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Design Analysis of Cassava Grating Machine for Commercialization

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Abstract: *For a better design to be achieve, good materials at possible lowest cost most be used. In this research work, design analysis of a cassava grating machine for commercialization was carried out. The materials and components used in the design of the machine were properly selected considering design requirements and considerations and this was used to justify the detailed design of the machine. The designed machine consists mainly of truncated pyramid hopper, electric motor, shaft, bearing, v-belt, sprocket, pulley and the grater for the cassava grinding. The v-belt attached to the pulley to drive the shaft impeded with the grater. To ensure that a perfect cassava grating machine with good grating efficiency and performance is designed, the power require to grate the cassava, length of v-belt, speed of driver and driven pulley, belt tension, torque transmitted by electric motor, bending moment, shear force and force require to grate the cassava were all calculated for. The density of the cassava tuber, speed ratio for belt drives, grating force, grating power, distance between driven and driving pulley, lap angle, torque, belt tension, shaft diameter, were obtained as 174.43 kg/m³, 1:3, 208.54 N, 2.5 hp, 0.4 m, 2.89 rad, 15.64 Nm, 2018.29 N, 40 mm. With this design parameters successfully designed for; the machine can be fabricated with ease.*

Keywords: *Cassava, Grating, Design, Material Selection, Processing Unit, Grating Force and Power*

INTRODUCTION

Nigeria is one of the largest producers of cassava in the world with an estimated annual output of over 34 million tons of tuberous roots (FAO, 2006). They are high yielding, more resistant to pest and diseases, with cyanide contents as low as 3.1mg/100g, (Ikuomenisan, 2001). Cassava is a major source of carbohydrate in most developing nations of the world. It is an important diet to more than eight hundred million (800,000,000) people around the world (Patrick *et al.,* 2013). Cassava is referred to as a food security crop (Agbetoye 2005); it can stay unharvested for an extended period of up to two (2) years, until required (Ceballos *et al.,* 2004).

Cassava is used mainly as a fresh food item, but can be processed into various food and non-food products, such as starch, flour, beverages, animal feeds, bio-fuels and textiles (Rehm and Espig, 1991). It can be used as binder in the textile industries as well as in many pharmaceutical and agro allied industries. In Nigeria, the crop can be processed into garri, lafun, paki, pupuru, fufu and cassava grit for direct human/livestock consumption. It can also serve as raw material for the production of bread, biscuit and other consumable and non-consumable products.

The commercial potential of cassava is currently under-utilized in Nigeria, with an annual production capacity of 34 million tons of fresh tubers (Ajibola, 2000). In Nigeria, it is eaten boiled; it can be pounded to be eaten with soup. Due to the economic viability and need for cassava, the Government of Nigeria and Ghana implemented a 'presidential initiatives' to increase cassava production for local consumption and export promotion (Quaye *et al.,* 2009).

Cassava has several advantages compared to other carbohydrate root crops, with much variation in nutrient quality (Davies *et al.,* 2008). The calorific value of cassava is high, compared to most starchy crops (Okigbo, 1983). The protein content is extremely low; however, it ranges between 1-3% (Buitrago, 1990; Tonukari, 2004; Salcedo *et al.,* 2010). A cassava root contains a number of mineral elements in appreciable amount, which are useful in the human diet. The root contains significant amounts of iron, phosphorus and calcium, and is relatively rich in vitamin C (Enidiok *et al.,* 2008). Root dry matter content is higher than other root crops at 3540%, giving optimum rates of 25:1 or better. Cassava starch has excellent agglutinant properties which make it especially suitable for shrimps and fish feeds, replacing expensive artificial agglutinants (Kawano, 2000). However, unit operations such as grating, drying, milling, pressing, sieving, frying and extrusion require mechanization for successful commercialization of cassava production in Nigeria (Ajibola, 2000; Orhorhoro *et al.,* 2017a; Orhorhoro *et al.,* 2017b). In this research work, design analysis is carried out on one of the unit operation (grating) and this was for the sole purpose of commercialization of cassava tuber processing.

