Development of an Automated Plantain Slicing Machine

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Abstract—the limitation attributed to traditional manual hand slicing of plantain, as well as manually operated plantain slicers, have led to a great difficulty in meeting the high rate of plantain demand by both medium and large scale plantain chip producing industries in Nigeria. As a result, a power operated plantain chip slicing machine was designed and developed. The machine slices a set of six plantains in 3.3 seconds, to uniform thickness of 2.2mm, by the action of a reciprocating blade and conveyor belt which serves as a feeding and discharge mechanism. Test performance carried out gave an efficiency of 81.93% and 91.07% for ripen and unripen plantain fingers respectively and a capacity of 285g/s (1026kg/h). The mean thickness of cut for the sliced chips was found to be 2.20 ± 0.012 mm. Further modification is in view to further improve on the efficiency.

Keywords — ***plantain chip, reciprocating blade, discharge mechanism, plantain fingers, mean thickness***

I. INTRODUCTION

Plantain (Musa spp.) is an important dietary source of carbohydrate in the humid tropical zones of Africa, Asia and South America (Robinson, 1996). It is rich in vitamins A, C and B group as well as minerals such as calcium and iron (Marriott and Lancaster, 1983). Musa spp. are useful as food to be consumed by human either as flour to be used in confectionaries or as jams and jellies; in chips etc. Its peel can be used as animal feed. All parts of the plantain plant have medicinal applications; the flower is uses in bronchitis and dysentery and on ulcers, cooked flowers are given to diabetic patients etc. Its leaves are also useful for lining cooking pots and for wrapping food materials. Improved processes have also made it possible to utilize plantain fiber for ropes, table mats and handbag (Chandler, 1995).

As a result of poor storage facilities, substandard transportation network and high standard of exportation requirements, leading African plantain producing countries like Nigeria and Ghana, lost lots of tons of plantains to inadequate post-harvest handling and management practices (Obeng, 2004). Hence, most plantain farmers are forced to sell their produce cheaply at meagre prices to cut their losses. Processing of these harvested plantain into various forms, most especially into chips, have not only proven to be a remedy to preventing post-harvest loses, but as a means of income and livelihood to the producers, since both ripen and unripen plantain can be used in this case.

In an effort to meet the high demand for plantain slices to industries, families and schools, several means have been devised in slicing plantain into pieces which is further processed into baked or fried chips and flour. The use of hand operated platform type or rotary type slicer by most of the entrepreneurs presently does the slicing of peeled plantain. However, some small scale entrepreneurs still use traditional household knives. These equipment have proven to be labor-intensive and cumbersome in operation, posing danger to operators' finger by inflicting injury while slicing. It also produces slices of non-uniform sizes, shapes, thickness and chips of poor end quality after frying. Hence, there is a need to develop an automated plantain chipping machine that will help to eliminate these challenges and yet effective for both small and large scale processing of plantain.

II. LITERATURE REVIEW

Plantain and other banana species are perennial crops that are staple and starchy in nature (Tchango et al., 1999). The origin of plantain can be traced to South East Asia because this location has been identified as the area where the earliest domestication of crop occurred. (Simmonds, 1962). Plantain belongs to the genus musa of the family musaceae consisting of about 40 different species (Simmonds, 1962 and Tchango et al., 1999). Nearly all edible plantain cultivar are derived from two major wild species, Musa acuminate and Musa balbisiana (Robinson, 1996). These wild species are classified on the basis of the proportion of the genetic constitution contributed by each parental source (Robinson, 1996).

Globally, plantains and bananas are one of the most important staple food, cultivated in large scale of about 10 million hectares of land, with an annual yield of 88 million tons. Its ability to produce fruit all through the year as well as its low labour requirements - when compared to other crops like potatoes, yam cassava, cowpea and rice - makes it attract farmers to engage in its production and trade. (Frison and Sharrock, 1999; Marriott and Lancaster, 1983; IITA, 1998).

Plantain is a tropical plant that requires a warm humid climate to grow successfully. A mean temperature of 26.7°C, rainfall of 100 mm/month and a deep, well-drained friable loamy soil with adequate organic matter is the ideal condition for its cultivation (Tchango et al., 1999; and IITA, 2015).

