BUSITEMA UNIVERSITY
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FACULTY OF ENGINEERING

DEPARTMENT OF CHEMICAL AND PROCESS ENGINEERING

FINAL YEAR PROJECT

DESIGN AND CONSTRUCTION OF A TOMATO SORTER

BY

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A final year project report submitted in partial fulfilment of the award of a bachelor's degree in Agro Processing Engineering of Busitema University.

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ABSTRACT.

Sorting and grading are the most important unit operations in packing houses by which it enables to obtain a good and appealing packing system. To standardize the tomatoes for marketing in the local and export markets, the rotary screen tomato sorter was developed. It consists of cylindrical wire meshed screens, pedal operated system. The performance evaluation was done to optimizing the peripheral speed and feed rate. As the tomatoes are fed through the hopper into the rotating drum like wire mesh, it gets separated according to size. It is portable and can be used in the field. By conducting different studies, the efficiency of the sorter at best speeds of 5rpm and 10rpm were found to be 86.5% and 75.8% with through put capacities of 89.6Kg/hr and 111 kg/h respectively at 10° inclination angle of the screens.

DECLARATION

I hereby declare that the contents of the synopsis, "design and construction of a tomato Sorter" are product of my own research and no part has been copied from any published source (except the references, standard mathematical or genetic models/equation/formulate/protocols etc.). I further declare that this work has not been submitted for award any other diploma/degree. The university may take action if the information provided is found inaccurate at any stage

Signature..

Name... OBURU RICHARD ....

APPROVAL

This project proposal is submitted to the Faculty of Engineering for examination with approval of my supervisors and the contents are satisfactory for the award of the degree in Agro Processing Engineering.

Supervisors name:

MRS. KABASA MARY SALLY

………………………………………………………………

DEDICATION

This report is dedicated to my beloved parents Mr. Oketch Stephen and Ms. Auma Jackline in appreciation for their selfless care and unflinching support provided to me since childhood, and for the spirit of hard word, courage and determination instilled into me, which attributes I have cherished with firmness and which have indeed made me what I am today.

ACKNOWLEDGEMENT

My greatest appreciation goes to the Only Wise, Gracious and Merciful God for being my Pillar through thick and thin of this study. He is faithful indeed!

Well acknowledged is my Sagacious and Scholarly Supervisor whom despite his tight schedules never failed to give me all the needed attention required to successfully complete of this research work.

I am heartily grateful to my amiable family for standing by me prayerfully, financially and morally to ensure that my aspiration is realized. May God reward you all for being so supportive even in the midst of challenges.

My thanks to the entire staff of the Department of Chemical and Process Engineering, Busitema University for providing me with the enabling environment suitable for research work of this kind.

With deep friendliness, I am thankful to my friends, colleagues and associates of Busitema University for their patience and understanding, the motivators and catalyst who never relented to ensure that I give-in my best to my study.

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1 CHAPTER ONE: INTRODUCTION

1.1 Background

Tomato (Solanum lycopersicum L.) is a juicy berry fruit of the nightshade family (solanaceae) and one of the most widely cultivated and extensively consumed horticultural crops globally consumed by millions of people daily ***(Grandillo S., 2002).***Tomato is one of the important products in human nutrition that is consumed by millions of people daily. According to FAO statistics, world tomato production was 314 million ha in 2010(***Omidi ARJENAKI, 2012***).

In Uganda, tomatoes are among the most important and prominent horticultural crops grown for both home consumption and the domestic market. Tomato is considered to be a top priority for production, viewed as the main income crop compared to other vegetables and is grown and consumed in every district of Uganda. Production of tomatoes in rural areas of the country has increased employment and improved farmers' livelihoods **(Tusiime, 2014).**In 2016 the total production of tomatoes was 38234 tons from 6,485 ha with areas including districts of Kasese, Kabale, Mbale, Kapchorwa, Mubende, Masaka, Mpigi, Wakiso and Mbarara **(Kennedy, 2008)** have the largest area of production. Ugandan farmers grow different commercial tomato cultivars in the different regions of the countrywhere about 3,000 small-scale farmers grow fresh fruits and vegetables for export with more than 20,000 smallholders growing vegetables for income (Sonko *et al*., 2005). Cultivars include, Marglobe, Pakmor, Tropic, VF 6203, Peto-C-8100159, Heinz1370, Moneymaker, Roma and Tengeru-97(***Marsic, 2005***). In African meals, tomatoes are consumed in sauces, soup, domestic meat or fish dishes, and fresh in salads. They can also be processed into purées, juices, and ketchup. Canned and dried tomatoes are additional important processed products **(Tusiime, 2014).**

(Post-harvest)Handling practices of fruits and vegetables like harvesting, precooling, cleaning and disinfecting, sorting and grading, packaging, storing, and transportation plays an important role in maintaining quality and extending shelf life ***(Areej Saif El-Deen Muhammad Babiker, 2015).***One of the most important processes in packaging and product supply to the market is sorting. This operation requires different parameters for quick identification and management. Parameters include maturity, color, shape, size, and defects. According to Jarimopas and Jaisin (2008), the efficiency and effectiveness of sorting governs the quality standard of the packing lines and the product, which, in turn, determines the marketability of the product. Accordingly, it is necessary to have a rapid, consistent, effective, and robust method for sorting. TheSorting and grading is the removal of rotten, damaged, or diseased fruits from the healthy and clean ones and categorizing them on the basis of color, size, stage of maturity, or degree of ripening. The damaged or diseased fruits can produce ethylene in substantial amounts which can affect the adjacent fruits **(Saltveit, 1999)**. The two processes are vital in maintaining postharvest shelf life and quality of harvested tomatoes. Sorting and grading limit the spread of infectious microorganisms from bad fruits to other healthy fruits during postharvest handling of tomatoes and also helps handlers to categorize fruits and vegetables in a given common parameter which enables easy handling. For instance, grading on the basis of color or maturity stage will help eliminate overripe fruits which will easily produce ethylene to hasten the ripening process in the whole batch. Manual sorting and grading is based on traditional visual quality inspection performed by human operators, which is associated with high labor costs, labor fatigue, inconsistency, and low precision due to various factors such as variations in ambient light intensity, differences in personal perception of quality, and scarcity of trained labor. ***(Dattatraya Londhe, 2013)***. A cost effective, consistent, superior speed and accurate sorting can be achieved with automated sorting. Color, shape and size are the most important features for accurate classification and sorting of tomatoes. Because of the ever-growing need to supply high quality fruits and vegetable products within a short time, automated grading of agricultural products is getting special priority among many farmer associations. Fruit size estimation is also helpful in Planning, packaging, transportation and marketing operations. Buyers will pay premium prices for fruit of uniform size, shape and color. In consumer use, sorted fruits are more attractive to the eye and allow the serving of uniformly sized portions.

1.2 Problem statement

During the harvesting of tomatoes, people tend to collect them together not considering the variable physical characteristics (for example shape, size or color). Due to increased demand for high quality sorted products on the market, farmers carry out sorting before taking the produce to the consumers. Currently in Uganda, sorting of tomatoes is manual based on traditional visual quality inspection performed by human operators, which is **tedious, time-consuming, slow and non-consistent** caused by various factors such as **variations in ambient light intensity, differences in personal perception of quality**, and **scarcity of trained labor** and it has become increasingly difficult to hire personnel who are adequately trained and willing to undertake the tedious task of inspection. Therefore, there is a need to design and construct a tomato sorter to overcome the challenges in the tradition manual sorting.

1.3 Justification

If the machine is implemented the following will be benefited

- ✓ Reduced labor costs
- ✓ Reduced damages due to manual sorting
- ✓ Increased market value which will lead to increased income of the farmers
- ✓ Reduced errors encountered in human eye sorted products

1.4 Objectives of the study

1.4.1 Main objective

To design and construct tomato sorter

1.4.2 Specific objectives

I. To design different components of tomato sorter.

II. To fabricate the prototype of the designed tomato sorter.

III. To test the performance of the prototype.

IV. To carry out economic evaluation of the prototype.

1.4 Scope

The project entirely covers designing, fabricating and assembling, testing and carrying out economic evaluation of tomato sorter

2 CHAPTER TWO: LITERATURE REVIEW.

2.1 Tomatoes

Tomato (Solanum lycopersicum L.) is one of the most widely cultivated and extensively consumed horticultural crops globally consumed by millions of people daily***(Grandillo S., 2002)***. The nutritional and economic importance of the crop has led to its global production. By weight, tomatoes rank second only to potatoes in global production of all horticultural produce.

2.1.1 Consumption and Nutritional benefits of tomatoes

Tomato can be eaten in various ways and in a countless number of dishes. In African meals, tomatoes are consumed in sauces, soup, domestic meat or fish dishes, and fresh in salads. They can also be processed into purées, juices, and ketchup. Canned and dried tomatoes are additional important processed products ***(Tusiime, 2014)***.