MATERIAL AND METHOD

The durability, safety and most importantly the performance of a machine depends on the material used. For a better design to be achieve, good materials at possible lowest cost most be used. How the materials and components used in the design of the cassava grating machine are selected, design in detailed are discussed in this section. The designed machine consists mainly of truncated pyramid hopper, electric motor, shaft, bearing, v-belt, sprocket, pulley and the grater for the cassava grinding. The v-belt attached to the pulley to drive the shaft impeded with the grater. To ensure that a perfect cassava grating machine with good grating efficiency and performance is designed, the power require to grate the cassava, length of v-belt, speed of driver and driven pulley, belt tension, torque transmitted by electric motor, bending moment, shear force and force require to grate the cassava were all calculated for. Feasibility study was carried out to ensure error is avoided.

2.1. **Feasibility Study**

A feasibility study aims to objectively and rationally uncover the strengths and weaknesses of an existing machine or proposed machine to design, opportunities and threats present in the environment, the resources required to carry through, and ultimately the prospects for success. Feasibility study was carried out on existing cassava grating. Different existing designs were look at, modification made, optimization for profit done, environment, ease of use and minimization for loss consider. From the feasibility study, design requirements were drawn.

2.2 Basic Component of the Machine

The machine is expected to have the following component:

2.2.1 Main Frame

Angle bar mild steel of 2 mm thickness was selected for the machine. The choice of mild steel material was due to its strength and rigidity for the overall machine.

2.2.2 Hopper

The hopper is the receptacle through which cassava is admitted into the machine for grating. It has a rectangular plan which tapers gradually.

2.2.3 Grating Unit

This unit consists of the shaft, perforated mesh, rolled sheet, circular disc and rivet pins. Drum is formed by the shaft pass through the rolled cylindrical sheet. This drum is then wrapped with the perforated mesh, they are attached by riveting.

2.2.4 Electric Motor and Pulley System

An electric motor is used to power the machine. A reduction pulley system is used to transmit power to the grater's drum at reduced speed and increased torque. This enables the drum to exhibit rotary motion thereby grating the cassava.

2.2.5 The Discharge Unit

This is a continuation of the grater's frame connected to the hopper. It directs the flow of the grated cassava to a storage pit or receptacle.

2.2.6 Shafts Design

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is transmitted by some tangential force and the resultant torque (or twisting moment) set up within the shafts permits the power to transferred to various machine or its elements linked up to the shaft. In order to transfer the power from the shaft, the various members such as pulleys, bearings, drum etc. are mounted on it. These members along with the force exerted upon them causes the shaft to bending. Therefore, we may say the shaft in this case is expected to bending moment and torsional forces.

2.2.7 Bearings

Bearings are precision design used to support the shaft and permit relative motion between the contact surfaces of the members while carrying load.

2.2.8 Speed Reducers

The function of speed reducers is as follow:

1. To deliver the power at lower speed to the presser mechanism.
2. To transmit power through the machine element that reduces the rotational speed.
3. To receiver power from the input source (engine) through a rotating shaft.

2.2.9 Fasteners

These are temporary or detachable fastening (bolts, nuts, keys screws, etc.). They are employed for joints and their main function is to make a connection that will ensure strength and tightness.

2.2.10 Base Support

The base support is made up of angle plate or angle iron and has been employed for a defined dual function. First, it provides the base seating for all the machines accessories or entire assembly and it also provide a link through which machine can be bolted to the foundation floor through the use of bolts and nuts in the slot provided effective rigidity and mounting.

2.3 Operating Principles of the Grating Machine

The grating machine is composed of the grating chamber where the pulverizing process takes place. The cassava tubers are fed into the grater through the hopper into the first grating chamber while the grated cassava flows down into the second grating chamber for more refining of texture before flowing out through the discharge unit. The whole unit is powered by electric motor of 2.5 hp with a speed of 1440rpm. When the engine is switch on, the first grating unit is rotated by a V-belt attached to the pulley to drive the shaft impeded with the grater. This consequently powers the second grating unit through a same driver system. The incorporation of a double grater cannot be over emphasized. The design has been well considered by the author with the view of addressing the problem of grating twice to refine the texture of the pulp.

