# DESIGN AND FABRICATION OF A CASSAVA CHIPPING MACHINE


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*M.ENG/SEET/2003/998*

DEPARTMENT OF

AGRICULTURAL AND BIO-RESOURCES ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA


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A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS (M.ENG) IN AGRICULTURAL AND BIORESOURCES ENGINEERING (PROCESSING AND STORAGE)


DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, MINNA, NIGERIA


NOVEMBER, 2009

# DECLARATION

I hereby declare that this research has been carried out and this thesis written solely by me, **Nnawuihe, Johnny Chinedu**. It has not been presented before in any previous application for a higher degree. All the sources of information are duly acknowledged in the references.

NNAWUIHE, JOHNNY CHINEDU

Students Name

Signature

12th November 2009

Date

## CERTIFICATION

This thesis titled "Design and Fabrication of a Cassava Chipping Machine" by Johnny Chinedu, Nnawuihe (M.Eng/SEET/998/2003/2004) meets the regulations governing the award of the degree of Masters in Engineering (M. Eng) of the Federal University of Technology, Minna and is approved for its contribution to scientific and literary presentation.

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## DEDICATION

This study is dedicated most importantly to my LORD JESUS CHRIST and to Mrs Ajuma Helen Nnawuihe, Able, Praise, Blessed, Members of the Onwunali family, members of the CAPRO family and members of Chapel of Grace.

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# ABSTRACT

Dustiness, high microbial content and colouration of dried cassava chips are problems in the feed/food industry. This is part of the basis of cassava chip quality determination. It is observed that chips produced mechanically are prone to disintegration, fragility and scattering into crumbs and dust, upon drying, packaging, and transportation. This project is to design and fabricate a machine that produces cassava chips that are stable in storage (Not disintegrating into crumbs and dust after drying, packaging and transportation). Most existing chippers shred the cassava tubers to produce the chips. The shredded cassava chips are fragile after drying, hence the ease to crumbling and dustiness. To overcome these problems, a motorized machine employing a crank/slider mechanism which produces chips not by shredding but by slicing and cutting of the tubers was designed and constructed using available cheap materials. Before the performance test, the tubers (sliced/cut) were washed and soaked in a solution of confectionery grade silphur dioxide to avoid change in colour. The machine gives a chipping output of 108kg/hr, a chipping efficiency of 75%, and an average wastage (losses) of about 2.2%. The chips produced by this machine were dried and stored for six months. The cost of construction of the machine totaled Sixty-one thousand naira.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Preamble

Cassava, "*manihot esculenta crantz*" is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world. It is called by different names according to the region in which it is cultivated, e.g. "**manioc**" in English speaking region, "**tapioca**" in French speaking region, and "**mandioca**" in Spanish speaking regions (Akande, 2001). It is described as a dicotyledonous perennial plant belonging to the botanical family "**Euphorbiaceae**". Cassava tuber geometry and cross section is illustrated in figure 1 below (IITA, 1996).

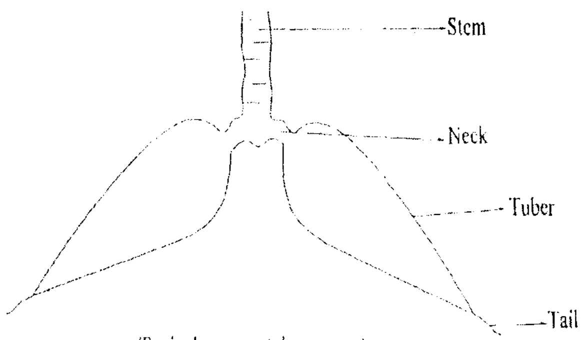



Fig. 1.1 (a) Typical cassava tuber geometry

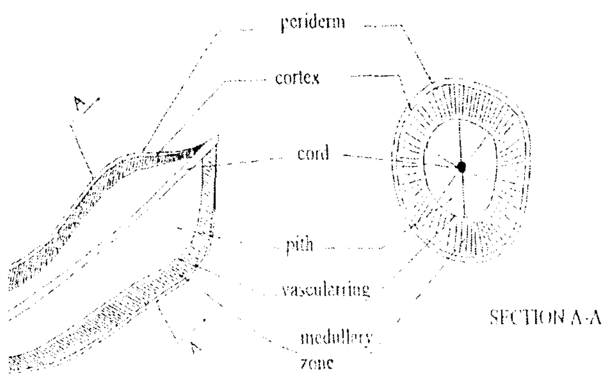



Fig. 1.1 (b) Sections through a cassava tuber

**Fig. 1.1 (a) and (b): Cassava tuber Geometry and Cross - Section**

Of the major important food crops produced world wide, wheat, rice, maize, potatoes, barley, millet–sorghum and cassava, cassava is the easiest to grow and will produce a reasonable yield in soils that will be unproductive to these other crops. In addition, it can be stored in the soil for about 2 years without any deleterious effect. It is therefore not surprising that it has become the crop used as staple food for most of the people in the sub Saharan Africa (Oke, 2004). Cassava thrives in zones ranging from latitudes $30^0$N and south of the equatorial belt and is restricted to zones less than 2000m above sea level. It receives an annual rainfall of 200–2000m and a temperature of $18^0$C to $35^0$C. The mature tuber reaches a length of about 1 m and a weight ranging from about 0.5kg to about 2.5kg.

Cassava in Nigeria is used mainly to make the traditional foods gari, lafun, foofoo, tapioca and boiled cassava (mainly in the North). These are produced at home or in small rural or urban cottage industries. Although more than half of the cassava produced in Nigeria is destined for sale, sometimes, the farmer waits for buyers who purchase the crop in the field. Prices for cassava roots and traditional food products such as gari follow a cycle that alternate high and low prices every two to three years. In times of cassava shortage, prices go up and the farmers feel motivated to plant plenty of cassava only to result a year or two later in a glut of cassava that leads to low prices and a reduction in the planting of cassava. Cassava farmers would steadily increase their production if they were assured of demand for their crop. Expansion of cassava is therefore, demand based. Recently observed changes in food habits of urban dwellers indicate an increased demand for cheap high caloric foods, which mean new market opportunities for cassava (Mpoko, 2004).

Cassava is a perishable crop consisting of about 60 – 70% water and has to be processed within 48 hours of harvesting, otherwise physiological changes take place and it deteriorates very rapidly (Oke, 2004). In addition, since it is not usually processed on the farm it means transporting a lot of water at an expensive price to the market and if not sold will have to be transported back again obviously at a loss. So sometimes when farmers are not sure of a suitable price, they prefer to leave it stored in the soil.

One of the most versatile products from cassava is cassava chips, which are the dried form of cassava, cut into small sizes to make for fast drying. The chips come in different shapes and sizes ranging from 2 cm to 6 cm. Chipping is the basis of most of the products from cassava. The chipping can be done manually or by locally fabricated machines. The chipping is done in a chipper most of which consists of a heavy rotating circular steel plates to which blades are attached and driven by a petrol, diesel or electric motors. The chips are then dried in a tray type drier fired by a charcoal, gas or electricity. The product is then bagged in polythene bags.

There are many machines for carrying this out both at the small, medium and large scales. Some of these machines include: Ajibola et al (1994), Akintunde et al (2001), etc. (See section 2.8 for more detailed review of existing cassava chipping machines). However, these machines mostly shred the cassava tubers to produce the chips. The chips produced this way tend to easily disintegrate into powder, crumbs or dust soon after drying and packaging. These problems of dustiness and high microbial content in cassava chips is recognized as still a current quality characteristics of cassava products for livestock feeds in Nigeria (Tewe, 2004). Put in another form, the chips cannot retain their shapes or forms which they had prior to drying. This can be explained by the fact that shredding tears down and distorts the structural forms and fibre conformations of the cassava tuber. With these distortions, the chips cannot remain stable in their initial shapes. The above stated facts called for the design of a chipper that employs cutting and dicing, rather than shredding. In this way, each chip retains the original structural fibre conformation. Hence, even after drying the chips will not crumble to dustiness.

Also in this project, there is a dimension of recommending a measure of treating freshly chipped cassava so that the chips will not change colour from white to brown or yellow immediately after the tuber is peeled and chipped.

## 1.2 Statement of the Problem

### 1.2.1 Cassava Chip Instability

The problem of dustiness of cassava chips is a known challenge in the feed/food industry, and has become part of the basis for cassava chip quality determination. Industries that need cassava chips do give specifications of the sizes of dry cassava chips bearing in mind the ends (products) to which they would put the raw material. Unfortunately, most of the chips arrive the industries already in crumbled, disintegrated, and powdered states, hardly measuring up to the chipped sizes even though the machines that chipped them were preset to the demanded sizes. This is not only a problem locally, it is much more pronounced in chips for exports. The ability of the dried cassava chips to remain stable in storage, withstanding handling and transportation hazards, and reaching desired destinations in their intact form is a great need in the food / feed industry.

This problem has for long been taken for granted and assumed to be due to the brittle nature of the dried cassava chips. This brittle delicate nature is assumed to be responsible for the ease with which the dried cassava chips fragment and scatter at the slightest handling. Of course, brittleness is not imparted to cassava by machines, since brittleness is an inherent property of a cassava tuber depending on the specie, and the moisture content of the chip. However, looking at chips produced through traditional methods where slashing, slicing, and cutting of the peeled cassava tubers are done by manually using knives, matches, and cutlasses; one does not find this problem of chip instability as such. Of course, mechanical production of cassava chips is faster, less tedious and even the chips produced are cleaner.

more regular in shapes and sizes than chips produced through manual cuttings etc. If the brittle nature of dried chips from machine chippers is an inherent characteristic of the cassava tuber, why is it not so much felt in those of the manual chippers evenwhen the chips come from the same cassava specie? What is in the manually chipped dried chips that is absent in the machine chipped chips that makes it less brittle after drying? What makes the machine-produced cassava chips very unstable while those of manual methods are very stable? It is the opinion of this researcher that the reasons for these could be found in the shredding action of the steel circular plates incorporated in these machine chippers on the cassava tubers that are pressed against it. The shredding action of these machines tear down and distort the natural fibre structure of these tubers thereby rendering them unstable as soon as the water content of the chips are removed through drying.There is therefore the need to have mechanical chippers that employ the slashing, slicing, and cutting principles similar to the traditional/manual methods. This project is a step in this direction. In other words, this project is a mechanization of the traditional/manual method of chipping cassava tubers.

### 1.2.2 Cassava chip Colouration

The problem of colouration of cassava(see pages 40,41 and 47 for details) chips is also a known challenge in the feed/food industry. Most traditionally processed cassava chips are colored yellowish or brownish. The issue of colouration is one of the bases for determining the quality of the chips produced. Finely processed chips must be colorless, pure white, and free from microbes. Already in Nigeria, because of the partial ban on wheat importation and the 10% substitution of wheat flour with cassava flour for bread and other confectionary used, much demand is being made for dried cassava chips that are colourless. This project is geared towards recommending a measure that can eliminate the colouration of cassava chips.

## 1.3 Justification of the Project

Most existing chippers consist of a heavy rotating circular steel plate with attached blades and driven by a prime mover. The manually operated chippers are driven by a wooden wheel, on which a cranking mechanism is mounted. Uniform chips are produced in strands of about 5mm in length and 3mm thick, as the peeled and washed cassava tuber presses against the circular chipping plate. Both the motorized and manual chippers require human hand to hold and press the tuber against the circular chipping plate/template one after the other. The chips are dried and packaged. Sometimes, the packaging process is rough, thereby tampering with the fragile nature of the chips. This results in crumbling, disintegration and powdering of the chips. The loading and off - loading of the sacks of chips into motor vehicles for haulage and transportation to destinations also create additional difficulty that further powder the scattered chips. Mechanical vibrations of the carrying vehicles due to rough roads play a part. There is therefore the need for the design and fabrication of a cassava chipping machine that will produce stable chips, even after drying, packaging and transportation.

Each cassava tuber is first sliced transversely into slices of about 1 cm in thickness, and each slice is further cut into four, longitudinally, resulting into chips with the shape of a quarter of circle. This means that the outer forms of the cassava tuber is neither shredded nor distorted. When the chips are dried and packaged, they are not easily prone to crumbling, scattering and disintegration. Hence, they can withstand the rough export- handling processes without grinding to powder en - route to end user.

Whereas shredding has been the operating principle in the cassava chippers available today, this project intends to promote slicing and dicing. This machine is therefore a mechanization of the traditional cassava chipping method of slicing and cutting.

## 1.4 Objectives

The objectives of this project are:

i. To design, construct a cassava chipping machine that will produce chips of good colour quality and cost effectiveness.

ii. To carry out a performance test of the constructed cassava chipping machine and recommend a way of preventing the discolouration of the produced cassava chips.

## 1.5 Scope and Limitations

This project is aimed at chipping cylindrically shaped cassava tubers into four parts longitudinally with respect to their centre and transversely cutting the tubers into slices of appreciable thickness. Figure 1.2 below illustrates this statement. Consequently, chips that will not crumble, disintegrate, and scatter upon drying; packaging and transporting will be produced.

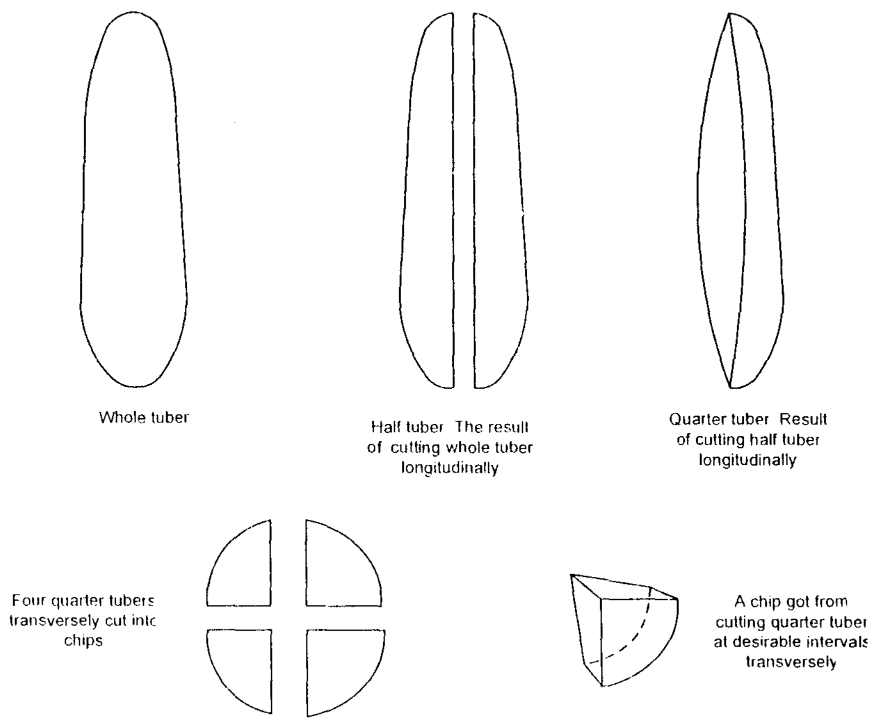



**Fig.1.2 Illustrating the project scope with respect to the longitudinal and transverse cutting of whole tubers**

The analysis and study of the processes, treatments, methods of processing cassava chips with respect to the chemical and bio chemical actions of microbes and environments are not part of this project.

The National Agency for Food and Drug Administration and Control (NAFDAC) requirement for the fabrication of any machine for food processing is that the materials for such machine fabrication must be stainless steel. Because of the high cost implication of using stainless steel, this machine will be constructed using mild steel in areas not directly in contact with food materials and stainless· steel in parts that are directly in contact with food materials. This cassava chipping machine will be electrically powered using electric motor and can likewise be modified for rural operations (locations without electricity) by substituting the electric motor with a gasoline or diesel engine.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Varieties of Cassava

Cassava is propagated through vegetative means from cuttings of its stem. There are basically two varieties of cassava – *manihot palmata* (sweet variety) and *manihot esculenta crantz* (Bitter variety). Many cassava varieties contain cyanogenic glucosides. The total amount of cyanogenic glucosides in cassava roots are often used to group cassava cultivators into two major groups:

- The bitter varieties in which the cyanogenic glucosides are distributed throughout the tuber and are at "high" level (*Manihot Esculenta Crantz*).
- The sweet varieties in which the cyanogenic glucosides are mainly confined to the peel and are at a "low" level (*Manihot Palmata*).

Categorization of cassava based on their hydrocyanic acid content recognized a third group the "medium" level. Viz

"High" (Bitter), HCN content $\geq$ 100mg cyanid/1kg of fresh tuber.

"Medium" (Bitter) with HCN content between 50mg - 100mg/1kg of fresh tuber.

"Low" (sweet) HCN content $\leq$50mg/1kg of fresh tuber.

The HCN content hitherto thought of as a distinguishing characteristic between bitter and sweet varieties is now known to be merely a function of the production practice employed and the environment from which the cassava is cultivated (Onyemere, 2001).

### 2.2 Cassava Production

Cassava can grow on less fertile lands where cereals and other crops do not grow well; it can tolerate drought and can grow in low - nutrient soils so depleted by repeated cultivation provided the soil texture is friable and allow the development of the tubers.

Cassava tubers vary in size depending on age, maturity, type of soil, variety and climatic conditions.

In Africa, cassava is grown in over 30 countries and mostly on small farms, usually intercropped with vegetables, plantation crops (such as coconut, oil palm and coffee), yam, sweet potato, melon, maize, rice, groundnut, and other legumes (IITA, 1996). It can also be planted as a single crop. Propagation is by vegetative means from cuttings. In Africa, the application of fertilizer remains limited among small - scale farmers due to the high cost and lack of availability. Roots can be harvested between 6 months and 3 years after planting. Because cassava roots can be stored in the ground for up to 24 months, and some varieties for up to 36 months, harvest may be delayed until market, processing or other conditions are favourable.

### 2.2.1 Cassava Production Statistics

Nigeria is the largest producer of cassava in the world. Estimates of her 2001 production ranged from about 34 million metric tons (MT) a year (FAO, 2002) to 37.9 million tons (MT) (CBN, 2002). Total area harvest of the crop in 2001 was 3.125 million hectares with an average yield of 10.83 MT per hectare (FAO, 2002). Nigeria will exceed the 60 – 65 MT annual production rate by 2020, if the current trend is maintained (Mpoko, 2004).

According to FAO (2002) estimates, 172 million tones of cassava was produced world wide in the year 2000. Africa accounted for 54%, Asia for 28%, and Latin America and the Caribbeans for 19% of the total world production. In 1999, Nigeria produced 33 million tonnes, making her the world's largest producer.

In terms of area cultivated a total of 16.8 million hectares were planted with cassava throughout the world in 2000; about 64% of this was in Sub - Saharan Africa (SSA).

The average yield in 2000 was 10.2 tonnes per hectare, but this varies from 1.8 tonnes per hectare in Sudan to 27.3 tonnes per hectare in Barbados. In Nigeria, the average yield was 10.6 tonnes per hectare.

Cassava, potato and sweet potato rank among the top 10 food crops produced in developing countries. Sub - Saharan Africa (SSA) is expected to experience the fastest growth in food demand for all roots and tubers, largely driven by rapid population's growth. SSA's share in the total demand for developing countries will be 53%, with cassava accounting for two-thirds of the increase (Pachico, 1998).

### 2.2.2 Cassava Production Constraints

The major pests of cassava in Africa are the cassava green mite, the cassava mealy bug, and the variegated grasshopper. The main diseases affecting cassava are cassava mosaic diseases, cassava bacteria blight, cassava anthracnose disease, and root rot. Pests and diseases, together with poor cultural practices, combine to cause yield losses that may be as high as 50% in Africa.

The production of cassava is dependent on a supply of good quality stem cuttings. The multiplication rate of these vegetative planting materials is very low compared to grain crops, which are propagated by true seeds. In addition, cassava stem cuttings are bulky and highly perishable as they dry up within a few days.

As a root crop, cassava requires considerable labour to harvest. Because they are highly perishable, roots must be processed into storable form soon after harvest.

Many cassava varieties contain cyanogenic glucosides, and inadequate processing can lead to chronic toxicity. Various processing methods, such as grating, sun drying, and fermenting, are used to reduce the cyanide content.

## 2.3 Cassava Utilization

Cassava is the basis of many products including food. In Africa and Latin America, cassava is mostly used for human consumption, while in Asia and parts of Latin America it is also used commercially for the production of animal feed and starch based products.

In Africa, cassava provides a basic daily source of dietary energy. Root are processed into a wide variety of granules, pastes, flours, chips, and other products or consumed freshly boiled or raw. In most of the cassava growing countries in Africa the leaves are also consumed as a green vegetable, which provides protein and vitamins A and B.

In Southeast Asia and Latin America, cassava has taken on an economic role. Cassava starch is used as a binding agent, in glutamate, an important flavoring agent in Asian cooking. In Africa, cassava is beginning to be used in partial substitution for wheat flour (IITA, 1996).

Information available from Cassava Farmers Association of Nigeria indicate that cassava plant (i.e. leaf, stem & root/tubers) have over 104 domestic and industrial uses. Progressive experiments and discoveries indicate that the cassava tuber alone can be used for more purposes than are presently known. For example, the cassava flour (one of the products of cassava) is found to be useful for the production of Bread, Snacks, Sausage Rolls, Meat Pie, etc (Oshogwe, 2005).

Cassava is an important staple food for about 800 million people. The annual per capital consumption of cassava is greatest in Africa where consumption exceeds 300kg/person/year and in Latin America where the average per capital consumption is about 35kg/person/year (Akande, 2001).

In Africa, nearly 200 million people rely on cassava as a staple food. In certain marginal areas and regions fraught by civil wars and other crises, cassava is often the only food crop which is readily available (Albert - Bell, 1998). Again in tropical Africa where cassava is an important staple food, more than half of the world's population by land area is located in SSA (Albert - Bell, 1998).

### 2.3.1 Cassava Tuber Shelf Life

While yam tubers can be stored for a lengthy period up to 12 months (that is the case in Benin) and still keep the physical integrity and taste, cassava roots are more perishable(perishing starts within 2 days). They deteriorate very quickly soon after harvest and this occurs in two separate phases:

- **Physiological or Primary Deterioration**

  Which begins within 24 hours after harvest and is characterized by blue or brown discolouration of the vascular bundles of the roots, called "vascular streaking".

- **Microbial or Secondary Deterioration**

This usually occurs 5 - 7 days after harvest and involves a wide spectrum of fungi and bacteria which develop in the flesh, causing a variety of wet and dry rots.

The rapid post - harvest deterioration of cassava roots represents a problem for the supply chain to processing plants. It is particularly difficult to set up buffer stock. In traditional small scale processing the conservation is done immersing the peeled roots in fresh water, which is renewed once a day for three days running. That is an avenue to explore for buffer stock setting to large - scale processing (Pachico, 1998).

### 2.3.2 Modes of Utilization

For utilization of cassava, the fresh peeled cassava tuber is eaten as a vegetable after boiling or roasting. In some West African countries, the boiled cassava is pounded with boiled plantain called "Fufu" which is consumed with vegetables and meat soup. Cassava tuber can also be sliced, dried, and ground into flour. The local cassava flour used in several homes among the South - west Nigeria is got through this process. While the people of the middle belts of Nigeria prepare theirs by first peeling the tubers, soaked in water for three to four days to ferment. the fermented pulp is squeezed to drain off water, sun dried on flat surfaces (concrete floors or along tared road sides) and then grounded into flour by mills. The fibres are removed by Sieving.

Actually, the main form in which cassava is eaten in West Africa is a fried granular product prepared from peeled, washed, grated, and fermented cassava roots known as "gari". "Akpu" is a popular food from cassava among the Ibos of South East Nigeria usually served with fresh vegetable soups spiced with meat or fish. It is prepared by soaking the peeled, washed tuber into clean water for 3 to 5 day until it ferments. The fibres are removed using basket sieves in water & the resulting pulp, drained of water using clean cloth - sacks. The resulting pulp can be turned into "Fufu" or "Akpu" by cooking in boiling water.

"Chickwangue" is another African food product, prepared by soaking the cassava tubers in water for 2 - 7 days until it softens, after which the roots are peeled and mashed. The fibres are removed and the resulting paste of pulp is wrapped in palm or banana leaves and then steamed for consumption.

Other food products are biscuits cakes, snacks, tapioca "African salad" etc.

Pellets and chips from cassava are sources of energy in animal feeds. The chips are product from fresh cassava tubers, washed, peeled and cut into slices of 3 - 6 cm long. The slices are dried on large concrete surfaces in the open air by both wind and sun drying.

Cassava's low amylose and high amylopectic properties give it the necessary viscosity for high quality adhesive which is needed in paper and textile industries. Thus, cassava is an important raw material for the non - food industries. Ethyl - alcohol (ethanol) is an industrial product made from cassava. Dextrins used in the manufacture of glues are also produced from cassava starch (Akande, 2001).

## 2.4. Cassava Processing

About two days (48 hours) after harvesting cassava tubers, deterioration sets in while about a week later, microbial deterioration begins. That's why cassava tubers are processed within two days (48 hours) after harvesting into various products that have longer shelf life, are easier to transport, increased market potential, lower cyanide content, and enhanced palatability. With moisture content of about 70%, fresh cassava tubers are difficult to transport to the urban markets for market purposes. The processed forms can be easily stored since less storage space and longer storage time are implied. Cutting the tubers into smaller pieces called pellets or chips is a way of hastening the drying rate and improving product quality. Other processed forms include garri, starch, etc. The flowchart of cassava tuber processing is shown in figure 2.1 under section 2.4.3 below.

### 2.4.1 Preparation of Cassava for Processing to Chips and Pellets

The roots/tubers of cassava and the leaves contain cyanogenic glucocides that are dangerous for human or animal consumption. These cyanide components have to be removed before the root and the leaves can be consumed. The toxic cyanide components are concentrated into the peel of cassava root. The ratio of glucocides to the starchy flesh varies between 5-10: 1. Hence, for a root composed of 15% peel with a total cyanide content of 950mg/kg (fresh' weight basis) and 35mg/kg in the flesh, 83% of the total cyanide is removed, by peeling (Pachico, 1998).

The traditional processing techniques of chips are labourious. In villages, women wash, peel, and cut the root to pieces. These are dried by sunshine on flat surfaces; on roofs, concrete surfaces, mats or along roadsides. One person can handle 25kg of roots per hour and the loss of weight could reach 25 – 30% of the initial weight of the fresh root. Mechanical peeling had been developed in Thailand, the Philippines and Indonesia that reduce the loss of weight to 10 - 15%.

Wind is a fundamental factor during the drying process, which comprises two phases:-

- **First Phase**: The chips lose moisture very quickly down to about 20% of moisture content (MC); wind speed passing over the chips is more important than air temperature and relative humidity. Under cloudy weather or even at night, the first drying phase can be completed so long as there is sufficient air movement through the chips.
- **Second Phase:** Drying is much slow and needs a relative humidity of not higher than 65% to dry the chips to a moisture content of 13% that is considered safe for long term storage. Except during periods of actual rain, in most places, the temperature will increase sufficiently during the day to reduce ambient humidity to the required level to complete this second stage of drying (Pachico, 1998).

### 2.4.2 Constraints in Traditional Cassava Chips Production

Traditional cassava chips are a common commodity in Africa's rural and urban markets. They vary from grey to brown in colour, and often have visible traces of mould and holes caused by insect attack. These characteristics often make them undesirable from a hygienic point' of view. The production of traditional chips has a series of drawbacks that show up in subsequent steps of the post - harvest system.

