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The Design of a Pedal Driven Pulverizing and Sieving Machine for Dewatered Grated Cassava

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Abstract- The post-harvest operation of cassava is still being done manually and therefore labour intensive. The need to mechanize this process makes it necessary to have a machine that will perform some of these processes. This paper presents the design of a pedal driven pulverizing and sieving machine for dewatered grated cassava. The components design includes the sieve bed mechanism, screening material, chain, shaft and pulverizing cylinder. This involves the mechanization of pulverizing and sieving of dewatered grated cassava. The Machine is designed to be driven like a bicycle, which sends rotary motion to the system for the desire work.

Index Terms- Pedal Driven, Pulverizing, Cassava, Sieving, Dewatered Grated Cassava.

I. Introduction

Cassava (*Manihot esculenta crantz*) is grown in many tropical countries of Africa, Asia and Latin America. However, Africa is the largest producer of Cassava, with 62 percent of the total world production. Nigeria is leading the world with nineteen percent of global market share [1]. The total world cassava utilization is projected to reach 275 million tons by 2020 [2]. Cassava production and processing is still carried out by manual labour using local, simple, farm implements such as hoes and knives in most parts of Nigeria. There is a limited absence of mechanized production to the local farmers who constitute the majority of the producers. Cassava roots are processed at household and cottage levels in the rural areas of the major cassava producing states by traditional methods handed down through time as cassava was adopted as food by the people. Processing at these levels involve mainly the production of 'Garri', fermented and unfermented flour, as well as a local delicacy called 'Fufu' for domestic consumption [3].

The traditional method of grating involves placing of the local grater, which is made of perforated metal sheet on the table where it is convenient for effective use and brushes sheet metal. The cassava turns into pulp and drop into container that is being used to collect the grated pulp cassava [4]. Adejumo [5] in his design used a wooden grater in which the cassava forced into a hopper is rubbed against the grater which is being electrically power. Enhanced quantity of cassava can be grated using this method. However, the durability of the grater is low because of its wooden nature. A pedal operated cassava grinder which is powered by human efforts applied to pedal has been design by Ndaliman [6]. The grinder pulverizes the cassava tubers into paste which can pass through a wire sieve with an effective performance of 60%. Olusegun and Ajiboye [7] design a vertical squeeze cassava pulp dewatering machine and conclude that the rapid rate of dewatering success of their design will enhance the production of 'gari' and thus assist development. Many other researchers has made contributions in the area of cassava tuber peeling and grating [8-16].

II. DESIGN ANALYSIS

2.1 Design Consideration

The machine is constructed so that it can be easily dismantled. The sprocket and chain drive arrangement are used, coupled along with a flywheel to ensure high torque. Hopper is used to ensure that all the materials pass through in order to pulverized and avoid minimum wastage.

The stand of machine has a wide base to increase stability of the machine both at the peddling section and that of the main frame. The chute is sloppy, so that the filtrate can slide downward and discharge by gravity. Above all, the design of the machine is considered to be cheap and of high economic viability when produced in mass production.

2.2 Determination of Sieve mechanism Load

The total loads of the sieve mechanism consist of: mass of the sieve bed, mass of container housing the balls, Mass of 'gari' in container and Mass of the screening material.

Mass of sieve bed

The mass of the sieve bed is given as;

$$m_{sb} = \rho_{sb} V_{sb} \qquad \textbf{(1)}$$

The volume of the sieve bed is given as:

$$V_{sb} = A_{sb} \times t_{sb} \qquad \textbf{(2)}$$

Where,

$$A_{sb} = 2(L_{sb} \times H_{sb}) + 2(B_{sb} \times H_{sb}) \qquad \textbf{(3)}$$

Where, m_{sb} is the mass (kg), ρ_{sb} is the density (kg/m^3), V_{sb} is the volume (m^3), B_{sb} is the breadth (m), L_{sb} is the length (m), t_{sb} is the thickness (m) and H_{sb} is the height (m).