The difference of the size of the hole (14 perforation) on the grater, implies that the surface of the first grater with larger holes (perforation) is made rougher than the other. The grater from the rougher flows to the lower slighter less rough grater, while produces the required or desired texture of the pulp and in the process, it reduces the grating time. As cassava tubers are fed into the grater through the hopper, the tubers are pressed mechanically against the grater. The presser mechanism converts a rotary motion to crank to reciprocating motion of the presser, thus eliminating the use of bare hands of feeding with the longer tuber. The driven shaft is also used to drive a speed reducer which in turns is used to drive the shaft that turns the crank. The pulps are collected through the chute to the basin.

2.4 Design Requirement or Functional Requirement

Establishing design requirements is one of the most important elements in the design process and this task is normally performed at the same time as the feasibility analysis. The design requirements control the design of the project throughout the design process. The following design requirements were drawn:

i. Estimation of power required by the cassava grating machine (watts)
ii. Determination of approximate length of the belt (m)
iii. Determination of load on shaft pulley and belt tensions (N)
iv. Determination of speed of driver and driven pulley
v. Determination of torque transmitted by electric motor
vi. Determination of bending moment
vii. Determination of shear force
viii. Determination of force require to grate the cassava
ix. Selection of bearing for shaft

2.5 Design Consideration

The design considerations phase is where you make a list of factors that need to be considered in broad terms. To achieve optimum function for this machine, proper considerations were made to specify and identify some problems which hindered effective performance as in the former machines and effort was put to identify the factors and constraints as put together below.

i. Functionality
ii. Reliability
iii. Durability
iv. Materials and labour use
v. Simplicity
vi. Portability and space
vii. Operational procedure
viii. Power supplier
ix. Usability
x. Maintenance
xi. Cost
xii. Safety

2.6 Detailed Design

Detailed design was carried out to know the detailed design of the required parameters and components. This phase builds on the already developed concept, aiming to further elaborate each aspect of the project by complete description through solid modeling, mathematical modeling, working drawing as well as specifications.

2.6.1 Determination of grating force of the cassava tubers

The grating force of the cassava tubers can be was calculated as follow:

$$W = M_T \times g \quad (1)$$

where,

M_T = Total Mass = Mass of cassava tubers for each cycle of grating+ Mass of bigger grater +Mass of smaller grater (2)

g = Acceleration due to gravity = 9.81m/sec^2

But,

Mass of cassava tubers for each cycle of grating = 5.68kg (Measured)

Mass of bigger grater M_G = 8.93kg (Measured)

Mass of smaller grater M_g= 6.67kg (Measured)

Therefore,

Total Mass M_T= Maximum number of cassava tubers for each cycle of grating M_C+ Mass of bigger grater M_G + Mass of smaller grater M_g = M_m+ M_G + M_g

$$= 5.68 + 8.93 + 6.67 = 21.28kg$$

Therefore,

Weight required by the grating machine $W = M_T \times g = F$

$$W = 21.28 \times 9.8 = 208.54N$$

Hence,

The grating force = 208.54N

2.6.2 Determination of volume of grating chamber

Volume of the grating chamber is calculated as follows:

$$V_C = V_P - V_G - V_g - V_B \quad (3)$$

where,

V_C = Volume of grating chamber

V_P = Volume of truncated pyramid

V_G= Volume occupied by bigger grater

Vg = Volume occupied by smaller greater

V_B = Volume of bearing housing

A. Volume of Truncated Pyramid (Hopper)

Fig. 1 show a truncated pyramid with the dimension

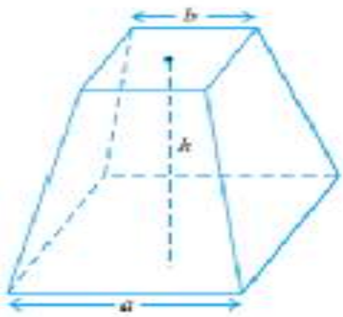

Fig. 1 Truncated pyramid with the dimension

where,
a= 460mm= 0.46m
b= 410mm=0.41m
h =600mm = 0.6m
The volume of the truncated pyramid (hopper) can be calculated as follows:

$$V_P = \frac{1}{3}(a^2 + ab + b^2)h \quad (4)$$

$$V_P = \frac{1}{3}(0.46^2 + 0.46 \times 0.41 + 0.41)0.6$$

$$V_P = 0.162m^3$$

B. Volume Occupied by the Bigger Grater

The grater is cylindrical in shape; therefore, it can be calculated as the volume of cylinder.

$$V_G = \pi R^2 H \quad (5)$$

where,
R = radius of the cylindrical grater
V_D= Volume of the grater
H = height of the grater = 580mm = 0.58m
But,
Circumference of the cylinder grater is given as:

$$L = 2\pi R \quad (6)$$

where,
L= 660mm = 0.66m
This implies that,

$$0.66 = 2 \times 3.142 \times R$$

Therefore,

$$R = \frac{0.66}{2\times 3.142} = 0.105m^3$$

Substituting value of R and H in equation 3.7

$$V_G = 3.142 \times 0.105^2 \times 0.58 = 0.02009m^3$$

C. Volume Occupied by the Smaller Grater

The grater is cylindrical in shape; therefore, it can be calculated as the volume of cylinder.

$$V_g = \pi r^2 h \quad (7)$$

where,
r = radius of the cylindrical grater
V_g= Volume of the grater
h = height of the grater = 560mm = 0.56m
But,
Circumference of the cylinder grater is given as:

$$L = 2\pi r \quad (8)$$

where,
L= 660mm = 0.66m
This implies that,

$$0.66 = 2 \times 3.142 \times r$$

Therefore,

$$r = \frac{0.66}{2\times 3.142} = 0.105m^3$$

Substituting value of r and h in equation 3.9

$$V_g = 3.142 \times 0.105^2 \times 0.56 = 0.0194m^3$$

D. Volume of Bearing Housing

The volume of bearing housing may be determined from the following equation:

$$V_B = \pi r^2 h \quad (9)$$

where;

r = Radius of bearing housing = 50mm = 0.05m

h = Height of bearing housing = 65mm = 0.065m

Therefore;

$$V_B = 3.142 \times 0.05^2 \times 0.065 = 0.000511\text{m}^3$$

Therefore, volume of grating chamber

$$V_C = V_P - V_G - V_g - V_B$$

$$= 0.162 - 0.02009 - 0.0194 - 0.000511 = 0.122m^3$$

2.6.3 Density of the Cassava Tubers

The density ρ_C of the cassava tuber is determined as;

$$M_T = \rho_C \times V_C \quad (10)$$

Therefore Density,

$$\rho_C = \frac{M_T}{V_C}$$

$$= \frac{21.28}{0.122}$$

$$= 174.43\text{Kg}m^3$$

2.6.4 Design for Speed Ratio for Belt Drive

Velocity ratio for belt drive is the ratio between the velocity of the driver and the follower (driven). It may be expressed mathematically as:

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad (11)$$

where,

D_1 = diameter of the driver = 50mm

D_2 = diameter of the driven = 150mm

That is,

N_1 = speed of the driver = 1440rpm

N_2 = speed of the follower =?

Therefore;

$$N_2 = \frac{(1440 \times 50)}{150} = 480rpm$$

2.6.5 Power Required to Grate the Cassava Tubers

$$P = FV \quad (12)$$

where,

P = Power required to turn the shaft

V = Speed

F= Force

$$V = \frac{\pi DN}{60} \quad (13)$$

where,

V= Speed

D= Diameter

N= Speed in revolution per minute

Therefore,

$$P = \frac{ma\pi DN}{60} \quad (14)$$

Therefore,

$$P = \frac{21.28 \times 9.8 \times 3.142 \times 0.05 \times 1440}{60} = 1249.56watts$$