A. Plantain harvesting

The size of plantain fruit increases, as it grows, accumulating starch until it reaches complete physiological maturity. It is ready for harvest when the bunch is well filled with fingers of relatively firm, thick and some few ripe plantain fruits.

The dwarf type plantain can be harvested by directly cutting the bunch from the pseudostem using a cutlass. In the case of tall breeds, the pseudostem is either cut at about 1.5m to 2m height from ground level, or close to the top level, allowing the stem to bend over due to the weight of the bunch. Using a machete, the plantain bunch is then cut away from the pseudostem (Wainwright and Burdon, 1991; Dadzie, 1994; and Tchango et al., 1999).

B. Post-harvest handling

The harvested bunches of plantain are cut into fragments, washed and then stored in plastic pellets. This is done to prevent the rate of mechanical damages on the plantains and for easy transportation and carriage. Being a fragile and perishable staple food, the rate of plantain postharvest losses varies from country to country based on the organization of market chains and modes of consumption. In many developing countries that produce plantain, there are no adequate data on the exact quantity of plantain lost during the postharvest stage of plantain production (IITA, 2015).

Determining plantain post-harvest losses is a relatively complex process. This is because both matured green fruits and overripe plantain fruits can be consumed or processed at various stages. However, some factors accelerate the rate of plantain losses after harvesting them. These include; poor handling, bad roads and transportation network in the production areas; harvesting matured crop close to fruit ripeness; and inadequate storage facilities. In the project carried out by FAO (1987), plantain post-harvest losses, in developing plantain producing countries, should not be more than 35% of the total harvested crops.

C. Plantain processing

Plantain is taken in various forms such as fried plantain, boiled plantain, roasted plantain, baked plantain, and plantain chips. The quality of processed plantain chips or flour are greatly affected by the stage of ripeness of the plantain (Yomeni et al., 2004). Slices of either unripe, slightly ripe or ripe plantain pulp, of about 2-4mm thick, can be processed into plantain chips by frying in vegetable oil and then packaged into sachets (Ekunwe and Ajayi, 2000). Fig. 1 shows the unit operations in processing plantains into fried chips.

Plantains can also be processed into dough (Amala) by peeling, slicing, air drying, milling into flour and preparing with boiled water to form dough which is served with vegetable stew. Slightly ripe plantain can also be roasted and served as snacks (booli). In some part of West Africa, plantain are fermented into beer and wine (Tchango et al., 1999). Plantain peels are used as feed for livestock as well as for soap production. The leaves can be used for packaging foods and as roofing materials. (Akinyemi et. al, 2010).

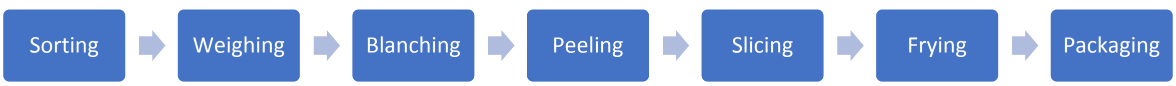

Fig. 1: Unit processing of plantain into fried chips(www.manufacturingtodaynigeria.com**)**

D. Technology of Slicing

Plantain slicing is a size reduction process that involves the application of shearing force on plantain with the aid of a cutter blade or knife to shear through the plantain to obtain a minimum deformation and rupture of the cell wall. The cutter blade could either be on a reciprocating or rotary motion. In some rare cases, the blades are made stationary while materials travel against it and gets sliced in the process (Yusuf and Abdullahi, 2007; and

Sonawane et al., 2011). According to Yusuf and Abdullahi (2007), slicing action could be accomplished through the following methods:

- **i.** Slicing action with a sharp smooth edge: This involves slicing and cutting action on bio-materials that result in the structural failure of the material due to shear, compression or tension. This method requires frequent sharpening of the blades.
- **ii.** Tearing action with a rough serrated edge: This method eliminates the limitation of frequent sharpening. It operates by a combination of both slicing and sawing action to cut through bio-materials.
- **iii.** High velocity single element impact with a sharp or dull edge
- **iv.** A two element scissor type action: Two knives or cutting elements move in opposite directions against one another and thereby getting the food item sliced in the process.