Tomato and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body. Tomato contains higher amounts of lycopene, a type of carotenoid with antioxidant properties***(Arab L. and S. Steck, 2000)***which is beneficial in reducing the incidence of some chronic diseases ***(Basu A. and V. Imrhan, 2007)***like cancer and many other cardiovascular disorders ***(Burton-Freeman B. and K. Reimers, 2011)***. They are also a great source of vitamin C, potassium, folate and vitamin K. The water content of tomatoes is around 95%. The other 5% consists of mainly carbohydrates and fiber. They are also considered to be beneficial for skin health, and may protect against sunburns. Average dry matter content of the ripe fresh fruit is between 5.0 and 7.5% ***(Petro-Turza.M., 1987)***The free sugars of commercial varieties of tomatoes are predominantly reducing sugars, and the quantity of sucrose is negligible. The pectins, arabinogalactans, xylans, arabinoxylans, and cellulose are the major polysaccarides. Glutamic acid comprises up to 45% of the total weight of free amino acids in fresh tomato juice with the next highest in concentration being aspartic acid. Citric acid is the most abundant organic acid with some malic acid also present***(Gould.W.A, 1983)***.

In regions where it is being cultivated and consumed, it constitutes a very essential part of the people's diet. The numerous uses of tomatoes is a contributing factor to its widespread production.

Table 2-1 Composition of dry matter content of tomato ***(Petro-Turza.M., 1987)***

Constituent	***Percentage (%)***
Fructose	25
Glucose	22
Saccharose	1
Citric acid	9
Malic acid	4
Protein	8
Dicarboxylic amino acid	2
Pectic substance	7
Cellulose	6
Hemicelluloses	4
Minerals	8
Lipids	2
Ascorbic acid	0.5
Pigments	0.4
Other amino acids, vitamins and polyphenols	1
Volatiles	0.1

2.2 Tomato production in uganda

In Uganda, tomatoes are among the most important and prominent horticultural crops grown for both home consumption and the domestic market. The tomato is considered to be a top priority for production, is viewed as the main income crop compared to other vegetables and is grown and consumed in every district of Uganda. Production of tomatoes in rural areas of the country has increased employment and improved farmers' livelihoods **(Tusiime, 2014).**

In 2016, the total production of tomatoes was 38,234 tons from 6,485 ha with areas including districts of Kasese, Kabale, Iganga, Mbale, Kapchorwa, Mubende, Masaka, Mpigi, Wakiso and Mbarara ***(Kennedy, 2008)***with the largest area of production.

2.2.1 Tomato varieties

Tomato varieties can be divided into several categories, mostly based on shape and size***(USDAVIS, 2015)***:

- ✓ Slicing or globe also known as round tomatoes, are used in processing or fresh consumption.
- ✓ Beefsteaks are large tomatoes often used for sandwiches.
- ✓ Plum tomatoes are bred for higher solids for use in tomato sauce and paste.
- ✓ Cherry tomatoes are small, round, often sweet, and used whole in salads.
- ✓ Grape tomatoes, a more recent variety, are a smaller variation of a plum tomato primarily used in salads.

Ugandan farmers grow different commercial tomato cultivars in the different regions of the country. Cultivars include, Marglobe, Pakmor, Tropic, VF 6203, Peto-C-8100159, Heinz1370, Moneymaker, Roma and Tengeru-97 ***(Marsic, 2005)***.

However, all the cultivars are defined by shape as round, oval, globe or ribbed as in the figures be below respectively.

Figure 1 tomato varieties

2.3 Postharvest Handling Practices for Tomatoes

Physical handling can have a drastic effect on the postharvest quality and shelf life of most harvested fruits and vegetables. For instance, rough handling during harvesting and after harvesting can cause mechanical injuries which can affect the postharvest quality and shelf life of harvested fruit like tomatoes. It is therefore important to know suitable postharvest handling practices needed to maintain the quality and extend the shelf life of harvested tomatoes for producers in developing countries. Some of the handling practices which include harvesting, precooling, cleaning and disinfecting, sorting and grading, packaging, transportation, and storage are discussed below.

2.3.1 Harvesting

The physiological maturity of any fruit at harvest has an important effect on postharvest quality of that fruit **(Beckles, 2012)**. Therefore, care must be taken as to when to harvest the fruit in order to attain the best quality. The shelf life of fruits and vegetables is described by postharvest physiologists in three stages: the maturation, ripening, and senescence stages. The maturation stage gives an indication of the fruit being ready for harvest **(FAO, 2008)**. Tomatoes can be harvested in either matured green, partially ripe, or ripe state. Tomato being a climacteric fruit can be harvested at the matured green state allowing ripening and senescence to occur during the postharvest period of the fruit. Producers targeting distant markets must harvest their tomatoes in a matured green state ***(Moneruzzaman K. M., 2009)***. Harvesting tomatoes in matured green state will not only give producers ample time to prepare the fruit for the market but also prevent mechanical injuries during harvesting. Unfortunately, most producers from developing countries especially those in Africa harvest tomatoes when they are partially or fully ripened. Fully ripened tomatoes are susceptible to mechanical injuries during harvesting resulting in shorter shelf life. Care must therefore be taken when harvesting tomatoes in ripe state to avoid these injuries which will hasten deterioration.

Table 2-2 Maturity and ripening stage of tomato (USDAVIS, 2012)

Color changes	Comment
GREEN 	The tomato surface is completely green and the shade of green may vary from light to dark.
BREAKERS 	There is a definite break of color from green to bruised fruit tannish yellow, pink or red or 10% less of the tomato surface.
TURNING TANNISH YELLOW 	Tannish yellow or pink or red color shows on cover 10% but not more than 30% of the tomato surface.
PINK 	Pink or red color shows on cover 30% but not more than 90% of the tomato surface.
LIGHT RED 	Pinkish red or red color shows on cover 60% but red color covers not more than 90% of the tomato surface.
RED 	More than 90% of tomato surface in aggregate is red

2.3.2 Precooling after Harvest

Field heat is usually high and undesirable at harvesting stage of many fruits and vegetables and should be removed as quickly as possible before any postharvest handling activity **(Earles, 2000).** Excessive field heat gives rise to an undesirable increase in metabolic activity and immediate cooling after harvest is therefore important***(Akbudak B., 2012)***. Precooling minimizes the effect of microbial activity, metabolic activity, respiration rate, and ethylene production (Shahi et al., 2012), whilst reducing the ripening rate, water loss, and decay, thereby preserving quality and extending shelf life of harvested tomatoes ***(Ferreira M. D., 1994.).*** The suitable temperature range of about 13–20°C for tomato handling can be attained either in the early hours of the morning or late in the evening

2.3.3 Cleaning or Disinfecting

Proper hygiene is a major concern to all produce handlers, because of not only postharvest diseases, but also incidence of food-borne illnesses that can be transmitted to consumers. According to a report by the Government of India ***(Workneh T. S., 2012)***Salmonella, Cryptosporidium, Cyclospora and hepatitis A virus are some examples of disease causing organisms that have been transmitted to consumers through fresh fruits and vegetables. Unfortunately, cleaning or disinfecting tomatoes after harvest is not a common practice for most tomato handlers in developing countries especially those from Africa. This practice may be attributed to either the unavailability of portable water at the production sites or the sheer ignorance of the practice. However, in places where water is not a constraint, the use of disinfectants in water either for washing or for cooling can reduce both postharvest and food-borne diseases in fruits and vegetables.

2.3.4 Sorting and Grading

One of the most important processes in packaging and marketing of fruit and vegetables is sorting ***(Arjenaki O., 2013)***and grading. Sorting is the removal of rotten, damaged, or diseased fruits from the healthy and clean ones. The damaged or diseased fruits can produce ethylene in substantial amounts which can affect the adjacent fruits **(Saltveit, 1999)**. Grading is also the process of categorizing fruits and vegetables on the basis of color, size, stage of maturity, or degree of ripening. The two processes are vital in maintaining postharvest shelf life and quality of harvested tomatoes. Sorting limits the spread of infectious microorganisms from bad fruits to other healthy fruits during postharvest handling of tomatoes. Grading also helps handlers to categorize fruits and vegetables in a given common parameter which enables easy handling. For instance, grading on the basis of coloror maturity stage will help eliminate overripe fruits which will easily produce ethylene to hasten the ripening process in the whole batch. Commercial tomato producers normally use sophisticated systems that require precise sorting and grading standards for their produce. Small-scale producers and retailers in developing countries in contrast may not use written down grading and sorting standards; however, the produce must still be sorted and sized to some degree before selling or processing it.

This may be done manually or by using a machine. Fruits are graded on the basis of their color, size and weight and sorted for freeness from damage/ diseases

At the sorting and grading table, trained workers wearing gloves sort out the oversized and undersized fruits, immature/scarred/blemished fruits, diseased/insect damaged fruits and as well as fruits with sap injury (in mango) under the supervision of quality supervisor.

The segregated fruits in the grader machine kept in plastic crates are removed at the end each working shift from the process area and are distinctly labeled for disposal.

Table 1-3 Difference between sorting and Grading

Sorting	Grading
Separation of products into various quality fractions according to physical parameters like size, shape and others	Classification of products into various quality fractions depending upon various commercial values

2.3.5 Packaging

Packaging is also one of the important aspects to consider in addressing postharvest losses in fruits and vegetables. It is enclosing food produce or product to protect it from mechanical injuries, tampering, and contamination from physical, chemical, and biological sources***(Prasad P. and A. Kochhar, 2014).*** Packaging as a postharvest handling practice in tomato production is essential in putting the produce into sizeable portions for easy handling. However, using unsuitable packaging can cause fruit damage resulting in losses ***(Idah, 2007)***

2.4 Review of the existing Sorting techniques.

2.4.1 Size sorting

Size sorting or sieving is the separation of solids into two or more fractions on the basis of differences in size. It is particularly important when the food is to be heated or cooled as the rate of heat transfer is in part determined by the size of the individual pieces and variation in size would cause over-processing or under-processing.

