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Design and Fabrication of an Electrically Powered Rotary Slicer for Raw Plantain Chips Production

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Abstract: - This work focused on the design and fabrication of an electrically powered rotary slicer for raw plantain chips production. The machine was designed for medium scale industries but can also be used for domestic purposes which also include the slicing of cucumbers. The machine works on shear cutting principle and has the capacity to produce raw plantain chips of uniform sizes in lesser time and can slice up to a maximum of 70mm diameter finger of raw plantain in just 2-3 seconds. Machine maintenance is simple and requires just lubrication of rotating members and proper cleaning after use.

Keywords: - *Domestic purposes, electrically powered, plantain chips, rotary slicer, uniform sizes.*

I. INTRODUCTION

Plantain is a type of banana which is common in tropical regions. It is starchier and less sweet when compared to bananas. Plantains are usually served steamed, boiled or fried, although ripe plantains can be eaten raw. They are a rich source of antioxidants, vitamin B-6 and minerals, and their soluble fiber content may help ward off intestinal problems [1]. Plantain for local consumption plays an important role in food and income security and has the potential to contribute to national food security and reduce rural poverty [2].

Plantains provide the essential minerals that help the body to function efficiently. A cup of sliced or cooked plantain has 49 milligrams of magnesium and 716 milligrams of potassium, giving the body 15 percent of the recommended daily intake for each of these minerals. The body needs magnesium for proper muscle contraction and nerve function, while potassium is a crucial component in the body fluids. A cup of plantains also contains 5 to 10 percent of the iron need of the body. Iron helps to carry oxygen through the bloodstream which serves as a benefit to the muscles of the body.

Although raw plantain is bitter and starchy, some people like them raw. They are more nutritious raw, with about 10 percent more magnesium, phosphorus and potassium. A cup of raw plantains has 27 milligrams of thiamin, a B-vitamin that helps the body's cells use carbohydrates as energy and helps ensure the proper functioning of the heart, muscles and the nervous system. A cup of cooked plantain has less than 1 milligram of thiamin [1]. Considering the enormous benefits of raw plantain, slicing it can create additional benefits in terms of post-harvest processing. Plantain processed into flour can be stored for up to a maximum of two years [2]. The purpose of the machine is to make slicing process less laborious especially for medium scale industries and for domestic purposes.

Obeng [3] developed a mechanized plantain slicer which took 5-7 seconds to slice a finger of plantain. When compared with the traditional method of cutting with a sharp knife, the traditional method took 40-80 seconds per finger of plantain. Because of the lesser time taken to slice a finger of raw plantain and uniformity of chips sizes produced, an electrically powered rotary slicer incorporating two feeding chuteshas technological edge over traditional slicing methods.

II. DESIGN ANALYSIS AND CALCULATIONS

The machine works on shear cutting principle. When the cutting blade impacts on the cylindrical surface of the raw plantain, the surface gets cut by shearing along a plane.

Determination of the Shearing Force for the Raw Plantain

Considering the shear strength of the raw plantain and the area under shear, the impact force required to shear the raw plantain may be obtained from the following equation:

$$F_P = A_P \times \tau_P \quad (1)$$

Where

F_P = Force required for shearing the raw plantain

A_P = Area under shear

τ_P = Shear stress of the raw plantain

The area under shear can be determined using the following equation:

$$A_P = \pi \frac{D_P{}^2}{4} \quad (2)$$

Where,

D_P = Diameter of raw plantain

The average force required to shear raw plantain of diameters ranging from 30-70mm is 33.15N [3]. This force reduces as the plantain ripens and softens. The measured diameter of the raw plantain was in the range of 30-70mm, averagely 50mm. From equation (2), we get

$$A_P = \pi \frac{(0.050)^2}{4} = 1.96 \times 10^{-3}\ m^2$$

Determination of the Power Required by the Cutter for Slicing the Raw Plantain

Cutter velocity is another important parameter in the slicing process. The optimum value of cutter velocity required for slicing is 2.65m/s [4]. The power required by the cutter to slice the raw plantain may be obtained from the following expression:

