DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF PLANTAIN SLICING MACHINE

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ABSTRACT

Plantain is commonly cultivated in many tropical and temperate regions. The traditional method of knife slicing of plantain has proven to be laborious, time consuming and unhygienic with low output. The design and development of plantain slicing machine is to solve the aforementioned problems. The design parameters determined are the diameter of the shaft (D), the motor power required (P), Belt and the pulleys size, and the bearing. The machine is electrically operated, with a 2Hp electric motor while the calculated shaft diameter was 20mm and the length of the belt calculated was given as 1039.85mm. A type of belt was selected. Results of the test carried out showed that the time required to slice equal length of plantain with the machine is less than the time required for traditional method. The machine capacity is about 52kg while the efficiency of the machine is about 80%.

Key words: - Plantain, slicing, blades, shaft, Efficiency and machine capacity.

INTRODUCTION

Plantain is a popular staple food in Africa and in many other countries of the world. Unripe plantain is also considered a major source of iron (Kachara et al 1995). Plantain is taken in various forms such as fried plantain, boiled plantain, roasted plantain and plantain chips. It can also be processed into plantain flour by slicing, drying and grinding. Plantain flour can be reconstituted in boiled water to form dough which is normally taken with vegetable soup in the South-Western part of Nigeria. The high demand for plantain slices in the society calls for an improved method of processing. The traditional way of processing is too cumbersome and unhygienic therefore it is necessary to improve the method of processing so as to meet the demand and for better quality product. The kitchen knife method remains a primitive way of producing plantain slices and cannot support large quantities needed in small, medium and large scale industries. The problems associated with this method are fatigue, low speed which leads to
poor output and low income generation, too many staff, hand injury, non uniformity of slice thickness, high production time and energy wastage. Manually operated plantain slicer is usually employed by small scale industries. The plantain is pressed and moved across the sharp blades of the machine and the major risk is that when it misses a cut, the operator gets his finger cut by the exposed sharp blades. It is also time consuming.

Plantain chips are prepared by frying round slices of unripe or slightly ripened plantain pulp in vegetable oil. The quality plantain chips can be obtained by frying slices of plantain of about 3mm thickness between temperature range of 160° C and 170° C. Anonymous 2005. In order to close the gap between the traditional method of slicing plantain and the costly imported plantain slicing machine, an affordable mechanised plantain slicer has been designed and developed for local plantain chip producers which can be used for commercial scale production.

**DESIGN CONSIDERATION**

The following are the design consideration used in the course of carrying out the design

1 The cost of the plantain slicer should be affordable.
2 Minimum labor requirements
3 The design should be simple, easy to maintain and should be able to eliminate the limitation of conventional method.

The following are the critical aspects of the plantain slicing machine:-.

(i.) The shaft
(ii.) The pulley and belt system
(iii.) Bearing
(iv.) The cutting disc and blade

**Determination of Slicing Shaft Loads and Reactions**

Figure 1 and 2 shows a schematic representation of the slicing machine loading in vertical and horizontal planes respectively. Assuming $X_1 = 0.25m$, $X_2 = 0.3m$ and $X_3 = 0.2m$

**Figure 1 : Free body diagram for Loads arrangement on the shaft**
Considered the free body diagram in figure 2 above, then applying the equilibrium conditions, then the value of $R_B = 41.02 \text{N}$, $R_D = 0.51 \text{N}$, and the load $P_1 = 22.19 \text{N}$ and $P_2 = 19.34 \text{N}$.

**Figure 2 : Shearing force and Bending moment diagram.**

**DESIGN OF THE SHAFT DIAMETER.**

Shaft design consist of primarily the determination of correct diameter to ensure satisfactory strength and rigidity when in operation under different loading conditions. The design diameter was in accordance with ASME standard load equation.

$$d_s = \left( \frac{16}{\pi \tau_s} \sqrt{(M_b K_b)^2 + (M_t K_t)^2} \right)^{1/2}$$  \hspace{1cm} (1)

where $d_s$ is shaft diameter; $K_b$ is combine shock and fatigue factor applied to bending moment; $K_t$ is combine shock and fatigue factor applied to torsional moment; $\tau_s$ is allowance shear stress for shaft;
\( M_t \) is Torsional moment; \( M_b \) is bending moment. Maximum bending moment is at \( M_b = M_t = M_{\text{max}} = 5547.5 \text{Nmm} \). Assuming a bending and torsion moment factors \( K_b = K_t = 1.5 \) and \( \tau_s = 42 \text{MPa} \), the values obtained from calculation using equation(1) is \( d_s = 15.0 \text{mm} \). Using a factor of safety of 2.0, the value adopted for the shaft diameter is \( d_s = 30 \text{mm} \).

**DESIGN OF PULLEY AND BELT**

**Determination of belt length**

The design of the pulley is expected to be in the ratio of 1:4

Diameter of small pulley (driver) \( d = 70 \text{mm} \)

Diameter of big pulley (driven) \( D = 280 \text{mm} \)

The required belt length was obtained using the expression given by Khurmi and Gupta 2004

\[
L = 2c + \frac{\pi}{2} (D + d) - \frac{D - d}{4c}
\]

(2)

\( L \) was calculated as 1039.85 mm

The approximation belt length of 1026 mm was selected from the table which falls with A-class belt type according to 2494-1794 Standard, by Khurmi and Gupta 2004.

Centre Distance \( (C) \) between the pulleys was obtained as given by Adekunle et al (2009)

\[
C = \left[ \frac{D + d}{2} \right] + d
\]

(3)

\( C \) was calculated as 245 mm

The smaller pulley angle of contact is given by

\[
sin\theta = \frac{R - r}{C}
\]

(4)

Where \( R \) is pulley radius of shelling shaft (140 mm), \( r \) is the pulley radius of the electric motor pulley (35 mm) and \( C \) is the distance (245 mm). The angle of contact is given as 19.5\(^0\).