➢ **Cutting**

Cutting cassava manually produces rather large, irregularly shaped chips with poor drying properties. Producing smaller chips with knives or machetes would require considerably more work. When large amounts of cassava roots are to be processed at a time, cutting can become quite a tedious task.

- **Drying**

Manually cut cassava chips dry slowly and not uniformly because they are rather large and irregularly shaped. Depending on the climatic conditions during the drying period, the process may take 2 to 3 weeks (Albert - Bell, 1998). As a result, the chips often go mouldy, become soiled or are attacked by beetles. After drying, large cassava chips retain higher amounts of cyanide than small chips. Thus, the overall quality of traditional chips tends to be rather poor. And during rainfall, the chips must be covered with plastic sheets or collected and stored in a safe place.

- **Storage And Transportation**

Traditional cassava chips are bulky and not easy to package. This causes some constraints in storage and transportation; they require a lot of space, and large quantities are difficult to handle.

- **Marketing**

The ease with which traditional cassava chips may be marketed depends, among other factors, on their quality. Chips which are mouldy or have a lot of holes produced by beetles are difficult to sell and often have to be fed to farm animals because they are not accepted by humans. As a result, a considerable amount of chips may be lost for human consumption.

- **Detoxification**

Depending on the variety, traditional (*Manihot Esculenta Crantz*) cassava chips may contain high amounts of highly poisonous cyanide. Lengthy detoxification procedures, such as soaking in water for about 3 to 5 days, fermentation, boiling or roasting are required during subsequent processing in order to avoid health hazards.

### 2.4.3 Flow Chart of Cassava Tuber Processing

The flow chart of cassava tuber processing is illustrated below in figure 2.1

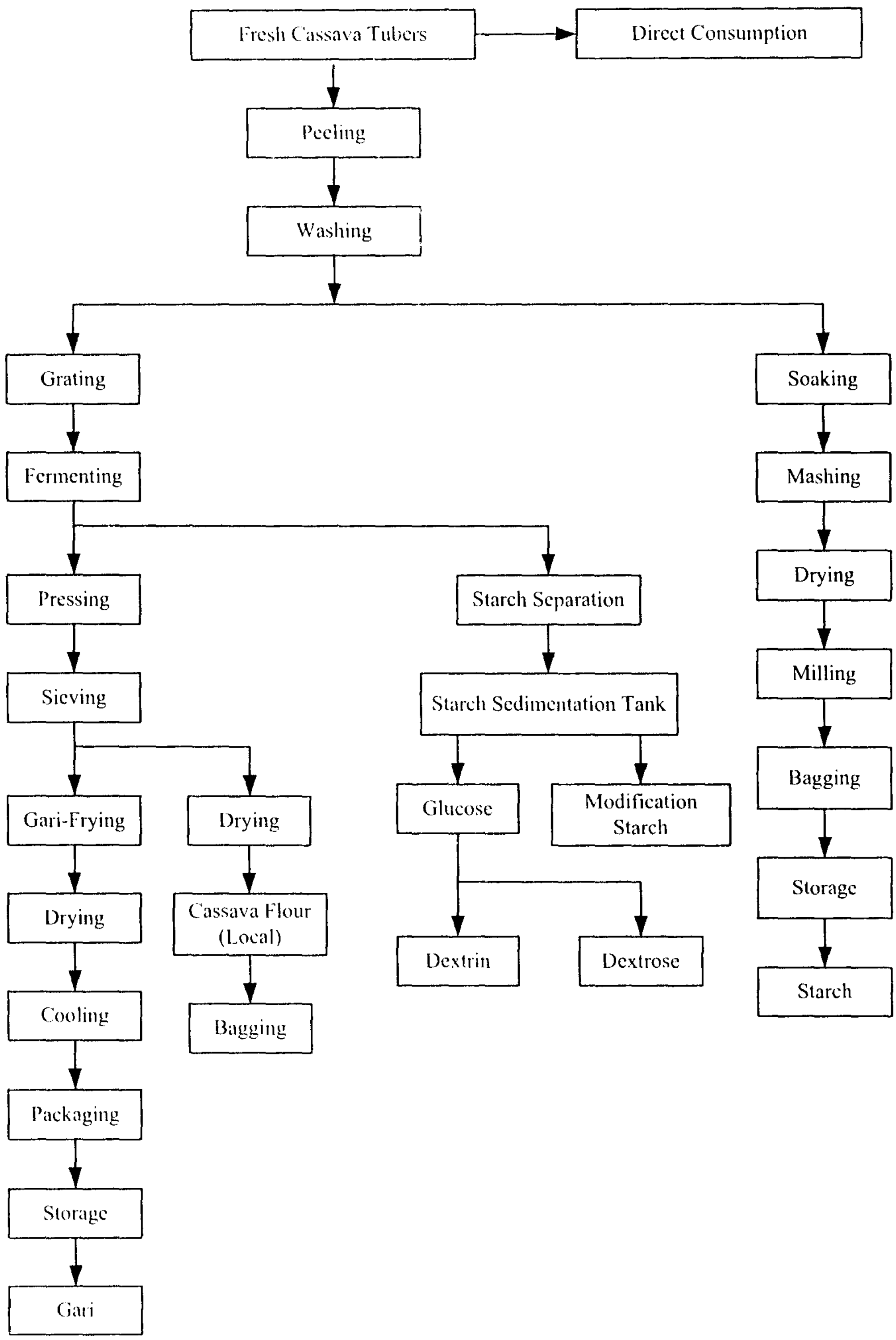



**Fig. 2.1: Flow Chart of Cassava Tuber Processing**

## 2.5 Summary on Activities of Cassava in Nigeria

**I. Improved Variety**: The International Institute of Tropical Agriculture (IITA) based in Ibadan Nigeria has played a leading role in the development of improved cassava varieties which are disease and pest resistant, low in cyanide content, drought resistant, early maturing, and high yielding. The improved varieties have been introduced throughout Africa's cassava belt. Varieties with resistance to the major diseases give sustained yields of about 50% more than the local varieties.

Today, 60% of the area cropped with cassava in Nigeria is planted with improved varieties and Nigeria is the current world leader in cassava production. Impact studies have revealed that in Nigeria the introduction of improved varieties has provided food for 50 million people. The benefits of IITA - improved varieties are not limited to Nigeria; improved cassava varieties are now used in most cassava - growing countries in Africa.

**II. Disease and Pest Control**

IITA's biological control programme has for a number of years been working to solve pest problems in cassava using natural and environmentally friendly methods. It has been a major player in the successful biocontrol of the cassava mealybug and cassava green mite. Through the introduction of natural enemies, there has been a 95% reduction in cassava mealy bug damage and a 50% reduction in damage caused by the cassava green mite.

**III. Multiplication Rate**

To overcome cassava's low multiplication rate, IITA (1996) has developed a technique to make 2 - node cuttings or mini stakes that can make 50 plants from each parent cassava instead of 10 stakes as before. These mini stakes are easily moved and protected in plastic sacks until they can be grown on and hardened in individual plastic bags or nursery beds before being planted in the fields.

### IV. Post Harvest Technology

In the area of post harvest, IITA's scientists have been developing effective and simple machines and tools which reduce processing time and labour, as well as production losses. With these machines losses can be reduced by 50% and labour by 75%.

### V. Training

During the past three decades, IITA has trained more than 900 researchers and technicians in Africa. For example, training in processing and utilization of high quality cassava flour has been carried out in 10 African countries. As a result, the private sectors in Madagascar, Nigeria, Tanzania, and Uganda have begun using high quality cassava flour as a raw material for processing into secondary products such as biscuits and noodles.

## 2.6 Cassava Leaves Potential

So far, we have concentrated attention on the root (tubers). The leaves could also be a valuable source of money. They are used as vegetables in Sierra Leone, Cameroon and Democratic Republic of Congo. It has high protein content. Planting them closely will give yields as high as 90t/ha which when dried could be used as hay in Europe and the US where they sell for about $1,000 per ton. In addition the protein of the leaves could be extracted by means of a pulpier to break the cell walls and then a press to squeeze out the juice, which carries most of the nutrients with it. On heating at about 90°C the protein is coagulated and then dried to give a green Leaf Protein Concentrate (LPC). This contains about 50 - 60% protein, 13 - 14% minerals and 0.09% vitamins. A teaspoonful of this taken twice a day is sufficient to satisfy the following requirement of a young boy of 10 years old (Oke, 2004):

300% of the vitamin A requirement.

100% of the iron.

50% of the acid.

According to Oke (2004), the Protein is of very high quality comparable to egg, milk and fish. In fact, it can be used instead of Soya beans as a supplement to garri to give a slightly greenish enriched garri (as opposed to yellowish garri) and so becomes a complete food.

The Vitamin A and iron are important nutrients in the immunity system of the body and hence it has been successfully used in the treatment of Aids. This work is in progress in Benin Republic and in Nicaragua and is about to start at the University College Hospital (UCH) Ibadan.

## 2.7 Export of Cassava Products

**A. Background:** At Nigeria's independence, agriculture was the main driving wheel of the economy of the country. Nigeria was an exporter of agricultural produce. Following the discovery of oil (petroleum) in Nigeria, the economy became oil driven as about 95% of our foreign earnings were oil based. Nigeria became an importer of food and agricultural products (processed and semi - processed). Agriculture not only declined, it was neglected. Various governments at sundry times introduced measures to revamp the agricultural sector and to resuscitate the non oil exports of the economy. The "Austerity Measures of the Shehu Shagari administration and the Structural Adjustment Programme (SAP) of the Babangida administration are examples.

**B. Nigeria Export Promotion Council:** The Nigerian Export Promotion Council (NEPC) established in 1976 by Decree No. 26 has been in the forefront of the pursuit of the promotion of the non oil exports. The council has been re-positioned through the introduction of several other decrees since its inception. The council through several incentives it has packaged has been wooing investors into the export of Nigeria's non oil products. Some of such incentives include 'mouth - watering' provisions like the new -. manufacture - in - Bond

Scheme; Export Development Fund, Duty Drawback Scheme, Export Expansion Grant Scheme, Manufacture - in - Bond Scheme, ECOWAS Trade Liberalization Scheme (ETLS), etc. The NEPC has been promoting many commodities, the latest of which is cassava.

C. **Cassava Export Initiative:** The United Nations Food and Agriculture Organization (FAO) in 2000 identified Nigeria as one of the countries that could grow cassava for use in Bread production instead of relying on imported wheat. FAO in partnership with Nigeria's IITA and the Federal Institute of Industrial Research began work on the composite flour technology in 2000 (Agric Digest, 2005). Part of the outcome of the partnership work are the partial ban on wheat importation into Nigeria, the gradual efforts towards a Cassava Bread Policy, the presidential committee on cassava export promotion, and the Commodity Exchange Market. Figure 2.2 represents the Nigerian Cassava generalized market structure for the industrial use of cassava. There are four major potential markets for industrial processing of cassava:

i the cassava flour market

ii the chip and pellet market for animal feed

iii the food grade ethanol market, and

iv the starch market

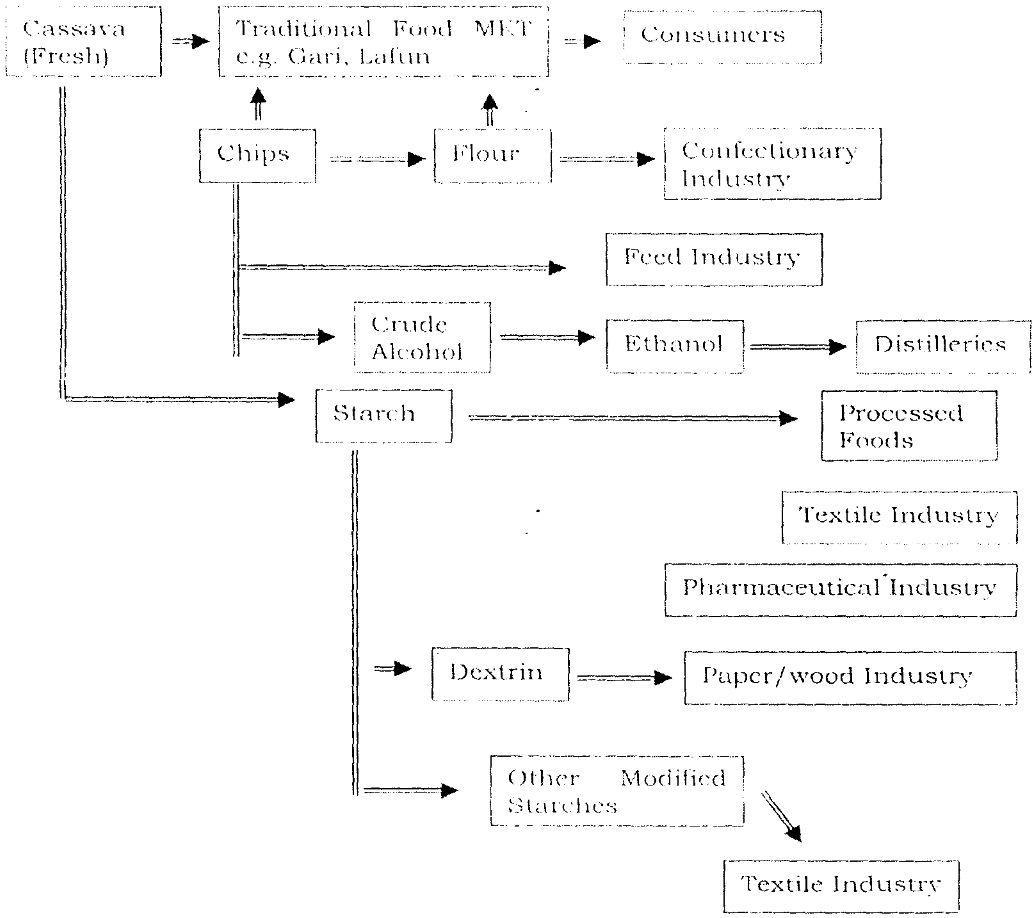



**Fig. 2.2 Market chain for Industrial Cassava Products (Source Kinpseer, 2003)**

**D. Partial Ban on Wheat Importation:** According to Tosin Adeleke (Agric. Digest, 2000), spokes- person of the Ministry of Agriculture and Rural Development, the Federal government intends to cut its' huge expenditure on food importation which is in excess of two billion US dollars annually especially when there is an alternative at home to the product like in the case of wheat. The ban imposes 10% restriction on the importation of wheat for bread production so that 10% cassava flour could be put to use. Wheat will retain a maximum of 90% of the composition.

This partial ban is the first phase of the plan to end the importation of wheat in Nigeria. Before the ban, Nigeria produces about 120,000 tons of cassava flour annually whereas it will take about 200,000 tons to adequately meet the local demand that would arise from the partial ban (Agric Digest, 2005).

**E. Towards a Cassava Bread Policy:** Nigeria spends US $400 million on wheat importation annually to meet local demand for flour by the baking industry. To reduce the importation of wheat flour and save foreign exchange, the president of Nigeria Chief Olusegun Obasanjo has directed that 10% of cassava flour be incorporated into the raw material for Bread production with effect from January 2005. The government hopes this would stimulate the local industries, encourage industrial cassava utilization, benefit the economy, and generate employment. The use of cassava for Bread and other confectionaries in the baking industry requires some level of quality and standards. The cassava flour required for this substitution must be:

- Unfermented flour
- Colour: Pure white
- Moisture Content: Not more than 11 - 12% MC.
- Degree of Fineness: 90% i.e. below 180 microns.
- Free from cyanide.

**F. Commodity Exchange Market:** This involves the provision of the state of the art digitalized trading software system that will enable a seller in any part of Nigeria to sell his goods from the comfort of his living room to a buyer in Lagos, London, New York, etc. To facilitate this market and thereby enhance the export of Nigerian made commodities, the Federal Executive Council of Nigeria took a decision to convert the Abuja Stock Exchange to a Commodity Market. This is certainly a great boost to non oil export commodities including cassava.

**G. The Presidential Committee on Cassava Export Promotion:** The production of cassava mainly for local food in Nigeria led to the seasonal fluctuation which occurs every 2 - 3 years, resulting in scarcity in one year and hence encouragement to farmers to produce more and then to a glut soon after thereby discouraging farmer to produce and some will even leave their crops in the soil to rot rather than use labour to harvest it at a loss (Eweka 2001). This killed the, "incentive to produce more cassava or to use the high yielding or pest and disease resistant varieties. The president of Nigeria has changed this scenario. There is the presidential initiative to make cassava more competitive resulting in the setting up of the presidential committee on Cassava Export promotion.

With this, the stage is now set to enter the international market for the export of cassava as a cash crop to save the country from depending mainly on oil as a source of foreign exchange. The president targets that the country could earn about one billion dollars ($1 bn) in the year 2005, and by 2007, the target is about $5bn. The market is already there in China, Japan, Indonesia, and even in the EU countries.

To make this dream come through, the Presidential Committee on Cassava Export Promotion organized a cassava stakeholder's forum and exhibition held at the Banquet Hall of the Presidential Villa Abuja between the 7th to 8th of June 2004, under the chairmanship of the Honourable Minister of Commerce - Ambassador A.D Idris Waziri. The forum with the theme "Unlocking the Potentials of Cassava for Sustainable Development aimed at:-

- Providing opportunity for stakeholders to make input into the Cassava Development and Export Promotion Programme.
- Exhibit Cassava Products, Machinery, equipment, etc.
- Providing a forum for all stakeholders to interact and develop business opportunities in the cassava industry.

The highlights of the communiqué released at the end of that forum pin points the scope, position, and direction of cassava in relation to Nigeria's present export drives.

The communiqué states as follows:

1. Nigeria ranks as the world's largest producer of cassava with an annual output estimated at about 35 metric tons.
2. At the end of the two - day forum, participants agreed that
   i. Cassava is a "wonder crop" that is capable of making Nigeria one of the most prosperous and wonderful countries in the world.
   ii. The full implementation of the presidential initiative on cassava as contained in the committee's short, medium, and long term plans which is based on the public private partnership.
   iii. Towards the realization of Mr. President's initiative and vision cassava should be put .at the center stage of our national economic development for the creation of wealth, food security, generation of employment and reduction in poverty. This is in line with the policy objectives of the government's economic blueprint, the New Economic Empowerment and Development Strategy (NEEDS).
   iv. There is the need to consistently produce large quantities of high quality cassava and cassava products for Nigeria's cassava to be competitive in the international market.
   v. To gain competitiveness, local food and beverage industries require polices that would provide tariff concessions, reduce the impact of multiple taxation and reduce the cost of infrastructural facilities.
   vi. The small - scale farmer should take advantage of available technology and right agronomic practices that would make cassava production possible through out the year.

vii. There is a need for an efficient market information system that would facilitate the development of cassava industry.

viii. Cassava is a ready and cheap source of raw material for ethanol. There is therefore the need for the setting up of appropriate commercial firms that will make the raw materials available.

ix. To achieve the objective of the presidential cassava Development initiative there is the need for all the stake holders including government to play their roles.

x. To ensure international competitiveness, good packaging standards of the cassava products should be embarked upon.

xi. There is need for the formation of associations such as Cassava Growers; Starch Producers, Ethanol Producers, Cassava Exporters etc.

xii. There should be adequate access to micro credit for small scale farmers to expand production and employ modern machinery, fertilizer and chemicals that would reduce the cost of production.

xiii. There is need for capacity building to enhance knowledge and skill of the farmers.

xiv. Government should intervene in the provision of basic infrastructure.

xv. Government should make a special fund available to the NACRDB to be loaned to cassava farmers at a low interest rate. This is in consonance with the acceptable social investment standard.

xvi. The International Institute for Tropical Agriculture (IITA) is willing to assist the Federal Government, in the rapid deployment of the best cassava varieties throughout the cassava zones of Nigeria. This facility should be fully explored.

xvii. There is the need for the establishment of small and medium scale flour industries in all the local government areas in Nigeria.

xviii. There should be development of farmers' clusters at the farm gate for small producers.

xix. In general, Research & Development should complement various interventions for the production, processing and marketing system for cassava.

xx. Fund can be sourced through:

* Existing sources like Banks - Banks of industry, Union Bank, First Bank, NACRDB, NEXIM, and SMIES Fund.
* Donor Agencies - UNIDO, USAID, ADB, FAO, IFAD, UNDP, CFC, ICT, (Ghana).
* Potential Sources - Private Sector (intending Nigerian investors that are foreign based), Chole Church, Commodity Exchange, Stock Exchange.

xxi. We recognize the importance of commodity exchange as a useful financial structure for commodity trading. Government should accord it priority and funding to meet the desirable regional and global challenges.

xxii. There is an urgent need for the creation of cassava Development Fund similar to the Education Tax fund.

xxiii. The 10% of SMIES (Small and Medium Industrial Enterprise Scheme) should be contributed to the development fund. In addition, the fund should attract funding from Donor Agencies, Development Partners, and others.

xxiv. Existing banks and the commodity exchange market should open special windows for cassava promotions.

xxv. There is an urgent need for the Cassava Unit Trust Scheme. This will facilitate the provision of long term funding for the development of the cassava industry.

**II. EPV- Export Production Village:** The Export Production Village (EPV) is a village or group of villages that have proven comparative advantage over other villages in the production of one or more export products.

Currently, NEPC is searching for appropriate places where cassava is produced in a very large quantity with a view to forming an EPV. The aim of this is to encourage the export of rural based products. The pilot scheme of the cassava EPV is located in Abia state, in a village called Ukwuano. Other export crops like ginger and coffee have their own EPV s located at Katchia (Kaduna State) and Jos (Plateau State) respectively. The concept of EPV s have been successfully used in Srilanka (1982) and Ghana. It has to be rural based.

## 2.8 Cassava Processing and Existing Chippers

Fresh cassava tuber is a perishable commodity, consisting about 60 - 70% water (Oke, 2004), and has to be processed within 24 to 48 hours after harvesting, otherwise physiological changes take place causing very rapid deterioration. Since it is not often processed on the farm, bulk transportation of this from the farm to the market is a problem and expensive as it means transporting a lot of water. Farmers leave it in the soil sometimes until they are sure of a ready market.

Dry cassava chips is one of the forms into which cassava is processed. The advantages of dry cassava chips include its longer shelf life; absence of about 60 - 65% water content, 15% peel and 0.5% fiber thereby eliminating transportation of unnecessary weights. Adaptation of chips to further processing into other end products like flour; starch, feeds etc is less cumbersome. Traditional and manual chipping methods are labourous, tedious, time consuming, and of poor product quality. This has led to the design and fabrication of machines that chip cassava better and more easily.

The size of cassava roots is usually reduced prior to further processing. At the home level, cassava roots are chipped manually using a knife. This process is slow and produces large, irregularly shaped chips that take 3 to 7 days to dry and impart a sour and musty taste, actually preferred by some rural consumers of the food made from dry chips.

Some of the chipping machines are manually operated while some are motorized. The qualities of the chips produced by these machines are higher than those of traditional methods. Mechanical chippers have the advantage of producing cleaner, smaller, and uniform chips that dry rapidly. The drying rate depends on the geometry of the chips and the amount of chips per unit of drying surface. Flat chips tend to stick to each other and reduce the flow of removal of moisture between chips that are stuck together.

### 2.8.1 The IITA Power Chippers

The International Institute of Tropical Agriculture (IITA) has designed a low - cost chipper that produces 'finger' chips of about 5mm thickness and a length depending on the size of the cassava roots (IITA, 1996). These chips can dry after 6 to 8 hours of exposure to the sun. When manually operated, the chipper has capacity of 60 - 80 kg/hr but an electric, gasoline, or diesel engine can power it with a capacity of 1000 kg/hr. Recently, IITA has fabricated and is marketing a chipper which they called IITA Power Chipper. It is powered by a 3.5 HP (2.61 KW) petrol engine or a 0.5 HP (0.368 KW) electric motor. It has a chipping capacity of 1.2 tonnes per hour, fuel consumption rate 0.8 liters/hr, and operating speed of 260 rpm. IITA also has a manual chipper of 200 kg/hr chipping capacity and a 60 rpm operating speed. These machines have their own draw - backs. The common of these draw - backs include the high cost and absence of electricity/petrol at the rural areas where cassava is mostly grown. The minimal useful life of the wood by which the manual chipper is made is also a problem. The production capacity is low compared to the energy input (Atshriru, 1998). The chips are fragile when dried and breaks readily when packaged. Each tuber is usually held tightly to the circular chipping plate by the operator one at a time.

### 2.8.2 Pedal Operated Chipping and Slicing Machine for Tubers

Another cassava chipping machine was designed using a bicycle attachment connected to a chipping plate. This machine was designated as pedal operated chipping and slicing machine for tubers. The plate carried knives that made it possible to both slice and chip. Two operators operate the machine: one pedaling, and the other feeding through the chute (Raji and Igbeka, 1994). Malaysia, Columbia and Thailand have chippers with common structures like this one designed by Raji and Igbeka. Clarke (1987) observed that various chipping machines have been developed and tested in various developing countries especially in the Caribbean's and South-East countries. The Central Tuber Crop Research Institute (CRCRI) India and the International Centre for Tropical Agriculture (CIAT) Colombia in 1983 and 1985 respectively developed motorized chipping machines for livestock feed production (CIAT, 1985).

### 2.8.3 Ajibola's Cassava Chipping Machine

In 1994, a Cassava Chipping Machine was designed and produced by a team of researchers under the International Society for Horticultural Science (ISHS) (Ajibola et al, 1994). It consists of mechanisms for slicing and dicing roots, in addition to feeding, power and the drive units. Performance of motor speeds between 360 and 400 rpm was rated satisfactory by the producers and dimensions of the sliced product (chip) was 25 mm. The machines' best chip geometry was obtained at a motor speed of 400 rpm and throughput of 0.27 kg/s (970 kg/hour). Dicing results were however, not satisfactory even to the producers and they acknowledged that there was need for further improvement in the design of the machine.

### 2.8.4 Ergonomic Evaluation of a Manually Operated Chipping Machine

The drudgery and tedious labour involved in manually chipping cassava tubers have been highlighted above as among the reasons that necessitated the need for machine chippers. The sad fact is that many of the developed machine chippers have not completely removed the drudgery and discomfort which cassava chippers experience. The acknowledgement of this fact has led to the ergonomics evaluations of some of the developed mechanical cassava chippers. A case in point is the ergonomics evaluation of a manually operated cassava chipping machine (McNeill and Westby, 1999). Six farmers took part in the study with physiological, postural and subjective measurements been taken. Using the machine resulted in postural discomfort. However, following an interactive design process and using appropriate anthropometric measurements, and improved, adjustable prototype was developed. This was tested with the six farmers and six novice users. It was found to reduce discomfort and physiological strain, allowed a faster work rate (with novice users) and was preferred by all users. This buttressed the fact that it is not enough to develop a machine, the designer must incorporate in the machine the welfare and ergonomics convenience of the user or the machine at work place.

### 2.8.5 A Mobile Motorized Cassava Grater and Chipper

A combined cassava grater and chipping machine designated as a mobile motorized cassava grater and chipper was designed and constructed in 1996 (Akintola, 1996).

The machine was conceived to provide mobile, versatile and profitable custom hiring operations. It had both the grating and chipping rotors mounted on a single shaft and allowed simultaneous grating and chipping operations. It was driven by a 5HP (3.73 KW) petrol engine and had a shaft speed of 900rpm and measured grating and chipping outputs of 1000kg/hr and 700kg/hr of fresh tubers respectively. The cost of the machine as at then, together with petrol engine, trailer and hitching attachments to motorcycle was put at about seventy thousand naira (₦70,000). The major components in the chipping unit consist of a steel framework supporting a feed hopper and a casing containing the chipping disc or chipping template of 375mm diameter and made from a thin 3mm gauge circular steel plate. The plate carries circular chipping teeth/elements arranged concentrically throughout the plate surface. The chipping template/disc is bolted to the end of the rotating machine shaft inside its casing.

