DESIGN AND DEVELOPMENT OF CONTINUOUS TYPE COCONUT SPLITTER

By

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(2019 - 18 - 014)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR - 679 573

KERALA, INDIA

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND

TECHNOLOGY, TAVANUR - 679 573

KERALA, INDIA

2022

DECLARATION

I, hereby declare that this thesis entitled **"DESIGN AND DEVELOPMNT OF CONTINUOUS TYPE COCOUNT SPLITTER"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title of any other University or Society.

Alankar

Place: Tavanur

Date: 28.02.2022

PACHANGANE ALANKAR ASHOK

(2019-18-014)

CERTIFICATE

Certified that this thesis entitled **"DESIGN AND DEVELOPMNT OF CONTINUOUS TYPE COCOUNT SPLITTER"** is a record of research work done independently by **PACHANGANE ALANKAR ASHOK (2019-18-014)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to him.

Place: Ambalavayal

Date: 28.02.2022

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Kelappaji College of Agrl. Engg. & Technology, Tavanur

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We, the undersigned members of the advisory committee of **PACHANGANE ALANKAR ASHOK (2019-18-014),** a candidate for the degree of **Master of Technology in Agricultural Engineering** with major in **Farm Power Machinery and Engineering,** agree that the thesis entitled **"DESIGN AND DEVELOPMENT OF CONTINUOUS TYPE COCONUT SPLITTER"** may be submitted by **PACHANGANE ALANKAR ASHOK,** in partial fulfilment of the requirement for the degree.

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DEDICATION

This thesis is dedicated to my God, Parents and Guide, who sacrificed much to bring me up to this level and to my lovely sisters, friends and their families for the devotion they made to make my life successful.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

SYMBOLS AND ABBREVIATIONS

Symbols		Abbreviations
<	:	Less than
>	:	Greater than
%	:	Per cent
±	:	Plus or minus
×	:	Multiplication
÷	:	Division
≤	:	Less than or equal to
≥	:	Greater than or equal to
°	:	Degree
^{0}C	:	Degree Celsius
AICRP		All India Coordinated Project
cm	:	Centimeter
cm^2	:	Square centimeter
cm^3	:	Cubic centimeter
et al.	:	and others
etc.	:	et cetera
F	;	Force
Fig.	:	Figure
g	:	Gram

g cm^{-3}	:	Gram per cubic centimeter
GI	:	Galvanized iron
H	:	Height
h	:	Hour
ha	:	Hectare
ha^{-1}	;	Per hectare
hp	:	Horse power
IS	:	Indian standards
J	;	Joule
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	Kilogram
kg cm	:	Kilogram centimeter
kg h^{-1}	:	Kilogram per hour
kg m	:	Kilogram meter
kg f	:	Kilogram force
N	:	Newton
kN m^2	:	Kilo newton per meter square
kw	:	Kilo watt
l	:	Length
l min^{-1}	:	Litre per minute

m	:	Meter
m min^{-1}	:	Meter per minute
MPa	:	Mega Pascal
m s^{-1}	:	meters per second
m^2	:	Square meter
m^3	:	Cubic meter
mm	:	Millimeter
mm^2	:	Square millimeter
MS	:	Mild steel
N	:	Newton
N cm^{-2}	:	Newton per square centimeter
N m^{-1}	:	Newton per meter
N m	:	Newton meter
Nos	;	Numbers
RARS	:	Regional Agricultural Research Station
rpm	:	Revolutions per minute
Sl. No.	:	Serial Number
T	:	Tons
viz.	:	Namely
V	;	Volt
W	:	Width
α	:	Alpha

θ	:	Theta
μ	:	mue
&	;	and
π	:	Pi
ρ	:	Rho
η	:	Efficiency
^{0}	;	degrees

CHAPTER - I

INTRODUCTION

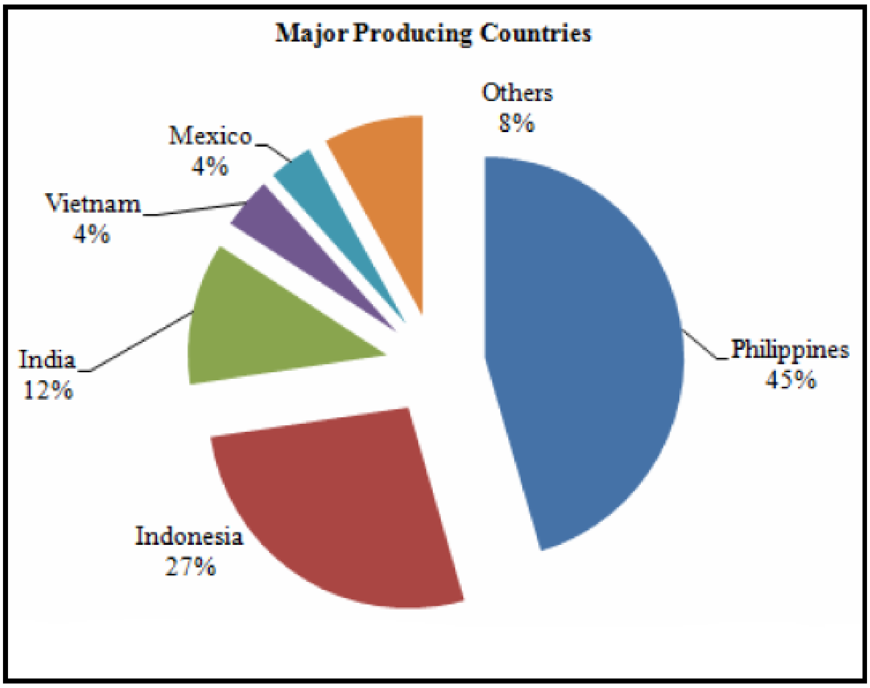
The coconut palm, the most important of all cultivated palms which is grown in more than 90 countries of the tropics. It is one of the most useful palms and has a variety of uses. Every part of the palm is useful to mankind in one way or the other. Botanically, the coconut palm is *Cocous nucifera L.* and belongs to natural order Arecaceae (Palmae), an important member of Monocotyledons.

The term "coconut" can refer to the whole coconut palm, the seed, or the fruit, which botanically is a drupe, not a nut. The coconut fruit consist of an outer epicarp, a mesocarp, and an inner endocarp. The epicarp, which is the outer skin of the fruit, and the mesocarp, which is heavy, fibrous, and tanned when dry, having many industrial uses. The endocarp is the hard dark core. Inside it solid white albumen of varied thickness, depending on the age of the fruit, and with an oily pulp consistency and a liquid albumen called coconut water that is thick, sweet, and slightly acidic.

1.1 AREA AND PRODCTION

Coconut is a source of food, beverage, medicine, natural fiber, fuel, wood and raw materials for units producing a variety of goods. Coconut is also interlinked with socio-economic life of large number of small and marginal farmers in India. Globally, coconut is grown on 11.92 million hectares with a production of 69,485 million nuts of which 89% is from Asia and Pacific countries. The Latin American countries and Caribbean Islands account for 5 per cent and African countries for 3 per cent of global production, followed by Philippines (23%), India (16%) and Sri Lanka (5%). Area wise coconut is grown on 3.62 million hectares in Philippines, 3.41 million hectares in Indonesia, 2.09 million hectares in India and 0.44 million hectares in Sri Lanka (Raghavi *et al.*, 2019). Recent estimates indicate that the crop is grown in an area of about 11.92

million hectares with an annual production of 69.48 billion nuts in 2018. Area under coconut cultivation is shown in Figure below;



Source: APCC Statistical Year Book 2018

Fig. 1.1 Area wise Coconut Cultivation

The area under cultivation, production and yield in the different coconut growing countries of the world is shown in Table 1.1.

Table 1.1 Area, production and yield of coconut in selected countries of the World

Sl. No.	Country	Area ('000 ha)	Production (Million Nuts)	Yield (Nuts /Ha)
1	Fiji	64	23	359
2	India	2097	23798	11349

3	Indonesia	3418	14201	4155
4	Malaysia	84	495	5893
5	Papua New Guinea	221	1483	6710
6	Philippines	3628	14726	4059
7	Samoa	99	267	2697
8	Solomon Islands	38	100	2632
9	Sri Lanka	440	2623	5961
10	Thailand	121	686	5669
11	Other areas	1712	11083	880

Source: APCC Statistical Year Book 2018

The graphical representation of area production and yield of some selected countries of the World is shown in the figure 1.2. Most of the world production is in tropical Asia, with Indonesia, Philippines, and India collectively accounting for over 72 per cent of the world total (Raghavi *et al.*, 2019).

1.2 STATUS OF COCONUT CULTIVATION IN INDIA

Even though India secures its place at third largest coconut producing country in the world, the per capita availability of the coconut is as low as 12 nuts per year, whereas it is as high as 282 nuts in the Philippines, 53 nuts in Indonesia and 156 nuts in Sri Lanka. Apart from the population factor in India, an important reason for this situation is those only specific states climates are favourable to coconut cultivation in the country mostly near coastal sites. Coconut being a coastal crop is mainly cultivated in Kerala, West Bengal, Tamil Nadu, Odisha, Karnataka, Maharashtra, and Pondicherry. Of late, coconut cultivation has been introduced to suitable sites in non-traditional states including Assam, Gujarat, Madhya Pradesh, Rajasthan, Bihar, Tripura, Manipur, and Arunachal Pradesh and in the neighbourhood regions of the coconut growing states (Raghavi *et al.*, 2019). The distribution of coconut in India is shown in Table 1.2

Table 1.2 Distribution of coconut in India (2019-20)

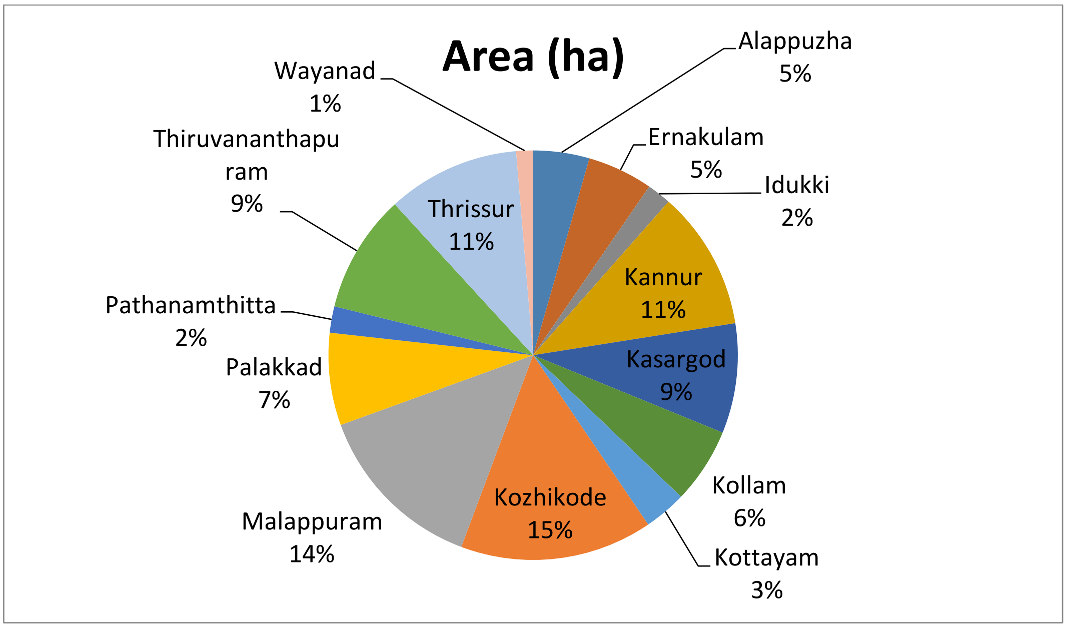
Sl. No.	**States/ Union Territories**	**Area ('000 Hectares)**	**Production (Million nuts)**	**Yield (Nuts/Ha)**
1	Andhra Pradesh	111.38	1555.82	13969
2	Assam	20.75	159.87	7704
3	Bihar	12.16	78.39	6444
4	Chhattisgarh	1.58	0.96	611
5	Gujarat	27.40	264.88	9667
6	Karnataka	624.03	4300.69	6892
7	Kerala	760.78	6980.30	9175
8	Maharashtra	29.95	523.66	17485
9	Mizoram	0.03	0.15	4350
10	Nagaland	1.06	9.02	8482
11	Odisha	51.70	354.57	6857
12	Tamil Nadu	437.57	5373.21	12280
13	Telangana	0.53	6.49	12330
14	Tripura	4.61	19.43	3996

15	West Bengal	31.30	389.16	12433
16	Others	58.43	293.10	5016
Total		**2173.28**	**20308.70**	**9345**

Source: Department of Agriculture & Farmers Welfare, Ministry of Agriculture and farmers welfare, Govt. of India

1.3 COCONUT CULTIVATION IN KERALA

Kerala ranks first in production and area of coconut. Presently, coconut is cultivated in the state in an area of 7.607 lakh ha with annual production of 6.980 billion nuts with an average yield of 9175 nuts per ha. Graphical representation of the area under coconut cultivation in different districts of the Kerala is shown in the Figure 1.4



Source: Directorate of Economics and Statistics, Thiruvananthapuram

Fig. 1.2 Area under coconut cultivation in different districts of Kerala

1.4 POST HARVEST OPERATIONS OF COCONUT

In India, the coconut harvesting is either at monthly intervals or at an interval of 45 days and nuts 10 to 11 months old are very often harvested. After harvesting nuts were collected and dehusking operation carried out. Harvested nuts are commonly placed together in a single layer on the ground. The nuts are kept near about one month to ripen on the ground. Coconuts with husk are very bulky. They are dehusked first before being transported from one place to other. Generally, Dehusking is done manually. The principal part of the dehusker is a sharp-pointed shard of steel positioned vertically with the point up and the broader part firmly placed on the ground. Alonge and Adetunji (2011) determined the relevant engineering properties to achieve this. Traditional methods of coconuts splitting include striking the shell against stone, using sharp or heavy object to hit the shell until it splits or throwing the nut against rocks.

Coconut water contains organic compounds having healthy growth promoting properties. It carries nutrients and oxygen to cells, raise the human metabolism, boost human immune system (Poduval *et al.*, 1998).

Two types of copra viz. milling and edible are made in India. Copra is required for the production of best grade coconut oil with desiccated coconut (DC), coconut cream, coconut milk, virgin coconut oil and spray dried coconut milk powder (Sangamithra *et al.*, 2013).

Presently there are certain manual and mechanical methods to split the coconut. Usually coconut is split using a sickle impact or by hitting nut on a solid surface or edge e.g. basalt rock or rigid metal edge but it could not succeed as lack of inefficiency. However, the traditional methods suffer lesser capacity and quantity of splitting owing to monotonous nature of splitting operation. Also, failure of these tools are due to improper cutting or due to accidents caused due to direct contact with the cutting tools and wastage of water or contanimation. Need for the improvement in current methods is the lack of manpower. This necessitates the use of appropriate machinery to aid various tasks in coconut plantation. The traditional devices are currently in use such as sickle is dangerous and minimum productive. Manually it is difficult to maintain pace with demand. Need a skilled labour. Oil industries and other food processing industries need splitting of coconut to be done in large count with reference to time. Splitting of coconut manually is a difficult task as it has to compensate thousands of coconuts in an hour. Labour scarcity is a huge challenge.

Plate 1.1 Conventional practice of coconut splitting

Regardless of of these uses, a common problem that many people are facing in a developing country like India is splitting the coconut. Present trends and tools used are unsafe, messy, time consuming and need skill, and training. The risk of injury in this process is also too high. There are some machines for splitting coconut, but until now no continuous machine exists to split the coconut and collecting the coconut water hygienically.

By considering these factors, a research work has been proposed to design and develop a continuous coconut splitter with provision for the collection of coconut water hygienically with the following objectives:

1 To study the physical and engineering properties and the breaking pattern of coconut

2 To design and develop a continuous type coconut splitter with provision for collecting coconut water

3 To evaluate the performance of the developed unit and to optimize the operational parameters.

CHAPTER - II

REVIEW OF LITERATURE

This chapter delivers a comprehensive review of research works carried out by numerous researchers across the world in the fields of botanical origin of coconut, various cultivation practices, physical and engineering properties influencing the breaking pattern of coconut and methods of splitting.

2.1 COCONUT ORIGIN

The origin of coconut palm is the subject of a controversy which once brings to mind the interest of a host of botanists. The first documented history of coconut in India dates back to period of Ramayanam. References are there in the Valmiki Ramayanam as coconut is there in Kishkindha Kanda and Aranya Kandam. The importance of coconut "Kalpavriksha or the tree of Heaven" can be appreciated when its innumerable advantages to mankind is considered. The tree and its products have deeper entry into our culture and have a record history of more than 4000 years (Sumy Sebastian *et al.,* 2016)

Ahuja *et al.* (2014) studied about the origin of coconut (*Cocos nucifera*) and its significance in the evolution and progress of human civilization. They found that Coconut palm is considered as a native of Malaysia, a bio-geographical region that includes Indonesia, Southeast Asia, New Guinea, Australia and several groups of Pacific Island. In Sanskrit scriptures of religious, Ayurvedic and agricultural importance, and travelogues of visitors from China, Italy and Arab, coconut has been recorded in epigraphic inscriptions and archaeological excavations. Its usefulness and multiplicity of uses has earned it epithets like "Tree of heaven", "Tree of life", "Kalpavriksha" (a tree that provides all necessities for living) and "Tree of abundance". In addition as a food, it has medicinal and cosmetic values too. Coconut finds a higher and a special place among the many articles used in religious offerings. Religious offerings are not acceptable without a coconut in India, even in regions where it is not cultivated. All parts are put to some working use in case of coconut.

2.2 COCONUT CULTIVATION

Nampoothiri (1999) studied the coconut cultivation practices. Coconut palms were divided into two groups, the talls and dwarfs. In general, the tall cultivators are available in the entire world. The tall cultivators are commonly available in the world as compared to dwarfs. Studied suggest that by nature, dwarf variety plants are shorter and less in life span as compared to plants of tall varieties. The author stressed the importance of irrigation or water supply to the coconut crops and the distribution water is very essential to coconut.

