = No. of teeth on larger sprocket = 68]

Where, N_1 = speed of rotation of motor, rpm = 1440 rpm

N_2 = speed of rotation of sprocket, rpm = N_2

T_1 = no. of teeth on smaller sprocket = 13

T_2 = no. of teeth on larger sprocket = 68

$\therefore$ $68 = \frac{13 \times 1440}{N_2}$

N_2 = 275 rpm

Velocity ratio = $\frac{1440}{275}$ = 5.23

We know that,

Design power = rated power × service factor (K_s)

Service factor, $K_s = K_1 \times K_2 \times K_3$

Where,

K_1 – load factor for variable load with heavy shock, 1.5

K_2 – lubrication factor for deep lubrication, 1.0

K_3 – rating factor for 16 hours/day, 1.25

$\therefore$ K_s = 1.875

So, design power = 2.2 × 1.875 = 4.125 kW

Corresponding to the pinion speed of 1440 rpm, the power transmitted for chain no. 6 is 2.73 kW per strand. ∴ a chain no. 6 with two strands can be used to transmit the required power. From the table, we find that

1. Pitch = 9.525 mm
2. Roller diameter, d = 6.35 mm
3. Width between inner plates, b = 5.72 mm
4. Breaking load, W_B = 16.9 kN

We know that the pitch circle diameter (PCD) of small sprocket or pinion,

$d_1 = P \text{ cosec } (\frac{180}{T_1})$

$= 9.525 \times \text{cosec } (\frac{180}{13})$

$= 39.801$ mm

PCD of large sprocket, $d_2 = P \text{ cosec } (\frac{180}{T_2})$

$d_2 = 9.525 \times \text{cosec } (\frac{180}{68})$

$= 206.24$ mm

Pitch line velocity of the smaller sprocket, $V_1 = \frac{\pi \times d_1 \times N_1}{60}$

$$V_1 = \frac{\pi \times 39.801 \times 10^{-3} \times 1440}{60} = 3.00 \text{ m/s}$$

Therefore, load on the chain, $W = \frac{rated\ power}{pitch\ line\ velocity} = 2.2 / 3.00 = 0.733$ kN

$= 733$ N

Factor of safety $= \frac{W_B}{W} = 16.9 \times 10^3 / 733 = 23.056$

This value should be more than 15 as per the table. So the design is safe. The minimum centre distance between the smaller and larger sprockets should be 30 – 50 times the pitch. Let us take it as 30 P.

So, the centre to centre distance = 30 x 9.525 = 285.75 mm

In order to accommodate the initial sag in the chain, the value of centre distance is reduced by 2 – 5 mm.

∴ Correct centre distance, x = 285.75 – 4

= 281.75 mm

We know that, the number of chain links,

$$K = \frac{T1 + T2}{2} + \frac{2\,x}{P} + \left[\frac{T2 - T1}{2\pi}\right]^2 \frac{P}{x}$$

$$= \frac{13 + 68}{2} + \frac{2 \times 281.75}{9.525} + \left[\frac{68 - 13}{2\pi}\right]^2 \frac{9.525}{281.75}$$

$$= 40.5 + 59.16 + 2.59$$

$$= 102.25 \approx 103 \text{ links}$$

Length of the chain, L = K.P

= 103 x 9.525

= 981.075 mm ≈ 1 m

The speed of rotation of about 275 rpm should be reduced to 160 rpm by means of sprockets of teeth, T_1 = 11 teeth and T_2 = 19 teeth.

N_1 = 275 rpm

$$\therefore N_2 = \frac{11 \times 275}{19}$$

$$= 159.2 \text{ rpm} \approx 160 \text{ rpm}$$

So, the design is safe and the sprocket of the above said teeth can be used and thereby the speed of the motor is reduced from 1440 rpm to 160 rpm.

APPENDIX VI

Cost economics

Continuous power operated coconut husking machine

A. Basic information

i. Fabrication cost of the machine including the cost of material, C

- 3 φ squirrel cage induction motor and Speed reduction unit, 30:1 – Rs. 22000/-
- Sprocket (6 No.s) – Rs. 2000/-
- Flange coupling (3 No.s) – Rs. 1150/-
- Bearing (10 No.s) – Rs. 1000/-
- Spring (15 No.s) – Rs. 300/-
- Switch – Rs.200/-
- 3m wire – Rs. 200/-
- Cost of material including labour charge – Rs. 8500/-

Therefore, C = 22000 + 2000 + 1150 + 1000 + 300 + 200 + 200 + 8500

= Rs. 35350

ii. Working hours per year, H = 800 h

iii. Average life in years, L = 10 years

iv. Salvage value @ 10 % of cost of machine, S = Rs. 3535/-

v. Interest on investment, i = 12 % per year (Short term interest)

