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Design of a Plantain Chips Slicing Machine

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ABSTRACT

A plantain chips slicing machine was designed, fabricated and tested. This is perhaps a major advancement in the development of plantain chips. A cam and spring return mechanism was used to achieve both the feeding and the slicing operations. The machine was made as simple as possible for easy repairs and maintenance. It is designed such that the machine slices one tuber of plantain over one revolution of the cam. A conveyor rolls sliced chips to a tray with the help of a Geneva drive mechanism (or timer). A variable speed pulley system was used to reduce the motor speed to desired value. Test performance gave an efficiency of 74 per cent. Further modification is in view to further improve on the efficiency.

Keywords: *Plantain chips; Geneva timer; Spring-return mechanism; Maintenance; Efficiency.*

1. INTRODUCTION

Plantain is a popular staple in Africa and in many other countries of the world. Although many Western consumers consider it a mere super-market bought, millions of people especially in Africa, see plantain as a starchy staple of major importance. Unripe plantain is also considered a major source of iron. Plantain is taken in various forms such as fried plantain, boiled plantain, roasted plantain, baked plantain, and plantain chips. It can also be processed via slicing, drying and grinding for production of plantain flour which is also consumed when baked. There is high demand for plantain slices in form of fried plantain chips by travelers, office workers, school children, and families as part of breakfast. In an effort to make it readily available, several means have been devised in slicing plantain into pieces which is further processed into chips, flour, baked or fried.

The kitchen knife method remains a primitive way of producing plantain chips in large quantities in small, medium and large scale industries. In this case, a sharp knife is used to slice the plantain usually placed on a wooden cutting board. The problems associated with this method are fatigue, low speed which leads to poor output and low income generation, too many staff, hand injury, poor uniformity of plantain chip thickness, and high productive time and energy consumption. The manually operated wooden platform plantain slicer is another slow method employed in small scale industries. The plantain is pressed and moved across the sharp blades of the machine. The major risk is that when it misses a cut, the machine operator gets his finger cut by the exposed sharp blades. It is also time consuming since the operator will be operating in a slow rate to avoid injury. Another method is the manually operated cutting knives in which the plantain tuber is placed on top of a sharp blade on the base frame of the machine, and the upper handle which also contains sharp blades pressed down thereby slicing the tuber into chips. The major problem here is that when off-loading, one gets his hands injured because of the chips stocked in-between the sharp blades. It is also time consuming because of the slow nature in off-loading and to avoid injury (Nwanekezie and Ukagu, 1999).

In view of these, there exists the need to develop a plantain slicing machine of commercial quality. The disadvantages associated with the above methods inevitably lead to low output by farmers with little or no income margin. However, the above methods are observed to have some common features such as the cutting mechanism, the feeding mechanism, the base frame for support, as well as the stability of the machine while in operation. This design is therefore an improved form of the manually operated versions.

2. DESIGN CONCEPT

Figures 2.1 and 2.2 show the assembly and orthographic views of the plantain chips slicing machine, respectively. Table 2.1 shows the component parts of the machine.

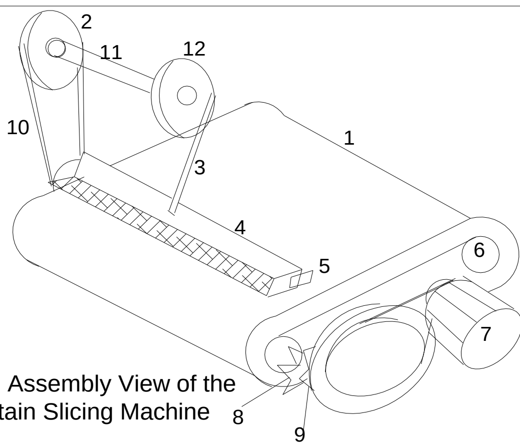

Fig.2.1 Assembly View of the Plantain Slicing Machine

Table 2.1 Component Parts of the Machine

S/N	Item	Quantity
1	Conveyor	1
2	Pulleys	3
3	Connecting Rod	1
4	Blade	1
5	Blade Guide	1
6	Sprockets	4
7	Electric Motor	1
8	Geneva Driven Wheel	1
9	Geneva Driver Wheel	1
10	Drive Belts	2
11	Blade Shaft	1
12	Flywheel	1