Chadrasekharan *et al.* (2012) estimated concurrent coconut production in Kerala. Coconut is major plantation crop that is grown in more or less all homesteads in the state. Primarily it is grown in small and marginal farms land holdings. Result revealed that Kerala has the largest area under the crop with 41.6 per cent of national acreage. The area under coconut increased from 4.09 lakh ha to 7.88 lakh ha and coconut production from 2026 million nuts to 6239 million nuts during the period 1950-51 to 2010-11. The contribution of Kerala in coconut production was 61.7 per cent in the country (1950-51). Its contribution was increased to 69.4 per cent during 1960-61 and its share in production was diminishing, 65.53 per cent during 1970-71. Further in 1980-81 state share production declined to 51.1 per cent. From 1980-81 to 2010-11 production increased at annual growth rate of 2.43 per cent and area increased by 0.56 per cent, indicating that increase in yield increased production. In Kerala the yield per ha was 4948 nuts in 1950-51, 6921 nuts per Ha in 1956-57 and followed by declining trend which bottomed at 4533 nuts in 1977-78. Yield per Ha varied from 4557 nuts to7918 nuts per Ha in the state over the period from 1980-81 to 2010-11.

Karunakaran and Gangadharan (2014) studied on supply response of coconut cultivation in Kerala. Study showed that during 1960s, 1970s and 1980s coconut crop cultivation took second place in Kerala state in terms of area expansion and after 1980s coconut area has increased to 56 per cent. The author focused on what are the determinant causes of changes in area coconut in Kerala state by adopting supply response method. The study covered 1960s to 2010. The study divided into six periods, from first 1960-61 period, second 1970-71 period; third period 1980- 81; fourth period 1990-91, fifth period 2000-01 and sixth period 2009-10. Result clearly shows that coconut production increase due to area increased. In Kerala, Irrigation and area plays vital role in increasing coconut cultivation. The rainfall and expected prices are the positive influence on the yield of coconut crop.

Sathya and Murugesh (2015) studied on coconut marketing with special reference in Pollachi taluk. Studies reviewed that India is at the second place for production of coconut in the world; contributed 24.24 per cent in production, first in productivity and third in area under cultivation (16 per cent). In Pollachi majority of the farmers cultivated coconut crop. According to author, 1500 coconut growers were in Pollachi. But for the study 250 sample respondents in four regions were selected based on convenient random sampling techniques. Result showed that most of the farmers were given long term yield of the coconut. Greater parts of the coconut farmers' coconut trees were affected mostly by pests and diseases. The chosen study area's farmers were unable to get good remuneration price, due to this slowly losing the cultivation.

Thamban *et al.* (2016) conducted a study on coconut production in Kerala – trends, challenges and opportunities. Coconut is an important cultivated crop in Kerala covering about 39 per cent of the net area sown in the state according to 2013-14 statistics. Kerala is the leading coconut producing states in India rank first in area and second in production of coconut. In 20l3-14 coconut annual production was 5921 million nuts under the area of 8.09 lakh ha. The coconut sector contributes around 15 per cent of total agricultural GDP of Kerala. It is estimated that there are about 35 lakhs holdings and at least 50 lakhs people depend on this crop directly or indirectly for their living. Per palm productivity of coconut in the Kerala is abysmally low at 42 nuts per plant, which is lesser than the national average.

Kishore and Murthy (2016) studied on growth in area production and productivity of coconut in Karnataka state of India. The growth in area, production and productivity of coconut in Karnataka and its districts was estimated by using compounded annual growth rate analysis. The required secondary data was collected for a period of fifteen years from 2000-2001 to 2014-15. In Karnataka state the growth rates in area, production and productivity of coconut were significant at 1 per cent and positive. Chitradurga, Tumkur, Hassan and Chikamagalur were the major coconut growing districts of Karnataka. Significantly positive growth was observed in ten districts and significantly negative growth rate in six districts at 1 and 5 per cent levels of significance. Chikkaballapura had the highest growth rate in production within a period of eight years with 5 per cent significance. Rural area of Bangalore had the highest negative growth rate. In Mandya area declining trend in coconut was found. The productivity of coconut was highest in districts of Yadgiri, Ramnagara, Chikkaballapura followed by others. The growth rates in productivity highly significant and were positive in twenty nine districts. Overall, the coconut scenario in Karnataka has been improving, particularly after 2007.

Karunkaran (2017) conducted a study on coconut cultivations in terms of its production and productivity. Study showed that coconut was grown in 90 countries, occupying about 10 million hectares of land. The production was nearly 42 billion nuts per year in the world. In India the production of coconut cultivation was 1.514 million hectares where 9.7 billion nuts are produced annually. Coconut is a dominant crop among the important commercial crops of Kerala. Kerala accounts for 38 percentage of the area under coconut and it contributes to 27 percentage of national production of the India. During the past five decades and more, coconut cultivation underwent increase in area under cultivation associated with rise in production. A comparison of the compound growth rates of coconut productivity during the five decades reveals a decrease in the growth of productivity and a slight decrease in recent years. It was observed that the coefficient of variation was higher as compared to 1960’s and 1970’s with regard to area and production. During this period, significant increase in production had occurred subsequent to increase in area and the productivity remains almost stagnant. Since 1985, change in production was mainly due to yield effect.

Raghavi *et al.* (2019) conducted a study on area, production, and productivity of coconut in India. In India about 120 lakhs people are dependent on the coconut sector in areas of cultivation, processing and trading activities. Coconut contribute about 15,000 crore rupees to India's GDP and 72 per cent of worlds total production. Coconut palms are grown in world, with a total production of over 59 million tonnes in 2016. In India coconut is major plantation crops with a total cultivated area of 1975.81 thousand hectares with a production of 21,665 million nuts which makes India stand third position in the world. India occupies the leading position in the world with an annual production of 13 billion nuts, overtaking Indonesia and the Philippines, the other two prominent coconut-growing countries. In India, the productivity of coconut is highest in Tamil Nadu, but production is high in Karnataka. Kerala tops in the area cultivation of coconut. In India 70 per cent of the coconut is used for the edible purpose and 5 per cent is consumed in the tender form for drinking purposes. Coconut is used for making copra, desiccated coconut powder, tender coconut. The rest coconuts are utilized as mature nuts for household, religious purposes and for the production of milling copra, edible copra and desiccated coconut.

2.3 PHYSICAL AND ENGINEERING PROPERTIES OF COCONUT

Mohsenin (1970) conducted study on physical properties of plant and animal materials. He found out that the engineering properties of biomaterials are an important for design of machines, processes, structures and controls. They are also useful in the investigation and determination of the efficiency of a machine or an operation, development of new products and equipment and the final quality of products. Mechanical properties provide the information about compressive strength which gives the data for the resistance of produce to cracking under harvesting and handling conditions and energy required in size reduction. Compressive strength is related in the choice of stack height to avoid produce destruction in storage. Frictional coefficient of a material on various structural surfaces is essential in expecting the movement of the materials in handling apparatus and the pressure applied on the storage structure walls. These engineering properties are not only valuable to the engineers but also to food scientists and processors, who may exploit them in their various disciplines.

Sahay and Singh (1994) conducted a study on unit operations of agricultural processing. They found out that engineering properties are useful and necessary in the design and operation of various equipment employed in the fields of agricultural processing and also for design and development of farm machinery. In the unit operations while handling of agricultural materials the properties which play an important role are physical, mechanical, frictional, rheological, are and hydrodynamic, electrical and optical properties of the bio materials. Basic information on these properties is of great importance and help for the engineers, food scientists and processors towards efficient process and equipment development. Physical properties (shape, size, surface area, volume, porosity, density, appearance and color) are important in design of certain equipment's or determining the behavior of the product while handling.

Alonge and Adetunji (2011) conducted study on properties of coconut (*Cocos nucifera L.)* relevant to its deshusking. Studies reviewed that coconut seed (*Cocos nucifera*) is a tropical plant valuable for its oil and fat fractions for the production of soap and milk. They are also used as diesel, for lighting and candles production. In developing, processing and handling for the seeds, several engineering properties (size, sphericity, roundness, volume, surface area, density, coefficient of friction) against different materials and compression test were studied. 100 seeds were randomly selected for the physical properties (size, density, shape, volume, surface area) experiments. Three principal dimensions were measured by Vernier Calliper (accuracy of 0.02 mm). Major diameter varied from 17.3 cm to 19.7 cm; surface area varied from 4,720 mm^2 to 5,795 mm^2, the seed volume varied from 600 cm^3 to 800 cm^3 with an average density of 1.062 g cm^{-3}, which shows that it float in water because the density is greater than that of water. The coefficient of friction is minimum for glass and high for plywood. The average modulus of elasticity is 153.598 N mm^{-1} with an average load at yield and deformation at yield at 5,390.4 N and 35.2 mm respectively on the major axis.

Relevant to cracking, Alonge and Folorunso (2012) found some engineering properties of coconut. Study revealed that Coconut seed (*cocos nucifera*) is a tropical plant that is grown in temperature between 20^0C and 25^0C. For the development of processing and handling equipment, engineering properties such were studied. Major diameter varied from 13.2 cm to 10.1 cm with a mean value of 11.2 cm, surface area varied from 5986.7 mm^2 to 4621.3 mm^2, the seed volume varied from 706 cm^3 to 435 cm^3, with an average density of 1.043 kg m^{-3}. The coefficient of friction is 0.53 for glass, 0.43 for plywood and 0.43 for galvanized steel.

2.4 BREAKING PATTERNS OF COCONUT

The fracture mechanics of the endocarp of coconut (C*ocos nucifera*) (Schmier *et al.* 2020) was studied in the laboratory. The hard inner shell of the coconut was mechanically characterized at various length scales and velocities. On a small scale the hierarchically structured coconut shell can be considered as transversely isotropic material. In case of larger, arch-shaped samples orientation affects the fracture behavior. Test velocity does not affect fracture behavior. When rectangular samples are applied normal to the endocarp surface, compressive strength is highest. Mechanical drawbacks caused by biological constraints, can be compensated by clever material arrangements and designs.

The parameters of energy and power for nut cracking play a key role in the design of shell-breaking equipment. There is no scientifically accurate measuring method to measure the energy and power of nut rupturing. To measure the force, energy, power a mechanical nut testbed was developed. It used to observe the generating process of nutshell cracking, breaking to reveal the shell-breaking mechanism. The system was tested with pecans and the results show that the tested can effectively realize the determination of nuts performance and data acquisition and analysis. The procedures and statistics can provide a theoretical guidance for the design and optimization of shell-breaking equipment and decrease kernel-breaking rate (Cao *et al.* 2017).

The cracking devices will show improvement in material handling, cracking time, capacity and efficiency, over the conventional technique. Ergonomic assessment preferred hydraulic-split device over other devices and methods. Per unit cracking capacity of the conventional method was very less while the cracking efficiency was found to be high. The hydraulic-split has the highest number of coconut split per hour with the highest handling capacity (Bello, 2020).

2.5 COCONUT SPLITTING MACHINES

Anitha and Shamsudeen (1997) developed a tender coconut punch and splitter. It consisted of a stainless steel punch connected to a lever in the form of a slider crank mechanism. The coconut seat provided with the help of a screw rod aided to hold nuts of varying sizes at the time of punching. After the coconut is placed in the seat, the screw rod is rotated to hold it in position. The lever is lowered and the punch is made to penetrate the tender coconut. The water is taken out through this hole by inversion with the help of a straw. The splitter assembly consisted of a knife pivoted at a convenient height. A 630 mm long lever was attached to the other end of the knife to another pivot point. After pacing the coconut below the knife, the lever is lowered and the knife is made to split open the coconut into two halves. The maximum force required to punch open a coconut 6 months and 8 months maturity were 78 and 109 kg, whereas that required for splitting were 132 and 152 kg.

Jippu (1998) developed a tender coconut punch, triggered by a slider crank mechanism. In tender coconut punch, a tender coconut was placed on a ring stand and as the main hand-lever was lowered. After that the punch moved downward and punched the husk and shell. Trouble was experienced in the punching more matured tender coconuts due to increased toughness of the shell.

Satip Rattanapaskorn and Kiattisak Roonprasang (2008) studied on design and development of semi-automatic cutting machine for young coconuts. A semi-automatic young coconut fruit cutting machine was designed, fabricated, tested, and evaluated. It designed on the concept that fruit cutting is accomplished by pneumatic press on a young coconut sitting on a sharp knife in a vertical plane. Machine frame, cutting base, knife set, pneumatic system, and tanks receiving coconut juice were the component of the prototype. The components of machine which comes in contact with edible parts of the fruit were made by food-grade stainless steel. For testing a coconut is placed on the cutting base and the pneumatic control was switched on. The coconut was automatically moved to the pressing unit and cut in half by a knife set. The coconut juice flows down to the tank whereas the cut fruits are separated and moved into the other tank. Every operation accomplished safely and smoothly. The machine worked safely without damage to the fruits. The machine capacity is 480 fruits per hour. Total operating cost was about 2.63 USD/1000 fruits.

Roshni *et al.* (2009) developed a power operated coconut punch-cum-splitter for extracting coconut water and coconut meat. The components of machine are screw rod, channel section, tapered roller bearings, pulleys, movable tray, and supporting frame, cutting blade, punch and electric motor. An electric motor is used to rotate the nut the screw rod. The tender coconut was placed on the top of the screw rod I natural rest position and was raised to press against either the punch or above the screen rod the blade fixed. The average energy requirement for punching and splitting of the selected ranges were found to be 11.74 kJ and 12.31 kJ.

Mownesh and Ashok Mehatha (2015) developed automatic punching and slicing a tender coconut machine consisting air compressor, pneumatic cylinders, direction control valve, hose pipe, punching bit, cutting blade and supporting frame. The punch cum splitter for tender coconut is operated by pneumatic system. The tender coconut is placed on the holder ring, once actuated the air compressor supplies the compressed air to the pneumatic cylinder the pneumatic cylinder containing a punching bit makes a hole in a downward direction and then move in backward position. After consuming its water it is placed on the other side of the frame for slicing operation. Similarly the slicing operation will be done. The force required to make punching a tender coconut and slicing a tender coconut measures to 250 N and 810 N.

Rajanikanth and Reddy (2015) conducted study on product design and development of tender coconut punching and splitting machine. Coconut is the "Tree of Heaven", that provides many necessities of life including food and shelter. Coconut is mainly cultivated for its nuts; it yields oil, oil cake and fiber. A common problem that many people are facing in a developing country like India is punching and splitting the tender coconut. This study was focused on the development of a manually operated coconut punch-cum-splitter for extracting coconut water and coconut meat. For this, customer needs statement was translated to the concept; by concept generation. Pugh matrix and concept scoring matrix was used to select best concept.

The selected concept comprises of lever and torsion spring mechanism operated punch. The operator places the sample (tender coconut) on the top of the holding mechanism under natural rest position and to punch a hole the lever is raised and pressed against the tender coconut. For splitting, the tender coconut is placed in the rest situation and the lever is raised and operated to split the tender coconut to extract the meat. The selected concept is analyzed further in terms of its functionality and cost economics. The prototype of the product in the present work, demonstrates the suitability in the said application. The testing of the prototype shows the total elimination of manual effort that was required in the case of traditional punch-cum-splitter. The split machine and punch can also split and punch hard nuts, which was difficult to manage using conventional splitter and punch.

Fulmali and Bhoyar (2015) studied on development of multipurpose coconut cutting machine. The research studied the problems faced during the young coconut cutting for commercial use. By considerate such problem the demand for efficient coconut cutting machine was developed. If the developed machine is commercialize the problem of use of coconut water at hotels and restaurants will get benefited. The aim of this research is developing, testing and evaluating the young coconut cutting machine. Study includes the description of the machine which also can be used to drink coconut water at gardens, coasts etc. Development of such machine reduces the fabrication cost by the application of screw jack.

Patil and Chendake (2017) developed of multipurpose punching and cutting machines. Two models of multipurpose machine viz. standing model and sitting model for punching a hole and splitting a tender coconut after drinking inside water, dehusking the ripened coconut, cutting raw mango into small pieces and for bottle corking and cutting a sugarcane bud chip were developed by Dr. D. Y. Patil College of Agricultural Engineering and Technology, Talsande, Kolhapur (M. S.) India in the year 2014. Performance of these two models were studied and compared with traditional machines/tools. The sitting model of multipurpose machine was able to perform six operations viz. tender coconut punching, tender coconut cutting or splitting matured coconut dehusking, raw mango cutting, bottle corking and sugarcane set cutting. This model performed best in punching of tender coconuts (69 coconuts h^{-1}) and matured coconut dehusking (75 coconuts h^{-1}) than other purposes of the machine when compared with standing model and traditional methods. Standing model of multipurpose machine was able to perform all operations that sitting model can perform except matured coconut dehusking and bottle corking. Best performance was found in standing model on cutting or splitting of tender coconuts (102 coconuts h^{-1}) and raw mangoes cutting (21.22 kg h^{-1}) than other purposes of the machine when compared with sitting model and traditional method. Poor performance was observed while in sugarcane set cutting by both the machines in comparison to conventional cutter.

CHAPTER - III

MATERIALS AND METHODS

This chapter elaborates the methodology adopted for various studies undertaken for the development of a continuous type of coconut splitter. A study was undertaken to investigate the physical and engineering properties of coconut to formulate criterion for design and the methods followed to determine the physical and engineering properties of matured coconut are explained in detail. An attempt was made to determine the splitting energy and splitting force requirements of coconut by fabricating an impact-test rig apparatus. The design analysis of a continuous coconut splitter is carried out separately for coconut feeder, impact tool and splitting mechanism and all related methodological are dealt in detail in the following sections.

To determine the physical and engineering properties of the coconut influencing in the design and development of coconut splitter, coconuts of different varieties were selected form the traders in Tavanur Panchayat of Malappuram district of Kerala.

3.1 ENGINEERING PROPERTIES OF THE COCONUT

Engineering properties of the material being handled and/or worked upon influence in the design and operation of various equipment or machine under development. In unit operations while handling of agricultural materials the properties which play an important role are physical, mechanical, frictional, rheological, aero and hydrodynamic, electric and optical properties of the bio materials. Basic information on these properties is of great importance and help for the engineers, food scientists and processors towards efficient process and equipment development (Sahay and Singh, 1994).

3.2 PHYSICAL PROPERTIES OF THE COCONUT

The physical properties such as size, shape, volume, surface area, density, porosity, colour, and appearance are important in designing specific equipment or determining the behaviour of the product for its handling. The shape of the product is an important parameter which affects conveying characteristics of solid material. The surface characteristics, colour and appearance are exploited for selective separation.

3.2.1 Shape and size

The following parameters are measured for describing the shape and size of agricultural materials.

(a) Colour and Appearance of the coconut

This was done mainly by direct visual observation of the coconut. The colour is green when mature and brown when ripe, containing of a light brown fibrous husk, a hard brown shell and large hollow seed with whitish oily edible flesh.