The density of the metal material used is given as 7800kgm^{-3}. Given that B_{sb}=450mm, L_{sb}=700mm, t_{sb}=2mm and H_{sb}=50mm, the mass of the sieve bed is obtained using equations (1) to (3) as 1.794 kg.

Mass of container

The mass of the container is given as;

$$m_c = \rho_c V_c \quad \textbf{(4)}$$

The volume of the container housing the balls is given as:

$$V_c = A_c \times t_c \quad \textbf{(5)}$$

Where,

$$A_c = 2(L_c \times H_c) + 2(B_c \times H_c) \quad \textbf{(6)}$$

Where, m_c is the mass (kg), ρ_c is the density (kg/m^3), V_c is the volume (m^3), B_c is the breadth (m), L_c is the length (m), t_c is the thickness (m) and H_c is the height (m).
The density of the metal material used is given as 7800kgm^{-3}. Given that B_c=440mm, L_c=610mm, t_c=2mm and H_c=110mm, the mass of the container is obtained using equations (4) to (6) as 3.6036 kg.

Mass of 'gari' in container

The mass of the gari in the container is given as;

$$m_g = \rho_g V_g \quad \textbf{(7)}$$

The volume of the gari in the container is given as:

$$V_g = L_g \times B_g \times H_g \quad \textbf{(8)}$$

Where, m_g is the mass (kg), ρ_g is the density (kg/ m^3), V_g is the volume (m^3), B_g is the breadth (m), L_g is the length (m) and H_g is the height (m).
For a dehydrated, grated cassava, the density is given as 563kgm^{-3} [17]. Given that B_g=440mm, L_g=610mm and H_g=60mm, the mass of the 'gari' in the container is obtained using equations (7) and (8) as 9.067 kg.

Mass of the screening material

The screening materials consist of the net and the net frame. The total mass of the screening material is therefore the sum of masses of the net and net frame.

The total mass of the screening material is given as

$$m_{sm} = m_n + m_f \quad \textbf{(9)}$$

Where, m_{sm} is the mass of sieve material (kg), m_n is the mass of the net (kg) and m_f is the mass of the net frame (kg).
Given that the mass of the net and the net frame are 0.003kg and 0.45kg respectively, the total mass of the screening material using equation (9) is 0.453 kg.

The total mass of the reciprocating sieve bed is given as:

$$m_{rsb} = m_{sb} + m_g + m_c + m_{sm} \quad \textbf{(10)}$$

Where, m_{rsb} is the total load of the sieve mechanism (Kg), m_{sb} is the mass of the sieve bed (Kg), m_c is the mass of container housing the balls (Kg), m_g is the mass of gari in container (Kg) and m_{sm} is the mass of the screening material (Kg).
Given that m_c=3.6036Kg, m_g=9.067Kg, m_{sm}=0.453Kg and m_{sb}=1.794Kg, the total load of the sieve mechanism is obtained using equation (10) as 14.9868Kg.

2.3 Maximum displacement of Sieve Bed

The maximum displacement of the sieve bed from the top dead centre position is given as:

$$x = r(1-\cos\theta) + \frac{r^2 \sin\theta^2}{2L} \quad \textbf{(11)}$$

Where, x is the displacement of sieve Bed (m), L is the length of the connecting rod (m), r is the crank radius (m), θ is the angle of crank with the horizontal (^{0}).
Given that L=0.25m and r=0.095m, and that the values for Ls when θ is 45^0, 90^0, 135^0, 180^0, 225^0, 270^0 and 315^0 are 35.83mm, 113.05mm, 171.23mm, 190mm, 171.25mm, 130.05mm and 15.03mm respectively, the maximum displacement occurs when the crank is at an angle of 180^0 with the horizontal as 190mm.

2.4 Chain Design Analysis

Pitch Diameter
The sprocket pitch diameter (P_d) is given as:

$$P_d = \frac{p}{\sin(\frac{180}{n})} \quad \textbf{(12)}$$

Where, P_d is the pitch diameter (mm), p is the chain pitch (mm), n is the number of teeth on small sprocket.
Using the American Chain Association (ACA) chart, a chain of pitch 12.7mm is adopted and n=22, the pitch diameter is obtained from equation (12) as 89.24mm.