vi. Number of labourers required = 1

vii. Labour wages per day of 6 hours = Rs. 500

viii. Repair and maintenance cost = 5 % of the machine cost

ix. Insurance and shelter = 1.5 % of average cost of machine per year

B. Cost calculation

1. Fixed cost per year

(i) Depreciation cost, A $= \frac{C-S}{L}$

$= \frac{35350-3535}{10}$

= Rs. 3181.5

(ii) Interest on investment, B $= \frac{C+S}{2} \text{ x } \frac{i}{100}$

$= \frac{35350+3535}{2} \text{ x } \frac{12}{100}$

= Rs. 2333.1

(iii) Insurance, shelter etc., C $= \frac{35350+3535}{2} \times \frac{1.5}{100}$

= Rs. 291.6375

Total fixed cost per year = A + B + C

= 3181.5 + 2333.1 + 291.6375

= Rs. 5806.24

Total fixed cost per hour = 5806.24 ÷ 800

= Rs. 7.26

2. Variable cost per hour

(i) Labour cost, D = 500 ÷ 6

= Rs. 83.33 = Rs. 84

(ii) Repair and maintenance, E $= 35350 \times \frac{5}{800\times100}$

= Rs. 2.209

(iii) Energy cost @ Rs. 2.5 per kWh, F = 0.762 × 2.5 = Rs. 1.905/-

Total variable cost per hour = D + E + F

= 84 + 2.209 + 1.905

= Rs. 88.114

Therefore, total operating cost of machine = Fixed cost + Variable cost

= 7.26 + 88.114

= Rs. 95.374

Number of nuts husked per hour = 356

Cost of husking per nut = 95.374 ÷ 356

= Rs. 0.267

Mechanical husker

1. Fixed cost
   a. Cost of mechanical dehusking machine = Rs. 51,000/-
      Expected life = 10 years
      Expected operational hours/year = 800 hours
      Salvage value @ 10 % of cost of machine = Rs. 5,100/-
   b. Depreciation (A) $= \frac{51000-5100}{10} =$ Rs. 4590
   c. Interest capital (B) $= \frac{51000+5100}{2} \times \frac{12}{100}$

= Rs. 3366

d. Insurance, shelter etc. (C) $= \frac{51000+5100}{2} \times \frac{1.5}{100}$

= Rs. 420.75

Fixed cost = A + B + C

= 4590 + 3366 + 420.75

= Rs. 8376.75

Fixed cost per hour = 8376.75÷ 800

= Rs. 10.47

2. Variable cost/h

e. Energy cost @ Rs. 2 kWh = 0.762 × 2 = Rs. 1.524/-

f. Labour charges @ Rs. 500/day = Rs. 85/h

g. Maintenance cost @ 2 % per year $= \frac{51000 \times 2 \times 1}{100 \times 800}$ = Rs. 1.275/h

Variable cost per hour = 1.524 + 85 + 1.275

= Rs. 87.799

Total cost of operation/h = 87.799 + 10.47

= Rs. 98.269/-

No. of nuts husked per hour = 335

Cost of husking per nut $= \frac{98.269}{335}$ = 0.293/-

Manual husking

No. of labours = 1

Working hours per day = 6

Labour charges per day	= Rs. 500/-
Labour charges per hour	= Rs. 84/-
No. of nuts husked per hour	= 110
Cost of husking per nut	= Rs. 0.75

APPENDIX VII

Specifications of the commercial model coconut husking machine

Height	165 cm
Length	74 cm
Breadth	70 cm
Weight	175 kg
Power	1.5 hp, single phase, 1440 rpm, electric motor with integral reduction gear box

Manufacturer: M/s. Process Ekuipment Engineers, Coimbatore.

DEVELOPMENT AND TESTING OF A CONTINUOUS POWER OPERATED COCONUT HUSKER

by

ANU, S. CHANDRAN
(2010-18-103)

ABSTRACT OF THE THESIS

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ABSTRACT

A continuous power operated coconut husking machine for large scale husking of coconuts was developed, tested and its performance evaluated. The major parts are feeding chute, a husking unit, a husk separating unit and power transmission unit. The coconut fed at the feeding chute and in the clearance between the inlet and the drum is slightly compressed and forced to execute rolling or revolutions. In the process, the blade penetrates the husk and punctures it along different planes. The shear force exerted upon the coconut by the blades of the rotating drum and the concave cause to rip open the husk along different planes. The full coconuts with punctured and softened husk fall into the husk separating unit which consists of two knurling rollers. There the softened and punctured husk is separated and the nut emerges at the outlet. The prime mover used is a 3 φ squirrel cage induction motor of 2.2 kW. This rotation is bifurcated to rotate the husking unit and to the separating unit. A speed reduction unit with gear ratio of 30:1 is used to reduce the motor speed from 1440 rpm to 48 rpm. The speed of the motor is also bypassed to the knurling rollers by means of chain drive, by which the speed is reduced from 1440 to 160 rpm through chain and sprockets units. All components are fixed on the frame. The studies show that the minimum and maximum time required for complete husking of a green coconut were 6 s and 22 s and that for a dry coconut was 3 s and 15 s respectively. Thus the mean time required for complete husking of green coconut is 11.6 s and that of dry coconut is 9.5 s. The average capacity of continuous power operated coconut husking machine is much better and found out as 356 nuts per hour compared to the manual method and by husking by commercial model. Also the efficiency, the percentage of nut breaking and the average energy requirement was 82.79 %, 3.83 % and 0.7365 W respectively. The total operating cost of continuous power operated coconut husking machine is Rs. 95.374 per hour and the cost of husking per nut is about Rs. 0.267. Considering its performances, the mechanism developed in this study is promising.