DESIGN AND FABRICATION OF AN AUTOMATED SLICING MACHINE FOR ROOT (YAM) AND PERENNIAL CROPS (BANANA, PLANTAIN AND CUCUMBER)

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BENIN CITY.

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CERTIFICATION

This is to certify that this dissertation was carried out by **FABELURIN OLUWASHOLA SAMUEL** with Matric Number **ENG1504042**, under my supervisors and that the thesis has been accepted and approved in partial fulfillment for the award of Bachelor of Engineering (B.ENG) degree in the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City.

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DEDICATION

This Thesis is dedicated to ALMIGHTY GOD, the creator of the universe for His guidance and protection whose loving mercy and grace has kept me this far during the course of my study. I also dedicate this to my beloved Mother who has been my backbone and to the entirety of engineering worldwide.

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ABSTRACT

Perennial crops (Plantain, cucumber and banana) and tuber crops (yam) are one of the alternative sources for low cost carbohydrates and is considered as one of the major crop in the Nigeria. They are perishable perennial and tuber crops that tends to easily deteriorates which in turn pose a problem in the society. Thus, the processing of plantain, cucumber, banana and yam after harvest is necessary to extend the shelf life of products in their raw form. Therefore, the aim of the project is to design and fabricate an automated slicing machine capable of slicing plantain, cucumber, banana and yam into chips that can also be readily made available in other processed forms whilst taking into consideration, fast and less labor processing, ease of use and hygienic design.

The major components of the machine that were incorporated in the machine to achieve the set out aim and objectives included the spring, pulley, bearing, electric motor, mainframe, belt drive, cutting disc, and slicing shaft. The machine was powered by a single-phase, 1440rpm, and 0.75KW electric motor. These machine specifications were induced to achieve the results. The performance of the machine was evaluated in slicing four selected agro-based crops (yam, plantain, cucumber, and banana) grouped into small sizes at machine speeds of 40 rpm, 80.12rpm, and 630rpm respectively. The parameters that were investigated were performance efficiency and capacity.

In performing the machine test, each fingers of plantain, cucumber, banana and yam were first peeled manually with a knife to remove its pericarp (outer covering), and then, these peeled sets of cucumber, plantain, banana and yam were loaded into the feeding inlet after the spring compression. During this process, the slicing process took place and the machine's capacity, efficiency, and thickness were determined in order to evaluate the machine's performance to slice plantain, cucumber, plantain and banana. A capacity of 59Kg/hr, performance efficiency of 92.1% and at speed of 40 rpm was obtained for yam, while a capacity of 62.4Kg/hr., performance efficiency of 89.99% at a speed of 630 rpm was obtained for banana, a capacity of 48.5Kg/hr., efficiency of 90.5% at a speed of 80.1rpm was obtained for cucumber and capacity of 72.7Kg/hr. and efficiency of 89.95%, at a speed of 630 rpm was obtained for plantain. The result of the study shows that the machine can slice root and tuber crops satisfactorily with slices ranging from 2mm to 2.5mm mean thickness. This machine was made with the intention of assisting cucumber, yam, plantain and banana chips producing industries.

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CHAPTER ONE

INTRODUCTION

In this chapter, agriculture and the basic information on banana, plantain, cucumber and yam snack production are introduced. Banana, plantain, cucumber and yam are foods that are directly related to this project whereby they will be the groups of food that will be processed by using this machine. Also, there will be a brief information on chips production that as well be discussed.

1.1.Background of the Study

Agriculture is the heart of civilization; however, farmers are facing a continuing population explosion which has confronted mankind with various problems. These problems include imminent starvation. Hence optimum production/processing is needed to attain the demand for food nowadays. In order to address the problem and ensure food sustainability, there is absolute need for adequate technology in terms automation/mechanization in processing various agricultural produce. (Gumanit and Pugahan, 2015).

Nigeria is predominantly still an agricultural society. Approximately 70 percent of the population engages in agricultural production at a subsistence level. Agricultural holdings are generally small and scattered. Agriculture provided 41 percent of Nigeria's total gross domestic products (Osakwe and Ojo, 1986). This percentage represented a normal decrease of 24.7 percent from its normal contribution of 65.7 percent to the GDP in 1957. The decrease will continue because, as economic development occurs, the relative size of the agriculture sector also decreases. This is in fact, a big blow on the Nigerian agricultural sector due to significant lack of Automation/mechanization practices adopted in the country (National Bureau of Statistics, GDP Report Q3 2019).

Manual processing (slicing) of yam, plantain, banana, and cucumber is laborious and intensive where there is retard process for producing such product. In rural areas, manual processing operation in the aforementioned agro based products is practiced because there are no locally available machineries. As the world is emerging with various type of technology for better quality of life and efficient production of food, automation and mechanization technology for agricultural machines are used for faster, lesser labor agricultural production for sustainable agriculture. Locally designed and fabricated chip slicing equipment is still low in some rural areas which further gives less production for local industry and provides hindrance to optimum production for local farmers. Thus, mechanization or automation contributes a valuable factor to the economic and industrial potential of the above agro based products as commodity. (Agbetoye, 2009).

Root and tuber crops occupy the same position in the tropics analogous to grains in the temperate regions as the major staple food. The storage potential of the different root and tuber crops differ, but generally, they do not store well in the fresh form and transportation is costly due to their bulkiness (Clarke, 1987; Martins, 1972; Ekechukwu et al., 1987). Processing into staple, non-perishable produce offers an alternative to storage in the fresh form. They are best preserved in the dried form by processing into flour, chips and pellets for both human and livestock consumption.

Generally, the size of food materials is often reduced during processing for many reasons chief among which are drying, boiling or steaming and frying or roasting. Slicing of crops before drying reduces the drying time by exposing more surface area to the air. The preservation of almost all processed root and tuber crop products depends on reducing the moisture to a level which prevents the growth of micro-organism. Crops are often sliced before cooking and steaming, either for direct consumption or as one step in a processing system. The process of cutting or slicing the crops give rise to faster cooking.

Crops are commonly sliced and prepared by frying in hot oil or roasting. Roasting is widely practiced throughout Africa where traditional techniques include burning the whole root in hot ashes or holding it in front of a fire. This practice of roasting food items without slicing the product takes longer time than when they are sliced (UNIFEM, 1993). Proper roasting is important to ensure a good quality product. Both frying and roasting enhance the flavor of the root crop and most importantly reduce its moisture content, so extending its shelf life. When packaged properly, fried, crisp products can have a shelf life of several months (UNIFEM, 1993).

The operations involved in processing root and tuber crops include washing, peeling, size reduction (chipping, slicing and grating), drying and milling. There are many processes involved in food size reduction. They include grinding or grating (cassava, yam), dicing (potato, yam, onion), slicing (carrot, onion, yam, onion and banana), milling (rice, corn and wheat), chipping (cassava, yam and banana).

Cucumber (Cucumis sativus) is **a widely-cultivated creeping vine plant** in the **Cucurbitaceae gourd family** that bears usually cylindrical fruits, which are used as vegetables. Considered an annual plant, there are three main varieties of cucumber — slicing, pickling, and burpless/seedless — within which several cultivars have been created. The cucumber originates from South Asia, but now grows on most continents, as many different types of cucumber are traded on the global market. In North America, the term wild cucumber refers to plants in the genera Echinocystis and Marah, though the two are not closely related. *Food Chemistry*, vol. 132, no. 1, pp. 428–432, 2012.

Cucumbers have a mild, refreshing taste and a high water content. They can help relieve dehydration and are pleasant to eat in hot weather. People eat cucumber as a savory food, but it is a fruit. It also features in some beauty products.

The cucumber is a member of the Cucurbitaceae family. Other members of the family include squash and different kinds of melon, including bitter melon. Cucumbers provide various nutrients but are low in calories, fat, cholesterol, and sodium. *Food Chemistry*, vol. 82, no. 4, pp. 619–623, 2003.

1.2. Statement of the Problem

Manual cutting and slicing of tubers and roots has proved to be very time consuming and is prone to risk of contamination of the food leading to high rates of foodborne diseases. Various methods have been implemented in the process of size reduction of roots and tubers ranging from manual, electric and automated.

Majority of the existing slicing machines are imported, expensive and sophisticated which are not easy to operate and maintain by the local farmers. Also, some of these machines are designed for a particular type of crop and cannot be used for other crops. Presently, there is need for increased preservation of root and tuber crops in the country in order to prolong storage period. Therefore, to boost the preservation of root and tuber crops in large quantity, there are need to design and fabricate a machine that will enhance preservation.

1.3. Aim and Objectives the Study

1.3.1. Aim of the Study

To Design and Fabricate an Automated Slicing/Cutting Machine of Agro-based Products (Yam), Perennial Crops (Plantain and Banana) and Cucumber.

1.3.2. Objective of the Study

This project is therefore conducted to achieve the following objectives:

i. To design and fabricate an automated slicing machine for agro-based tuber products
ii. To evaluate the performance of the machine in slicing plantain, banana, cucumber and yam at different cutting speed.
iii. To select appropriate materials for the manufacture of the machine

1.4.Scope of the Study

The scope of this study is to design and fabricate an automated slicing machine that is able to slice yam, plantain, banana and cucumber into desired chip sizes.

1.5.Significance of the Study

The need for increase in productivity and ease of operation for local farmers and traders led to production of an Automated Slicing Machine specifically for tubers and roots. This study sets to compare manual process and automatic means with the help of a pulley system to improve productivity at reduced stress rate.

Also, it seeks to compare the unique cutting speed and angle of cut/slice of the machine to other pre-existing slicing/cutting machines.

CHAPTER TWO

LITERATURE REVIEW

The development of automated slicing machine is necessary in order to produce machine that is portable and at the same time high in performance compare to its' size. Industries nowadays are trying hard to improve machine efficiencies to maximize outputs. The higher the efficiencies the more amounts of energy and cost are reduced. Hence, this will directly increase the profit. But, for automated machine wise, the higher the efficiency, the easier the machine would be operated for it requires less energy (man power). Existing machine may need to be improved in terms of durability, efficiency, weight, speed or cost (Burr and Cheantham, 1995). This chapter will briefly discuss on foods which are directly related to the project and overview different types of cutting machine; manual or electrically powered with different cutting method in order to increase the production rate.

A review of other relevant studies is also provided. The review is organized chronologically to give a comprehensive view of how past research efforts have laid the groundwork for subsequent studies, including the present research effort.

2. Tuber Crops (Yam) and Perennial Crops (Banana and Plantain)

Tuber crops are utilized extensively for human and livestock consumption as well as for industrial purposes. In order to expand the utilization of the tubers, there is need for an extensive exploration of their value addition by improving the shelf life of the products and enhancing foreign exchange. However, the processing of the tubers, especially the peeling operation, is usually labor intensive and requires a high level of mechanization in order to meet the high demand for the products. The peeling operation has become a major bottleneck in tuber processing, especially for cassava and yam, because of the difference in their physical and mechanical properties. (Fang et al).

Fig 2. 1 Yam

Root and tuber crops (cassava, plantain, sweet potato, yam, cocoyam, etc.) are among the most valuable food source for tens of millions of people in West Africa. Increased production of root crops in Nigeria has about the need for the development of appropriate processing technology. Cassava considered as an important source of energy diet in Nigeria, which plays a major role in alleviating food because of its efficient production of food energy, year-round availability, tolerance to extreme stress condition, ability to present farming and food system in Africa. World consumption of cassava for food (fresh or processed) is concentrated in developing countries. The wide production is about 84 million tons. Highest production is in Africa- 99.1, 51.5 and 33.2 million tons in A Latin America respectively. Nigeria has annual output potential for cassava production of 75.5 million. In Asia over 40% of the cassava is for direct human consumption, with much of the remainder expended as chips. The major consumers are concentrated in India and Indonesia. In India, baked roots are converted in chips and flour. In Indonesia, 57% of production is for human consumption while 43 percent are eaten and processed into dried chips.

Nigeria is by far the world's largest producer of yam, accounting for over 70–76 percent of the world production. According to the Food and Agricultural Organization (FAO) report, Nigeria produced 18.3 million yams from 1.5 million hectares, representing 73.8 percent of total yam production in Africa.

Yam production in Nigeria has nearly doubled since 1985. In this perspective, the world's second and third largest producer of yams, Côte d'Ivoire and Ghana, only produced 6.9 and 4.8 tons of yams in 2008 respectively. According to International Institute of Tropical Agriculture, Nigeria accounted for about 70 percent of the world production amounting to 17 million tons from land area 2,837,000 hectares under yam cultivation. Yams are grown in the coastal region and rain forests, wood savanna and southern savanna habitats. In Nigeria, yam-producing areas refer to 'yam is food and food is yam'.

Starchy root and tuber crops are second only in importance to cereals as global sources of carbohydrates. They provide a substantial part of the world's food supply and are also an important source of animal feed and processed products for human consumption and industrial use. Starchy roots and tubers are plants which store edible starch material in subterranean stems, roots, rhizomes, corms, and tubers and are originated from diversified botanical sources. Potatoes and yams are tubers, whereas taro and cocoyams are derived from corms, underground stems, and swollen hypocotyls. Cassava and sweet potatoes are storage roots and canna and arrowroots are edible rhizomes. All these crops can be propagated by vegetative parts and these include tubers (potatoes and yams), stem cuttings (cassava), vine cuttings (sweet potatoes), and side shoots, stolons, or corm heads (taro and cocoyam). The contribution of roots and tubers to the energy supply in different populations varies with the country. The relative importance of these crops is evident through their annual global production which is approximately 836 million tons. Asia is the main producer followed by Africa, Europe, and America. Asian and African regions produced 43 and 33%, respectively, of the global production of roots and tubers. A number of species and varieties are consumed but cassava, potatoes, and sweet potatoes consist of 90% global production of root and tuber crops. Nutritionally, roots and tubers have a great potential to provide economical sources of dietary energy, in the form of carbohydrates. The energy from tubers is about one-third of that of an equivalent weight of rice or wheat due to high moisture content of tubers. However, high yields of roots and tubers give more energy per land unit per day compared to cereal grains. In general, the protein content of roots and tubers is low ranging from 1 to 2% on a dry weight basis. Potatoes and yams contain high amounts of proteins among other tubers. Sulphur-containing amino acids, namely, methionine and cystine, are the limiting ones in root crop proteins. Cassava, sweet potatoes, potatoes, and yam contain some vitamin C and yellow varieties of sweet potatoes, yam, and cassava contain β-carotene. (Chang, 2010).

2.1.Properties of Tuber Crops (Yam) and Perennial Crops (Banana and Plantain)

Plants producing starchy roots, tubers, rhizomes, corms, and stems are important to nutrition and health. They play an essential role in the diet of populations in developing countries in addition to their usage for animal feed and for manufacturing starch, alcohol, and fermented foods and beverages. Roots and tuber crops are important cultivated staple energy sources, second to cereals, generally in tropical regions in the world. They include potatoes, cassava, sweet potatoes, yams, and aroids belonging to different botanical families but are grouped together as all types produce underground food. An important agronomic advantage of root and tuber crops as staple foods is their favorable adaptation to diverse soil and environmental conditions and a variety of farming systems with minimum agricultural inputs. In addition, variations in the growth pattern and adopting cultural practices make roots and tubers specific in production systems. However, roots and tuber crops are bulky in nature with high moisture content of 60–90% leading them to be associated with high transportation cost, short shelf life, and limited market margin in developing countries. (Thompson, 2009).

2.1.1. Yam

Yam is the common name for members of the genus Dioscorea (family Dioscoveacoae). They are more than 600 species of yam. Certain species are planted for the food consumption of their starchy tubers in Africa, Asia, Latin America and Oceania. Potatoes and sweet potatoes are examples of plants that been consume in similar manner as yam. There are hundreds of varieties among the cultivated species (PFAF, 1997). The yam has a rough skin which is difficult to peel, but which softens after heating.

Fig 2. 2 Yam Property

Yam skins vary in color from dark brown to light pink. The majority of the yam is composed of a much softer substance known as the flesh within. This substance ranges in color from white to bright orange in ripe yams. Yam is a very easily grown plant that succeeds in most fertile well-drained soils (PFAF, 1997). Position in full sun is preferred, though it will also grow in semi-shade condition. The root edible and can grow up to 1 meter long and weight 2 kilos or more if it is grown in a fertile deep soil. Once when get it out, the root has a very nice flavor with a floury texture when baked, but it is not as tasty as a sweet potato. It makes an excellent staple food and, since yams are now becoming a more common food in Malaysia, it has a very good potential as a commercial crop here. The tubers can be boiled, baked, fried, mashed, grated and added to soups. They store well and for a long time. They contain about 20% starch. 75% water, 0.1% vitamin B1, 10 - 15 mg % vitamin C (PFAF, 1997).

2.1.2. Banana

Banana is one of the most common and widely grown fruit crops around the world. Banana is well adapted to well-drained, loamy, soil that is rich in organic matter (Banana.com, 1995). Areas with an average rainfall of 4000 millimeters (mm) a year are ideal sites for a banana plantation. A temperature between 27 to 30 degrees Celsius is most favorable for it to grow. Banana grows at sea level up to 1,800 meters altitude. It is susceptible to root rot when exposed to too much water. The true origin of Bananas, one of the world's most popular fruit, is found in the region of Malaysia California Rare (Fruit Growers, 1996). By way of curious visitors, bananas traveled from Malaysia to all around the world. Banana fruit is normally consumed fresh. It also has various uses. The ripe fruit is pureed, candied, and preserved in various forms when not eaten fresh. Its extract is used in the manufacture of catsup, vinegar, and wine. The unripe fruit is powdered and chipped. (*Wayne P.* "Identification of Major Fruit Types"*)*

Fig 2. 3 Banana

2.1.2.1. Chip Production

Fried food products are very popular among the citizen both locally and globally. Banana, tapioca, and yam are among of the few types of fruits and vegetables that important in the local chips snack industry. They are considered as a rich source of energy producing food. It is prepared and processed into various types of forms especially deep-fried chips. Major share of banana and yam production in the country is consumed in the fresh form and only small amount of it is exported.

Fig 2. 4 Banana Chips

Fig 2. 5 Plantain Chips

Chips are the age-old snacks and fast foods in Nigeria. Figure above shows the fried banana and plantain chips. They are consumed as snack food which very healthy and taste great as well.

In rural areas, the young leaves are pounded to suppress bleeding and treat wounds (Morton, 2001). The leaves are also widely used as packing materials for fruits and vegetables in market centers. Banana fiber is manufactured into rope, sack, and mat. Sheets of paper and paperboards are also made from banana peel. Banana blossom is exported dried. Filipino housewives use it in special dishes. The ripe banana is utilized in a multitude of ways in the human diet from simply being peeled and eaten out offhand to being sliced and served in fruit cups and salads, sandwiches, custards and gelatins; being mashed and incorporated into ice cream, bread, muffins, and cream pies. Ripe bananas are often sliced lengthwise, baked or broiled, and served (perhaps with a garnish of brown sugar or chopped peanuts) as an accompaniment for ham or other meats.

Ripe bananas may be thinly sliced and cooked with lemon juice and sugar to make jam or sauce, stirring frequently during 20 or 30 minutes until the mixture jells. Whole, peeled bananas can be spiced by adding them to a mixture of vinegar, sugar, cloves and 8 cinnamon which has boiled long enough to become thick, and then letting them cook for 2 minutes. Green plantains are popular sliced crosswise, fried until partially cooked, pressed into a thickness of 1/2 in (1.25 cm), and fried in deep fat till crisp. The product is called 'tostones" and somewhat resembles French-fried potatoes.

Commercial production and marketing of fried green plantain and banana chips has been increasing in various parts of the world over the past 25 years and these products are commonly found in retail groceries alongside potato chips and other snack foods. Because of their impressive potassium content, bananas are highly recommended by doctors for patients whose potassium is low. One large banana, about 9 inches in length, packs 602 mg of potassium and only carries 140 calories (Banana.com, 1995). That same large banana even has 2 grams of protein and 4 grams of fiber. No wonder the banana was considered an important food to boost the health of malnourished children. Those reducing sodium in their diets can't go wrong with a banana with its mere 2 mgs of sodium. For the carbohydrate counters there are 36 grams of carbohydrates in a large banana. Clearly banana is among the healthiest of fruits. The plantain, when cooked, rates slightly higher on the nutritional scale in vitamins and minerals but similar to the banana in protein and fiber content.

2.1.2.2. Mechanical Property of Banana

In India, banana is abundantly cultivated. Banana fiber can be easily obtained from the pseudo stem after the fruit is utilized. It is obvious that ecological materials satisfy fundamental requirements like pollution prevention and control. The use of agricultural by-products, which are environmentally friends, such as rice husk, coconut fibers, minimizing energy consumption, conserving non-renewable natural resources, reducing pollution and maintain environment. Banana is the core of these materials that fulfils these advantages. Natural fibres have become popular material for fibre reinforced polymer composite developments. These reinforcements can replace the convention glass as an alternative material. Other than these natural fibers, banana is another interesting material considered as a great potential to be used in polymer composite industry, ease of use. The mechanical properties of different natural fibers such as sisal, vakka, banana, bamboo was compared and it was discovered that banana fibers have much higher tensile and flexural properties than other fibers.

Banana is one of the ecological materials for which it has many distinct characteristics such as:

- Unbreakable, maintenance free, durable
- Fire retardant and water resistant
- UV, acid and alkali resistant
- Less abrasive
- Less costly

- Biodegradable
- Renewable
- Eco-friendly

2.1.2.3. Physical and Mechanical Properties of Banana

No	Properties	Banana Varieties Dwarf Cavendish / Nendren
1	Diameter (Max) (mm)	23.34 / 37.08
2	Length (Max) (mm)	137.00 / 194.50
3	Width (Max) (mm)	66.50 / 50.00
4	Average Weight of single fruit (g)	97.84 / 210.43
5	Average pulp/peel ratio	1.39 / 2.32
6	Average specific gravity	0.933 / 1.005
7	Load required to cut (Max) (mm)	22.4 / 28.20
8	Cutting load per unit width (N/mm)	0.754 / 0.821

Table 2. 1 showing the mechanical properties of Banana

Source: (Sonawane, Sharma,Pandya, 2011)

2.1.2.4. Physical and Mechanical Properties of Plantain

No	Properties	Values
1	Diameter (max) (mm)	30 – 70
2	Length (max) (min)	200
3	Average weight of single fruit (g)	201.43
4	Average Specific gravity	1.005
5k	Force required to cut plantain (max) (N)	33.15
6	Cutting load per unit width (N/mm)	0.821

Table 2. 2 showing the mechanical properties of Plantain

Source: (Sonawane, Sharma, and Pandya, Obeng, 2004)

2.1.2.5. Cucumber

2.1.2.5.1. Plant Description

Cucurbitaceae is a plant family, also known as gourd family, which includes crops like cucumbers, squashes, luffas and melons. Cucurbits form an important and a big group of vegetables crops cultivated extensively in the subtropical and tropics countries. The family consists of about 118 genera and 825 species. Plants of this family have many medicinal and nutritional benefits Cucumber (Cucumis sativa L) is one of the monoecious annual crops in the Cucurbitaceae family that has been cultivated by man for over 3, 000 years. With respect to economic importance, it ranks fourth after tomatoes, cabbage and onion in Asia. (Jonathan, 1985)

2.1.2.6. Physical and Mechanical Properties of cucumber

No	Properties	Values
1	Diameter (max) (mm)	52.15 – 229.5
2	Length (max) (min)	52.15 – 68.87
3	Average weight of single fruit (g)	273.8 – 470.4
5	Force required to cut plantain (max) (N)	70

Table 2. 3 showing the mechanical properties of cucumber

Fig 2. 6 Showing Cucumber fruit before slicing

2.2. Slicing and Size Reduction

Slicing is a form of size reduction and the general term "size reduction" includes slicing, cutting, crushing, chopping, grinding and milling. The reduction in size is brought about by mechanical means without change in chemical properties of the material and uniformity in size and shape of individual units of the end product. Such processes as slicing of yams to be dried for flour, cutting and slicing of bananas and plantains for chips, cutting of fruits or vegetables for canning, shredding sweet potatoes for drying, slicing onion for salad, chopping corn fodder, grinding grain for livestock feed and milling flour are size reduction operations. Reducing the size of food raw materials is an important operation to achieve a definite size range (Henderson and Perry, 1980). Size reduction may help in the extraction of desirable constituents from raw materials e.g., crushing palm fruits for extraction of palm oil, milling grains for the production of flour, crushing fruits for juice or for fermentation. Some other operations in food processing and preservation are facilitated by smaller size particles, for examples, when a food material such as yam is to be dried, it is cut into slices to expose more surface area to the drying medium. Similarly, in drying of okro or tomatoes, the vegetables and fruits are sliced into smaller pieces to facilitate heat transfer and removal of moisture from the pieces.