Additionally, foods which have a uniform size are said to be preferred by consumers. Screens with either fixed or variable apertures are used for size sorting***(Liberty, 2015)***. The screen may be stationary or, more commonly, rotating or vibrating.

Fixed Aperture Screens

Two common types of fixed aperture screen are the flat bed screen (or sieve) and the drum screen (rotary screen or reel).

The multi deck flatbed screen has a number of inclined or horizontal mesh screens, which have aperture sizes from 20 to 125 mm, stacked inside a vibrating frame. Food particles that are smaller than the screen apertures pass through under gravity until they reach a screen with an aperture size that retains them. The smallest particles that are separated commercially are of the order of 50mμ ***(Liberty, 2015).***

Variable-aperture screens

Variable-aperture screens have either a continuously diverging aperture or a stepwise increase in aperture. Both types handle foods more gently than drum screens and are therefore used to sort fruits and other foods that are easily damaged. Continuously variable screens employ pairs of diverging rollers, cables or felt-lined conveyor belts. These may be driven at different speeds to rotate the food and thus to align it, to present the smallest dimension to the aperture.

Stepwise increases in aperture are produced by adjusting the gap between driven rollers and an inclined conveyor belt. The food rotates and the same dimension is therefore used as the basis for sorting (for example the diameter along the core of a fruit).

Multi deck flatbed screen

The capacity of a screen is the amount of food that passes through per square metre per second. The rate of separation is controlled by:

- ✓ The shape and size distribution of the particles
- ✓ The nature of the sieve material
- ✓ The amplitude and frequency of shaking
- ✓ The effectiveness of methods used to prevent blocking (or blinding) of the sieves.

These types of screens are widely used for sorting dry foods (for example flour, sugar and spices).

The main problems encountered are:

- ✓ excessive moisture or high humidity, which causes small particles to stick to the screen or to agglomerate and form larger particles, which are then discharged as oversize
- ✓ blinding, particularly if the particle size is close to that of the screen aperture
- ✓ high feed rates, which cause the screens to become overloaded and small particles are discharged with the oversized particles.

Where vibration alone is insufficient to separate particles adequately, a gyratory movement is used to spread the food over the entire sieve area, and a vertical jolting action breaks agglomerates and dislodges particles that block sieve apertures. Many types of drum screen are used for sorting small-particulate foods (for example nuts, peas or beans) that have sufficient mechanical strength to withstand the tumbling action inside the screen.

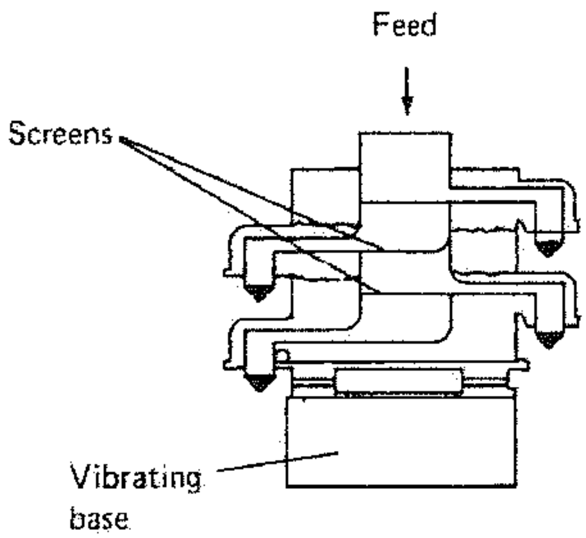


Figure 2 Multi-deck flatbed screen(Liberty, 2015)

Drum screens

These are almost horizontal (5–10° inclination), perforated metal or mesh cylinders. They may be concentric (one inside another), parallel (foods leave one screen and enter the next) or series (a single drum constructed from sections with different sized apertures). All types have a higher capacity than flatbed screens and problems associated with blinding are less severe than with flatbed screens. The capacity of drum screens increases with their speed of rotation up to a critical point. Above this the food is held against the screen by centrifugal force and results in poor separation. Similarly, there is an increase in capacity with the angle of the screen up to a critical angle. Above this the residence time is too short and products pass through without separation.

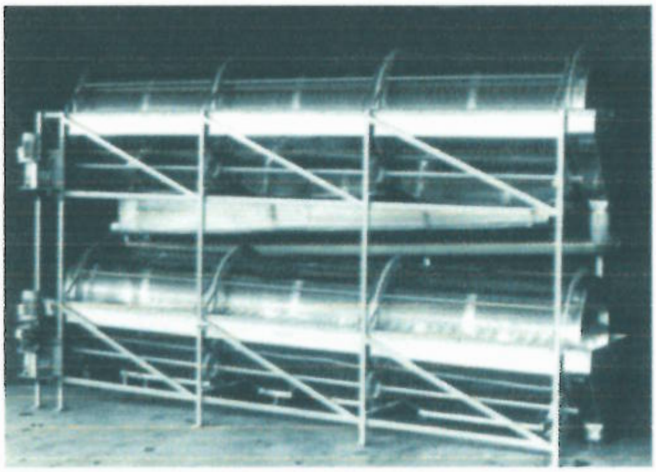


Figure 3 (Liberty, 2015)Parallel drum screen

2.4.2 Color sorting

Manual sorting by color is still widely used but is increasingly expensive in both labor costs, operator training and the space required for sorting tables. There has therefore been considerable development of machine vision sorting systems which are said to have lower operating costs and greater accuracy than manual methods. These include monochrome (black and white), bi-chrome (4100 shades of red and green) and trichromatic or full color (262 000 shades of red, green and blue, with optional infrared). Each is controlled by a programmable logic controller which has pre-set programs for different products that are easily changeable by operators using a video display. They are used for example, to sort potatoes for defects and blemishes by identifying dark areas on the potato surface. Light sensitive cells in the camera (termed 'pixels') produce a voltage that is proportional to the intensity of light received. An electronic circuit that receives a lower voltage than the pre-set value can thus detect darker objects or areas which reflect less light than normal.

The voltage produced in the electronic circuit can be adjusted to alter the sensitivity of detection. Up to 10 tons of product per hour pass beneath the cameras on conveyors operating at 150–180 m per min. Defective items are removed by electronically controlled air jets that can operate for 20 milliseconds, thus covering 50 mm of the belt length in a single blast. In another system, vegetables in free-fall are scanned 1000 times per second, as they leave a conveyor belt, using concentrated helium-neon or laser light beams and a high-speed rotating mirror. The machine detects differences in reflectivity between good product and unwanted material.

Small-particulate foods may be automatically sorted at high rates using microprocessor controlled color sorting equipment. Particles are fed into the chute one at a time. The angle, shape and lining material of the chute are altered to control the velocity of the pieces as they pass a photo detector. The color of the background and the type and intensity of the light used for illuminating the food (including infrared and ultraviolet options) are closely controlled for each product. Photo detectors measure the reflected color of each piece and compare it with pre-set standards, and defective foods are separated by a short blast of compressed air. The computer can store 100 named product configurations to enable rapid changeover to different products using an operator touchpad. Typical applications include peanuts, rice, diced carrot, maize kernels, cereals, snack foods and small fruits.

A different type of equipment employs a sensor located above a conveyor belt, which views products as they pass beneath. The sensor detects up to eight colors and provides an alarm or control signal whenever a pre-selected color passes the detector beam. It is also able to distinguish between different colored foods which are to be processed separately. In a more sophisticated system, foods which have variations in color over their surface are color sorted by image processing. The foods are fed in rows on a roller conveyor beneath a video camera. The relative intensities of reflected red, green and yellow light are transmitted to the microcomputer which constructs a composite image of each piece of food, showing both the spread of color and the mean color of inspected foods. The computer compares the constructed image with pre-set specifications and activates a compressed air ejector or a mechanical deflector to remove rejected food. When this type of system is used to sort baked goods, it is also used to control directly the gas or electricity supply to the ovens, which is reported to reduce energy consumption in ovens by 20%. The sorter can be easily adapted to different foods, by operators using the microprocessor keypad.

(Liberty, 2015)

2.4.3 Weight sorting

Weight sorting is more accurate than other methods and is therefore used for more valuable foods (for example eggs, cut meats and some tropical fruits). Eggs are sorted at up to 12 000 per hour into six to nine categories with a tolerance of 0.5 g. They are first graded by 'candling' and then pass to the weight sorter. This consists of a slatted conveyor which transports the eggs above a series of counterbalanced arms. The conveyor operates intermittently and while stationary, the arms raise and weigh the eggs. Heavy eggs are discharged into a padded chute and lighter eggs are replaced on the conveyor to travel to the next weigher.

Aspiration and flotation sorting use differences in density to sort foods and are similar in principle and operation to aspiration and flotation cleaning. Grains, nuts and pulses are sorted by aspiration. Peas and lima beans are sorted by flotation in brine (specific gravity, 1.1162–1.1362). The denser, starchy, over-mature pieces sink whereas the younger pieces float.