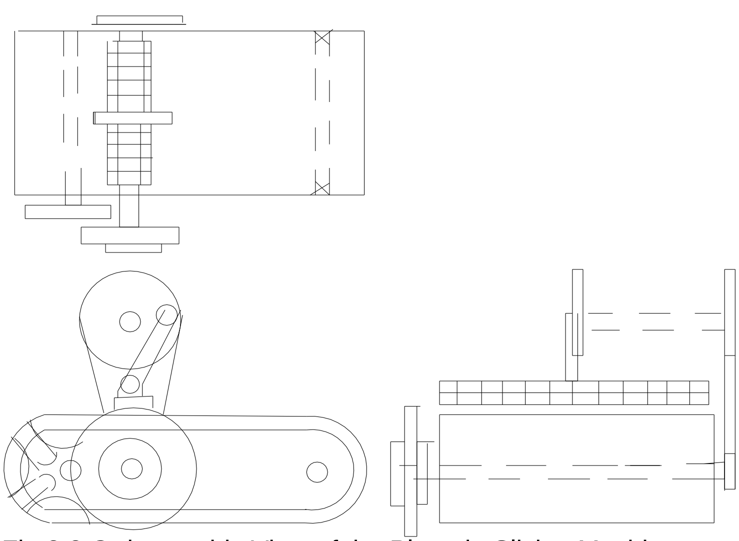

Fig.2.2 Orthographic View of the Plantain Slicing Machine

2.1 Description

The machine is made up of the cutting device, a feeding mechanism, the support frame and an electric motor as a source of power. The cutting mechanism consists of the stainless steel blades, a connecting rod, a guide frame for the blades, pulleys and the flywheel. The blades are arranged perpendicular to the plantain tubers. The feeding and the discharge mechanisms consist mainly of the Geneva drive meant to deliver intermittent motion to the conveyor, thereby causing the conveyor to move in a start-stop fashion. The Geneva wheel is fitted with four equi-spaced radial slots. The crank has a pin that enters the radial slot and causes the Geneva wheel to turn through a portion of a revolution. When the pin leaves the slot, the wheel remains stationary until the pin enters the next slot; thereby giving an intermittent rotation of the Geneva wheel. The conveyor controls both the feeding and discharge operations. Connected to chain and sprockets, the conveyor is made up of equally spaced iron segments welded on both ends and covered by a thin layer of aluminum sheet. Chains are connected to both sides of the conveyor to form a continuous cyclic motion. The base frame suspends and provides a firm support to the machine. The drive shaft is supported by two ball bearings mounted on the base frame and which provide support for both radial and thrust loads.

2.2 Operation Principle

Power is transmitted from electric motor to input shaft via a pulley system. The input shaft transmits power both to the cutting and feeding mechanisms. It rotates alongside with the driving wheel of the Geneva drive which in turn engages the slots on the driven wheel thereby effecting movement of the conveyor. The conveyor remains still when the drive pin disengages on the slots (during dwell). At the same time the rotating flywheel gives the cutter an upward vertical motion on an idle stroke. As the conveyor remained still, the continuous motion of the flywheel causes the cutter to come down on a working stroke, thereby slicing the awaiting plantain tuber in the slicing chamber. The connecting rod linking the flywheel to the blades converts the flywheel rotation to an upward-downward motion which causes intermittent slicing of the plantain tubers. Again, when the cutter is on an upward motion the Geneva pin engages on the slots thereby causing the conveyor to carry away the plantain chips and at the same time positioning another plantain tuber into the cutting chamber. Thus, the conveyor feeds the tubers into the slicing chamber whilst cutting takes place within the period the conveyor is stationary. Each motion of the conveyor is therefore a feeding and discharging process. Thus, feeding, slicing and discharging take place for every one revolution of the flywheel.

3. DESIGN ANALYSIS

3.1 Capacity of the Machine

The machine is designed to cut 1 tuber of plantain in 4seconds.

That is;

Production Rate = 1 plantain tuber in 4 seconds

This means that the machine processes 1 tuber of plantain in 4 seconds during one full revolution of the input shaft (or flywheel).

3.2 Material Selection

This is considered a very important aspect of the design, especially when the machine is to process a consumer item. Thus, fabrication materials were carefully selected to ensure high quality standard. The following were carefully considered in selecting the materials of construction (Eugene and Avallone, 1999).

i. Physical and Mechanical Properties of the Material
ii. Reliability of the Material
iii. Availability
iv. Maintainability, and
v. Cost Effectiveness

3.3 Electric Motor Specifications

Motor Speed = 75 rev/min

Current, I = 6 Amperes

Voltage, V (domestic voltage generation in Nigeria) = 24 volts

Power, P = IV = 144 Watts = 0.2 hp

3.4 Input Shaft Speed

Diameter of Motor Pulley, D_1 = 100 mm

1 tuber of plantain is processed in 4 seconds in one revolution of the input shaft

Thus, (60 x 60)/4 = 900 tubers of plantain is processed in 1 hour, and this is achieved at an input shaft speed of

(60 min/4) = 15 rev/min.