$$P_C = F_P \times V_C \quad (3)$$

Where,

P_C = Power required by the cutter

V_C = linear velocity of the cutting blade = 2.65m/s

From equation (3), we get

$$P_C = 33.15 \times 2.65 = 87.85\ W$$

Determination of the Power Required by the Electric Motor

The power required by the electric motor may be obtained from the following equation:

$$P_M = P_C \times P_F \quad (4)$$

Where,

P_M = Power of electric motor

P_F = Power factor = 1.5

From equation (4), we get

$$P_M = 87.85 \times 1.5 = 131.78W$$

Selected capacity of electric motor = 0.37kW (0.5Hp)
Speed = 1400rpm

Determination of the Driving Pulley Diameter

For a belt velocity of 4.98m/s, the driving pulley diameter is calculated using the relation below:

$$D_1 = \frac{V_1 \times 60}{\pi \times N_1} \qquad (5)$$

Where,

D_1 = Driving pulley diameter

V_1 = Peripheral velocity of the belt on the driving pulley

N_1 = Speed of driving pulley = 1400rpm

From equation (5), we get

$$D_1 = \frac{4.98 \times 60}{\pi \times 1400} = 68mm$$

Determination of the Driven Pulley Diameter

The relation between the driving pulley diameter and the driven pulley diameter is given by:

$$\pi \times D_1 N_1 = \pi \times D_2 N_2 \Rightarrow \frac{D_1}{D_2} = \frac{N_2}{N_1} \qquad (6)$$

Where,

N_2 = Speed of driven pulley

D_2 = Diameter of driven pulley

For N_2 = 400rpm. Substituting into equation (6) and simplifying, we get

$$D_2 = \frac{D_1 N_1}{N_2} = \frac{68 \times 1400}{400} = 238mm$$

Determination of the Belt Tension

The expression which shows the relationship between the power transmitted, belt tension and linear velocity is given as [5]:

$$P_M = (T_1 - T_2) \times V_1 \qquad (7)$$

Where,

T_1 = Tension in the tight side of the belt

T_2 = Tension in the slack side of the belt

From equation (7), we get

$$T_1 - T_2 = \frac{0.37 \times 10^3}{4.98} = 74.30 \qquad (8)$$

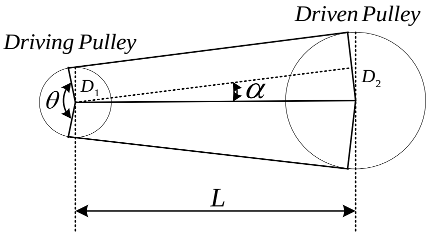

Figure 1: Belt Drive Geometry

From figure 1,

$$\sin \alpha = \frac{D_2 - D_1}{2L} \qquad (9)$$

Where,

α = angle of cap on the smaller pulley

From equation (9), we get

$$\sin\alpha = \frac{238-68}{2\times 440} \Rightarrow \alpha = \sin^{-1}(0.1932) = 11.14^{o}$$

The angle of contact may be obtained from

$$\theta = (180-2\alpha)\frac{\pi}{180} \qquad (10)$$

Where,
θ = Angle of contact on the smaller pulley

From equation (10), we get

$$\theta = (180-2\times 11.14)\frac{\pi}{180} = 2.75$$

The relation between the belt tensions in the tight and slack side in terms of the coefficient of friction and the angle of contact or angle of lap is given as [5]:

$$\frac{T_1}{T_2} = e^{\mu\theta} \qquad (11)$$

Where,
μ = Coefficient of friction between belt and pulley = 0.3

$$\frac{T_1}{T_2} = e^{0.3\times 2.75} = 2.28 \Rightarrow T_1 = 2.28\times T_2 \qquad (12)$$

Substituting equation (12) into (8), we get

$$(2.28-1)T_2 = 74.30 \Rightarrow T_2 = \frac{74.30}{1.28} = 58.05N \qquad (13)$$

Substituting equation (13) into (12), we get

$$T_1 = 2.28\times 58.05 = 132.35N$$

Determination of Bending Moments acting on the Shaft
Figure 2 shows the vertical load diagram.