(Liberty, 2015)

2.5 Comparison of the Sorting Methods

2.5.1 Manual sorting

Sorting is often combined with grading, but in some applications both phases are separated from each other and the sorting phase is only for removing produce with surface deformities or blemishes and foreign / unwanted objects. During this type of task, the worker usually stands in an upright position for long periods. The working height is fixed and unlikely to be adjustable to suit the particular height of the worker. This may cause continuous forward flexion and rotation of the neck and back. The alternative position is sitting on a chair, but then the upper body will probably be twisted. And this results in *musculoskeletal disorders (MSD).*

The method used by the farmers and distributors to sort agricultural products is through traditional quality inspection and handpicking which is time-consuming, laborious and less efficient. The maximum manual sorting rate is dependent on numerous factors, including the workers experience and training, the duration of tasks, and the work environment (temperature, humidity, noise levels, and ergonomics of the work station). More fundamentally, viewing conditions (illumination, defect contrast, and viewing distance) must be optimal to achieve maximum sorting rates. Attempts to develop automatic produce sorters have been justified mostly by the inadequacies of manual sorters, but few authors provide results that demonstrate the degree of manual sorting inefficiencies. Flaws were more accurately identified when the inspector knew that only one type of flaw was present in the sample. The detectability of each flaw decreased when the sample contained more than one type of flaw. The authors indicated that different flaws must be mentally processed separately in a limited amount of time, and that these separate decisions may interfere with each other when more than one flaw is present in the sample. It was also proposed that a speed-accuracy relationship existed.

Disadvantages of manual sorting

- ✓ Time-consuming
- ✓ Laborious
- ✓ Less efficient
- ✓ Its tedious and can cause *musculoskeletal disorders (MSD)*

2.5.2 Mechanical sorting

Mechanical sorters are machines, usually integrated to a **conveyor belt**, over which agriculture products are sorted by external criteria like shape, dimensions and weight. Such equipment is based on mechanical apparatus triggered by these criteria. For example, a product, be it fruit or vegetable, is dropped into a bucket when its weight or diameter are measured at higher values than a given threshold. When values are lower, it simply travels on the conveyor belt towards the following test. Mechanical sorters are fast and reliable. However, they are limited in that they test only generic criteria, be the quality of detection. This is a real industry challenge, since grading performance may vary depending on personal skills: when these are below par, the results may be profit losses and damage to the reputation of the producer or the distributor.

Gravity based fruit sorter.

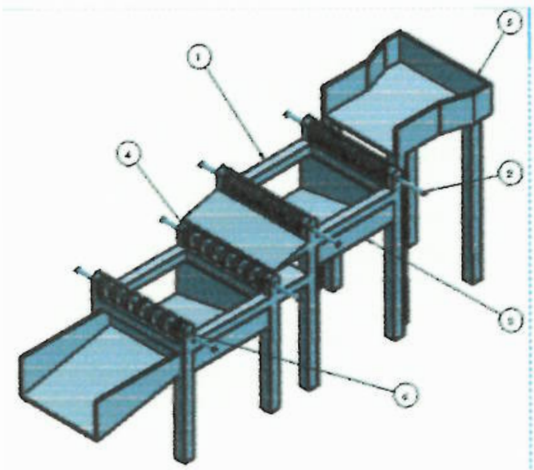
This was developed by *S.K. RUPNAR, R.T. JADHAR AND A.K. RUPNAR* in 2017.

The fruits are fed from hopper into the sorting unit that consists of four spirals, having slope of 20°.The spirals have holes of different diameter ranging from 2.5cm to 17cm. There is a narrow clearance kept between the shafts where the fruits are to be fed and sufficient slope is provided for the spiral so that by gravity, fruits could be rolled and graded efficiently. The spirals were made up of from 22gauge sheet. For collecting unit cushioning material was provided so that fruits graded should not be damaged.

Figure 4 Gravity fruit sorter.

Size based tomato sorting machine.

This tomato sorting machine was built to sort the tomatoes in three grades based on their size that is Small, Medium and Large. The machine works on belt and pulley arrangement. Tomatoes are fed through feeding tray into the machine.



Description

1. Frame

2. Shaft

3. Collecting Bin

4. Pulley

5. Feeding tray

6. Deep Groove Ball Bearing 6304

Figure 5 Machine assembly

Disadvantages of the above size sorting machine

- ✓ High blockage of rubber pathways
- ✓ High costs incurred in the development of the machine
- ✓ Limited to medium and large scale farmers
- ✓ Needs skilled labor to operate it

2.5.3 Automatic grading of fruit

Computer vision system can simulate human vision to perceive the three dimensional feature of spatial objects and has partial function of human brain. The system will transfer, translate, abstract, and identify the perceived information, and consequently work out a decision and then send a command to carry out expectant task. The simple computer vision system consists of illuminating chamber, CCD camera, image collecting card and computer. The chamber maintains an optimal work condition for the camera, namely, keeping a symmetrical and identical illumination in CCD vision area. CCD camera is an image sensor for capturing image. The image collecting card abstracts the image and translate video signal into digital image signal. The computer handles and identifies the digital signal to work out a conclusion and explain.

Fruit color detection

Color is extrinsic reflection of intrinsic quality of fruit. Consequently, it becomes an important study object and a basis of grading in computer vision system. Some color models should be adopted for evaluating color feature of the fruit surface in color discrimination, **(Arjenaki O., 2013)**

Fruits Sorting and Grading using Fuzzy Logic

The system utilizes image-processing techniques to classify and grade fruits. The developed system starts the process by capturing the fruit's image using a regular digital camera. Then, the image is transmitted to the processing level where feature extraction, classification and grading is done using MATLAB. The fruits are classified based on color and graded based on size. Both classification and grading are realized by Fuzzy Logic approach, **(Omidi ARJENAKI, 2012)**

However, automatic tomato sorters are slow in operation in that they require a lot of time to sort a given quantity volume, they are complicated and sophiscated systems, expensive and hard to maintain hence not applicable and favorable to local farmers whose incomes are low.

3 CHAPTER THREE: MATERIAL AND METHODS

In regard to the purpose of the study, this chapter presents the discussion on how the study will be conducted to achieve the specific objectives from the identified gaps in the literature review. This section presents the proposed design methodology for the Tomato sorter.

3.1 Machine description

The prototype consists of majorly the following components; the hopper, sorting drum, pedal power system, sorting screens, the shaft and the frame

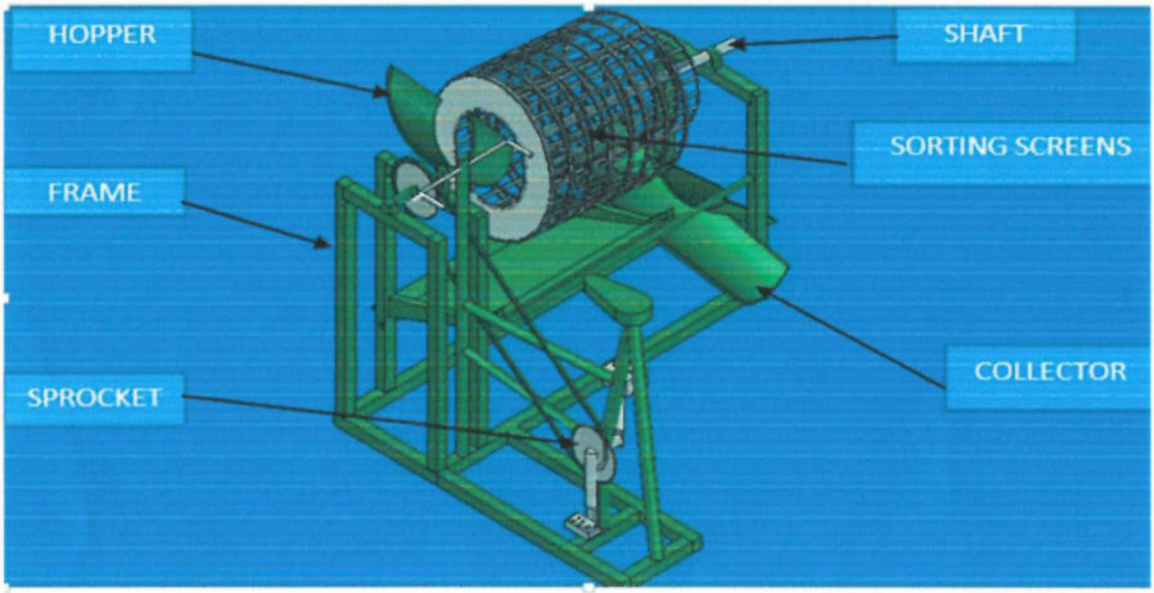


Figure 6 The machine prototype

3.1.1 Component description

The hopper

The hopper is mounted onto the frame. It is the feeding unit of tomatoes into the sorting screens

The sorting sieves

The sorting screen is made of carbon steel rods meshed up in cylindrical pattern with rectangular sieves. This component forms the most essential unit of the system, it sorts tomatoes into three varying grades.

Power unit

The power unit consists of sprockets, chain and shaft. The chain transmits power from the pedals to the shaft to enable the rotational moment of the drum. The seat enables the operator pedal with ease and therefore achieving a constant speed of rotation of the shaft

3.2 Design consideration

3.2.1 Design of the sieves

a) Design of the sorting drum screen

According to Eugene and Theodore (1996), mass of the drum *m* is given by,

$m_d = \rho_d V_d$ ……………………………………………………………………*Equation 1*

Where ρd is the density of the drum material (7850Kg/ m^3),

Vd = (volume of the drum)

$Vd = \pi Dlt$ ……………………………………………………………………*Equation 2*

Where Vd is volume of the cylinder

D =diameter of the drum

L= length of the drum

t= thickness of the drum

b) Design of the screen meshes

The size of the holes was determined basing on the diameter range of large, medium and small tomatoes which are summarized in the table below

Table 2-1 Tomato diameter description **(CODEX STAN 293-2008)**

Hole description	**Average hole diameter (mm)**	
	Oval	**Round**
Small	$> 20 \leq 30$	$> 30 \leq 40$
Medium	$> 30 \leq 45$	$> 45 \leq 55$
Large	> 45	> 55

3.2.2 Driving mechanism

The prototype uses pedal system with chain and two sprockets of equal diameter and number of teeth.