Thus, Diameter of Input Shaft Pulley, $D_2 = (D_1 \times N_1) / N_2$ (Khurmi and Ghupta, (2004)

Where N_1 and N_2 are speeds of electric motor and input shaft, respectively.

D_2 = (100 x 75) / 15 = 500 mm

3.5 Power Required to Cut One Tuber of Plantain

Depending on the thickness of plantain chips, a tuber of plantain gives an average of 12 chips.

Energy required to cut one slice of plantain (measured value) = 0.0736 kgm

Torque required to cut a slice of plantain = Energy x Gravitational Acceleration

Torque, T = 0.0736 x 9.81 = 0.72 N-m

Considering a factor of safety of 1.5;

Required Torque, T = 0.72 x 1.5 = 1.08 N-m

But angular velocity, $\omega = 2\pi N/60 = 2\pi\,(75)/60 = 7.86$ rad/sec

Thus, power needed to cut a slice of plantain, P = Tω = 1.08 x 7.86 = 8.48 Watts

Power required to cut 12 slices of plantain, P = 12 x 8.48 = 101.8W = 0.102 kW = 0.137 hp

3.6 Size of Feeder Shaft

The feeder shaft drives the driven wheel of the Geneva stop device and the conveyor belt drive wheel.

Weight of Geneva wheel = 0.95 kg = 9.5N

Weight of conveyor wheel = 0.85kg = 8.5N

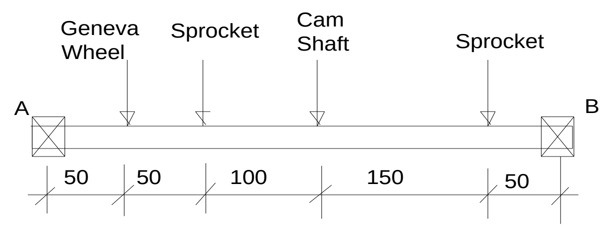

Fig.3.1 Feeder Shaft Loading

Total weight of cam shaft and the wheels = 4.555kg = 45.6N

Thus, weight of cam shaft = 45.6 – (9.5+8.5 + 8.5) = 19.1N

Considering equilibrium condition and taking summation of all vertical forces (Khurmi and Ghupta, 1976);

$R_A + R_B$= (9.5 + 8.5 + 8.5 + 19.1) N = 45.6 N

Taking moment about A;

$\Sigma F_V = 0$; 9.5 (50) + 8.5 (100) + 19.1 (200) + 8.5 (350) - 400 R_B = 0

R_B = (475 + 850 + 3820 + 2975) / 400 = 20.3 N

R_A = 45.6 – 20.3 = 25.3 N

Bending Moment of Geneva wheel about reaction support at A

= 9.5 x 0.05 = 0.475 N-m

Bending moment of the conveyor sprockets;

i. 8.5 x 0.1 = 0. 85N-m

ii. 8.5 x 0.350 = 2.975 N-m

Bending moment of cam shaft = 19 1 x 0.2 = 3.82 N-m

Thus, maximum bending moment is caused by cam shaft = 3.82 N-m

But $d^3 = (16/\pi\tau) \sqrt{M^2 + T^2}$

Where d = Shaft diameter

τ = Maximum shear stress, 56 MPa = 56 x 10^6 N/m^2 (James, 1980)

M = Maximum bending moment, 3.82 N-m

T = Torsional moment acting on the shaft

But T = (9550 x kW) / RPM (Allens e tal, 1980)

T = (9550 x 0.144)/75 = 18.336 N-m

$d = \{(16/\pi \times 56 \times 10^6) \sqrt{3.82^2 + 18.34^2}\}^{1/3}$ = 30mm

Use feeder shaft diameter = 40mm

3.7 Size of Main Shaft

The main shaft takes power directly from the electric motor and transmits same to the feeder shaft. It carries the driving wheel of the Geneva stop device as well as a drive pulley.

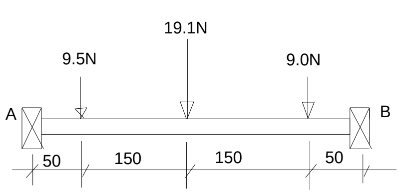

Fig.3.2 Main Shaft Loading

Considering equilibrium of all vertical forces;

$\Sigma F_V = 0$; $R_A + R_B$ = 9.5 + 19.1 + 9.0 = 37.6 N

Taking moment about bearing support at A;

$\Sigma M_A = 0$; 9.5 x 0.05 + 19.1 x 0.2 + 9 x 0.350 = 0.4 R_B

R_B = 18.61N, and R_A = 19 N

Obviously, maximum bending moment acts at force 19.1N

Thus, Maximum bending moment, M = 19.1 x 0.2 = 3.82 N-m

Size of main shaft, $d = \{(16/\pi \times 56 \times 10^6) \sqrt{3.82^2 + 18.34^2}\}^{1/3}$ = 30mm

Use main shaft diameter = 40mm

3.8 Geneva Stop Mechanism

Figure 3.3 shows a four-stop Geneva mechanism (Robert, 1999).