### 2.8.6 Akintunde's Motorized Cassava Chipping Machine

This was another motorized cassava chipping machine developed by a team of two agricultural engineers-the Akintundes of Federal College of Agriculture, Moor Plantation, Ibadan and the department of Mechanical engineering, the Polytechnic Ibadan, all in Oyo state, Nigeria. The machine was said to be easy to assemble, operate, and maintain. The chipping unit consisted mainly of a steel rotating circular chipping plate and the housing. When tested with cassava, chips of length 60mm, width 15mm, and thickness 2mm were produced using the machine (Akintunde and Tunde-Akintunde, 2001). The main design features essentially consisted of the main frame, the chipping plate, chipping unit housing and the power unit. The operational principle was that the tubers were peeled and washed before being fed into the machine through the hopper. The base of the hopper was inclined at $45^0$ to the frame to enable the tubers to slide towards the chipping plate under the action of gravitational force. The power was provided by an electric motor, which drove the pulley of the chipping machine and thus causes the chipping plate to rotate. As the chipping plate rotates, the cutting edges along the plate cut the chips. The cut chips pass through the punched holes in the plate and fall through the discharge outlet at the bottom of the housing.

### 2.8.7 Onyemere's Cassava Chipping Machine

A cassava chipper designed at the Agricultural Engineering Department of the Federal University of Technology Minna (Onyemere, 2001) to chip peeled, washed, fresh tubers consists of an assemblage of about 28 knives vertically in a rectangular box encasement that acts as a piston undergoing a reciprocating motion and linked to a connecting bar (crank mechanism). The human labour envisaged in the operation of even a motorized version of this machine is much as the tubers are placed in the machines feeding area one at a time. The machine can also be called a slicer since the tubers are only sliced transversely, producing slices of 5mm thickness and diameters as large as those of the tubers.

### 2.8.8 Integrated Cassava Project/Post Harvest Equipment

In the year 2005, the IITA in collaboration with the Federal Ministry of Agriculture and Rural Development (FMA&RD) and other stake holders in agriculture like the federal government of Nigeria, the Niger-Delta Development Commission (NDDC), Shell Petroleum Development Company (SPDC) of Nigeria, United States Agency for International Development (USAID), and states in southern Nigeria, organized an agricultural conference of post harvest equipments under the integrated cassava project. The IITA has published a list of several available cassava chipping machines, under the integrated cassava project (IITA, 2005). These are summarized in table 2.1 below.

**Table 2.1: Summary of available Cassava Chipping Machines (IITA, 2005)**

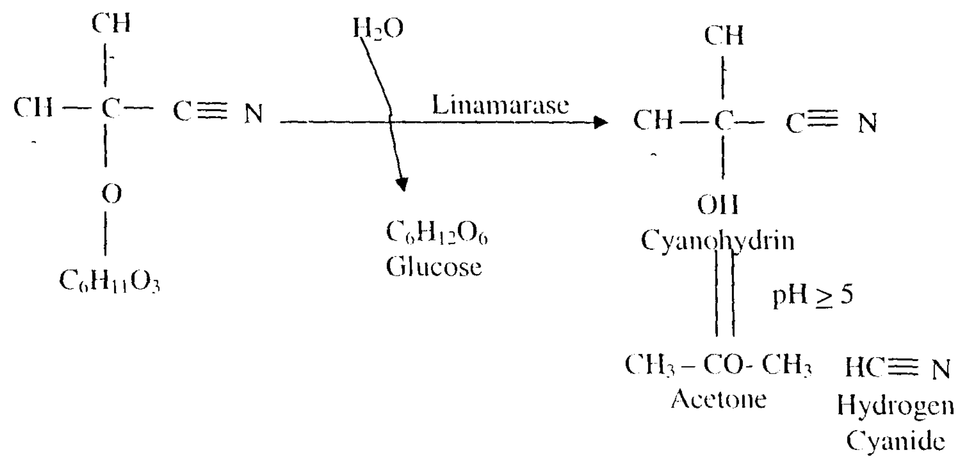
| S/ No. | Name | Capacity (Kg/hr) | Power Drive | Size (mm) | Use |
|---|---|---|---|---|---|
| 1 | Doala Ageh Cassava Chipping Machine | 500 | Diesel engine | 1015× 710 ×1015 | |
| 2 | Indian Cassava Chipping Machine | 300-1100 | | | Produces chips of thickness:2.5-10mm |
| 3 | IITA Power Chipper | 1200 | Petrol engine(2.61 KW)/ Electric motor( 0.37 KW) | | Slicing, chipping roots and tuber crops: cassava, yam, sweet potato and plantain. |
| 4 | NCAM Cassava Chipper | | | | |
| 5 | NOVA Cassava Chipper | 1200 | Diesel/Petrol/Electric motor (3.73 KW) | | |
| 6 | Hanigha Cassava Chipper | | | | |
| 7 | B & T Ventures Cassava Chipper | | | | |
| 8 | S. Adiss Cassava Chipper | 1000-2000/day | Electric motor (3.73-11.19 KW)/ Diesel engine (4.48-7.46 KW) | | For chipping dry yam, cassava, milling grains. |
| 9 | ARCEDEM Manual Chipper | | Manual/Diesel/Petrol engine/Electric motor (2.4 KW) | 645×6 30 ×780 | Can share engines easily with other machines such as cassava grater and dry milling machines. |
| 10 | NCAM Manual Chipper | 350 | Manually operated | | |

## 2.9 Cassava Chip Colouration Explained

Cassava tubers change colour (turning from white to brown or yellow) immediately after peeling. This colour change is said to be due to the presence of sulphuric compounds in the product and enzymic actions - Linamarase, Pero - oxidase, and Maillard reactions. The two cyanogenic glucosides present in cassava root - Linamarin and Lotaustralin, in addition to being highly soluble in water, tending to decompose when heated to temperatures above 150°C, also are influenced by the enzyme Linamarase which is present in the cassava root (Enwere, 1998). The hydrolysis of the glucosides which can be invitro or invivo, yields free toxic hydrogen cyanide, a sugar moiety and a keto compound as shown inequation 2.1 below.

$$\text{Glucoside} \xrightarrow[\text{hydrolysis}]{\text{invitro/invivo}} \text{HCN} + \text{Keto Compound} + \text{Sugar moiety} \qquad 2.1$$

In the intact cassava tissue, Linamarin segregated from the endogenous enzyme, Linamarase. However, when the root is bruised, cut, gratted, or otherwise disintegrated, Linamarin and endogenous Linamarase come in contact resulting in the hydrolysis of Linamarin to yield hydrogen cyanide as shown in equation 2.2 below. (Okaka, 1997).




2.2

Similarly, Mailard reaction is said to take place when proteins (amino acids) especially of the lysine group react with reducing sugar (carbohydrate containing food genetinized, converted to simpler sugars e.g. Sucrose) resulting in nonenzymatic browning. Water content and temperature are important factors in determining the rate and extent of maillard browning. Higher temperature and lower water content generally lead to browner colour, and probably to greater loss in protein nutritive value (Beckett, 1995).

Pero - oxidase refer to the discoloration as a result of surface darkening due to oxidation. Most traditionally processed cassava chips are coloured. The chips meant for export must meet the industrial and international quality standards:-

- Unfermented
- Not more than 11% moisture content
- Fineness of 90%, below 180 micros
- Pure white and
- HCN free

## 2.10 Material Selection

One of the goals in designing a machine is that the strength of the part should have a factor of safety (also called factor of uncertainty or factor of ignorance) greater than one. To meet this goal, it is necessary to know the properties of the materials to be used for the different parts of the machine. Such properties include: strength of the material under loading and unloading conditions, physical properties of the material, thermal, mechanical, chemical properties; availability of the materials and their workability (Ojo, 1996).

The Material selection is further complicated by the fact that the material properties are influenced by the manufacturing process, the geometry of the component, and types of forces acting on it. Hence, it is important that the performance of the component in service rather than the behaviour of each unit material should count.

Economic consideration on materials cannot be solely based on the cost of the materials (Olateru, 1998). Procedure for material selection can therefore be summarized as follows:

(i) Analysis of the material for selection.

(ii) Development of alternative solution to the problem of material selection.

(iii) Evaluation of different solutions.

(iv) Decision on the optimum material.

## 2.11 Machines and Farm Power Systems

The various sources of power on the farm are as follows: Human, animals, engines (usually a diesel or petrol engine installed in a tractor with its own self-contained fuel supply), electrical, solar, wind, water, biomass etc. A machine, of whatever type, requires a power input to make it produce a specified output effect such as cultivation, seed planting, weeding, grinding, chipping, grating, threshing, etc. The power input defines the rate at which energy is supplied and so controls the rate at which the output effect is achieved. Most agricultural crop processing operations (cassava chip production inclusive) are time-sensitive and products may spoil if they are not completed with due timeliness. Timeliness depends upon good management backed up by suitable equipment and adequate levels of power. The relationship between the input power, good management with due timeliness, and the resulting output is illustrated in fig. 2.3.

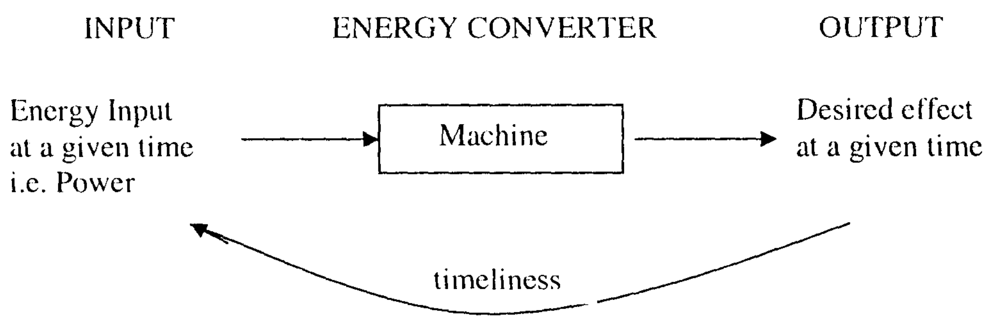



**Fig. 2.3 Timeliness and need for power in an agricultural operation**

A timely and effective mechanized operation depends upon : a clearly specified output, i.e. the desired effect; an adequate, available and sustainable input of mechanical power; and a machine, matched to the available power source, which can produce the desired output effect.

As farm operations are mechanized, more power becomes available as the progression is made from human labour to animal power and then to engine power. The fundamental question arises of how to use the extra power to best advantage. Selection of a suitable source of mechanical power for a particular operation is specific to local circumstances. Major factors which can be used as a checklist in selection are that the power source should be accessible to the farmer, available when needed, user friendly, sufficiently powerful, sustainable in use, economically viable, socially acceptable. Based on these facts, the source of power for this machine should be electrical.

## 2.12 Material Reliability

In present day technological setups, machines and equipments, industrial establishments etc constitute a multitude of interacting mechanisms and components. The failure of one component disrupts the operation of the system as a whole. This result in huge expenditure and repairs, time waste, interrupted power supply, water supply transport systems' temporary coming to a halt, unskilled plans, destruction of certain installations, and at times, lost of lives. The property of an object or material to retain (in time) with in the predetermined limits, all the parameters ensuring the performance of the functions in the present condition is called the reliability of the material or the object.

The reliability theory deals with the following objectives (objects):

**Article:** A unit product manufactured by given enterprise or production shops e.g. a bearing, transmission belt, motor vehicle etc.

**Component:** The simplest element of an article for the purpose of a given function.

**System:** A number of interacting components intended for independent performance of desired functions

The concepts of component and systems are interchangeable, depending on the functions they perform. Thus a machine is considered a system of individual components-mechanisms, parts, etc. when its own reliability is estimated, while the same machine may be considered a component in the study of reliability of an automated flow line.

Reliability of materials can be defined as the probability that it will perform the intended service for the expected life without failure. But material reliability is difficult to measure because it is dependent on both the materials inherent nature and properties. It is also largely a function of the material's production and processing history, the environment in which the components will operate and the coefficient of thermal expansion of all materials involved. All Materials used in fabricating a part may have to be similar to avoid differing thermal stresses (Olateru, 1998).

## CHAPTER THREE

## 3.0 METHODOLOGY, DESIGN ANALYSIS & CALCULATIONS

### 3.1 Design Considerations

The following are the design considerations for this machine.

(i) The tubers to be chipped should be peeled, washed, and treated to prevent de-colouration. The cassava variety mostly used here is the bitter variety (*Manihot Esculenta Crantz*) bought at the Gwari Market in Minna, Niger State.

(ii) Cassava tubers have irregular oblong shapes with geometric mean diameter of about 70mm (Akande, 2001), and a mean length of about 1m (Onwueme, 1982), therefore, the area of the slicing knife (44550mm$^2$), and the hopper base area (14400mm$^2$) are designed to take care of tubers even much bigger than the average tuber sizes. See section 4.1.2 and 4.1.3 for details.

(iii) The density of cassava for 100kg of cassava tubers is about 501kg/m$^3$ (Baderinwa, 2000), so the mainframe/table (see section 4.1.1) was constructed using 5mm guage angle bar that can carry the weight of about 200Kg of tubers of cassava in the carriage bin.

(iv) As a fibrous crop, cassava posses resistance during cutting: average cutting force of cassava is 68.99 N (Onyemere, 2001).

(v) Generally, cassava chips for marketing are chipped according to the specifications of the buyer. However, this machine is designed to give chips of about 10mm thickness and having the shape of a sector of a circle.

### 3.2 Design Methodology and Physical Properties of Cassava

Cassava tubers are classified as a fibrous crop. Hence slicing or cutting it encounters some degree of resistance because of the fibers in the tuber. The local or traditional varieties(*Manihot Esculenta Crantz*) have more fibers than the IITA – Improved varieties, and consequently, harder to slice than the improved varieties. The design considerations of this machine are based on the traditional varieties (*Manihot Esculenta Crantz*) bought at the Gwari Market in Minna, Niger State. With the machine chipping the local cassava varieties efficiently, that of the improved varieties requires less force. (From experience, the improved varieties are softer to cut, easier to cut than the traditional varieties of the same specie. They take lesser days to ferment when soaked in water than the traditional varieties. When the fermented tuber is mashed in water, removing the pulp, the resultant fibre is more from the traditional than the improved variety.) Cassava tuber is oblong or cylindrically shaped. Some are irregularly shaped. This design suggests that the irregularly shaped tuber should be slashed by cutlass into the desired cylindrical or oblong shapes during the peeling operation or just before entry into the machine hopper.

## 3.3 Methodology of De–Colouration Treatment (Bio-Chemical Properties and Pre-chipping Treatment)

The problems of enzymic browning and carcinogenic properties of cassava are well known. Cassava tubers to be chipped must be selected on the basis of average size, within 24 hours of harvesting and have not been damaged during the cutting. To prevent browning, the fresh cassava tuber is peeled, washed immediately after peeling, and washed again in water solution of sodium metabisulphate or confectionary grade sulphur dioxide. The sodium meta Bisulphate is first mixed in water at a ratio of 1:4 (l/l). The resulting solution is again mixed with water at a ratio of 1:50 (l/l) (Oshogwe, 2005). That gives, a concentration ratio of about 1:200 (l/l) chemical to water.

After removing the tubers from the solution, they are taken to the chipping machine for chipping. After the chipping, the chips are again treated with that or similar solution (or same solution as the case may be). The chips are removed from this solution to be dried. Sun drying can be used, but for faster drying rate and better hygienic condition, and electric dryer is preferred. Commercially, the chips are dried to specified moisture content (10 – 12 %) according to the requirement of the buyer. The drying temperature is below $70^0$ C. The chips are turned in the dryer at intervals of 15 minutes to prevent "charppiness" of the resultant starch. Electric oven was used for this project because electric dryer was not available and the chips were turned at 30 minutes intervals.

### 3.4 Construction Concept of This Machine

This machine is intended to perform two separate but related functions on an already peeled, washed and chemically treated (for those interested in de – colouration treatment) cassava tuber. These are slicing and dicing. The tubers are lifted from the chemical solution into the machine hopper in batches of ten to thirty tubers at a time, hence the provision for the sieve/drain or carriage bin. The volume/capacity of the sieve/drain could be enlarged or redesigned to accommodate over a hundred tubers at a time, as this is envisaged in the choice and capacity of the main frame materials used in the construction.

The two tapered ends of the tuber are slashed off during peeling with either a sharp matchet or a cutlass. If this is not done, the operator is expected to do so before feeding the tubers into the machine hopper. This design suggests that the slashing of the two tapered ends of a cassava tuber is not a big wastage as such, since those ends are more or less extensions of the tubers' mid cord or neck/tail regions which are full of fibres. This slashing provides the tuber a sharp horizontal edge with which it can stand vertically on the cassava tuber stand (see section 4.1.4). It is considered that the tubers will stand longitudinally (vertically) in the hopper and so, the slicing action is on the tuber's transverse section (horizontal section, producing slices of about 10mm in thickness. If more or less thickness is required, the machine has an inbuilt adjuster to accomplish this. The slices are circular at the sliced surface. The dicer or further cutter slams this circular surface to divide the circular sliced piece into four equal sizes with respect to the centre of the circle (see fig. 3.1).

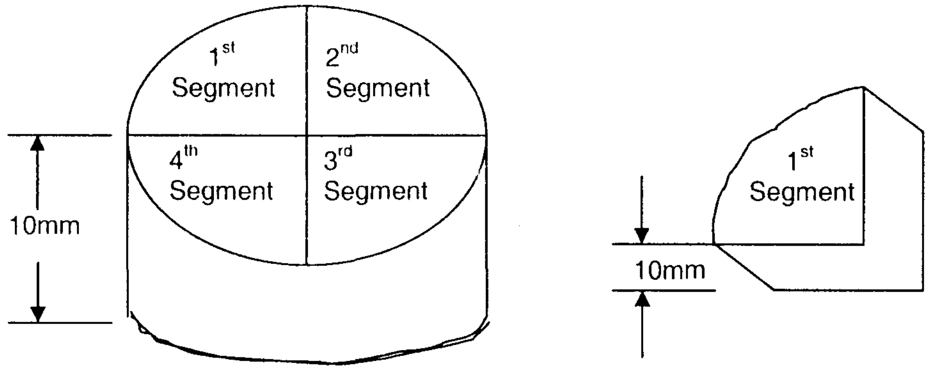



**Fig. 3.1 The shape of the chips produced by slicing and dicing action of the machine**

The machine is electrically powered. And the operator can operate the machine in a sitting or standing position. This machine can be called a Cassava Chipping machine or simply a Cassava Chipper.

### 3.5 Machine Components

The basic component parts of this cassava chipping machine are:

(i) The hopper

(ii) The slicer

(iii) The slider crank mechanism

(iv) The tray/conveyor

(v) The dicer and its crank mechanism

(vi) The dicer spring arrangement

(vii) The electric motor

(viii) The belts and pulley systems

(ix) The chip guide and chip collector

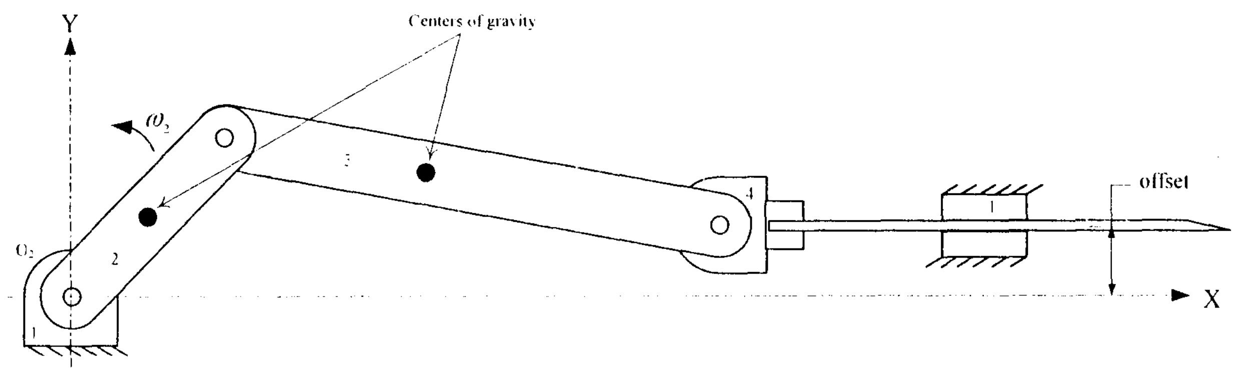
(x) The table or frame

(xi) Water drain

### 3.6 Design Analysis and Calculations

The design analysis of the crank-connecting rod-slider mechanism is shown in figure 3.2. Figure 3.3 is the free-body diagram of the mechanism showing position vectors loop and velocity vectors.

A complete kinematics calculation for intervals of $15^0$ for the input link angle $\theta_2$ is done in order to carry out the dynamic calculation. The procedure involved in calculating that of input angle $60^0$ is shown in detail while the complete results of other calculations are shown in tables 3.1 and 3.2, starting with shaft 1(Slicer shaft) and followed by that of shaft 2 (Chipper Shaft).




Link 1 = Ground Link

Link 2 = Crank

Link 3 = Connecting Rod

Link 4 = Slider

**Fig 3.2 The slider-Crank Mechanism**

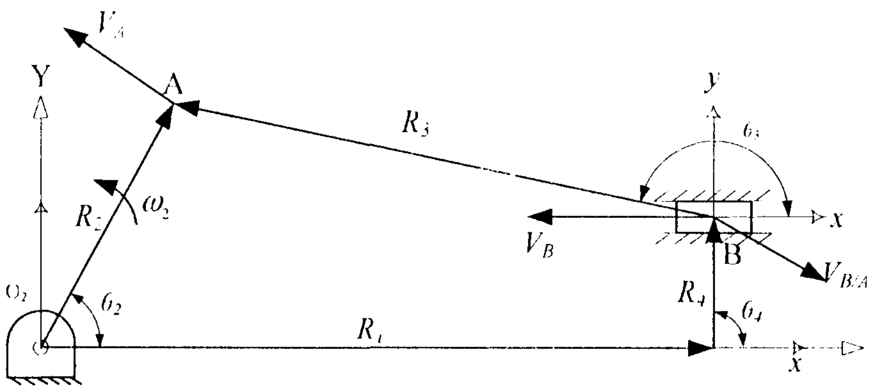



**Fig. 3.3 Position vectors loop and velocity vectors**

### 3.6.1 Determination of Positions

From figure 3.3, the required vector equation is:

$$R_2 - R_3 - R_4 - R_1 = 0 \qquad 3.1$$

Where $R_2$, $R_3$, $R_4$ are position vectors of links 2, 3 and 4 respectively.

$R_1$ is the instantaneous position of the slider.

Representing $R_2$, $R_3$, $R_4$, *and* $R_1$, with a, b, c, and d respectively, the equation becomes

$$a - b - c - d = 0 \qquad 3.2$$

Complex number equivalent of equation 3.2 is:

$$ae^{j\theta 2} - be^{j\theta 3} - ce^{j\theta 4} - de^{j\theta 1} = 0 \qquad 3.3$$

Substituting with the Euler equivalents

$$a(\cos\theta_2 + j\sin\theta_2) \quad b(\cos\theta_3 + j\sin\theta_3) \quad c(\cos\theta_4 + j\sin\theta_4) \quad d(\cos\theta_1 + j\sin\theta_1) = 0 \qquad 3.4$$

Where $\theta_2$ represents the angle of the input link (crank)

$\theta_3$ represents the angle of link 3

$\theta_4$ represents the angle of link 4

$V_A$ represents the velocity of point A

$V_B$ represents the velocity of point B

$\theta_1$ represents the angle of ground link

Separating the real and imaginary parts and taking note that $\theta_1 = 0°$, and $\theta_4 = 90°$;
we shall have:

$$a\cos\theta_2 - b\cos\theta_3 - c\cos\theta_4 - d = 0 \qquad 3.5$$

$$a\sin\theta_2 - b\sin\theta_3 - c\sin\theta_4 = 0 \qquad 3.6$$

Solving equations 5 and 6 simultaneously gives:

$$\theta_{31} = \sin^{-1}\left(\frac{a\sin\theta_2 - c}{b}\right) \quad 3.7$$

$$\theta_{32} = \sin^{-1}\left(\frac{-a\sin\theta_2 - c}{b}\right) + 180 \quad 3.8$$

Where $\theta_{31}$ is the value of $\theta_3$ for the first circuit and

$\theta_{32}$ is the value of $\theta_3$ for the second circuit.