The Chain is used for transferring rotational motion from the sprocket to the shaft because it gives no slip during chain drive, hence perfect velocity ratio is obtained with high transmission efficiency (up to 98 percent) hence transmitting more power than belts and it permits high speed ratio of 8 to 10 in one step.

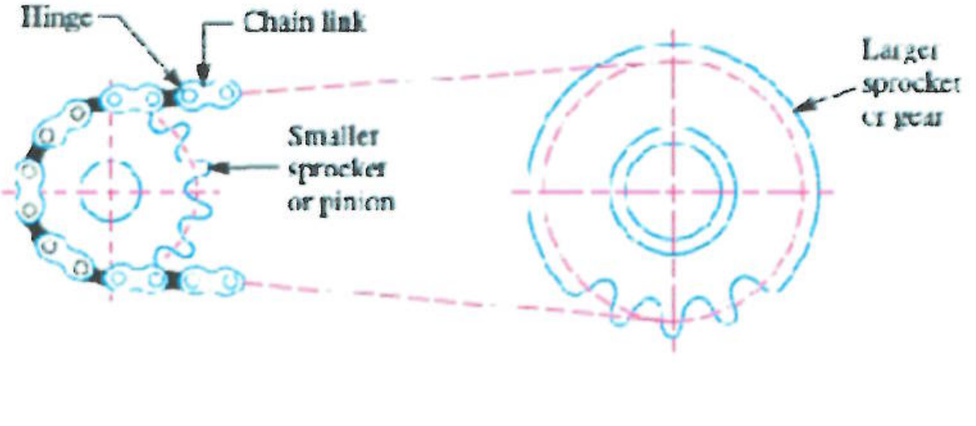


Figure 7 chain and sprocket

a) Pitch Diameter

The sprocket pitch diameter (Pd) is given as;

$$Pd = \frac{p}{sin(\frac{180}{n})} \text{..........} \textit{Equation 3}$$

Where, Pd is the pitch diameter (mm), p is the chain pitch (mm), n is the number of teeth on small sprocket.

b) Speed ratio

The speed of the larger sprocket to the shaft sprocket was calculated as the length of the belt is a function of the pulley diameters and the center distance between them. This was calculated using the equation below as given by Serrate (2005).

$$VR = \frac{N1}{N2} = \frac{Z2}{Z1} \text{..........} \textit{Equation 4}$$

Where $N1$ and $N2$ are the number of teeth on the sprockets respectively also $z1$ and $z2$ are the speed of rotation for smaller and large sprockets respectively.

c) Chain Velocity (Angular velocity)

Using the leg, an allowable design pioneer of about 74.5W and a speed of between 45rpm to 50rpm is recommended, ***(Konz, 1983).*** Therefore, the angular velocity of the chain is obtained from the relation;

$$V = \frac{\pi dn}{60} \text{..........} \textit{Equation 5}$$

Where: V is the velocity of the chain (m/s), n is the number of teeth on crank sprocket, d is the pitch diameter of crank sprocket (mm).

d) Torque generated by the chain

The torque due to the chain was obtained from the equation below

$T = \frac{H}{V}$ ……………………………………………Equation 6

Where H is the power (W), V is the velocity of the chain (m/s) and T is the torque generated.

e) Chain Length (L)

The chain length for the drive will be given by

$L = \frac{p}{2}(N1 + N2) + 2C + (\frac{p}{2}\cos(\frac{180}{N1}) - \frac{p}{2}\cos\left(\frac{180}{N2}\right))$ ………………………………… Equation 7

Where, L is the length of chain (m), C is the Centre distance (m), N1 is the number of teeth on small sprocket, and N2 is the number of teeth on large sprocket.

Centre distance (C) is obtained from the formula given by;

$C = \frac{D+d}{2} + 30$ ………………………………………………………………………Equation 8

Where p is the pitch of the chain

N2 Number of teeth in the large sprocket

N1 Number of teeth in the small sprocket

L length in pitches

D diameter of the large sprocket

d diameter of the small sprocket

3.2.3 Design of the Transmission Shaft and its components

a) Design of the shaft

During the design of the shaft it was considered that the shaft is subjected to both bending and torsional moments without any axial forces. The shaft is designed according to the maximum shear stress theory which is more applicable to ductile materials since the shaft should be made of ductile materials for good performance of the shaft.

The diameter of the shaft was calculated according to the theory of maximum shear stress ***(Khurmi and Gupta, 2005)***

$d^3 = \frac{16}{\pi \tau max} \sqrt{((K_b M_b)^2 + (K_t M_t)^2)}$ ....Equation 9

Where

d = Shaft diameter (m)

τmax = allowable design shear stress for bending and torsion (N/m^2)

For selection of K_b = combined shock and fatigue applied to bending moment

K_t = combined shock and fatigue applied to torsional moment

M_b = bending moment (Nm)

Mt= torsional moment (Nm)

The material for construction of shaft the following criteria is considered:

- ✓ Strength of the material
- ✓ Availability of material in the local market
- ✓ High wear resistant properties
- ✓ Cost of the material

Considering the above criteria for selection of the material for construction of shaft, carbon steel 40C8 is found to be a material that readily exhibits high strength, available on the market, exhibits high wear resistant properties and its relatively cheap.

To estimate the shaft diameter using the above equation, the unknown values of terms that is; Maximum (allowable) shear stress for bending and torsion, τmax, Maximum bending moment, Mb, and Maximum torsional moment Mt, need to be estimated first as follows:

i) Determining the Maximum shear stress in the shaft.

The maximum shear stress, τmax in the shaft is estimated as (V B Bhandari, 2007):

$\tau max = \frac{Syc}{fs} = \frac{0.5Syt}{fs}$..Equation 10

Where τmax = Maximum shear stress (N/m^2)

Syc = Compressive yield strength of the shaft (N/m^2)

Syt = Yield strength of the shaft (N/m^2)

Fs = Factor of safety

For this design, the factor of safety selected is chosen to be 4 since the recommended values of factor of safety range between 3 and 6 based on the critical loading of the component ***(V B Bhandari, 2007)***.

The Yield strength, *Syt* of carbon steel 40C8 material used to construct the shaft is 320MPa ($3.2x10^8$ N/M2) ***(R.S. Khurmi and J.K. Gupta, 2005).***

Therefore, $\tau max = (0.125x3.2x10^8) = 4.0x10^7 N/m^2$

ii) Estimation of maximum bending moment

To estimate the maximum bending moment acting on the shaft, a bending moment analysis of the force loadings acting on the shaft was carried out.

iii) The maximum torsional moment (Mt)

The torsional moment, Mt was calculated using;

$Mt = \frac{H}{V}$ ....*Equation 11*

Where H is the power required to rotate the shaft and drum and V the velocity

$V = \frac{2\pi N}{60}$ ....*Equation 12*

Where N is the estimated speed in rpm

b) The centripetal force acting on the sieve drums (F_C)

The rotational motion from the shaft of the prime mover (pedal sprocket) is transmitted to the driven sprocket carrying the screen drums ***(Hannah and Stephens 1984).***

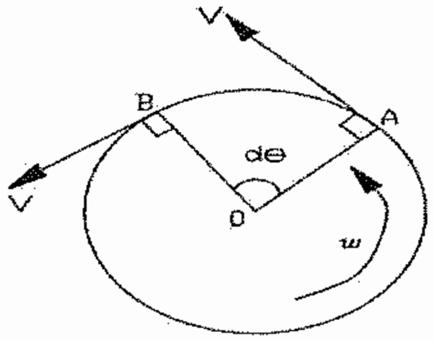


Figure 8 Sieve drum experiencing circular motion

For drums of mass M moving in a circular motion, its acceleration is directed towards the center of the drums and their linear velocity will be tangential to the radius of the shaft. The force helps to establish the power required by the drums. The centripetal force therefore was calculated from;

$F_C = Ma = M\omega^2 r$..*Equation 13*

Where; a = acceleration = $\omega^2 r$; M = mass of the drums; r = radius of the big sieve; F_C = centripetal force; ω = angular velocity

Angular velocity $\omega = \frac{2\pi n}{60}$............................ *Equation 14*

Where n = number of revolutions per minute

c) Power delivered by the shaft to rotate drums

Power required by the screen drums was determined from;

$P_r = F_C \omega r$.............................. *Equation 15*

d) Rotational Torque (T) of the shaft on drums

The value of torque developed by a rotational shaft is given as the product of the force causing the motion multiplied by the radius of rotation

$T = F_c x\, r$.............................. *Equation 16*

3.2.3 Design of the frame

In the design of the machine, the force exerted on the machine includes all the loads due to the sorting drums, shaft, machine operator and the weight of the tomatoes. This frame is designed for stability and strength so as to accommodate all that weight.

Hollow sections were used as the material for constructing the machine frame because they are light in terms of weight and can allow the machine to be easily carried from one point to another, are able to support the weight of the peeling drum and its content, readily available in local market and relatively cheaper.