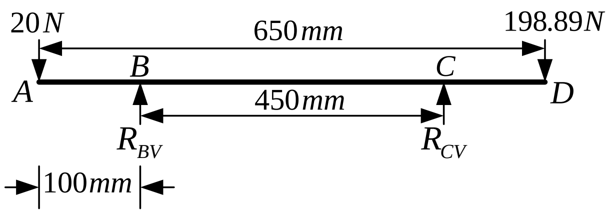

Figure 2: Vertical Load Diagram

Summing forces in the vertical direction gives;

$$R_{BV} + R_{CV} = 20 + 198.89 = 218.89N \qquad (14)$$

Taking moment about B, we get

$$R_{CV}\times 0.45 = 198.89\times 0.55 - 20\times 0.10 \Rightarrow R_{CV} = 238.64N$$

From equation (14), we get

$$R_{BV} = 218.89 - R_{CV} = -19.75N$$

From figure 2,

$$M_{AV} = 0Nm$$

$$M_{BV} = -20\times 0.10 = -2Nm$$

$$M_{CV} = -20\times 0.55 - 19.75\times 0.45 = -19.89Nm$$

$M_{DV} = -20 \times 0.65 - 19.75 \times 0.55 + 238.64 \times 0.10 = 0 Nm$

Figure 3 shows the horizontal load diagram.

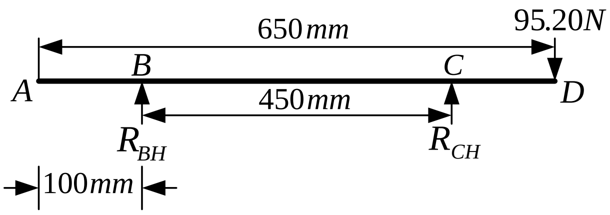

Figure 3: Horizontal Load Diagram

Summing forces in the horizontal direction gives;

$$R_{BH} + R_{CH} = 95.20N \quad (15)$$

Taking moment about B, we get

$$R_{CH} \times 0.45 = 95.20 \times 0.55 \Rightarrow R_{CH} = 116.36N$$

From equation (15),

$$R_{BH} = 95.20 - R_{CH} = -21.16N$$

From figure 3,

$$M_{AH} = 0 Nm$$

$$M_{BH} = 0 Nm$$

$$M_{CH} = -21.16 \times 0.45 = -9.52 Nm$$

$$M_{DH} = -21.16 \times 0.55 + 116.36 \times 0.10 = 0 Nm$$

Resultant bending moment at A

$$M_A = \sqrt{(M_{AV})^2 + (M_{AH})^2} = 0 Nm \quad (16)$$

Resultant bending moment at B

$$M_B = \sqrt{(M_{BV})^2 + (M_{BH})^2} = 2 Nm \quad (17)$$

Resultant bending moment at C

$$M_C = \sqrt{(M_{CV})^2 + (M_{CH})^2} = 22.05 Nm \quad (18)$$

Resultant bending moment at D

$$M_D = \sqrt{(M_{DV})^2 + (M_{DH})^2} = 0 Nm \quad (19)$$

From equation (18), the maximum moment occurs at C with a value of 22.05Nm

Determination of the Twisting Moment acting on the Shaft

Twisting moment acting on the shaft may be obtained from the following equation:

$$M_t = \frac{30 \times P_M}{\pi \times N_2} \quad (20)$$

From equation (20), we get

$$M_t = \frac{30 \times 370}{\pi \times 400} = 8.83 Nm$$

Determination of the Shaft Diameter

A shaft is a rotating cylindrical machine element which is used to transmit power from one place to another. One important approach to designing a transmission shaft is to use American Society of Mechanical Engineers

(ASME) code [6]. For a solid shaft having little or no axial loading, the shaft diameter may be determined from the following ASME code equation [6]:

$$D^3 = \frac{16}{\pi\tau_{max}}\sqrt{(k_b M_b)^2 + (k_t M_t)^2} \qquad (21)$$

Where,
D = Shaft diameter
τ_{max} = Permissible shear stress
M_b = Maximum value of bending moment
M_t = Maximum value of twisting moment
k_b = Combined shock and fatigue factor applied to bending moment
k_t = Combined shock and fatigue factor applied to twisting moment

The ASME code for shaft design is based on the maximum shear stress theory of failure [6]. According to the ASME code, the maximum permissible working stresses in tension or compression may be taken as [5]
(a) 112 MPa for shafts without allowance for keyways.
(b) 84 MPa for shafts with allowance for keyways.