From equation 5,

$$d = a\cos\theta_2 - b\cos\theta_3 \quad 3.9$$

Considering the centers of gravity, $R_{G2}$ and $R_{G3}$

$R_{G2} = R_{12}$ and $R_{G23} = R_{23}$

$$R_{G2} = fe^{j(\theta_2+\delta_2)} = f(\cos(\theta_2+\delta_2) + j\sin(\theta_2+\delta_2)) \quad 3.10$$

$$R_{G3} = ge^{j(\theta_3+\delta_3)} = g(\cos(\theta_3+\delta_3) + j\sin(\theta_3+\delta_3)) \quad 3.11$$

Where $\delta_2$ is the angle between $R_{G2}$ and $R_2$

$\delta_3$ is the angle between $R_{G3}$ and $R_3$

But $\delta_2 = 0$ and $\delta_3 = 0$ . Therefore,

$$R_{G2} = f(\cos\theta_2 + j\sin\theta_2) \quad 3.12$$

And $$R_{G3} = g(\cos\theta_3 + j\sin\theta_3) \quad 3.13$$

Considering equations 3.7 to 3.9, for Shaft 1 where

a = 0.07m, b = 0.2m, c = 0, $\alpha_2 = 0$, $\omega_2 = 37.6991$ rads$^{-1}$ (360 rpm), $\theta_2 = 60^0$

$$\theta_3 = \sin^{-1}\left(\frac{a\sin\theta_2 - c}{-b}\right) + 180$$

$$\theta_3 = \sin^{-1}\left(\frac{0.07\sin 60 - 0}{-0.2}\right) + 180 = 162.3556^0$$

$$d = a\cos\theta_2 - b\cos\theta_3$$

$$= 0.07\cos 60 - 0.2\cos 162.3556^0 = 0.2256\text{m}$$

From equations 3.10, 3.11, and figure 3.5

$$R_{12x} = \frac{-a}{2}\cos\theta_2 = \frac{-0.07}{2}\cos 60 = -0.0175m$$

$$R_{12y} = \frac{-a}{2}\sin\theta_2 = \frac{-0.07}{2}\sin 60 = -0.0303m$$

$$R_{32x} = \frac{a}{2}\cos\theta_2 = \frac{0.07}{2}\cos 60 = 0.0175m$$

$$R_{32y} = \frac{a}{2}\sin\theta_2 = \frac{0.07}{2}\sin 60 = 0.0303m$$

$$R_{23x} = \frac{-b}{2}\cos\theta_3 = \frac{-0.2}{2}\cos 162.3556 = 0.0953m$$

$$R_{23y} = \frac{b}{2}\sin\theta_3 = \frac{0.2}{2}\sin 162.3556 = -0.0303m$$

$$R_{43x} = \frac{b}{2}\cos\theta_3 = \frac{0.2}{2}\cos 162.3556 = -0.0953m$$

$$R_{43y} = \frac{-b}{2}\sin\theta_3 = -\frac{0.2}{2}\sin 162.3556 = -0.0303m$$

Considering equations 3.7 to 3.9, for Shaft 2 where

a = 0.06m, b = 0.2m, c = 0,

$$\theta_3 = \sin^{-1}\left(\frac{a\sin\theta_2 \; - c}{-b}\right)$$

$$\theta_3 = \sin^{-1}\left(\frac{0.06\sin 60 - 0}{-0.2}\right) = 164.9^{\circ}$$

$$d = a\cos\theta_2 - b\cos\theta_3$$

$$= 0.06\cos 60 - 0.2\cos 164.9^{\circ} = 0.2231\text{m}$$

From equations 3.10, 3.11, and figure 3.5

$$R_{12x} = \frac{-a}{2}\cos\theta_2 = \frac{-0.06}{2}\cos 60 = -0.015m$$

$$R_{12y} = \frac{-a}{2}\sin\theta_2 = \frac{-0.06}{2}\sin 60 = -0.026m$$

$$R_{32x} = \frac{a}{2}\cos\theta_2 = \frac{0.06}{2}\cos 60 = 0.015m$$

$$R_{32y} = \frac{a}{2}\sin\theta_2 = \frac{-0.06}{2}\sin 60 = 0.026m$$

$$R_{23x} = \frac{-b}{2}\cos\theta_3 = \frac{-0.2}{2}\cos 164.9 = 0.0966m$$

$$R_{23y} = \frac{b}{2}\sin\theta_3 = \frac{0.2}{2}\sin 164.9 = -0.026m$$

$$R_{43x} = \frac{b}{2}\cos\theta_3 = \frac{0.2}{2}\cos 164.9 = -0.0966m$$

$$R_{43y} = \frac{-b}{2}\sin\theta_3 = -\frac{0.2}{2}\sin 164.9 = -0.026m$$

### 3.6.2 Determination of Velocities

Differentiating equation 3.3 with respect to time, gives the expression for the velocities.

$$ja\omega_2 e^{j\theta_2} - jb\omega_3 e^{j\theta_3} - \dot{d} = 0 \qquad 3.14$$

i.e. $V_A - V_{AB} - V_B = 0$ 3.15

Where $\dot{d}$ represents the linear velocity of the slider

$\omega_2$ represents the angular velocity of the input link

$\omega_2$ represents the angular velocity of the connecting rod

Converting equation 3.14 into Euler equivalents:

$$ja\omega_2(\cos\theta_2 + j\sin\theta_2) - jb\omega_3(\cos\theta_3 + j\sin\theta_3) - \dot{d} = 0$$

$$a\omega_2(-\sin\theta_2 + j\cos\theta_2) - b\omega_3(-\sin\theta_3 + j\cos\theta_3) - \dot{d} = 0 \qquad 3.16$$

Separating into Real and imaginary parts give:

$$-a\omega_2\sin\theta_2 + b\omega_3\sin\theta_3 - \dot{d} = 0 \qquad 3.17$$

$$a\omega_2\cos\theta_2 - b\omega_3\cos\theta_3 = 0 \qquad 3.18$$

Solving equation 3.17 and 3.18 simultaneously gives:

$$\omega_3 = \frac{a\omega_2\cos\theta_2}{b\cos\theta_3} \qquad 3.19$$

From equation 3.17,

$$\dot{d} = -a\omega_2\sin\theta_2 + b\omega_3\sin\theta_3 \qquad 3.20$$

Comparing equation 3.15 and 3.16,

$$V_A = a\omega_2(-\sin\theta_2 + j\cos\theta_2) \qquad 3.21$$

$$V_{AB} = b\omega_3(-\sin\theta_3 + j\cos\theta_3) \qquad 3.22$$

$$V_B = \dot{d} \qquad 3.23$$

Considering the centres of gravity, and differentiating equations 3.12 and 3.13 respectively with respect to time give:

$$V_{G2} = jfe^{j\theta_2\omega_2} = f\omega_2(-\sin\theta_2 + j\cos\theta_2) \quad 3.24$$

And $$V_{G3} = jge^{j\theta_3\omega_3} = g\omega_3(-\sin\theta_3 + j\cos\theta_3) \quad 3.25$$

Considering equations 3.19 and 3.20, for shaft 1,

Where $\omega_2 = 37.6991$ rads$^{-1}$ (360 rpm), $\theta_2 = 60^0$

$$\omega_3 = \frac{a\omega_2\cos\theta_2}{b\cos\theta_3} = \frac{0.07x37.6991\cos 60}{0.2\cos 162.355} = -6.923 \text{ rads}^{-1}$$

$$\dot{d} = -a\omega_2\sin\theta_2 + b\omega_3\sin\theta_3$$

$$\dot{d} = -0.07\times 37.699\sin 60 + 0.2\times -6.923\sin 162.3556$$

$$= -2.71 \text{ ms}^{-1}$$

The minus sign indicates that the velocity is acting in the reverse direction.

Considering equations 3.19 and 3.20, for shaft 2,

Where $\alpha_2 = 0$, $\theta_2 = 60^0$ and $\omega_2 = 16.7552$ rads$^{-1}$ (160 rpm)

$$\omega_3 = \frac{a\omega_2\cos\theta_2}{b\cos\theta_3} = \frac{0.06\times 16.7552\cos 60}{0.2\cos 164.9} = -2.6026 \text{ rads}^{-1}$$

$$\dot{d} = -a\omega_2\sin\theta_2 + b\omega_3\sin\theta_3$$

$$\dot{d} = -0.06\times 16.7552\sin 60 + 0.2\times(-2.6026)\sin 164.9$$

$= -1.01$ ms$^{-1}$

### 3.6.3 Determination of Accelerations

Differentiating equation 3.14 with respect to time gives

$$\left(ja\alpha_2 e^{j\theta_2} + j^2 a\omega_2^2 e^{j\theta_2}\right) - \left(jb\alpha_3 e^{j\theta_3} + j^2 b\omega_3^2 e^{j\theta_3}\right) - \ddot{d} = 0 \quad 3.26$$

$$\left(ja\alpha_2 e^{j\theta_2} - a\omega_2^2 e^{j\theta_2}\right) - \left(jb\alpha_3 e^{j\theta_3} - b\omega_3^2 e^{j\theta_3}\right) - \ddot{d} = 0 \quad 3.27$$

i.e $A_A - A_{AB} - A_B = 0$ and $A_{BA} = A_{AB}$ 3.28

where $\ddot{d}$ represents the linear acceleration of the slider

$\alpha_2$ represents the angular acceleration of the input link

$\alpha_3$ represents the angular acceleration of the connecting rod

Substituting equation 3.27 with the Euler equivalent gives (Norton, 1999):

$$a\alpha_2(-\sin\theta_2 + j\cos\theta_2) - a\omega_2^2(\cos\theta_2 + j\sin\theta_2) - b\alpha_3(-\sin\theta_3 + j\cos\theta_3) +$$

$$+ b\omega_3^2(\cos\theta_3 + j\sin\theta_3) - \ddot{d} = 0 \qquad 3.29$$

Separating the real and imaginary parts gives

$$-a\alpha_2 \sin\theta_2 - a\omega_2^2 \cos\theta_2 + b\alpha_3 \sin\theta_3 + b\omega_3^2 \cos\theta_3 - \ddot{d} = 0 \qquad 3.30$$

$$a\alpha_2 \cos\theta_2 - a\omega_2^2 \sin\theta_2 + b\alpha_3 \cos\theta_3 + b\omega_3^2 \sin\theta_3 = 0 \qquad 3.31$$

Solving equations 30 and 31 simultaneously gives:

$$\alpha_3 = \frac{a\alpha_2 \cos\theta_2 - a\omega_2^2 \sin\theta_2 + b\omega_3^2 \sin\theta_3}{b\cos\theta_3} \qquad 3.32$$

From equation 3.30,

$$\ddot{d} = -a\alpha_2 \sin\theta_2 - a\omega_2^2 \cos\theta_2 + b\alpha_3 \sin\theta_3 + b\omega_3^2 \cos\theta_3 \qquad 3.33$$

Comparing equations 3.27 and 3.28,

$$A_A = (A_A^t + A_A^r) = (ja\alpha_2 e^{j\theta_2} - a\omega_2^2 e^{j\theta_2}) \qquad 3.34$$

$$A_{BA} = (A_{BA}^t + A_{BA}^r) = -(jb\alpha_3 e^{j\theta_3} - b\omega_3^2 e^{j\theta_3}) \qquad 3.35$$

$$A_B = A_B^t = \ddot{d} \qquad 3.36$$

For the centres of gravity, differentiating equations 3.24 and 3.25 respectively with respect to time:

$$A_{G2} = j\alpha_2 f e^{j\theta_2} - \omega_2^2 f e^{j\theta_2} = f\alpha_2(-\sin\theta_2 + j\cos\theta_2) - f\omega_2^2(\cos\theta_2 + j\sin\theta_2) \qquad 3.37$$

$$A_{G3} = j\alpha_3 g e^{j\theta_3} - \omega_3^2 g e^{j\theta_3} = g\alpha_3(-\sin\theta_3 + j\cos\theta_3) - g\omega_3^2(\cos\theta_3 + j\sin\theta_3) \qquad 3.38$$

From equations 3.32 to 3.38, where for shaft 1, $\alpha_2 = 0$ then

$$\alpha_3 = \frac{a\alpha_2 \cos\theta_2 - a\omega_2^2 \sin\theta_2 + b\omega_3^2 \sin\theta_3}{b\cos\theta_3}$$

$$\alpha_3 = \frac{0.07 \times 0 \times \cos 60 - 0.07 \times 37.6991^2 \sin 60 + 0.2(-6.923)^2 \sin 162.3556}{0.2\cos 162.3556}$$

$= 401.7573 \text{ rads}^{-1} = 401.76 \text{ rads}^{-1}$

$$\ddot{d} = -a\alpha_2 \sin\theta_2 - a\omega_2^2 \cos\theta_2 + b\alpha_3 \sin\theta_3 + b\omega_3^2 \cos\theta_3$$

$$\ddot{d} = -0.07 \times 0 \times \sin 60 - 0.07 \times 37.6991^2 \cos 60 + 0.2 \times 401.7573 \sin 162.3556$$
$$+ 0.2(-6.923)^2 \cos 162.3556$$

$= -34.5223 \text{ ms}^{-2} \approx -34.52 \text{ ms}^{-2}$

From equations 36 and 37, and where $f = \frac{a}{2}, g = \frac{b}{2}$,

$$A_{G2x} = \frac{-a}{2}\alpha_2 \sin\theta_2 - \frac{a}{2}\omega_2^2 \cos\theta_2$$

$$A_{G2x} = \frac{-0.07}{2} \times 0 \times \sin 60 - \frac{0.07}{2} \times 37.6991^2 \cos 60$$

$$= -24.8714\text{ms}^{-2} = -24.87\text{ms}^{-2}$$

$$A_{G2y} = \frac{a}{2}\alpha_2 \cos\theta_2 - \frac{a}{2}\omega_2^2 \sin\theta_2$$

$$A_{G2y} = \frac{0.07}{2} \times 0 \times \cos 60 - \frac{0.07}{2} \times 37.6991^2 \sin 60$$

$$= -43.0785\text{ms}^{-2} = -43.08\text{ms}^{-2}$$

$$A_{G3x} = \frac{-a}{2}\alpha_3 \sin\theta_3 - \frac{a}{2}\omega_3^2 \cos\theta_3$$

$$A_{G3x} = \frac{-0.07}{2} \times 0 \times \sin 162.3556 - \frac{0.07}{2} \times (-6.923)^2 \cos 162.3556$$

$$= -7.6103\text{ms}^{-2} = -7.61\text{ms}^{-2}$$

$$A_{G3y} = \frac{a}{2}\alpha_3 \cos\theta_3 - \frac{a}{2}\omega_3^2 \sin\theta_3$$

$$A_{G3y} = \frac{0.07}{2} \times 0 \times \cos 162.3556 - \frac{0.07}{2} \times (-6.923)^2 \sin 162.3556$$

$$= -39.7384\text{ms}^{-2} = -39.74\text{ms}^{-2}$$

From equations 3.32 to 3.38, where for shaft 2, $\alpha_2 = 0$ then

$$\alpha_3 = \frac{a\alpha_2 \cos\theta_2 - a\omega_2^2 \sin\theta_2 + b\omega_3^2 \sin\theta_3}{b\cos\theta_3}$$

$$\alpha_3 = \frac{0.06 \times 0 \times \cos 60 - 0.06 \times 16.7552^2 \sin 60 + 0.2(-2.6026)^2 \sin 164.9}{0.2\cos 164.9}$$

$$= 68.5162 \text{ rads}^{-1} = 68.52 \text{ rads}^{-1}$$

$$\ddot{d} = -a\alpha_2 \sin\theta_2 - a\omega_2^2 \cos\theta_2 + b\alpha_3 \sin\theta_3 + b\omega_3^2 \cos\theta_3$$

$$\ddot{d} = -0.06 \times 0 \times \sin 60 - 0.06 \times 16.7552^2 \cos 60 + 0.2 \times 68.5162 \sin 164.9 + 0.2(-2.6026)^2 \cos 164.9$$

$= -6.1701 \text{ ms}^{-2} = -6.17 \text{ ms}^{-2}$

From equations 3.37 and 3.38, and where $f = \frac{a}{2}, g = \frac{b}{2}$,

$$A_{G2x} = \frac{-a}{2}\alpha_2 \sin\theta_2 - \frac{a}{2}\omega_2^2 \cos\theta_2$$

$$A_{G2x} = \frac{-0.06}{2} \times 0 \times \sin 60 - \frac{0.06}{2} \times 16.7552^2 \cos 60$$

$$= -4.2110 \text{ ms}^{-2} = -4.21 \text{ ms}^{-2}$$

$$A_{G2y} = \frac{a}{2}\alpha_2 \cos\theta_2 - \frac{a}{2}\omega_2^2 \sin\theta_2$$

$$A_{G2y} = \frac{0.06}{2} \times 0 \times \cos 60 - \frac{0.06}{2} \times 16.7552^2 \sin 60$$

$$= -7.2937\text{ms}^{-2} = -7.29 \text{ ms}^{-2}$$

$$A_{G3x} = \frac{-a}{2}\alpha_3 \sin\theta_3 - \frac{a}{2}\omega_3^2 \cos\theta_3$$

$$A_{G3x} = \frac{-0.06}{2} \times 68.5162 \times \sin 164.9 - \frac{0.06}{2} \times (-2.6026)^2 \cos 164.9$$

$$= -1.126 \text{ ms}^{-2} = -1.13 \text{ ms}^{-2}$$

$$A_{G3y} = \frac{a}{2}\alpha_3 \cos\theta_3 - \frac{a}{2}\omega_3^2 \sin\theta_3$$

$$A_{G3y} = \frac{0.06}{2} \times 68.5162 \times \cos 164.9 - \frac{0.06}{2} \times (-2.6026)^2 \sin 164.9$$

$$= -6.7923\text{ms}^{-2} = -6.79 \text{ ms}^{-2}$$

### 3.6.4 Determination of Mass–Moment of Inertia

Figure 3.4 shows the notations of the dimensions for rectangular and cylindrical links. With m as mass, the moment of inertia is given for a rectangular link as (Norton, 1999):

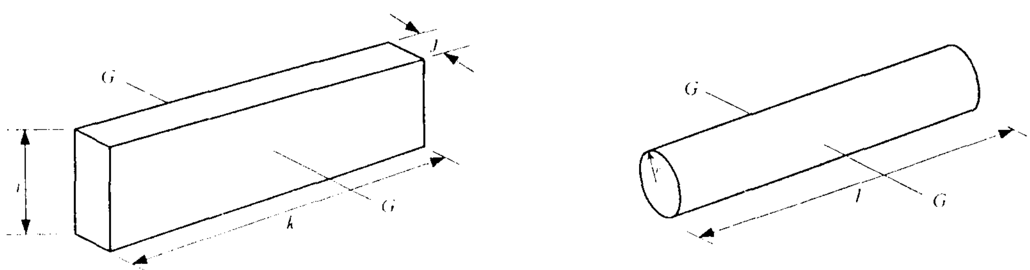


**Fig. 3.4 Rectangular and Cylindrical links**

$$I_G = \frac{m(k^2 + i^2)}{12} \qquad 3.39$$

$$= \frac{\rho v(k^2 + i^2)}{12} \qquad 3.40$$

Where $\rho$ is the density of material, and $v$ the volume. Also, for a cylindrical link,

$$I_G = \frac{m(3r^2 + i^2)}{12} \qquad 3.41$$

$$= \frac{\rho V(3r^2 + i^2)}{12} \qquad 3.42$$

$v = ijk$ (for rectangular mass) 3.43

$v = \pi r^2 i$ (for cylindrical mass) 3.44

From equations 3.39 to 3.44, for shaft 1, where $i_2 = 0.04$m, $j_2 = 0.006$m, $k_2 = 0.12$m, $\rho$ = 7850kgm$^{-3}$, $i_3 = 0.03$m, $j_3 = 0.006$m, $k_3 = 0.022$m.

Therefore $v_2 = i_2 \times j_2 \times k_2 = 0.04\text{m} \times 0.006\text{m} \times 0.12\text{m}$

$= 2.88 \times 10^{-5}\text{m}^3$

$m_2 = \rho v_2 = 7850 \times 2.88 \times 10^{-5}$

$= 0.226 \text{ kg} = 0.23 \text{ kg}$

$$I_{G2} = \frac{m_2(k_2^2 + i_2^2)}{12} = \frac{0.226(0.12^2 + 0.04^2)}{12}$$

$= 3.0144 \times 10^{-4} \text{ kgm}^2 = 3.01 \times 10^{-4} \text{ kgm}^2$

$v_3 = i_3 \times j_3 \times k_3 = 0.03 \times 0.006 \times 0.022$

$= 3.96 \times 10^{-5}\text{m}^3$

$m_3 = \rho v_3 = 7850\text{kgm}^{-3} \times 3.96 \times 10^{-5}\text{m}^3$

$= 0.311\text{kg} = 0.31\text{kg}$

$$I_{G3} = \frac{m_3(k_3^2 + i_3^2)}{12} = \frac{0.311(0.022^2 + 0.03^2)}{12}$$

$= 1.2771 \times 10^{-3} \text{ kgm}^2 = 1.28 \times 10^{-3} \text{ kgm}^2$

**Determination of Mass of Slider (Slicer)**

Length, $l$ = 0.22m, breadth, $b$ = 0.18m, Height, $h$ = 0.003m

Therefore volume, $v_s = l \times b \times h = 0.22\text{m} \times 0.18\text{m} \times 0.003\text{m}$

$= 0.000119\ m^3 = 1.19 \times 10^4\ m^3$

Mass of slider $m_4 = \rho v_s = 7850 \times 0.000119$

$= 0.933$ kg $= 0.93$ kg

From equations 3.39 to 3.44, for shaft 2, where $i_2 = 0.04$m, $j_2 = 0.006$m, $k_2 = 0.1$m, $\rho = 7850$kgm$^{-3}$, $i_3 = 0.004$m, $j_3 = 0.006$m, $k_3 = 0.22$m.

Therefore $v_2 = i_2 \times j_2 \times k_2 = 0.04\text{m} \times 0.006\text{m} \times 0.1\text{m}$

$= 2.4 \times 10^{-5} m^3$

Mass of crank 2, $m_2 = \rho v_2 = 7850\text{kgm}^{-3} \times 2.4 \times 10^{-5}\text{m}^3$

$= 0.1884$ kg $= 0.19$ kg

$$I_{G2} = \frac{m_2(k_2^2 + i_2^2)}{12} = \frac{0.1884(0.1^2 + 0.04^2)}{12}$$

$= 1.8212 \times 10^{-4}$ kgm$^2$ $= 1.82 \times 10^{-4}$ kgm$^2$ i.e. crank's moment of inertia.

For the connecting rod,

$v_3 = i_3 \times j_3 \times k_3 = 0.04\text{m} \times 0.006\text{m} \times 0.22\text{m}$

$= 5.28 \times 10^{-5}\ m^3$

mass of connecting rod, $m_3 = \rho v_3 = 7850\text{kgm}^{-3} \times 5.28 \times 10^{-5}\text{m}^3$

$= 0.4145$kg $= 0.41$ kg

$$I_{G3} = \frac{m_3(k_3^2 + i_3^2)}{12} = \frac{0.4145(0.04^2 + 0.22^2)}{12}$$

$= 1.727 \times 10^{-3}$ kgm$^2$ $= 1.73 \times 10^{-3}$ kgm$^2$

Mass of slider, $m_4 = 6.5$ kg (measured)

### 3.6.5 Determination of Forces and Torques

The use of Newton's law (Norton, 1999) is applied and written as the summation of all the forces and torques in the system. i.e

$$\sum F_x = ma_x \ ; \sum F_y = ma_y \ ; \sum T = I_G \alpha \qquad 3.45$$

Applying these equations to each of the moving links as illustrated in figure 3.5 gives the following set of simultaneously equations.

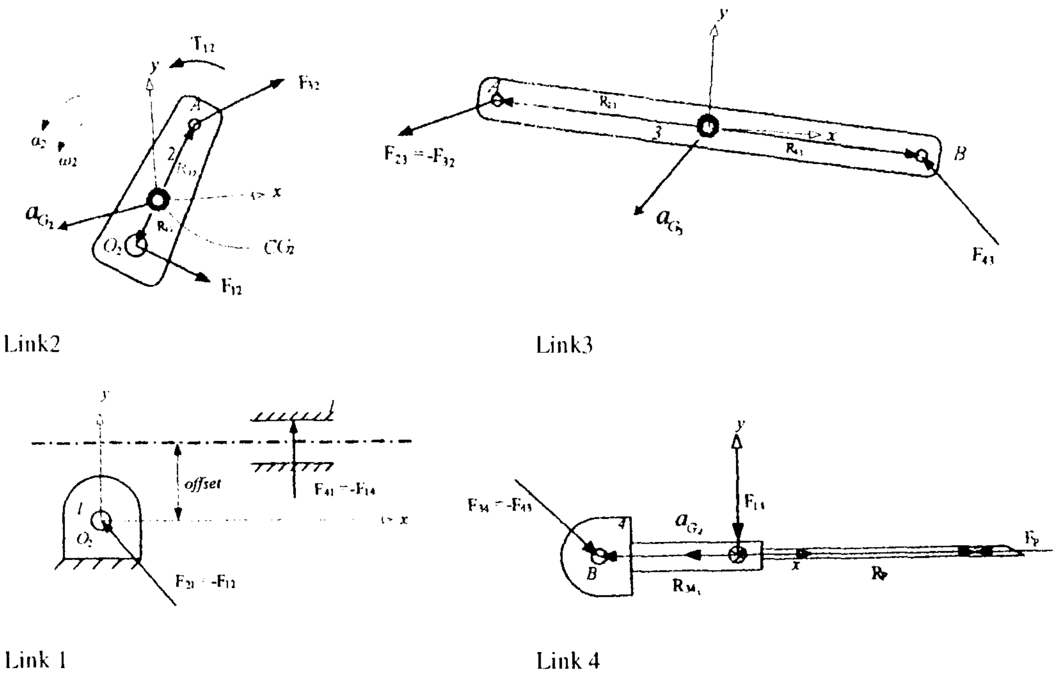



**Figure 3.5 Free-body diagram of each link disconnected**

From link 2 (crank):

$$F_{12x} + F_{32x} = m_2 a_{G2x} \qquad 3.46$$

$$F_{12y} + F_{32y} = m_2 a_{G2y} \qquad 3.47$$

$$T_{12} + (R_{12x}F_{12y} - R_{12y}F_{12x}) + (R_{32x}F_{32y} - R_{32y}F_{32x}) = I_{G2}\alpha_2 \qquad 3.48$$

For link 3 (Connecting Rod):

$$F_{43x} - F_{32x} = m_3 a_{G3x} \qquad 3.49$$

$$F_{43y} - F_{32y} = m_3 a_{G3y} \qquad 3.50$$

$$(R_{43x}F_{43y} - R_{43y}F_{43x}) - (R_{23x}F_{32y} - R_{23y}F_{32x}) = I_{G3}\alpha_3 \qquad 3.51$$

For link 4 (Slider):

$$F_{14x} + F_{43x} + F_{Px} = m_4 a_{G4x} \qquad 3.52$$

$$F_{14y} + F_{43y} + F_{Py} = m_4 a_{G4y} \qquad 3.53$$

$$(R_{14x}F_{14y} - R_{14y}F_{14x}) - (R_{34x}F_{43y} - R_{34y}F_{43x}) + (R_{Px}F_{Py} - R_{Py}F_{Px}) = I_{G4}\alpha_4 \qquad 3.54$$

But $a_{G4y} = 0$ (Linear acceleration which has no y--component.) 3.55

And $\alpha_4 = 0$ (Link 4 has no angular acceleration and no angular velocity.) 3.56

Note that frictional force exists between link 4 (slider) and link 1 (frame). Let the frictional force be denoted as $f$, then

$$f = \pm \mu N$$

Where $\mu$ = coefficient of friction and frictional force acts in x–direction with its sign opposite to that of the velocity of the slider.

N = the normal force.

Therefore $F_{14x} = \pm \mu F_{14y}$ 3.57

Substituting equations 3.55, 3.56, and 3.57 into equation 3.52, 3.53, and 3.54 appropriately results to:

$$\pm \mu F_{14x} + F_{43x} + F_{Px} = m_4 a_{G4x} \qquad 3.58$$

$$F_{14y} - F_{43y} + F_{Py} = 0 \qquad 3.59$$

$$(R_{14x}F_{14y} - R_{14y}F_{14x}) - (R_{34x}F_{43y} - R_{34y}F_{43x}) + (R_{Px}F_{Py} - R_{Py}F_{Px}) = 0 \qquad 3.60$$

Having the unknowns to be $F_{12x}$, $F_{12y}$, $F_{32x}$, $F_{32y}$, $F_{43x}$, $F_{43y}$, $F_{14x}$, $F_{14y}$, and $T_{12}$ ; nine equations are needed. Therefore, equations 3.46, 3.47, 3.48, 3.49, 3.50, 3.51, 3.58, 3.59, 3.60 will be solved simultaneously for the unknowns.

Forming matrices from the listed equations with the coefficients of the unknown variables forming the matrix A, the unknown variables as the B vector, and the constant term as the C vector; we have (Norton, 1999):

$$[A] \times [B] = [C]$$

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -R_{12y} & R_{12x} & -R_{32y} & R_{32x} & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & R_{23y} & -R_{23x} & -R_{43y} & R_{43x} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & \pm\mu & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & R_{34y} & -R_{34x} & -R_{14y} & R_{14x} & 0 \end{bmatrix} \begin{bmatrix} F_{12x} \\ F_{12y} \\ F_{32x} \\ F_{32y} \\ F_{43x} \\ F_{43y} \\ F_{14x} \\ F_{14y} \\ T_{12} \end{bmatrix} = \begin{bmatrix} m_2 a_{G2x} \\ m_2 a_{G2y} \\ I_{G2}\alpha_2 \\ m_3 a_{G3x} \\ m_3 a_{G3y} \\ I_{G3}\alpha_3 \\ m_4 a_{G4x} - F_{Px} \\ -F_{Py} \\ R_{Py}F_{Px} - R_{Px}F_{Py} \end{bmatrix}$$

3.61

Remembering that $a_{G4x} = \ddot{d}$

$F_{12}$ stands for force of link 1 on link 2; $R_{12}$ denotes the position vector of point of application of $F_{12}$ and the centre of gravity of link 2. $T_{12}$ is the source torque from link 1 to the driver link 2. This is the torque needed to drive the entire link system at the given angular speed $\omega_2$ of the driver link 2 and at angular acceleration $\alpha_2$.