Speed ratio

The speed of the larger sprocket to the shaft sprocket can be calculated as:

$$\frac{RP_{m1}}{RP_{m2}} \quad \text{OR} \quad \frac{N_2}{N_1} \quad \textbf{(13)}$$

Where, RP_{m1} is speed of small sprocket, RP_{m2} is speed of large sprocket, N_1 is number of teeth on small sprocket, N_2 is number of teeth on large sprocket.
Given that N_1=22 and N_2=22, the ratio is 2:1.

Chain Velocity
Konz [18] have recommended an allowable design pioneer of about (74.5W) and a speed of 50rpm involving the use of the leg. Therefore, Velocity of the chain is obtained from the relation

$$V = \frac{\pi d n}{60} \quad \textbf{(14)}$$

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).
Given that d=178.02mm and n= 50, the velocity of the sprocket from equation (14) is 0.466m/s.

Chain Load

The relations give the total load on the chain:

$$T_2 = \frac{H}{V} \quad \textbf{(15)}$$

Where, H is the power (W), V is the velocity of chain (m/s), T_2 is the torque (hp).
Given that H=74.5W and the value of V from equation (14), the chain load is 159.85N.

Chain Length

The chain length for sieve shaker is given by:

$$L = 2C + \left[\frac{N_2 + N_1}{2}\right] + \left[\frac{N_2 - N_1}{4\pi^2 C}\right] \quad \textbf{(16)}$$

Where, L is the length of chain (m), C is the centre distance (m), N_1 is the number of teeth on small sprocket, N_2 is the number of teeth on large sprocket.

Effective Chain Power

The effective chain power transmitted through the chain is given as:

$$P = \frac{(T_1 - T_2)V}{1000} \quad \textbf{(17)}$$

Where, P is the chain power (W), V is the velocity (m/s). T_1 is the tensions on the tight side (N), T_2 is the tension on the slack side (N).

2.5 Flywheel Effect

The centrifugal force on the flywheel is given by:

$$F_T = mr\omega^2 \quad \textbf{(18)}$$

The angular velocity is given by;

$$\omega = \frac{2\pi N}{60} \quad \textbf{(19)}$$

The mass of the flywheel is given by;

$$m = \frac{\pi D^2 t}{4 * \rho} \quad \textbf{(20)}$$

The mass of the disc is given by;

$$m_d = \frac{\pi D_d{}^2 t_d}{4 * \rho} \quad \textbf{(21)}$$

Where, F_T is the centrifugal force (N), m is the mass of the flywheel (Kg), t is the thickness of disk (m), D is the diameter of flywheel (m), ρ is the density of steel (Kg/m^3), r is the radius of disk (m), ω is the angular velocity of disk (rad/s), N is the speed of shaft (rpm).
Given that t=3.8mm, t_d=4mm D=260mm, D_d=190mm ρ =7800 Kg/m^3, r =0.13m and N=122.2rpm. The mass of the flywheel, the mass of the disc and the centrifugal force are obtained from equations (18) to (21) as 1.5737Kg, 0.8846Kg and 33.51N respectively.

2.6 Shaft Design

The load acting on the shaft is that of the sprocket and the pulverizing cylinder. The pulverizing cylinder loads consist of the loads due to cylinder drum, spikes rod and cassava lumps. The loads due to sprocket consist of the weight of sprocket and that due to the tension of the tight sprocket.