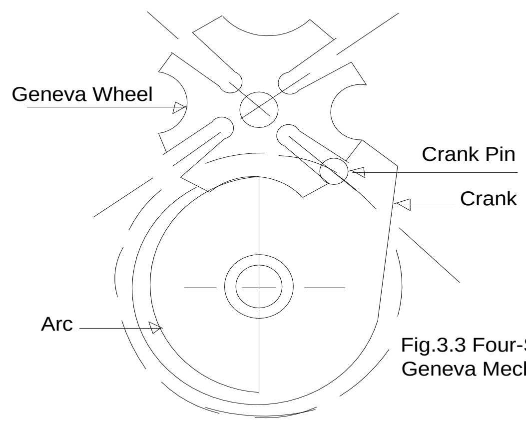

Fig.3.3 Four-Stop Geneva Mechanism

The Geneva drive indexes over an angle of 360^o divided by the number of slots or stations on its wheel. Thus, each index of a four-station tangent drive will be 90^o. The time ratio of a tangent drive is expressed by the arc (in degrees) of each revolution as well as the arc of each revolution the wheel is at rest (or dwell). The time ratio refers to each resolution of the driver, and thus remains constant regardless of the driver speed.

In one revolution of the driving wheel, the driven wheel makes a quarter of revolution.
Thus, 360^o revolution of the driver wheel = 360/4 = 90^o revolution of the driven wheel
Also, $2\pi r$ linear displacement of the driver wheel = $2\pi r/4$ linear displacement of the driven wheel
= $\pi r/2$ displacement of driven wheel
Thus, for a driven wheel of 148 mm in diameter, linear displacement = (π x 74)/2) = 116.2 mm
This represents the length of each motion interval on the conveyor/feed table. Thus, with a 148 mm diameter driven wheel, the conveyor will cover a distance of 116.2 mm between each start and stop interval.

Stress on Drive Pin

The stress developed is due mainly to the impact made by the drive pin on the slots of the driven wheel.

$\delta = F/A \{1 + \surd 1 + (2hAE)/FL\}$

Where δ = Impact Stress

F = Force acting on driven wheel

E = Modulus of elasticity, 200 kN/mm^2

H = Height of drive pin, 41 mm

L = Length of drive pin, 164 mm

But $F = mv^2/r = (1.2 \times 7.85^2) / 0.074 = 1000N$

$A = \pi d^2/4 = 314.2\ mm^2$

$\delta = 1000/314.2 \{1 + \surd 1 + (2 \times 41 \times 314.2 \times 200 \times 10^3)/1000 \times 164\} = 567.34\ N/mm^2$

4. PERFORMANCE TEST

The machine was operated for 10 minutes which gave a total of 1328 plantain chips. The machine was however designed to give an average of 12 slices in 4 seconds. Thus, 10 minutes production time should give a total of 1,800 plantain chips.

Efficiency = (1,300 / 1,800) x 100 = 73.8%

5. DISCUSSION

The thickness of the plantain chips was fairly uniform. However a production efficiency of 74% is not good enough. There is an obvious need for improvement on the design.

RECOMMENDATIONS

The timing of the cutting mechanism with the forward motion of the feed conveyor should be re-examined. A provision should be made for adjusting the cutting mechanism to give a desired thickness of cutting. This will help in processing different but uniform tubers of plantain.

REFERENCES

Allens, H., Alfred, R.H., and Herman, G.L. (1980). Theory and Problems of Machine Design. Schaum's Outline Series. Mc Graw-Hill Book Company, New York.

Eugene, A. and Avallone, A. (1999). Marks Standard Handbook for Mechanical Engineers.Mc Graw-Hill Company Inc. USA.

James, C. (1980). Mechanical Engineer's Data Handbook. Stanley Thornes Publishers Ltd. UK.

Khurmi, R.S. and Ghupta, J.K. (1976). Theory of Machines. 14th Edition. Eurasaia Publishing House (PVT) Ltd. India.

Khurmi, R.S. and Ghupta, J.K. (2004). A Textbook of Machine Design. 25th Edition. Eurasaia Publishing House (PVT) Ltd. India.

Nwanekezie, C. and Ukagu, J.C. (1999). *Nigeria food Journal*. Vol.17. pp.55.

Robert, L.N. (1999). Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines. 2nd Edition. McGraw-Hill Inc. USA.