Zhou et al. (2006) reported that, the fracture of a material, which is a result of the interaction between the blade edge and the material, depends both on the material properties and the knife geometry. Mahvash and Hayward (2001) formulated a relationship between the cutting force and depth of cut during slicing. Atkins et al. (2004) further clarified why there is a smaller cutting force required when pressing and slicing contrasted with the application of only pressing force while slicing.

Another factor that influences the cutting forces is the blade sharpness. This is because it has direct impact on the cutting moments and the forces applied by the operator (McGorry et al., 2005). The interaction between the blade and the material is an area, which can be shown from the microstructure of a knife (Tech Edge, 2005). Figures 2 and 3 are a simplified model that illustrates the cutting force acting on a semi-infinite body as reported by Zhou et al. (2006). Fig. 2 demonstrates the interaction between the blade and the material. It can be seen that the contact length between the blade edge and the material is l having a coordinate of (−0.5l, 0.5l) in x direction and the width of the blade edge is 2a with a (−a, a) coordinates in y direction.

Fig. 3 illustrates the force exerted on the material by the blade. Two assumptions were made; firstly, it is assumed that the blade exerts a constant slicing force in the direction parallel to the x-axis, and secondly, the blade has a cutting force distribution in the yz plane. The blade has force of a maximum intensity q at [-s, s] coordinates in the y direction and it linearly decreased to zero at -a, and a. The cutting force P acting on the surface of the body has two components; the Normal force $P_n$along the z direction and the Tangential force $P_t$along the x direction. α is defined as the slicing angle of the force P from the positive z direction. Based on the assumption that the blade exerts a constant cutting force on the material, the area pressures $p_n$and $p_t$can be used to calculate total force $P_n$and $P_t$as follows:

$$P_n = \int_{-l/2}^{l/2} \int_{-a}^{a} p_n \, ds \, dv \qquad 1$$

$$P_t = \int_{-l/2}^{l/2} \int_{-a}^{a} p_t \, ds \, dv \qquad 2$$

Where

P_t = Tangential force, N.
P_n = Normal force, N.
l = The contact length between the blade edge and the material, m.
a = The blade edge-width, nm
s = blade shape (Zhou *et al.*, 2006).

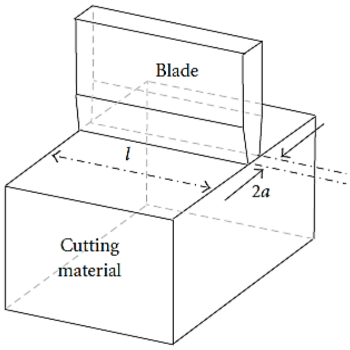

Fig. 2:Interaction between the blade and the material while cutting (Zhou et al., 2006**)**

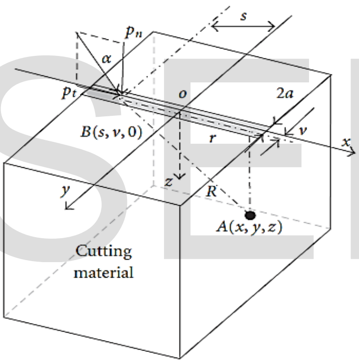

Fig. 3: The cutting forces acting on the material (Zhou et al., 2006**)**

E. Existing Plantain Chipping Machines

Researchers have put lots of efforts in developing automated slicers to chip plantain and other food materials with similar properties. This effort was aimed at developing slicers to meet the requirements of large scale processing industries and eliminate drudgery and other limitations associated with manual hand slicing. Yet only a few of such machines have been developed to the minimum required standard. The trend of development of these machines are examined below showing their methods of operations, merits and limitations.

i. Hand operated plantain slicer

Ojuloge (1999) developed a manual hand operated equipment for chipping plantain for small scale plantain chip producing industries. In this design, a peeled plantain fed to the hopper is stopped by the adjustable plate. The plate is also responsible for adjusting the chip thickness. The hand crank is manually rotated to transmit motion to the bevel gears. The bevel gear converts this motion from the vertical plane to the horizontal plane and supplies it to the cutter blades. The cutter blades slice the fed plantain in the hopper. On testing the machine, it was discovered that the machine capacity increases with an increase in chip thickness. The maximum machine capacity and efficiency of 382.7 kg/h and 100% was recorded for a 15mm thick fully ripened plantain. The maximum chip loss of 57.1% was recorded for unripen 15mm thick plantain. Hence, the machine can be best used for chipping fully ripened plantain.