2.6.1 Loads due to Pulverizing Cylinder

Force due to Cylinder drum
The force applied by the cylinder will be resolved with respect to the force due to cylinder drum is given as;

$$F_c = V_c \rho g \quad \textbf{(22)}$$

The volume of the pulverizing cylinder drum is given as;

$$V_c = \pi r_c{}^2 l_c \quad \textbf{(23)}$$

Force due to Spikes Rod
The force due to the spike rod is given as;

$$F_s = V_s \rho g \quad \textbf{(24)}$$

The volume of the spikes rod is given as;

$$V_s = \pi r_s{}^2 l_s \quad \textbf{(25)}$$

It is recommended that 80 spikes be used, with 20 spikes each in 4 rows perpendicular to the horizontal plane of the shaft. The total force of spikes is given as:

$$F_{st} = F_s \times n_s \quad \textbf{(26)}$$

Force due to Cassava lumps
Assuming that the machine will accept 5kg of cassava lump through the inlet at any given time during operation, the force due to the cassava lump is given as:

$$F_l = m_l g \quad \textbf{(27)}$$

Total Force due to Pulverizing Cylinder

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The total force due to the pulverizing cylinder is given by:

$$F_{pc} = F_c + F_{st} + F_l \quad \textbf{(28)}$$

Where, F_c is the force due to cylinder drum (N), V_c is the volume of cylinder (m^3), r_c is the radius of cylinder (m), l_c is the length of drum (m), F_s is the force due to spikes rod (N), V_s is the volume of spikes rod (m^3), r_s is the radius of spikes rod (m), l_s is the length of spikes rod (m), F_{pc} is the total force due to the pulverizing cylinder (N), F_{st} is the total force of spikes (N), F_l is the force due to the cassava lump (N), m_l is the mass of the lump (kg), n_s is total number of spikes, ρ is the density of the material (kg/m^3), g is the acceleration due gravity (m/s^2).
Given that r_c=23mm, l_c=500mm, r_s=10mm, l_s=54mm, and ρ=7800kg/m^3, the total force due to the pulverizing cylinder is obtained using equations (22) to (28) as 216.479N (292.539N/m).

2.6.2 Loads due to sprocket

Load due to sprocket weight

The force due to the sprocket weight is given as:

$$F_{sp} = m_{sp} g \quad \textbf{(29)}$$

Load due to sprocket

The vertical force due to the tension of the sprocket is given as:

$$F_{tv} = T_1 * Cos\theta \quad \textbf{(30)}$$

The total vertical force due to the sprocket is given as

$$F_T = F_{tv} + F_{sp} \quad \textbf{(31)}$$

The horizontal force due to the tension of the sprocket is given as:

$$F_{th} = T_1 * Sin\theta \quad \textbf{(32)}$$

Where, F_{sp} is the force due to the sprocket weight (N), m_{sp} is the mass of sprocket, F_{tv} is the vertical force due to sprocket tension (N), F_{th} is the horizontal force due to sprocket tension (N), T_1 is the effective pull of the sprocket (N) and θ is the chain transmitting angle (^{0}).
Given that θ=40^0, m_{sp}=0.12kg and T_1=303.118N. The total vertical and horizontal forces due to the sprocket was obtained from equations (29) and (32) as 233.38N and 194.84N respectively.

2.6.3 Determination of Shaft diameter

The total vertical and horizontal forces due to the sprocket and that due to the pulverizing cylinder are illustrated in Figure 1 below.

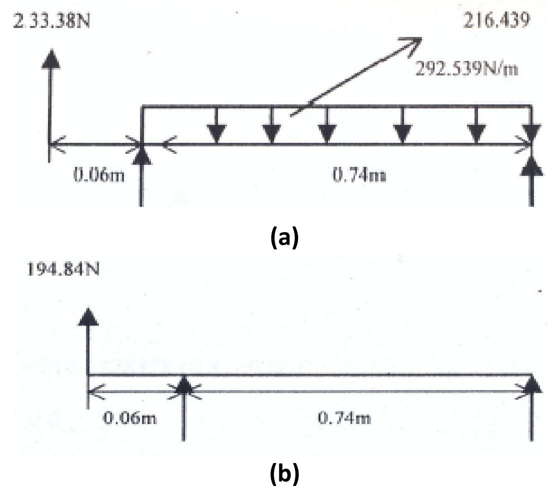

Figure 1: Force distribution on shaft; (a) vertical loading, (b) Horizontal loading

Correct shaft diameter design will ensure satisfactory and rigidity when shaft is transmitting under various operating load conditions. A solid shaft of circular cross-section is used considering analysis of stresses such as torsional and bending stresses.