But;
750watts = 1horse power (hp)
This implies that:
1249.56watts = 1.666hp
Considering a safety factor of 1.5 for optimum performance, reliability and durability

Therefore;

$$P = 1.5 \times 1.666 = 2.5\text{hp}$$

2.5 hp (1,875watts) will be preferable

2.6.6 Distance between Driven and Driving Pulley

The centre to centre distance between driver and driven pulley is given as:

$$C = 2D_1 + D_2 \quad (15)$$

where,
D_1 = Diameter of the driver = 50mm = 0.05m
D_2 = Diameter of the driving = 150mm = 0.15m
C= Centre to centre distance between driving pulley and driven pulley
Therefore;

$$C = 2 \times (50 + 150) = 400mm = 0.4m$$

2.6.7 Determination of Belt Length

The belt length can be obtained as follow:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1+D_2}{4C} \quad (16)$$

$$= 2 \times 0.4 + \frac{\pi}{2}(0.05 + 0.15) + \frac{(0.05 + 0.15)}{4 \times 0.4} = 1.24m$$

2.6.8 Determination of Lap Angle

The equation is expressed as follow:

$$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right) \quad (17)$$

where,
α_1 = Angle of lap for driving pulley (rad)
α_2 = Angle of lap for driven pulley
C = Centre to centre distance between driving pulley and driven pulley
However, for open belt, angle of lap is given as

$$\alpha = 180 - 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$$

Therefore;

$$\alpha = 180 - 2\sin^{-1}\left(\frac{0.15-0.05}{2\times0.4}\right) = 165.64^0$$

Converting the angle from degree to radian;

$$165.64° \times \frac{\pi}{180°}$$

= 2.89rad

2.6.9 Determination of Torque

The torque is obtained from the equation as follow:

$$T = FR \tag{18}$$

where,
T = Torque
F = Force
R = $\frac{D}{2} = \frac{150}{2} = 75mm = 0.075m$
Therefore;

$$T = 208.54 \times 0.075m = 15.64Nm$$

2.6.10 Determination of Belt Tension

The belt tension can be calculated as follow:

$$2.3log\left(\frac{T_1}{T_2}\right) = \mu\alpha \tag{19}$$

where,
α = angle of wrap of an open belt
μ= coefficient of friction = 0.4 (Appendix 1)
T_1= Tension in the tight side of the belt
T_2= tension in the slack side of the belt
Also;

$$P = (T_1 - T_2)V \tag{20}$$

Where,
P = Belt power (watts)
V = Belt speed (m/sec)
T_1 and T_2 are tension on the tight and slack sides respectively (N)
Therefore;

$$1{,}875 = (T_1 - T_2)3.77$$

$$T_1 - T_2 = \frac{1{,}875}{3.77} = 497.35 \tag{21}$$

Also;

$$2.3log\frac{T_1}{T_2} = 0.40 \times 2.89$$

$$log\frac{T_1}{T_2} = \frac{0.40 \times 2.89}{2.3} = 0.503$$

$$\frac{T_1}{T_2} = e^{0.503} = 1.654$$

$$T_1 = 1.654T_2 \tag{22}$$

From Equation 21,

$$T_1 = 497.35 + T_2 \tag{23}$$

Equating both equation 22 and 23,

$$1.654 = 497.35 + T_2$$

$$1.654 - T_2 = 497.35$$

$$0.654T_2 = 497.35$$

Therefore;

$$T_2 = \frac{497.35}{0.654} = 760.47N$$

Hence;

$$T_1 = 497.35 + 760.47 = 1{,}257.82N$$

However;

$$T = T_1 + T_2 = 1{,}257.82 + 760.47N = 2{,}018.29N$$

2.6.11 Design of Shaft

$$T_d = \frac{60PK_L}{2\pi N} \quad (24)$$

$$T_d = \frac{60 \times 1875 \times 1.75}{2 \times \pi \times 1440} = 21.757$$

T_D= Design torque
K_L= Load factor=1.75 for line shaft
Thus, for diameter of shaft

$$d^3 = \frac{16}{\pi S_S}\sqrt{(K_b M)^2 + (K_t T_d)^2} \quad (25)$$

$$d^3 = \frac{16}{\pi \times 2{,}103.61}\sqrt{(3 \times 1{,}262.17)^2 + (3 \times 21.757)^2}$$

$$\approx 40mm$$

where,
M=Bending moment

For suddenly applied load (heavy shock), the following values are recommended for K_b and K_t
K_b= 2 to 3
K_t= 1.5 to 3
Selecting material of shaft SAE 1030
S_{ut}= 527MPa
S_{yt}=296MPa