**ANGLE OF TWIST OF THE SHAFT**

\[
\theta = \frac{504 M_t L}{G d^4}
\]

(5)

Where \( \theta \) = angle of twist in degree

\( L \) = Length of the shaft (750 mm)

\( G \) = Torsional modulus of rigidity \((80000 \text{N/mm}^2)\)
ds = diameter of the shaft (30mm)
\theta = 0.037^\circ

**BEARING DESIGN**

The maximum load on cutter plate is given [Khunmi and Gupta 2004]

\[ L_o = \lambda Pd \]

(6)

Where \( \lambda = \) bearing length (mm)

\( P = \) Allowable mean bearing pressure (varies from 172.4 to 17235kpa for normal service)

\( ds = \) Shaft diameter (mm)

\( L_o = \) Bearing Load (N)

Given \( \lambda = 32\text{mm} \) \( ds = 30\text{mm} \) and \( P = 200\text{kpa} \approx 0.2\text{N/mm}^2 \)

\[ L_o = 2.56\text{N} \]

The bearing load is given by

\[ \frac{L_o}{g} = \frac{256}{9.81} = 26.1\text{kg} \]

Hence the bearing specification in use was the pillow type bearing from table FS 206 was selected.

**CUTTING BLADE**

![Cutter plate Assembly](image)

Cutter plate diameter \( d = 0.3\text{m} \), Thickness \( t = 0.004\text{m} \)

The centrifugal force of the disc is given by James (1980). \( F_c = mv^2 \)

(8)

Where \( v = 1.6345\text{m/s} \).  

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m= mass of the disc plate (kg).

Fc=0.3339N.

Power output of the cutter plate is given by Eugene and Avallone 1999

\[ P = \frac{2\pi FrN}{60 \times 1000} \text{ (kw)} \quad (9) \]

Power transmitted by the pulley and belt arrangement on the shaft is;

\[ P = \frac{2\pi \times (29.14 + 0.3339) \times 140 \times 350}{000000} \text{ (Kw)}; \]

\[ P = 0.15 \text{kw}. \]

**PERFORMANCE AND EVALUATION OF THE SLICING MACHINE**

Performance of the machine was evaluated to determine time of slicing, the capacity and efficiency of the machine. The capacity of the machine was determined by the time it takes the machine to slice one plantain rod of a particular weight completely.

The capacity of machines is expressed as average weight of peeled plantain sliced in kg per unit time in hour.

The efficiency of the plantain slicing machine is given by

\[ \eta = \frac{Q_T - Q_U}{Q_T} \times 100\% \quad (10) \]

Where:

\[ \eta \] – Slicing efficiency (%)

\[ Q_T \] – Total quantity of plantain sample (g)

\[ Q_U \] – Quantity of waste or unsliced plantain (g)

Efficiency \( S\eta = 81\% \).
RESULTS AND DISCUSSION

Table 1A and 1B show the result of performance evaluation of the machine. The results showed that there was sharp reduction in time of mechanical slicing when compared with traditional slicing. These are clearly shown in figure 5A and 5B. Reduction in time is about 38% and 48% for unripe and ripe plantain respectively. The result also showed that the thickness of plantain slices for mechanical slicing were uniform while there were non-uniform in plantain slices from traditional slicing. The non-uniformity is as a result of non-uniformity in application of forces during traditional slicing. For mechanical slicing, as the length of plantain increases, the slicing time increases while there was no consistency in time of slice for different length of plantain for traditional slicing. The machine capacity is about 52kg while the efficiency of the machine is about 80%.
<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Time (s)</th>
<th>Slices Thickness (mm)</th>
<th>Waste (mm)</th>
<th>Waste (g)</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<td>MS</td>
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<td>MS</td>
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</table>

Table 1.A: Results for Traditional Slice (TS) and Mechanical Slice (MS) for ripe plantain

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Time (s)</th>
<th>Slices Thickness (mm)</th>
<th>Waste (mm)</th>
<th>Waste (g)</th>
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</thead>
<tbody>
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</table>
Figure 5. A: Time of slicing unripe plantain against length for Traditional Slicing (TS) and Mechanical Slicing

Figure 5.B: Time of slicing ripe plantain against length for Traditional Slicing (TS) and Mechanical Slicing
CONCLUSION
The plantain slicing machine has been designed, developed and tested to determine its performance evaluation. The machine will solved the problem of non-uniformity in chip thickness associated with traditional slicing process. It will also reduce time of slicing which is high for traditional slicing. The results and analysis carried out showed that the machine performed satisfactorily and show improvement over the traditional method.

ISOMETRIC VIEW OF THE PLANTAIN SLICING MACHINE
EXPLODED VIEW OF THE PLANTAIN SLICING MACHINE

<table>
<thead>
<tr>
<th>S/N</th>
<th>COMPONENTS</th>
<th>MATERIALS</th>
<th>QTY</th>
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<tr>
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<td>RUBBER</td>
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</tr>
<tr>
<td>2</td>
<td>PULLEY</td>
<td>MILD STEEL</td>
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</tr>
<tr>
<td>3</td>
<td>SHAFT</td>
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</tr>
<tr>
<td>4</td>
<td>CUTTER PLATE</td>
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<tr>
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ORTHOGRAPHIC VIEW OF THE PLANTAIN SLICING MACHINE
EXPLODED VIEW OF THE PLANTAIN SLICING MACHINE

REFERENCES