The expression in equation 3.61 is solved for certain intervals of angular positions of link 2, $\theta_2$. For this project, $15^0$ intervals and the corresponding unknowns are solved for, using any matrix solver.

The torques obtained for each angular position is denoted as $T_0$, $T_{15}$, $T_{30}$, . .$T_{345}$ for one complete cycle of the driver link 2. The position with the highest value of torque is the peak torque $T_{peak}$ position. At this position is the peak power $P_{peak}$.

For shaft 1, considering equation 3.61 and entering the calculated unknowns. Also for a design where

$R_{34y} = 0.02m$, $R_{34x} = -0.1m$, $R_{14y} = 0.001m$, $R_{14x} = 0m$, $F_{px} = -100N$, $F_{py} = 0$ N,

$R_{px} = 0.1m$, $R_{py} = 0$, we shall have:

$$
\begin{bmatrix}
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0303 & -0.0175 & -0.0303 & 0.0175 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & -0.0303 & -0.0953 & 0.0303 & -0.0953 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & \pm 0.1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0.02 & 0.1 & -0.001 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
F_{12x} \\ F_{12y} \\ F_{32x} \\ F_{32y} \\ F_{43x} \\ F_{43y} \\ F_{14x} \\ F_{14y} \\ T_{12}
\end{bmatrix}
=
\begin{bmatrix}
0.1319(-24.8714) \\
0.1319(-43.0785) \\
1.717\times10^{-4}(0) \\
0.2638(-7.6103) \\
0.2638(-39.7384) \\
1.293\times10^{-3}(401.7573) \\
0.933(-34.5223)+100 \\
0 \\
0(-100)-0.1(0)
\end{bmatrix}
$$

Note that $A_{G4x} = \ddot{d}$ and $\mu = \pm 0.1$, $\mu = -0.1$ when $\ddot{d}$ is positive, and $\mu = 0.1$ when $\ddot{d}$ is negative.

Using the computer software "MatCAD" to solve the above 9 × 9 matrix gives the following results:

$F_{12x}$ = -44.4204N = -44.42N, $F_{12y}$ = -25.2196N = -25.22N

$F_{32x}$ = 38.8975N = 38.90N, $F_{32y}$ = 15.4804N = 15.48N

$F_{43x}$ = 36.5318N = 36.53N, $F_{43y}$ = 3.1273N = 3.13N

$F_{14x}$ = 1043.37N = 1043.37N, $F_{14y}$ = 3.1273N = 3.12N

$T_{12}$ = 1.8162Nm = 1.82Nm

The calculated results corresponding to the unknowns of the other input angles/intervals are shown in table 3.1.

**Table 3.1: Calculated Result for Shaft 1 (Slicer Shaft)**

| $\theta_2$ | $\theta_3$ | $d$ | $\dot{d}$ | $\ddot{d}$ | $F_{12}$ | $F_{32}$ | $F_{43}$ | $T_{12}$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 180 | 0.2700 | 0.0000 | -134.3056 | 57.6166 | 68.8588 | 63.5431 | 0.1116 |
| 15 | 175 | 0.2668 | -0.9149 | -129.3547 | 6.6633 | 17.6288 | 12.4269 | -0.2202 |
| 30 | 170 | 0.2575 | -1.7257 | -108.6283 | 19.3467 | 8.1478 | 11.1204 | 0.0802 |
| 45 | 166 | 0.2433 | -2.3427 | -75.0842 | 37.3533 | 26.6607 | 25.9884 | 0.7962 |
| 60 | 162 | 0.2256 | -2.7051 | -34.5223 | 51.1674 | 41.8848 | 36.6654 | 1.8162 |
| 75 | 160 | 0.2063 | -2.7944 | 5.3468 | 60.8843 | 53.3069 | 44.6694 | 2.9448 |
| 90 | 160 | 0.1873 | -2.6389 | 37.1710 | 66.0379 | 60.7996 | 50.8281 | 3.9128 |
| 105 | 160 | 0.1701 | -2.3037 | 56.8444 | 66.7824 | 64.4054 | 55.6084 | 4.4713 |
| 120 | 162 | 0.1556 | -1.8657 | 64.9633 | 64.1749 | 65.1147 | 59.6006 | 4.4922 |
| 135 | 166 | 0.1443 | -1.3894 | 65.6097 | 60.3623 | 64.8852 | 63.6636 | 3.9973 |
| 150 | 170 | 0.1363 | -0.9133 | 63.6858 | 58.8137 | 66.7603 | 69.5012 | 3.0974 |
| 165 | 175 | 0.1316 | -0.4511 | 62.8367 | 66.1667 | 76.6185 | 81.8240 | 1.6613 |
| 180 | 180 | 0.1300 | 0.0000 | 64.6656 | 105.4824 | 116.7271 | 122.1879 | -0.1116 |
| 195 | 185 | 0.1316 | 0.4511 | 68.7958 | 126.5026 | 115.7977 | 112.6036 | 2.5956 |
| 210 | 190 | 0.1363 | 0.9133 | 73.2626 | 225.0735 | 216.2273 | 216.6151 | 9.5337 |
| 225 | 194 | 0.1443 | 1.3894 | 75.0842 | 633.9392 | 628.0676 | 632.4413 | 37.6702 |
| 240 | 198 | 0.1556 | 1.8657 | 71.0612 | 1577.7351 | 1580.0781 | 1572.3007 | -108.0973 |
| 255 | 200 | 0.1701 | 2.3037 | 58.7364 | 471.6125 | 470.4733 | 460.5068 | -32.8010 |
| 270 | 200 | 0.1873 | 2.6389 | 37.1710 | 355.5769 | 351.4007 | 340.7010 | -22.9719 |
| 285 | 200 | 0.2063 | 2.7944 | 7.2388 | 390.9060 | 384.3127 | 374.3679 | -21.9781 |
| 300 | 198 | 0.2256 | 2.7051 | -28.4244 | 1049.7279 | 1041.3642 | 1033.6013 | -48.9256 |
| 315 | 194 | 0.2433 | 2.3427 | -65.6097 | 314.6694 | 324.2158 | 328.6487 | 11.8180 |
| 330 | 190 | 0.2575 | 1.7257 | -99.0515 | 72.5323 | 82.7829 | 83.4061 | 2.2300 |
| 345 | 185 | 0.2668 | 0.9149 | -123.3957 | 19.2376 | 29.8201 | 27.1721 | 0.5656 |
| 360 | 180 | 0.2700 | 0.0000 | -134.3056 | 57.6166 | 68.8588 | 63.5431 | 0.1116 |

For shaft 2, considering equation 3.61 and entering the calculated unknowns. Also for a design where:

$R_{34y} = 0.03$m, $R_{34x} = -0.12$m, $R_{14y} = 0.003$m, $R_{14x} = 0$m, $F_{px} = -200$N, $F_{py} = 0$ N,

$R_{px} = 0.2$m, $R_{py} = 0$, we shall have:

$$
\begin{bmatrix}
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0433 & -0.050 & -0.0433 & 0.0250 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & -0.0433 & -0.1447 & 0.0683 & -0.1447 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & \pm 0.1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0.03 & -0.12 & -0.003 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
F_{12x} \\ F_{12y} \\ F_{32x} \\ F_{32y} \\ F_{43x} \\ F_{43y} \\ F_{14x} \\ F_{14y} \\ T_{12}
\end{bmatrix}
=
\begin{bmatrix}
0.2355(-7.0184) \\
0.2355(-12.1562) \\
4.7296\times10^{-4}(0) \\
0.8385(-3.8927) \\
0.8385(-11.3877) \\
8.0984\times10^{-3}(74.7479) \\
6.5(-6.2513)+200 \\
0 \\
0(-200)-0.2(0)
\end{bmatrix}
$$

Note that $A_{G4x} = \ddot{d}$ and $\mu = \pm 0.1$, $\mu = -0.1$ when $\ddot{d}$ is positive, and $\mu = 0.1$ when $\ddot{d}$ is negative.

Using the computer software "MatCAD" to solve the above 9 × 9 matrix gives the following results:

$F_{12x}$ = 130.4963N =130.50 N $F_{12y}$ = 33.2167N

$F_{32x}$ = -131.2896N, $F_{32y}$ = -34.5908N

$F_{43x}$ = -131.7563N, $F_{43y}$ = -37.4061N

$F_{14x}$ = 281.3809N, $F_{14y}$ = -37.4061N

$T_{12}$ = -5.7843Nm

The calculated results corresponding to the unknowns of the other input angles/intervals are shown in table 3.2.

**Table 3.2: Calculated Results for Shaft 2 (Chipper Shaft)**

| $\theta_2$ | $\theta_3$ | $d$ | $\dot{d}$ | $\ddot{d}$ | $F_{12}$ | $F_{32}$ | $F_{43}$ | $T_{12}$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 180.0 | 0.2600 | 0.0000 | -21.8974 | 63.2062 | 64.7929 | 63.7492 | 0.0183 |
| 15 | 175.5 | 0.2574 | -0.3358 | -21.0291 | 55.5589 | 57.1178 | 58.1343 | -0.6304 |
| 30 | 171.4 | 0.2497 | -0.6347 | -17.7312 | 72.7085 | 74.1808 | 73.£991 | -1.6430 |
| 45 | 167.8 | 0.2379 | -0.8652 | -12.4849 | 100.6393 | 101.9650 | 102.2887 | -3.3400 |
| 60 | 164.9 | 0.2231 | -1.0059 | -6.1701 | 134.6575 | 135.7700 | 136.9633 | -5.7843 |
| 75 | 163.2 | 0.2069 | -1.0498 | 0.1010 | 168.9003 | 169.7262 | 171.5844 | -8.6740 |
| 90 | 162.5 | 0.1908 | -1.0053 | 5.2972 | 197.8260 | 198.2906 | 200.3965 | -11.3626 |
| 105 | 163.2 | 0.1759 | -0.8923 | 8.8201 | 218.1789 | 218.2189 | 220.0744 | -13.0877 |
| 120 | 164.9 | 0.1631 | -0.7354 | 10.6740 | 230.0756 | 229.6567 | 230.8455 | -13.3025 |
| 135 | 167.8 | 0.1530 | -0.5568 | 11.3363 | 236.3313 | 235.4658 | 235.7849 | -11.8623 |
| 150 | 171.4 | 0.1458 | -0.3706 | 11.4437 | 240.6762 | 239.4331 | 238.9492 | -8.9503 |
| 165 | 175.5 | 0.1414 | -0.1846 | 11.5113 | 246.1692 | 244.6723 | 243.6888 | -4.8861 |
| 180 | 180.0 | 0.1400 | 0:0000 | 11.7909 | 309:6830 | 308.0963 | 307.0498 | -0.0183 |
| 195 | 184.5 | 0.1414 | 0.1846 | 12.2501 | 302.8888 | 301.3911 | 360.7155 | 5.9876 |
| 210 | 188.6 | 0.1458 | 0.3706 | 12.6201 | 297.6619 | 296.4179 | 296.4201 | 11.0641 |
| 225 | 192.2 | 0.1530 | 0.5568 | 12.4649 | 291.1772 | 290.3117 | 291.0993 | 14.6209 |
| 240 | 195.1 | 0.1631 | 0.7354 | 11.4030 | 280.3119 | 279.8941 | 281.3758 | 16.2128 |
| 255 | 196.8 | 0.1759 | 0.8923 | 9.0439 | 262.5384 | 262.5800 | 264.5234 | 15.7481 |
| 270 | 197.5 | 0.1908 | 1.0053 | 5.2972 | 236.7542 | 237.2206 | 239.3247 | 13.5909 |
| 285 | 196.8 | 0.2069 | 1.0498 | 0.3247 | 203.7615 | 204.5891 | 206.5350 | 10.4520 |
| 300 | 195.1 | 0.2231 | 1.0059 | -5.4411 | 166.2582 | 167.3719 | 168.8589 | 7.1292 |
| 315 | 192.2 | 0.2379 | 0.8652 | -11.3363 | 128.4291 | 129.7549 | 130.5507 | 4.2560 |
| 330 | 188.6 | 0.2497 | 0.6347 | -16.5547 | 95.2934 | 96.7643 | 96.7766 | 2.1612 |
| 345 | 184.5 | 0.2574 | 0.3358 | -20.2902 | 71.9973 | 73.5541 | 72.8868 | 0.8441 |
| 360 | 180.0 | 0.2600 | 0.0000 | -21.8974 | 63.2062 | 64.7929 | 63.7492 | 0.0183 |

### 3.6.6 Determination of Flywheel Sizes

The values of torque obtained from the preceding section are summed by integration using Simpson's rule (Shigley and Mischke, 2001). This gives the value of energy that can be delivered to the load during one cycle as:

$$E = \int_{x_0}^{x_n} f(x)dx = \frac{h}{3}(T_0 + 4T_{15} + 2T_{30} + \ldots + T_{345}) \qquad 3.62$$

Where $h = \frac{(x_n - x_0)}{n}, \quad x_n > x_0$ 3.63

$n$ = Number of intervals

$x_n - x_0 = 2\pi$ (i.e. one cycle)

The mean torque is given by:

$$T_m = E / 2\pi \qquad 3.64$$

Generally, on the torque-displacement diagram, the loop yielding the largest speed change is the largest positive loop(Shigley and Mischke, 2001). Subtracting $T_m$ from each of these torques give:

$$L_P = T_\theta - T_m \qquad 3.65$$

Where p = 1, 2, 3, … , … , 12 and

$\theta = 0^o, 15^o, 30^o, \ldots, 345^o$

Substituting these parameters into Simpson's approximation gives the value of change in kinetic energy, $E_2 - E_1$. Therefore,

$$E_2 - E_1 = \int_{x_0}^{x_n} f(x)dx = \frac{h}{3}(L_0 + 4L_1 + 2L_2 + \ldots + L_{12}) \qquad 3.66$$

Furthermore, $E_2 - E_1 = C_S \frac{1}{2} I(\omega_2^2 - \omega_1^2)$ (Shigley and Mischke, 2001) 3.67

Where $I$ = moment of inertia of flywheel

$\omega_2$ = Maximum speed

$\omega_1$ = Minimum speed

$C_s = \dfrac{\omega_2 - \omega_1}{\omega}$ = Coefficient of speed fluctuation.

But $\dfrac{\omega_2^2 - \omega_1^2}{2} = \omega^2$ = mean speed.

Therefore, $E_2 - E_1 = C_s I \omega^2$

$$I = \frac{E_2 - E_1}{C_S \omega^2} \qquad 3.68$$

Finally, the flywheel size is given by the following equation (Norton, 1999) when a disc is used, as:

$$I = \frac{\rho \pi r^4 t}{2} \qquad 3.69$$

where $\rho$ = density of material of flywheel

$r$ = radius of flywheel

$t$ = thickness of flywheel

For shaft 1, applying equations 3.62 to 3.69 and referring to table 3.1, the size of the flywheel on it is determined thus: (i.e. summing up all the torques using Simpson's ⅓ rule to get the mean torque, (Shigley and Mischke, 2001)).

$n = 24,\ x_n - x_0 = 2\pi, \qquad h = \frac{2\pi}{24} = 0.2618$

$E = \frac{0.2618}{3}$ [0.1116 + 4 (-0.2202) + 2(0.0802) + 4(0.7962) + 2(1.8162) + 4(2.9448) + 2(3.9128) + 4(4.4713) + 2(4.4922) + 4(3.9973) + 2(3.0974) + 4(1.8613) + 2(-0.1116) + 4(2.5956) + 2(9.5337) + 4(37.6702) + 2(-108.0973) + 4(-32.8010) + 2(-22.9719) + 4(-21.9781) +2 (-48.9256) +4 (11.8180) +2 (2.2300) +4(0.5656) + 0.1116]

E = -23.0897 Nm rad = -23.09Nm rad

∴ $T_m = \frac{E}{2\pi}$ = -23.0897/2π = -3.6748Nm = -3.67Nm

To get the total change in energy ($E_2 - E_1$), we firstly subtract $T_m$ from each of the torques:

$L_p = T_\theta - T_m$ where p = 1, 2, 3 ...

and θ = 0°, 15°, 30° ...

$L_1 = T_o - T_m$ = 0.1116 – (-3.6748) = 3.7864

$L_2 = T_{15} - T_m$ = -0.2202 – (-3.6748) = 3.4546

$L_3 = T_{30} - T_m$ = 0.802 – (-3.6748) = 3.755

$L_4 = T_{45} - T_m$ = 0.7962 – (-3.6748) = 4.471

$L_5 = T_{60} - T_m$ = 1.8162 – (-3.6748) = 5.491

$L_6 = T_{75} - T_m$ = 2.9448 – (-3.6748) = 6.6196

$L_7 = T_{90} - T_m$ = 3.9128 – (-3.6748) = 7.5876

$L_8 = T_{105} - T_m$ = 4.4713 – (-3.6748) = 8.1461

$L_9 = T_{120} - T_m$ = 4.4922 – (-3.6748) = 8.167

$L_{10} = T_{135} - T_m$ = 3.9973 – (-3.6748) = 7.6721

$L_{11} = T_{150} - T_m$ = 3.0974 – (-3.6748) = 6.7722

$L_{12} = T_{165} - T_m$ = 1.8613 – (-3.6748) = 5.5361

$L_{13} = T_{180} - T_m$ = -0.1116 – (-3.6748) = 3.5632

$L_{14} = T_{195} - T_m$ = 2.5956 – (-3.6748) = 6.2704

$L_{15} = T_{210} - T_m$ = 9.5337 – (-3.6748) = 13.2085

$L_{16} = T_{225} - T_m$ = 37.6702 – (-3.6748) = 41.345

$L_{17} = T_{240} - T_m$ = -108.0973 – (-3.6748) = -104.422

$L_{18} = T_{255} - T_m = -32.8010 - (-3.6748) = -29.1262$

$L_{19} = T_{270} - T_m = -22.9719 - (-3.6748) = -19.297$

$L_{20} = T_{285} - T_m = -21.9781 - (-3.6748) = -18.303$

$L_{21} = T_{300} - T_m = -148.9256 - (-3.6748) = -45.250$

$L_{22} = T_{315} - T_m = 11.8180 - (-3.6748) = 15.4928$

$L_{23} = T_{330} - T_m = 2.2300 - (-3.6748) = 5.9048$

$L_{24} = T_{345} - T_m = 0.5656 - (-3.6748) = 4.2404$

Entering these values into Simpson's 1/3 rule gives the value of change kinetic energy $E_2 - E_1$:

$$E_2 - E_1 = \frac{0.2618}{3}[3.7864 + 4(3.4546) + 2(3.755) + 4(4.471) + 2(5.491) + 4(6.6196) + 2(7.5876) + 4(8.1461) + 2(8.167) + 4(7.6721) + 2(6.7722) + 4(5.5361) + 2(3.5632) + 4(6.2704) + 2(13.2085) + 4(41.345) + 2(-104.4225) + 4(-29.1262) + 2(-19.2971) + 4(-18.3033) + 2(-45.2508) + 4(15.4928) + 2(5.9048) + 4.2404]$$

$$= -0.6414 \text{ Nm}$$

$$I = \frac{E_2 - E_1}{C_S \omega^2} \qquad \text{Where } C_s = 0.1$$

$$I = \frac{-0.6414}{0.1 \times 37.6991^2} = -0.00451 kgm^2 = 4.51 \times 10^{-3} kgm^3$$

Also, $I = \dfrac{\rho \pi r^4 t}{2}$

$$\Rightarrow r = \sqrt[4]{\frac{2I}{\pi t \rho}} \qquad for\ t = 0.03m \ \ and \ \ \rho = 7850 kgm^{-3}$$

$$r = \sqrt[4]{\frac{2 \times (-0.00451)}{0.03\pi \times 7850}} = 0.0654m$$

d = 2 x r = 0.1308m ≈ 0.130.8 mm

Weight of flywheel = $9.81\pi r^2 t \rho$

= 9.81x π x $0.0654^2$ x 0.03 x 7850

= 20.6984 N ≈ 20.7N

For shaft 2, equations 3.62 to 3.69 are also applied to determine the size of the flywheel on it.

With n = 24, $x_n - x_o = 2\pi$

$$h = \frac{2\pi}{24} = 0.2618$$

$$E = \frac{0.2618}{3} [0.0183 + 4(-0.6304) + 2(-1.6430) + 4(-3.3400) + 2(-5.7843) + 4(-8.6740) + 2(-11.3626) + 4(-13.0877) + 2(-13.3025) + 4(-11.8623) + 2(-8.9503) + 4(-4.8861) + 2(-0.0183) + 4(5.9876) + 2(11.0641) + 4(14.6209) + 2(16.2128) + 4(15.7481) + 2(13.5909) + 4(10.4520) + 2(7.1292) + 4(4.2560) + 2(2.1612) + 4(0.8441) + 0.0183]$$

E = 4.6594 Nm rad

$$T_m = \frac{E}{2\pi} = \frac{4.6594}{2\pi} = 0.7416 \text{ Nm} = 0.74 \text{ Nm}$$

From $L_p = T_\theta - T_m$

$L_1 = T_0 - T_m = 0.0183 - 0.7416 = -0.7233$

$L_2 = T_{15} - T_m = -0.6304 - 0.7416 = -1.372$

$L_3 = T_{30} - T_m = -1.6430 - 0.7416 = -2.3846$

$L_4 = T_{45} - T_m = -3.3400 - 0.7416 = -4.0816$

$L_5 = T_{60} - T_m = -5.7843 - 0.7416 = -6.5259$

$L_6 = T_{75} - T_m = -8.640 - 0.7416 = -9.4156$

$L_7 = T_{90} - T_m = -11.3626 - 0.7416 = -12.1042$

$L_8 = T_{105} - T_m = -13.0877 - 0.7416 = -13.8293$

$L_9 = T_{120} - T_m = -13.3025 - 0.7416 = -14.0441$

$L_{10} = T_{135} - T_m = -11.8623 - 0.7416 = -12.6039$

$L_{11} = T_{150} - T_m = -8.9503 - 0.7416 = -9.6919$

$L_{12} = T_{165} - T_m = -4.8861 - 0.7416 = -5.6277$

$L_{13} = T_{180} - T_m = -0.0163 - 0.7416 = -0.7599$

$L_{14} = T_{195} - T_m = 5.9876 - 0.7416 = 5.246$

$L_{15} = T_{210} - T_m = 11.0641 - 0.7416 = 10.3225$

$L_{16} = T_{225} - T_m = 14.6209 - 0.7416 = 13.8793$

$L_{17} = T_{240} - T_m = 16.2128 - 0.7416 = 15.4712$

$L_{18} = T_{255} - T_m = 15.7481 - 0.7416 = 15.0065$

$L_{19} = T_{270} - T_m = 13.5909 - 0.7416 = 12.8493$

$L_{20} = T_{285} - T_m = 10.4520 - 0.7416 = 9.7104$

$L_{21} = T_{300} - T_m = 7.1292 - 0.7416 = 6.3876$

$L_{22} = T_{315} - T_m = 4.2560 - 0.7416 = 3.5144$

$L_{23} = T_{330} - T_m = 2.1612 - 0.7416 = 1.4196$

$L_{24} = T_{345} - T_m = 0.8441 - 0.7416 = 0.1025$

$L_{25} = T_{360} - T_m = 0.0183 - 0.7416 = -0.7233$

**Change in kinetic energy**

$$E_2 - E_1 = \frac{0.2618}{3}[-0.7233 + 4(-1.372) + 2(-2.3846) + 4(-4.0816) + 2(-6.5259) +$$
$$4(-9.4156) + 2(-12.1042) + 4(-13.8293) + 2(-14.0441) + 4(-12.6039)$$
$$+ 2(-9.6919) + 4(-5.6277) + 2(-0.7599) + 4(5.246) + 2(10.3225) +$$
$$4(13.8793) + 2(15.4712) + 4(15.0065) + 2(12.8493) + 4(9.7104) + 2(6.3876)$$
$$+ 4(3.5144) + 2(1.4196) + 4(0.1025) + (-0.7233)]$$

$E_2 - E_1 = 0.1294$ Nm

$$I = \frac{E_2 - E_1}{C_S \omega^2} = \frac{0.1294}{0.2 \times 16.7552^2} = 0.00461 \text{ Kgm}^2$$

Also, $I = \dfrac{\rho \pi r^4 t}{2}$

With $\rho = 7850\text{kgm}^{-3}$ and for t = 0.02m

Then $r = \sqrt[4]{\dfrac{2I}{\pi t \rho}}$

$$= \sqrt[4]{\frac{2 \times 0.00461}{\pi \times 0.02m \times 7850}}$$

$= 0.0658$m

$\therefore d = 2 \times r = 2 \times 0.0658$m

$d = 0.1315$m = 0.131.5 mm

Weight of flywheel $= 9.81\ \pi\ r^2\ t\ \rho$

$= 9.81 \times \pi \times 0.0658^2 \times 0.02 \times 7850$

$= 20.9207\ N \approx 20.9N$

### 3.6.7 Determination of Tensions in Belts

For a Vee-belt, the relationship between tensions $T_1$ and $T_2$ (Khurmi and Gupta, 2005) is expressed as:

$$2.3\ \text{Log}\ (T_1/T_2) = \mu\ \theta\ \text{cosec}\beta \qquad 3.70$$

Where $\mu$ = coefficient of friction

$\theta$ = angle lopped by belt on drive pulley

$\beta$ = half of groove angle

From equation 70, let the ratio $\frac{T_1}{T_2}$ be denoted by $k$ :

$$\frac{T_1}{T_2} = Log^{-1}\left(\frac{\mu\theta\cos ec\beta}{2.3}\right) = k \qquad 3.71$$

Torque transmitted, $T_{12} = (T_1 - T_2)\,R$ 3.72

Where, $T_1$ = tension on the tighter side of belt,

$T_2$ = tension of the slack side of belt,

$R$ = radius of pulley,

$T_{12}$ = torque transmitted from shaft to crank.

$k$ = ratio of tensions in the belt

Solving equations 3.71 and 3.72 simultaneously gives:

From equation 3.72,

$$T_1 = (\,T_{12}/R\,) + T_2 \qquad 3.73$$

From equation 3.71,

$$T_1 = kT_2 \qquad 3.74$$

$$\frac{T_{12}}{R} + T_2 = kT_2$$

$$\frac{T_{12}}{R} = kT_2 - T_2$$

$$= T_2(k-1)$$

Therefore, $$T_2 = \frac{\left(T_{12}/R\right)}{(k-1)}$$ 3.75

From equations 3.70 to 3.75, and for pulley on shaft 1 (double groove pulley) and given $\beta = 17.5^0$, $\mu = 0.25$, $\theta = 192^0 = 3.351$ rad.

$$K = \log^{-1}\left(\frac{0.2 \times 3.351 \times \cos ec17.5}{2.3}\right) = 16.2664$$

With R = 0.1m and Peak Torque 1 and Peak Torque 2 = 108.0973 and 16.2128 respectively

$$T_{12}^{'} = 108.0973 + 16.2128 = 124.3101 \text{ Nm} \approx 124.31 \text{ Nm}$$

Tension on the slack side of pulley $T_2$ for shaft 1

$$T_2^{'} = \frac{T_{12}^{'}/R}{(K-1)}$$

$$T_2^{'} = \frac{124.3101/0.1}{(16.2664-1)} = 81.4271\,N$$

Tension on the tighter side of pulley $T_1$ for shaft 1

$$T_1^{'} = KT_2^{'} = 16.2664 \times 81.4271\,N$$

$$= 1324.5281 \text{ N} \approx 1324.53 \text{ N}$$

From equations 3.70 to 3.75 and for the pulley on shaft 2 (single grove), where $\beta = 17.5$, $\mu = 0.2$, $\theta = 202°$ = 3.5256 rads.