2.3.Different Types of Cutting Machine

There are several types of food cutting machine or slicing machine in the market. Each type of cutting machine has different cutting principle but the purpose is the same which is to cut or slice the food into small pieces for further process.

2.3.1. Banana and Yam Cutting Machine

Hiong (2007) has designed and constructed an affordable banana and yam cutting machine for making snacks. Working principle of the machine is very simple; it is powered by electric motor. The power generated by motor is transfer to cutting wheel through belting system. The cutting blades have two cutting edges, which means when the cutting blade made one cycle, it will cut eight slices of chips. The machine has four holes of the upper chute. The upper chute is where the raw material such as banana, tapioca or yam will be placed and feed to be sliced. The material fed through upper feeder will dropdown to the cutting blade by gravity and the material will slice into small piece and drop to delivery chute. Delivery chute is the place to collect pieces of the sliced product for further process.

Fig 2. 7 Banana and Yam Cutting Machine

[Extracted from Kuan Voon Hiong (2007). Design and Construction of an Affordable Banana and Yam Cutting Machine for Making Snacks. Thesis B.Eng Hons, UNIMAS.]

The local farmer that used the machine in the snack production, the machine performs well (Kadir, 2007). The machine can slice approximately 26250 slices of bananas and 22720 slices of yams just one hour. He added, if the machine is compared to the manual slicer, the machine cutting speed is estimated to be about 275% - 425% faster depends on the type of material to be cut. Meaning to say, when it is use to produce chips, the production rate will increase by 275% - 425% if the cutting speed is properly set to maximum. Mr. Ronny Friday (2008) has come out the improved design of the banana and yam cutting machine. The working principle is more or less the same with the previous version which is done by Mr. Kuan Voon Hiong.

Fig 2. 8 Improved Banana and Yam Cutting Machine

[Extracted from Ronny Friday (2008). Improvement of Banana and Yam Cutting Machine for Village Industry Application. Thesis B.Eng Hons, UNIMAS.]

The improved machine has four upper feeders with two different sizes that allow the diameter of the raw material that up to 80mm. Also, the new improved cutting wheel has three cutting blades that enable the machine to cut twelve slices of product per rotation compare to only eight slices per cutting wheel rotation of the rotation of the previous machine. These two factors directly increase the rate of chips production of the new machine. The new improved machine is able to produce 660 slices of banana chips per minute compared to the previous machine that produce 437 slices per minute. For yam slicing, this improved machine produces 540 slices per minute compared to the previous machine that slices 379 slices per minute. It is estimated an increase of 29% - 34% in terms of production rate. This enables the farmer to make higher rate in their chips production.

2.3.2. Banana Slicer

Mr. Augustin (2001) from India has designed and developed a typical banana slicer. He works as a teacher and do farming as well. He has a deep knowledge about the agricultural products. Mr. Augustin has developed a device which was practical for bakery and for chip processing which is the banana slicer.

Fig 2. 9 Banana Slicer Developed by Mr. Augustin.

[Extracted from http://www.nifindia.org/bananaslice.html]

This banana slicer is a device that has five cylinders to put bananas and it is working manually by operator. With the help of a blade set attached on a round plate, the banana can be sliced. There is a holder having spring-action in the cylinders to keep the banana vertically in it. In order to keep the banana tightly in the cylinders a spring load system is attached, which operates easily. There is a mechanism to reduce or enlarge the thickness of the piece in the machines itself. The machine has a very high performance that it can slices 1200 pieces of banana in one minute. The operation of the machine is simple. The operator just has to raise the spring load system and the bananas are inserted into the cylinders. Spring load system is then released and the handle of the machine is rotated. The bananas are sliced as the blade rotates.

2.3.3. Multipurpose Slicer/Cutter

An existing blade that consists of a hand-held, hand-operated blade is commercially available. Multi-purpose slicer also called manual slicer; it is widely used in Malaysia. Home usage of multi-purpose slicer/cutter operated by manual is only can used as a kitchen gadget. The multi-purpose slicer is a versatile classic that enjoys many uses, perhaps because the multi-purpose slicer remains as one of the safest, easiest and most simple kitchen items in use. However, while an excellent multi-purpose slicer can be used for all sorts of vegetables like onions, yam, zucchinis, carrots, turnips, cucumbers, radishes, squash etc., the traditional use of a multi-purpose slicer is to make everybody's favorite, "French fries". (Radha, 1995)

Fig 2. 10 Multi-Purpose Slicer

2.4. Operation of Cutting and Slicing Machine

There are several types of cutting and slicing machine, generally the working principle of every machine actually quite similar. Operate or tend machines to cut or slice any of a wide variety of products or materials, such as banana, yam, tobacco, food, paper, roofing slate, glass, stone, rubber, cork, and insulating material.

2.4.1. Required Knowledge of Cutting and Slicing Machine for Operators and Tenders

Operator for any cutting and slicing machine must have knowledge of production and processing, mechanical knowledge and design knowledge (careerplanner.com, 2004). Production and processing knowledge is of raw materials, production processes, quality control, costs, and other techniques for maximizing the effective manufacture and distribution of goods. Mechanical knowledge is of machines and tools; including their designs, uses, repair, and maintenance. Design knowledge is of design techniques, tools, and principals involved in production of precision technical plans, blueprints, drawings, and models.

2.4.2. Cutting and Slicing Skills

To operate the cutting or slicing machine, the operator must possess the basic cutting and slicing skills. These skills include operation and control, operation monitoring, installation and quality control analysis (careerplanner.com, 2004). Also, operation and control in charged on controlling operations of equipment or systems. The operator must be able to control and familiar with all of the cutting and slicing machine equipment. Operation Monitoring involve watching gauges, dials, or other indicators to make sure a machine is working properly, installation involve Installing equipment, machines, wiring, or programs to meet specifications and quality control analysis is conducting tests and inspections of products, services, or processes to evaluate quality or performance.

2.4.3. Cutting and Slicing Activities (Procedures)

The knowledge of general cutting and slicing activities and cutting principle can help to standardize cutting equipment design. The basic cutting and slicing process are:

i. Controlling machines and processes - Using either control mechanisms or direct physical activity to operate machines or processes.

ii. Handling and moving objects - Using hands and arms in handling, installing, positioning, and moving materials, and manipulating things.

iii. Performing general physical activities - Performing physical activities that require considerable use of arms and legs to accomplish the cutting activities.

iv. Monitor processes, materials, or surroundings - Monitoring and reviewing information from materials, events, or the environment, to detect or assess problems.

v. Documenting/recording information - Entering, transcribing, recording, storing, or maintaining information in written or electronic/magnetic form.

vi. Equipment, structures, or material inspecting - Inspect the machines equipment, structures, or materials to identify the cause of errors or other problems or defects.

vii. Repairing and maintaining mechanical equipment - Besides operating the machine, operator must know a little about machine servicing, repairing, adjusting, and testing machines, devices, moving parts, and equipment that operate primarily on the basis of mechanical and also electrical principles.

viii. Evaluating information to determine compliance with standards – Using relevant information and individual judgment to determine whether events or processes comply with laws, regulations, or standards.

2.5.Review of Existing Slicing Machines

Several slicing and chipping machines have been designed and tested in various developing countries especially the Caribbean and South East Asian countries as reported by Clarke (1987). Various types of machines are manufactured from small hand-operated batch-types to large automatic continuous operation models. Some are petrol, diesel or electric motor operated. There are cassava chippers, tomato slicers, okro slicers and other root and vegetable choppers. Ukatu and Aboaba (1996) designed, constructed and evaluated a machine for slicing yam and it was reported that the machine's thickness of cut can be varied from 2 mm to 20 mm and the slicing efficiency ranged from 82 to 93% and the rate of work is 45 cuts per minute. The 'Crypto peerless' abrasive drum peeler is an example of a typical commercial machine in which a rotating abrasive drum rubs the skin from the material passed through (UNIFEM, 1993).

It is most commonly used to peel potatoes. Various sizes of such machines are available from as small as 1.3 kg/batch. They are powered by electric motors. Raji and Igbeka (1994) designed, fabricated and tested a pedal-operated chipping and slicing machine for tubers and it was reported that the machine performed satisfactorily with production of slices of uniform thickness ranging from 1 mm to 13 mm thickness and a throughput of about 376kg/h at an efficiency of about 83%. Ingram (1972) observed that peeling and slicing of tubers were done manually.

In Nigeria, a number of researchers have worked on production of slicing machine for various crops such as okro, onion and tubers (Odigboh 1976 and 1983). According to UNIFEM (1993), the department of Agricultural Chemistry and Food Science in the Philippines has designed a simple slicer which is said to cut sweet potatoes much faster than manual methods. The sweet potato is held on the cutting platform against a plate, which controls the thickness of slice. Slices are then cut off with the hinged cutting blade. Capacity is 21 – 23 kg per hour. UNIFEM (1993) reported that Nardi Francesco and Figli of Italy produced a manually operated root – chopper containing a rotating disc fitted with four blades. They further reported that P. T. Kerta Laksana of Indonesia had made a pedal – driven cassava slicer fitted with one large slicing blade. It claimed to have a capacity of up to 500 kg per hour.

Olajide et al. (1997) evaluated an okro slicer and found out that there are higher losses in the manual knife slicing of okro than in the okro slicer. Hummel and Nave (1979) developed an impact cutting system of soybean plants on the combine header losses and on the acceleration of the several plants.

The cutter bar, however, is still the major offender, accounting for 80 percent of the combine header harvesting losses (Quik, 1973).

A belt cutting system (Teel, 1977) developed for harvesting vegetation is an impact cutting device. However, the belt system's nominal cutting speed of 40 m/s may limit its usefulness for harvesting soybeans. There are also several manually operated kitchen–size chipping and slicing machines in the market. Some of these chipping and slicing machines are either imported or fabricated locally. The imported ones are sophisticated and may not be easily operated and maintained by local users, therefore adaptability of the techniques locally is difficult. Furthermore, some of these slicing machines are designed for only a particular type of vegetable and fruit and cannot be used for others because of their peculiar rheological properties. Kordylas (1991) reported that plantain is best preserved in the dried form by processing into flour and chips for human and livestock consumption.

Haven puts of efforts in developing automated slicers to chip plantain and other food materials with similar properties as in the case of banana and yam aimed at developing slicers to meet the requirements of small, medium and large-scale processing industries, eliminate drudgery, increase the through-put capacity, and enhance hygienic and safe working conditions and other limitations associated with manual hand slicing. Yet only a few of such machines have been developed to the minimum required standard. The trend of development of these machines are examined below showing their methods of operations, merits and limitations.

2.5.1. Kitchen Knife Slicing Method

This method of slicing the aforementioned agro based products can be likened to be the most used traditional method. This method of slicing requires a whole lot of human energy and time to perform the slicing operation. This same method poses to be unsafe and not hygienic as accident to the fingers and hand is more likely to occur which in turn, contaminates the food raw materials.

Fig 2. 11 Image showing the kitchen knife slicing method

2.5.2. Mechanized Plantain Slicer

Obeng (2004), developed a mechanized slicer that slices plantain into chips of relatively uniform thickness and improved speed when compared to manual knife slicing. It completely slices a single plantain for a duration of about 5 to 7 seconds, depending on the length. The chip thickness produced by this machine ranges between 2.5mm and 3.5mm. The major components of the machine are; series of a 2mm curved stainless steel blades arranged in such a distance to represent the required chip thickness, a wooden mesher and a container positioned beneath the cutter blades for collecting the sliced chips. The machine diagram can be seen in Fig. 4.

Limitations

i. There exists a large variation in chip thickness.
ii. Ripened and over-ripened chips tend to stick to the mesher and the edges of the blades.
iii. The thin stainless-steel blades tend to bend during cutting action and hence, altering blade interval and chip thickness.
iv. There is difficulty in removing and sharpening of blades.

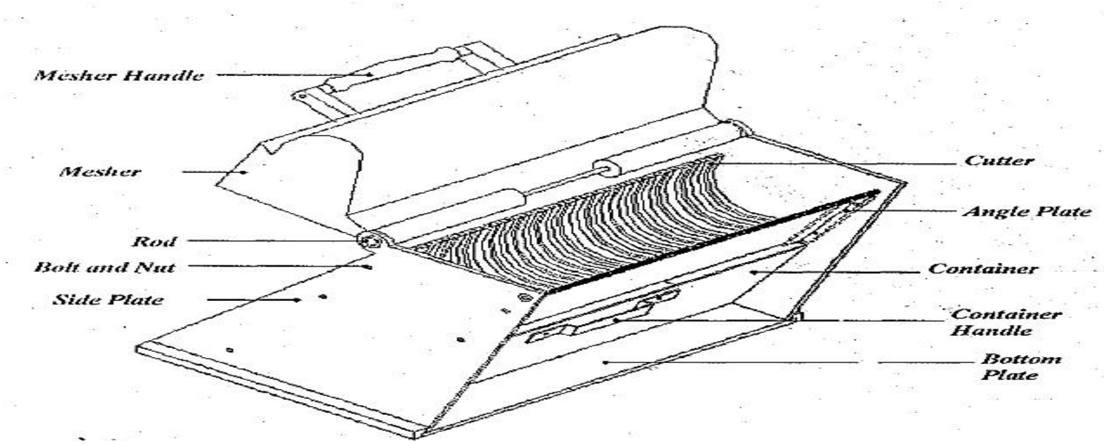


Fig 2. 12 Mechanized plantain slicer (Obeng, 2004)

2.5.3. Motorized Plantain Slicer

An electric powered plantain slicer was developed by Adewumi et al. (2011). This was a slight modification of Ojuloge (1999) version of the machine. The machine has a single cutter blade and an electric motor that serves as a power source. It produced a maximum machine capacity and efficiency of 451.39 kg/h and 97.25% respectively for a 15mm thick fully ripened plantain. The machine capacity and performance efficiency are expected to increase with an increase in number of blades. The machine is shown in Fig.

Fig 2. 13 Motorized plantain slicer (Adewumi et al., 2011)

2.5.4. Power Operated Banana Slicer

Sonawane et al., (2011), designed and fabricated an electric power operated plantain chipping machine for use in small and medium scale plantain chipping industries. The machine is equipped with a feeder assembly, an electric motor, a cutter plate and a base support. The feeder assembly is made up of a push plate for pushing the plantain to the cutter blade, a push rode and a spring. The cutter plate is made up of three stainless steel blades which are powered by an electric motor rotating at a speed of 360rpm through a V-belt. The machine has an efficiency of 93% and a mean thickness of 2.0mm (having ±0.2 mm maximum mean deviation). Figure 7 and 8 illustrate the cutter blade design and the machine parts respectively.

Limitations

i. It could only slice a few plantains at a time

ii. Some over-ripened plantain tends to stick to the blade while some are whirled to other parts of the cutter section.

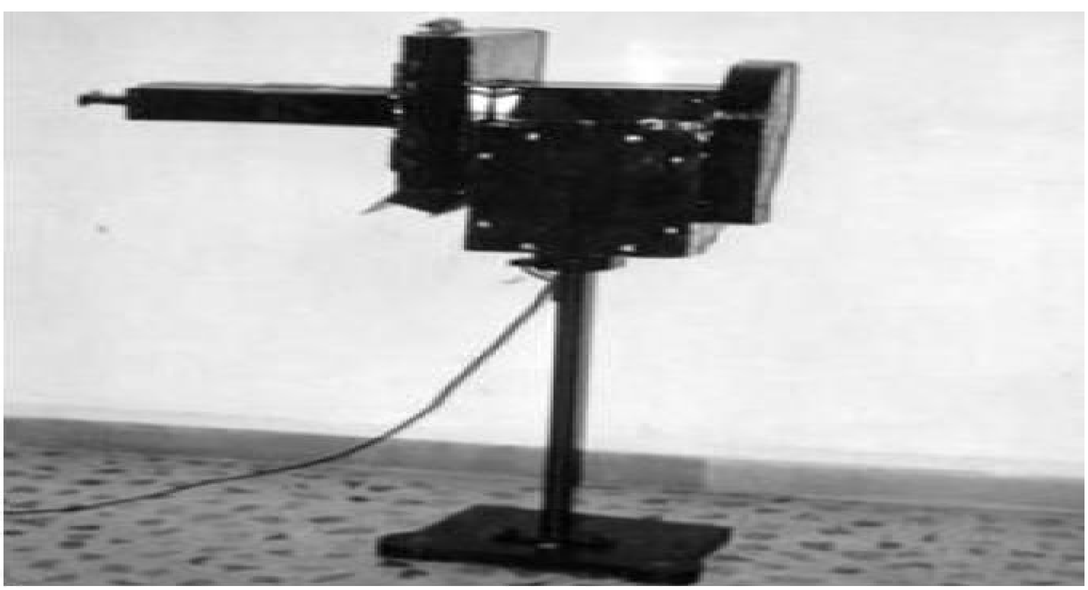


Fig 2. 14 Power operated banana slicer (Sonawane et al., 2011)

2.5.5. Development of a Plantain Slicing Machine

Adesina et al., 2015 developed an automated electric powered plantain slicer with an efficiency of 80% and a machine capacity of 52kg/hr. The machine can uniformly slice a single plantain for about 16 to 20 seconds, depending on the plantain length, as against 40 to 60s of manual slicing method. The major machine parameters are; the cutter plate, a 2-horse powered electric motor, belt, bearings and pulleys. Plantain is fed through the collector into the cutting chamber of the machine. The motor supplies rotary motion through the belt and pulley drive to the cutter plate. This performs the cutting action that slices the plantain into chips of relatively uniform sizes.

Fig 2. 15 Development of a Plantain slicing machine (Adesina et al., 2015)

Limitations

i. Possesses more weight which could hinder free and easy movement
ii. Has a very low machine capacity of 52Kg/hr. which could have been attributed to the number of inlets and blades adopted.
iii. Materials employed seems to be less adequate as food contamination ought to be brought to the barest minimum.
iv. Takes more time of about 16 – 20 seconds to slice a single finger of plantain.

2.6. Existing Theories for Peeling and Slicing

Kachru et al. (1996) reported that the design of a slicing disc for banana was based on cutting velocity, shear angle, bevel angle and number of blades. The diameter of cutting disc on which blades were to be mounted was 22 cm i.e., approximately three times the maximum effective width of banana.

Visvanathan et al. (1990) stated that, the energy consumed in cutting a fruit and the velocity of cut by different blades were calculated using the following expressions:

$$E = WpRc\ (\text{Cos}\theta c - Cos\theta o) \qquad 2.1$$

$$V = \frac{Lx2E}{I} \qquad 2.2$$

Where;

E = Minimum energy required to cut a slice, kg-cm

Wp= Weight of pendulum, kg

Rc = Position of center of gravity of the pendulum from axis of rotation, cm

θc & θo = Angles subscribed by the pendulum after equilibrium position, when released from rest at any angle in the absence of cutting and after cutting, respectively.

V = Velocity of cutting, cm/s

L = length of pendulum, cm

I = moment of inertia, kg ms-2

The torque available on chipping disc was calculated from equation 3;

$$V = \frac{\pi DN}{60} \qquad 2.3$$

Where;

D = Diameter of cutting disc, cm

N = Speed of rotation of disc, rpm

According to Balasubramanian et al. (1993), the power of cutting disc is given by equation 4;

$$P = \frac{2\pi NT}{4500\eta} \qquad 2.4$$

Where;

P = Power required by cutting disc, N

T = Torque available on disc, kg - cm

η = Mechanical efficiency %

The possible number of slices which could be cut in one rotation of disc was given by equation 5;

$$N = \frac{T}{E} \qquad 2.5$$

The total energy stored in the rotating disc was given by equation 6;

$$E = I\omega^2C \qquad 2.6$$

Where;

$$\omega = \frac{2\pi N}{60} \qquad 2.7$$

$$I = \frac{\omega d\, R^2}{g} \qquad 2.8$$

$$Wd = \pi\omega^2 t\gamma \qquad 2.9$$

ω = Angular velocity

Cs = Fluctuation of speed, kg

Wd = Weight of disc in kg

R = Radius of cutting disc, cm

G = Acceleration due to gravity, 9.81 cm/s2

T = Disc thickness, mm

γ = Density of disc material, (2300 kg/m3)

$$\alpha = \frac{[Mass\ of\ all\ slices - Mass\ of\ damaged\ slices]}{Weight\ of\ slices} \text{ x } 100 \qquad 2.10$$

Where;

α = Efficiency of slicing, %

$$E.C = O.C \text{ x } \frac{\alpha}{100} \qquad 2.11$$

Where;

E.C =Effective capacity of the machine, kg/h

O.C = Operating capacity of the machine, kg/h

The roundness of each slice was calculated using the following expression (Mohsenin, 1981).

$$\text{Roundness} = \frac{Ap}{Ac} \qquad 2.12$$

Where;

Ap = Projected area of a slice resting on most stable position, mm2

Ac = Area of smallest circumscribing circle to the slice, mm2

Ukatu and Aboaba (1996) measured the slicing efficiency of the machine for slicing yam tubers using this expression in equation 13;

$$\text{Slicing Efficiency (\%)} = \frac{Li - Lo}{Li} \times 100 \qquad 2.13$$

Where;

Li = tuber initial length, mm

Lo = length of off – cut, mm

Ozumba et al. (2004) determined slicing capacity of a cassava grater by using equation 14;

$$Sc = \frac{Ws}{T} \qquad 2.14$$

Where;

Sc = Slicing capacity, kg/h

Ws = Weight of sliced material, kg

T = Time taken, sec

CHAPTER THREE

METHODOLOGY

3. Design Considerations

In order to obtain the desired output in terms of efficiency, effectiveness, reliability and acceptability during the operation and testing of the machine, the machine had undergone several important considerations for designing with respect to the FIT, FORM AND FUNCTION of processing the aforementioned agro based products (Plantain, banana and yam).

3.1.Machine Description

The machine is made up of a support mechanism, a cutting mechanism, an automatic feeder mechanism, an outlet chute and an electric motor. Its basic function is to slice plantain, banana and yam loaded in the inlet, and then assisted by an automatic plunger.