Limitations

a. Irregularities in speed was experienced since the machine is manually powered. Hence, it requires an electric motor to obtain constant speed during operation.
b. Over-ripened plantain tends to stick to the cutter blades during operation. A limitation that can be overcome using a scrapper.
c. The machine performance was so poor while slicing unripen plantain.
d. More time is required on chipping large quantity of plantain since the machine hopper can only accommodate one plantain at a time.

ii. Mechanized plantain slicer

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

Limitations

a. There exist a large variation in chip thickness.
b. Ripened and over-ripened chips tend to stick to the mesher and the edges of the blades.
c. The thin stainless steel blades tends to bend during cutting action and hence, altering blade interval and chip thickness.
d. There is difficulty in removing and sharpening of blades.

Fig.4: Hand operated plantain slicer (Ojuloge, 1999)

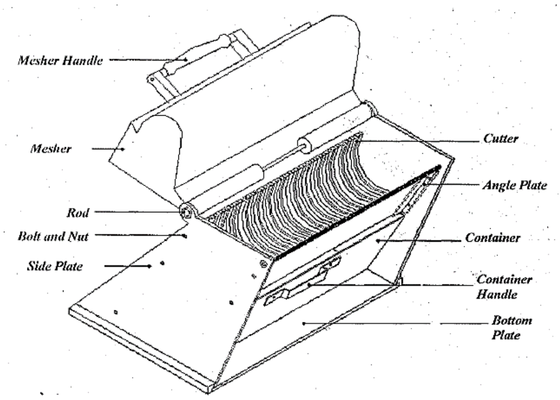

Fig.5:Mechanized plantain slicer (Obeng, 2004)

iii. Motorized plantain slicer

An electric powered plantain slicer was developed by Adewumi *et al.* (2011). This was a slight modification of Ojuloge (1999) version of the machine. The machine has a single cutter blade and an electric motor that serves as a power source. It produced a maximum machine capacity and efficiency of 451.39 kg/h and 97.25% respectively for a 15mm thick fully ripened plantain. The machine capacity and performance efficiency is expected to increase with an increase in number of blades. The machine is shown in Fig. 6.

iv. Power operated banana slicer

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

Limitations

- **a.** It could only slice a few plantain at a time
- **b.** Some over-ripened plantain tends to stick to the blade while some are whirled to other parts of the cutter section.

Fig. 6: Motorized plantain slicer (Adewumi *et al.*, 2011)

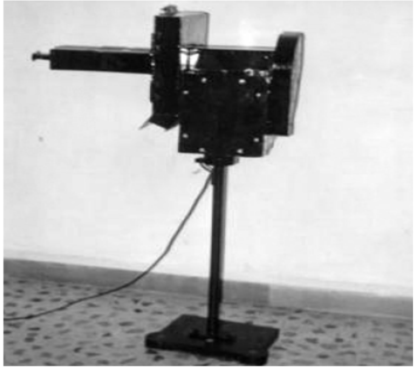

Fig. 7: Power operated banana slicer (Sonawane *et al*., 2011)

v. Design of aplantain chip slicing machine

Okafo and Okafo (2013) designed a plantain slicer for small scale industries. It is made up of a cutter chamber, an electric motor and a feed and discharge mechanism. The cutter chamber consists of a stainless steel blade, a flywheel and a connecting rod. The Geneva and the conveyor make up the feed and discharge mechanism. The machine was developed to slice a single plantain in 4 seconds during a single revolution of the input shaft. The machine efficiency is 73.8%.

Limitations

a. Chip thickness cannot be varied or controlled.
b. Irregularities were observed in chip thickness due to the momentary fluctuations between the time of cut and the time the conveyor moves.

vi. Development of a plantain slicing machine

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

Fig. 9: Development of a Plantain slicing machine (Adesina *et al.,* 2015)

III. MACHINE DESCRIPTION

The machine is made up of a support mechanism, a cutter mechanism, a feeder mechanism, an outlet chute and an electric motor.