R = 0.215m and $T_{12}^{''} = 16.2128$ Nm

$$K = \log^{-1}\left(\frac{0.2 \times 3.556 \text{ cosec } 17.50}{2.3}\right)$$

$$= 10.4593 \approx 10.46$$

Tension on the slack side of the pulley of shaft 2

$$T_2'' = \frac{T_{12}''/R}{K-1}$$

$$T_2'' = \frac{16.2128/0.215}{10.4593-1}$$

$$= 7.9718 \text{ N} \approx 7.97 \text{ N}$$

Tension on the tighter side of pulley of shaft 2

$$T_1'' = KT_2''$$

$$= 10.4593 \times 7.9718 \text{ N} = 83.3802 \text{ N} \approx 83.38 \text{ N}$$

### 3.6.8 Determination of Sizes of Shafts and Pins

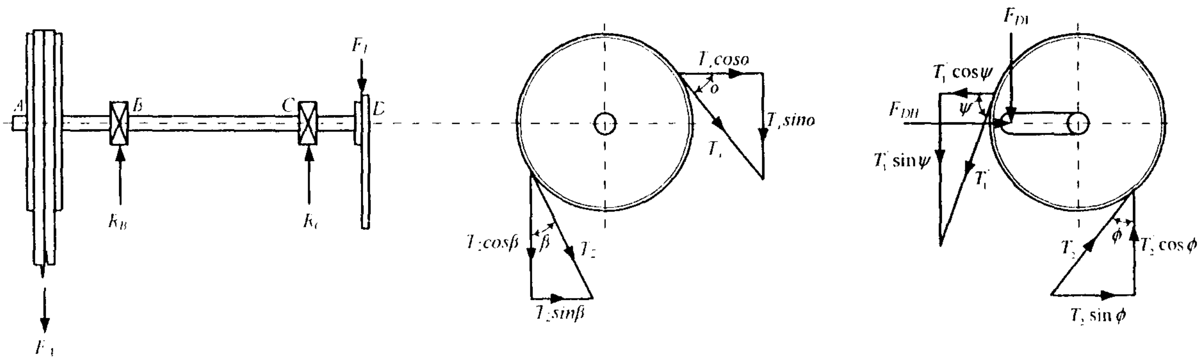


**Figure 3.6 Components on Shaft 1(Slicer Shaft)**

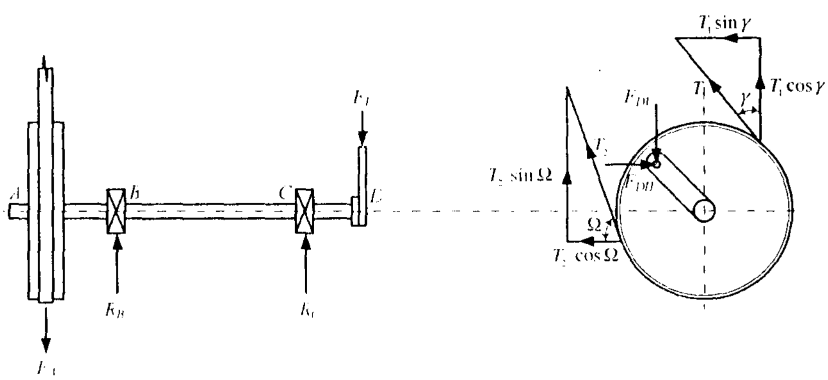


**Figure 3.7 Components on Shaft 2 (Chipper Shaft)**

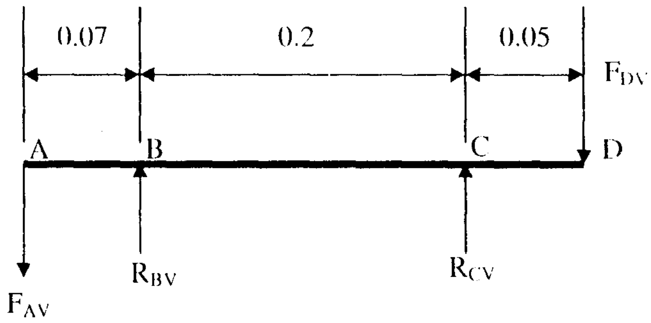



**Figure 3.8 (a) Vertical forces/reactions**

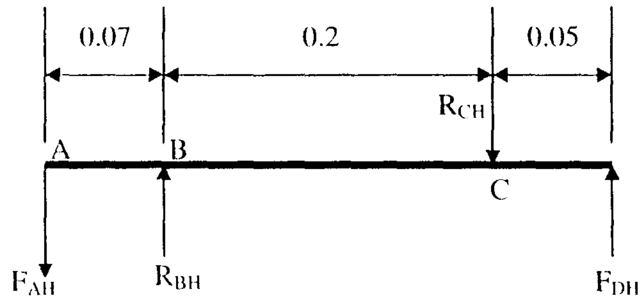



**Figure 3.8 (b) Horizontal Forces/Reaction**

Let the pin connecting link 2 and 3 be denoted as $P_{23}$, and the pin connecting link 3 and 4 be denoted as $P_{34}$.

#### 3.6.8.1 Determination of Diameter of Shaft 1 And 2

With the notations as shown in figures 3.6 and 3.7, both shafts are represented with the vertical and horizontal force diagrams in figure 3.8. The reason is because both loadings are identical except for their belt drives. From figure 3.8 (a),

Summation of moments about point C = 0; i.e $\sum Mc = 0$

$$0.27\ F_{AV} - 0.2\ R_{BV} - 0.05F_{DV} = 0$$

$$0.2\ R_{BV} = 0.27F_{AV} - 0.05F_{DV}$$

$$R_{BV} = (0.27F_{AV} - 0.05F_{DV}) / 0.2 \qquad 3.76$$

Summation of downward and upward forces = 0; i.e $\sum F\downarrow$ and $\sum F\uparrow = 0$

$$R_{CV} + R_{BV} - F_{AV} - F_{DV} = 0$$

$$R_{CV} = F_{AV} + F_{DV} - R_{BV} \qquad 3.77$$

From figure 3.8 (b), Summation of moments about point C = 0

$$0.27F_{AH} - 0.2R_{BH} + 0.05F_{DH} = 0$$

$$0.2R_{BH} = 0.27F_{AH} + 0.05F_{DH}$$

$$R_{BH} = (0.27F_{AH} + 0.05F_{DH}) / 0.2 \qquad 3.78$$

Summation of downward and upward forces = 0

$$F_{AH} - R_{BH} + R_{CH} - F_{DH} = 0$$

$$R_{CH} = R_{BH} + F_{DH} - F_{AH} \quad 3.79$$

Vertical Bending Moments

$$BM_{AV} = BM_{DV} = 0 \quad 3.80$$

$$BM_{BV} = 0.07F_{AV} \quad 3.81$$

$$BM_{CV} = 0.27F_{AV} - 0.2R_{BV} \quad 3.82$$

Horizontal Bending Moments:

$$BM_{AH} = BM_{DH} = 0 \quad 3.83$$

$$BM_{BH} = 0.07F_{AH} \quad 3.84$$

$$BM_{CH} = 0.27F_{AH} - 0.2R_{BH} \quad 3.85$$

Resultant Bending Moments:

$$BM_{AR} = BM_{DR} = 0 \quad 3.86$$

$$BM_{BR} = \sqrt{(BM_{BV})^2 + (BM_{BH})^2} \quad 3.87$$

$$BM_{CR} = \sqrt{(BM_{CV})^2 + (BM_{CH})^2} \quad 3.88$$

Noting that the shaft is subjected to combined torsional and bending moments, based on maximum shear stress theory, the size of the shaft is given (Khurmi and Gupta, 2005) as:

$$d_1 = \left[\frac{16\sqrt{(Mk_m)^2 + (Tk_t)^2}}{\pi\sigma_{max}}\right]^{1/3} \quad 3.89$$

Where $d_1$ = diameter of shaft, mm

$M$ = Maximum bending moment on shaft, Nmm

$\sigma_{(max)}$ = Maximum allowable shear stress , MN/mm$^2$ (KPa)

$T$ = torsional moment on shaft, Nm

$K_m$ = combined shock and fatigue factor for bending

$K_t$ = combined shock and fatigue factor for torsion.

For Shaft 1, from equations 3.76 to 3.96 and considering figures 3.6, 3.7 and 3.8;

$F_{DV} = F_{32y}$ at 240° = – 482.3612 N

$F_{DH} = F_{32x}$ at 240° = 1504.651 N

$W_p = 20.6984$ N

$\beta = 25.2°$

$\alpha = 42.4°$

$\phi = 26.5°$

$\Psi = 76°$

$$F_{AV} = W_p + T_2'' \cos\beta + T_1'' \sin\alpha + T_1' \sin\psi + T_2' \sin\phi$$

$$= 20.6984 + 7.9718 \cos 25.2° + 83.3802 \sin 42.4° + 1324.5281 \sin 76°$$

$$+ 81.4271 \sin 26.5$$

$$= 1442.1908 \text{ N} \approx 1442.19 \text{ N}$$

$$F_{AH} = T_2'' \sin\beta - T_1'' \cos\alpha + T_1' \cos\psi + T_2' \sin\phi$$

$$= -7.9718 \sin 25.2 - 83.3802 \cos 42.4 + 1324.5281 \cos 76 + 81.4271 \sin 26.5°$$

$$= 291.7981 \text{ N} \approx 291.80 \text{ N}$$

$$R_{BV} = \frac{0.27 \times F_{AV} - 0.05 F_{DV}}{0.2}$$

$$= \frac{0.27 \times 1442.1908 - 0.05(-482.3612)}{0.2}$$

$$= 2067.5479 \text{ N} \approx 2067.55 \text{ N}$$

$$R_{CV} = F_{AV} + F_{DV} - R_{BV} = 1442.1908 - 482.3612 - 2067.5479$$

$$= -1107.7183 \text{ N} \approx -1107.72 \text{ N}$$

$$R_{BH} = \frac{0.2 / F_{AH} + 0.05 F_{DH}}{0.2} = \frac{0.27 \times 291.7981 + 0.05 \times 1504.651}{0.2}$$

$$= 770.0902 \text{ N} \approx 770.09 \text{ N}$$

$$R_{CH} = F_{BH} + F_{DH} - F_{AH} = 770.0902 + 1504.651 - 291.7981$$

$$= 1982.9431 \text{ N} \approx 1982.94 \text{ N}$$

**Vertical Bending Moment:**

$$BM_{AV} = BM_{DV} = 0$$

$BM_{BV} = 0.07F_{AV} = 0.07 \times 1442.1908 = 100.9534 \text{ Nm} \approx 100.95 \text{ N}$

$BM_{BV} = 0.07F_{AV} = 0.07 \times 1442.1908$

$BM_{CV} = 0.27\ F_{AV} - 0.2\ R_{BV} = 0.27 \times 1442.1908 - 0.2 \times 2067.5479 = -24.1181 \text{ Nm}$

**Horizontal Bending Moment:**

$BM_{AH} = BM_{DH} = 0$

$BM_{BH} = 0.07\ F_{AH} = 0.07 \times 291.7981 = 20.4259 \text{ Nm}$

$BM_{CH} = 0.27\ F_{AH} - 0.2\ R_{BH} = 0.27 \times 291.7981 - 0.2 \times 770.0902 = -75.2326 \text{ Nm}$

**Resultant Bending Moment:**

$BM_{AR} = BM_{DR} = 0$

$$BM_{BR} = \sqrt{(BM_{BV})^2 + (BM_{BH})^2} = \sqrt{(100.9534)^2 + (20.4259)^2}$$

$$= 102.999 \text{ Nm} \approx 103.00 \text{ Nm}$$

$$BM_{CR} = \sqrt{(BM_{CV})^2 + (BM_{CH})^2} = \sqrt{(-24.1181)^2 + (-75.2326)^2}$$

$$= 79.0039 \text{ Nm} \approx 79.00 \text{ Nm}$$

Substituting M for $BM_{BR}$ and T for $T_{240}$, (See Graph 2, Torque @ $\theta = 240°$)

$BM_{BR} = M = 102.999$ Nm and $T_{240} = T = -108.0973$

For $K_m = 1.2$, $K_t = 1.2$ and $\sigma_{max} = 48 \times 10^6 \text{ Nm}^{-2}$

$$\text{From } d_1 = \left[\frac{16\sqrt{(MK_m)^2 + (Tk_t)^2}}{\pi\,\sigma_{max}}\right]^{\frac{1}{3}}$$

$$= \left[\frac{16\sqrt{(102.999 \times 1.2)^2 + (1.2 \times (-108.0973))^2}}{\pi \times 48 \times 10^6}\right]^{\frac{1}{3}} = 0.0261 \text{ m} = 30 \text{ mm}$$

Similarly, for shaft 2, considering equations 3.74 to 3.84, and figure 3.6, 3.7 and 3.8 and with

$F_{DV} = F_{32y}$ at $180° = 0.3054$ N

$F_{DH} = F_{32x}$ at $180° = 308.0962$ N

$W_P = 278.7026$

$\Omega = 64.8°$

$\lambda = 47.6°$

$F_{AV} = W_P - T''_{2} \sin \Omega - T'_1 \cos \lambda$

$= 278.7026 - 7.9718 \sin 64.8 - 1324.5281 \cos 47.6° = 215.266$ N

$F_{AH} = T''_2 \cos \Omega + T' \sin \lambda$

$= 7.9718 \cos 64.8 + 1324.5281 \sin 47.6 = 64.9668 \text{ N} \approx 64.97$ N

$$R_{BV} = \frac{0.27 F_{AV} - 0.05 F_{DV}}{0.2} = \frac{0.27 \times 215.266 - 0.05(0.3054)}{0.2}$$

$= 290.6854 \text{ N} \approx 290.69$ N

$R_{CV} = F_{AV} + F_{DV} - R_{BV}$

$= 215.266 + 0.3054 - 290.6854 = -75.7248 \approx 75.72$ N

$$R_{BH} = \frac{0.27 F_{AH} + 0.05 F_{DH}}{0.2} = \frac{0.27 \times 64.9668 + 0.05 \times 308.0962}{0.2}$$

$= 164.7292 \text{ N} \approx 164.73$ N

$R_{CH} = R_{BH} + F_{DH} - F_{AH}$

$= 164.7292 + 308.0962 - 64.9668 = 407.8586 \text{ N} \approx 407.86$ N

**Vertical Bending Moment:**

$BM_{AV} = BM_{DV} = 0$

$BM_{BV} = 0.07F_{AV} = 0.07 \times 215.266$

$= 15.0686 \text{ Nm} \approx 15.07$ Nm

$BM_{CV} = 0.27F_{AV} - 0.2R_{BV} = 0.27 \times 215.266 - 0.2 \times 290.6854$

$= -0.0153 \text{ Nm} \approx -0.02$ Nm

**Horizontal Bending Moment:**

$BM_{AH} = BM_{DH} = 0$

$BM_{BH} = 0.07 F_{AH} = 0.07 \times 64.9668$

$= 4.5477 \text{ Nm} \approx 4.55$ Nm

$BM_{CH} = 0.27\ F_{AH} - 0.2\ R_{BH}$

$= 0.27 \times 64.9668 - 0.2 \times 164.7292 = -15.4048\ \text{Nm} \approx -15.40\ \text{Nm}$

**Resultant Bending Moment:**

$BM_{AR} = BM_{DR} = 0$

$$BM_{BR} = \sqrt{(BM_{BV})^2 + (BM_{BH})^2}$$

$$= \sqrt{15.0686^2 + 4.5477^2}$$

$$= 15.7399\ \text{Nm}$$

$$BM_{CR} = \sqrt{(BM_{CV})^2 + (BM_{CH})^2}$$

$$= \sqrt{(-0.0153)^2 + (-15.4048)^2}$$

$$= 15.4048\ \text{Nm} \approx 15.40\ \text{Nm}$$

When $M = BM_{BR} = 15.7399$ Nm and $T = T_{120} = 16.2128$, Km = 2, Kt = 2 and $\sigma_{max} = 48 \times 10^6\ \text{Nm}^{-2}$

$$d_2 = \left[\frac{16\sqrt{(MK_m)^2 + (TK_t)^2}}{\pi\ \sigma_{max}}\right]^{\frac{1}{3}}$$

$$= \left[\frac{16\sqrt{(15.7399 \times 2)^2 + (16.2128 \times 2)^2}}{\pi \times 48 \times 10^6}\right]^{\frac{1}{3}}$$

$$= 0.0169\ \text{m} = 16.9\ \text{mm}$$

### 3.6.8.2 Determination of Sizes of $P_{23}$ and $P_{34}$

Allowable stress $\sigma = \dfrac{F}{A}$

Therefore $A = \dfrac{F}{\sigma}$ 3.90

Where: F = force acting on pin, N

A = cross sectional area of pin, $\text{mm}^2$

$A = \pi \dfrac{d^2}{4}$ 3.91

Where d = diameter of pin

Putting equation 3.91 into equation 3.90 gives:

$$\pi \frac{d^2}{4} = \frac{F}{\sigma}$$

$$\therefore d = \sqrt{\left(\frac{4F}{\pi \sigma}\right)} \quad 3.92$$

Note: $F_{32} = \sqrt{F^2{}_{32x} + F^2{}_{32y}}$ 3.93

$$F_{43} = \sqrt{F^2{}_{43x} + F^2{}_{43y}} \quad 3.94$$

Therefore, for pin $P_{23}$;

$$d_{23} = \sqrt{\frac{4F_{32}}{\pi \sigma}} \quad 3.95$$

For pin $P_{34}$,

$$d_{34} = \sqrt{\frac{4F_{43}}{\pi \sigma}} \quad 3.96$$

Calculation for pin sizes for shaft 1

$$F_{32} = \sqrt{F^2{}_{32x} + F^2{}_{32y}} = \sqrt{(1504.651)^2 + (-482.3612)^2} = 1580.0781\text{N}$$

$$F_{43} = \sqrt{F^2{}_{43x} + F^2{}_{43y}} = \sqrt{1501.3375^2 + (-467.0283)^2} = 1572.3007\text{ N}$$

$$d_{23} = \sqrt{\frac{4F_{32}}{\pi \sigma_{max}}} = \sqrt{\frac{4 \times 1580.0781}{\pi \times 48 \times 10^6}}$$ : ($d_{23}$ is diameter of pin connecting link 2 to link 3.)

= 0.0065 m = 10mm

$$d_{43} = \sqrt{\frac{4F_{43}}{\pi \sigma_{max}}} = \sqrt{\frac{4 \times 1572.3007}{\pi \times 48 \times 10^6}}$$ ; ($d_{43}$ is diameter of pin connecting link 4 to link 3.)

= 0.0065 m = 10 mm

Calculation for pin sizes for shaft 2

$$F_{32} = \sqrt{F^2{}_{32x} + F^2{}_{32y}} = \sqrt{(-308.0962)^2 + (-0.3054)^2} = 308.0963\text{ N}$$

$$F_{43} = \sqrt{F^2{}_{43x} + F^2{}_{43y}} = \sqrt{(-307.0489)^2 + (0.7418)^2} = 307.0498\text{ N}$$

$$d_{23} = \sqrt{\frac{4F_{32}}{\pi \sigma_{max}}} = \sqrt{\frac{4 \times 308.0963}{\pi \times 48 \times 10^6}} = 0.0029\,m = 2.9\text{ mm}$$

$$d_{43} = \sqrt{\frac{4F_{43}}{\pi\,\sigma_{max}}} = \sqrt{\frac{4\times 307.0498}{\pi\times 48\times 10^6}} = 0.0029\,m = 2.9 \text{ mm}$$

### 3.6.9 Determination of Power

The power required to drive any of the input links (link 2 on either shafts) is given by the relation:

$$P = T\omega \qquad 3.97$$

Where P = Power

T = Torque

ω = angular velocity

Therefore,

$$\text{Peak Power, } P_p = T_p\omega \qquad 3.98$$

And,

$$\text{mean Power, } P_m = T_m\omega \qquad 3.99$$

$$\text{Total Peak Power, } P_{Pl} = P_{P1} + p_{P2} \qquad 3.100$$

$$\text{Total mean Power, } P_{tM} = P_{P1} + p_{P2} \qquad 3.101$$

For shaft 1, from equations 3.97 to 3.101, with

$T_p$ = 108.0973 Nm, $T_m$ = 3.6748 N, $\omega$ = 37.6991 rads$^{-1}$ ≈ 37.70 rads$^{-1}$

∴ $P_{p1}$ = 108.0973 × 37.6991 = 4075.1722 W

$Pm_1$ = 3.6748 × 37.6991 = 138.5385 W

For shaft 2: $T_p$ = 16.2128 Nm, $T_m$ = 0.7416 Nm, $\omega$ = 16.7552 rads$^{-1}$ ≈ 16.76 rads$^{-1}$

∴ $P_{p2}$ = 16.2128 × 16.7552 = 271.6481 W ≈ 271.65 W

$P_{m2}$ = 0.7416 × 16.7552 = 12.4252 W ≈ 12.43 W

Total Peak Power, $P_{tP}$ = $P_{p1}$ + $P_{p2}$

$= 4075.1722\ W + 271.6481\ W$

$= 4346.8203\ W \approx 4346.82\ W$ or 5.8 Hp

Total mean power, $P_{TM} = P_{m1} + P_{m2}$

$= 138.5385\ W + 12.4252\ W$

$= 150.9637\ W = 0.2024$ Hp or $< 1$ Hp

## 3.7 DESCRIPTION OF THE COMPONENTS OF THE MACHINE

### 3.7.1 Construction

The construction of this machine started with the wooden model (Figure 3.9 and 3.10) in order to have a pictorial model of the machine to be constructed. The operation of the wooden model was demonstrated manually and the design was considered workable. Hence, the actual machine construction was commenced.

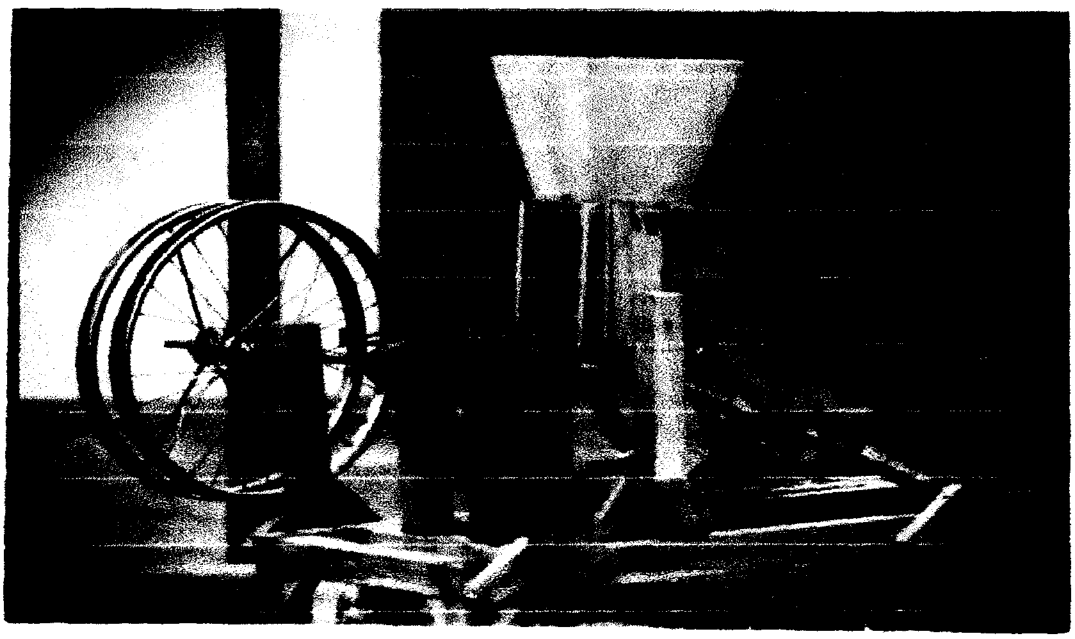


**Fig. 3.9 Picture showing the wooden model of the machine (initial design), side view**

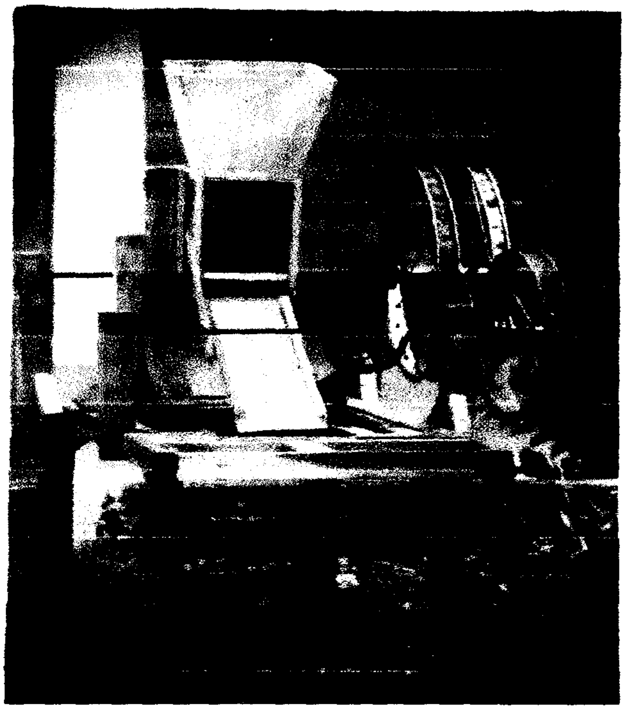


**Fig. 3.10 Picture showing the wooden model of the machine (initial construction), frontal view**

### 4.1.1 The Main Frame

The main frame (figures 4.3, 4.4 and no. 17 of figure 4.8) was the first component constructed. It was constructed using a 5mm gauge angle bar of mild steel capable of withstanding the weights of other components and about 200Kg weight of cassava tubers in the carriage bin/drain. The main frame serves as a platform on which other components are anchored. The main frame has a height of about 574mm from the ground a length of 1010 mm and a width of 512 mm (see part list No.12 on the design drawing in the appendix and no. 17 of figure 4.8). It has four legs on which the machine stands and made up of the same material for strength purposes. The legs are braced posteriorly and anteriorly with an angle iron bar of 3mm gauge at a height 150.5mm from the ground and length wise, midway the width at a distance of 212 mm from each of the side legs. The top of the main frame table is cylindrically shaped, not by cutting and joining the angle iron, but by "chamfering" and

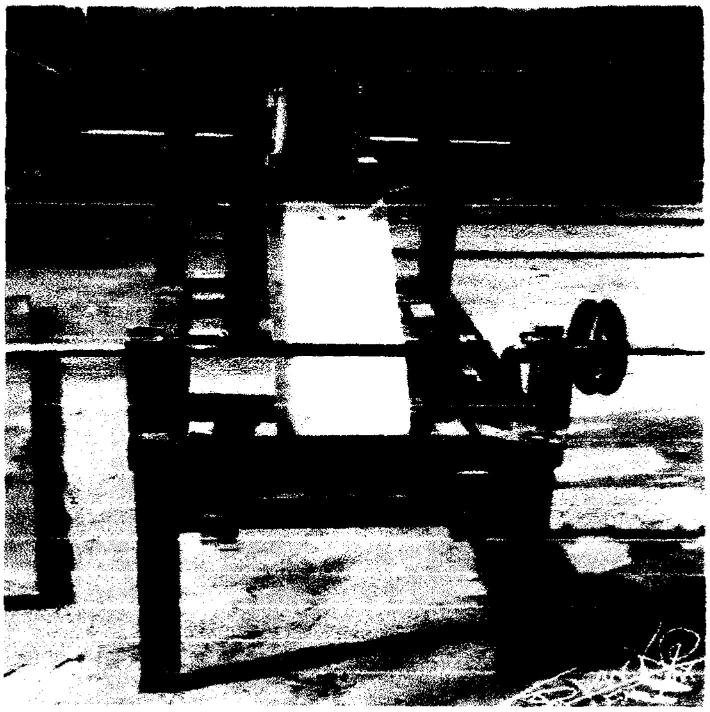


Fig 3.11 **Picture showing the frontal view of the machine (initial construction) at early stage – showing some components**

Fig. 3.12 **Picture showing the frontal view of the machine (initial construction) showing the mainframe, stamping spring, and slicer stand**

bending in order to achieve maximal strength. The result is a continuous run of the angle iron without much joining here and there. As part of the main frame is a 731.5 mm long angle iron bar of 5mm gauge welded at the table top and braced with same material for strength. This bar carries the hopper (figure 3.11), the drain/container carriage, and the drain container (bin) itself. It is referred to as the hopper and carriage bin support.