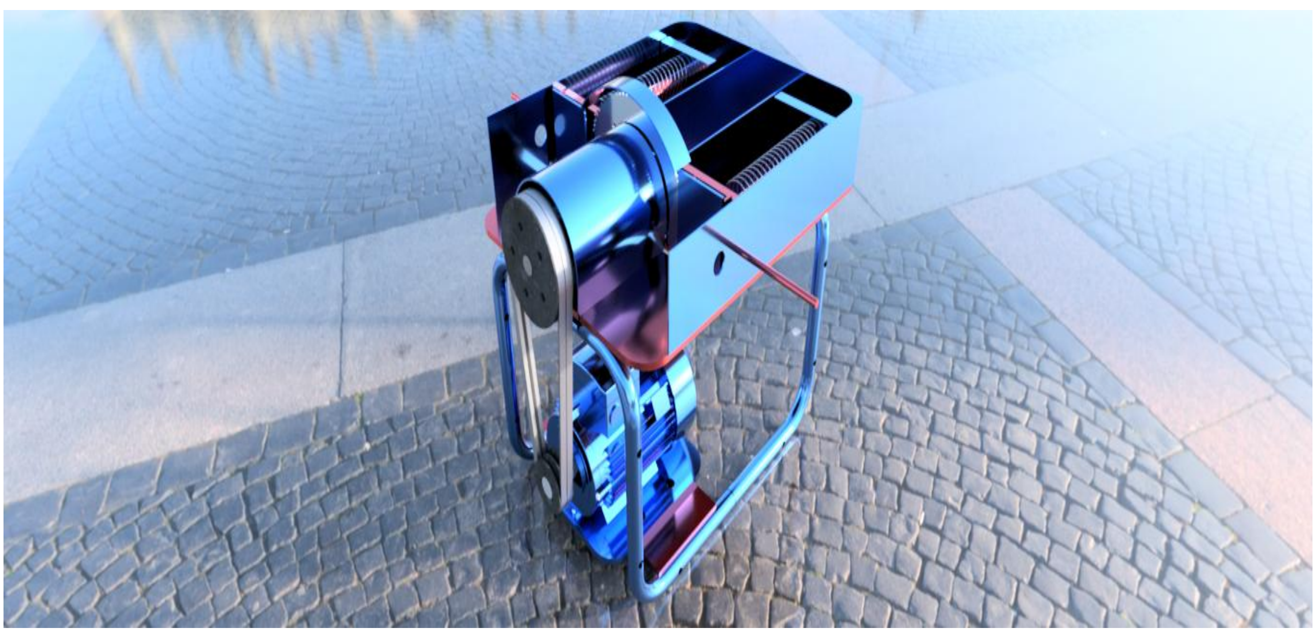


Fig 3. 1 Machine diagrammatic representation

3.1.1. Mechanisms of Operation

3.1.1.1. The Support Mechanism

The support mechanism comprises a 20mm diameter by 3mm thick mild pipe which is used for the fabrication of the frame, and mount for an electric motor comprises of a U-Channel mild steel material. The frame is a 600mm long, 420mm wide and 420mm high angle iron, welded firmly together with electric arc welding machine using gauge 12 steel electrode. The frame was designed for high strength, rigidity, low weight and vibration resistance. The motor seat is a 371mm long, 40mm wide and 5.655mm high and 2.5mm thick, serving as a basement to which electric motor is bolted to.

3.1.1.2. Power transmission Mechanism

The electric motor is the prime mover that supplies power to the entire system. It is a three-phase motor rated 4Hp 2.984KW and a speed of 1440rpm. Power is transmitted from the electric motor to the blade and the crank. The peeled plantains loaded in the inlets are conveyed by means of a plunger automatically controlled by a slider crank mechanism towards the blade. The crank, screwed to the driven shaft, intercepts the plantains to control the feed rate and prevent overlapping of plantain fingers. The blade slices the plantain as the plunger simultaneously conveys the sliced plantain chips towards the outlet chute. The sliced chips are discharged through the outlet chute to a collecting vessel or tray placed beneath it.

3.1.1.3. Slicing mechanism

The slicing mechanism comprises the blade, blade housing, and cutting crank or disc. The blade is a removable 1.5mm thick stainless-steel sheet, of 260mm wide and 60mm high. The cutter is bolted to the crank and rotational motion is transferred from the driven shaft in order to cause the cutting action. In order to increase the processing through-put capacity and efficiency of the raw materials, three blades on both sides of the machine are adopted which in turn makes it a dual slicing machine

3.1.1.4. Feeding mechanism

The electric motor is also the prime mover that supplies power to the feeding system and works with the slider crank mechanism principle. It is a three-phase motor rated 0.32 KW and a speed of 700rpm. The feeder mechanism consists of a crank, connecting rod and plunger. This act as the automatic feeding mechanisms which supports the flow of the raw products to the rotating crank/cutter and then discharged when it moves the sliced products out of the outlet chute.

The crank was designed to travel at a speed of 80rpm for plantain and banana and 65rpm for yam. The outlet chute is the discharge point of the machine where sliced raw products are collected. It is made up of a stainless-steel sheet inclined at an angle of 90degrees vertically such that sliced plantain falls by gravity to the collecting tray.

3.1.2. Machine System

The machine system should conform to the following design considerations;

i. The machine should be designed to reduce weight to the barest minimum whilst being agronomical (safe and convenient) to reduce human effort in feeding and slicing.
ii. The machine should be designed using good modelling practices to ensure efficiency and reusability, in terms of applying industry standards component parts **(DIN, ANSI or ISO** standards) which in turn describes proper material selection.
iii. The machine should be designed to meet assembly requirements in terms of ease of assembly and disassembly while maintaining the right **FIT** in all component parts.
iv. The machine should be designed to meet lifecycle requirements in terms of adequate usability, safety and maintenance access in order to ensure sustainability.
v. The machine components or elements shall be appropriate and follow standard manufacturing catalogues while using computer aided theoretical analysis and design procedures.

3.2.Design analysis

3.2.1. Blade/Cutter Design

A common issue with blades for slicing food products with a high-water content is sticking to the side of the blade. Understanding this relationship allowed the design of the blade with features that could prevent sticking.

The Functional requirements of the blade focused on ensuring the following: that the

i. Blade could slice through the specific food raw materials
ii. That sliced food was prevented from sticking to the blade
iii. The blade could be used and cleaned properly.

Selected specific design parameters that would accomplish each functional requirement are as follows;

i. Blade's sharpness; which directly impacts the blade's ability to slice the food products.
ii. The tip radius which is a key parameter for the blade's ability to initially break through the food, as a larger radius would make the blade too dull
iii. The edge angle of the blade which is important for slicing through the food after the initial shearing.

However, in the analysis of the design of the machine and for the purpose of selection of crops (agricultural produce) which the machine is centered on, the following properties for each crops are considered from table 3.1 – table 3.4

No	Properties	Banana Varieties Dwarf Cavendish / Nendren
1	Diameter (Max) (mm)	23.34 / 37.08
2	Length (Max) (mm)	137.00 / 194.50
3	Width (Max) (mm)	66.50 / 50.00
4	Average Weight of single fruit (g)	97.84 / 210.43
5	Average pulp/peel ratio	1.39 / 2.32
6	Average specific gravity	0.933 / 1.005
7	Load required to cut (Max) (mm)	22.4 / 28.20
8	Cutting load per unit width (N/mm)	0.754 / 0.821

Table 3. 1 Mechanical/Physical properties of banana

Source: Vol. 57, 2011, No. 4: 144–152S.P. Sonawane, G.P. Sharma, A.C. Pandya,

No	Properties	Values
1	Diameter (max) (mm)	30 – 70
2	Length (max) (min)	200
3	Average weight of single fruit (g)	201.43
4	Average Specific gravity	1.005
5	Force required to cut plantain (max) (N)	33.15
6	Cutting load per unit width (N/mm)	0.821

Table 3. 2 Mechanical/Physical properties of plantain

Source: (S.P Sonawane, G.P, Sharma, and A.C Pandya, Obeng, 2004)

Stress	Unpeeled Tuber	Peeled Tuber
Poison's Ratio	0.38	-
Shear Stress (Nm^{-2})	3.22	0.28
Peeling Stress (Nm^{-2})	0.3	-
Cutting Force (N)	500	140
Rupture Stress (Nm^{-2})	0.95	0.7

Table 3. 3 Physical properties of yam

Source: (L.A.S. Agbetoye and A. Balogun, 31 August - 02 September 2009)

No	Properties	Values
1	Diameter	52.15 – 229.5
2	Length	52.15 – 68.87
3	Average weight of single fruit (g)	273.8 – 470.4
5	Force required to cut plantain (max) (N)	70

Table 3. 4 Table showing some physical and mechanical properties of cucumber

Source (El Salid; Mervat; Khalil; El Lithy, 2011)

3.2.2. Determination of force required by the blade to shearing raw plantain, banana, cucumber and yam

Banana

According to the figure 3.1, (Sonawane, Sharma, Pandya, *2011),* a power operated rotary raw banana slicer was designed and developed with a chosen machine speed of 630 rpm, the slicing efficiency obtained was 93–94% which was acceptable for both varieties with optimum capacity 100 kg/h for three-blade cutter, which meets the requirements of small scale processing unit.

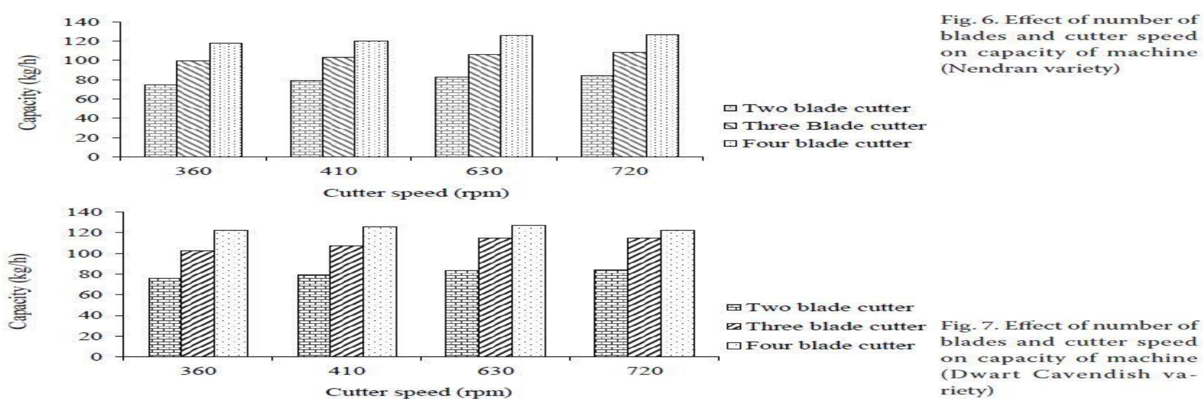


Fig. 6. Effect of number of blades and cutter speed on capacity of machine (Nendran variety)

Fig. 7. Effect of number of blades and cutter speed on capacity of machine (Dwart Cavendish variety)

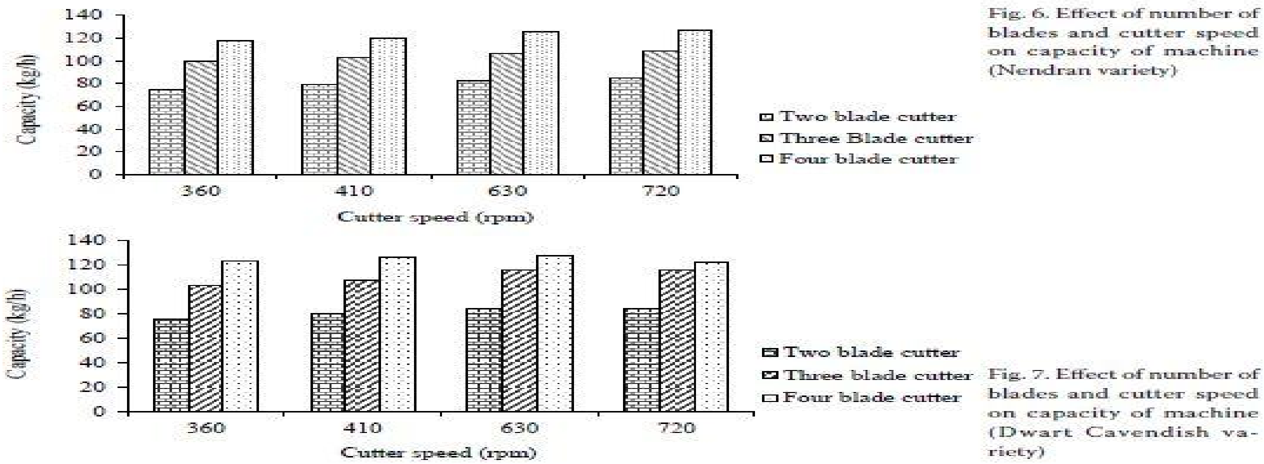


Fig 3. 2 Graphs showing the effective cutting speed of banana variety

Source :(Sonawane, et al, *2011)*

Considering the shear strength of the raw banana and the area under shear, the impact force required to require by the blade to shear the raw banana may be obtained from the following equation below (Saeed):

$$\boldsymbol{\tau_p = \frac{F_p}{A_p}} \qquad (3.1)$$

$$\boldsymbol{F_p = A_p \times \tau_p} \qquad (3.2)$$

WhereF_p = Average force required for shearing raw banana (N**) = 25.3N**

A_p = Area under the shear, m^2

τ_p = Shear stress of raw banana

The area under shear can be determined using the equation below

$$\boldsymbol{A_p = \frac{\pi\, D^2}{4}} \qquad (3.3)$$

Where D = Average diameter of raw banana = **30.21mm**

The range of force required to shear raw banana of diameters ranging from **23.34 - 37.08**mm was reported to be **22.4N - 28.20N (**Source: Sonawane, et al., 2011).

This force reduces as the banana ripens and softens. The area is calculated from equation below:

Therefore $A_p = \frac{3.142 \times\ 0.03021^2}{4} = 7.0695\ \times 10^{-4} m^2$

Recall from equation 3.1

$\tau_p = \frac{25.3}{7.0695 \times 10^{-4}} = \mathbf{35.8KN/}\boldsymbol{m^2}$

3.2.2.1. Determining the power required by the blade for slicing the raw banana

Cutter velocity is another important parameter in the slicing process. The power required by the cutter to slice the raw banana may be obtained from the following expression by (**Seed, 2007)**:

$\boldsymbol{P_c = F_p \times V_c}$ (3.4)

Where, P_c= Power required by the cutter

F_p = linear velocity of the cutting blade

$\boldsymbol{V_c}$ **= w × r** (3.5)

$\mathbf{W} = \boldsymbol{\frac{2\pi N}{60}}$ (3.6)

Where N = Speed of shaft = 630rpm

From the table above, the effective cutting speed for slicing was found to be 630rpm from maximum efficiency.

W = Angular velocity

r = Radius of the cutting disc

$W = \frac{2 \times 3.142 \times 630}{60} = 66\text{rad/s}$

Therefore, from equation 3.5

$V_c = 66 \times 0.13 = 8.54\text{m/s}$

$P_c = 25.3 \times 8.54 = 216.062\text{watts}$

$\boldsymbol{P_c}$ **= 0.216KW**

3.2.2.1.1. Determination of the power required by the Electric Motor

The power required by the electric motor was obtained from equation below:

$$P_M = P_c \times P_F \quad (3.7)$$

Where: P_M = Power of electric motor

P_c = 0.216KW

P_F = Power factor = 2

P_M = 216.062 × 2

P_M = 432.124W

$\boldsymbol{P_M} \approx$ **0.432KW**

Plantain

Considering the shear strength of the raw plantain and the area under shear, the impact force required to shear the raw plantain may be obtained from the following equation below (Saeed, 2007):

$$\boldsymbol{\tau_p = \frac{F_p}{A_p}} \quad (3.8)$$

$$\boldsymbol{F_p = A_p \times \tau_p} \quad (3.9)$$

Where F_p = Force required in shearing raw plantain. N

A_p = Area under the shear, m^2

τ_p = Shear stress of raw plantain

The area under shear can be determined using the equation below

$$\boldsymbol{A_p = \frac{\pi D^2}{4}} \quad (3.10)$$

Where D = Average diameter of raw plantain

The average force required to shear raw plantain of diameters ranging from 30-70 mm was reported to be **33.15N (Obeng, 2004)**. This force reduces as the plantain ripens and softens. The area is calculated from equation below:

Therefore $A_p = \frac{\pi \times 0.05^2}{4} = 0.002m^2$

Recall from equation 3.8

$\tau_p = \frac{33.15}{0.002} = \mathbf{16.9KN/m^2}$

3.2.2.2. Determining the power required by the cutter for slicing the raw plantain

Cutter velocity is another important parameter in the slicing process. The power required by the cutter to slice the raw plantain may be obtained from the following expression by Seed:

$$\boldsymbol{P_c = F_p \times V_c} \quad (3.11)$$

Where, P_c= Power required by the cutter

F_p = linear velocity of the cutting blade

$$\boldsymbol{V_c = w \times r} \quad (3.12)$$

$$\mathbf{W} = \boldsymbol{\frac{2\pi N}{60}} \quad (3.13)$$

Where N = Speed of shaft = 630rpm

Since ripe banana and plantain have almost same moisture content of 80 to 85 W.b %, they can both be sliced effectively and efficiently at same revolutions per minute (Sonawane, et al, *2011)*

W = Angular velocity

r = Radius of the cutting disc

$W = \frac{2 \times 3.142 \times 630}{60} = 66$rad/s

Therefore, from equation 3.12

$V_c = 66 \times 0.13 = 8.58$m/s

$P_c = 33.15 \times 8.58 = 284.427$watts

$P_c = 0.284$KW

3.2.2.2.1. Determination of the power required by the Electric Motor

The power required by the electric motor was obtained from equation below:

$$P_M = P_c \times P_F \tag{3.14}$$

Where: P_M = Power of electric motor

P_c = 0.284KW

P_F = Power factor = 2

$P_M = 284.427 \times 2$

P_M = 568.854W

$\boldsymbol{P_M} \approx$ **0.569KW**

<u>Cucumber</u>

Considering the shear strength of the raw cucumber and the area under shear, the impact force required to shear the raw cucumber may be obtained from the following equation below (Saeed):

$$\boldsymbol{\tau_p = \frac{F_p}{A_p}} \tag{3.15}$$

$$\boldsymbol{F_p = A_p \times \tau_p} \tag{3.16}$$

Where F_p = Force required in shearing raw cucumber. N

A_p = Area under the shear, m^2

τ_p = Shear stress of raw cucumber

The area under shear can be determined using the equation below

$$\boldsymbol{A_p = \frac{\pi D^2}{4}} \tag{3.17}$$

Where D = Average diameter of raw cucumber

The average force required to shear raw cucumber of diameter 52.15 mm was reported to be 70N

Source (Salid, et al, 2011)

This force reduces as the cucumber ripens and softens. The area is calculated from equation below:

Therefore $A_p = \frac{\pi \times 0.005215^2}{4} = 0.004m^2$

Recall from equation 3.15

$\tau_p = \frac{70}{0.002}$ = **35KN/$\boldsymbol{m^2}$**

3.2.2.3. Determining the power required by the cutter for slicing the raw cucumber

Cutter velocity is another important parameter in the slicing process. The power required by the cutter to slice the raw cucumber may be obtained from the following expression by Seed:

$$\boldsymbol{P_c = F_p \times V_c} \quad (3.18)$$

Where, P_c= Power required by the cutter

F_p = linear velocity of the cutting blade

$$\boldsymbol{V_c = w \times r} \quad (3.19)$$

$$\mathbf{W} = \frac{\boldsymbol{2\pi N}}{\mathbf{60}} \quad (3.20)$$

Performance evaluation of cucumber cutter at different moisture content of cucumber according to (Vishal, et al, 2016) was done at optimum speed of blade. From their findings, a low speed of 80.12rpm at blade angle of 20 degrees was calculated to serve as the optimum required speed and angle to slice cucumber.

Where N = Speed of shaft = 80.12rpm

W = Angular velocity

r = Radius of the cutting disc

W = $\frac{2 \times 3.142 \times 80.12}{60}$ = 8.39rad/s

Therefore, from equation 3.19

V_c = 8.39 × 0.13 = 1.09m/s

P_c = 52.15 × 1.09= 57watts

P_c = 0.057KW

3.2.2.3.1. Determination of the power required by the Electric Motor

The power required by the electric motor was obtained from equation below:

$$P_M = P_c \times P_F \quad (3.21)$$

Where: P_M = Power of electric motor

P_c = 0.057KW

P_F = Power factor = 2

P_M = 0.057× 2

P_M = 114W

$\boldsymbol{P_M}$ **≈ 0.114KW**

Yam

Considering the shear strength of the raw yam and the area under shear, the impact force required to shear the raw yam may be obtained from the following equation below (Saeed):

$$\boldsymbol{\tau_p = \frac{F_p}{A_p}} \quad (3.22)$$

$$\boldsymbol{F_p = A_p \times \tau_p} \quad (3.23)$$

WhereF_p = Average force required for shearing raw peeled yam **= 140N**

A_p = Area under the shear, m^2

τ_p = Shear stress of raw yam

The area under shear can be determined using the equation below

$$\boldsymbol{A_p = \frac{\pi D^2}{4}} \quad (3.24)$$

Where D = Average diameter of small yam = **39.7mm**

The average force required to shear small raw peeled yam of diameters ranging **37-42.3mm** was reported to be **140N (**Source: Keir, et al, 2015)

Therefore $A_p = \frac{3.142 \times 0.0397^2}{4} = 1.238 \times 10^{-3} m^2$

Recall from equation 3.22

$\tau_p = \frac{140}{1.238 \times 10^{-3}}$ = **113.085KN/$\boldsymbol{m^2}$**

3.2.2.4. Determining the power required by the cutter for slicing the raw peeled yam

Cutter velocity is another important parameter in the slicing process. The power required by the cutter to slice the raw banana may be obtained from the following expression by **Seed**:

$$\boldsymbol{P_c = F_p \times V_c} \quad (3.25)$$

Where, P_c= Power required by the cutter

F_p = linear velocity of the cutting blade

$$\boldsymbol{V_c = w \times r} \quad (3.26)$$

$$\mathbf{W} = \frac{2\pi N}{60} \quad (3.27)$$

According to (Agbetoye, et al, 2009), he designed a slicing machine for yam chips and calculated and optimum slicing speed of yam to be 40rpm

Where N = Speed of shaft = 40rpm

From the figure above, it was observed that the average effective cutting speed for yam of small size was 40rpm

W = Angular velocity

r = Radius of the cutting disc

$W = \frac{2 \times 3.142 \times 40}{60} = 4.2\text{rad/s}$

Therefore, from equation 3.26

$V_c = 4.2 \times 0.13 = 0.564\text{m/s}$

$P_c = 140 \times 0.564 = 76.44\text{watts}$

3.2.2.4.1. Determination of the power required by the Electric Motor

The power required by the electric motor was obtained from equation below:

$$P_M = P_c \times P_F \quad (3.28)$$

Where: P_M = Power of electric motor

$P_c = 76.44\text{W}$

P_F = Power factor = 2

$P_M = 76.44 \times 2$

$P_M = 152.88\text{W}$

$\boldsymbol{P_M \approx 0.153\text{KW}}$

From the above analysis, it could be observed that raw peeled plantain required higher power of 0.569KW as compared to banana as 0.432KW, cucumber as 0.114KW and yam as 0.153KW. Then a single phase 1Hp/0.746KW Electric Motor was selected.