(b) Roundness

It is a measure of the sharpness of the solid material. The most accepted methods for determining the roundness of irregular particle are given below (Sahay and Singh, 1994),

$$\text{Roundness} = \frac{\text{Largest projected area of the particle when it is in natural rest position, Ap}}{\text{Area of smallest circumscribing circle, Ac}}$$

for Fig 3.1 (a) ... 3.1

$$\text{Roundness ratio} = \frac{\text{Radius of curvature,r of the sharpest corner}}{\text{Mean radius of the particle, R}}$$

for Fig. 3.1 (b) ... 3.2

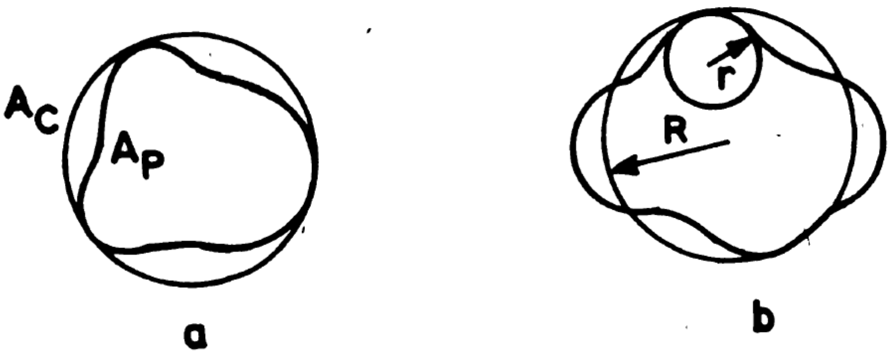


Fig. 3.1 Diagram for roundness and roundness ratio of a particle

(c) Sphericity

Sphericity may be defined as the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle. This parameter shows the shape character of the particle relative to the sphere having same volume. If D_e is the diameter of a sphere having same volume as that of the particle and D_c is the diameter of the smallest circumscribing sphere, then the sphericity can be expressed as under (Sahay and Singh, 1994),

$$\text{Sphericity} = \frac{De}{Dc} \qquad \text{..... 3.3}$$

Consider the volume of the particle is equal to the volume of ellipsoid having three axes with intercepts *l*, b and t and diameter of the circumscribed sphere is the largest intercept, the degree of sphericity can be expressed as given by

$$\text{Sphericity} = \sqrt[3]{\frac{Volume\ of\ the\ particle}{Volume\ of\ the\ circumscribed\ sphere}} \qquad \text{... 3.4}$$

$$= \left[\frac{\frac{\Pi}{6} l\,b\,t}{\frac{\Pi}{6} l^3}\right]^{\frac{1}{3}} \qquad \text{... 3.5}$$

$$= \frac{(l\,b\,t)^{1/3}}{l} \qquad \text{... 3.6}$$

$$= \frac{geometric\ mean\ diameter}{majoir\ intercept} \quad \ldots 3.7$$

Where,

l = largest intercept

b = largest intersect perpendicular to l

t = largest intersect perpendicular to l and b

It is not necessary that the three intercepts of the particle intersects each other at a common point.

The geometric mean diameter of the particle is also called as the "equivalent diameter".

The sphericity can also be expressed as;

$$\text{Sphericity} = \frac{D_i}{D_c} \quad \ldots 3.8$$

Where,

D_i = diameter of the largest inscribing circle

D_c = diameter of the smallest circumscribing circle

The D_i and D_c are shown in Fig. 3.2 below

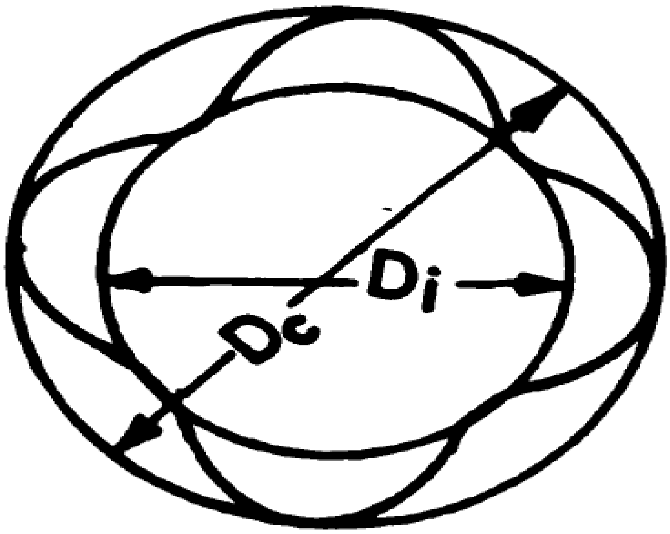


Fig. 3.2 Diagram of smallest circumscribing and largest inscribing circles of a particle

Plate 3.1 Tracing the projected area of the coconut

(d) Volume

The volume of randomly selected coconuts was determined by water displacement method using a measuring beaker. The difference between the final volume water displaced and the initial volume gives the volume of the coconut.

Plate 3.2 Volume determination of coconut by water displacement method

(e) Density

The density of any material may be expressed as below (Sahay and Singh, 1994),

$$\text{Density} = \frac{Weight\ of\ the\ material, kg}{Volume\ of\ the\ material, m^3} \qquad \ldots\ 3.9$$

The selection of coconuts was done randomly. The samples were first weighed to get the mass, later the volume was determined for each sample by immersing in water to get the volume of the water displaced using a measuring beaker. The readings were taken immediately when the coconuts were immersed into the beaker. The ratio of each mass of the sample obtained from the volume gives the density.

3.3 SPLITTING ENERGY AND FORCE

3.3.1 Splitting Energy

The energy required for splitting the matured coconut was determined with the help of an impact test rig. The pendulum arm of the apparatus allows swinging freely in a vertical plane. By the principle of conservation of energy, as the pendulum releases from the initial position (upswing), its potential energy is converted to kinetic energy. There will be a continuous exchange of energy of the oscillating arm from its maximum potential energy at the upswing position to maximum kinetic energy at its lower point of oscillation. Hence, the specimen to be split is placed at the point of maximum kinetic energy of the oscillating arm. When the pendulum hit the specimen, a part of is kinetic energy was utilized for splitting the material and with the remaining energy pendulum will continue its oscillation. The frictional losses of the swinging arm and the air resistance are small in magnitude and hence possibly neglected (Yiljep and Mohammed, 2005).

The pendulum arm was provided with splitting blade at its free end. At the time of experiment, the specimen mature coconut was hold vertically at the lower point of oscillation of the pendulum arm with the help of a vice. The pendulum arm was then released from an angular displacement of θ_1. The blade splits the specimen at the lower point of oscillation and move forward up to an angular displacement of θ_2 (Dange *et al.*, 2011).

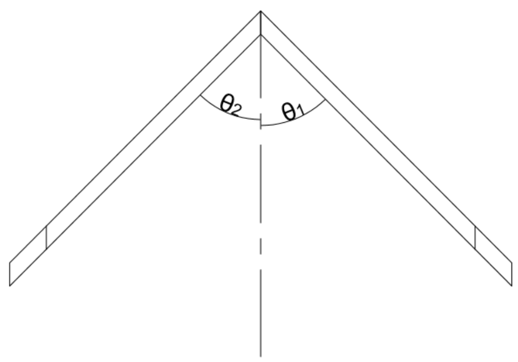


Fig. 3.3 Pendulum arm assembly

The energy utilized for splitting a matured coconut is calculated by the following equation

$$E = m \cdot g \cdot L\,(\cos\theta_2 - \cos\theta_1) \qquad \text{... 3.10}$$

Where,

E	:	Splitting energy required for matured coconut, Nm
m	:	Mass of oscillating pendulum, kg
g	:	Acceleration due to gravity, ms^{-2}
θ_1	:	Maximum angle of deflection of the pendulum from vertical at initial position, Degree
θ_2	:	Maximum angle of deflection of the pendulum from vertical after cutting, Degree
L	:	Effective length of oscillating pendulum, m

The effective length of the pendulum arm was determined by oscillating the arm freely before the test specimen (matured coconut) was clamped on the vice. The time taken (*t*) for 10 oscillations were noted. Three replications of the reading were taken to get the average time. Then the effective length of the pendulum arm was calculated with the help of equations 3.11 and 3.12.

$$T = \frac{Time\ taken\ for\ 10\ oscillations\ (t)}{10} \qquad \text{... 3.11}$$

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad \text{... 3.12}$$

Where,

L	:	effective length of pendulum arm, m
g	:	acceleration due to gravity, m s^{-2}

3.3.2 Splitting force

The maximum splitting force requirement was calculated from the splitting energy as per the procedure explained under section 3.3.1. The splitting force increases from zero at initial of cutting and start i.e., the initial contact point to a maximum value, and becomes zero when splitting completes. The splitting force can be calculated by using the following formula,

$$E = F_{max} \times \frac{d}{2} \qquad \text{... 3.13}$$

$$F_{max} = \frac{2 \times E}{d} \quad \ldots 3.14$$

Where,

E	:	Splitting energy required for matured coconut, N m
F_{max}	:	Maximum splitting force required for splitting of matured coconut, N
d	:	Major diameter of the matured coconut, m

3.3.3 Construction details of test rig

The test apparatus works on the principle of cutting energy was designed and fabricated in the research workshop of Kelappaji College of Agricultural Engineering and Technology, Tavanur. The fabricated impact test rig was similar to an izod impact apparatus for metal cutting. It consists of base frame, supporting frame, pendulum arm, pendulum shaft, splitting blade arrangement, dial gauge and a coconut holder.

3.3.3.1 Base frame

A 550×550 mm square base frame was made of mild steel angles (ISA 3030). It was designed to provide enough structural stability and support. It acts as a mounting platform for supporting frame and coconut holder.

3.3.3.2 Supporting frame

A supporting frame of 1 m height was provided. It was made of two hollow square pipes (20×20 mm) of mild steel. It was bolted to the base frame. A rectangular MS plate (150×50 mm) was welded at the top of supporting frame, act as a platform for mounting the pendulum shaft.

3.3.3.3 Pendulum shaft

A horizontal shaft of 235 mm long was made of mild steel. It was supported only at one end, by welding it to the supporting frame. The free end of the shaft acts as a pivot point to the oscillating pendulum. The shaft was fabricated in stepped with two diameters, 20 mm and 15 mm. The length of shaft with 20 mm diameter was 200 mm measured from the supporting end. And the remaining 35 mm length of shaft has a diameter of 15 mm.

3.3.3.4 Pendulum arm

The long pendulum arm was made of mild steel rod of 10 mm diameter and 800 mm length. It was suspended at the free end of horizontal shaft by means of a ball bearing (6203-2Z) with inside diameter 17 mm. The pendulum arm was designed to swing freely in vertical plane with splitting blade attached to its lower end.

The splitting arrangement for matured coconut consisted of a rectangular blade of 65 × 95 × 1.5 mm dimensions sandwiched between two rectangular plates. The top and bottom plates were fabricated using mild steel with dimensions 35 × 95 × 3 mm and 114 × 95 × 3 mm respectively. The pendulum arm along with the splitting blade weighs 2.462 kg.

Plate 3.3 Rectangular type blade used in test apparatus

3.3.3.5 Dial gauge

The angle of deflection of the oscillating pendulum arm was determined by using a dial gauge. It consisted of an angular scale and a pointer mounted on the pendulum shaft. The angular scale of 250 mm diameter was graduated from 0º to 180º in one vertical half, and similarly in the other half. Pointer of length 130 mm was fabricated using mild steel. It was designed such that it moved together with the pendulum arm during its forward swing, after splitting the specimen. The pointer moved up to the maximum displacement point of the pendulum arm and remained at that position while the arm returns. The angular displacement of the pendulum arm could be read by the position of pointer before and after splitting the specimen. The dial gauge is shown in plate 3.4.

Plate 3.4 Dial gauge needle

3.3.3.6 Coconut holder

A 150 mm drill machine vice (code: GS - 131) was used to hold the specimens firmly during the experiments. The vice as bolted to the base frame at the point of maximum kinetic energy.

3.3.4 Measurement of splitting energy

The fabricated test rig was kept in AICRP on Farm Implements and Machinery, lab KCAET, Tavanur for the determination of splitting energy. The splitting energy and splitting force of the matured coconut were determined for the samples collected from the local market. For the measurement of the splitting energy and force the coconuts are divided in three groups as small, medium and big depending on the size, major axes, minor axes and volume. The readings were taken for nearly about 50 samples. The measurement of the splitting energy for matured coconut was done with the help of impact test apparatus as shown in Plate below:

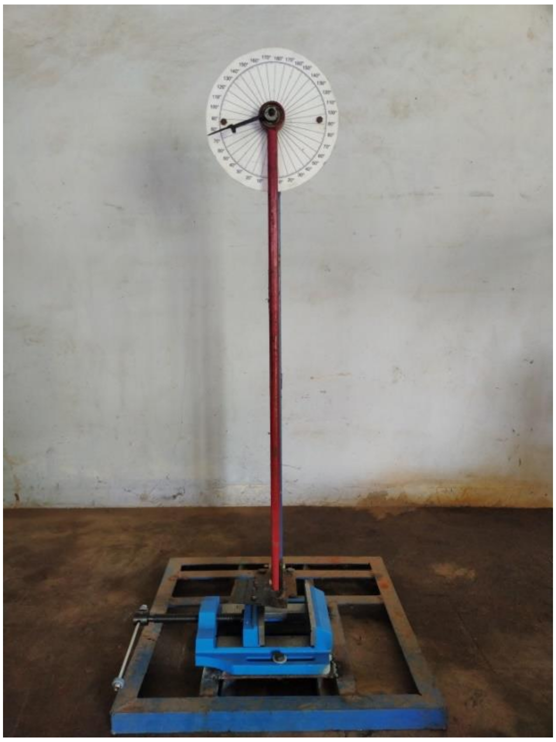


Plate 3.5 Impact test apparatus

Plate 3.6 Bearing- pendulum arm

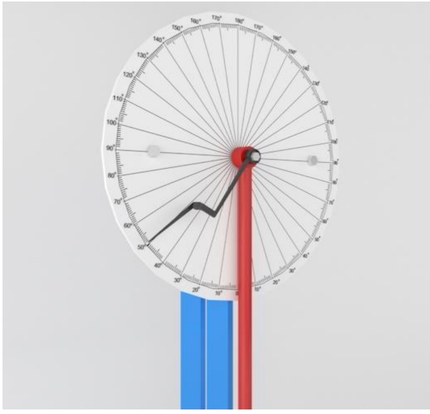


Plate 3.7 Dial gauge

3.4 DESIGN OF CONTINUOUS COCONUT SPLITTER

Based on the physical and engineering properties of coconut, splitting energy and force needed to split the coconut the continuous coconut splitting machine operated by electric motor was developed. The main purpose was to design the splitter which would require minimum power, complete splitting in two halves with safe of coconut splitting operation at economic cost of operation.

3.4.1 Functional requirements of continuous coconut splitter

Different components of coconut splitter were designed from the stand point of its functional requirement. The following functional requirements were considered for the design of splitter.

i. Single operator should handle the machine with minimum efforts.
ii. The machine should be simple in design construction
iii. The machine should be low in cost, easy to split coconuts continuously into two halves.
iv. The machine should minimize the wastage of time.
v. The machine should split the coconut in faster rate.
vi. The machine should be achieving risk free operation.
vii. It should easy for transportation.
viii. Repair and maintenance should minimum

Based on the functional requirements envisaged the conceptual design of the machine was developed and the basic components identified were electric motor as prime mover, reduction gearbox for providing appropriate speed to the splitting component, power transmission system, coconut water collecting trough and a basket for holding coconut.

3.4.2 Selection of prime mover

To select the suitable prime mover, the total power required for the operation of the splitting of the coconut should be known. The total power required was the sum of the power required to run the splitting mechanism and the coconut feeder system. The prime mover was also selected in such a way that the maximum number of coconut be splits by using the machine.

The torque transmitted by the shaft was computed using the following equation

$$T = F \times r \qquad \dots 3.15$$

Where,

T = Torque transmitted by the shaft, N m

F = Impact force required to split the coconut, N

r = Radius of the impact tool, m

Power required (in watts) was calculated as follows

$$P = \frac{2\Pi N \times T}{60} \qquad \dots 3.16$$

Where,

T = Torque transmitted by the shaft, N m

N = Speed of the shaft, rpm

3.4.3 Length of an open belt drive

In an open belt drive, both the pulleys rotate in the same directions as shown in Fig. 3.4

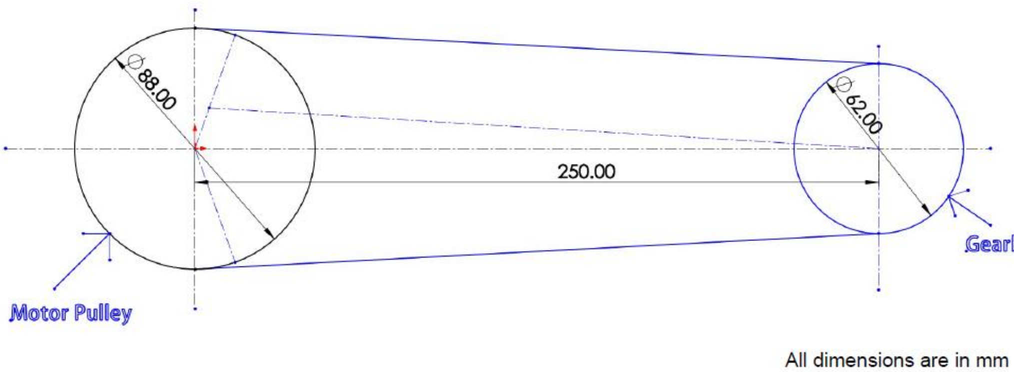


Fig. 3.4 Open belt drive

The length of the belt drive was decided by the following formula (Khurmi and Gupta, 2018).

$$L = \frac{\Pi}{2} \times (d_1 + d_2) + 2x + \frac{(d_1 - d_2)^2}{4x} \qquad \dots 3.17$$

Where,

L = Total length of the belt, m

x = Distance between the centres of the two pulleys, m

d_1 = Diameter of the larger pulley, m

d_2 = Diameter of the smaller pulley, m

. The velocity ratio of a belt drive was given by the following relationship,

$$\frac{N_{driven}}{N_{driver}} = \frac{D_{driver}}{D_{driven}} \quad ... 3.18$$

Where,

N_{driver} = Speed of driver, rpm

N_{driven} = Speed of driven, rpm

D_{driver} = Diameter of the driver pulley, m

D_{driven} = Diameter of the driven pulley, m

3.4.4 Reduction gear box

In continuous coconut splitter, power at lower speed and high torque was required, therefore the purpose of the reduction gear box was to provide speed reduction and multiply the torque received from the electric motor.