### 3.7.3 The Slicer and its Drive Mechanism

The next component constructed was the slicer and its drive mechanism. The slicer is a stainless steel 270mm×165mm×3mm plate sharpened at one end (the posterior or the slicing end), thereby turning it into a very wide sharp knife (part list No. 4 of Design Drawing in the appendix, and part no. 3 of figure 3.16). The slicer is positioned in place by two slicer guides (one at each edge) along the length of the slicer. Each slicer guide(no. 4 of figure 3.16) is constructed using three rectangular mild steel bars (200×8×4mm) welded side by side each other to form two groves inside which the knife is positioned. Each slicer guide is welded to a support (see part list No. 6 on the Design Drawing in the appendix) slicer guide support, which in turn is welded to a cross angle bar on the main frame. The slicer guide supports are two angle iron bars of mild steel, 390.5×50×3mm.

To drive the slicer forward for the slicing action on the tubers and backward for the return action, a cam and follower mechanism was initially designed and constructed. Figures3.9, 3.12 and 3.13 show the cam lobe initially constructed. Problems of noise, profile of the cam lobe, return spring mechanism and complexities of the design analysis necessitated a change to the crank shaft and connecting rod mechanism with which the machine now operates. The crank 1 (crank on shaft 1. See no. 6 of figure 3.16) is constructed using a 120×40×6mm steel bar welded to a hardened circular steel shaft (shaft 1) of length 374 mm and diameter 20 mm (see design drawing part list No. 1). This steel shaft passes through two steel bearings housed each by a bearing housing (1). The bearing housing (1) is constructed by folding a piece of a circular steel pipe to the desired diameter and then welded. The bearing housing is positioned by a bearing housing support 1, which is an angle iron of 433.5×50×3.5mm. Top end of this support is welded to the bearing housing and the lower end is welded to the main frame (see part list 3 of the design drawing in the appendix).

**Fig 3.13 Picture showing the hind view of the machine at early stage (initial construction) showing some components**

The other end of the crank has a hole drilled 10 mm diameter, and using size 14 bolt and nut, this end is connected to another rod – the connecting rod (1) 230×30×6mm (see part list No. 16 of the design drawing in the appendix and no. 5 of fig. 3.16). The connecting rod is fastened to the slicer using three bolts and nuts arrangement.

A double grove pulley with 200 mm diameter of mass 5.2 kg is fastened to the shaft using a bolt and nut arrangement. A fly wheel of mass 8.8kg is also attached. The double grooved pulley is driven using a B108 gauge belt. The oscillating motion of the pulley is transmitted through the shaft to the crank and from the crank to the connecting rod causing the connecting rod to slide forward and backward rhythmically. This rhythmic sliding forward and backward motion of the connecting rod is transmitted to the slicer which is connected to the connecting rod. The slicer in this case acts as the piston of the engine whose forward and backward reciprocating motion exerts a cutting force on any cassava tuber placed in the hopper to which it comes into contact.

**Fig. 3.14 Picture showing the side view of the completed machine with top and side covers removed**

### 3.7.4 The Hopper

The hopper was constructed in two detachable segments- the upper (no. 2a of figure 3.16) and the lower (no. 2b of figure 3.16) segments using aluminium materials for the upper segment and stainless steel material for the lower segment respectively. The lower segment is a stainless steel material of thickness 3 mm folded into a square of length 120 mm, breath 120 mm, and height 200 mm. The square shape was constructed by first marking out the dimensions, chiseling along the marked lines, bending, hammering and folding the material until the square was formed. The last edge was then welded. At 15 mm from the bottom end of the hopper, a 10 mm wide opening is made cutting through two sides of the steel hopper. This opening is where the slicing knife enters the hopper in order to reach any cassava tuber placed in the hopper. The width of this stainless steel hopper was determined by the length of the crank which in turn affects the extent of reach of the slicer knife, through the connecting rod. Figure 3.11 shows the stainless steel segment of the hopper mounted on the hopper and carriage bin support bar.

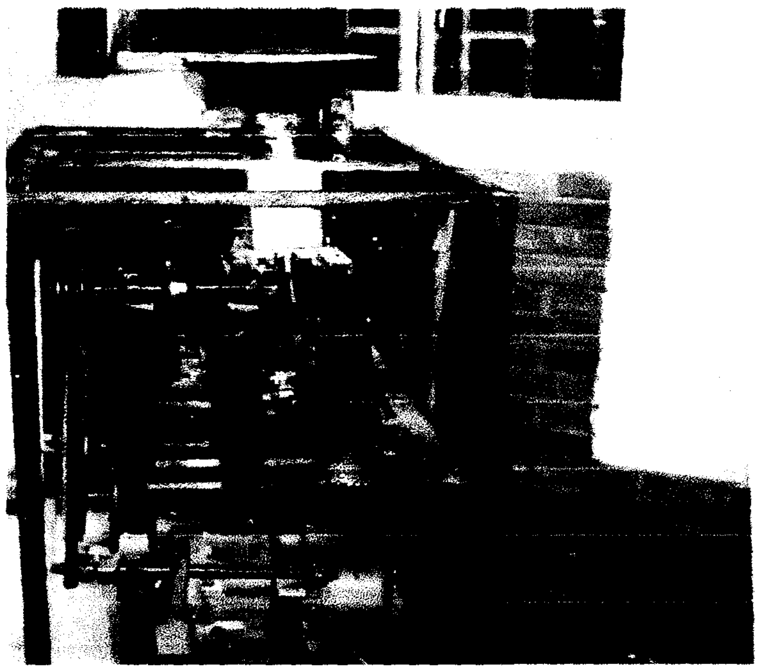


**Fig. 3.15 Picture showing the hind view of the completed machine with top and two side covers removed**

The steel hopper has four hooks, two on the upper side and two on the lower side by which the hopper is anchored to the steel angle bar carrying the hopper and carriage Bin support. The four hooks are on the back side of the hopper. The hopper has incorporated into it, two stainless steel plates cut midway in finger-like or folk forms 82 mm long and 5 mm wide designed to help keep any tuber in a vertical position. This is adjustable and has a 5 mm slit/opening on the walls of the hopper to enable these adjustments.

To minimize cost, the entire hopper could not be constructed using stainless steel. Hence, the upper segment of the hopper is constructed using aluminum sheet. The aluminum hopper segment (hopper 2a of fig. 3.16) is 115 mm square on the base region and a funnel mouth (top region) of 280 mm square. The base region has a height of about 190 mm while the funnels region has a height of about 110 mm. The aluminum hopper is constructed by folding and riveting principles using aluminum pins as aluminum could not be welded. This hopper is usually pushed 60 mm into the stainless steel hopper at its lower end for support and anchorage as it does not have a separate hook. Figures 3.14, 3.15 and 3.16 show both the upper segment aluminium and the lower segment stainless steel in their joined positions.

### 3.7.5 Cassava Tuber Stand

This is a platform on which every cassava tuber stands, while in the hopper undergoing the slicing action of the slicing knife. The stainless hopper hides it from view. It is designed separately from the hopper and consists of a stainless steel plate of 100mm×170mm to which is welded a hanger at midway of the width of one of the edges. The hanger consists of a 130 mm×30mm mild steel plate with a 17 gauge bolt welded to it at the base of the bolt. With a 50 mm × 20 mm opening in the Hopper support angle bar, the bolt from the hanger passes through and is anchored by a washer and nut arrangement on the other side of the Hopper support angle bar. The 50mm × 20mm opening on the angle bar serves as an adjustment system for the hanger where the cassava tuber stands. The sliding upward or sliding downward of this hanger corresponds to a reduction or an increment in the thickness of the slices of the cassava tubers made by the slicer knife. The bolt serves as the handle at which the hanger is held.

### 3.7.6 The Chipping Mechanism

From the posterior end of the machine toward the centre, and at a distance of 400mm from the posterior end, is mild steel rectangular bar 404 mm × 40 mm × 10 mm called the puncher carriage. This rectangular steel bar has welded to it at both ends, an angle iron bar 150 mm × 46 mm to balance it and enable it to slide on the two side rails of the main frame without shifting position. At the centre of the puncher carriage is an L shaped steel bar (50 mm each arm) welded to the centre of the rectangular bar and its other end has a 15 mm diameter hole drilled to it. To this hole is connected a 14 gauge bolt and nut which joins this puncher carriage to the connecting rod of the puncher drive system's mechanism connecting rod 2 (Chipper connecting).

Each further cutter or puncher (No. 14 on the part list of the design drawing in the appendix) is an arrangement of two short stainless steel knives 140 mm long arranged to crisscross each other vertically and horizontally in the shape of a cross. The two knives are welded to a stainless steel plate as a base. The other side of this stainless steel plate knife base is welded a mild steel ring 18.5 mm in height and 36 mm in diameter. (There are two cutters/chipper arranged in a row side by side each other). Into this mild steel ring is pushed the top of the puncher spring 36 mm diameters and fastened with a bolt and nut. The puncher spring consists of a top, 36 mm diameter, a 97 mm long stainless circular shaft surrounded by a stainless steel spring of same length and a cylindrical mild steel base of 100 mm length, and 55 mm diameter at both ends of this base. The cylindrical base is welded to a square bar of thickness 10 mm and length and width 76 mm. The entire puncher spring assemblage was purchased whole from the "scraps" market, and adapted.

The puncher spring assemblage was modified by welding a 20 mm diameter circular steel rod around the base forming a 135 mm ring to which is welded two 21 gauge bolts. These bolts are made to pass through holes drilled on the puncher carriage. Using two 21 gauge nuts and washers, each puncher spring is fastened to the puncher carriage by means of these bolts and nuts. The advantage of these bolts and nuts to welding is that the entire arrangement can be dismantled and reaffixed when necessary.

The puncher carriage, along with the puncher spring assemblage, and the cutter/chipper components is moved forward and backward by connecting it through the connecting rod 2 to crank shaft 2 mechanism. The connecting rod 2 consists of a rectangular steel rod 217 mm × 40 mm × 6 mm with a 20 mm diameter a hole drilled at each end of the bar 180 mm apart. The two ends of both connecting rod 1(Slicer connecting rod) and connecting rod 2 (Chipper connecting rod) are smoothened to remove sharpness. The other drilled hole on the connecting rod is the point of attachment between the crank (crank 2) and the connecting rod. The crank (crank 2 or Chipper crank) is a 100mm × 40mm × 6mm steel plate welded at the centre of one of the ends to a steel circular shaft 350 mm of diameter 25 mm. This is the crank shaft (no. 12 of fig. 3.16) that drives the puncher mechanism. The other end of the shaft passes through two ball bearings of outer diameter 53 mm and bore size 24 mm enclosed in two bearing housings and supports 2. The bearing housing and support (2) is made up of H shaped mild steel 100 mm× 91.5 mm × 5.1 mm, the centre of which has a whole bored through it. In this hole is fixed a circular ring constructed by cutting a piece of a circular pipe and folding same to the diameter 53 mm, and welded to the H shaped steel. The outer end of the steel shaft after it has passed through the steel bearings has fastened to it a big steel pulley (Pulley 2.See no. 11 of fig. 3.16) with diameter 435 mm and 10 mm thickness.

This pulley which serves as both a pulley and a flywheel consists of two circular steel plates constructed by welding them together with a 12 mm wide and 17 mm deep single grove along which a B 108 gauge industrial belt runs while driving the mechanism. At the centre of this pulley is construct a hole through which a short 50 mm and 20 diameters circular steel pipe is passed. The length of the steel pipe is 57 mm. This steel pipe is made to protrude 25mm on the other side of the pulley thereby providing a space for a 10mm diameter hole to be drilled though the pipe on which a 24 gauge bolt and nut arrangement is fixed. This bolt and nut is for locking the pulley to the shaft. This locks the pulley to the shaft and ensures that the pulley does not shift position when in motion.

The rotating movement of this pulley 2 (no. 11 of fig.3.16) is transmitted through the shaft 2 to the crank 2 and then is passed to the connecting rod 2. At the connecting rod, this motion becomes oscillatory, moving linearly backward and forward, dragging and pushing respectively, the puncher carriage and all connected mechanisms along with it. The forward/pushing motion of the puncher carriage transmits a force which passes through the puncher spring to the cutter/puncher. This force stamps the puncher knives blades against the puncher back-plate, thereby chipping any cassava slice that may have been positioned on its path of motion. The return stroke of the connecting rod also drags the puncher knives out of the puncher back plate, thereby crating space for new cassava slice to be positioned for chipping.

### 3.7.7 The Puncher Back Plate

The puncher back plate has been mentioned briefly in the last paragraph above. It consist of a stainless steel board 330 mm×194 mm×2 mm to which is welded on the reverse side an array of three mild steel rectangular bars for support so that the board can withstand the punching impacts of the puncher/cutter knives. The extension of the mild steel rods beyond the lengths of the stainless steel board provided points on which four 15 mm diameter holes are drilled. Through these four holes are passed four bolts and nuts (gauge 30) which fastens the puncher back plate board to the posterior legs of the main frame. This board has a detachable stainless panel for sustaining the slices in position. Openings are made on this panel through which the knives pass through the panel, in order to reach the board.

### 3.7.8 Cassava Chute

This is a stainless steel plate 750 mm×180 mm× 3 mm with the two edges folded inward at an angel of about 45°, thereby turning it into a tray. The top end of this tray has one part of this folded edge cut off 130 mm to enable the tray be hanged on a steel rod welded to Hopper support angle bar. The hanging of the tray is facilitated by constructing two 20 mm diameter mild steel pipes 120 mm long and welding some 30 mm apart near each other. The folded edges are filed and trimmed at their lower end. The angle of tilt (45°). of this tray (no. 15 of fig. 3.16) was determined by repeated trials until when the slices slide down smoothly. This is because the angle of repose of fresh cassava on stainless steel was not found.

### 3.7.9 The Carriage Bin/Drain

The carriage Bin/drain (no.1 of fig. 3.16) is the bin where freshly peeled and washed fresh cassava tubers to be chipped by the machine are loaded into. Not only that some of the waters are drained off into the bin, it also affords the operator an easy reach, from where he picks the tubers to be placed into the hopper for the chipping operation. Initially, this bin consisted of a plastic rubber Jeri-can 347×325.5×400 mm with the top end removed, and a 347×100 mm opening/slit made on one of the sides 40mm from the bottom end. But this bin has now been replaced with galvanized steel material after the preliminary testing and demonstrations. Two side handles have also been welded to it for lifting purposes.

### 3.7.10 The Electric Motor

From the design of the machine a 0.2 HP (150.96W) electric motor (no. 10 of fig. 3.16) could drive the machine (see section 3.6.9). But a 1HP (746W) motor was installed. The sitting of the motor and its drive pulley was initially located outside the main frame at a height 150 mm away from the anterior legs of the mainframe. A separate belt was to drive the motor's pulley and the crank-shaft of the slicer drive mechanism using one of the groves on the double grove pulley. That was the reason for the double grove pulley on shaft 1 (Slicer

Shaft). After the preliminary tests (see section 3.9.1), the location of the motor and its pulley was changed to be within the main frame and under the table to enhance the machines portability. With this new location, a single belt B 108 was adequate to drive both the motors pulley, the double grove pulley of shaft 1, and the single grove pulley of shaft 2. To enable a B108 belt drive the three pulleys simultaneously, the grooving on the pulley accompanying the 2 Hp (1.49 KW) electric-motor had to be expanded and deepened. This was achieved by machining using a lathe machine.

Connected to the electric motor is a 5yd (4.57 m) electric cable, gauge 2.5 mm, with a 15 mm ampere electric plug fixed at its end for connection to the electric mains. A platform was constructed for anchoring the electric motor to the machine using mild steel angle bars welded to the bracing on the legs of the main frame. Holes were bored on these steel bars where bolts are passed to grip both the motor and the steel platform. Tightening these bolts with appropriate nuts ensures the anchor of the motor to the frame. Some of the holes were made long, creating a path for forward or backward adjustment of the motor position before screwing up to tighten the bolt, washer, and nut arrangements. With this arrangement, tensing or slacking of the belts can be carried out.

### 3.8 Mode of Operation of the Machine

Figure 3.16 shows the isometric drawing of the designed and constructed cassava chipper. It operates in such a way that the operator detaches the carriage bin (No.1 in fig 3.16) and brings it down; into which is loaded (batch loading) several freshly peeled and washed cassava tubers to be chipped. The carriage bin containing the tubers is lifted up with the aid of the bin's two handles and positioned unto the machines carriage bin support stand (Part list No.11 in Appendix C). The machine is put on by plugging the 15 AMP electric plug. to the mains and switching on the mains switch. Through the electric motor ( No 10 in fig

3.16). electric power is converted into rotary motion which drives the motors shaft and the pulley on the motor. The belt transmits this rotary motion of the motor's shaft to the double grove pulley (No. 9 in fig 3.16) which activates simultaneously the slicer shaft's (shaft 1. no.8 of fig.3.16) double grove pulley. The shaft 1 transmits the rotary motion to the crank (crank 1) and by the connecting rod (connecting rod 1, no.5 of fig. 3.16) arrangement. the motion becomes oscillatory-a linear backward and forward motion. Thus. the connecting rod (no.5 of fig. 3.16) pushes the slicer (no.3 of fig. 3.16) forward and backward continuously. thereby slicing any tuber it meets in the stainless steel hopper (no.2b of fig. 3.16).

The same belt links the double groove pulley to the big steel single groove pulley (no.11 of fig. 3.16) which drives the punching/chipping mechanism. following similar shaft. crank. connecting rod. puncher principle as explained earlier. Cassava slicing in the stainless hopper (no.2b of fig. 3.16) follows a pre-set thickness by moving the hanger of the cassava tuber stand either upward or downward and locking the chosen position using the bolt. washer. and nut arrangement. The slices from each tuber slide downward on the stainless steel tray/conveyor (no.15 of fig. 3.16) until it falls unto the puncher back plate (no.13 of fig.3.16) where it is met by knives from the puncher/cutter. These knives blades further cut the cassava slices and the resulting chips are collected through the chute that leads posteriorly outward into a plastic bowl. tray. or collector placed there for that purpose.

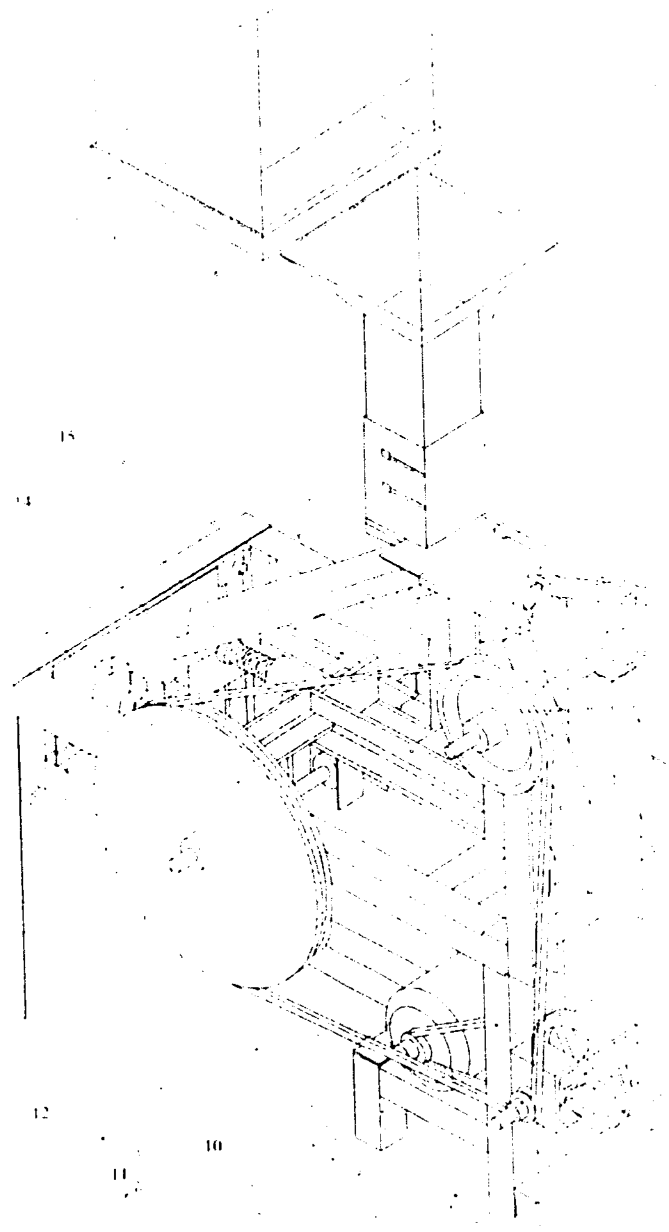


**Fig. 3.16 The Isometric drawing of the designed and constructed cassava chipper**

### 3.9 Machine Testings

#### 3.9.1 Preliminary Test and Modifications

Immediately after the construction of the machine, preliminary performance tests were carried out. With an operating speed of the motor as 1400 rpm, the force of the impact of the slicer on the tubers resulted in three things: (a) Violent throwing off of the cassava slices 300-600mm far away from the conveyor tray, (b) Violent tumbling of the slices along the stainless steel tray, (c) Punching impact of the knives/punchers on the puncher back plate/board was excessive, noisy, and too hard.

The above observations necessitated a modification in the construction to achieve a significant speed reduction of 3:1 ratio, using a locally fabricated steel pulley of 160 mm diameter and a D 86 gauge industrial belt. This reduced the speed of the electric motor to 467 rpm. Hence, speed of the slicer shaft was now 117 rpm and that of the chipper shaft was now 54 rpm.

Besides the carriage bin which was changed from plastic to galvanized steel (as already mentioned above), other modifications included the creation of two side vents for air exchanges on the side cover pans, the increase of the puncher/knife from two sets to four sets, and the reduction of the tray/conveyor length by 100 mm.

#### 3.9.2 Final Test

After carrying out the necessary modifications on the machine, final performance tests were carried out to know the throughput rate, the machine's chipping efficiency and the ergonomic convenience of the personnel operator. Freshly harvested Cassava tubers of the *Manihot Esculenta Crantz* variety bought at the Gwari market in Minna, Niger State numbering about 17 were peeled manually with a knife and their ends slashed off. The peeled tubers were washed in confectionery grade sulphur dioxide solution (ratio 1:200 Chemical to water) and then weighed. The seventeen tubers weighed 9kg. They were poured into the machines carriage-bin and the machine switched on via cables to the electric mains. From the carriage bin, the operator in a standing-sitting position feeds the hopper one tuber at a time. Immediately after chipping the chipps are washed again in same or similar sulphur dioxide solution. They are then taken from this solution to the dryer and drying commenced.

### 3.10 Maintenance Procedure

Maintenance procedures are activities that should be performed to keep the machine in good working condition and also prolong the machines durability. The following activities are suggested:

1. After each chipping operation, the hopper and the blades should be washed clean with water to remove cassava liquid stains and cassava particles that could initiate corrosion of metal parts.
2. Knife could be dismantled and sharpened when blunt and re-fixed back in place.
   a. Points of contact of moving parts that need lubrication should be regularly lubricated to eliminate friction, stiffness or tear.
   b. Bolts and nuts should be occasionally oiled to prevent corrosion.
3. The machine should not be left in the rain as the electric motor incorporated underneath may be damaged if the machine functions when the motor is wet.
4. The cover pans should be fixed in place when the machine is not in use to minimize dust and dirty particles.

# CHAPTER FOUR

# 4.0 RESULTS

## 4.1 Slicing and chipping Results

The slicing and chipping of cassava tubers with the fabricated machines gave the test results recorded in table 4.1.

**Table 4.1: Slicing and Chipping Results of the fabricated machine**

| S/No. | Qty Fed Into Machine | | | Operation Time (s) | | Qty Sliced (kg) | Qty Chipped (kg) | Qty Irregularly Sliced (kg) |
|---|---|---|---|---|---|---|---|---|
| | No of tubers | Weight (Kg) | | | Per no. of tubers | | | |
| | | | Per tuber | | | | | |
| 1. | 6 | 5.10 | 0.85 | 210 | 35 | 4.99 | 3.74 | 0.11 |
| 2. | 7 | 5.95 | 0.85 | 210 | 30 | 5.82 | 4.37 | 0.13 |
| 3. | 17 | 9.00 | 0.53 | 360 | 21.18 | 8.80 | 6.60 | 0.20 |
| Mean value | 10 | 6.68 | | 260 | 28.72 | 6.54 | 4.90 | 0.05 |

## 4.2 Performance Results

The machine's performance result is summarized as follow:

Total mean power: 150.96 W (0.02 HP)

Slicer shaft mean power: 138.54 W

Chipper shaft mean power: 12.43 W

Slicer shaft speed: 117 rpm

Chipper shaft speed: 54 rpm

Electric motor speed: 1400 rpm

## 4.3 Drying Result of the produced Cassava Chips

To test the effect of the decolouration treatment of the cassava tuber, two samples of the cassava chips were dried in the electric oven. Sample A were from the tubers that were peeled, washed in clean water, chipped by the machine, washed again in clean water after chipping, weighted and put in the oven for drying. Sample A was not washed in solution of confectionery grade sulphur dioxide. Cassava chips of sample B were peeled, washed immediately in solution of confectionery grade sulphur dioxide, chipped by the machine, washed again immediately after chipping in same or similar solution of confectionery grade sulphur dioxide, weighted and put in the oven for drying. Table 5.5 gives the summary of the drying results of the two cassava chips samples.

**Table 4.2: Summary of the results of drying of cassava chips samples**

| Drying stages | Items | Sample A (no chemical treatment)(kg) | Sample B (chemically treated) (kg) |
|---|---|---|---|
| 1 | Qty put into oven<br>Oven Temp. 70$^0$C<br>Duration in oven 5hrs<br>Turning intervals: After every 30 mins<br>Power outage/disconnection duration 13hrs | 4.8 | 1.65 |
| 2 | Ovens Temp. 100$^0$C<br>Duration 4hrs<br>Turning Interval: After every 1hour | | |
| 3 | Ovens Temp. 60$^0$C<br>Duration 6hrs<br>Turning Interval: After every 1hour<br>Power Outage Duration: Nil<br>Qty got after Drying<br>Moisture content removed from the chips(wet basis) | 1.25<br><br>74 % | 0.5<br><br>70 % |

## 4.4 Cost Analysis

The cost of this cassava chipping machine is classified into three:

1. Materials cost

2. Labour cost

3. Overhead cost

### 4.4.1 Material Cost Analysis

Table 4.1 below shows the material cost of the machine. Material cost is the cost of the materials used in the construction of the parts of this machine. Most of the materials were bought from the scrap's market -- "Panteka" here in Minna as bits and pieces of other unserviceable, dismantled and discarded machine parts and had to be converted into their present useful forms.