3.3.Blade Selection

The components of the blade itself included the following:

a. Cutting edge

b. Non-cutting edge

c. Thickness of the blade

Selecting a blade thickness was dependent on the overall area under the shear of the products to be sliced, the force required to shear and standard sheet dimension. The area under the shear for an average diameter of raw plantain, banana, cucumber and yam according to the parameters in equation (3.3), (3.10), (3.17) and (3.24) were calculated to be $0.002\,m^2$, $7.0695\ \times 10^{-4}m^2$, $0.004m^2$ and $1.238\ \times 10^{-3}m^2$ respectively.

The force required to shear an average diameter of raw peeled plantain, banana, cucumber and yam according to the parameters in Tables (3.1), (3.2), (3.3) and (3.4) were found to be 33.15N, 25.3N, 70N and 140N

3.3.1. Blade profile determination

According to (Evan Bossio et, al, 2017), the relationship between knife surface features and food sticking to the side of the blade were examined. Since no existing literature was found on the subject, they developed original blade designs and testing procedures.

The set of knives that were tested for best efficiencies according to (Evan Bossio et, al, 2017), were the control knife, convex knife, shark scale knife.

From Fig 3.3 and 3.4, according to (Evan Bossio et, al, 2017), **the convex profile knife** performed better than the control knife, all the cuts were clean and did not have damaging effects on the sliced foods but still had some little food sticking effects about **15% to 20%** as compared to the control knife having about **40% to 95%** of food items sticking on the knife (Evan Bossio et, al, 2017).

Convex Knife				
Slices that stuck (out of 5 slices)				
Operator	Bananas	Onions	Cucumbers	Tomatoes
1	2	1	0	1
2	0	0	0	1
3	1	2	2	1
4	0	1	2	1
avg %	15%	20%	20%	20%

Fig 3. 3 Results from convex knife

Control Knife				
Slices that stuck (out of 5 slices)				
Operator	Bananas	Onions	Cucumbers	Tomatoes
1	4	2	2	3
2	5	2	2	3
3	5	2	2	3
4	5	2	2	3
avg %	95%	40%	40%	60%

Fig 3. 4 Results from control knife testing

(Evan Bossio et, al, 2017)

According to (Evan Bossio et, al, 2017), the type of knife profile shown in Figure 3.5 had two downsides though with no food item sticking to the blade. In this design, the scales were causing some deformities to the sliced food items (Plantain, Banana, Cucumber and Yam) and the knife being difficult to clean. Having deformities in the sliced food items tends to reduce the overall efficiency of the machine and difficulties in cleaning the knife after use tends to contaminate the food items (Plantain, Banana, Cucumber and Yam)

Shark Scale Knife				
Slices that stuck (out of 5 slices)				
Operator	Bananas	Onions	Cucumbers	Tomatoes
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
avg %	0%	0%	0%	0%

Fig 3. 5 Results from shark scale knife testing (Evan Bossio et, al, 2017).

Therefore, from the blade profile test results shown in Fig 3.3, 3.4 and 3.5, according to (Evan Bossio, et, al, 2017), the blade with the convex profile performed best for slicing food products having more moisture contents like banana, cucumber, plantain, onions, tomatoes and even yam as the case may be.

The figure 3.5 below shows the blade with a convex profile which was tested to performed better than the control knife, produced clean cuts and did not have damaging much effects on the sliced foods but still had some little food sticking effects about **15% to 20%** (Evan Bossio et, al, 2017).

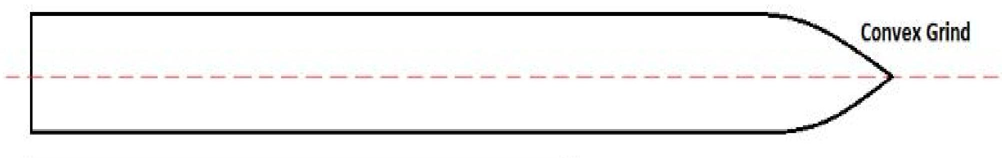


Fig 3. 6 Blade profile for convex grind (Evan Bossio et, al, 2017).

3.3.2. Blade angle/thickness

The edge angle or blade angle is the angle measured from the center of the blade to the external side of the blade. Having a large edge or blade angle and large blade thickness increases the weight, makes slicing penetration difficult and with the usage of higher cutting speeds and specific energies (Singh et al., 2016).

According to (Vishal Singh et, al, 2016), knife angles between **15° to 20°,** provided the best sharpening angles, according to (Vishal Singh et, al, 2016), blade thickness of **1mm** to **2.5mm** and cutting edge thickness very small almost as **0.5mm to 0.6mm**, provided the best blade thickness and cutting edge thickness for slicing food materials to include plantain, yam, cucumber and banana A 1.5mm thick stainless steel blade with a 15° to 20° grind can provide a rigid and clean slice of food materials (yam, plantain, banana and cucumber) without undergoing any form of distortion when slicing operation takes place due to the choice of material selection (stainless steel) which has high corrosion resistant properties, high toughness and very high yield stress of about 270Mpa (Khurmi and Gupta, 2004, Strength of materials) as compared to the calculated allowable shear stress required by cucumber plantain, banana and yam.

Blade Geometry justification

Cutting area of blade = Length × cutting edge thickness

Cutting area = 97mm × 0.5mm

Cutting area = 48.5mm^2

Compressive stress for yam

$$\boldsymbol{\tau_y = \frac{F}{A}} \tag{3.29}$$

Where F = 140N

And A = 146mm

Therefore, $\boldsymbol{\tau_p} = \dfrac{\mathbf{140}}{\mathbf{48.5} \times 10^{\mathbf{-6}}}$

$\boldsymbol{\tau_p}$ **= 2.89Mpa**

Compressive stress for plantain

$$\boldsymbol{\tau_p = \frac{F}{A}} \tag{3.30}$$

Where F = 33.15N

And A = 146mm

Therefore, $\boldsymbol{\tau_p} = \dfrac{\mathbf{33.15}}{\mathbf{48.5} \times 10^{\mathbf{-6}}}$

$\boldsymbol{\tau_p}$ **= 0.69Mpa**

Compressive stress for banana

$$\boldsymbol{\tau_p = \frac{F}{A}} \tag{3.31}$$

Where F = 25.3N

And A = 146mm

Therefore, $\boldsymbol{\tau_p} = \frac{\mathbf{25.3}}{\mathbf{48.5} \times 10^{-6}}$

$\boldsymbol{\tau_p}$ **= 0.52Mpa**

Compressive stress for cucumber

$$\boldsymbol{\tau_p} = \frac{\boldsymbol{F}}{\boldsymbol{A}} \qquad (3.32)$$

Where F = 70N

And A = 146mm

Therefore, $\boldsymbol{\tau_p} = \frac{\mathbf{70}}{\mathbf{48.5} \times 10^{-6}}$

$\boldsymbol{\tau_p}$ **= 1.44Mpa**

Obtaining the factor of safety of the blade under the shearing conditions

Yield stress of stainless steel = 270MPa ((Khurmi and Gupta, 2004), Strength of materials).

Maximum Allowable Stress on blades due to calculated compressive stress required by to slice cucumber, plantain, banana, and yam = 3MPa. 3Mpa was selected as a rounded figure to encompass individual compressive stress.

$$\text{FOS} = \frac{\textit{Yield Stress of stainless steel blade}}{\textit{Allowable compressive stress of products}} = \frac{270}{3} = 90 \qquad (3.33)$$

The calculated factor of safety of the blade justified the blade geometry selection as the factor of safety is greater than 1 (Gupta, 2005, Strength of materials) which implies that no failure on the blade would occur.

Furthermore, the factor of safety is this large because of the constraints of material selection of the foodstuff (stainless steel) and the size of plantain, cucumber, banana, yam and cucumber to chip.

3.3.3. Blade Selection Criteria/specification

Blade material = Stainless steel. Selected because it has high corrosion resistant properties and prevents rust contamination to sliced cucumber, plantain, banana and yam.

Factor of safety = 9. Obtained from calculated result in equation 3.33

Blade profile = Convex (Evan Bossio et, al, 2017)

Blade edge angle 20° (Vishal Singh et, al, 2016)

Blade thickness = 1.5mm (Vishal Singh et, al, 2016)

Cutting edge thickness = 0.5mm (www.kitchenknifeforum.com)

Blade length = 97mm

Blade dimensions discussion

The Figure 10 shows first angle orthographic projections of the designed blade assembly (cutting disc and blade). It could be observed from detail **B (1:2)** that the designed blade had a convex profile with a **20°** and **1.5mm** thick (Vishal Singh et, al, 2016).

The blade length of **97mm** was determined by considering the following criteria: largest diameter of products to be sliced, which in the case of the design, yam had the largest average diameter of **52.15mm** (Keir, et al, 2015). Therefore, the length of the blade had to be greater than the diameter of yam to perform a good slice (Keir, et al, 2015). Since the blade length was designed to be **97mm** and was larger than the average diameter of yam to be sliced, it was satisfactory (Keir, et al, 2015). The blade length was also constrained to a safe 97mm length considering the available distance between the shaft's hole and the circumference of the cutting disc in order to ovoid protrusion out of the cutting disc or interference with shaft's hole.

From the front view of the orthographic projections as shown in the Fig 10, the blade assembly (cutting disc) was designed in such a way that sliced plantain, banana, cucumber and yam chips could easily pass through the rectangular opening created on the surface of the rotating disc as the slicing operation takes that could prevent continuous sticking of plantain, banana, yam and cucumber chips on the blade while in operation.

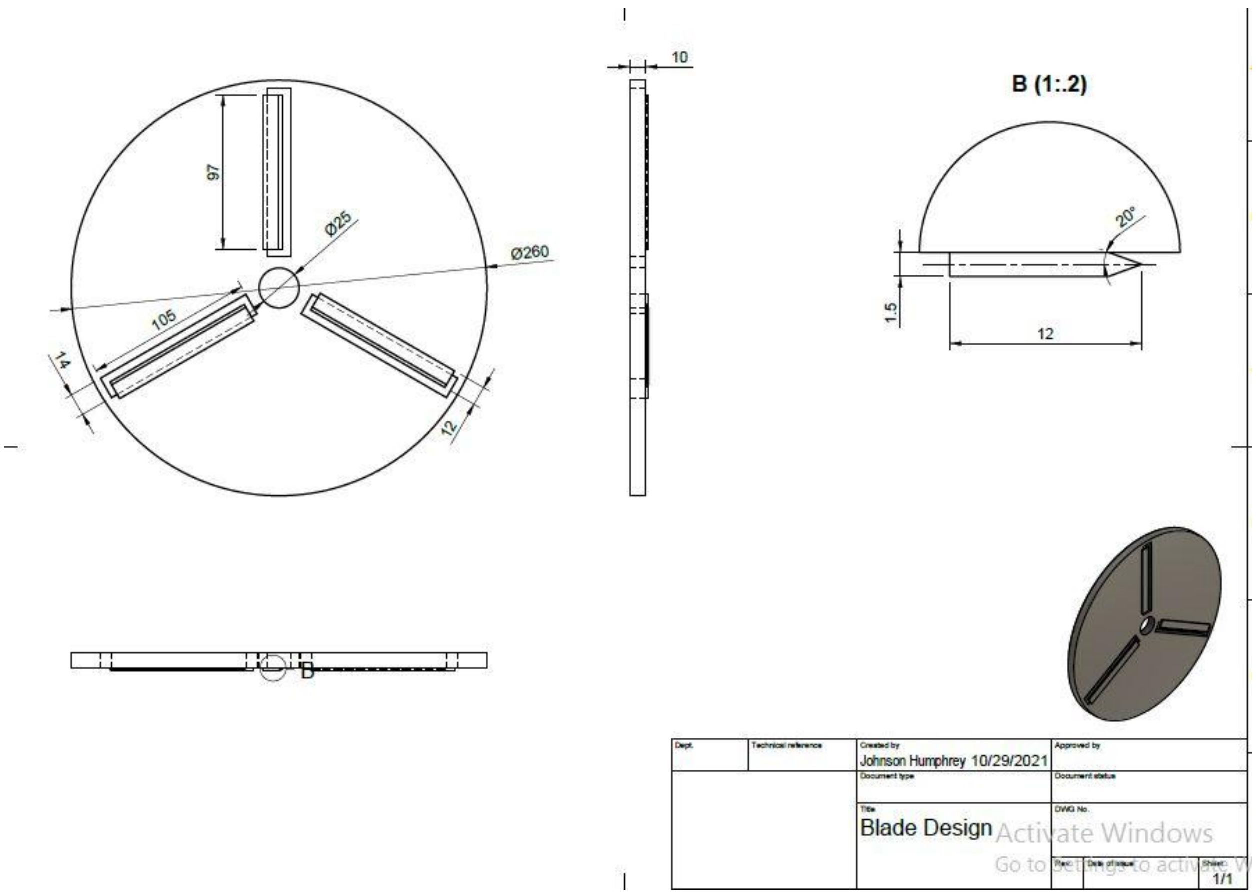


Fig 3. 7 Diagram showing the Blade Geometry

3.4.V-Belt Design Analysis

1. Setting Conditions Required in the Design Work

Selecting appropriate conditions for the design analysis of the machine depended the following which included the type of machine, transmission power, running hours per day, induction motor pulley speed and speed ratio. Therefore, since the machine is being designed for small and medium scale applications, it is meant to operate in the following set out standard conditions.

a. Type of machine**: Light Duty Machine** (Machine between 0.7 – 3.7KW). (Khurmi, 2005)

b. Transmission power: **Single Phase 1HP/0.746KW**

c. Running Hours Per day**: 8 -12hrs** (Machine between 0.7 – 3.7KW). (Khurmi, 2005)

d. Small Pulley Speed: **1440rpm**

e. Speed Ratio: **2**

Operating Condition	**Operating Hours Per day**		
	3 -5	8 – 12	16 -24
Normal Duty	1.0	1.1	1.2
Light Duty	1.1	1.2	1.3
Medium Duty	1.2	1.3	1.4
Heavy Duty	1.3	1.4	1.5

Table 3. 5 showing standard service correction factor under different operating conditions (Standard V-Belt Manual, DIN Standard)

Belt Section	**Power range in KW**	**Min Pitch Dia(mm)**	**Top Width(b) mm**	**Thickness (t) mm**
A	0.7 - 3.7	71	13	8
B	2 – 15	125	17	11
C	7.5 – 75	200	22	14
D	20 - 150	335	32	19
E	30 - 350	500	38	23

Table 3. 6 showing dimensions of standard V-belts (Khurmi and Gupta, 2004). According to IS: 2494 – 1974).

1. **Setting the Design Power**

The design power of the machine is the product of the induction motor transmission power and the service correction factor, mathematically represented as;

$$P_d = P \times F_S \qquad (3.34)$$

Where P_d = Design power

P = Transmission power

F_S= Service correction factor

Therefore, P_d **= 0.746 ×1.2 = 0.8952**

Design power is approximately **0.9KW**

2. **Selecting the V-Belt type**

Selecting the suitable belt type depended on the design power with respect to the corresponding standard induction motor speed.

The **Figure 3.8** represents the most important parameters necessary for the belt type selection. On the y-axis of the figure represents the speeds at which the electric motor is being run and the x-axis of the figure represents the calculated design power of the electric motor.

Therefore, in order to obtain the belt type of the machine, two parameters were considered, which includes; design power and electric motor speed. From calculated results, the design power and speed of the electric motor was calculated to be **0.9KW and 1440rpm** which fall under the **A-Section** belt type. Therefore, from standard manufacturing catalogue, the corresponding cross section of the belt is **an A-Section V-Belt type.**

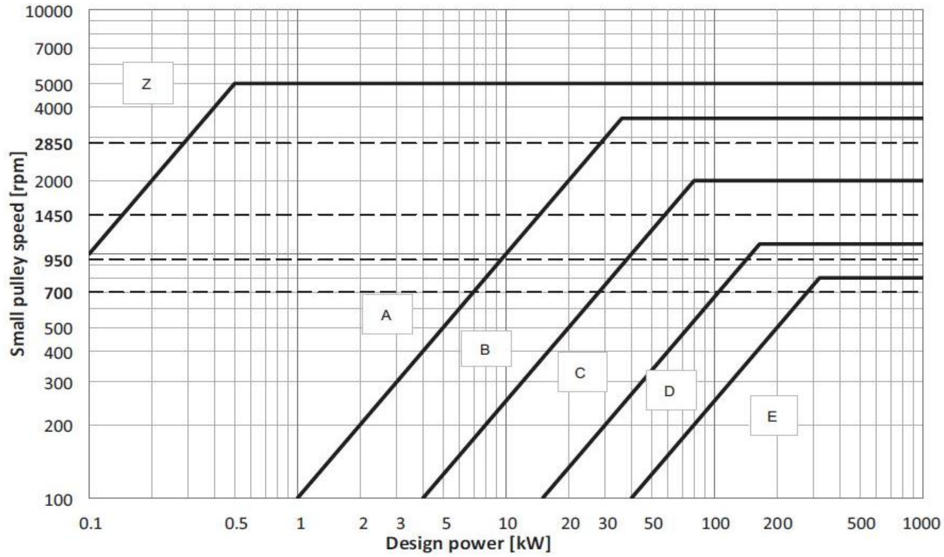


Fig 3. 8 Standard cross section selection catalogue for classical V-Belt

3. **Selecting the standard V-Belt Cross section**

   From **Table 3.6**, the standard dimension of the A-type V-Belt has its nominal width as **13mm** and has its nominal thickness as **8mm**

4. **Selecting the standard driver pulley size**

   In this case, the driver pulley size is also known as the induction motor pulley size. Since the minimum recommended pulley diameter for efficient industrial applications is found to be **71mm** according to the standard chart as shown in **Table 3.5**, a standard pulley size of **75mm** pitch diameter was selected for the design.

5. **Selecting the standard driven pulley size**

   In this case, the driven pulley size is also known as the shaft pulley size. Obtaining a standard driven pulley size depended on the speed ratio and the driver pulleys size required for the design work.

   $$\mathbf{D = I \times d} \qquad (3.35)$$

   Where D = Driven pulley diameter =?

   I = Speed ratio = 2

d = Driver pulley size = 75mm

Therefore, **D = 2 × 75mm = 150mm**

Since a pulley size of **150mm** is a standard pulley size, 150mm driven pulley size was selected.

6. Determining the approximate center to center distance between pulleys

The approximate center to center distance between the induction motor pulley and shaft's pulley was computed using the equation 3.36, below.

$$C_1 = 1.5(D+d) \tag{3.36}$$

Where D = Shaft pulley diameter

d = Induction motor pulley diameter

Therefore C = 1.5 (150 + 75)

C_1**= 337.5mm**

7. Determining the maximum belt speed for selected conditions

According to (Khurmi and Gupta, 2004), the maximum recommended belt speed for light duty condition is **10m/s.**

8. Determining the Design Belt Speed

The design belt speed of the machine was computed using the equation 3.37 below:

$$V_b = \frac{\pi d N}{60} \tag{3.37}$$

Where d = motor pulley diameter

N = Motor Pulley speed

V_b = Design belt speed

Therefore,

$$V_b = \frac{3.142 \times 75 \times 1440}{60} = 5.6556\text{m/s}$$

Therefore, the design belt speed is calculated to be **5.6556m/s.** This satisfies the condition stated by Khurmi and Gupta, 2004 that the design belt speed must be less than the maximum belt speed for light duty condition.

9. Determining the inside belt length

Obtaining the belt length depends on the approximate center to center distance between the two pulleys. The belt length can be calculation using the equation 3.38 below;

$$\mathbf{Li} = \frac{pie}{2}(D + d) + 2C + \frac{(D+d)^2}{4C} \qquad (3.38)$$

Where D = Shaft pulley diameter

d = Motor pulley diameter

C = Center to center distance

Therefore,

$$Li = \frac{3.143}{2}(150 + 75) + 2(337.5) + \frac{(150+75)^2}{4(337.5)}$$

Li = 1044.321mm

I. Interim Datum Belt Length

The interim belt datum length is also referred to as the approximate inside length of the belt. In order to obtain the interim datum length of the belt, we need to convert the inside belt length to the approximate inside belt length by subtracting a value **30mm** from it. The **Figure 3.9** below represents the cross section of the selected type of belt, the appropriate belt length conversion factor, the recommended minimum pulley diameter and the maximum recommended belt speed. From the **Figure 3.9,** it could be seen that the belt length conversion factor was found to be **30mm**. This obtained conversion factor was necessary to calculate for the interim datum length of the belt.

Section	ISO 4184 DIN 2215	Z 10	A 13	B 17	C 22	D 32	E 40
Top belt width	bo (mm)	10	13	17	22	32	40
Datum width	bd (mm)	8.5	11	14	19	27	32
Height of belt	h (mm)	6	9	11	14	19	25
Datum length	Ld≒Li+ (mm)	22	30	43	52	75	82
Distance down to datum line	hd (mm)	2.5	3.3	4.2	5.7	8.1	12
Outer length	La≒Li+ (mm)	38	50	69	88	126	157
Recommended minimum Pulley datum diameter	dd (mm)	45 (40)	71 (63)	112 (90)	180 (140)	315	450
Recommended maximum Belt speed	V (m/s)	30					

Fig 3. 9 Cross section dimension of classical V-Belts according to ISO 4148 DIN 2215 standard

Therefore, $L_d = L_i - 30mm$ (3.39)

$$L_p = 1044.321 - 30mm$$

$$L_p = 1014.321\text{mm}$$

From the **Figure 3.9**, the A-section V-Belt has an inside length to datum length conversion factor of 30mm.

10. Selecting the standard belt length closest to the interim datum belt length

In order to select the belt length closest to the interim datum belt length or approximate inside belt length, we need to refer to the standard chart **Figure 3.5**

The **Figure 3.10** represents the belt designation that corresponded to the calculated inner length or interim datum length of the belt. From calculated results, according to **Equation 3.34**, the calculated inner length or interim datum length of the belt was **1014.321mm**. obtaining the appropriate inner length required the selection of an inner belt length closest to the calculated inner of the belt.

Therefore, from the **Figure 3.10**, the inner length of belt closest to **1014.321mm,** was found to be **1016mm** and had a corresponding belt designation as **A-40.** This obtained belt designation would enable the correct purchase of the appropriate belt drive to adopt during manufacture**.**

A-Section					
Belt Code	Inner length Li (mm)	Datum length Ld (mm)	Belt Code	Inner length Li (mm)	Datum length Ld (mm)
20	508	538	71	1800	1830
21	535	565	72	1825	1855
22	560	590	73	1854	1884
23	585	615	74	1880	1910
24	610	640	75	1900	1930
25	630	660	76	1930	1960
26	660	690	77	1956	1986
27	686	716	78	1980	2010
28	710	740	79	2000	2030
29	730	760	80	2032	2062
30	767	797	81	2060	2090
31	787	817	82	2083	2113
32	813	843	83	2110	2140
33	838	868	84	2134	2164
34	864	894	85	2160	2190
35	889	919	86	2180	2210
36	914	944	87	2210	2240
37	940	970	88	2240	2270
38	965	995	89	2260	2290
39	990	1020	90	2286	2316
40	1016	1046	91	2310	2340
41	1041	1071	92	2337	2367
42	1060	1090	93	2360	2390
43	1100	1130	94	2388	2418
44	1120	1150	95	2413	2443
45	1143	1173	96	2438	2468
46	1168	1198	97	2464	2494
47	1200	1230	98	2500	2530
48	1220	1250	99	2515	2545
49	1250	1280	100	2540	2570

Fig 3. 10 Interim Belt Length for Classical V-Belt according to ISO 4148/ DIN 2215 Standard.

a. **Recommended pitch belt length**

Obtaining the recommended pitch length of the belt depended on the inside length to datum length conversion factor and the standard inside belt length. This was computed using the following equation 3.40.

$$L_p = L_i + 30 \quad (3.40)$$

$$L_p = 1016 + 30$$

$$\boldsymbol{L_p} = \mathbf{1046mm}$$

From the Figure 3.5, the corresponding standard pitch length or datum length was found to be **1046mm**

11. Determining the recommended center to center distance between pulleys

Obtaining the recommend center to center distance between pulleys depended on the recommended pitch length of the belt and the approximate center to center distance between pulleys.