To determine whether the hollow sections of mild steel material selected to construct the machine frame support the sorting drum and its content without fail, the compressive stress on each machine leg/stand were estimated. The machine is composed of nine stands/legs, therefore the compressive stress on each stand/leg is estimated as:

$\sigma y = FnA$ ....*Equation 17*

Where F is the total force due to the load of the components supported by the frame

A is the area of cross section of the leg

n number of legs.

a) Determining the total force:

Force due to weight of the sprocket, WS calculated from,

$WS = = \frac{Rated\ power}{Pitch\ line\ velocity}$ ....*Equation 18*

$WS = \frac{H}{\pi x d x n 60}$

Where H is the rated power (W), d is the pitch diameter of the sprocket on the shaft, n is the number of teeth of the sprocket on the shaft

Total force on the frame (W_t), was calculated from

$W_T = Wd + Ws + Wt + WH$ ....*Equation 19*

The frame cross sectional area A was obtained from

$A = lxw$ ....*Equation 20*

Table 3-2 Specifications of tomato sorting machine components.

Machine components		Dimensions
Sorting screens	Inner screen	Diameter 0.3m, length 0.73m, holes 0.055mx0.095m
	Outer screen	Diameter 0.5m, length 0.58m, holes 0.045mx0.08m
chain and sprockets		Chain length 7640mm N1=N2=46
Shaft		Length 1.2m, diameter 0.03m
Frame		Angle bars 40mmx40mmx1mm

3.3 Fabrication of the Tomato sorter

The fabrication of the prototype will involve the procedures for selection of materials and fabrication processes that will be used.

3.3.1 Material Selection Criteria

Materials to be used for fabrication of each of the components will be selected after a careful study of the desired characteristics according to the considerations below;

- ✓ Availability of the material on the market
- ✓ The mechanical properties of the material for example strength, toughness, ductility, malleability, brittleness and hardness.
- ✓ Manufacturing considerations for example machinability, weld-ability and cast- ability.
- ✓ Material costs

Table 3-3 Material selection criteria

Machine component	Type of material used	Selection criteria	Recommendation
Sorting screen	Carbon steel	Availability, strength, low cost	Stainless steel
Hopper	Mild steel	Strength	Mild steel
Frame	Mild steel angle bars and hollow section	Straight to weight ratio, durability, affordable	Mild steel
Shaft	Mild steel	Impact resistance	Stainless steel

3.3.2 Fabrication Methods and Processes used

In the Construction of the sorter, the following processes will be used; welding, drilling, machining, cutting, grinding, chiseling and marking out.

The following are the tools, equipment's and machines that will be used to perform the processes.

- ✓ **Drilling machine**; for drilling holes where bolts and nuts will be fixed.
- ✓ **Milling machine.** This will be employed to in all the machining operations on shafts, gears, center punching etc.
- ✓ **Grinders and cutting disc**; they will be used to grind and surface finish the welded joints of the components and also for cutting the sheet metal and other parts.

- ✓ **Welding equipment**; this will consist of the welding transformer and welding electrodes corresponding to the material to be used.

- ✓ **Square**, Tape measures or meter rules; they will be used to take measures of the materials for specified dimensions especially before cutting.

- ✓ **A pair of pliers**; they will be used for tightening of the nuts and bolts.

- ✓ **Bolts and nuts**; they will play an important role in mechanical fastening of separable components.

- ✓ **Measuring and Marking Out Process**. Marking out is the scribing of lines on the surface of a work piece, this will be done in order to indicate the work piece outline and to show the excess material that will be removed. The scribed lines will act as a guide to the extent to which hacksawing will be carried out and a guide to setting up the work piece on a machine.
- ✓ **Machining Process.** This process will involve cutting the marked out work pieces, drilling, machining, by the aid of tools.
- ✓ **Joining Process.** Most of the components of the machine will be joined together by mechanical fasteners including nuts, bolts, screws for their great advantage of easy de-assembling and reassembling without much damage to the joint and also arc welding will be applied.

3.4 Testing the Performance of the Prototype

The sorting efficiency

$$\eta_{ss} = \frac{total\ weight\ of\ correctly\ sorted\ tomatoes}{total\ weight\ of\ tomatoes\ fed} x100\% \ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 21}$$

The percentage of mis sorting (error) was evaluated using the equation below:

$$\%Miss\ sorting\ (error) = \frac{weight\ of\ mis\ sorted\ tomatoes\ in\ all\ the\ collectors}{total\ weight\ of\ tomatoes\ fed.} x100\% \ldots.. \textit{Equation 22}$$

The percentage damage of tomatoes was calculated as below

$$\%damage = \frac{total\ weight\ of\ damaged\ tomatoes\ in\ all\ the\ collectors}{total\ weight\ of\ tomatoes\ fed} x100\% \ldots\ldots\ldots\ldots \textit{Equation 23}$$

Overall machine efficiency η_c

$$\eta_c = \frac{\eta_{ss} - (\%error + \%damage)}{\eta_{ss}} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 24}$$

Machine Through put Capacity (MTC)

$$MTC = \frac{fed\ volume}{time\ taken} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 25}$$

3.5 The Economic Evaluation of the Prototype

The prototype will be economically evaluated using the following methods

Simple Payback

This method calculates the time in years, required to recover the original investment through the net savings realized or net income derived from the investment and it is calculated as shown below;

$$Simple\ Payback\ Period = \frac{Initial\ Investiment}{annual\ net\ profit\ Cash\ flows} \ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 26}$$

- ✓ The advantages of simple payback analysis are that it requires simple computation and is easily to understand as an economic screening indicator.

- ✓ The disadvantages of this method are that it does not consider the time value of money and that sometimes it is unrealistic because project service life is not considered.

Simple Rate of return

This calculates the percentage or rate at which an investment is going to return. This iscalculated in percentage as shown below;

$$Rate\ of\ return = \frac{annual\ net\ profit\ cash\ flows}{Initial\ investment} x100\% \text{...} Equation\ 27$$

The simple rate of return is the reciprocal of payback expressed as a percentage and therefore has the same advantages and disadvantages as payback.

Present value (PV)/present worth analysis

This is a means of equating an amount received or paid in the future in today's dollars. All cash flow in every year of the project, whether costs, savings, or net cash flow, are related to each other in a way that accounts for when they occur.

Given some anticipated future value (FV) or future worth of savings over a number of years, PV calculations are used to determine the dollar amount today (PV) that is equivalent to some anticipated FV amount. The equivalence depends on the rate of interest that can be earned on investments during the period under consideration, or the discount rate. The PV of a future sum of money over a number of periods at a given interest rate per period is calculated by the formula shown below.

$$PV = \left(\sum_i^n \frac{FV}{(1+r)^i}\right) - \boldsymbol{i_0} \text{..} Equation\ 28$$

Where;

n = Number of periods over which the value is calculated

$\frac{1}{1+r}$is the discounting rate, FV= Future value, $\boldsymbol{i_0}$= Initial Investment

r = Threshold interest rate or discount rate per period

4 RESULTS AND DISCUSSIONS

This chapter constitutes of the following:

- ✓ The design results
- ✓ The testing process of the tomato sorting prototype and the different equipment used to carry out the testing process.
- ✓ The results obtained from the testing process and analysis of the results.
- ✓ The economic evaluation of the fabricated the tomato sorting prototype.

4.1 The design results

4.1.1 The sorting screens.

For the purpose of weight and easy sorting (ergonomic), the inner sorting drum was considered to have a length (ld) of 730mm and diameter (Dd) of 300mm and the outer drum of length 580mm and diameter of 500mm

Volume of the inner drum = πx0.3x0.73x0.001 =0.0007m^3

Weight of inner drum = 8750x0.0007x9.81 = 60.1N

Volume of the outer drum =πx0.5x0.58X0.001 = 0.00091m^3

Weight of the outer drum =8750x0.00091x9.81 = 78.1N

Total weight of the drums Wd= 60.1+78.1 = 138N

Volume and weight of the tomatoes to be sorted depend on the volume of the inner drum screen

For easy sorting, the volume of tomatoes was taken to be 80% of the drum screen volume

Vt = 0.8x0.0007 = 0.00056m^3

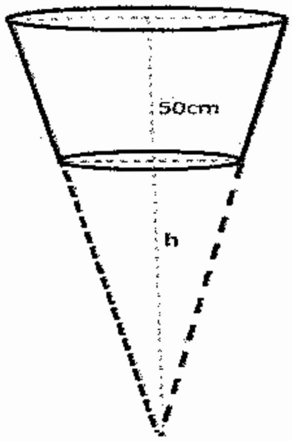
Weight of tomatoes = ρvg, ρ (tomato bulk density) =481Kg/m^3

Weight of tomatoes = 481x0.00056x9.81 = 2.6N

Weight of tomatoes and the sorting drum screens

=2.6+78.1+60.1 = 140.8N

The hopper was sized depending on the tomato volume in the drum per unit time thereafter which its v volume was determined as below



$V = 1/3\ (\pi r^3(h+0.5) - 1/3(\pi r^3 h)$

$=1/3(\pi\ (0.185^3 x2.64)) -1/3((\pi(0.15^3 x2.142)$

$= 0.1m^3$

The hopper was inclined at 40^0 basing on the angle of repose of tomatoes

4.1.2 Driving mechanism

a) Pitch diameter

Assuming a standard link distance (for bicycle chain) of ½ Inch, p=14.6mm and n=46, the pitch diameter is obtained as

$$P_d = \frac{14.6}{\sin(\frac{180}{46})}$$

Pd=186.1mm

b) *Speed ratio*

Considering two sprockets of N1=46 and N2=46, speed ratio is,

$VR = \frac{46}{46}$, therefore, $VR=1:1$

c) ***Chain Velocity (Angular velocity)***

Using the equation of the pitch diameter for n=46, d=186.1mm.

$$V = \frac{\pi x 186.1 x 10-3 X 46}{60}$$

$V=0.45 m/s$

d) ***Torque generated by the chain***

The torque due to the chain,T

Given that H=75W and V=0.45m/s,

then the Torque, T=167N

4.1.3 The Transmission Shaft and its components

a) Design of the shaft

i) The Maximum shear stress in the shaft.