The support mechanism comprises a 5mm by 20mm mild steel angle iron which is used for the fabrication of the frame, and seats for an electric motor and a crankshaft. The frame is a 650mm long, 300mm wide and 300mm high angle iron, welded firmly together with electric arc welding machine using gauge 12 steel electrode. The frame was designed for high strength, rigidity and vibration resistance. The motor seat is a 150mm long, 100mm wide and 100mm high, serving as a basement to which electric motor is bolted to. The crank seat is the part of the support mechanism whose function is to provide suitable platform for proper functioning of the crankshaft. It has a dimension of 80mm long, 90mm wide and 200mm high.

The cutter mechanism comprises the blade, blade housing, connecting rod and crank. The blade is a removable 0.5mm thick stainless steel sheet, of 300mm wide and 70mm high, bolted firmly to the blade housing. Its basic function is to slice plantain, loaded on the conveyor, by reciprocation. The blade housing is pair of hollow cylindrical pipe of 30mm diameter and 100mm long. It is welded fixed to the frame to serve as a guard which allow free reciprocation of the blade in the vertical axis. The connecting rod links the blade to the crank and mainly function to transfer motion from the crank to the blade. The crank converts rotational motion from the electric motor to a reciprocating motion to power the blade.

The feeder mechanism consist of a conveyor belt mounted on two rollers. This act both as feeding and discharge mechanisms. The conveyor was designed to travel at a speed of 80rpm. It acts as a feeder mechanism when it conveys loaded plantain to the reciprocating blade and act as a discharge mechanism when it moves the sliced plantain from the blade to the outlet chute. The roller is a pair of mild steel hollow shaft of length 300mm and a diameter of 50mm machined to a solid shaft of length 450mm and diameter 30mm.

The outlet chute is the discharge point of the machine where sliced plantain are collected. It is made up of a stainless steel sheet inclined at an angle of 30^o to the horizontal such that sliced plantain falls by gravity to the collecting tray.

The electric motor is the prime mover that supplies power to the entire system. It is a three phase motor rated 0.735 KWat and a speed of 1400rpm.

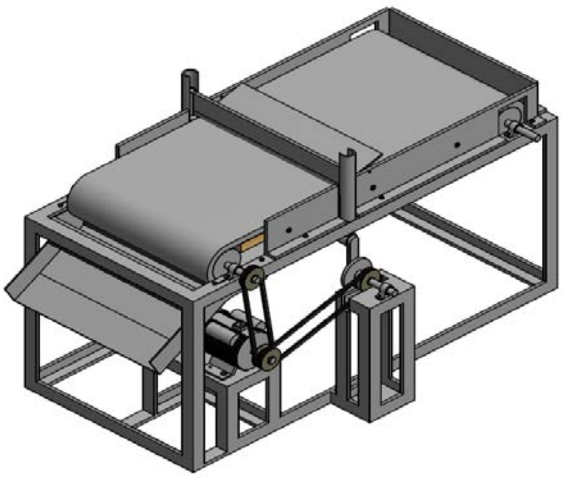

Fig. 10 : Isometric view of the slicer

A. Mechanism of operation

Power is transferred from the electric motor to the blade and the conveyor belt. The peeled plantains loaded on the conveyor are conveyed towards the blade. The adjustable slide, hinged to the conveyor guard, intercepts the plantains to control the feed rate and prevent overlapping of plantain fingers. The plantains are then conveyed to the position of the reciprocating blade. The blade slices the plantain as the conveyor simultaneously conveys the sliced plantain chips towards the outlet chute. The sliced chips are discharged through the outlet chute to a collecting vessel or tray placed beneath it.

B. Design Analysis

1. Belt and pulley design for electric motor and main roller shaft pulley

i. Determination of driven pulley diameter

The main pulley diameter, according to Khurmi and Gupta (2005), can be obtained from the relationship given in the equation below:

$$N_m D_m = N_d D_d \qquad 3$$

Where N_m and N_d represent the speed of the motor and the main shaft respectively. D_m and D_d are the diameter of the motor and the main shaft respectively.

2. Determination of distance between centers

The distance between the small and the large pulley centers was estimated using the equation:

$$x = \frac{D_d + D_m}{2} + D_d \qquad 4$$ (Hall *et al.*, 1961)

ii. Determination of belt tension

To determine the belt tension of the tight and slack sides of the belt drive, it is required that we first determine the angle of wrap between the small and large pulleys. This can be computed using equation 10 and 11 below. Figure 3.2 illustrates the geometry of the belt drive.