This was computed using the equation 3.41below.

$$\boldsymbol{L_p = \frac{pie}{2}(D + d) + 2C + \frac{(D+d)^2}{4C}} \quad (3.41)$$

Where L_p = Recommended pitch length

D = Shaft pulley diameter

d = Motor pulley diameter

C = Recommended center to center distance

$$1046 = \frac{3.142}{2}(150 + 75) + 2C + \frac{(150+75)^2}{4C}$$

$$8C^2 + 2700C + 1442 = 0$$

C = 336.965mm

Therefore, the recommended center to center distance between the two pulleys was calculated to be approximately 337mm

12. Obtaining the Required Number of Belts

Calculating the required number of belts depended on the base power rate required by the induction motor pulley, arc of contact correction factor **KΘ**, and the belt length correction factor **Ke**.

Therefore, calculating the required number of belts was obtained using the equation 3.42 below;

$$\boldsymbol{n_b = \frac{P_d}{P_c}} \quad (3.42)$$

Where P_d = Design power

P_c = correction power rating

$$P_c = P_r \times \text{Ke} \times \text{K}\Theta \tag{3.43}$$

The values of Ke, KΘ and P_r were obtained from the standard chart tables below

Arc of contact Correction factor

Figure 3.11 represents the contact angle of between the belt's V-side of and the groove of the pulley. It was necessary to have appropriate contact angle in order to avoid unnecessary belt slip while in operation and thus prevent failure of the machine. The act of contact angle depended on the diameter of the driver and driven pulley and the recommended center to center distance between both pulleys which in turns gives the appropriate arc of contact correction factor. According to **Equation 3.45 and 3.45b** the calculated act of contact angle was calculated to be **167.2**° and **192.7**° for the small and large pulley respectively. Since the tension would be based on the motor pulley because it is the driver, the corresponding arc of contact correction factor in **Figure 3.11**, would be based of the angle of wrap of the motor pulley. Therefore, arc of contact correction factor that corresponded to the angle of wrap of the driver pulley was found to **be 0.97** in **Figure 3.611**

Therefore, the corresponding Arc of contact correction factor was found to be **KΘ=0.97**

$\frac{Dd-dd}{C}$	Contact angle on small pulley θ(°)	Kθ
0.00	180	1.00
0.10	174	0.99
0.20	169	0.97
0.30	163	0.96
0.40	157	0.94
0.50	151	0.93
0.60	145	0.91
0.70	139	0.89
0.80	133	0.87
0.90	127	0.85
1.00	120	0.82
1.10	113	0.80
1.20	106	0.77
1.30	99	0.73
1.40	91	0.70
1.50	83	0.65

Fig 3. 11 Arc of contact Correction factor

Belt length correction factor

Figure 3.12, represents the belt length correction factor. This factor was necessary to allow for allowance when installation takes place thus preventing damage or failure of the belt drive while in operation. The belt length correction factor determination depended on the on the design belt designation. Since the belt code/designation was calculated to be an **A-40** belt section and can found between the values of **A38 – A41**, then Belt length correction factor was found to be **Ke = 0.89**

Length designation	A	B	C	D	E
20 ~ 25	0.77	0.72			
26 ~ 30	0.82	0.76			
31 ~ 34	0.85	0.79			
35 ~ 37	0.87	0.81	0.71		
38 ~ 41	0.89	0.83	0.73		
42 ~ 45	0.91	0.85	0.75		
46 ~ 50	0.93	0.87	0.77		
51 ~ 54	0.94	0.89	0.78		
55 ~ 59	0.96	0.91	0.80		
60 ~ 67	0.98	0.93	0.82		
68 ~ 74	1.01	0.95	0.84		
75 ~ 79	1.03	0.97	0.86		
80 ~ 84	1.04	0.98	0.87		
85 ~ 89	1.05	0.99	0.89		
90 ~ 95	1.07	1.01	0.90		
96 ~ 104	1.08	1.03	0.91	0.81	
105 ~ 111	1.10	1.04	0.93	0.82	
112 ~ 119	1.12	1.06	0.94	0.84	
120 ~ 127	1.13	1.07	0.96	0.85	
128 ~ 144	1.15	1.09	0.98	0.87	0.85
145 ~ 154	1.18	1.11	1.00	0.89	0.87
155 ~ 169	1.19	1.13	1.02	0.91	0.88
170 ~ 179	1.21	1.15	1.03	0.92	0.90
180 ~ 194	1.23	1.17	1.05	0.94	0.91
195 ~ 209	1.25	1.18	1.07	0.95	0.93
210 ~ 239	1.27	1.21	1.09	0.98	0.95
240 ~ 269	1.30	1.24	1.12	1.00	0.98
270 ~ 299	1.33	1.26	1.14	1.03	1.00
300 ~ 329	1.35	1.29	1.17	1.05	1.02
330 ~ 359	1.38	1.31	1.19	1.07	1.04
360 ~ 389	1.40	1.33	1.21	1.09	1.06
390 ~ 419		1.35	1.22	1.11	1.08
420 ~ 479		1.38	1.25	1.13	1.10
480 ~ 539		1.41	1.28	1.16	1.13
540 ~ 600		1.44	1.31	1.18	1.16
601 ~ 660		1.46	1.33	1.21	1.18

Fig 3. 12 Belt length correction factor

Basic power rating

From Figure 3.12, the basic power rating represented the required voltage for smooth running of the electric motor. It also shows the permissible maximum amount of current which can easily flow through the electric motor which allows for a chance of breakdown if the electric motor goes beyond the limit. The basic power rating accounts for overload capacity and starting torque of the electric motor. Obtaining the appropriate basic power rating was necessary to avoid unnecessary breakdown of the machine. Therefore, basic power rating depended on the diameter and speed of the motor pulley. Therefore, corresponding basic power rating was found to be $\boldsymbol{P_r}$ **=0.98KW**

small pulley speed nd(rpm)	Basic power rating for small pulley datum diameter : Ps															Additional power rating for speed ratio (Pa)			
	Small pulley datum diameter dd (mm)															Speed ratio			
	71	75	80	90	95	100	106	112	118	125	132	140	150	160	180	1.01 to 1.05	1.06 to 1.26	1.27 to 1.57	1.57<
700	0.51	0.61	0.73	0.96	1.08	1.20	1.34	1.48	1.62	1.78	1.94	2.12	2.34	2.56	3.00	0.01	0.08	0.12	0.15
950	0.62	0.75	0.91	1.22	1.37	1.53	1.71	1.89	2.07	2.28	2.49	2.72	3.02	3.30	3.87	0.02	0.11	0.16	0.20
1450	0.80	0.98	1.21	1.66	1.89	2.11	2.37	2.63	2.89	3.18	3.48	3.81	4.22	4.62	5.40	0.03	0.18	0.25	0.31
2850	1.04	1.36	1.75	2.52	2.90	3.27	3.70	4.12	4.53	4.99	5.44	5.93	6.51	7.06	8.04	0.05	0.34	0.49	0.60
100	0.12	0.13	0.16	0.20	0.22	0.24	0.26	0.28	0.31	0.33	0.36	0.39	0.43	0.47	0.55	0.00	0.01	0.02	0.02
200	0.20	0.24	0.27	0.35	0.39	0.43	0.47	0.52	0.56	0.61	0.66	0.72	0.80	0.87	1.01	0.00	0.02	0.03	0.04
300	0.28	0.32	0.38	0.49	0.54	0.60	0.66	0.73	0.79	0.87	0.94	1.03	1.13	1.24	1.45	0.01	0.04	0.05	0.06
400	0.34	0.40	0.47	0.62	0.69	0.76	0.85	0.93	1.01	1.11	1.21	1.32	1.45	1.59	1.86	0.01	0.05	0.07	0.08
500	0.40	0.48	0.56	0.74	0.83	0.91	1.02	1.12	1.22	1.34	1.46	1.59	1.76	1.93	2.25	0.01	0.06	0.09	0.11
600	0.46	0.54	0.65	0.86	0.96	1.06	1.18	1.30	1.42	1.56	1.70	1.86	2.06	2.25	2.63	0.01	0.07	0.10	0.13
700	0.51	0.61	0.73	0.96	1.08	1.20	1.34	1.48	1.62	1.78	1.94	2.12	2.34	2.56	3.00	0.01	0.08	0.12	0.15
800	0.56	0.67	0.80	1.07	1.20	1.33	1.49	1.65	1.80	1.98	2.16	2.37	2.62	2.87	3.36	0.01	0.10	0.14	0.17
900	0.60	0.72	0.87	1.17	1.32	1.46	1.64	1.81	1.99	2.18	2.38	2.61	2.88	3.16	3.70	0.02	0.11	0.15	0.19
1000	0.64	0.78	0.94	1.27	1.43	1.59	1.78	1.97	2.16	2.38	2.60	2.84	3.14	3.44	4.03	0.02	0.12	0.17	0.21
1100	0.68	0.83	1.01	1.36	1.54	1.71	1.92	2.13	2.33	2.57	2.80	3.07	3.40	3.72	4.36	0.02	0.13	0.19	0.23
1200	0.72	0.87	1.07	1.45	1.64	1.83	2.05	2.28	2.50	2.75	3.00	3.29	3.64	3.99	4.67	0.02	0.15	0.21	0.25
1300	0.75	0.92	1.13	1.54	1.74	1.94	2.18	2.42	2.66	2.93	3.20	3.50	3.88	4.25	4.97	0.02	0.16	0.22	0.27
1400	0.78	0.96	1.19	1.62	1.84	2.05	2.31	2.56	2.81	3.10	3.39	3.71	4.11	4.50	5.26	0.03	0.17	0.24	0.30
1500	0.81	1.00	1.24	1.70	1.93	2.16	2.43	2.70	2.96	3.27	3.57	3.91	4.33	4.74	5.54	0.03	0.18	0.26	0.32

Fig 3. 13 Basic power rating

In summary,

From Fig 3.6, $\frac{D-d}{C} = \frac{150-75}{337}$ =0.22 (3.44)

$\Theta = 180^\circ - 57.3(\frac{150-75}{337}) = 167.2^\circ$ (Angle of wrap for the motor pulley) (3.45)

$\Theta = 180^\circ + 57.3(\frac{150-75}{337}) = 192.7^\circ$ (Angle of wrap for the Shaft pulley) (3.45b)

$K\Theta$ = Arc of contact correction factor = 0.97

Ke = Belt length correction factor = 0.89

P_r = Base Power rate = 0.98KW

Therefore, $\boldsymbol{n_b = \frac{0.9}{0.98 \times 0.89 \times 0.97} = 1.07}$ (3.47)

Only two Belts was used for maximum efficiency and effectiveness and to avoid operational failure.

13. Determining the tensions in the belt

The tensions in the belt includes; effective tension, tension in the slack side, tension in the tight side and the minimum static tension. Obtaining the tensions in the belt followed the following design flow.

a. Obtaining the span length of the belt

The span length of the belt depended on the shaft pulley diameter, motor pulley diameter and the recommended center to center distance between the pulleys. This was computed using the equation (3.48) below;

$$L_s = \sqrt{C^2 - \frac{(D-d)^2}{4}} \qquad (3.48)$$

$$L_s = \sqrt{337^2 - \frac{(150-75)^2}{4}}$$

$$\boldsymbol{L_s = 334.91\text{mm}}$$

b. Calculating the minimum static tension

The minimum static tension in the belt was computed using the equation (3.49) below

$$\boldsymbol{T_o = 0.9\ (500 \times \frac{(2.5 - K\Theta)P_d}{K\Theta \times n_b \times V} + W \times V^2} \qquad (3.49)$$

Where $K\Theta$ = Arc of contact correction factor = 0.97

P_d = Design power = 0.9KW

V^2 = Belt speed = 5.6556m/s $\quad$ n_b = No of belt = 2

W = Weight of belt per unit weight = 0.12Kg/m

Figure 3.14 represents the mass of one meter length of and A-Section belt in order to obtain the tensions in the tight and slack side of the belt which is due to Centrifugal force defined as the mass of the belt per one-meter length of the belt. From Figure 3.14, the weight of A section belt drive per meter length is represented as 0.12W (Kg/m).

Belt Section	W(kg/m)	Y(N/pc)
Z	0.05	9.8
A	0.12	14.7
B	0.20	19.6
C	0.30	29.4
D	0.65	58.8
E	1.00	108

Fig 3. 14 Table showing the weight of belt per metre for A belt section

$T_o = 0.9\ (500 \times \frac{(2.5 - 0.97)0.9}{0.97 \times\ 2 \times 5.6556} + (0.12 \times 5.6556^2)$

$0.9\ (500 \times \frac{1.377}{10.971864} + 3.83829)$

$\boldsymbol{T_o}$ **= 59.96N (Approximately 60N)**

c. Calculating the effective tension

The effective tension in the belt was computed using the equation (3.50) below

$$\boldsymbol{T_e = \frac{1000 \times P_t}{V}} \qquad (3.50)$$

Where T_e = Effective tension =?

V = Belt speed = 5,6556m/s

P_t = Transmission power = 0.746KW

Therefore, $T_e = \frac{1000 \times 0.746}{5.6556} =$ $\boldsymbol{T_e}$ **= 132N**

d. Calculating Tension in the tight side

Calculating the tension in the slack side of the belt was computed using the equation (3.51) below

$$\boldsymbol{T_s = \frac{1000 \times P_d}{n_b \times V} \times \frac{2.5 - 2(K\theta)}{2(K\theta)} \times W + V^2} \qquad (3.51)$$

$$T_s = \frac{1000 \times 0.9}{2 \times 5.6556} \times \frac{2.5-2(0.97)}{2(0.97)} \times 0.12 + 5.6556^2$$

$$T_s = \frac{900}{11.3112} \times \frac{0.56}{1.94} \times 0.12 + 5.6556^2 = \boldsymbol{T_s} = \mathbf{35N}$$

e. Calculating the Tension on the tight side

Obtaining the tension on the tight side of the belt was computed using the equation (3.52) below

$$\boldsymbol{T_t} = \left(\frac{\mathbf{1000} \times \boldsymbol{P_d}}{\boldsymbol{n_b} \times \boldsymbol{V}} \times \frac{\mathbf{2.5}}{\mathbf{2}(\boldsymbol{K\Theta})} \times \mathbf{W}\right) + \boldsymbol{V^2} \quad (3.52)$$

$$T_t = \frac{1000 \times 0.9}{2 \times 5.6556} \times \frac{2.5)}{2(0.97)} \times 0.12 + 5.6556^2$$

$$T_t = \left(\frac{900}{11.3112} \times \frac{2{,}5}{1.94} \times 0.12\right) + 5.6556^2 = \boldsymbol{T_t} = \mathbf{106N}$$

f. Calculating the power transmitted through the belts

The power transmitted per belt was computed using the equation (3.53) below

$$\boldsymbol{p_b} = (\boldsymbol{T_t} - \boldsymbol{T_S})\boldsymbol{V} \quad (3.53)$$

Where T_t = Tension on the side of the belt = 106N

T_S = Tension on the slack side of the belt = 35N

p_b = Power transmitted per belt =?

V = Velocity of the belt = 5.6556m/s

Therefore, $p_b = (106 - 35)\ 5.6556$

$\boldsymbol{p_b}$ **= 401.5476W or 0.402KW**

For maximum efficiency, an induction motor of 0.746KW/1440rpm transmission power/speed and 0.9KW design power was used.

g. Calculating the torque required by the belt

The torque required by the belt was computed using the equation (3.54) below

$$\boldsymbol{T_q} = \boldsymbol{T_e} \times \frac{\boldsymbol{d}}{\mathbf{2}} \times \frac{\mathbf{1}}{\mathbf{1000}} \quad (3.54)$$

$$T_q = 132 \times \frac{75}{2} \times \frac{1}{1000}$$

$T_{q=}$ **4.95N-m**

h. Obtaining the tensioning ratio

The tensioning ratio was computed using the equation (3.55) below

$$\boldsymbol{T_r} = \frac{\boldsymbol{T_t}}{\boldsymbol{T_s}} \qquad (3.55)$$

$T_r = \frac{106}{35}$ = **3.03N**

3.5.Shaft Design Analysis

The shaft design analysis required by the machine followed the following the design Flow;

1. Obtaining the Torque in the shaft
2. Bending moments of the shaft
3. Equivalent twisting moment
4. Ideal diameter of the shaft
5. Torsional stress on the shaft
6. Bending stress on the shaft

1. Obtaining the torque in the shaft

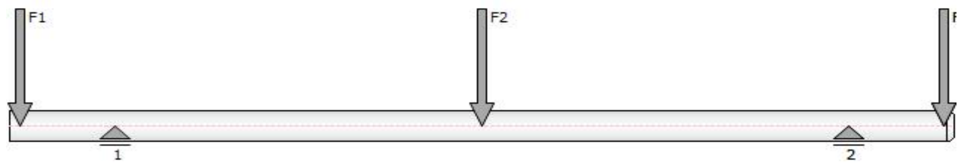
Obtaining the toque developed on the shaft was computed using the equation **(**3.56) below

$$\mathbf{T} = \frac{\boldsymbol{P_d} \times \mathbf{60}}{\mathbf{2\pi N}} \qquad (3.56)$$

$$T = \frac{900 \times 60}{2 \times 3.142 \times 720}$$

T = 11.93507Nm or 11.93507 × $\mathbf{10^3}$ Nmm

2. Calculating the Bending



Mome

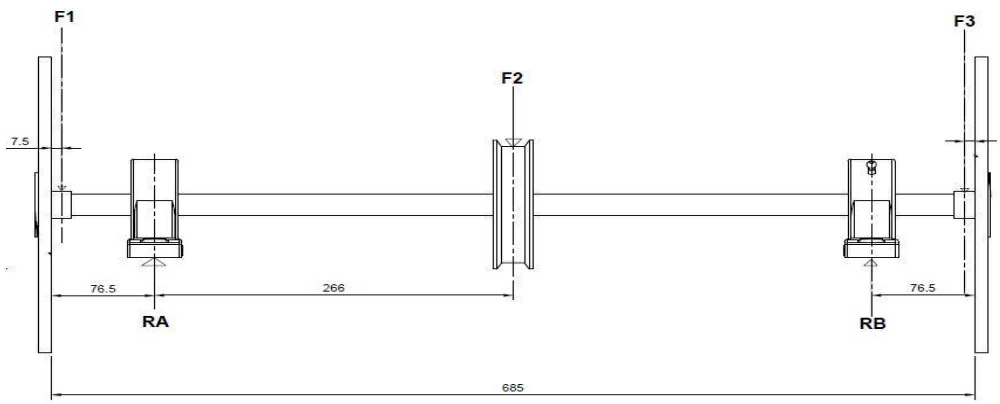


Fig 3. 15 Diagrammatic representation of overall loading on shaft

From fig 3.12, a shaft length of 685mm with two bearing acting as reaction forces to the forces induced from the weight of the pulley, tensions in the belt and loads from the bladed and cutting discs.

Therefore, for this loading condition,

1. We would use a shaft length of 685mm.
2. We would consider both the tensions on the belt and the weight of the pulley and the force required to slice any of the agro based products which has the largest force. In the case of this design, yam possesses the largest force required for slicing.
3. We would also consider the weight of the cutting disc and weight of the cutter

Where W = Weight of pulley = 40N

T_s = Belt tension on the slack side = 35N

T_t = Belt tension on the tight side = 106N

R_A = Bearing reaction at A

R_A = Bearing reaction at B

L = Length of shaft = 685mm

$\boldsymbol{F_2}$ **=** Weight of pulley, tension of belt in the slack and tight side

$\boldsymbol{F_3}$ And $\boldsymbol{F_1}$ **=** Weight of cutting disc, cutter and largest force required to slice product

Therefore, $\boldsymbol{F_2}$ **= W +** $\boldsymbol{T_t +\ T_t}$ **= 40 +35 +106 = 181N** (3.57)

$\boldsymbol{F_3}$ And $\boldsymbol{F_1}$ **= 224.68 + 140 + 178.03 = 542.71N** (3.57)

Analyzing the shaft for the following set of conditions

I. Weight of the pulley

II. Tension in the belts

$\boldsymbol{\Sigma F_y \mid = 0}$

R_A – W + R_B = 0

R_A – 181 + R_B = 0 (3.59)

$R_A +\ R_B$ - 181 = 0

$\boldsymbol{\Sigma M_{B(counter\ clockwise+)} = 0}$ (3.60)

- R_A(685) + 181(342.5) = 0

-685R_A = -61992.5

$\boldsymbol{R_A}$ **= 90.5N**

From equation (3.24)

R_A – 181 +R_B = 0

181 – 90.5 +R_B = 0

-90.5 = - R_B

$\boldsymbol{R_B = 90.5N}$

Therefore, $R_A = R_B = 90.5N$

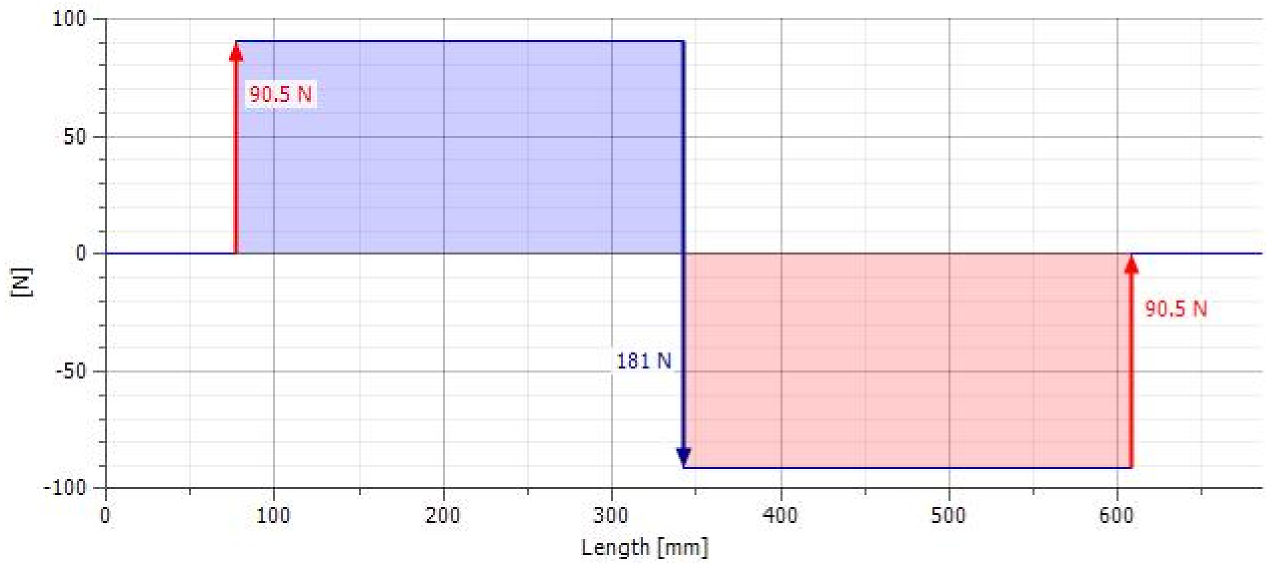


Fig 3. 16 Shear Force diagram of shaft under loading conditions of the pulley weight and the tensions in the belt.