3.4.5 Design of transmission system in splitting mechanism

Power transmission from motor to impact tool and continuous coconut feeder was done with the help of gear box, chain and sprocket drives.

3.4.5.1 Calculation of the speed of input of gear box, splitting mechanism, and coconut feeder

The speed of the input of the gear box was calculated by using the equation

$$\frac{N_G}{N_M} = \frac{D_M}{D_G} \quad ...3.19$$

Where,

N_G = Speed of input of gear box, rpm

N_M = Speed of motor, rpm

D_M = Diameter of the motor pulley, m

D_G = Diameter of the gear box pulley, m

A. Calculation of the speed at second sprocket

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} \quad \text{… 3.20}$$

Where,

N_1 = speed of output of gear box, rpm

N_2 = speed of second sprocket, rpm

T_1 = Teeth of the gear box sprocket

T_2 = Teeth of the second sprocket

B. Calculation of the speed at fourth sprocket

$$\frac{N_4}{N_3} = \frac{T_3}{T_4} \quad \text{… 3.21}$$

Where,

N_3 = speed of third sprocket, rpm

N_4 = speed of fourth sprocket, rpm

T_3 = Teeth of third sprocket

T_4 = Teeth of fourth sprocket

C. Calculation of the speed at sixth sprocket

$$\frac{N_6}{N_5} = \frac{T_5}{T_6} \quad \text{… 3.22}$$

Where,

N_5 = speed of fifth sprocket, rpm

N_6 = speed of sixth sprocket, rpm

T_5 = Teeth of fifth sprocket

T_6 = Teeth of sixth sprocket

D. Velocity ratio of chain drives

The velocity ratio of a chain drive is given by

$$V.R. = \frac{N_1}{N_2} = \frac{T_2}{T_1} \quad \dots 3.23$$

Where,

N_1 = Speed of rotation of smaller sprocket, rpm

N_2 = Speed of rotation of larger sprocket, rpm

T_1 = Number of teeth on smaller sprocket

T_2 = Number of teeth on larger sprocket

From the chain pitch selection chart which was available in the *design handbook,* the tentative required chain pitch was selected based on the velocity ratio and sprocket rpm

The average velocity of the chain was given by

$$v = \frac{T\ p\ N}{60} \quad \dots 3.24$$

Where,

T = Number of teeth on sprocket

p = Pitch of the chain, m

N = Speed of the sprocket, rpm

E. Length of chain and centre distance

An open chain drive system connecting the two sprockets is shown in Fig. 3.5

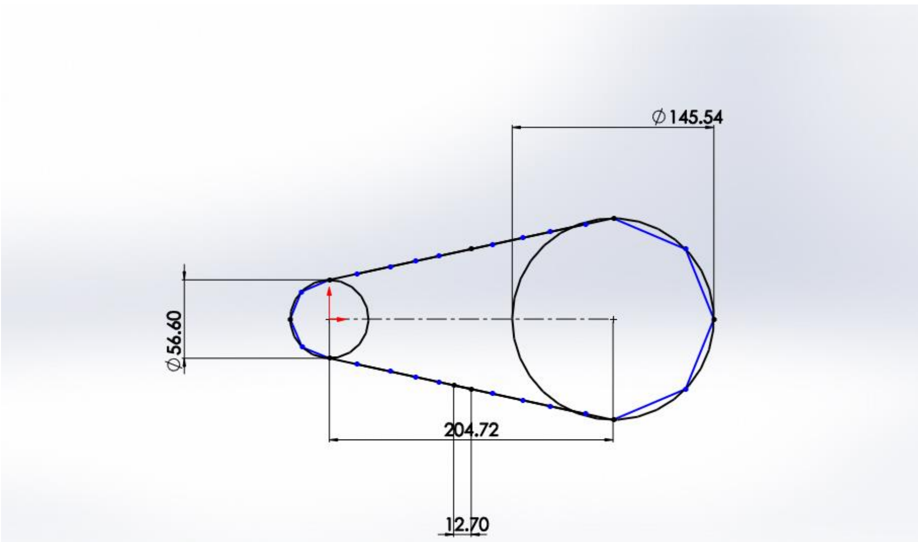


Fig. 3.5 Length of chain

The length of the chain (L) must be equal to the product of the number of the chain links (K) and the pitch of the chain (p). Mathematically, length of the chain expressed as

$$L = K \times p \qquad \dots 3.25$$

The number of chain link may be obtained from the following expression,

$$K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2\Pi}\right]^2 \frac{p}{x} \qquad \dots 3.26$$

Where,

K = Number of chain links

T_1 = Number of teeth on smaller sprockets

T_2 = Number of teeth on larger sprockets

p = Pitch of the chain, m

x = Centre distance, m

The value of K as obtained from the above expression must be approximated to the nearest even number.

The centre distance is given by

$$x = \frac{p}{4}\left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1 + T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\Pi}\right)^2}\right] \qquad \dots 3.27$$

In order to accommodate initial sag in the chain, the value of the centre distance obtained from the above equation should de decrease by 2 to 5 mm.

3.4.6 Frame

Base being the rigid structure on which entire machine components were placed. Base should have enough strength to withstand the whole machine components and vibration occurred during the operation. The angle bars of mild steel were used as frame material.

Dimensions of the frame

Width: 400 mm

Length: 800 mm

Height: 855 mm

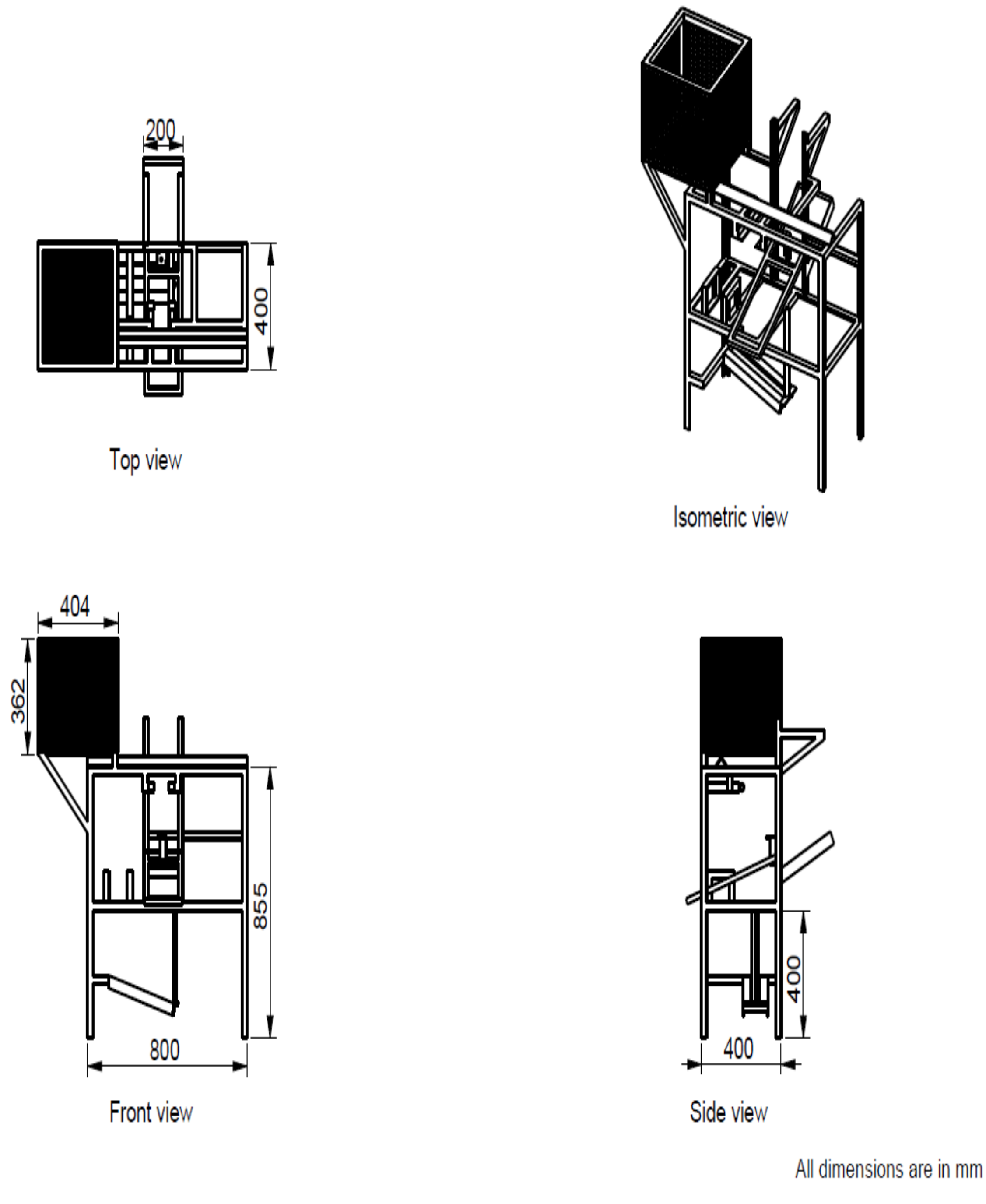


Fig. 3.6 Details of the frame

3.4.7 Splitting Mechanism

Impact type splitting mechanism was used to split the coconut. Impact tool operated by cam fitted on the shaft. The impact tool was connected with tension helical springs in order to obtain sufficient impact force for splitting the coconut.

The splitting mechanism consisted of impact type tool. The impact tool was made up of M.S. material. The length, width and thickness of the blade were taken as 510, 110, and 8 mm respectively. The impact tool was fitted on the cam connected with springs. The cam was fitted on the shaft having diameter of 20 mm rotated with the help of chain and sprocket drive. Schematic sketches of impact tool and cam profile of splitting mechanism are as shown in Fig. 3.7 and Fig. 3.8

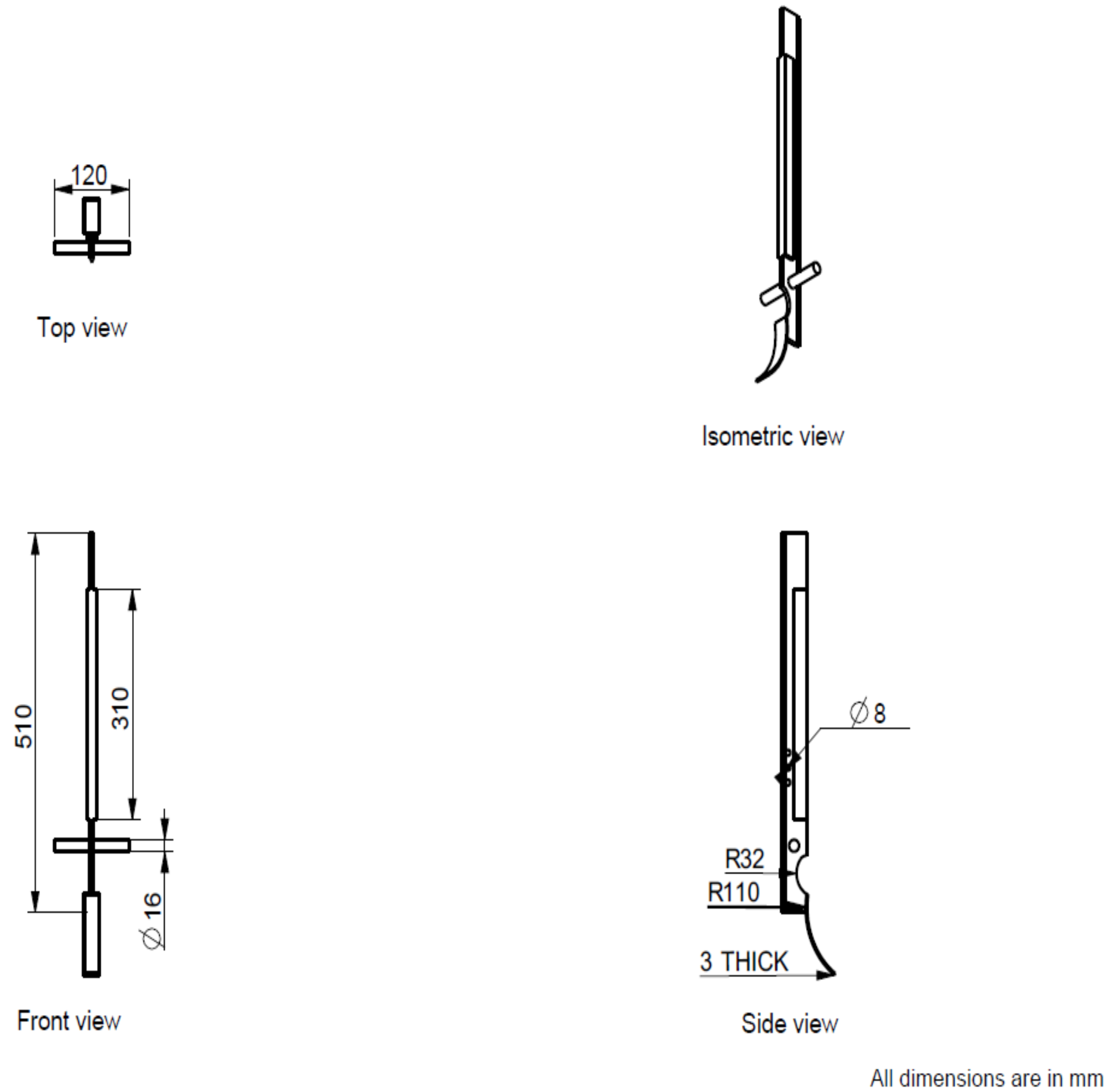


Fig. 3.7 Impact tool

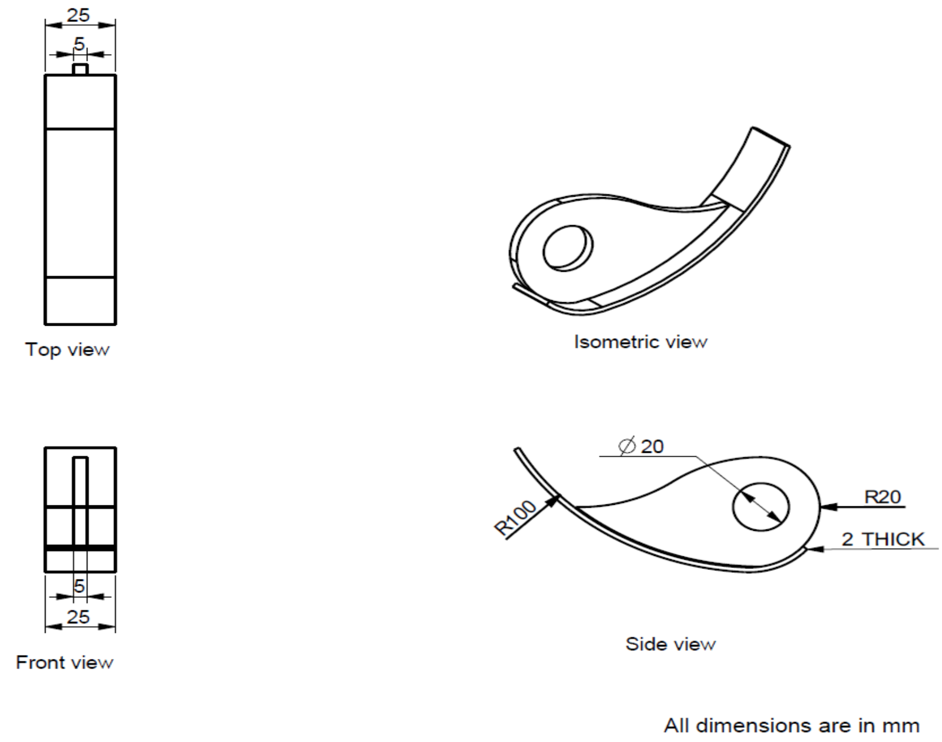


Fig. 3.8 Cam profile of splitting mechanism

3.4.8 Design of spring

Impact force developed in the machine was due to the elastic energy of the spring. Two springs of same type were used to generate force required for splitting the coconut. These two springs are attached to the impact tool at a fixed position. Cam on the shaft lifts the impact tool, as the impact tool was connected with the spring from one end at the distance of 180 mm and the other end of the spring was fixed with the help of nut and bolt.

When the cam lifts the impact tool, elongation take place in the spring attached to the impact tool. This induces the force to split the coconut.

For design of spring, the outside diameter, length of spring and deflection were taken as 18 mm, 130 mm and 15 mm respectively. Applied load was 385.91 N and two springs were selected for the impact tool in splitting mechanism. Spring was made of SS 302 and designed spring as shown in the Fig. 3.9. Modulus of rigidity and density of SS 302 was found out as 73000 Pa and 7600 kg

m^{-3} respectively, from design data. Spring Index is the ratio of the mean diameter of a coil to the diameter of the wire. Mean diameter and inside diameter of spring were assumed as 15 mm and 12 mm.

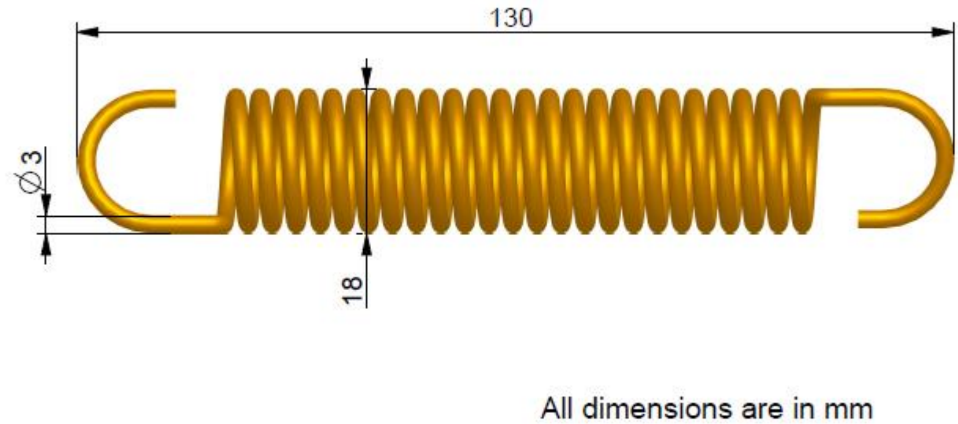


Fig. 3.9 Spring for splitting mechanism

Force induced by the spring is given by expression

Force induced in one spring = $k \times x$ ... 3.28

3.4.9 Shafts

It is rotating element, usually circular in cross section, which was used to transmit power from one part to another, or in which the operating member itself will be mounted on. The various members such as pulleys, gears were mounted on it. A transmission shaft was used to transmit power from gear box to the splitting mechanism and coconut feeder. The torsional shear stress of the shaft was taken as 130 MPa.