$\tau_{max \leq 0.30 S_{yt}}$

$\tau_{max \leq 0.18 S_{ut}}$

Where,
S_{ut}= Ultimate yield strength

2.7 Components of the Machine and Material Justification

The components of the machine and material justification are shown in Table-1.

Table-1 Components Parts, Material Selected and Justification

S/N	Component part	Material used	Justification
i.	Hopper	Mild steel sheet	❖ Readily available ❖ It undergoes plastic deformation ❖ Does not wear easily
ii.	Shaft	Stainless Steel	❖ High tensile strength ❖ Ability to resistance corrosion ❖ Ability to withstand shear force and compressive force.
iii.	Frame	Mild steel angle bar	❖ Readily available ❖ It undergoes plastic deformation ❖ Does not wear easily
iv.	Grating Element	Stainless steel	❖ Toughness and strength ❖ Corrosion resistance
vi.	Bearing	High carbon steel	❖ Resistance to wear and corrosion, hard, tough and has high strength
vii.	Pulley	Cast iron	❖ Tough, hard, low cost and has high strength
ix.	Angle bar	Mild steel (Low carbon steel)	❖ Ability to withstand shear force and compressive force.
x.	V-belt	Fibre reinforced rubber	❖ It is strong, flexible and durable ❖ It has a high coefficient of friction
xi.	Metal sheet	Stainless Steel	❖ Ability to resist corrosion. ❖ At high temperatures it prevents scale and maintains strength.

RESULTS AND DISCUSSION

Table-2 shows the results of detailed design of the machine. The analysis of the results showed that a total mass and weight of 21.28 kg and 208.54 N were desirable for the machine. Also, the volume of the grating chamber which was the difference of volume of truncated pyramid and sum of volume occupied by bigger grater, volume occupied by smaller greater, and volume of bearing housing was determine as 0.122 m^3. Considering the fact that the grating process is continuous, that volume is enough to grate tons of cassava tubers on a daily basis. The density of the cassava tuber, speed ratio for belt drives, grating force, grating power, distance between driven and driving pulley, lap angle, torque, belt tension, shaft diameter, were obtained as 174.43 kg/m³, 1:3, 208.54 N, 2.5 hp, 0.4 m, 2.89 rad, 15.64 Nm, 2018.29 N, 40 mm.

Table-2 Results of Detailed Design

S/N	Parameters	Unit	Calculated Data
1	Total mass required	kg	21.28
2	Total weight required	N	208.54
3	Volume of the grating chamber	m^3	0.122
4	Density of the cassava tuber,	Kg/m^3	174.43
5	Speed ratio for belt drive	-	1:3
6	Grating force	N	208.54
7	Grating power	hp	2.5
8	Distance between driven and driving pulley	m	0.4
9	Lap angle	rad	2.89
10	Torque	Nm	15.64
11	Belt tension	N	2018.29
12	Shaft diameter	mm	40

Fig. 2 shows the forces acting on cassava grating machine.

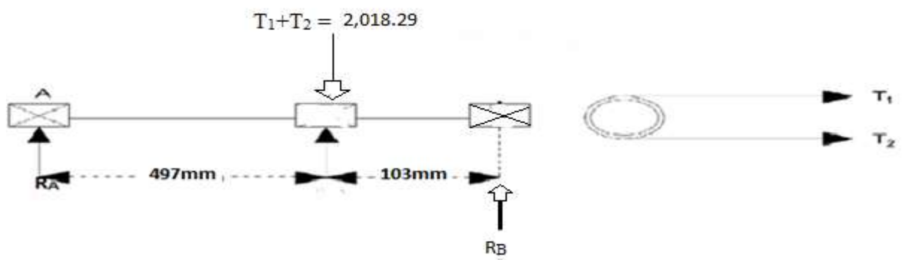

Fig. 2 Forces acting on the machine

Fig. 3 shows the shearing force diagram analysis. As depicted in Fig. 2, the upward and downward forces are equal, thus the system is in state of equilibrium.