From figure 3.13, it was observed that the reaction force of the two bearings A and B were calculated to be 90.5N with a maximum sheer force of 181N occurring at the midpoint of the shaft.

Analyzing the shaft for the following set of conditions

I. Weight of the cutting disc
II. Weight of the blade
III. Weight of the pulley
IV. Tension in the belt

$\boldsymbol{\Sigma F_y | = 0}$ (3.61)

$R_A + R_B$ – 542.17 – 542.17 - 181 = 0

$R_A + R_B$ = 1266.42N (3.62)

$\Sigma M_{B(counter\ clockwise+)}$ **= 0**

542.17(601) - R_A(532) +181(266) -542.17(69) = 0

326187 - 532R_A +48146 – 37446.99 = 0

336886.01 = 532R_A

R_A = 633.24N

R_A = R_B = 633.24N (3.63

The little consideration will show that the maximum bending moment lies at each bearings

Obtaining the Maximum bending moment

Recall that $B.M_{max}$ = W L (According to Khurmi, Theories of machine, 2005) (3.64)

Where W = Reaction force at one of the bearings

L = Distance from the reaction force from one bearing, since they have equal reaction forces, to the cutting disc.

$B.M_{max}$ = 633.24 (69)

$B.M_{max}$ = 43693.56Nmm

Obtaining the equivalent twisting moment

$$T_e = \sqrt{(M_B)^2 + (M_t)^2} \quad (3.65)$$

M_B = Maximum Bending Moment

M_t = Torque

$$T_e = \sqrt{(43693.56)^2 + (11.93507)^2} \quad (3.66)$$

T_e = 45294.29Nmm

Obtaining the ideal diameter of the shaft

Calculating the ideal diameter of the shaft was computed using the equation below

$$\boldsymbol{d^3 = \frac{16}{\pi\tau} \times \sqrt{(K_m \times M_B)^2 + (K_t \times M_t)^2}} \quad (3.67)$$

Where τ = Maximum permissible shear stress for shafts with keyways = 40Mpa

K_m = for suddenly applied load in rotating shafts (Khurmi and Gupta, 2004) = 1.5

M_B= Maximum bending moment = 43693.56Nmm

K_t = for suddenly applied load in rotating shafts (Khurmi and Gupta, 2004) = 1.5

M_t = Torque generated = 11935.07Nmm

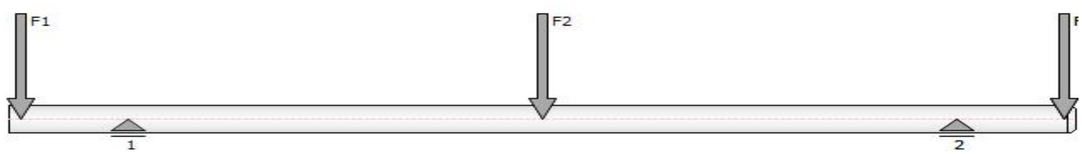
$$d^3 = \frac{16}{3.142 \times 40 \times 10^6} \times \sqrt{(1.5 \times 43693.56)^2 + (1.5 \times 11935.07)^2}$$

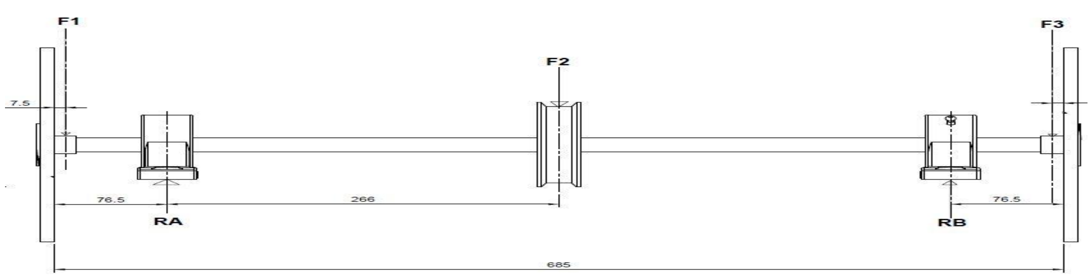
$d^3 = 8944.688$

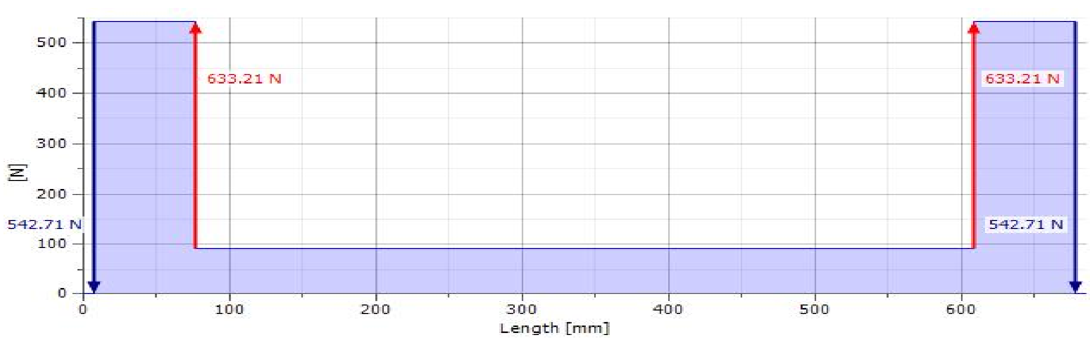
d = $\sqrt[3]{8944.688}$

d = 20.758mm

From the ideal diameter diagram, it could be seen that the recommended shaft diameter for the shaft's final loading condition is 20.758mm and should not go below this value. Since we would need to select a standard shaft size for maximum efficiency, a shaft size of 25mm was chosen.







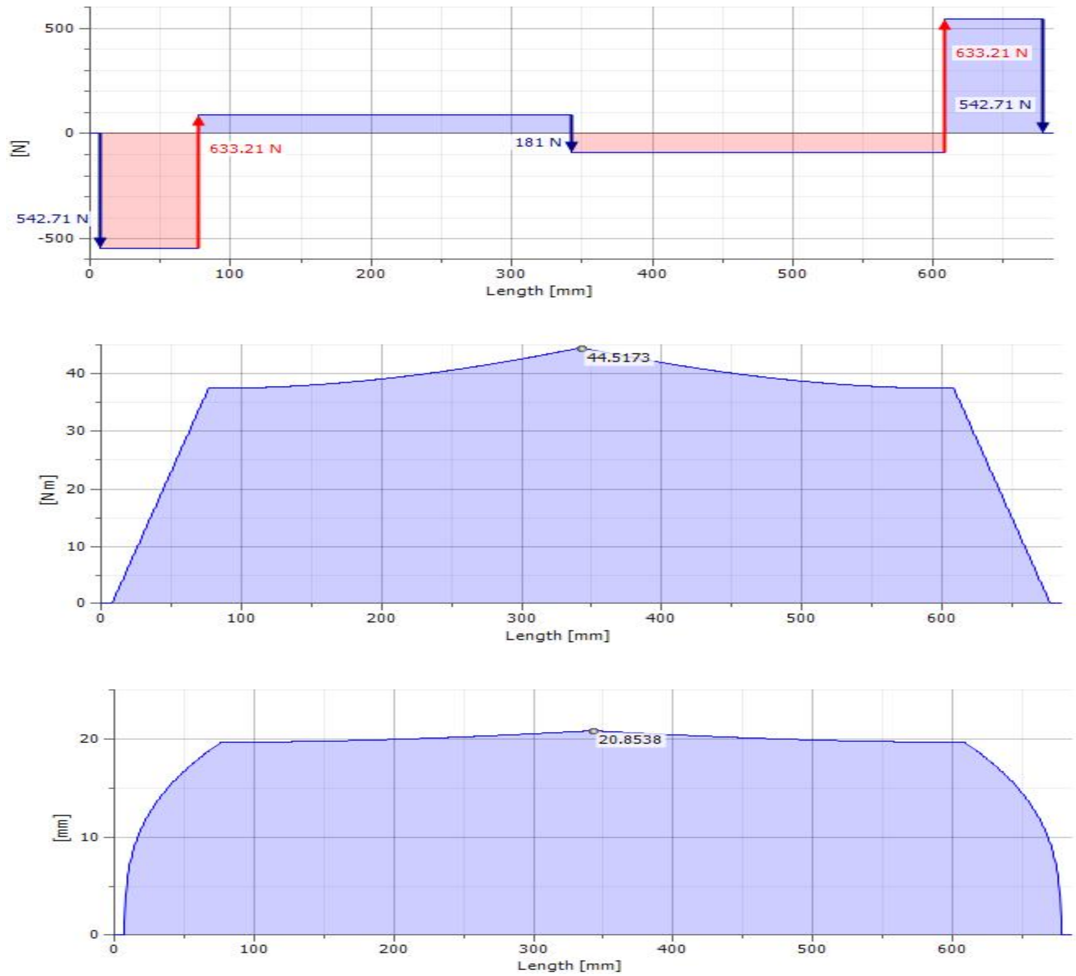


Fig 3. 17 Shear force, bending moment and ideal diameter diagram of shaft analysis from Autodesk Inventor Professional Design Software (2016 Version).

Fig 3.16 is the shaft analysis and showed design compliance with design calculations. Little allowable discrepancies observed were due to software version.

3.6.Bearing Design and Selection

The single row deep groove ball bearing was chosen because of its high load carrying capacity and suitability for high running speed. Considering the diameter of the shaft which is 25mm, a bearing of bore 25mm was then used for this calculation. The specific static load rating or capacity C_o (Arvid, 1945).

3.6.1. Bearing Design and Selection

$$Co = \frac{1}{5} \times ko \times i \times z \cos \alpha Dw^2 \qquad (3.68)$$

Where:

C_o = Specific Static Load rating or Capacity (Pillow Block Bearing) = 10kN (Arvid, 1945).

Ko = Bearing factor

D_w = Diameter of the ball =?

α = Nominal angle of contact = 25° (Arvid, 1945)

i = Number of rows of ball in any one bearing = 1 (Khurmi and Gupta, 2005)

D_w = Diameter of the ball

z = Number of balls per row in the groove = 6

$$Ko = \frac{RA}{Dw} = \frac{633.21}{26.034} = 31.6 \qquad (3.69)$$

RA= bearing load = 633.21N (From shaft analysis, equation 20)

Equation 64 is ball diameter computation formula

$$Dw = \sqrt{\left(\frac{Co \times 5}{Ko \times i \times z \cos \alpha}\right)} \quad \text{(Budynas et al, 2008)} \qquad (3.70)$$

$$Dw = \sqrt{\frac{10000 \times 5}{31.6 \times 1 \times 6 \times \cos\ 25°}}$$

Dw **= 13.13mm**

Then the maximum bearing load Q_{max} becomes:

$Q_{max} = K_o \times D_w^2$ (Arvid, 1945) (3.71)

$Q_{max} = 31.6 \times 172.41$

Q_{max} = **5.5KN**

The single row deep groove ball bearing which is also known as a pillow block bearing with an inner diameter of 25mm and outer diameter of 55mm, then was chosen under these set of criteria

I. High load carrying capacity up to 5.5KN

II. suitability for high running speed

III. Considering the calculated diameter of the shaft as 25mm, a bearing of bore 25mm was then used for this calculation.

3.7.Spring Design

The spring design for the machine was necessary to automatically feed in the products right through the inlet.

Considerations for the spring design is as follows

1. Outer diameter of the coil, Wire diameter of the spring and spring length
2. Spring index
3. Wahl Factor
4. Allowable shear stress
5. Spring rate or Spring Stiffness

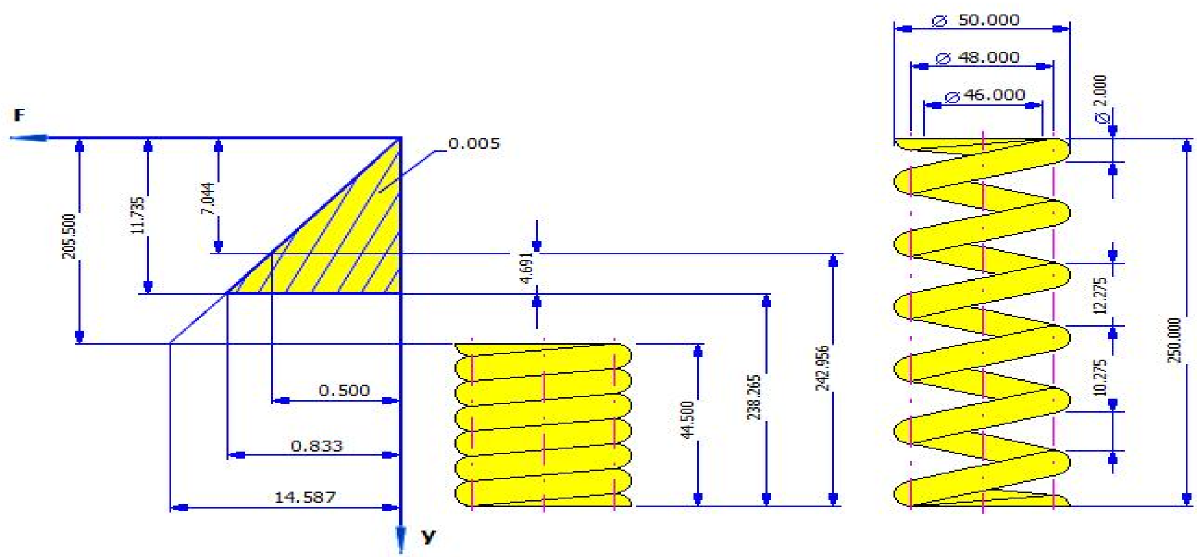


Fig 3. 18 Working Diagram of Compression Spring Design

I. <u>Outer Diameter Wire Diameter of spring & spring length</u>

Selecting appropriate diameter for the spring depended on the diameter of the inlet of the machine. The outer diameter of the spring and the loose spring length should be less than the inner diameter of the inlet and the length of the inlet.

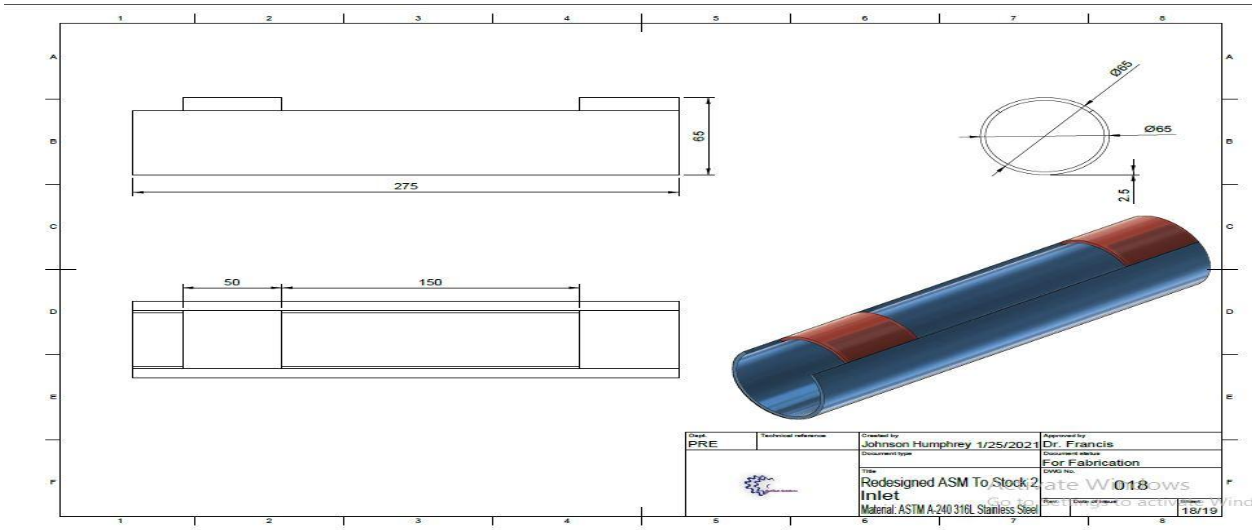


Fig 3. 19 Inlet Geometry

From Fig 3.18, inlet diameter = 65mm, Inlet Length = 255mm

Due to the fact that the inlet diameter and inlet length of the machine was modelled to be 65mm and 255mm respectively, a 50mm coil diameter spring having a loose spring length of 250mm spring length fitted in perfectly.

d = Wire thickness of spring = **2mm**. A 2mm wire diameter of the spring meets the criteria for a low stiffness spring (Khurmi and Gupta, 2005)

<u>Calculations</u>

a. Obtaining the mean diameter of the spring

$$Dm = D - d \quad (3.72)$$

Where D = outer diameter of the spring

d = Wire diameter of the spring

Dm = 50 – 2

Dm = 48mm

II. Obtaining the spring index

$$C = \frac{Dm}{d} \tag{3.73}$$

Where C = spring index

Dm = Mean coil diameter

D = wire diameter

Therefore, $C = \frac{48}{2}$ = **24**

III. Obtaining the Wahl Factor

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \tag{3.74}$$

Where K = Wahl factor

C = spring index

Therefore, $K = \frac{4(24)-1}{4(24)-4} + \frac{0.615}{24}$

K = 1.058

IV. Obtaining the maximum load stress

$$S_S = \frac{8KFD}{\pi d^3} \tag{3.75}$$

Where S_S = maximum load stress under the spring loading condition

K = Wahl Factor

F = spring load = m × g = 0.085 × 9.81

F = 0.83N

D = Outer diameter of the spring

d= Wire diameter

Therefore, $S_S = \frac{8 \times 1.058 \times 0.833 \times 50}{3.142 \times 2^3}$

S_S = 13.4Mpa

V. Obtaining the spring stiffness K

$$K = \frac{9913 \times d^4}{n \times D^3} \tag{3.76}$$

Where $d^4 = Wire\ diamter$

$D^4 = Mean\ coil\ diameter\ of\ spring$

n = no of coils

$K = \frac{9913 \times 2^4}{3.142 \times 48^3}$

K = 0.071N/mm

VI. Obtaining the minimum deflection of the spring

$$y = \frac{8FD^3}{d^4 \times G} \tag{3.77}$$

Where F = Spring Load

D = Mean diameter of spring

d = wire diameter

G = Modulus of rigidity of steel = 80Gpa

Therefore,

$y = \frac{8 \times 0.833 \times 0.043^3}{0.002^4 \times 80 \times 10^3}$

y = 11.52mm

VII. Number of coils confirmation

$$n = \frac{dG}{K \times 8C^3} \quad (3.78)$$

Where n = Number of coils

G = Modulus of rigidity, C = spring index

Therefore, $n = \frac{2 \times 80}{0.071 \times 8 \times 24^3}$

n = 0.0203 n **≈ 20 Number of coils**

From equation 3.76, the calculated spring stiffness of 0.071N/mm was considered a low stillness spring as it requires very little amount of force of 0.071N to compress 1mm length of spring. This calculated low stiffness spring was considered as the criteria for the spring selection.

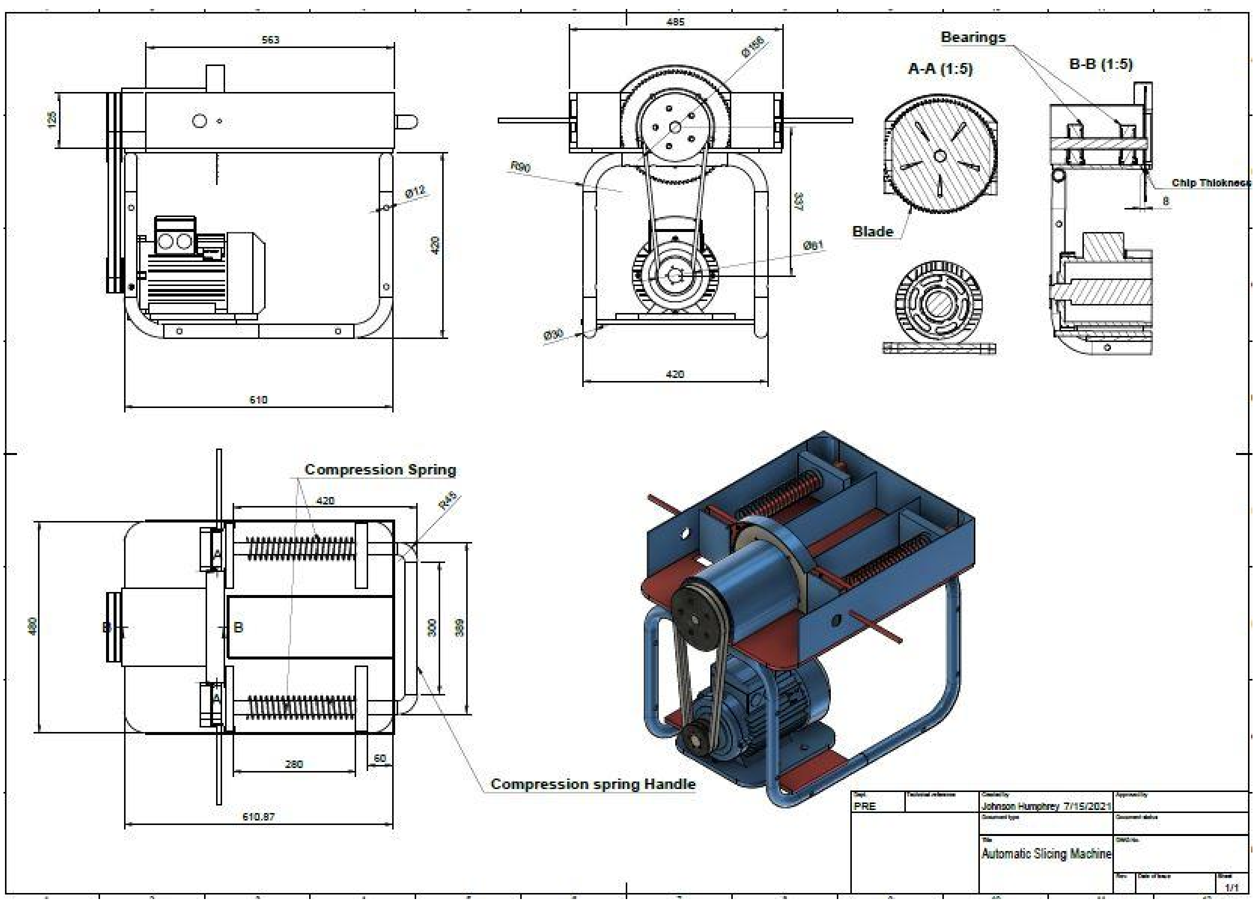


Fig 3. 20 Overall machine orthographic projection

3.8.Principle of Operation of the Machine

Two mechanisms were involved in the operation. These are the Slicing and Spring-Loaded Mechanism. These steps involved are described below;

STEP 1: Ensure that the machine and every other appliances are turned off before use

STEP 2: Ensure the machine is on a leveled ground to avoid distortion due to vibration of the motor and wobbling of the driving and driven shaft of the machine.