The maximum permissible shear stress may be taken as
(a) 56 MPa for shafts without allowance for key ways.
(b) 42 MPa for shafts with allowance for keyways.

For suddenly applied load, $k_b = 2.0$ and $k_t = 1.5$. From equation (21), we get

$$D = \sqrt[3]{\frac{16}{\pi \times 42 \times 10^6}\sqrt{(2.0 \times 22.05)^2 + (1.5 \times 8.83)^2}} = 17.74mm$$

A standard size of 25mm was selected.

Determination of the Shaft Torsional Rigidity

The permissible angle of twist varies from about 0.25^o per meter length for machine tool applications to about 3^o per meter length for line shafts. The torsional rigidity may be determined from the torsion equation [6]

$$\theta = \frac{584 \times M_t \times L}{G \times D^4} \qquad (22)$$

Where,
θ = Angle of twist in degree
G = Modulus of rigidity of shaft material = 70GPa
L = Length of shaft subjected to twisting moment

From equation (22), we get

$$\theta = \frac{584 \times 8.83 \times 0.65}{70 \times 10^9 \times 0.025^4} = 0.12^o / m$$

Since the value obtained is within the range quoted for shafting, the selected diameter is safe.

III. TESTING

Before testing was carried, the machine was properly assembled and aligned. Lubrication was also done to reduced friction in the rotating members. Figure 4 shows the photograph of the fabricated electrically powered rotary slicer in its assembled form. The electric motor was then switched on and test running was done for ten minutes so as to study the behavior of the machine. It was observed during this process that blade rotated without wobbling. Testing of the machine with load was then carried out, and during this process, the raw plantain held by hand was forced into the chute and with the aid of a short wooden stick with a stopper, the raw plantain was forces into the cutter which slices it in the shortest possible time. In this case, it took 2-3 seconds, depending on the length, to slice a finger of raw plantain.

Figure 4: Electrically Powered Rotary Slicer

IV. CONCLUSION

The work centered on the design of an electrical rotary slicer for raw plantain chips. Fabrication was carried out using materials that were sourced locally. Though this machine was designed for medium scale industries for raw plantain chips production, it can also be used for domestic purposes. The machine can slice up to a maximum of 70mm diameter raw plantain and is capable of slicing a finger of raw plantain in just 2-3 seconds. Maintenance of the machine is simple requires just lubrication of rotating members and proper cleaning after use.

REFERENCES

[1] Maia Appleby. Plantain benefits. NASM-CPT, Demand Media http://healthyeating.sfgate.com/plantain-benefits-5583.html, February 20, 2014.
[2] Arisa NU, Adelekan AO, Alamu AE and Ogunfowora EJ. The effect of pretreatment of plantain (Musa Parasidiaca) flour on the pasting and sensory characteristics of biscuit, International Journal of Food and Nutrition Science. 2013; 2(1): 10-24.
[3] Obeng GY. Development of a mechanized plantain slicer, Journal of Science and Technology. 2004; 24(2): 126-133.
[4] Prasad J and Gupta CB. Mechanics properties of maize stalks as related to harvesting. Journal of Agricultural Engineering Research. 1975; 20(1): 79-87.
[5] Khurmi RS and Gupta JK. A textbook of machine design (S. I. Units), Eurasia Publishing House (PVT.) Ltd., Ram Nagar, New Delhi-110055. 2005; 509-600, 677-714.
[6] Bhandari VB. Design of machine elements, Tata McGraw-Hill Education. 2010; 330-334.