Torque transmitted by the shaft was expressed as

$$T = \frac{\Pi}{16} \times \tau \times d^3 \quad \text{… 3.29}$$

By using this equation, the diameter of the shaft was calculated by the equation expressed as

$$D = \sqrt[3]{\frac{T \times 16}{\tau \times \Pi}} \quad \ldots 3.30$$

Where,

D = Diameter of the shaft, mm

T = Torque transmitted by the shaft, N-mm

τ = Torsional shear stress, MPa

3.4.10 Coconut feeder system

A feeder system was necessary to convey the coconuts continuously to the splitting mechanism. The feeder system in the design was of rotary type and had four slots where the coconuts are to be placed one after other when the system is being rotating. The coconut feeder system was fabricated using two mild steel plates having thickness of 5 mm. The coconut feeder system was fabricated in circular section having diameter of 490 mm with 25 mm hole at its centre in order to fix the system on the transmission shaft.

3.4.11 Water collecting trough and strainer

Water collecting trough was used to deliver the coconut water safely in the water collecting bucket. Water collecting trough was fabricated by using stainless steel in order to maintain the hygiene. Strainer was used to stain the coconut water after splitting. The strainer used in the fabrication was stainless steel in order to maintain the hygiene. The water collecting trough and strainer are as shown in Fig. 3.9 and Fig. 3.10

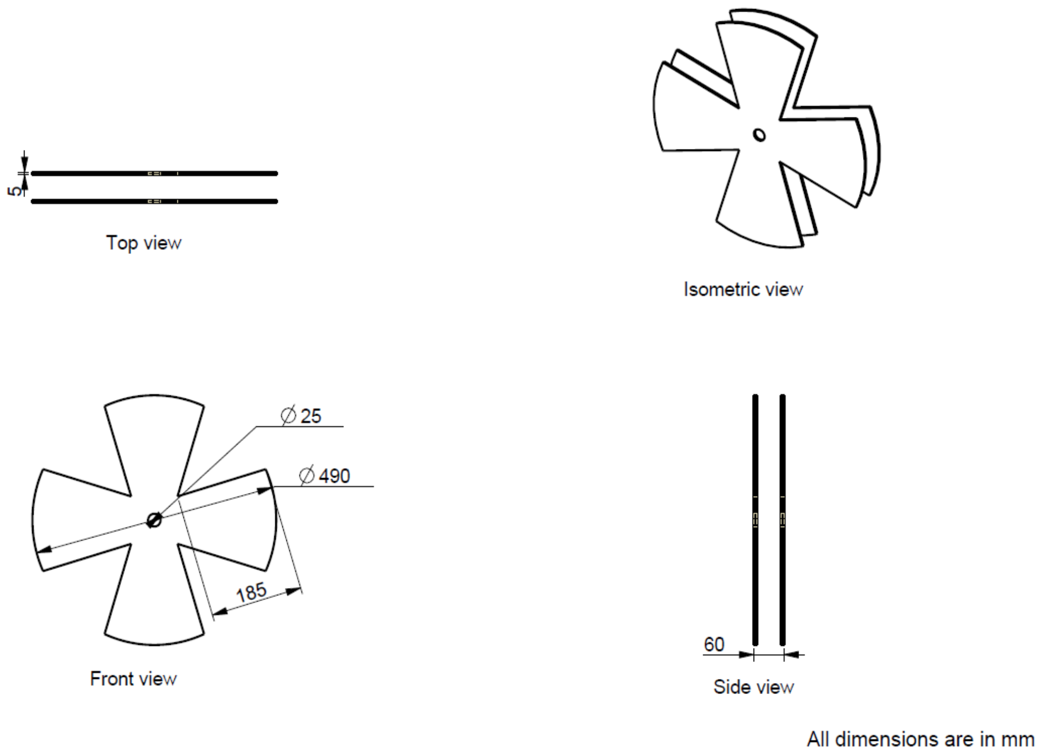


Fig. 3.10 Coconut feeder system

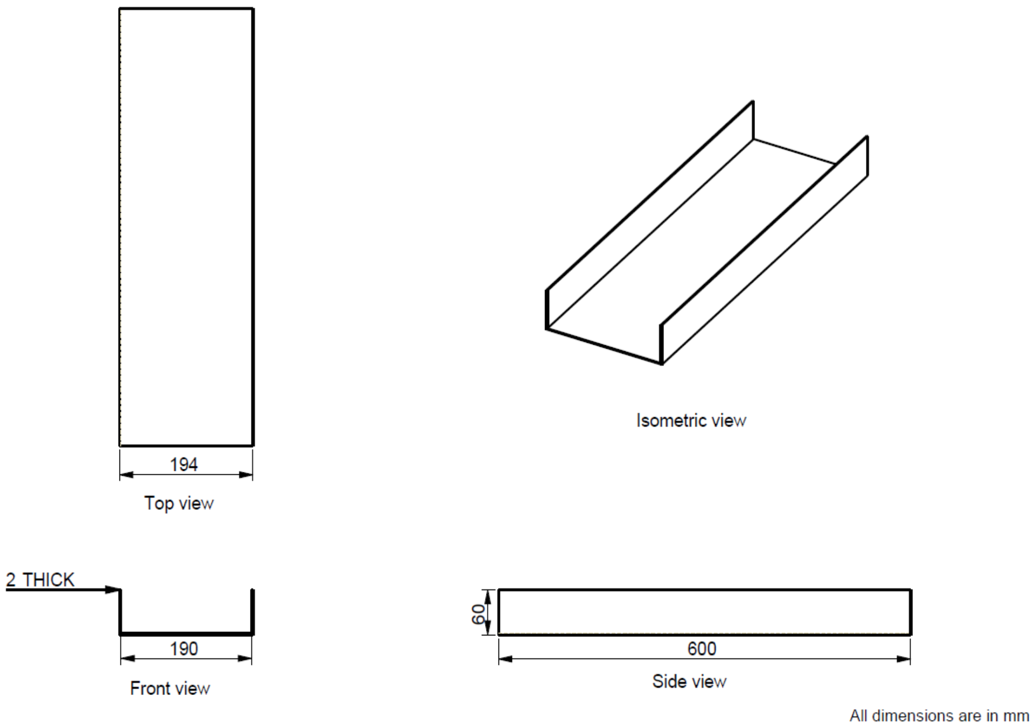


Fig 3.11 Coconut water collection trough

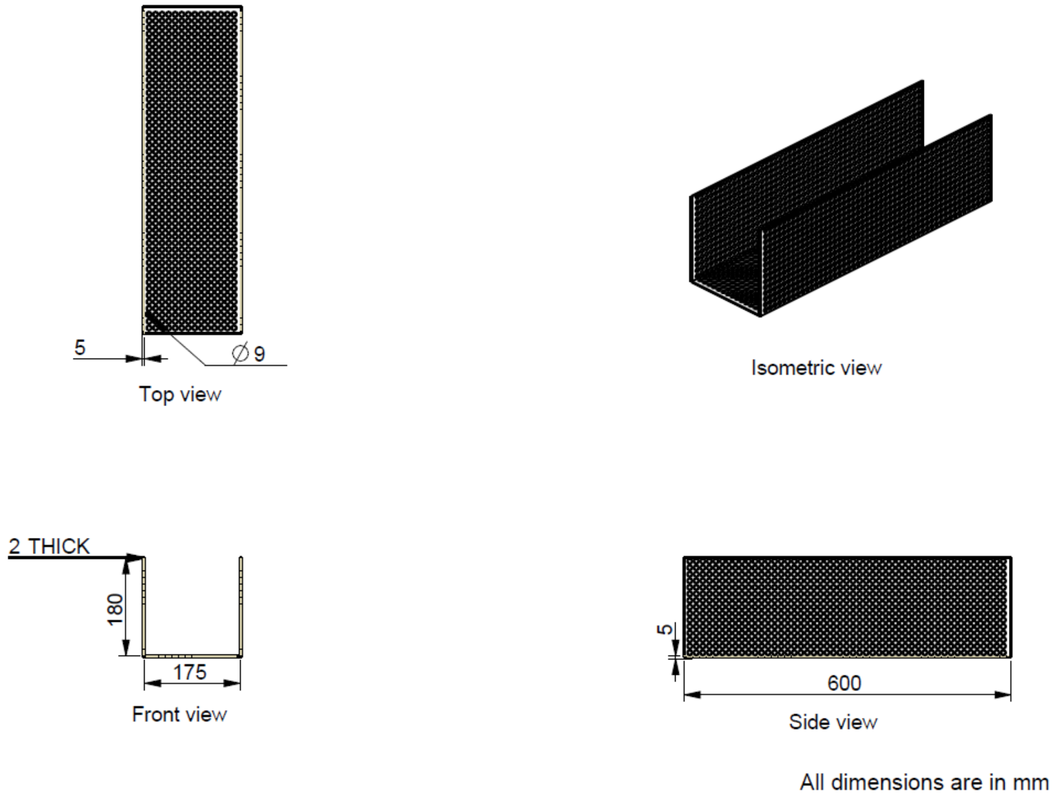
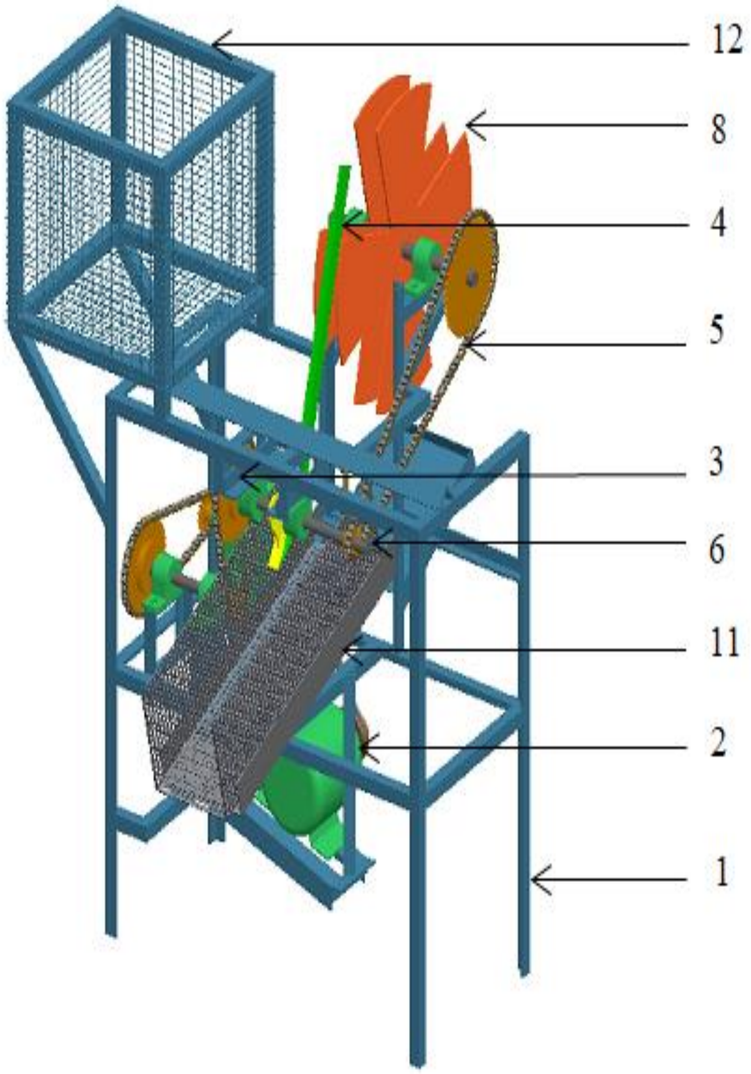


Fig. 3.12 Coconut water strainer

3.4.12 Coconut Basket

A basket was used to store the coconuts. It consisted of a rectangular box of dimension 404 × 362 mm. The coconut basket was fabricated by using the mild steel.

The 3D model of the coconut machine is shown in Fig. 3.13 below. The coconut splitting machine splits off the coconut via mechanically controlled impact tool. It consisted of electric motor, with speed 1353 rpm and transmitted the power to gear box through belt drives. Gear box of 20:1 was used to decrease the speed of motor. The output of gear box was transmitted to shaft of the impact tool and feeder with the help of chain and sprockets. The impact tool rotated at low speed and interns split the coconut. Isometric view of the machine is shown in Fig. 3.14 below.



1.Frame, 2.Electric motor, 3.Gear box, 4.Splitting mechanism (Impact tool), 5.Chain and sprocket drive, 6.Transmission shaft, 8.Feeder, 11.Water collection trough and strainer, 12.Coconut basket

Fig. 3.13 3D Model of continuous coconut splitting machine

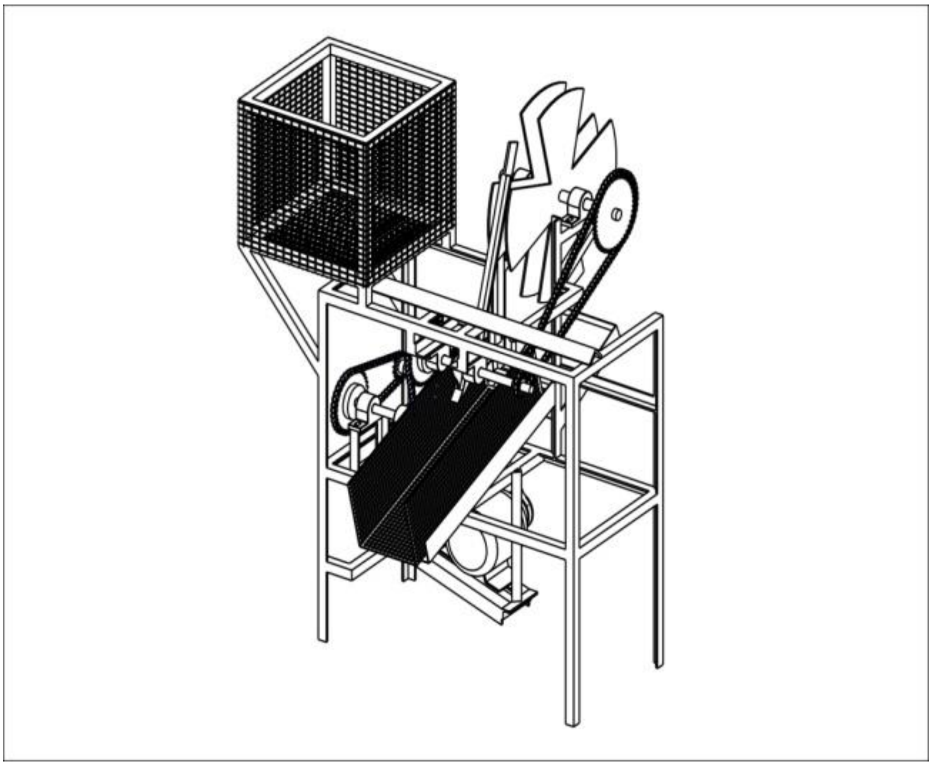


Fig. 3.14 Isometric View of continuous coconut splitting machine

Plate 3.8 Prototype of the continuous coconut splitter

3.5 PERFORMANCE EVALUATION OF CONTINUOUS COCONUT SPLITTER

The following tests were carried out to evaluate the performance of developed machine

3.5.1 Time required to split the coconut

The time required for splitting each coconut was measured using the stopwatch. The total time required for splitting includes time for coconut fixing and splitting.

3.5.2 Splitting efficiency

Splitting efficiency is expressed as the effect of splitting to open a coconut compares to known device performance. Splitting efficiency was calculated by using the equation (Bello, 2020),

$$\text{Splitting efficiency} = \frac{Length\ of\ obervable\ crack}{Diameter\ of\ coconut\ across\ the\ axis} \times 100\% \qquad \text{... 3.31}$$

3.5.3 Machine output capacity

The splitting capacity of the machine was determined from the average splitting time required to split the coconut. It is expressed as the quantity of coconut split per unit time of measurement (kg h^{-1}) (Bello, 2020),

$$\text{Machine output capacity} = \frac{Total\ weight\ of\ coconut\ split}{Time\ taken} \qquad \text{... 3.32}$$

3.5.4 Number of coconuts split per hour

Total number of coconuts split per unit time of measurement was expressed as (Bello, 2020),

$$\text{Total number of coconuts split} = \frac{Machine\ capacity}{Mean\ unit\ weight\ of\ coconut\ split} \qquad \text{... 3.33}$$

3.5.5 Efficiency of machine

The efficiency of the machine was the ratio of the number of coconuts split to the total number of coconuts feed during the evaluation of the machine. The efficiency of the machine was calculated by using the expression,

$$\text{Efficiency of the machine} = \frac{Number\ of\ coconuts\ split}{Total\ numbers\ of\ coconuts\ feed} \times 100 \qquad \text{... 3.34}$$

3.5.6 Uniformity in splitting

Uniformity in splitting of coconut was determined by using Karl Pearson's Chi-square (x^2) test. This involves testing of significance of difference between observed coconut diameter and expected diameter on some prior hypothesis or rule. If O_i was a set of observed diameter of the coconut after splitting and E_i was corresponding set of expected diameter of the coconut after splitting, the Karl Pearson's Chi-square (x^2) is given by

$$x^2 = \sum \left[\frac{(Oi - Ei)^2}{E_i}\right] \qquad \text{… 3.35}$$

CHAPTER - IV

RESULTS AND DISCUSSION

This chapter deals with the relevant physical and engineering properties of coconut of different varieties of the coconut cultivated in the Tavanur Panchayat of Malappuram Districts of Kerala viz., Lakshaganga, Keragangan, Anadaganga, Kerasree, Kerasowbhagya and Kerasagara are determined and summarized. The details of lab experiments done to determine the splitting energy and splitting force requirement of matured coconut discussed in this chapter. This chapter also deals with the evaluation of developed machine.

4.1 PHYSICAL AND ENGINEERING PRPOERTIES OF THE COCONUT

Physical as well as engineering properties of the coconut such as shape and size, weight, colour and appearance, roundness, sphericity, volume, and density were determined.