STEP 3: Select the produce to slice in order to determine the working condition of the machine.

STEP 4: Turn on the power supply from the mains then turn on the machine for further operation.

STEP 5: Adjust the compressive spring to allow for loading of the produce using the plunger.

STEP 6: Load the products directly to the inlet.

STEP 7: Release the plunger gradually to allow for extension of the spring

STEP 8: Collect the resulting produce (reduced size) in form of chips after cut.

STEP 9: Repeat this process for different selected crops.

STEP 10: Turn off the machine first, then switch off the mains.

STEP 11: Clean up the machine with a damped clothe for maintenance purpose.

3.9.Manufacturing Process/Material Selection of the machine

The manufacturing processes/diagrams for each of the components used in the development of the slicing/cutting machine are as follows:

1. **Motor Frame**

   Material: Mild Steel (Hollow Pipe). This material was selected to serve as a factor for weight reduction of the machine.

   Manufacturing Process: Bending, Welding and Drilling

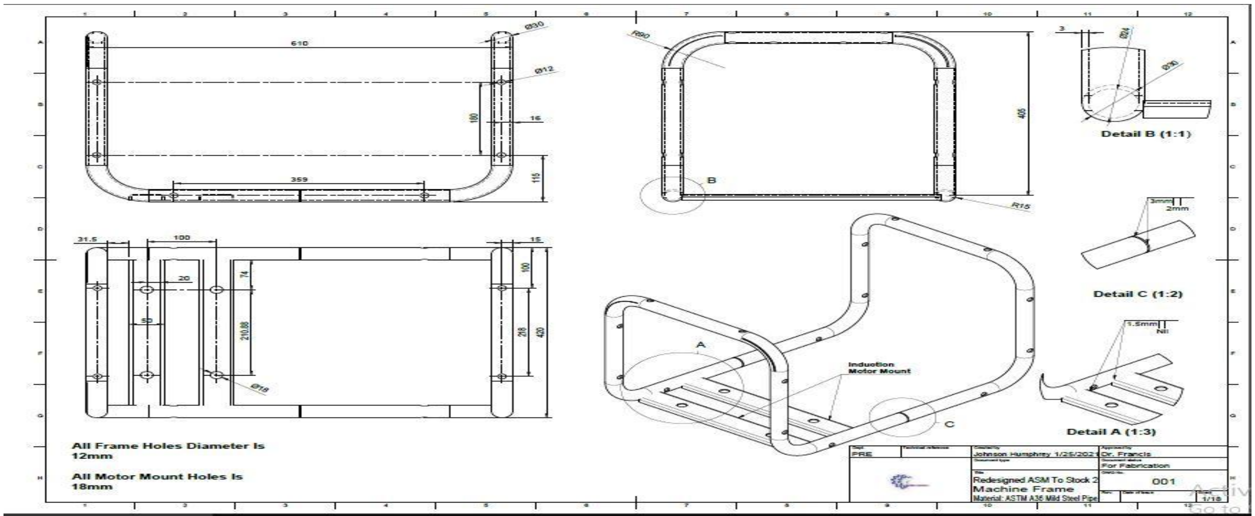


Fig 3. 21 Showing machine frame assembly

Fig 3. 22 Showing machine frame preparation

2. Motor Mount

Material: Mild Steel (U-Channel). This material was selected due to its high ductile properties to withstand static loads from the electric motor.

Manufacturing Process: Bending, Welding to the machine frame, then Drilling

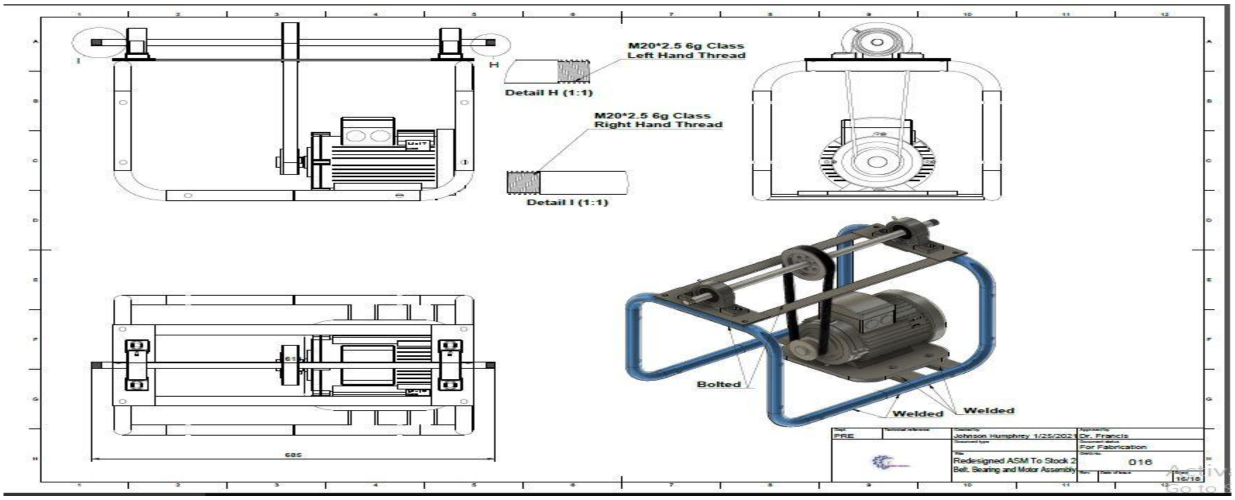


Fig 3. 23 Showing welding and bolting points

Fig 3. 24 Showing Frame motor assembly preparation

3. Machine Frame Side Cover

Material: Mild Steel Sheet. This material was selected due to its high ductile properties to withstand bending stresses and its local availability.

Manufacturing Process: Bending, Drilling, Cutting and Bolting

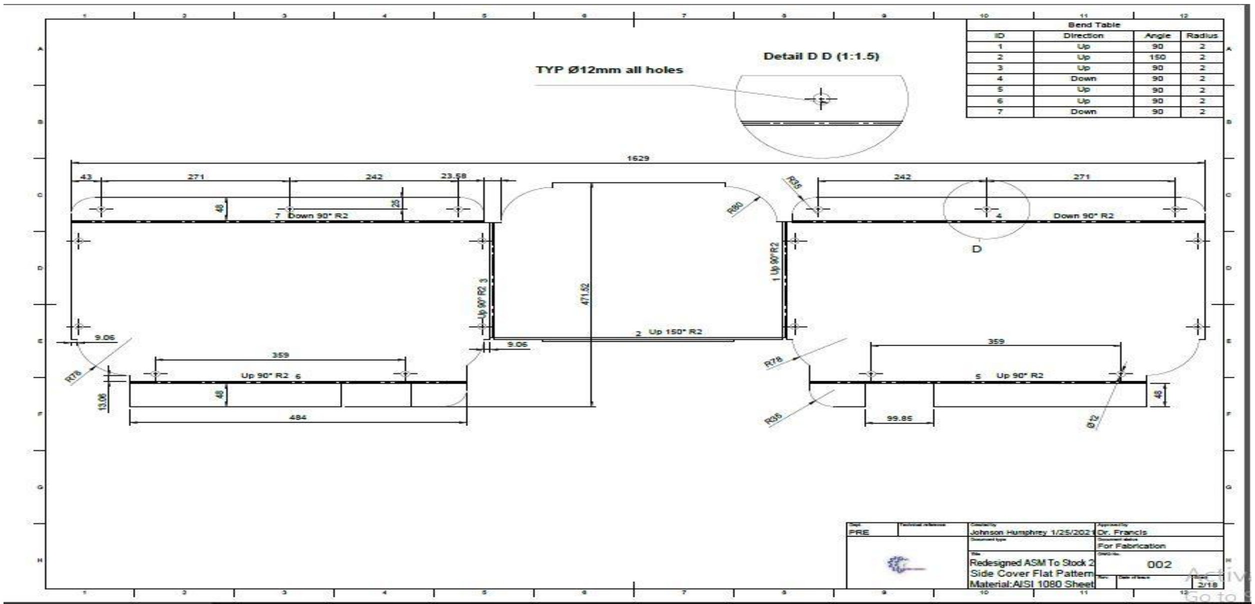


Fig 3. 25 flat pattern drawing for manufacture

4. **Machine Frame Front Cover**

Material: Mild Steel Sheet. This material was selected due to its high ductile properties to withstand bending stresses and its local availability.

. Manufacturing Process: Bending, Drilling, Cutting and Bolting

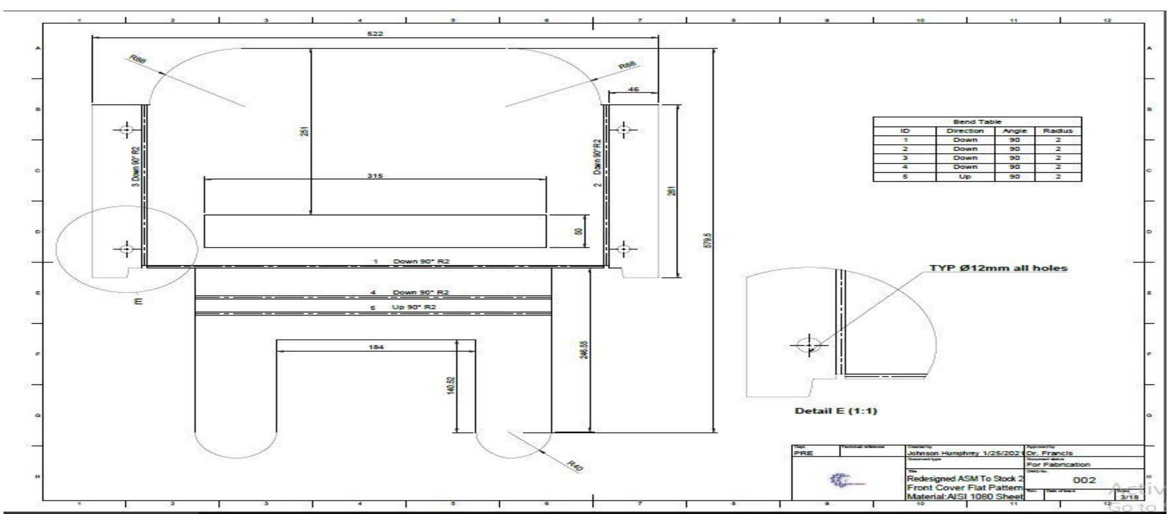


Fig 3. 26 Showing flat patter drawing for manufacture

5. **Machine Frame Top Cover**

Material: Mild Steel Sheet. This material was selected due to its high ductile properties to withstand bending stresses and its local availability.

Manufacturing Process: Bending, Drilling, Cutting and Bolting

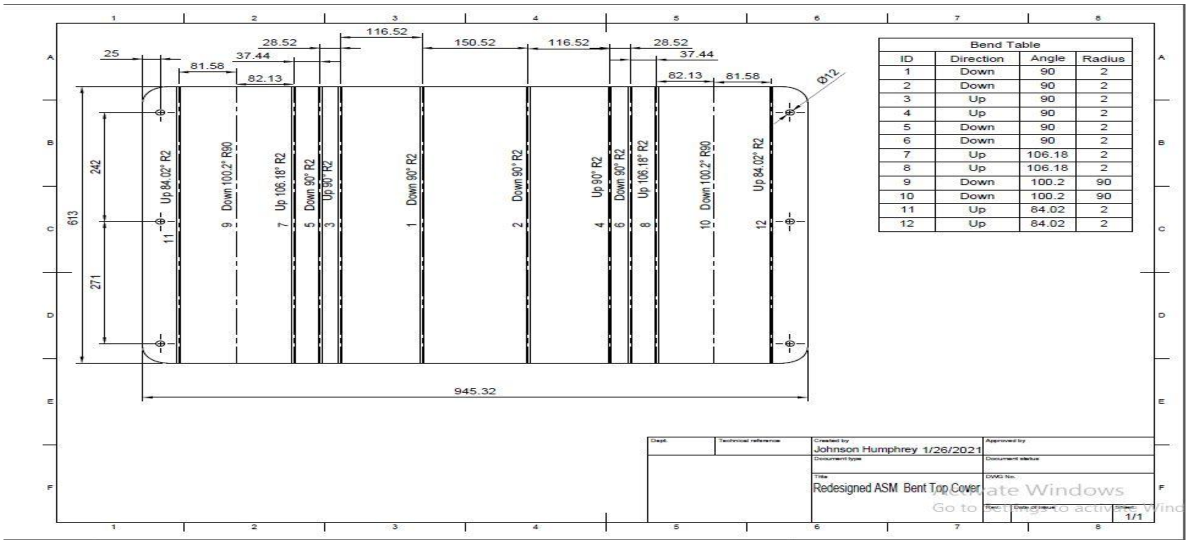


Fig 3. 27 Showing flat pattern drawing for manufacture

6. Driven Shaft

Material: Mild Steel Bar. This material was selected due to its high ductile properties to withstand bending moment, stresses and torsion and also its local availability.

Manufacturing Process: Machining

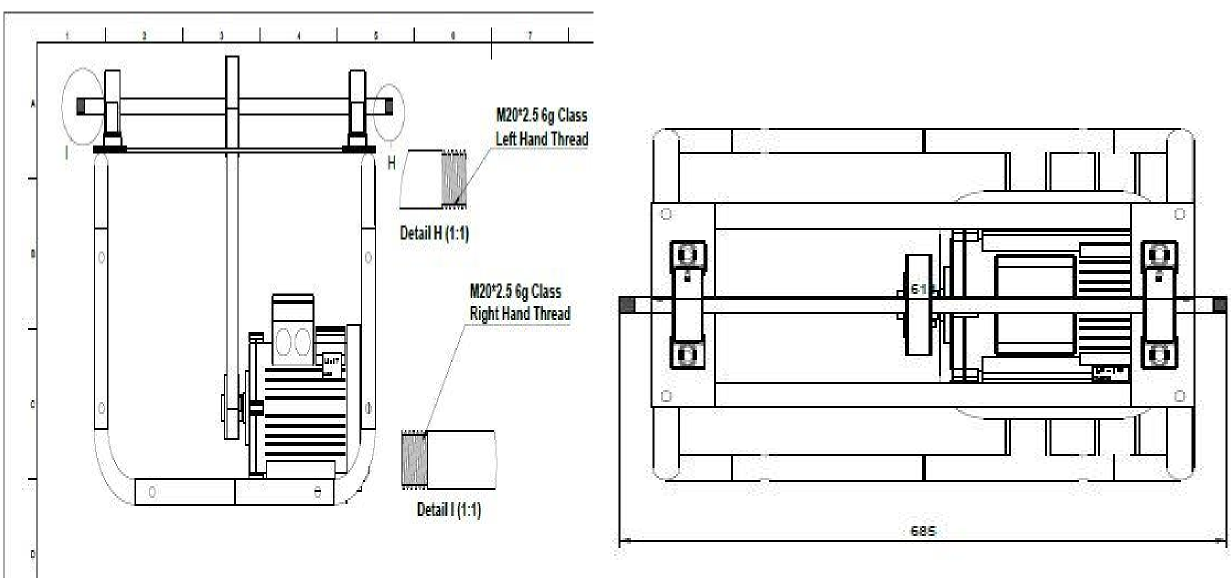


Fig 3. 28 Showing Shaft geometry

Fig 3. 29 Showing Shaft preparation

7. **Pulleys**

Material: Cast Iron. This material was selected due to its high rigidity property capable of balancing selected shaft induced in the design.

Manufacturing Process: Machining, bolting and drilling

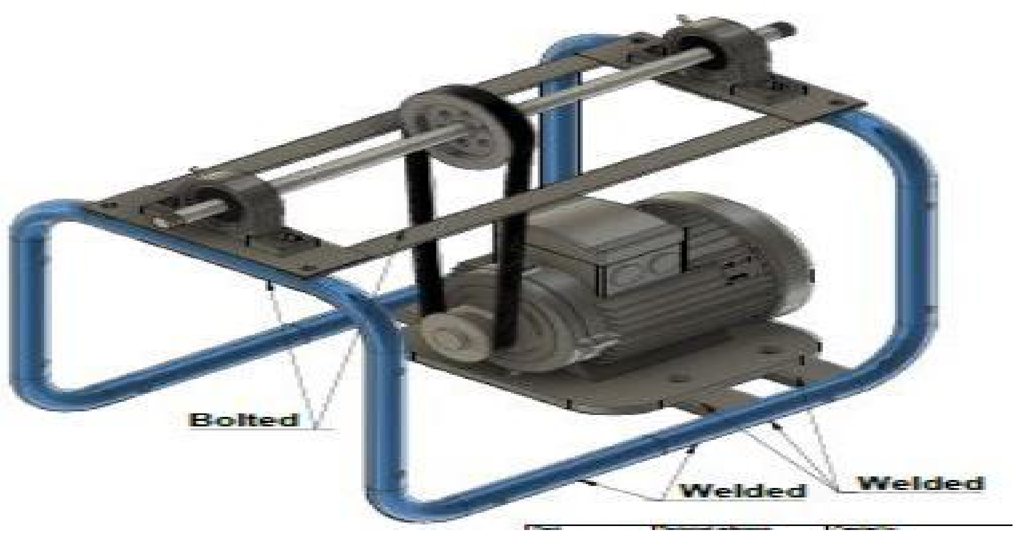


Fig 3. 30 Showing Pulleys assembly

8. **Cutting Blade Disc**

Material: Stainless Steel. This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Machining, Cutting, Grinding and Drilling

Fig 3. 31 Showing cutting blade testing

9. Cutting Blade Crank

Material: Stainless steel. This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Machining, Cutting, Drilling and Threading

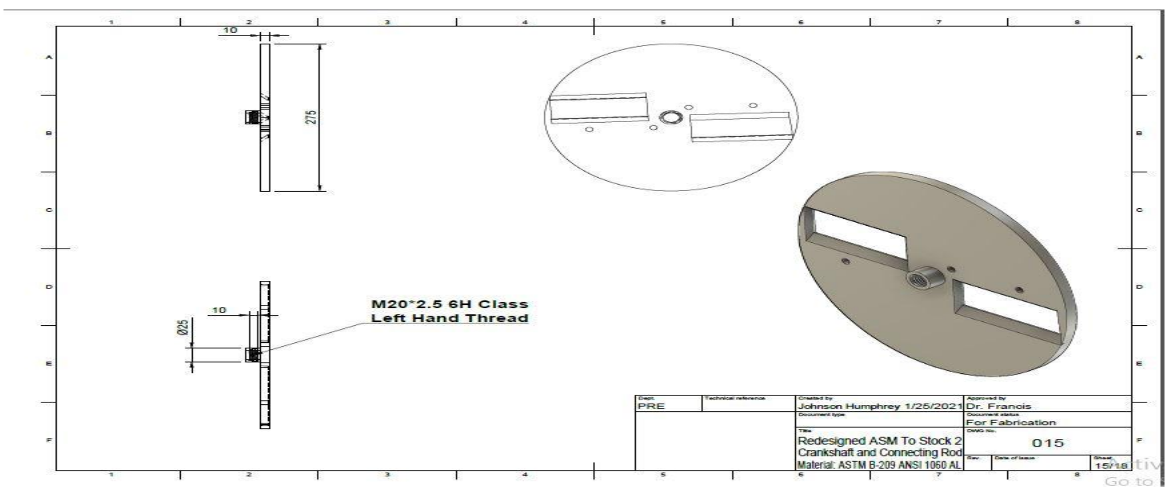


Fig 3. 32 Showing cutting blade crank for manufacture

10. Inlet

Material: Stainless Steel (Tube). This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Bending and Welding

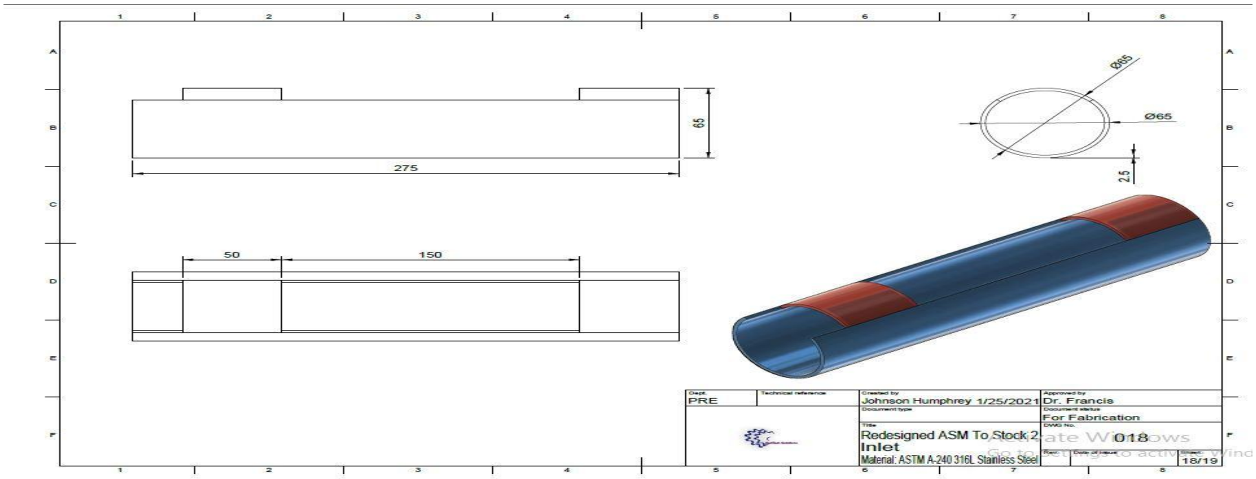


Fig 3. 33 Showing Inlet Geometry

Fig 3. 34 Showing Inlet Casing

11. Induction Motor

Specification: Single Phase, 1 H.P, 1440 rpm

Manufacturing/Sorting Process: Purchased and Bolted to the motor mount

Fig 3. 35 Showing Induction motor

12. Spring Assembly

Material: Mild Steel. This material was selected due to its high ductile properties to withstand bending moment, stresses and torsion when compressed, and also its local availability.