**Table 4.3: The Cost of The Material**

| S/No | Description of Item | Quantity | Unit Price (₦) | Amount (₦) |
|---|---|---|---|---|
| 1. | Angle iron (50 x 50 x 5)mm and length 2.5m | 5 | 1,200.00 | 6,000.00 |
| 2. | Angle iron (35 x 35 x 3)mm of length 2m | 5 | 320.00 | 1,600.00 |
| 3. | Angle iron (25 x 25 x 3)mm of length | 2 | 1,100.00 | 2,200.00 |
| 4. | Bearing (20mm) | 2 | 50.00 | 100.00 |
| 5. | Bearing (25mm) | 4 | 50.00 | 200.00 |
| 6. | Rod in spring with steel circular base | 2 | 150.00 | 300.00 |
| 7. | Stainless steel plates 130cm x 22cm x 2mm | 1 | 800.00 | 800.00 |
| 8. | Stainless steel plates 23cm x 16cm x 0.8mm | 1 | 400.00 | 400.00 |
| 9. | Stainless steel plates 16cm x 12cm x 0.5mm | 1 | 200.00 | 200.00 |
| 10. | Stainless steel pan 40cm x 20cm x 0.3mm | 2 | 60.00 | 120.00 |
| 11. | Steel shaft 20cm length and diameter 20mm | 2 | 50.00 | 100.00 |
| 12. | Steel shaft length 90cm and diameter 25mm | 1 | 100.00 | 100.00 |
| 13 | Steel circular plate diameter 45cm | 2 | 700.00 | 1,400.00 |
| 14 | Double grooved Pulley (diameter 22cm) | 1 | 600.00 | 600.00 |
| 15 | Steel pan (240cm x 120cm x 0.6mm) | 3 | 1,700.00 | 5,100.00 |
| 16 | Electric motor (2 HP) | 1 | 12,000.00 | 12,000.00 |
| 17 | Pulley (Diameter 6cm) | 2 | 1,000.00 | 2,000.00 |
| 18 | Pulley (Diameter 15cm) | 1 | 400.00 | 400.00 |
| 19 | Aluminum sheet (60 cm x 60cm) | 1 | 200.00 | 200.00 |
| 20 | Flywheel (Diameter 26cm x 3 cm) | 1 | 200.00 | 200.00 |
| 21 | Drive belt (B 40) | 1 | 300.00 | 300.00 |

| S/No | Description of Item | Quantity | Unit Price (₦) | Amount (₦) |
|---|---|---|---|---|
| 22 | Driven Belt (B 108) | 1 | 500.00 | 500.00 |
| 23 | C – Channel (80 x 35 x 4)mm | 4 | 30.00 | 120.00 |
| 24 | Circular steel pies: | | | |
| | 2cm Diameter and 15cm length | 1 | 100.00 | 100.00 |
| | 3cm diameter and 15cm length | 1 | 130.00 | 130.00 |
| | 4cm diameter and 15cm length | 1 | 150.00 | 150.00 |
| 25 | Paint (Citizen gloss), 4 litres tin | 1 | 1,000.00 | 1,000.00 |
| 26 | Electric cables (2.5mm) | 5 Yds | 100.00/yd | 500.00 |
| 27 | Socket plug (15 amps) | 1 | 100.00 | 100.00 |
| 28 | Bolts and nuts | | | |
| | Size 12 | 1 | 20.00 | 20.00 |
| | Size 13 | 1 | 20.00 | 20.00 |
| | Size 14 | 7 | 30.00 | 210.00 |
| | Size 17 | 16 | 30.00 | 480.00 |
| | Size 18 | 4 | 50.00 | 200.00 |
| | Size 19 | 1 | 110.00 | 110.00 |
| | Size 30 | 5 | 120.00 | 600.00 |
| 29 | Screw pins/bolts and nuts | 100 | 5.00 | 500.00 |
| 30 | Rectangular bar: | | | |
| | 50cm x 2.5cm x 1cm | 1 | 50.00 | 50.00 |
| | 10cm x 3.5cm x 1cm | 1 | 70.00 | 70.00 |
| | 40cm x 6cm x 1cm | 1 | 180.00 | 180.00 |
| 31 | Galvanized steel pan | 3 | 700.00 | 2,100.00 |
| | **TOTAL** | | | **42,460.00** |

**Therefore, the material cost of the machine is ₦ 42,460.00.**

### 4.4.3 Labour Cost

20% of the material cost is taken to be the labour cost

i.e. labour cost $= \frac{20}{100} \times 42460 = N8,492.00$

### 4.4.4 Overhead Cost

10% of the material cost is taken to be the overhead cost

$$:- \text{Overhead cost} = \frac{10}{100} \times 42,460$$

$$= \text{N}4,246.00$$

### 4.4.5 Fabrication cost

Material Cost + Labour cost + Overhead cost

= 42,460.00 + N8, 492.00 + N4, 246.00

= N55, 198.00

### 4.4.6 Contingencies

Contingency is taken to be 10% of the fabrication cost.

$$\text{Therefore, Contingency} = \frac{10}{100} \times 55198.00$$

=N 5,519.80

### 4.4.7 The Overall cost of the Machine

= Contingency + fabrication cost

= N5, 519.80 + N55, 198.00

= N60, 717.80

# CHAPTER FIVE

## 5.0 DISCUSSION OF RESULTS

### 5.1 Discussions on Slicing and Chipping Results

From the results in table 4.1, we can observe that a batch of six (6) peeled, washed, chemically treated cassava tubers with both posterior and anterior ends slashed of weighed 5.10kg while another batch bought three weeks earlier had 17 tubers weighing just 9kg. A third sample of 7 tubers weighed 5.95 kg. These demonstrate the varying sizes weights of cassava tubers. Though all the tubers were of the *Manihot Esculenta Crantz* variety, they were neither from the same farm nor were they harvested the same day. Hence, their weight (kg) per tuber ratio varies correspondingly as 0.53, 0.85, and 0.85 respectively. This gives a mean weight per tuber of 0.74kg.

Cassava tuber weight is affected by the moisture content of the tuber as well as the weight of the solid matters of the tubers. Similarly, cassava tuber moisture content may be affected by the amount of moisture in the farm soil at any point in time or at any season of the year. Since the sample tubers were harvested around Minna, Niger state at about the same dry season (February to May), it can be assumed that they were under the same environmental condition and same moisture content. Even after the peeling and slashing off of the ends of the tubers, the interval of time of washing the tubers in clean water and the confectionary grade sulphur dioxide solution before they are taken to the machine was precisely the same. No batch can be assumed to have absorbed more water from the washing medium than the other; hence, their moisture content during the chipping operation is the same.

The operation time is the period taken for a batch of Cassava tubers loaded in the carriage bin to be completely fed into the hopper for the slicing and chipping action of the machine (with no tubers remaining in the hopper) and chips collected at the chute. It can be observed that whereas it took an average of 21.18s to chip one tuber of Cassava in the first batch (row 1), it took an average of 35s to chip another tuber in the second batch (row 2). The difference in operation time per tuber is accounted for by the sizes of the tubers. This confirms that the tubers of the second batch (row 2) are not only different from the tubers of the first batch by weight; they are also different by sizes. Tuber sizes here refer to the tubers physical parameters as tuber length. mid diameter. anterior/posterior diameters etc. We can therefore conclude that tuber size, along with such other factors as tuber moisture content, cassava tuber variety, sharpness of the slicing /chipping knife, and of course the cutting force of the machine are factors that affect the operation time of the cassava chipper.

Quantity (Qty) sliced refers to the amount of cassava tubers by weight which are sliced or cut transversely by the slicer at an appreciable thickness according to the preset desirable dimension. With the operator picking one tuber at a time from any given batch in the carriage bin and feeding same into the hopper while the machine is on. each tuber's weight presses the cassava tuber stand and the lower end is sliced off. This slicing at the beginning is mostly at the preset dimension. Similarly, when the operator holds some very short tubers with his hands and presses them on the tuber stand the slicing is also according to the preset dimension. But once the cassava tuber standing in the hopper becomes small as a result of the slicing, that small portion's weight is too small to balance on the stand. It vibrates on the cassava tuber stand inside the hopper, resulting in the slicer slicing it at odd dimensions of thickness. The quantity sliced at dimensions, and in shapes other than the preset are the ones referred to as irregularly sliced. We also noticed a difference between the mean quantity fed into the machine through the hopper (6.68kg) and the mean quantity sliced by the slicer (6.54kg). The difference (0.14kg) is accounted for by the small portions of the tuber tips that escape the slicing knife and fall onto the conveyor tray to meet the chipper. Some of these get chipped even though they were not sliced to dimensions. These result in the irregularly shaped chips.

From table 4.1, we can calculate the machine's chipping rate as the quantity (weight) of cassava tubers chipped over the time spent to chip them. Using the mean values, we shall have:

$$\text{Chipping rate} = \frac{\text{quantity chipped by the machine}}{\text{operation time of chipping}}$$

$$= \frac{6.68\text{kg}}{260\text{s}} = 0.02569 \text{ kg/s} = 0.03 \text{ kg/s}$$

Therefore, in one hour, we shall have a chipping rate $= 0.03 \times 60 \times 60$

$= 108$ kg/hr.

## 5.2 Efficiency of the Machine

Efficiency here is in terms of performance efficiency and is viewed as a ratio of what is gotten out of the machine as compared with what is put into it and is expressed in percentage. i.e. $\eta = \frac{output}{input} \times 100$

Machine's efficiency could be assessed in two separate segments: The slicing segment and the further cutting/chipping segment. Tables 5.1 and 5.2 show the slicing segment efficiency and the chipping segment efficiency.

**Table 5.1: Calculation of slicing segment efficiency**

| Items | 1st Test | 2nd Test | 3rd Test | Mean value |
|---|---|---|---|---|
| Wt of tubers fed into the machine (kg) | 5.10 | 5.95 | 9.00 | 6.68 |
| Wt of pieces irregularly sliced (kg) | 0.11 | 0.13 | 0.2 | 0.15 |
| ∴ Wt of properly sliced pieces(kg) | 4.99 | 5.82 | 8.8 | 6.54 |
| Slicing Efficiency, η (%) | 97.84 | 97.82 | 97.78 | 97.81 |

Average Slicing Efficiency = (97.78 + 97.84 + 97.82) / 3 = 97.81%

**Table 5.2: Calculation of Chipping Segment efficiency**

| Items | 1st Test | 2nd Test | 3rd Test | Mean value |
|---|---|---|---|---|
| Wt of tubers fed into the machine (kg) | 5.10 | 5.95 | 9.0 | 6.68 |
| Wt of properly sliced pieces (kg) | 4.99 | 5.82 | 8.8 | 6.54 |
| ∴ Wt of properly sliced, properly chipped (kg) | 3.74 | 4.37 | 6.6 | 4.90 |
| Wt of properly sliced but not chipped (kg) | 1.25 | 1.45 | 2.2 | 1.63 |
| Chipping efficiency to slicing, η (%) | 74.95 | 75.09 | 75.00 | 75.00 |

Average chipping efficiency to slicing = (75 + 74.95 + 75.09) / 3 = 75.01%

Table 5.3 gives the overall efficiency. Overall efficiency is the percentage by weight of cassava chips from the machine's chute with respect to total tuber input.

**Table 5.3: Calculation of overall efficiency**

| Item | 1st Test | 2nd Test | 3rd Test | Mean value |
|---|---|---|---|---|
| Chipping Efficiency relative to slicing (overall efficiency), η (%) | 73.33 | 73.33 | 73.45 | 73.37 |

Average overall efficiency = (73.33 + 73.33 + 73.45) / 3 = 73.37%

**Loss (wastages)**

Loses in this machine is viewed as the difference between the output and the input.

Losses = input – Output

In terms of material losses (wastages) there are no material losses or wastages. But if we view losses in terms of shapes of products (chips) which differ from the intended shapes (see figures 1.2 and 3.1), and then the irregularly shaped ones are the losses.

Hence, percentage losses = (0.2/9) × 100 = 2.2%

But these are cassava chips and are useful. They can not therefore, be considered as losses.

### 5.3 Discussions on the Results of Drying Of the Produced Cassava Chips

Drying of agric products dates back to the beginning of civilization. The amount of moist air in a product is designated on the basis of the weight of water and expressed in percentages. The moisture content (wet basis) is used here, and is obtained by dividing the weight of water in cassava chips by the total weight of water in the cassava tubers. The direct method (oven drying) was used. Water found in plant product is more or less "available". Availability of water in products varies from one product to the other according to its biochemical composition and its moisture content. There are three drying stages used here. The first could be referred to as the constant rate drying period. During this stage the drying takes place from the surface of the cassava chips. It is similar to evaporation from a free water surface. In this phase, effort is to remove dampness in the environment of the chips which could encourage microbial proliferation. A temperature of $70^0$C and a turning interval of 30 minutes were selected considering that the chips can surfer case-hardening if not checked often in the oven especially as the drying pan was not flat to give a good surface area exposure.

After about 5 hours of continuous heating in the oven it would have been time to lower the temperature. Unfortunately there was 13 hours of power outage. At resumption of power, the chips had become slightly sticky (gummy) when touched. Each chip that had this sticky (gummy) appearance ended up having a slightly brownish colouration. To promptly eliminate this substance from the appearances of the chips a higher temperature of $100^0$C and a longer turning interval of 1 hour was selected. Within four hours this was arrested. and there was recourse to the falling rate drying period exemplified by stage 3 of the drying. The period of stable power witnessed no change in colouration of the chips. This explains why commercial cassava chips producers use electric driers to dry their chips since that makes for faster drying and area of chips surface exposure to heat is more.

### 5.4 Observations

1. It was observed that the slicing segment produces cassava slices in accordance to pre-set dimension when a whole length tuber is standing on the cassava tuber stand in the hopper or when a short tuber is pressed tightly to the hopper base by the operator. Otherwise the slice thickness could vary because of the vibration induced on the tuber due to the cutting action of the slicer.
2. It was observed that because of the varying diameter of cassava tubers some chips get trapped at the 'further cutting'/chipping knife teeth, necessitating the operator to occasionally push them out with an operating stick.
3. The chips produced by this machine retained their shapes after drying, packaging, handling, and have been in storage for about 6 months.
4. The colour quality of the cassava chips sample treated with confectionery grade sulphur dioxide did not change much when compared to the sample that was not chemically treated.
5. Both sample chips suffered from the effect of power outage of the drying oven. Continuous drying without power outage is good for drying cassava chips.
6. A quicker drying of cassava chips helps prevent cassava chips colouration while a prolonged drying period can engender chip colouration. Figures 5.1 and 5.2 show pictures of the two samples of chips after their drying.

**Fig.5.1 Picture showing dried cassava chips produced by the machine: pure white quality (chemically treated sample). Suffered from power outage as well.**

**Fig. 5.2 Picture showing dried cassava chips produced by the machine (slightly coloured due to power outage during drying). No chemical treatment.**

## 5.5 Conclusions

The chips produced by this machine did not scatter, disintegrate, and reduce to crumbs or powdery forms even after drying, packaging, and handling for about 6 months. This is because slicing and cutting is employed in the design of this machine as opposed to shredding which most other chippers employed.

The colour of the cassava chips produced did not change even after peeling, chipping, drying, and storage. Thus the quality and stability are maintained. The objectives of this project are therefore achieved.

The machine gave a chipping output of 108kg/hr, a chipping efficiency of 75%, and an average wastage (losses) of about 2.2%. The cost of construction of the machine totaled Sixty-one thousand naira.

## 5.6 Recommendations

This machine is recommended to Cassava Chip Processors/Producers who are interested in having cassava chips that remain stable even after drying and packaging. This machine should be commercialized, mass-produced and popularized among stake holders in the Cassava chip industry.

The Cassava colour-change remedy canvassed in this project thesis should be popularized through agric extension workers and among cassava chip stake holders as this method is simple and less complicated

There are possibilities that this design could be modified to reduce the bulkiness of this machine and make it more portable.

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## APPENDIX A

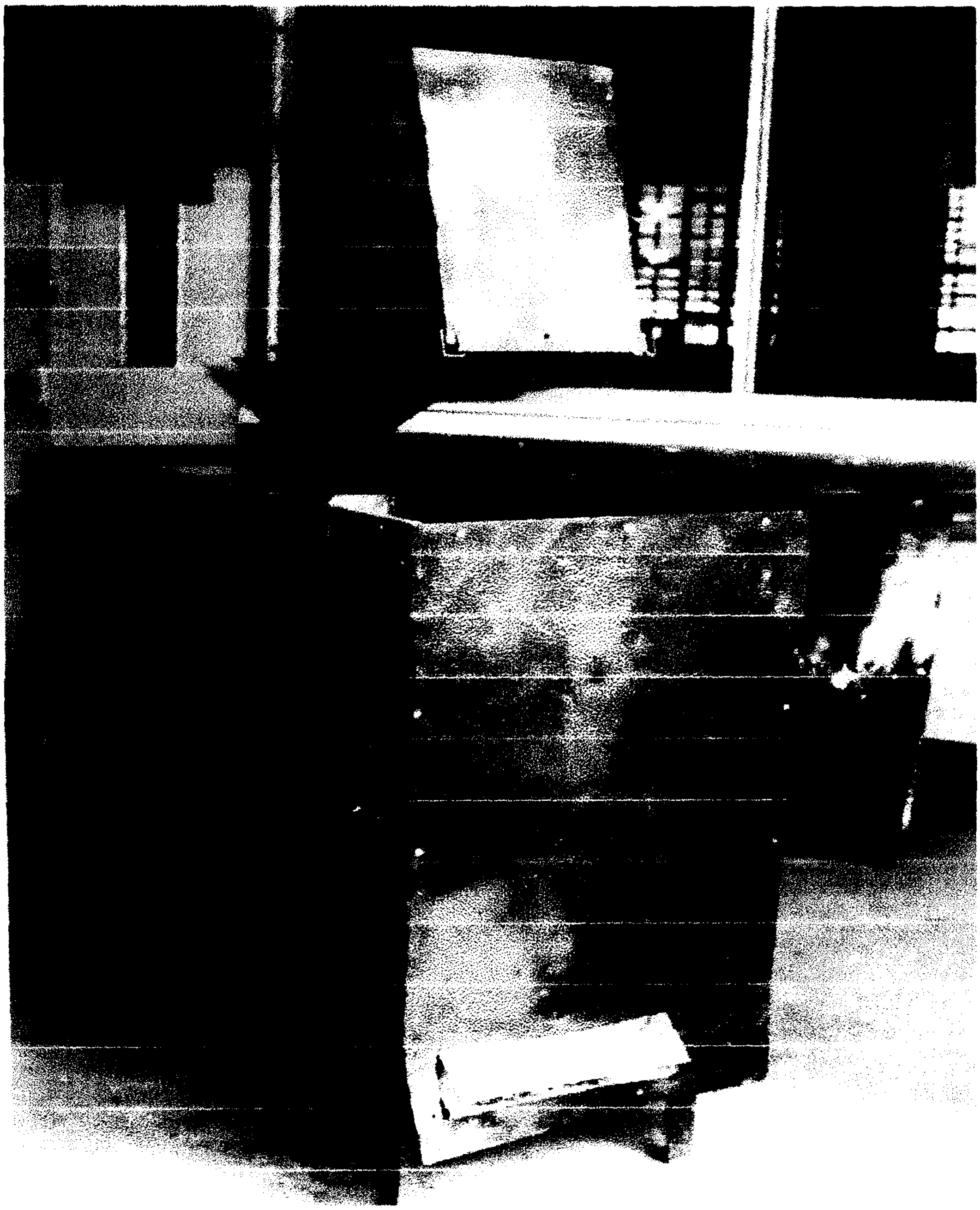
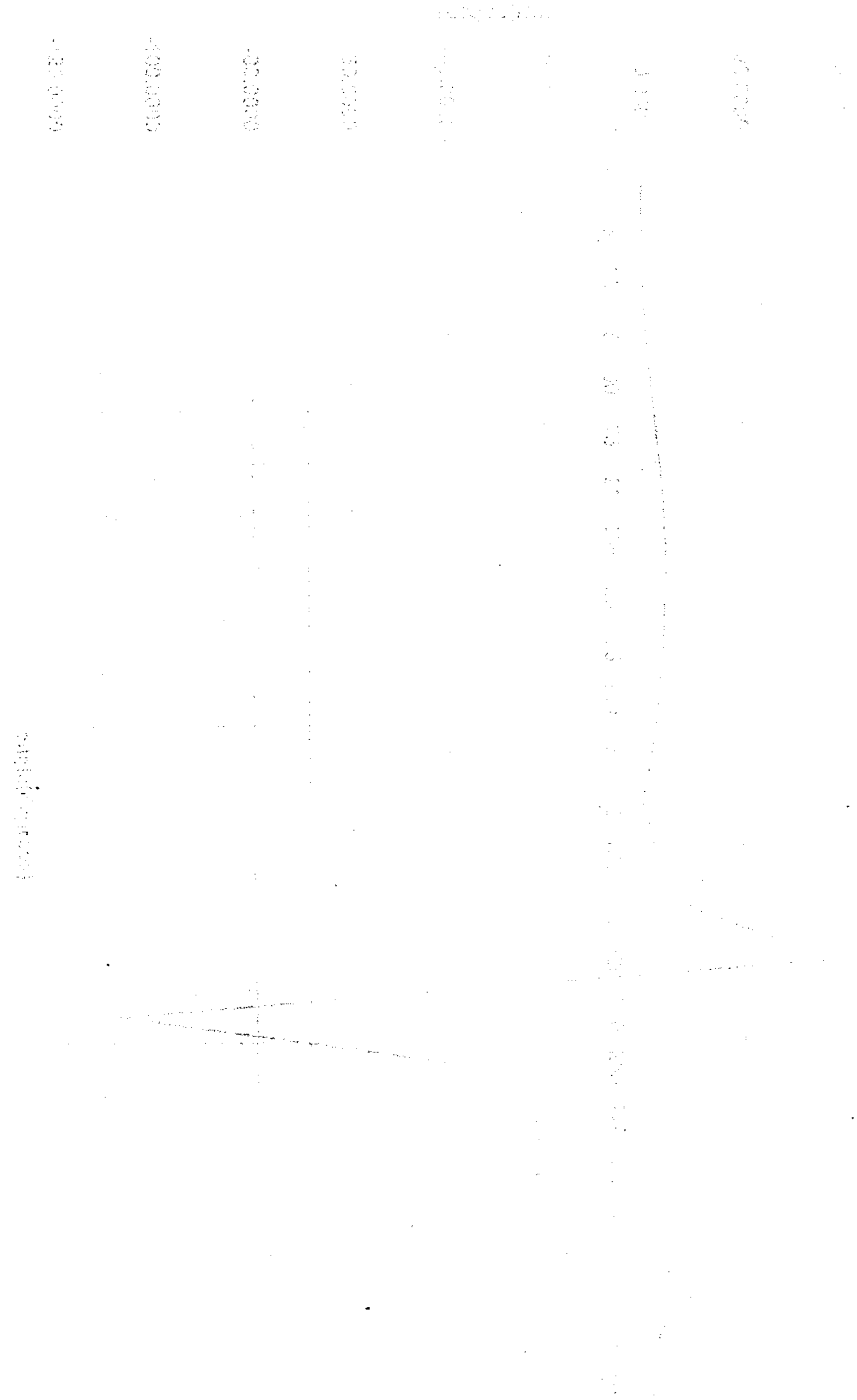
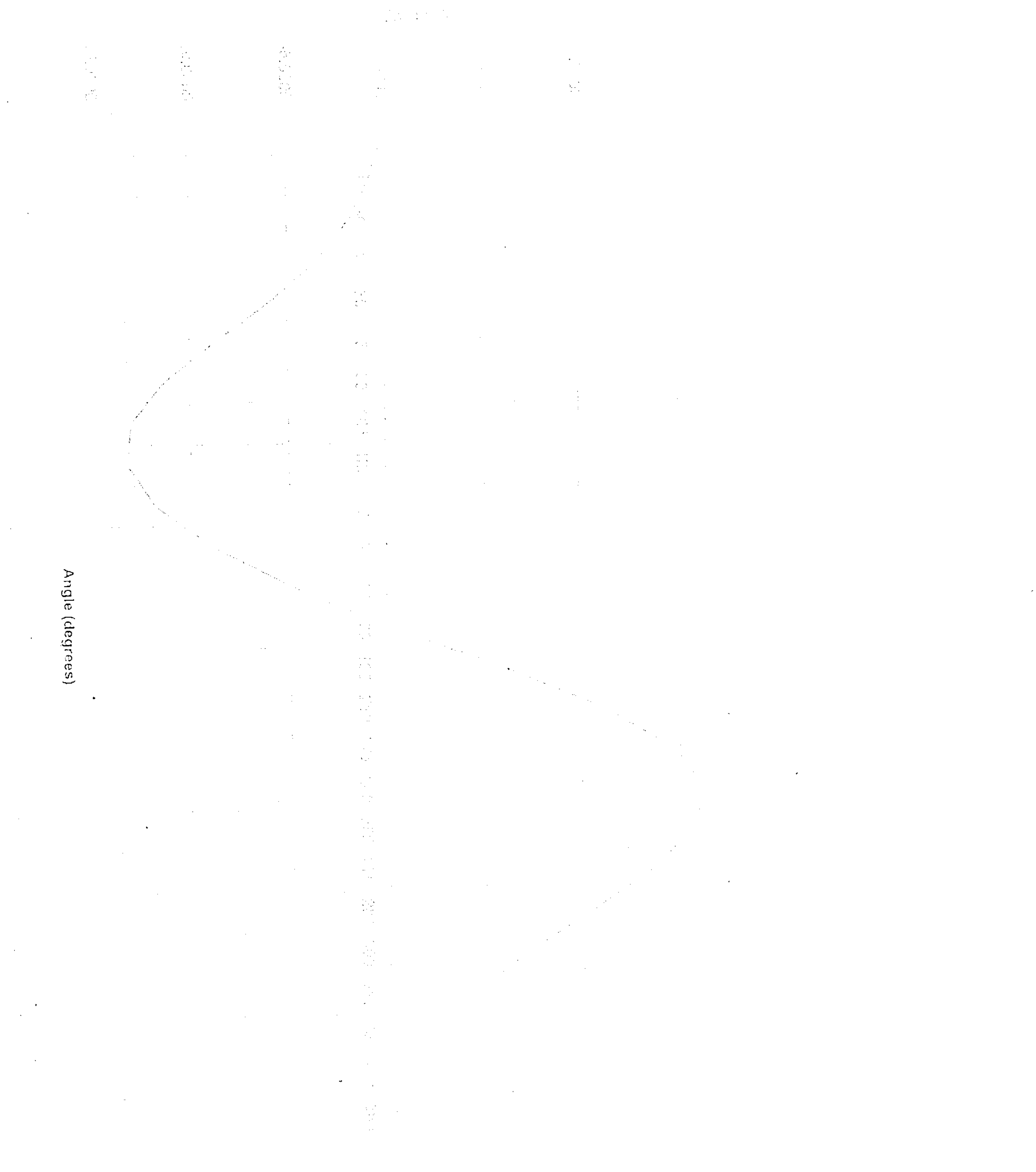


**Plate 1: Front View of the Completed Machine Showing Top cover opened**

# APPENDIX B
# GRAPHS



Graph 1, From Table 3.1 and for Shaft 1(Slicer Shaft). Behavior of torque at various degrees.




Graph 2, From Table 3.2 and for Shaft 2 (Chipper Shaft). Behavior of torque at various degrees