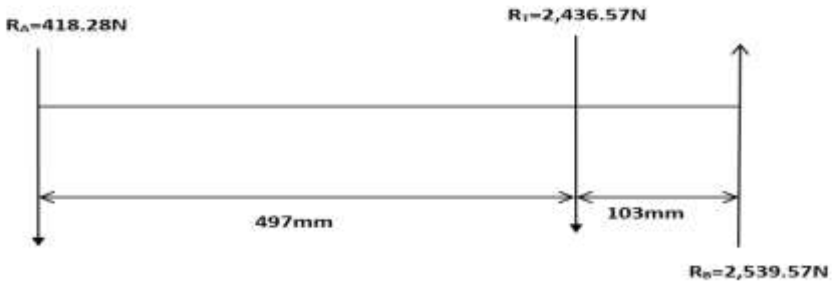

Fig. 3 Shearing force diagram analysis

Let S be the sharing force.
S_A =- -435.96N
S_A+B = -435.96N + 2,539.57N = 2,103.61N
S_B-T= 2,103.61-2,103.61 =0

Fig. 4 shows the bending moment diagram analysis
M_A = 0
M_B = 0.497 x 2,539.57N = 1,262.17N
M_C =0

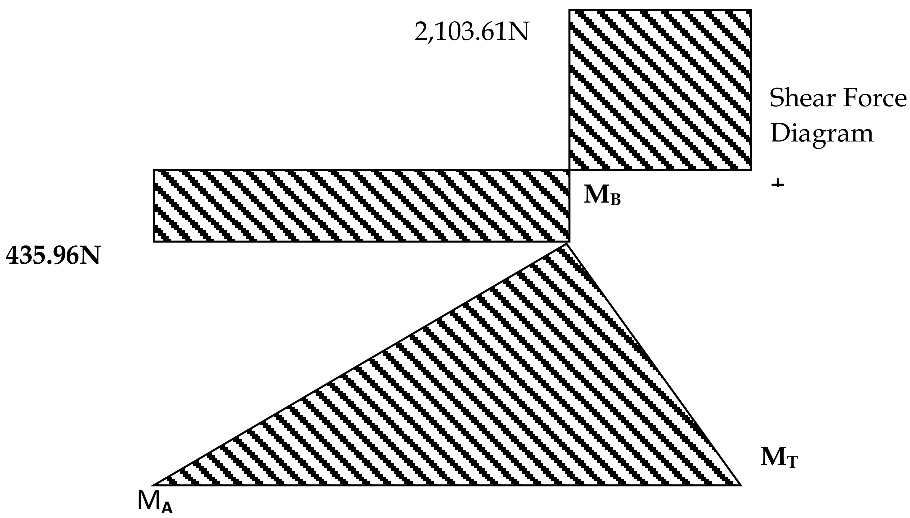

Fig. 4 Bending moment diagram analysis

CONCLUSION

A cassava grating machine was successfully designed and analyzed for commercial purpose. The density of the cassava tuber, speed ratio for belt drives, grating force, grating power, distance between driven and driving pulley, lap angle, torque, belt tension, shaft diameter, were obtained as 174.43 kg/m^3, 1:3, 208.54 N, 2.5 hp, 0.4 m, 2.89 rad, 15.64 Nm, 2018.29 N, 40 mm. More so, all selected components and materials for this design were successfully justified. The out of the design analysis reveal that the machine was successfully design and can be fabricated for commercialization.

CONFLICT OF INTEREST

We declare that no conflict of interest will arise whatsoever in publishing of this research work.

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