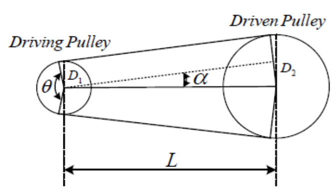

Fig. 11: Belt geometry of the electric motor and main roller shaft pulley (Khurmi and Gupta, 2005).

$$\sin\alpha = \frac{D_2 - D_1}{2L} \qquad 5$$

Angles of wrap for the smaller (θ_1) and larger (θ_2) pulleys, respectively can be obtained from the expressions below:

$$\theta_1 = (180 - 2\alpha)\frac{\pi}{180} \qquad 6$$

The smaller pulley governs since it transmit the maximum power with the belt on the point of slip.

Khurmi and Gupta (2005) related the coefficient of friction μ, the contact angle θ, and the tensions in the tight and slack sides of a belt using equation 12.

$$\frac{T_1}{T_2} = e^{(\mu\theta)} \qquad 7$$

With known motor power (P) and belt velocity (v), the tensions in the tight (T_1) and slack (T_2) sides can be determined using the relationship in equation 3 as given below:

$$P = (T_1 - T_2)v$$

Where

P = Motor power, w.

T_1 = Tension at the tight side, N.

T_2 = Tension at the slack side, N.

v = Belt speed, it can be calculated as:

$$v = \frac{\pi DN}{60} \qquad 8$$

iii. Determination of the length of belt

$$L = \frac{\pi}{2}(D_d + D_m) + 2x + \frac{(D_d - D_m)^2}{4x} \qquad 9$$

2. Belt and pulley design for electric motor and crankshaft pulley

i. Determination of distance between centers

Applying equation 9, the distance between centers of the two pulley gives:

$$x = \frac{D_c + D_m}{2} + D_c$$

Where

x = Distance between centers, m.

D_c = Crankshaft pulley diameter, m.

D_m = Motor pulley diameter, m.

iii. Determination of the length of belt

$$L = \frac{\pi}{2}(D_c + D_m) + 2x + \frac{(D_c - D_m)^2}{4x}$$

3. Bending moment diagrams Figure 3.8 is a schematic representation of the bending moment diagrams of the vertical, horizontal and resultant moments acting on the main roller shaft

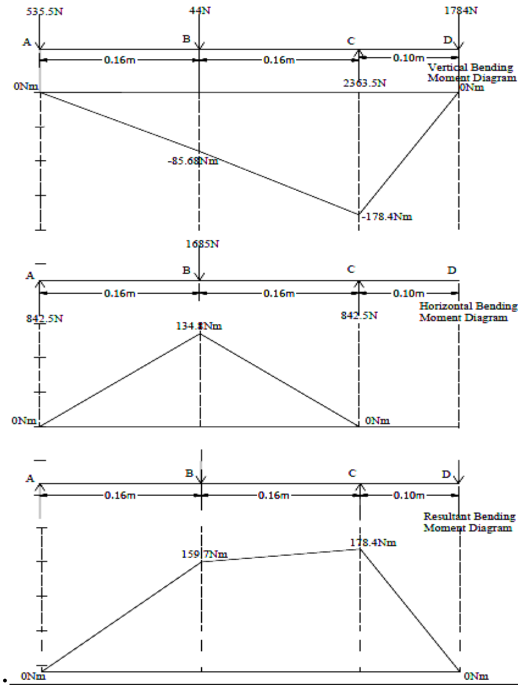

Fig. 12: Bending moment diagrams for the main roller shaft

4. Torsional moment

The torsional moment (M_t) can be obtained from the relation

$$P = \frac{2\pi N M_t}{60} \qquad 10$$

Where; P= Power; N= Speed; M_t= Torsional moment (Hall *et al.*, 1961)

$$M_t = \frac{60 \times P}{2\pi N}$$

5. Shaft diameter

By Equation 6, the shaft diameter can be calculated using a value of S_S = 55MN/m^2; K_t and K_b valves of 1.0 and 1.5 respectively since the load are gradually applied.

$$d^3 = \frac{16}{\pi S_S}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

6. Driven roller shaft design

i. Vertical loading

Figures 3.9 (a) and (b) illustrate the vertical loads acting on the driven roller shaft.