4.1.1 Colour and appearance of coconut

This was done mainly by direct visual observation of the coconut. The colour of the matured coconut was observed to be brown, consisting of a hard brown shell and one very large hollow seed with whitish oily edible flesh. Matured coconut was ovoid or ellipsoid in shape.

4.1.2 Size determination

The size of the coconut was determined by measuring major axes, intermediate axis and minor axis. The selected seeds were carefully handled in order to measure their three principle dimensions using vernier calliper with an accuracy of 0.02 mm; which are major, minor and intermediate diameters respectively. The principle dimensions i.e. major, minor and intermediate diameters were measured for two hundred forty coconuts. The value of major diameter ranges from 101.45 mm to 132.33 mm with a mean of 117.24 mm and standard deviation of 9.00. The value of minor diameter ranges from 87.51 mm to 107.29 mm with a mean of 97.09 mm and standard deviation of 5.57. The value of intermediate diameter ranges from 85.47 mm to 101.07 mm with a mean of 93.29 mm and standard deviation of 4.59 as shown in Table 4.1. The observations and calculations are presented in Appendix I.

4.1.3. Roundness

The roundness ranges from 0.46 to 0.82 with a mean value of 0.65 and standard deviation of 0.10 as shown in Table 4.1. The roundness of the coconut was determined by test procedure as explained in section. 3.2.1 (b). The calculations of roundness are presented in Appendix I.

4.1.4 Sphericity

The sphericity of the coconut was determined by test procedure as explained in section. 3.2.1 (c). The sphericity ranges from 0.73 to 0.96 with a mean value of 0.83 and standard deviation of 0.05 as shown in Table 4.1. The calculations of sphericity are presented in Appendix I.

4.1.5 Weight

The weight of the coconut ranges from 370.01 g to 781.69 g with a mean value of 579.99 g. and standard deviation of 104.56 as shown in Table 4.1. The calculations of the weights of the coconut are presented in Appendix I.

4.1.6 Volume

The volume of coconuts measured by using the procedure as explained in section 3.2.1 (d). The volume ranges from 425.89 cm^3 to 713.45 cm^3 with a mean value of volume of 556.20 cm^3 and standard deviation of 64.07 as shown in Table 4.1. The calculations of the volume of the coconut are presented in Appendix I.

4.1.7 Density

The density of the coconuts ranges from 0.80 g cm^{-3} to 1.30 g cm^{-3} with mean value of 1.04 g cm^{-3} and standard deviation of 0.14 as shown in Table 4.1. The calculations of the density of the coconuts are presented in Appendix I.

Table 4.1 Physical and engineering properties of the matured coconut

Property	**Mean**	**Maximum**	**Minimum**	**Standard Deviation**
Major Diameter (mm)	117.24	132.33	101.45	9.00
Minor Diameter (mm)	97.09	107.29	87.51	5.57
Intermediate Diameter (mm)	93.29	101.07	85.68	4.59
Roundness	0.65	0.82	0.46	0.10
Sphericity	0.83	0.96	0.73	0.05
Weight (g)	579.99	781.69	370.01	104.56
Volume (cm^3)	556.21	713.45	425.89	64.07
Density (g cm^{-3})	1.04	1.30	0.80	0.14

4.2 Splitting energy and force requirement of matured coconut

The energy required for splitting coconuts was determined experimentally. The experimental results of splitting force and splitting force were given in Appendix II. The splitting of coconut is achieved by the combined effect of shear failure accompanied by the deformation due to bending and compression (Kepner *et al.,* 1987). The matured coconut provide enough inertia of being split to support the opposing force required in shearing, the effect of shear failure was prominent in splitting action than bending. The splitting energy and splitting force of matured coconut was discussed in the following sub-divisions.

4.2.1 Splitting energy of coconut

The splitting energy required to split matured coconut was determined by the test procedure as discussed in section 3.3.1. Figure 4.1 shows the splitting energy and force requirement of coconut for the rectangular blade. The splitting energy for rectangular blade ranges from 35.24 to 36.38 with a mean value of 35.84 and standard deviation of 0.37. Splitting energy requirement of the rectangular blade is shown in Table 4.2. The calculations of the splitting energy are presented in Appendix II.

Table 4.2 Splitting energy and force of rectangular blade

Sl. No.	Splitting energy J	Splitting force N
1	35.94	568.12
2	35.24	647.91
3	35.42	649.60
4	36.38	704.29
5	36.24	594.75
Range	1.14	179.57
Mean	35.84	609.20
S.D.	0.37	50.51

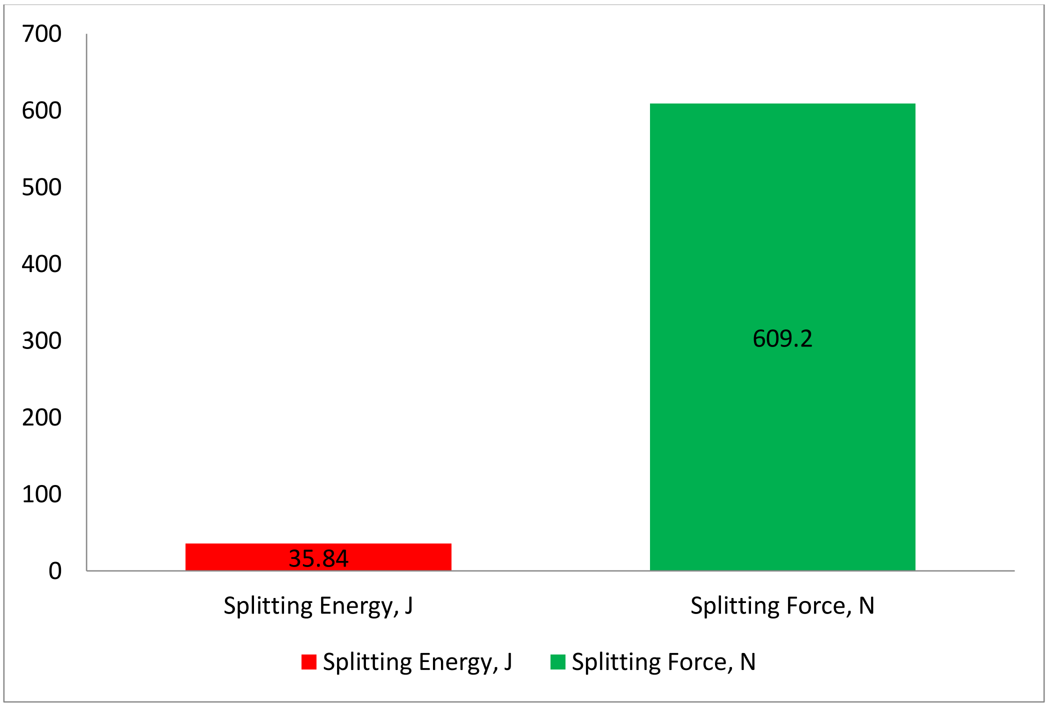


Fig. 4.1 Splitting energy and force of matured coconut

4.2.2 Splitting force of matured coconut

The splitting force required to split matured coconut was determined by the test procedure as discussed in section 3.3.2. Figure 4.1 shows the splitting force of matured coconut for the rectangular blade. The splitting force required to split the matured coconut for the rectangular blade the splitting force ranges from 535.97 N to 715.54 N with a mean value of 609.20 N and standard deviation of 50.51. Splitting fore requirement of the rectangular blade is shown in Table 4.1. The calculations of the splitting force are presented in Appendix II.

4.3 DESIGN OF CONTINUOUS COCONUT SPLITTER

The continuous coconut splitting machine was designed and developed by considering physical and engineering properties of the coconut, impact energy and force required to split the coconut utilizing the power of electric motor. The main purpose was to design the machine for splitting for splitting of matured coconuts with minimum power requirement, maximum splitting efficiency, low damage to coconut and less electricity consumption along with maximum efficiency of the machine at economic cost of operation. The machine consisted of main frame, power transmission system, splitting mechanism, coconut feeder, coconut water strainer and trough.

4.3.1 Selection of prime mover

A suitable prime mover was selected based on the calculated total power requirement for the operation of coconut splitting machine. The total power requirement was found as 0.71 hp. Based on this power requirement a 1.0 hp single phase electric motor is selected as a prime mover for the design of splitting machine. The specifications of the selected prime mover are presented in the Table 4.3. The detail calculations for the selection of the prime mover were presented in Appendix III.

Table 4.3 Specifications of the prime mover

Make	:	Lakshmi
Phase	:	Single phase
Power rating	:	1 Hp / 0.746 kW
Power source	:	Electricity
Speed	:	1353 rpm
Weight	:	9.5 kg

4.3.2 Length of belt

The belts were used to transmit power from on shaft to another by means of pulleys which rotate at the same speed or at different speeds. The length of the belt and velocity ratio of the belt was calculated by using standard procedure given by Khurmi and Gupta. The length of belt was found out as 730 mm. The calculations of the length of belt are presented in Appendix III. By considering this length of the belt B27 grade belt was used for the transmission of power from motor pulley to the gear box input pulley.

4.3.3 Design of transmission system

The power transmission system was designed by using the chain and sprockets drives. The design of power transmission system was done to found the speed and number of teeth's of the sprockets. The speed of the input gear box was found out as 1920 rpm. The output speed of the gear box was found out as 96 rpm. The speed of the second and third sprockets was found out as 37 rpm. The speed of fourth and fifth sprockets was found out as 14 rpm. The speed of the sixth sprocket and the coconut feeder was found out as 3.5 rpm. The velocity ratio of the belt drive was found out as 1.41. From the chain pitch selection chart which is available in the design handbook, the tentative required chain pitch is selected based on the velocity ratio and sprocket rpm. The calculations of the transmission system are presented in Appendix III.

4.3.4 Length of chain

The length of the chain and the number of the chain links were found out by using the test procedure as explained in section 3.5.5.1. The length of the chain, number of chain links for the first drive was found out as 762 mm and 60 with the centre distance of 204 mm. The length of chain and number of chain links for the second drive was found out as 685 mm and 54 with the centre distance of 178 mm. The length of the chain and number of the chain links for the third drive was found out as 1397 mm and 110 with the centre distance of 516 mm. The calculations for the length of the chain are presented in Appendix III.

4.3.5 Frame

The main frame was made of mild steel channel for mounting prime mover, gear box, power transmission system, splitting mechanism, coconut feeder unit. The overall dimension of the main frame was 800 × 400 mm.

4.4.6 Splitting mechanism

The impact tool was made up of M.S. material. The length, width and thickness of the blade were taken as 510, 110, and 8 mm respectively. The impact tool was fitted on the cam connected with springs at the distance of 180 mm. The cam was fitted on the shaft having diameter of 25 mm rotated with the help of chain and sprocket drive.

4.4.7 Design of springs

Two tension helical springs were selected for the design of the continuous coconut splitting machine. These two springs were connected to the impact tool at the distance of 180 mm from the cam shaft. The impact tool rotates at low speed and interns the impact force in the springs. This induced force in the spring is used to split the coconut. The specifications of the spring used in the prototype continuous coconut splitting machine are presented in Table 4.2

Table 4.4 Specification of the spring

Diameter of spring wire (d)	:	3.02 mm
Outer diameter of spring (D_{Outer})	:	18.00 mm
Inner diameter of spring (D_{inner})	:	11.95 mm
Mean diameter of the spring (D_{Mean})	:	14.97 mm
Length inside hook (L_{free})	:	12.00 mm
Number of active coils	:	17.00
Body length (L_{body})	:	77.07 mm
Hook length 1	:	8.97 mm
Hook length 2	:	8.97 mm
Total hook length	:	17.93 mm

Rates and loads		
Spring rate (or spring constant) k	:	7.51 N mm^{-1}
Maximum load possible (F_{max})	:	385.91 N
Maximum load possible considering Hook stress, (F_{maxHS})	:	319.12 N
Initial tension ($Tension_{init}$)	:	99..81 N
Safe travel		
Maximum safe travel ($Travel_{max}$)	:	38.07 mm
Maximum safe travel considering Hook stress ($Travel_{maxHS}$)	:	29.18 mm

Force induced in one spring = 7.51 × 58

= 435.85 N

As two springs were used in the impact mechanism, the total force induced in the two springs is 871.71 N which was sufficient to spit the coconut into two halves.

4.4.7 Design of shaft

The torque transmitted by the shaft and the diameter of the shaft was determined by the test procedure as explained in the section 3.4.9. The diameter of the shafts for the power transmission was thus decided as 25 mm. The calculations for the selection of shaft diameter are presented in Appendix III.

4.4.8 Coconut feeder system

The coconut feeder was determined keeping in view the ease of holding the coconut firmly during splitting. By considering the roundness and sphericity of the coconut V shaped groves were made on the both the section to hold the coconut firmly during the splitting action with the depth of 185 mm.

4.4.9 Water collecting trough and strainer

The length, width and thickness of the coconut water collector were taken as 600, 194 and 2 mm respectively. The strainer consisted of perforated wholes having diameter of 9 mm and the length, width and thickness of the water strainer 600, 175 and 5 mm respectively. In order to collect the coconut water and split coconuts the water trough and strainer were fixed at the bottom of coconut feeder at angle varied from 15 to 25 deg. with the horizontal.

4.5 DEVELOPMENT OF CONINUOUS TYPE COCONUT SPLITTER

The prototype of the continuous coconut splitting machine consisted of main frame, power transmission system, splitting mechanism, coconut feeder, water collection trough and strainer, and coconut basket. Specifications of prototype continuous coconut splitter are presented in Table 4.3

The main frame was made of mild steel angle bars for mounting power transmission system, splitting mechanism and coconut feeder unit. The overall dimension of the main frame is 800×400×855 mm.

The power transmission system has been made at two stages, first from electric motor to the reduction gear box from which power was transmitted to splitting mechanism and coconut feeder unit with the help of transmission shafts.

The splitting mechanism consisted of rectangular impact tool fitted on the shaft operated by cam. The impact tool was attached with two tension helical springs in order to generate the force required to split the coconut. The impact tool was made of M. S. of size L×W×T as were 510×110×8 mm. The impact tool was fitted in the middle of coconut feeder unit in order to split the coconut in two halves.

Depending on the roundness and sphericity of the coconut feeder unit consisted of the V groves to hold the coconut firmly during the splitting. The two plates were made of mild steel of 5 mm thickness and spacing between these two plates was 60 mm.

Table 4.5 Specifications of the continuous coconut splitter

Diameter of the motor pulley	:	88 mm
Diameter of the gear box pulley	:	62 mm
Number of teeth on first sprocket (T_1)	:	14
Number of teeth on second sprocket (T_2)	:	36
Number of teeth on third sprocket (T_3)	:	14
Number of teeth on fourth sprocket (T_4)	:	36
Number of teeth on fifth sprocket (T_5)	:	11
Number of teeth on sixth sprocket (T_6)	:	44
Speed of motor shaft	:	1353 rpm
Speed of gear box input pulley	:	1920 rpm
Speed of gear box output (first sprocket)	:	96 rpm
Speed of second sprocket (N_2)	:	37 rpm
Speed of third sprocket (N_3)	:	37 rpm
Speed of fourth sprocket (N_4)	:	14 rpm
Speed of fifth sprocket (N_5)	:	14 rpm
Speed of sixth sprocket (N_6)	:	3.5 rpm
Length of belt	:	736 mm
Length of chain for first drive	:	762 mm
Length of chain for second drive	:	685 mm
Length of chain for third drive	:	1397 mm
Gear reduction ratio	:	20:1
Cam or Blade hitting speed	:	14 rpm

Feeder speed	:	3.5
Number on slots on feeder	:	4
Total number of coconuts fed in one minute	:	14

4.6 PERFORMANCE EVALUATION OF CONTINUOUS TYPE COCONUT SPLITTER

The developed continuous coconut splitting machine was evaluated for its performance. The trials were conducted at the food processing laboratory of RARS, Amabalavayal, and the performance evaluation was conducted at instructional farm, KCAET, Tavanur.

Plate.4.1 Performance evaluation of continuous type coconut splitter

The observations made during the performance evaluation of the developed machine including the time required to split the coconut, splitting efficiency, machine output capacity, number of coconuts split per hour and uniformity in splitting of coconut were discussed in the following sub-divisions.

4.6.1 Time required for splitting the coconut

The time required for splitting each coconut was measured using the stopwatch. The total time required for splitting includes time for coconut fixing in the feeder and splitting. Table 4.3 shows the splitting time of two methods i.e. conventional method and developed machine. The splitting time generally varied from 15 to 23 seconds for conventional method while for the developed machine the splitting time varies from 4 to 6 seconds.

Table 4.6 Time taken to split the coconut for different methods

Method	Time taken to split coconut (s)
Conventional	19
Developed machine	5

4.6.2 Splitting efficiency

The splitting efficiency of the developed machine was determined by using the standard procedure given in the section 3.6.2. The average splitting efficiency of the continuous coconut splitting machine was found to be 85.51 per cent which ranges from 59.57 to 99.40 per cent and standard deviation of 8.2501. Figure 4.2 shows the splitting efficiency of the developed machine and conventional method of coconut splitting. The effect of human control in conventional splitting method was considered a critical factor responsible for higher splitting efficiency, while machine factors such as mechanical accuracies and component machining had some influence on the low splitting efficiency. The calculations of the splitting efficiency are presented in Appendix IV.