The maximum shear stress, τmax.

For this design, the factor of safety selected is chosen to be 4 since the recommended values of factor of safety range between 3 and 6 based on the critical loading of the component ***(V B Bhandari, 2007).***

The Yield strength, Syt of carbon steel 40C8 material used to construct the shaft is 320MPa ($3.2x10^8$ N/M2) ***(R.S. Khurmi and J.K. Gupta, 2005).***

Therefore, $\tau max = (0.125x3.2x10^8) = 4.0x10^7 N/m^2$

ii) **Estimation of maximum bending moment**

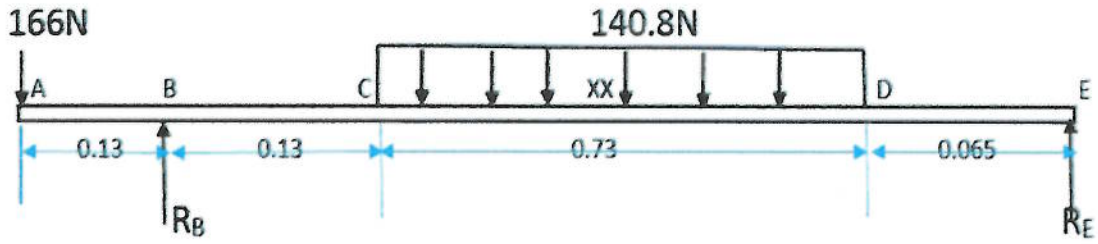


*Figure 9 **Force diagram showing loadings on the shaft***

Loading on the shaft

Where Ls = length of the shaft (m) =1.055m

WT = Total weight exerted on the shaft due to the sorting drum

WS = Load on the shaft due to the sprocket

RB and RC =Reactions on the shaft

The reactions of the bushes on the shaft, RB and RC are estimated using the following conditions:

- ✓ The algebraic sum of forces acting on the shaft is equal to zero

$RB+RE-WS-WT=0$

$RB+RE-166-140.1=0$

$RB+RE=306.1$

The algebraic sum of moments about any point on the shaft are equal to zero

Taking moments about point E

$\Sigma MR_E=0$

$[(140.1)(0.365+0.065)]+(166\text{x}1.055)-RBx0.925=0$

$RB=242.5N$

$R_E=63.6\text{N}$

Taking moments at point B

$\Sigma M\text{RB}=(242.5\text{x}0.365)+(63.6\text{x}0.935)-(166\text{x}0.13)$

$\Sigma M\text{RB}=126.4\text{N}$

Taking moments about point xx

$\Sigma MXX=(242.5x0.495)-(166x0.625)+(63.6\text{X}0.43)$

$\Sigma MXX=43.6$

Therefore, from the above calculations, the maximum bending moment is that of;

$Mbmax$=126.4N

iii) **The maximum torsional moment (Mt)**

The torsional moment, Mt

V=1.05m/s

H=74.5W

Mt=71.4NM

$d^3 = [\frac{16}{3.14x4.0x107} \sqrt{(1.5X126.4)^2+(1x71.4)^2}]$

d=0.0295m

d = 0.03 was used

b) The centripetal force acting on the sieve drums (F_C)

For n= 10rpm,

ω = 1.05rads/s

M = 14.1Kg

F_c = 7.8N

c) Power delivered by the shaft to rotate drums

Power required by the screen drums P_r;

$P_r = 7.7 \times 1.05 \times 0.5$

$= 4.04W$

Rotational Torque (T) of the shaft on drums

The value of torque developed by a rotational shaft T,

$T = 7.7 \times 0.5 = 3.85Nm$

4.1.4 The frame

a) The total force acting on the frame:

Force due to machine operator, WH =650N (considering a human of about 65kg)

Force due to weight of the drum, Wd= 138.6N

Force due to weight of the tomato, Wt = 2.6N

Force due to weight of the sprocket,

$WS == \frac{74.5x60}{\pi x186.1x10-3x46}$

Therefore, WS=166N

Total force on the frame (W_t)

WT=138+166+2.6+650 = 956.6N

Cross sectional area of each stand, A was given by;

A= 0.04x0.04 = 0.0016m^2,

For 9 stands, A = 9X0.0016 = 0.0144m^2

Therefore, compressive stress, $\sigma y = \frac{956.6}{=0.0144}$ = 66.4X10^3N/M

Therefore, failure does not occur when the compressive stress is less than the ultimate tensile strength.

4.2 Testing process and the equipment used for testing

During the testing process, tomatoes to be sorted were measured on the weighing scale to determine the weight and then feed into the sorting unit at given intervals of one batch after the other through the hopper. The machine is run for some time and the sorted and damaged tomatoes of each collector are weighed on the weighing scale. The equipment used during the testing process included:

- ✓ Weighing scale to measure weights of both the unsorted and sorted tomatoes before and after the sorting process respectively.
- ✓ The stop clock to measure the time taken to carry out the sorting process.

Testing process is carried out to determine the output of sorted tomatoes by the machine in a given period of time.

4.2.1 Results obtained and their analysis

The results obtained during the different tests to determine the rate of sorting efficiency are summarized in table 4-1 below.

Table 4-1 Prototype test results at 5rpm speed

Tests	Feed volume (Kg)	Time taken (mins)	Correctly sorted tomatoes (Kg)	Mis-sorted tomatoes (Kg)	Damaged tomatoes (Kg)

1	20	15	19.5	0.4	2
2	30	20	28.9	0.9	3.1
3	50	32	47.5	1.8	5

Table 4-2 Test results at 10rpm

Tests	Feed volume (Kg)	Time taken (mins)	Correctly sorted tomatoes (Kg)	Mis-sorted tomatoes (Kg)	Damaged tomatoes (Kg)
1	20	10	19	0.8	3.5
2	30	16	27	2	5
3	50	28	45	4	7

Table 3-3 Test results at 15rpm

Tests	Feed volume (Kg)	Time taken (mins)	Correctly sorted tomatoes (Kg)	Mis-sorted tomatoes (Kg)	Damaged tomatoes (Kg)
1	20	7	16	2.4	4.6
2	30	12	22.1	5.8	6.7
3	50	20	38	8.2	10

Table 4-4 Test results at 20rpm

Tests	Feed volume (Kg)	Time taken (mins)	Correctly sorted tomatoes (Kg)	Mis-sorted tomatoes (Kg)	Damaged tomatoes (Kg)
1	20	4	11.4	5.2	6.2
2	30	7	18	11.8	9
3	50	12	31	16.5	16

4.3 Testing performance of the prototype

At 5rpm,

The sorting efficiency

$\eta_{ss} = ((\frac{19.5}{20} + \frac{28.9}{30} + \frac{47.5}{50})/3)x100\% = 96.3\%$

The percentage of missorting (error) was evaluated using the equation below:

$\%Miss\ sorting\ (error) = ((\frac{0.4}{20} + \frac{0.9}{30} + \frac{1.8}{50})/3)x100\% = 2.9\%$

The percentage damage of tomatoes was calculated as below

$\%damage = ((\frac{2}{20} + \frac{3.1}{30} + \frac{5}{50})/3)\ x100\%) = 10.1\%$

Overall machine efficiency η_c

$\eta_c = \frac{96.3-(2.9+10.1)}{96.3} x100\% = 86.5\%$

The through put capacity = (20+30+50) / (15+20+32) = 89.6Kg/hr

At 10 rpm

The sorting efficiency

$\eta_{ss} = ((\frac{19}{20} + \frac{27}{30} + \frac{45}{50})/3)x100\% = 91.5\%$

The percentage of missorting (error) was evaluated using the equation below:

$\%Miss\ sorting\ (error) = ((\frac{0.8}{20} + \frac{2}{30} + \frac{4}{50})/3)x100\% = 6\%$

The percentage damage of tomatoes was calculated as below

$\%damage = ((\frac{3.5}{20} + \frac{5}{30} + \frac{7}{50})/3)\ x100\%) = 16.1\%$

Overall machine efficiency η_c

$\eta_c = \frac{91.5-(16.1+6)}{91.5} x100\% = 75.8\%$

The machine through put capacity = (20+30+50) / (10+16+28) = 111Kg/hr

At 15 rpm

The sorting efficiency

$\eta_{ss} = ((\frac{16}{20} + \frac{22.1}{30} + \frac{38}{50})/3)x100\% = 76.6\%$

The percentage of missorting (error) was evaluated using the equation below:

$\%Miss\ sorting\ (error) = ((\frac{2.6}{20} + \frac{5.8}{30} + \frac{8.2}{50})/3)x100\% = 17.2\%$

The percentage damage of tomatoes was calculated as below

$\%damage = ((\frac{4.6}{20} + \frac{6.7}{30} + \frac{10}{50})/3)\ x100\%) = 21.8\%$