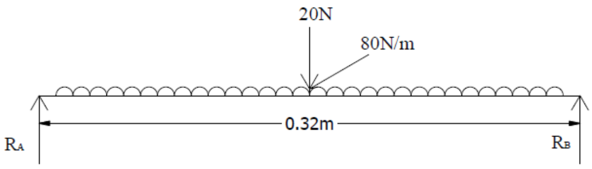

Fig. 13: Vertical loading of the driven roller shaft (Uniformly Distributed Load)

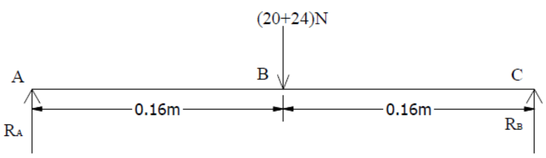

Fig. 14: Vertical loading of the driven roller shaft (Point Load)

Taking moment about A to determine the reactions at both supports;

$$44 \times 0.16 - R_B \times 0.32 = 0$$

$$R_B = \frac{44 \times 0.16}{0.32}$$

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R_B = 22N

∑Upward forces = ∑downward forces

R_A + R_B = 44

R_A = $44 - 22$

R_A = 22N

ii. Vertical bending moment

Figure 3.10 is a representation of the forces acting on the driven roller shaft which is used in determining the vertical bending moment acting on the shaft.

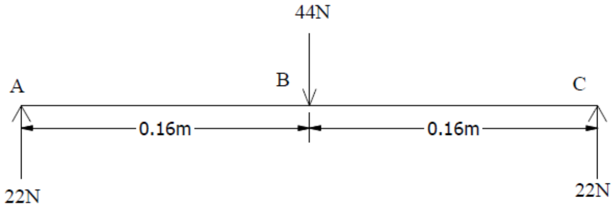

Fig. 15: Vertical bending moment of the driven roller shaft

Bending moment at point A = $22 \times 0 = 0$

Bending moment at point B = $22 \times 0.16 = 3.52Nm$

Bending moment at point C = $(22 \times 0.32) + (-44 \times 0.16) = 0$

iii. Horizontal loading

Figure 3.11 illustrates the horizontal component forces acting on the shaft

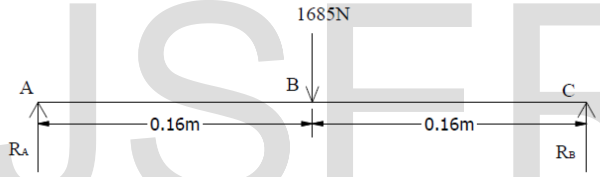

Fig. 16: Horizontal loading of the driven roller shaft

The driven roller shaft experience same loading as that of the driving roller shaft and hence they experience same reactions at A and B(R_A *and* R_B), same bending moment and same torsional moment.

R_A = 84.25N

R_B = 84.25N

Bending moment at A = 0

Bending moment at B = 134.8Nm

Bending moment at C = 0

iv. Resultant bending moment

At point A; M_V = 0, M_H = 0

Resultant BM at A= $\sqrt{0^2 + 0^2}$ = 0

At point B; M_V = 3.52Nm, M_H = 134.84Nm

Resultant BM at B= $\sqrt{3.52^2 + 134.84^2}$

= 134.85Nm

At point C; M_V = 0, M_H = 0

Resultant BM = 0

IV. FABRICATION OF MACHINE COMPONENTS

The various steps, techniques and procedures employed while fabricating each machine component is given below.

A. Frame

The frame was fabricated using a mild steel angle iron. The lengths and position of holes were marked-out on the angle iron and four 650mm and 300mm and 300mm long were cut out using the power hacksaw. The marked-out holes were drilled where necessary on the angle iron before welding the irons perpendicular to one another. The motor seat, 150mm long and 100mm wide, and crankshaft seat, 80mm long, 90mm wide and 200mm high, were then marked-out, cut and welded permanently to the frame.

B. Roller

The roller was fabricated from the combination of a hollow shaft, 300mm long and 50mm external diameter, and a solid shaft, 450mm long and 30mm diameter. The shafts were machined and fastened together permanently by electric arc welding.