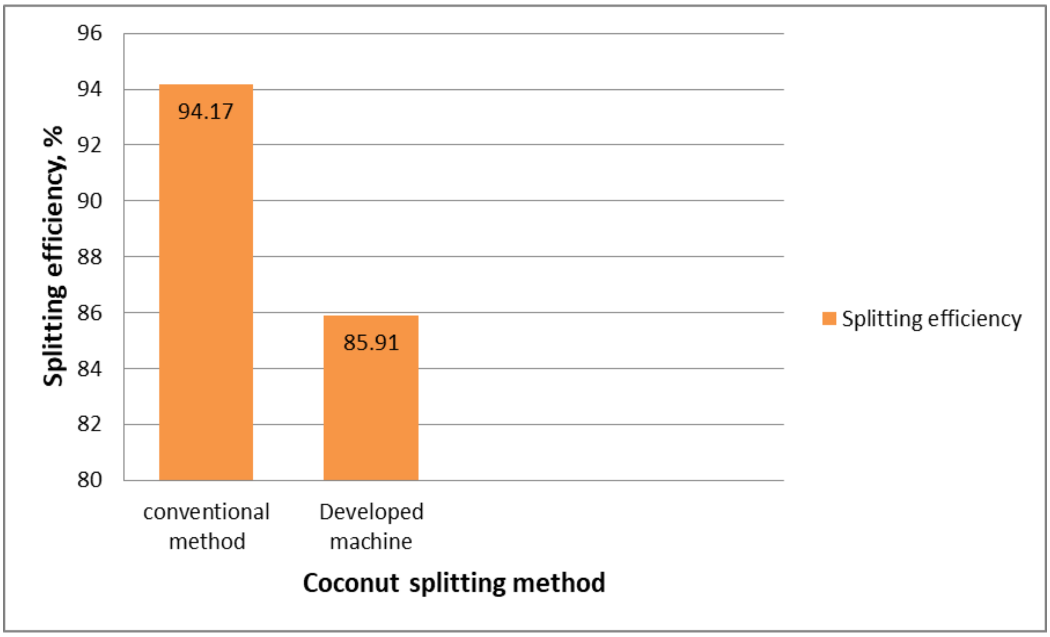


Fig 4.2 Splitting efficiency of two coconut splitting methods

4.6.3 Machine output capacity

The output capacity of the machine was determined by using the procedure given in the section 3.6.3. The splitting capacity of the developed machine was determined from the average splitting time required to split the coconut. The conventional method of splitting of the coconut has least output capacity of 110.09 kg h^{-1} while the output capacity of the developed machine was found to be 372.4 kg h^{-1}.

4.6.4 Number of coconuts split per hour

The average splitting capacity of two methods was evaluated by the total number of coconuts split per hour. Conventional method recorded the all-time low average capacity of 210 coconuts split per hour whereas the develop machine found 720 coconuts split per hour.

4.6.5 Efficiency of the machine

The efficiency of the machine was determined by using the procedure given in section 3.6.5. During the evaluation of the machine the total numbers of coconuts which split were noted down along with the total number of coconuts feed in the machine. The efficiency of the machine was found to be 85.71 per cent.

4.6.6 Uniformity in splitting

The uniformity in splitting of coconut is determined by using the procedure given in section 3.6.6. The *p*-value of x^2 was obtained by using Excel software for the 54 degrees of freedom was 1.00. Based on the *p*-value, we accept the null hypothesis and conclude that there is uniformity in the splitting of coconut. The calculations of the uniformity in splitting are presented in Appendix V.

4.6.7 Comparative performance

The comparative performance of two methods i.e. conventional and developed machine is given in Table below

Table 4.7 Operational performance of splitting methods

Performance index	Conventional	Developed machine
Power	89.18 W	456.9 W
splitting time	17.73 sec	4 – 6 sec
Damage	Shatter	Clean split
Capacity (kg h^{-1})	110.09	372.24
No. per hour	210	720
Ease of use	Difficult	Easy
Effort required	Very high	Quite easy
Wastage	Few	Much less

CHAPTER - V

SUMMARY AND CONCLUSIONS

Coconut (*Cocous nucifera L.*) is a commercial crop in India. The coconut palm, the most important of all cultivable palms is grown in more than 90 countries and territories of the world. The coconut palm has a variety of uses. Every part of the palm is useful to mankind in one or the other. Coconut palm provides food and livelihood to the large population in the world predominantly Asia Pacific Countries. The coconut palm is praised as KALPAVRIKSHA by considering the versatile nature of the crop and multi-uses for its products.

Presently there are few methods to split the coconut which includes manual and mechanical methods. By using certain mechanism coconut splitting is generally by sickle or by hitting it in a scale but it could not succeed as lack of inefficiency. Present trend and tools used are unsafe, messy, time consuming and need skill and training. The risk of injury is also too high.

Splitting energy and the splitting force requirement are some of the vital information in the design aspects of the continuous coconut splitter. Hence it becomes requisite to conduct a study on the physical and engineering properties of the coconut. Physical properties of a coconut were recorded. The splitting energy and splitting force of the coconut were determined with the help of impact test apparatus.

The impact test apparatus mainly consisted of a base, supporting frame, pendulum arm, splitting blades attached tom the free end of pendulum arm, dial gauge and a vice to hold coconut. The measurements were taken in the AICRP lab at Kelappaji College of Agricultural Engineering and Technology.

The machine was designed to split the raw coconuts into two half. There was a coconut feeder where the nuts were placed manually. A 1.0 HP motor was fixed to dive the gear box, impact tool and the coconut feeder. A single person was employed to place the nut in the feeder. The nuts were placed continuously in the feeder. The force required to split the coconut was induced by the springs attached to the impact tool. The coconut water was collected by using the stainless steel water trough in the bucket for the diversified products. The coconut water and the split coconuts are collected at the bottom.

Conclusions

- The different varieties of the coconut which were cultivated in the Tavanur Panchayat of Malappuram District of Kerala were found out as Lakshanganga, Keraganga, Anandaganga, Kerasree, Kerasowbhagya and Kerasagara. The physical and engineering properties of these varieties of the coconut were determined.
- The major diameter of the coconut was in the range 101.45 mm to 132.33 mm and the mean value was 117.24 mm. The minor diameter ranged between 87.51 mm to 107. 29 mm with mean of 97.09 mm. The intermediate diameter of the coconut ranged between 85.68 mm to 101.07 mm with the mean value of 93.29 mm.
- The shape of the coconut was found to be approximately as that of a ovoid or ellipsoid.
- The mean value of roundness of the coconut was found to be 0.65 with a standard deviation of 0.10.
- The mean value of the sphericity of the coconut was found to be 0.83 with a standard deviation of 0.05.
- The weight of the coconut ranges between 370.01 g to 781.69 g with a mean value of 579.99 g and standard deviation was found to be 104.56 g
- The average volume of the coconut was found to about 556.21 cm^3 with a standard deviation of 64.07 cm^3.
- The average density of the coconut was found to be about 1.04 g cm^{-3} with a standard deviation of 0.14 g cm^{-3}.
- There was no significant relation found between physical properties and splitting energy and force of the coconut.
- Rectangular type was used to determine the splitting energy and splitting force of the coconut.

- The average splitting energy and splitting force for rectangular blade was found to 35.84 J and 609.20 N respectively.
- Rectangular blade was found to be superior to split the coconut.
- In the splitting of the coconut, the splitting action was accomplished with the combined effect of bending and shearing.
- The performance evaluation of the developed machine was conducted and the observations were recorded.
- The splitting time required to split one coconut was found to be 5 seconds.
- The splitting efficiency of the machine ranges between 59.57 per cent to 99.40 per cent with an average of 85.51 per cent.
- The output capacity of the machine was found out to be 372.4 kg h^{-1}.
- The total number of coconuts split per hour was found to be 720.
- The efficiency of the machine was found to 85.71 per cent.
- As the impact type splitting mechanism was used to split the coconut, there was no direct contact of the coconut water and meat with the impact tool as well as the operator which leads the collection of both coconut water and coconut meat hygienically.

Suggestion for future work

The following are the suggestions for future work on similar or related research problems.

- Since the motor used was of low power, a high power motor can be used for better performance along with the attachment of dehusking operation
- The feeder slot for coconut holding can be increased in number, for more number of coconuts to be fed in one rotation of the shaft.
- The developed prototype has only one coconut feeder system and analyzed multiple feeder system can be employed for higher number of coconuts to be split per hour in future studies.

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APPENDICES

APPENDIX I

A. Physical and engineering properties of the coconut

Sl. No.	Major diameter (mm)	Minor diameter (mm)	Intermediate diameter (mm)	Sphericity	Roundness	Weight (g)	Volume (cm^3)	Density (g cm^{-3})
1.	131.87	97.42	95.58	0.77	0.58	586.92	642.57	0.91
2.	111.21	107.19	96.63	0.90	0.72	643.47	602.80	1.07
3.	103.50	91.39	87.45	0.87	0.53	563.29	432.90	1.30
4.	116.53	93.15	99.57	0.84	0.67	516.94	565.64	0.91
5.	127.57	105.06	94.5	0.81	0.73	579.68	662.78	0.87
6.	122.69	91.75	92.83	0.79	0.66	522.87	546.90	0.96
7.	118.81	103.04	88.73	0.83	0.67	599.47	568.41	1.23
8.	118.73	106.05	87.38	0.83	0.47	624.42	575.77	1.08
9.	126.96	97.00	87.62	0.77	0.66	504.23	564.70	0.89
10.	131.28	90.58	97.23	0.76	0.63	473.64	605.09	1.28
11.	124.77	93.99	85.74	0.77	0.63	470.63	526.21	0.89
12.	127.68	103.65	92.09	0.80	0.65	629.15	637.78	0.99
13.	131.17	96.62	99.29	0.78	0.78	690.90	658.51	1.05

14.	101.67	104.53	95.65	0.94	0.55	497.55	531.99	0.93
15.	110.93	105.38	86.60	0.86	0.81	519.66	529.77	0.98
16.	132.23	98.74	88.25	0.76	0.61	520.21	602.99	0.86
17.	117.57	106.83	94.72	0.86	0.82	552.68	622.62	0.89
18.	130.45	90.65	86.98	0.74	0.71	619.48	538.26	1.15
19.	127.64	97.82	96.01	0.79	0.50	623.14	627.35	0.99
20.	112.00	91.46	89.50	0.83	0.68	604.23	479.76	1.26
21.	106.90	101.96	95.57	0.90	0.50	489.51	545.17	0.90
22.	118.22	90.77	97.61	0.82	0.51	502.97	548.14	1.28
23.	127.21	102.43	91.19	0.79	0.61	622.53	621.86	1.00
24.	112.69	95.22	89.53	0.84	0.68	543.60	502.75	1.08
25.	109.61	98.86	86.41	0.85	0.74	567.40	490.05	1.16
26.	115.9	99.14	99.04	0.86	0.59	573.97	595.59	0.96
27.	101.71	99.83	98.39	0.94	0.79	630.43	522.86	1.20
28.	116.40	89.02	86.85	0.79	0.79	434.16	470.96	0.92
29.	110.54	95.58	100.73	0.88	0.61	563.65	556.97	1.01
30.	117.37	92.15	100.96	0.84	0.77	523.68	571.47	0.92
31.	128.82	99.17	88.57	0.77	0.57	596.83	592.16	1.00
32.	132.19	101.34	87.11	0.76	0.60	676.18	610.68	1.11

33.	120.38	103.32	100.10	0.85	0.53	646.74	651.56	0.99
34.	126.72	90.83	94.38	0.77	0.63	665.85	568.54	1.17
35.	103.30	92.15	88.95	0.87	0.56	490.84	443.09	1.11
36.	122.03	103.45	89.45	0.81	0.48	543.67	590.99	1.26
37.	102.78	89.52	92.57	0.88	0.70	415.88	445.69	0.93
38.	121.42	100.34	90.93	0.81	0.71	487.65	579.77	0.84
39.	109.10	90.11	88.38	0.83	0.62	370.01	454.69	0.81
40.	126.78	98.71	94.45	0.80	0.47	502.06	618.60	1.13
Mean	**117.24**	**97.09**	**93.29**	**0.83**	**0.65**	**579.99**	**556.20**	**1.04**
Max	**132.23**	**107.29**	**101.07**	**0.96**	**0.82**	**781.69**	**713.45**	**1.30**
Min	**101.45**	**87.51**	**85.68**	**0.73**	**0.46**	**370.69**	**425.67**	**0.80**
Range	**30.78**	**19.78**	**15.39**	**0.22**	**0.36**	**521.68**	**287.56**	**0.50**
S.D.	**9.00**	**5.57**	**4.59**	**0.046**	**0.10**	**104.56**	**64.07**	**0.14**
CV %	**7.68**	**5.74**	**4.93**	**5.54**	**15.77**	**18.028**	**11.52**	**13.75**

APPENDIX II

A. Splitting energy and force requirement for splitting of matured coconut for rectangular type blade

Trial No.	Major Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Splitting Energy, J	Splitting Force, N
1.	131.87	110	16	36.09	545.03
2.	111.20	110	21	35.42	637.08
3.	103.50	110	17	36.38	697.38
4.	116.52	110	17	36.09	619.44
5.	127.57	110	23	35.94	568.12
6.	122.69	110	18	35.42	574.39
7.	118.80	110	20	35.24	602.21
8.	118.73	110	18	35.94	602.59
9.	126.96	110	20	35.60	555.10
10.	131.28	110	23	36.09	547.46
11.	124.78	110	22	36.09	580.83
12.	127.68	110	16	35.60	567.62
13.	131.17	110	23	35.60	542.86
14.	101.67	110	19	35.94	715.54
15.	110.93	110	18	35.24	647.91
16.	132.23	110	22	35.94	545.88
17.	117.57	110	20	35.42	616.42
18.	130.44	110	23	35.77	548.48
19.	127.64	110	22	35.42	569.97
20.	112.00	110	20	35.77	635.75
21.	106.90	110	18	35.24	680.55
22.	118.22	110	23	35.24	605.18
23.	127.21	110	23	36.24	562.41
24.	112.69	110	16	36.09	634.87
25.	109.61	110	21	35.42	649.60
26.	115.90	110	16	36.24	625.31

27.	101.71	110	17	35.60	715.25
28.	116.40	110	23	36.38	624.99
29.	110.54	110	22	35.42	658.16
30.	117.37	110	23	36.38	603.61
31.	128.82	110	18	35.94	547.06
32.	132.19	110	19	36.24	546.05
33.	120.38	110	21	35.94	591.50
34.	126.72	110	18	36.09	556.14
35.	103.30	110	20	36.38	704.29
36.	122.03	110	16	36.09	577.51
37.	102.78	110	18	36.38	696.14
38.	121.42	110	19	35.42	596.87
39.	109.10	110	19	36.09	649.38
40.	126.78	110	19	35.60	555.87
41.	123.43	110	22	35.42	582.30
42.	110.16	110	17	35.94	643.14
43.	114.45	110	16	35.94	625.15
44.	108.11	110	22	35.24	664.79
45.	119.72	110	18	36.24	594.75
46.	108.75	110	21	36.09	657.91
47.	121.76	110	23	35.42	581.85
48.	131.49	110	22	36.38	535.97
49.	113.93	110	20	36.38	621.84
50.	111.26	110	21	35.60	651.41
Mean				**35.84**	**609.20**
Max				**36.38**	**715.54**
Min				**35.24**	**535.97**
Range				**1.14**	**179.57**
SD				**0.37**	**50.51**

APPENDIX III

Design calculations

1. Selection of prime mover

The torque transmitted by the shaft

$$T = F \times r \qquad \ldots 1$$

Where,

F = 715.54 N

r = 0.51 m

T = 715.54 x 0.51

= 364.93 N-m

Power required (in watts) was calculated as follows

$$P = \frac{2\Pi NT}{60} \qquad \ldots 2$$

T = 364.9, N-m

N = 14 rpm

$$P = \frac{2 \times 3.14 \times 14 \times 364.93}{60}$$

P = 534.74 W

P = 0.71 HP and selected as 1 HP

2. The length of the belt drive

1. The length of the belt drive was decided by the following

$$L = \frac{\Pi}{2} \times (d_1 + d_2) + 2x + \frac{(d_1 - d_2)^2}{4x} \qquad \ldots 3$$

Where,

L = Total length of the belt, m

x = 0.25 m

d_1 = 0.088 m

d_2 = 0.062 m

$$L = \frac{3.14}{2} \times (0.088 + 0.062) + 2 \times 0.25 + \frac{(0.088 - 0.062)^2}{4 \times 0.25}$$

$$L = 0.7362 \text{ m} = 730 \text{ mm} = 73 \text{ cm}$$

3. Speed of the gear box and sprocket drives

1. The speed of the input of the gear box was calculated by using the equation

$$\frac{N_G}{N_M} = \frac{D_M}{D_G} \quad \ldots 4$$

Where,

N_G = Speed of input of gear box, rpm

N_M = Speed of motor = 1353 rpm

D_M = Diameter of the motor pulley = 0.088 m

D_G = Diameter of the gear box pulley = 0.062 m

$$N_G = \frac{0.088}{0.062} \times 1353$$

$$N_G = 1920 \text{ rpm}$$

2. Calculation of output speed of gear box (first sprocket)

Output speed of gear box = Reduction ratio × Input speed

$$= \frac{1}{20} \times 1920$$

$$= 96 \text{ rpm}$$

3. Calculation of the speed at second sprocket

$$\frac{N_2}{N_1} = \frac{T_1}{T_2} \quad \ldots 5$$

Where,

N_1 = speed of output of gear box = 96

N_2 = speed of second sprocket, rpm

T_1 = Teeth of the gear box sprocket = 14

T_2 = Teeth of the second sprocket = 36

So, speed at second sprocket $N_2 = \frac{14}{36} \times 96$

= 37.33 rpm and selected as 37

Speed at third sprocket N_3= 37 rpm (It was on same shaft with second sprocket)

4. Calculation of the speed at fourth sprocket

$$\frac{N_4}{N_3} = \frac{T_3}{T_4} \quad \ldots 6$$

Where,

N_3 = speed of third sprocket =37 rpm

N_4 = speed of fourth sprocket, rpm

T_3 = Teeth of third sprocket = 14

T_4 = Teeth of fourth sprocket = 36

So, speed at fourth sprocket $N_4 = \frac{14}{36} \times 37$

= 14.38 rpm and selected as 14

Speed at fifth sprocket = 14 (It was on same shaft with sprocket fourth)

5. Calculation of the speed at sixth sprocket

$$\frac{N_6}{N_5} = \frac{T_5}{T_6} \quad \ldots 7$$

Where,

N_5 = speed of fifth sprocket = 14rpm

N_6 = speed of sixth sprocket, rpm

T_5 = Teeth of fifth sprocket = 11

T_6 = Teeth of sixth sprocket = 44

So, speed at sixth sprocket $N_6 = \frac{11}{44} \times 14$

= 3.5 rpm

The speed of feeder was found to be 3.5 rpm.