For solid shaft having little or no axial load is given by;

$$d^3 = \frac{16}{\pi s_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \textbf{(33)}$$

For a shaft transmitting power (Kw) at a rotational speed (rpm), the transmitting torque is given as:

$$M_t = \frac{Power}{Speed} \quad \textbf{(34)}$$

Where, M_t is the torsional moment, M_b is the bending moment, K_b is the combined shock and fatigue applied to bending moment, K_t is the combined shock and fatigue applied to torsional moment, S_s is the allowable stress.
The values of forces on Figure 1 are used to obtain the bending moment of the shaft as 47.368Nm. Given that K_t=1.0, K_b =1.5 and S_s=40x10^6 N/m^2, the diameter of the shaft is 23.45mm. From a standard shaft, 25mm diameter is preferred for this design [19].

2.7 Friction between Bearing and Rail

Figure 2 shows the equilibrium of forces for the ball

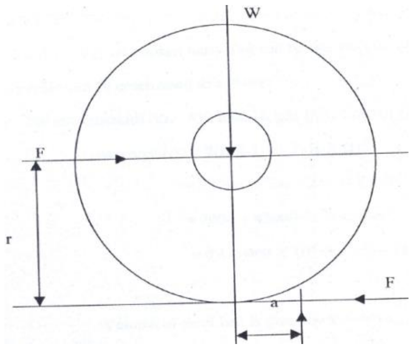

Figure 2: Balls in equilibrium.

The force required to rolling of the ball is given as

$$Fr = wa \quad \textbf{(35)}$$

Where,

$$w = mg \quad \textbf{(36)}$$

Where, F is the force required to cause rolling (N), w is the weight of ball, r is the radius of ball bearing, a is the distance (coefficient of rolling friction) for ball bearing, m is the mass (Kg) and g is acceleration due to gravity.

Given that m=14.655Kg, g = 9.81kg/m^3, a=0.0012 and r=0.0235m. The force required to cause rolling of bearing is obtained from equations (35) and (36) is 7.341N. Figure 3 shows the schematics side view of the designed machine.

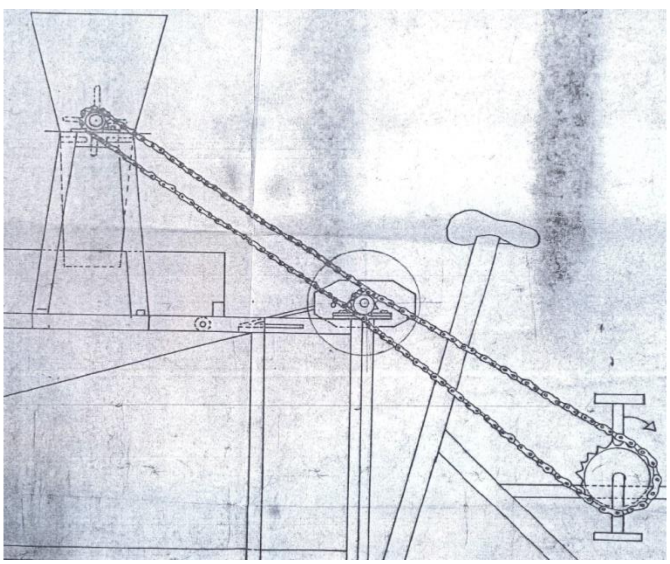
Figure 3. Side view of the design Machine

III. CONCLUSION

The design of a pedal driven pulverizing and sieving machine for dewatered grated cassava has been presented. The components design includes the sieve bed mechanism, screening material, chain, shaft and pulverizing cylinder. The Machine is designed to be driven like a bicycle, which sends rotary motion to the system for the desire work. When fabricated, the pulverizing and sieving of dewatered grated cassava will be achieved mechanically using human effort of bike pedal.

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