C. Outlet chute

The outlet chute consist of two pairs of rectangular stainless steel plates. The first pair, 120mm long and 300mm wide, and the second pair, 300mm long and 300mm wide, were welded to form a rectangular box. It was inclined at an angle of 30^o to the frame horizontal to allow sliced plantain to fall freely by gravity as the cut is made.

D. Conveyor guard

The material used in this regard was a pair of galvanized sheet of 650mm long and 120mm wide. The 120mm width was bent 20mm outward, at right angle to the remaining 100mm sheet. Holes for nuts and bolts were drilled, were necessary, and spaces to accommodate bearings and blade were cut out.

E. Assemblage of Machine Components

The outlet chute was permanently welded to the frame to enhance stability. The bearings and the electric motor were firmly bolted to their respective positions on the frame. The pair of rollers and the crankshaft were inserted to the inner race of their respective bearings. The conveyor belt was then fixed upon the pairs of rollers and protected by bolting the conveyor guard around the frame edges. A wooden support was inserted between the tight and slack sides of the conveyor belt. It was bolted to the conveyor guard to help prevent sagging of the conveyor as well as enhance the cutting action of the blade. The blade was positioned firmly perpendicular to the conveyor and connected to the crankshaft by the connecting rod.

Finishing touches was carried out where necessary on the assembled machine for enhanced beauty and aesthetics. Finally the machine was sprayed with color brown paint to serve as coating which prevent rusting of the mild steel frame as well as for beautification purpose. A pictorial representation of the assembled machine can be seen in Plates 3.1 and 3.2.

Fig 17: Assembled machine during testing

Fig 18: Front view of the machine during testing

V. MACHINE TESTING

The test was carried out in the Agricultural and Environmental Engineering Departmental Workshop, Federal University of technology, Akure (FUTA). The plantain slicer was tested under no load condition for 10 minutes to insure that all components are working perfectly fine without any wobbling or malfunctioning. Having ascertained this, the machine was then tested with a set of six ripen and unripen plantain fingers, for three trials, to evaluate its performance with regards to the chip thickness, machine capacity, machine efficiency and quality performance efficiency of the machine.

The machine capacity was obtained by expressing the weight of sliced plantain output, irrespective of damage or irregularity in size, per unit time (Hall *et al*, 1961). The machine and quality performance efficiencies of the machine were determined using the expression in equations 18 and 19 respectively (Adewumi *et al.*, 2011 and Sonawane *et al.*, 2011):

$$f = \frac{P_a}{P_t} \times 100\% \qquad 11$$

$$q = \frac{P_a - P_b}{P_t} \times 100\% \qquad 12$$

Where

f = field efficiency

q = quality performance efficiency

P_a = quantity of sliced plantain that are good
P_b = quantity of sliced plantain that are bad
P_t = total quantity of plantain that were sliced

VI. CONCLUSIONS

A power operated plantain chip slicing machine was designed and developed. Tests were carried out to analyze its performance and output capacity. Results from these tests indicate a slicing efficiency of 81.93% and 91.07% for ripen and unripen plantain fingers respectively. The maximum efficiency of the machine was obtained at moderate cutter speed of 1000rpm for both ripen and unripen plantain fingers. A capacity of 285g/s (1026kg/h) was also obtained. This meets the requirements of both medium and large scale plantain chip processing industries. The chip thickness, for both ripen and unripen plantain, was found to be significantly uniform with a mean thickness of 2.20mm and a maximum deviation of ±0.012mm.

i. It was found that chip thickness had the most significant effect on the machine capacity. It is affected by the machine speed and the feed rate for both ripen and unripen plantain.
ii. The slicing time, of 3.3s obtained for slicing a set of six plantain, was found to be independent in the chip diameter and the ripeness level of the plantain.
iii. The efficiency of the machine for unripen plantain (91.07%) was higher than that of a ripen plantain (81.93%) due to high moisture and damageable nature of ripen plantain slices.

VII. RECOMMENDATIONS

At the end of this project, the following recommendations are hereby suggested for improved machine efficiency and performance.

i. The timing of the cutter blade in relation with the forward motion of the conveyor belt should be worked upon.
ii. Provision should be made for adjusting the cutter blade to obtain slices of any desired thickness of cut so as to give a different but uniform chip thickness.

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