4. Velocity ratio of chain drives

The velocity ratio of a chain drive is given by

$$V.R. = \frac{N_1}{N_2} = \frac{T_2}{T_1} \quad \ldots 8$$

Where,

N_1 = Speed of rotation of smaller sprocket, rpm

N_2 = Speed of rotation of larger sprocket, rpm

T_1 = Number of teeth on smaller sprocket

T_2 = Number of teeth on larger sprocket

$$V.R. = \frac{96}{37} = \frac{36}{14} = 2.57$$

5. Velocity ratio of belt drive

$$V.R. = \frac{N_{driven}}{N_{driver}} = \frac{D_{driver}}{D_{driven}} \qquad \text{... 9}$$

Where,

N_{driver} = Speed of driver = 1353 rpm

N_{driven} = Speed of driven = 1920 rpm

D_{driver} = Diameter of the driver pulley = 0.088 m

D_{driven} = Diameter of the driven pulley = 0.062 m

V.R. of belt drive = $\frac{1920}{1353} = \frac{0.088}{0.062} = 1.41$

6. Length of chain and center distance

Length of the chain is given by the expression

$$L = K \times p \qquad \text{… 10}$$

Where,

L = Length of the chain, m

K = Number of the chain links

P = Pitch of the chain, m (from *design data* book)

The number of chain link may be obtained from the following expression,

$$K = \frac{T_1+T_2}{2} + \frac{2x}{p} + \left[\frac{T_2-T_1}{2\Pi}\right]^2 \frac{p}{x} \qquad \text{… 11}$$

Where,

K = Number of chain links

T_1 = Number of teeth on smaller sprockets

T_2 = Number of teeth on larger sprockets

p = Pitch of the chain, m

x = Centre distance, m

The value of K as obtained from the above expression must be approximated to the nearest even number.

The centre distance is given by

$$x = \frac{p}{4}\left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1+T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\Pi}\right)^2}\right] \quad \ldots 12$$

In order to accommodate initial sag in the chain, the value of the centre distance obtained from the above equation should de decrease by 2 to 5 mm.

1. Length of chain and number of chain links for first drive

$$K = \frac{T_1+T_2}{2} + \frac{2x}{p} + \left[\frac{T_2-T_1}{2\Pi}\right]^2 \frac{p}{x}$$

Where,

T_1 = 14

T_2 = 36

p = 0.0127 m (*Design data hand book*)

x = 0.202 m

$$K = \frac{14+36}{2} + \frac{2 \times 0.202}{0.0127} + \left[\frac{36-14}{2\Pi}\right]^2 \frac{0.0217}{0.202}$$

K =58.12 and selected as 60

The center distance is given by

$$x = \frac{p}{4}\left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1+T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\Pi}\right)^2}\right]$$

$$x = \frac{0.0127}{4}\left[60 - \frac{14+36}{2} + \sqrt{\left(60 - \frac{14+36}{2}\right)^2 - 8\left(\frac{36-14}{2\Pi}\right)^2}\right]$$

x = 0.204 m = 204 mm = 20.4 cm

Now, Length of chain L for first drive was calculated as

L = 60 × 0.0127

= 0.762 m = 762 mm = 76.2 cm

2. Length of the chain a number of chain links for second drive

$$K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2\Pi}\right]^2 \frac{p}{x}$$

Where,

$T_1 = 14$

$T_2 = 36$

$p = 0.0127$ m (*Design data hand book*)

$x = 0.178$ m

$$K = \frac{14+36}{2} + \frac{2 \times 0.178}{0.0127} + \left[\frac{36-14}{2\Pi}\right]^2 \frac{0.0217}{0.178}$$

K =53.52 and selected as 54

The center distance is given by

$$x = \frac{p}{4}\left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1+T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\Pi}\right)^2}\right]$$

$$x = \frac{0.0127}{4}\left[54 - \frac{14+36}{2} + \sqrt{\left(54 - \frac{14+36}{2}\right)^2 - 8\left(\frac{36-14}{2\Pi}\right)^2}\right]$$

x = 0.178 m = 178 mm = 17.8 cm

Now, Length of chain L for second drive is calculated as

$L = 54 \times 0.0127$

= 0.685 m = 685 mm = 68.5 cm

3. Length of the chain and number of chain links for third drive

$$K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left[\frac{T_2 - T_1}{2\Pi}\right]^2 \frac{p}{x}$$

Where,

$T_1 = 11$

$T_2 = 44$

$p = 0.0127$ m (*Design data hand book*)

$x = 0.516$ m

$$K = \frac{11+44}{2} + \frac{2 \times 0.516}{0.0127} + \left[\frac{44-11}{2\Pi}\right]^2 \frac{0.0217}{0.516}$$

K =109.91 and selected as 110

The center distance is given by

$$x = \frac{p}{4}\left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1+T_2}{2}\right)^2 - 8\left(\frac{T_2 - T_1}{2\Pi}\right)^2}\right]$$

$$x = \frac{0.0127}{4}\left[110 - \frac{11+44}{2} + \sqrt{\left(110 - \frac{11+44}{2}\right)^2 - 8\left(\frac{44-11}{2\Pi}\right)^2}\right]$$

x = 0.516 m = 516 mm = 51.6 cm

Now, Length of chain L for third drive is calculated as

L = 110 × 0.0127

= 1.397 m = 1397 mm = 139.7 cm

7. Design of shaft

Torque transmitted by the shaft is expressed as

$$T = \frac{\Pi}{16} \times \tau \times d^3 \qquad \dots 13$$

By using this equation, the diameter of the shaft is calculated by the equation expressed as

$$D = \sqrt[3]{\frac{T \times 16}{\tau \times \Pi}} \qquad \dots 14$$

Where,

D = Diameter of the shaft, mm

T = 364.93 N-mm

τ = 130 MPa

$$D = \sqrt[3]{\frac{364.93 \times 10^3 \times 16}{130 \times \Pi}}$$

D = 24.27 mm and selected as 25 mm

APPENDIX IV

Splitting efficiency of the developed machine

Sl. No.	Length of Observable crack (cm)	Diameter of coconut across the axis (cm)	Splitting efficiency
1.	8.35	9.45	88.36
2.	8.30	9.25	89.73
3.	9.80	10.85	90.32
4.	8.00	8.90	89.89
5.	9.20	10.85	84.79
6.	9.60	10.75	89.30
7.	7.85	9.95	78.89
8.	7.05	9.20	76.63
9.	8.00	8.85	90.40
10.	8.40	9.25	90.81
11.	8.05	9.40	85.64
12.	8.30	9.65	86.01
13.	7.00	8.70	80.46
14.	7.30	7.70	94.81
15.	8.40	9.55	87.96
16.	7.80	9.30	83.87
17.	9.30	10.10	92.08
18.	8.60	9.80	87.76
19.	8.00	8.30	96.39
20.	9.60	10.45	91.87
21.	9.80	10.35	94.69
22.	8.60	10.20	84.31
23.	9.50	10.50	90.48
24.	8.60	9.10	94.51
25.	8.45	9.55	88.48
26.	8.20	9.90	82.83
27.	8.50	9.80	86.73

28.	7.45	10.40	71.63
29.	7.40	8.85	83.62
30.	8.20	8.75	93.71
31.	8.00	9.15	87.43
32.	9.50	10.05	94.53
33.	9.00	9.70	92.78
34.	9.80	10.20	96.08
35.	9.65	10.30	93.69
36.	8.15	9.85	82.74
37.	8.20	9.00	91.11
38.	8.70	9.55	91.10
39.	7.20	8.80	81.82
40.	7.40	10.65	69.48
41.	8.20	10.35	79.23
42.	8.95	9.40	95.21
43.	8.15	10.40	78.37
44.	10.15	11.20	90.63
45.	8.95	11.90	75.21
46.	9.20	10.00	92.00
47.	8.85	9.50	93.16
48.	7.60	10.70	71.03
49.	9.25	10.00	92.50
50.	10.15	11.20	90.63
Mean	**8.23**	**9.62**	**85.61**
Max	**10.15**	**11.90**	**99.40**
Min	**5.60**	**7.40**	**59.57**
Range	**4.55**	**4.50**	**39.83**
S.D.	**0.9770**	**0.8012**	**8.2501**

APPENDIX V

Uniformity in splitting

X^2 test for goodness of fit

If O_i is a set of observed diameter of the coconut after splitting and E_i is corresponding set of expected diameter of the coconut after splitting, the Karl Pearson's Chi-square (x^2) is given by

$$x^2 = \sum \left[\frac{(Oi - Ei)^2}{E_i} \right]$$

We assume that there is uniformity in the splitting of coconut. That means, the top part diameter is in agreement with expected diameter of the coconut after splitting. Now we can compute the value of x^2 as shown below.

Sl. No.	Top part diameter (O_i)	Expected diameter (E_i)	$(O_i - E_i)$	$(O_i - E_i)^2$	$\frac{(Oi - Ei)2}{Ei}$
1.	8.35	5.73	2.63	6.89	1.20
2.	6.40	5.63	0.78	0.60	0.11
3.	7.45	6.43	1.03	1.05	0.16
4.	5.55	5.45	0.10	0.01	0.00
5.	7.45	6.43	1.03	1.05	0.16
6.	6.85	6.38	0.48	0.23	0.04
7.	7.85	5.98	1.88	3.52	0.59

8.	7.05	5.60	1.45	2.10	0.38
9.	5.95	5.43	0.53	0.28	0.05
10.	8.40	5.63	2.78	7.70	1.37
11.	8.05	5.70	2.35	5.52	0.97
12.	6.80	5.83	0.98	0.95	0.16
13.	7.00	5.35	1.65	2.72	0.51
14.	5.30	4.85	0.45	0.20	0.04
15.	8.40	5.78	2.63	6.89	1.19
16.	6.90	5.65	1.25	1.56	0.28
17.	5.90	6.05	-0.15	0.02	0.00
18.	6.95	5.90	1.05	1.10	0.19
19.	5.70	5.15	0.55	0.30	0.06
20.	6.40	6.23	0.18	0.03	0.00
21.	7.60	6.18	1.43	2.03	0.33
22.	6.50	6.10	0.40	0.16	0.03
23.	7.20	6.25	0.95	0.90	0.14
24.	7.65	5.55	2.10	4.41	0.79
25.	5.50	5.78	-0.28	0.08	0.01

26.	6.15	5.95	0.20	0.04	0.01
27.	6.45	5.90	0.55	0.30	0.05
28.	7.45	6.20	1.25	1.56	0.25
29.	7.40	5.43	1.98	3.90	0.72
30.	8.20	5.38	2.83	7.98	1.48
31.	6.35	5.58	0.77	0.60	0.11
32.	9.50	6.03	3.48	12.08	2.00
33.	5.70	5.85	-0.15	0.02	0.00
34.	6.15	6.10	0.05	0.00	0.00
35.	6.90	6.15	0.75	0.56	0.09
36.	7.60	5.93	1.68	2.81	0.47
37.	8.00	5.50	2.50	6.25	1.14
38.	8.70	5.78	2.93	8.56	1.48
39.	7.00	5.40	1.60	2.56	0.47
40.	7.40	6.33	1.08	1.16	0.18
41.	8.20	6.18	2.03	4.10	0.66
42.	8.95	5.70	3.25	10.56	1.85
43.	8.15	6.20	1.95	3.80	0.61

44.	10.15	6.60	3.55	12.60	1.91
45.	8.95	6.95	2.00	4.00	0.58
46.	6.05	6.00	0.05	0.00	0.00
47.	8.85	5.75	3.10	9.61	1.67
48.	7.60	6.35	1.25	1.56	0.25
49.	6.70	6.00	0.70	0.49	0.08
50.	10.15	6.60	3.55	12.60	1.91
51.	7.60	5.80	1.80	3.24	0.56
52.	6.30	5.30	1.00	1.00	0.19
53.	5.90	5.40	0.50	0.25	0.05
54.	6.10	5.30	0.80	0.64	0.12
55.	8.45	6.00	2.45	6.00	1.00
					28.68

The *p*-value of x^2 is obtained by using Excel software for the 54 degrees of freedom is 1.00. Based on the *p*-value, we accept the null hypothesis and conclude that there was uniformity in the splitting of coconut.

APPENDIX VI

Cost Analysis

A. Basic information

1)	Cost of the machine	:	29485
2)	Useful life, year	:	4
3)	Hours of use per year	:	960 (4 x 240)
4)	Number of labours required	:	1
5)	Rate of interest	:	10%
6)	Salvage value (10% of investment cost)	:	2948.5
7)	Output capacity of machine	:	372.24 kg h^{-1}
8)	Electricity consumption	:	0.746 kW h^{-1}

B. Various costs

1. Fixed cost

(i) Depreciation cost per year, Rs

$$= \frac{Initial\ cost - salvage\ cost}{Usefull\ life}$$

$$= \frac{29485 - 2948.5}{4}$$

$$= 6634.125$$

(ii) Interest on investment per year, Rs

$$= \frac{Initial\ cost + salvage\ cost}{2} \times 0.10$$

$$= \frac{29485+2948.5}{2} \times 0.10$$

$$= 1621.675$$

(iii) Housing, insurance and shelter per year, Rs

= Initial cost x 0.03

= 29485 x 0.03

= 884.55

(iv) Total fixed cost per year, Rs = 6634.5 + 1621.675 + 884.55

= 9140.35

(v) Total fixed cost per hour, Rs $= \frac{Total\ fixed\ cost\ per\ year}{Hours\ \ of\ use\ per\ year}$

= 19.04

2. Variable cost

(i) Repair and maintenance per hour, Rs $= \frac{Initial\ cost\ \times 0.05}{Hours\ of\ use\ per\ year}$

= 3.071

(ii) Electricity cost per hour, Rs = Units required x Electricity rate

= 0.746 x 4.80

= 3.58

(iii) Labour cost per hour, Rs = 50

(iv) Total variable cost per hour, Rs = 3.071 + 3.58 + 50

= 56.65

3. Total cost per hour

= Fixed cost + Variable cost

= 19.04 + 56.65

= 75.69

C. Break Even Point

$$BEP = \frac{AFC}{CF-C}$$

Where,

BEP	=	Break-even point, h yr^{-1}
AFC	=	Annual fixed cost for the machine, Rs. yr^{-1}
CF	=	Custom fee, R. h^{-1}
C	=	Operating cost Rs. h^{-1}
CF	=	Cost of operation h^{-1} + 25 per cent overhead charges) + (25 per cent profit over new cost)

Annual fixed cost Rs. yr^{-1} = 9140.35

Custom fee, Rs. h^{-1} = (Cost of operation h^{-1} + 25 per cent overhead charges) + (25 per cent profit over new cost)

Custom fee, Rs. h^{-1} = (75.69 + 75.69 × 0.25) × 1.25

Custom fee, Rs. h^{-1} = 118.26

Operating cost, Rs. h^{-1} = 56.65

$$BEP = \frac{9140.35}{118.26-56.65}$$

= 148.36 h per annum say 150 h yr^{-1}

Annual utility = Electricity consumption × Annual utility period

= 0.746 × 960

= 716.16

Therefore, BEP is achieved about (4 × 100)/716.16 = 99.44 per cent of annual utility rate of 960 hours of the splitting machine.

D. Pay-back period

$$PBP = \frac{IC}{ANP}$$

Where,

PBP	=	Payback period, yr
IC	=	Initial cost of machine, Rs
ANP	=	Average net annual profit, Rs. yr^{-1}
ANP	=	(CF – C) × AU

Where,

AU = Annual use, h yr^{-1}

Initial cost of machine, Rs = 29485

Average net annual benefit, Rs = (Custom fee h^{-1} – Total cost of operation h^{-1}) × Annual utility rate, h

= (118.26 - 75.69) × 960

= 40867.2

Therefore, payback period = 29485/40867.2

= 0.72 year say 9 months

E. Benefit cost ratio

Benefit cost = Cost of manual splitting – cost of machine splitting

Therefore,

$$\text{Benefit cost ratio} = \frac{Benefit\ cost}{Cost\ of\ machine\ splitting}$$

Benefit cost = 400 - 75.69 =324.31

$$\text{B:C ratio} = \frac{324.31}{75.69}$$

= 4.28

DESIGN AND DEVELOPMENT OF CONTINUOUS TYPE COCONUT SPLITTER

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ABSTRACT

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DESIGN AND DEVELOPMENT OF CONTINUOUS TYPE COCONUT SPLITTER

ABSTRACT

Coconut (*Cocous nucifera L.*) is one of the most prominent commercial crops in tropical and is usually referred as “tree of heaven”. The seed or the fruit of the coconut palm, which is also referred as coconut must be dehusked and split before using for various purposes. Although there are different techniques and tools for splitting or cracking open the mature coconut, there is no suitable machine for continuous splitting of nut with provision for collecting the coconut water hygienically. Development of such machine requires a detailed investigation on the physical and engineering properties of coconut. Splitting energy and splitting force required are certain other vital information necessary for the design. Hence this study was undertaken for investigating the design parameters for the development of a continuous coconut splitting machine.

The physical properties of the coconut were determined using standard procedures and the splitting energy requirement was determined using an impact test apparatus. The maximum splitting force was then calculated from the splitting energy. Based on the maximum splitting force and physical properties, the design parameters were evolved, and a machine was designed and developed. The trails of the machine were then conducted to evaluate the performance in comparison with the conventional splitting method.

The average major diameter of the coconuts were obtained as 117.24 mm with standard deviation of 9.00 mm. The average minor diameter of the coconuts were recorded as 97.09 mm with standard deviation of 5.57 mm. The average intermediate diameter of the coconuts were found to be 93.29 mm with a standard deviation of 4.59 mm. The average weight of the coconuts were observed as 579.99 g with a standard deviation of 104.56 g. The average roundness of the coconuts were measured and found to be 0.65

with a standard deviation of 0.10. The average sphericity of the coconuts was 0.83 with a standard deviation of 0.05. The average volume of the coconuts were 556.20 cm^3 with a standard deviation of 64.07 cm^3. The average density was 1.04 g cm^{-3} with a standard deviation of 0.14 g cm^{-3}. The maximum splitting energy and force needed to split coconuts were recorded as 35.84 J and 609.25 N respectively.

The machine was designed to split coconut by impact force, by making an impact tool hitting the nut positioned in continuously rotating feeder. The impact tool held in position by a tension spring, was actuated by a cam, which in turn receives power from an electric motor of 0.746 kW. Speed reduction gear box, chain and sprockets were used for transmitting the power from motor to the impact tool. Water collecting trough and strainer were fixed beneath the feeder and impact tool.

The performance evaluation of continuous type coconut splitter was conducted, and it was found that time require to split the coconut is 5 seconds. The average splitting efficiency of the machine was obtained as 85.51 per cent with a standard deviation of 8.25. The output capacity of the developed machine was 372.4 kg h^{-1}. The total number of coconuts split per hour was obtained as 720. The efficiency of the machine was obtained as 85.71 per cent.

Keywords: *Coconut, Splitting energy, Splitting force, Impact tool, splitting efficiency, machine output capacity, efficiency of the machine.*