Overall machine efficiency η_c

$\eta_c = \frac{76.6-(17.2+21.8)}{76.6} x100\% = 49.1\%$

The machine through put capacity = (20+30+50) / (7+12+20) = 153.8Kg/hr

At 20 rpm

The sorting efficiency

$\eta_{ss} = ((\frac{11.4}{20} + \frac{18}{30} + \frac{31}{50})/3)x100\% = 59.7\%$

The percentage of missorting (error) was evaluated using the equation below:

$\%Miss\ sorting\ (error) = ((\frac{5.2}{20} + \frac{11.8}{30} + \frac{16.5}{50})/3)x100\% = 32.7\%$

The percentage damage of tomatoes was calculated as below

$\%damage = ((\frac{6.2}{20} + \frac{9}{30} + \frac{16}{50})/3)\ x100\%) = 31\%$

Overall machine efficiency η_c

$\eta_c = \frac{59.7-(32.7+31)}{59.7} x100\% = (-6.7)\%$

The machine through put capacity = (20+30+50) / (4+7+12) = 434.7Kg/hr

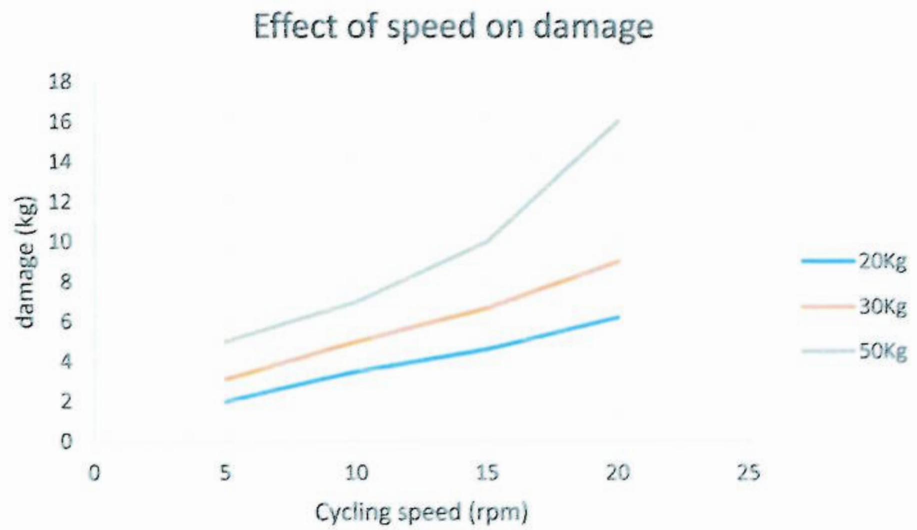


Figure 10 effect of speed on tomato damage.

S/N	**ITEM**	**QUANTITY**	**UNIT COST**	**AMOUNT**

4.4 Economic analysis of the prototype

The economic evaluation of the machine involves estimating the cost of the machine by considering cost of all expenses incurred to fabricate it and the profit margin. The cost of capital was considered to be 10% of the total cost of all expenses incurred to manufacture the machine. Considering the total annual costs of Ugx 2,000,000, annual cash inflow of Ugx 6,000,000, machine life time of 5 years and a salvage value of Ugx 200,000.

4.4.1 Estimated cost of the tomato sorter

All the costs incurred in the design and development of a tomato sorter are shown in the Table 4-3 below

Table 4-3 Estimated costs of a tomato sorter.

1	Materials for the machine parts			300000
2	Labor	1	150000	150000
3	Paint	0.5L	16000	8000
4	Tomato fruit samples	40Kg	3000	120000
5	Transport			80000
6	Airtime and internet			20000
7	Printing and binding of reports			60000
	TOTAL			738000

4.4.2 Cost evaluation analysis

Table 4-4 cost evaluation analysis

Year	Narrative	Cash flows (UgX)	Discounting factor at 10%	Present value
0	Investment	(727800)	1	(738000)
1-5	Annual cash inflow	6,000,000	3.2745	19,647,000
1-5	Total costs	(2,000,000)	3.2745	(6,549,000)
5	Salvage value	200,000	0.4972	99,440
			NPV =	12,459,440

Since the project has a positive NPV, it seems viable

4.3.3 profitability index (PI)

$$PI = \frac{\text{Net present value}}{\text{initial investment}} = \frac{12459440}{738000}$$

=16.88

Therefore, the return on every amount invested in the tomato sorter is 16.88

5 CHAPTER5: CONCLUSSIONS AND RECOMMENDATIONS

5.1 CONCLUSSIONS

The results obtained from the machine testing, show that the overall efficiency of 86.5%, 75.8%, 49.1%, and -6.7%, mis sorting of 2.9%, 6%, 17.2%, and 32.7%, damage of 10.1%, 16.1%, 21.8%, and 31% with machine through put capacity of 89.6Kg/hr, 111Kg/hr, 153.8Kg/hr and 434.7Kg/hr were obtained at speeds of 5rpm, 10rpm, 15rpm and 20rpm respectively hence showing better speeds of operation as 5rpm and 10rpm

The efficiency of the machine was much affected by the internal bruising of tomatoes and this was mainly due to the effect of the big falling distance of tomatoes into the sorting screen (gap between the hopper feeding edge and the receiving screen)

The machine is affordable to the local farmers and can easily be used by anyone, can easily be repaired and maintained.

However, according to the machine set up, it can be used to sort other fruits like oranges and mangoes.

5.2 RECOMMENDATIONS.

The machine may be modified to one that sorts to more quality parameters of tomatoes like color, damage, weight, and others

The machine may be adopted for commercial use in Uganda

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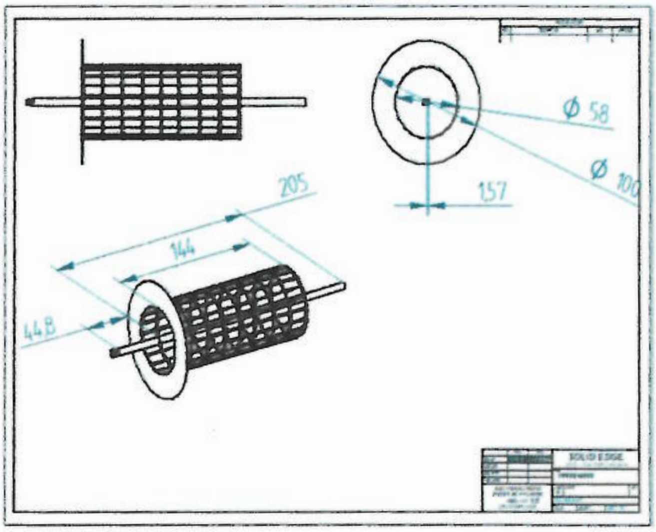
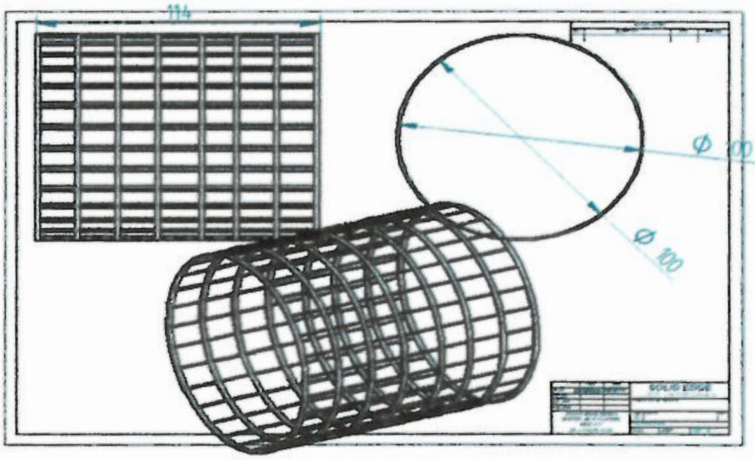
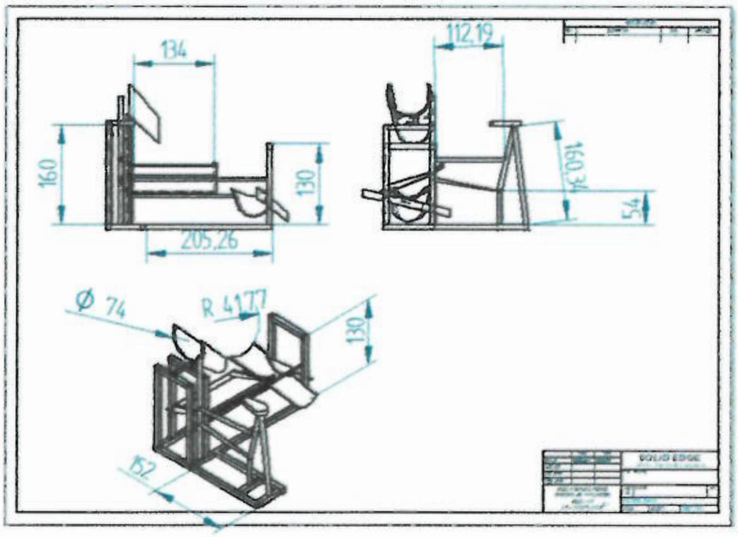
APPENDICES



Appendix A.1 The inner drum screen



Appendix A.2 The outer drum screen



Appendix A.3 The frame

Appendix A.4 The machine prototype before and after completion.