Manufacturing Process: Fabricated and Welding

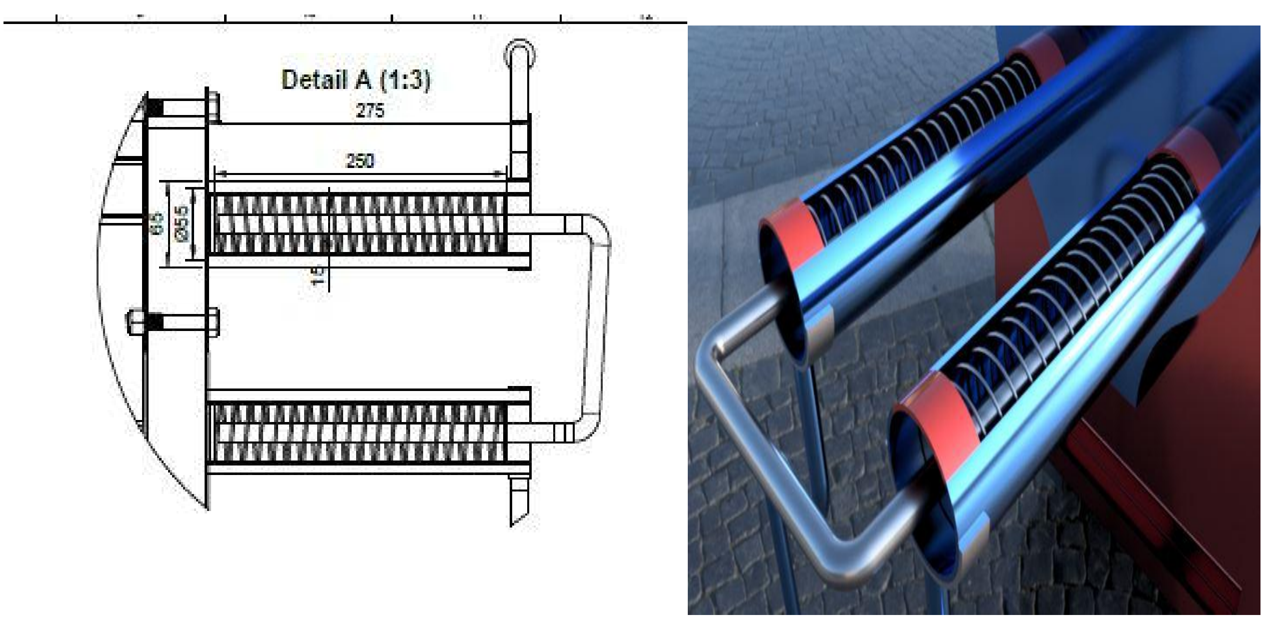


Fig 3. 36 Showing Compressive Spring Assembly

Fig 3. 37 Showing Compressive Spring Assembly

13. Spring Push Lead

Material: Stainless Steel. This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Welding, using the electric arc welding process

14. Spring Plunger

Material: Stainless Steel (Hollow Pipe). This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Welding, bending and cutting

15. Belt Drive

Material Specification: Rubber-A40

Sorting Process: Purchased

16. Variable Speed Controller/ Power Switch

Sorting Process: Purchased

Fig 3. 38 Showing variable speed controller

17. Bolt and Nut

Material Category: M8, M12 and M18

Sorting Process: Purchased

18. Collecting Tray

Material: Stainless Steel. This material was used due to its high corrosion resistance to prevent contamination.

Sorting Process: Purchased

19. Bearing

Material: Plummer block Cast iron

Sorting process: Purchased

20. Discharge/Discharge Casing

Material: Stainless Steel. This material was used due to its high corrosion resistance to prevent contamination.

Manufacturing Process: Bending, Welding/Bolting

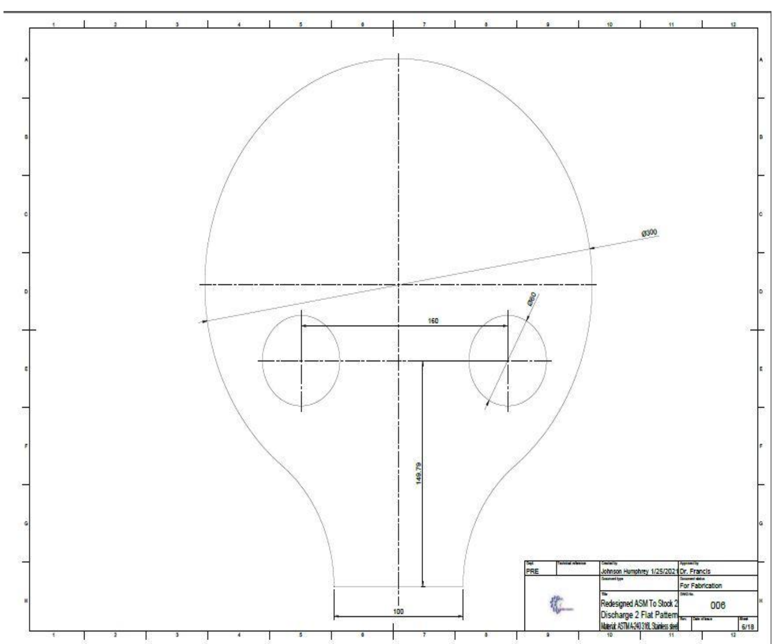


Fig 3. 39 Showing Outlet flat pattern assembly

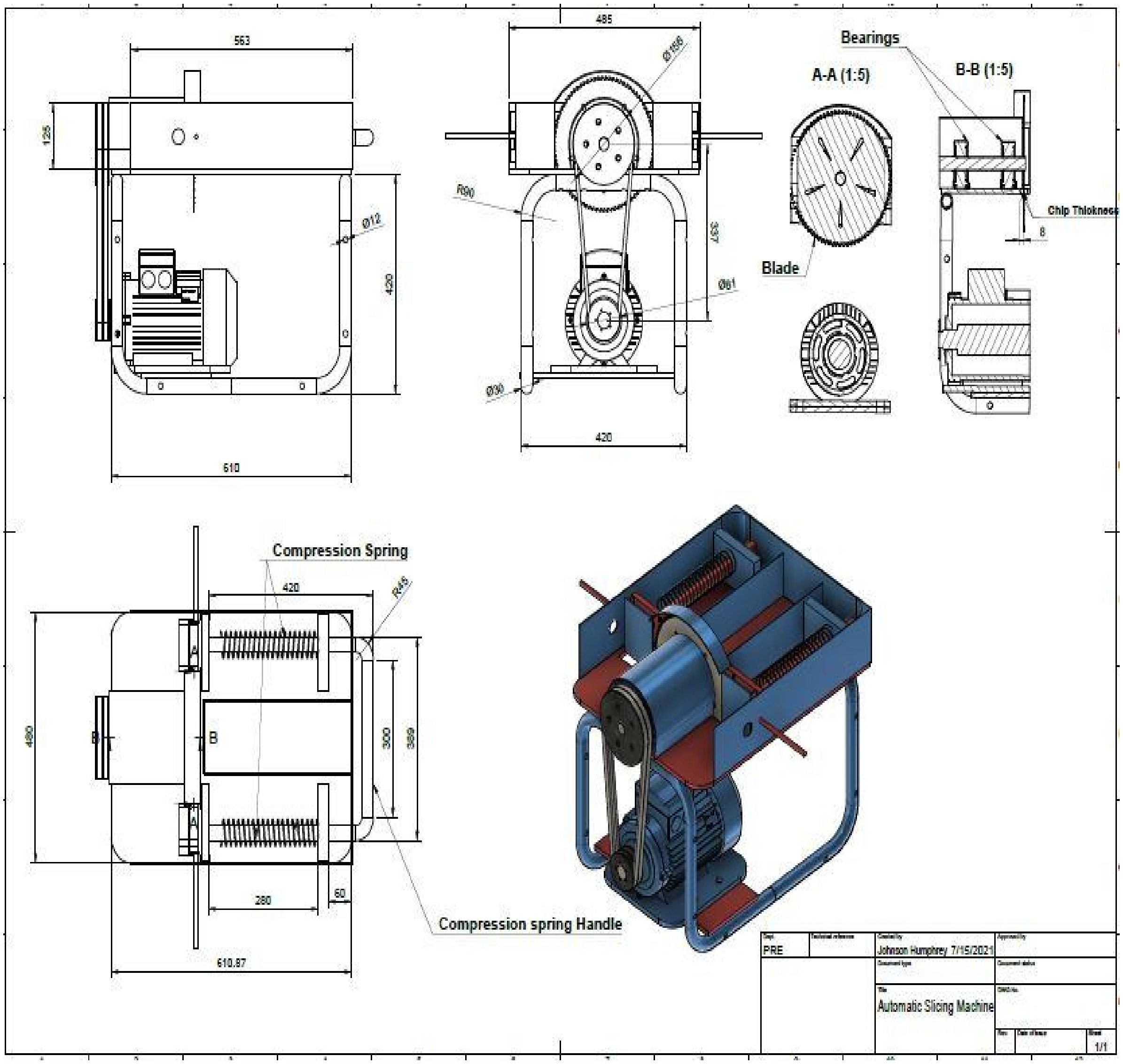


Fig 3. 40 Full Orthographic Projection

CHAPTER FOUR

PERFORMANCE AND EVALUATION

4. Testing, Evaluation, Bill of Engineering Quantities

Before testing was carried, the machine was properly assembled and aligned. The automated slicer was tested under no load condition for 10 minutes to ensure that all components are working perfectly fine without any wobbling or malfunctioning. It was observed during this process that blade rotated without wobbling and very little vibration was observed. The agro based products were peeled manually with a knife to remove its pericarp (outer cover), then peeled products which was loaded into the feeding inlet after spring compression. During this process, sliced products (chips) passed through the discharged outlet.

Having ascertained this, the machine was then tested with a set of three ripen plantain, yam and banana fingers respectively, for three trials, to evaluate its performance with regards to the chip thickness, machine capacity, machine efficiency and quality performance efficiency of the machine.

The plantains, bananas, cucumber and yams were sliced for **21.2 seconds** and **23.2 seconds, 20.5,** and **23.8 seconds** respectively, the weights of unsliced peeled banana fingers, round sliced and broken sliced plantains were obtained as follows **0.210 kg, 0.199kg** and **0.0102 kg**, respectively and that of plantain had weights of **0.201kg, 0.1909kg** and **0.0101kg** respectively, cucumber had weights of **0.274kg, 0.261kg** and **0.013kg** respectively and that of yam had weights **0.38Kg, 0.365Kg. 0.015Kg** respectively.

Operating capacity:

The machine capacity was obtained by expressing the weight of sliced plantain output, irrespective of damage or irregularity in size, per unit time (Hall *et al*, 1961) and the machine performance efficiencies were determined using the expression in equations 4.1 and 4.2 respectively (Adewumi *et al.,* 2011 and Sonawane *et al.,* 2011):

Table 4. 1 Tabulated readings for results obtained

Products	Time taken(s)	W1(Kg)	W2(Kg)	W3(Kg)	Speed rpm	capacity (Kg/hr)	Efficiency (%)
Plantain	21.2	0.210	0.199	0.0102	630	72.7	89.95
Banana	23.2	0.201	0.1909	0.0101	630	62.4	89.99
Cucumber	20.5	0.274	0.261	0.013	80.12	48.5	90.5
Yam	23.8	0.38	0.365	0.015	40	59	92.1

Where:

W_1 = Weight of unsliced products (Kg)

W_2 = Weight of round sliced products (kg)

W_3 = Weight of damaged sliced products (Kg)

4.1.Banana Capacity and Efficiency

$$\mathbf{C} = \frac{W}{t} \quad (4.1)$$

W =Total weight of sliced banana finger (kg)

t = total time taken to slice (s)

It took the slicing machine 23.2 seconds to slice one finger banana.

23.2 sec is equivalent to 0.00644hrs

Therefore, $C = \frac{\mathbf{0.210}}{0.00322}$

C= 62.4Kg/hr

Capacity of banana obtained was calculated to be (**62.4Kg/hr)**

Performance Efficiency: The slicing efficiency (%) of the machine was determined as expressed by Gupta and Khurmi (2004):

$$\eta = \frac{W_1 - W_2}{W_1} \times 100 \quad (4.2)$$

Where W_1 = Weight of unsliced banana finger (Kg) = 0.210kg

W_2 = Weight of round sliced banana finger (kg) = 0.199kg

W_3 = Weight of damaged slices (Kg) = 0.0102kg

W_4= Total weight of sliced banana fingers (Kg) = 0.210

$$W_3 = W_1 - W_2 \quad (4.3)$$

$$W_3 = 0.21 - 0.199$$

$$\mathbf{W_3 = 0.0102Kg} \quad (4.4)$$

Weight of damaged banana slices was found to be 0.035Kg

Therefore, $\eta = \frac{0.199 - 0.0102}{0.210} \times 100$

ŋ = 89.994%

The **Performance Efficiency** of the machine to slice banana was calculated to be approximately **90%**

No	Speed(rpm)	Chip Thickness(mm)
1	630	2.2
2		2.5
3		2.4
4		2.0
5		2.9

Table 4. 2 Chip thickness result for banana

Mean chip thickness = $\frac{2.2+2.5+2.4+2.0+2.9}{5} = \frac{10}{5}$ = 2mm

Range of thickness = 2.9 – 2.2 = 0.7mm

Average chip thickness of banana slices products by the machine was found to be 2mm

4.2.Plantain Capacity and Efficiency

$$\mathbf{C = \frac{W}{t}} \quad (4.6)$$

It took the slicing machine 21.2 seconds to slice plantain.

21.2 sec is equivalent to 0.00588hrs

$$C = \frac{0.210}{0.0029}$$

C = 72.7Kg/hr

The capacity of the machine to slice plantain was calculated to be **72.7 Kg/hr**

$$\textbf{Performance Efficiency } \eta = \frac{W_1 - W_2}{W_1} \times 100 \quad (4.7)$$

Where W_1 = Weight of unsliced plantain finger (Kg) = 0.201kg

W_2 = Weight of sliced plantain finger (kg) = 0.1909 kg

W_3 = Weight of damaged slices (Kg) 0.0101 kg

W_4= Total weight of sliced plantain fingers (Kg) = 0.201kg

$$W_3 = W_1 - W_2 \quad (4.8)$$

$$W_3 = 0.201 - 0.1909$$

$$W_3 = 0.0101\text{Kg}$$

Weight of damaged plantain slices was calculated to be 0.0101Kg

Recall that

$$E = \frac{0.1909 - 0.0101}{0.201} \times 100$$

ŋ = 89.95%

The **Performance Efficiency** of the machine to slice plantain was calculated to be approximately **90%**

No	Speed(rpm)	Chip Thickness(mm)
1		2.1
2		2.3
3	630	2.5
4		2.7
5		2.9

Table 4. 3 Chip thickness result for plantain

Mean chip thickness = $\frac{2.1+2.3+2.5+2.7+2.9}{5} = \frac{12.5}{5}$ = 2.5mm

Average chip thickness of plantain slices products by the machine was found to be 2.5mm

Range of thickness = 2.9 – 2.1= 0.8mm

4.3.Cucumber Capacity and Efficiency

$$\mathbf{C} = \frac{W}{t} \quad (4.6)$$

It took the slicing machine 20.5 seconds to slice plantain.

20.5 sec is equivalent to 0.00569hrs

$C = \frac{0.274}{0.00569}$

C = 48.5Kg/hr

The capacity of the machine to slice plantain was calculated to **48.5Kg/hr**

$$\textbf{Performance Efficiency } \eta = \frac{W_1 - W_2}{W_1} \times 100 \quad (4.7)$$

Where W_1 = Weight of unsliced banana finger (Kg) = 0.274kg

W_2 = Weight of sliced plantain finger (kg) = 0.261kg

W_3 = Weight of damaged slices (Kg) 0.013kg

W_4= Total weight of sliced plantain fingers (Kg) = 0.274kg

$W_3 = W_1 - W_2$ (4.8)

$W_3 = 0.274 - 0.261$

$W_3 = 0.013$Kg

Weight of damaged plantain slices was calculated to be 0.0101Kg

Recall that

$E = \frac{0.261 - 0.013}{0.274} \times 100$

ŋ = 90.5

The **Performance Efficiency** of the machine to slice cucumber was calculated to be approximately **90.5%**

No	Speed(rpm)	Chip Thickness(mm)
1	80.1	1.8
2		2.5
3		2.2
4		2.7
5		2.6

Table 4. 4 Chip thickness result for plantain

Mean chip thickness = $\frac{1.8+2.5+2.2+2.7+2.6}{5} = \frac{11.8}{5} = 2.36$mm

Average chip thickness of plantain slices products by the machine was found to be 2.5mm

Range of thickness = 2.7 – 1.8= 0.9mm

4.4.Yam Capacity and Efficiency

Root and tuber crops for tests were purchased from a local market in Edo State, Nigeria. The tubers were peeled and cut into samples sizes required for effective fit in the feeding chute.

4.4.1. Test Variables and Experimental Design

Many factors which could affect the performance of the machine include cutting resistance of the crop, age of the crop, orientation of the inlet, moisture content, machine speed, size of crops, type of crops and variety of crops. Kachru, (1996) developed a plantain-slicing machine and evaluated its performance with respect to parameters such as cutting velocity, orientation of hopper, shear angle, level angle, number of blades of the machine. In the present work, three factors, which were considered critical to the performance of the multi-crop slicing machine were investigated including size of crop, speed of knives and type of crop. Tests were conducted at rotational speeds of the blade i.e., 40rpm, in slicing and yam grouped into small sizes.

4.5.Results and Discussion for Yam

4.5.1. Performance Criteria for Yam

Test parameters that were measured in evaluating the performance of the machine are throughput capacity and slicing efficiency. Throughput capacity was defined as

$$\boldsymbol{S_c} = \frac{\boldsymbol{W_s}}{\boldsymbol{T}} \qquad (4.9)$$

Where;

Sc = Throughput capacity, kg/h

Ws = Weight of peeled sliced yam, kg

T = Time taken, sec

It took the slicing machine 23.2 seconds to slice medium sized yam.

23.2seconds is equivalent to 0.00644hrs

$$S_c = \frac{0.38}{0.006444}$$

Therefore, $S_c = \mathbf{59 Kg/hr}$

The **Performance Efficiency** was defined as the weight of all slices minus weight of damaged slices to the weight of all slices multiplied by 100%

Performance Efficiency $\eta = \frac{W_1 - W_2}{W_1} \times 100$ (4.10)

Where W_1 = Weight of unsliced yam tuber (Kg) = 0.38Kg

W_2= Weight of round sliced yam tuber (kg) = 0.365 Kg

W_3 = Weight of damaged yam slices (Kg) = 0.015 Kg

W_4 = Total weight of sliced yam tuber (Kg) =0.38 Kg

$\boldsymbol{W_3 = W_1 - W_2}$ (4.11)

$W_3 = 0.38 - 0.365$

W_3 = 0.015Kg

$\eta = \frac{0.365 - 0.015}{0.38} \times 100$

η = 92.1%

The **Performance Efficiency** of the machine to slice banana was calculated to be **92.1%**

No	Speed(rpm)	Chip Thickness(mm)
1		1.6
2		1.5
3	40	2.2
4		2.1
5		2.4

Table 4. 5 Chip thickness result for yam

Mean chip thickness = $\frac{2.2+2.5+2.4+2.0+2.9}{5} = \frac{9.8}{5}$ = 1.96mm

Range of thickness = 2.4 – 1.5 = 0.9mm

Average chip thickness of yam slices products by the machine was found to be 1.96mm

4.6.Maintenance Procedures of the Automated Slicing Machine

The Automated Slicing machine is a rugged equipment, but some steps were necessary to ensure its optimal functionality and effectiveness. The following steps were recommended for its maintenance:

The machine should not be operated in the rain as it is powered using electricity. Heavy moisture would hamper its functionality and at the same time could put the operator at risk of electric shock.

After usage in slicing ripen banana, plantain and yam, the machine should be properly cleaned and dried with a clean dry rag before storage to avoid failure caused by rust and crops tends to have some appreciable amount of moisture content. Before mowing, it should be ensured that the automated slicer is free from all forms of obstruction like large stones, wooden objects, glasses etc. in order to avoid any form of misalignment of assembled parts.

In event of failure, the power switch should be turned off immediately. After usage, the automated slicer should be stored and kept in a safe place, far from the reach of children because of its exposed blades and electrical wiring.

Fig 4. 1 Full Machine Assembly

Fig 4. 2 Full Machine Top View Assembly

4.7.Bill of Engineering Quantities

S/N	Machine Components	QTY	Cost(#)	Description	Materials	Standard Dimensions(mm)
1	Frame (1&2)	2	Nil	Weldment	Mild Steel	**4000mm × 48.3mm × 3.68mm**
2	Side Cover	1		Sheet metal	Aluminium	
3	Front Cover	1	30000	Sheet metal	Aluminium	**2400mm × 1200mm × 2.5mm**
4	Top Cover	1		Sheet Metal	Aluminium	
5	Discharge/cover	2		Sheet metal	Stainless Steel	**1200mm × 600mm × 2.5mm**
6	Inlet (Tube)	1	30000	; Sheet metal	Stainless Steel	**L 275mm × OD 65mm × 3mm**
7	Feeder	2		Pneumatic	Stainless Steel	
8	Slicing Blade	3		Sheet metal	Stainless Steel	**260mm × 60mm × 2.5mm**
9	Cutting Crank	2	8000			**300mm × 10mm**
10	Drive Shaft	1	5000	Metal Bar	Stainless Steel	**1200mm × 20mm**
11	Electric Motor	1	32000			**491mm × 317mm**
12	Drive Pulley	1	2500	V - Belt	Cast Iron	**DIA ø70mm**
13	Driven Pulley	1	2500	V - Belt	Cast Iron	**DIA ø350mm**
14	Bolts and Nuts (1)	6	300	Hex	Stainless Steel	**M12 × 1.5**
15	Bolts and Nuts (2)	6	300	Hex	Stainless Steel	**M10 × 1.5**
16	Belt Drive	1	3000	V - Belt	Rubber	**A40**
17	Pedestal Bearing	2	5000	Pillow Block	Cast Iron	**; Hole Dia = ø20mm**
18	Motor Mount	6	Nil	Weldment	Mild Steel	**80mm × 45mm × 450mm**
						WT=6mm, FT= 8mm
19	Compression Spring	1	4000	Weldment	mild steel	L.250mm × 50mmDIA
20	Electrode(E6013)	1pk	3800			
21	Electrode(Stainless)	half pk	7500			
22	Speed Controller	1	800			
23	Switch	1	1200			
		TOTAL	**135,100**			

Table 4. 6 Bill of Materials

CHAPTER FIVE

5. Conclusions and Recommendations

5.1.Conclusion

The Automated Slicing machine for yam, cucumber, plantain and banana has been designed, fabricated and evaluated. With this designed, fabricated and evaluated automated slicing machine, the problems of safety, quality and quantity of sliced plantain, banana and yam associated with manual slicing and existing slicer has been brought to the barest minimum. The automated slicer is user friendly and does not require and special skill to operate. It could therefore be concluded to be a machine suitable for the cutting of agricultural produce into regular slices for the purpose of drying, roasting or frying. Test results with the machine in slicing samples of yam, banana and plantain indicated satisfactory performance.

Tests were carried out to analyze its performance and output capacity. Results from these tests indicate a performance efficiency of **89.95%** for ripen plantain fingers, **89.94%** for ripen banana fingers, **90.5%** for ripen cucumber and **92.1%** ripen yam tuber.

The maximum efficiency of the machine was obtained at moderate cutter speed of 1440rpm for ripen agro based products of concern. A capacity of **72.7Kg/hr.** was also obtained for plantain, **62.4Kg/hr**. for banana, **48.5Kg/hr.** was obtained for cucumber and **59Kg/hr.** for yam. This meets the requirements of small scale plantain, banana and yam chip processing industries. The chip thickness for the ripen agro based products of concern, was found to be significantly uniform with a mean thickness of **2.5mm** for plantain, **2.0mm** for banana, **1.96mm** for cucumber and **1.96mm** for yam.

Further modification of the machine is necessary to improve the performance of the machine.

5.1.1. Findings

I. It was found that chip thickness had the most significant effect on the machine capacity. It is affected by the machine speed and the feed rate for the ripen products.

II. The slicing time obtained for slicing individual agro based products, was found to be independent in the chip diameter and the ripeness level of the plantain.

5.2.Recommendations

Further modification of the machine necessary to improve the performance of the machine is as follows:

I. That multiple inlets be designed and fabricated in order to allow for increased throughput capacity.

II. Larger inlet size could be designed and fabricated in order to allow for greater agro based product size to be fed in.

III. Provision should be made for adjusting the cutter blade to obtain slices of any desired thickness so as to give a different but uniform chip thickness.

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