DESIGN OF A MAIZE GRINDING MACHINE USING LOW COST STAINLESS STEEL AND DUAL ENERGY SOURCE FOR ALTERNATIVE POWERING

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ABSTRACT

The specific objectives were to study existing grinding machines, determine the problems from literature and user perspectives, carry out materials study and design the machine. Secondary and ethnographic data collection were considered in the method from existing machines and users, as well as data of market survey of materials cost, thereafter the use of relevant theories for the design of the machine, and analysis. The hopper capacity of the 8.5kg maize grinding need was found to be 0.011m^3 with a sheet thickness of 1mm made from ferritic stainless steel. It was predicted that the machine's throat would be 0.00057m^3 in volume made from 2mm thick sheet, and the diameter of the shaft passing through it was calculated to be 18mm. 0.5kW was calculated to power the machine using a belt and pulley system. Driver and driven pulley diameters were 30mm and 150mm, with speeds of 1500rpm and 300rpm accordingly, having belt lengths of 1230mm and 1190mm for engine-grinder pulleys and the electric motor-grinder pulleys respectively. The modified dimensions of table height, height from table to centre of grinder pulley, and table length were 441.4mm, 200mm and 800mm respectively.

Keywords: Low Cost Stainless Steel, Dual Energy Source, Maize Grinding Machine

INTRODUCTION

Crops such as tomatoes, pepper, and maize among others are used to prepare local foods by Nigerians. The processes of making these foods may involve grinding which can be achieved by traditional methods or the use of modern machines. Grinding food items is a very important part of food processing

(Erameh and Adingwupu, 2019). Sometimes grinding is also carried out in the process of preservation of these agricultural produce. Maize is a food grain that is widely grown in the country as well as a major staple food for households. Maize is widely cultivated and consumed of all cereals after wheat and rice in the world (Polatci et al., 2020). It has wide application including in livestock feeds, raw materials in breweries, cornflakes, pap production etc. Both small and large scale processes often demand the use of grinding machines to reduce particle size of grains. Food processing sometimes involves mechanical processes that utilize large mixing, grinding, chopping and emulsifying equipment in the production (Gana et al., 2014). This helps to save time, meet product demand, reduce human labour, and in value addition.

Maize grains are normally soaked at normal temperature for about 36 hours, rinsed before being grinded. Soaking helps to soften the maize kernels and maximize (enhance) the pap extraction. The soaking softens the grain kernels for milling operation, and usually takes 24 to 48 hours (Gana et al., 2014; Akingbala et al., 1987; Nche et al., 1996). Another method is hot soaking which can be carried out at higher temperatures. During soaking, the surface area, size and volume of the grain are increased with increased time. The sphericity, true density and bulk density all increased in all the varieties with increase in the soaking period. Beyond 36 hours of soaking an irregular decline was observed; and hot soaking at 65^{o}C only caused an insignificant change (Bolaji et al., 2017). These characteristics enable suitable machine design such as in the grinder. The physical properties are necessary considerations in the design and effective utilization of the machine used in post harvest technologies such as processing, transportation, storage, and packaging treatments of biological materials (Polatci et al., 2020); in the moisture range, the angle of repose varied from 23 to 28.55^{o} for grains (Bhise et al., 2014).

The grinding machine usually include a hopper for loading the grains, a barrel (throat) through which a shaft with a helix pattern passes, a prime mover to power the machine using a belt and pulley mechanism for power transmission. The conventional foodstuff grinding machine is operated with the aid of a prime mover which could be in the form of an internal combustion engine or an electric motor (Adetunji and Quadri, 2011). The shaft crushes the grains and passes them to two grinding discs which can be adjusted using a lever to further smoothen the paste before exiting at the chute (outlet). The grinding is done by means of two discs with rough surfaces. One disc is stationary and attached to the body of the grinder while the second disc is attached to the shaft and rotates as the shaft rotates, and the output of the grinder depends on the distance between the two discs (Kilanko et al., 2021). A number of design solutions proffered by various researchers considered cost consideration, electricity concern, corrosion etc. Hand operated grinders considers the use of worm gear mechanism to magnify human turning effort. Using the selected transmission ratio of 6:1 for the gears used, this translate to 300 rpm at the main shaft (Erameh and Adingwupu, 2019); the conveyor shaft was made of two parts, worm and shaft (Kilanko et al., 2021). Edun et al. (2019) developed an improved grinding machine using stainless steel to solve the problem of metal contamination, corrosion effect from machine parts and manual means of applying water. As for the grinding machine designed by Desta and Oumer (2022) the crushing member used in the grinding is rotating hammer mill for crushing locally available grains of maize, sorghum, wheat etc.

The use of poor quality material for making the grinder such as locally fabricated cast iron can increase corrosion problem. Results reveal that metallic contaminants are always contained in grinded food processed with local grinding discs (Odusote et al. 2017). Aluminium alloys and stainless steels are generally corrosion resistant. Aluminiun alloy was used in the work of Kilanko et al. (2021) design and construction of manual food grinder. Literature reviewed where stainless steel was used in the design of grinding machines did not specify the grades of steel. For example in Edun et al. (2019) the designed prototype stainless steel pepper grinding machine, which is the development of an improved pepper grinding machine. In the same vein in the paper by Erameh and Adingwupu (2019) design and development of a hand operated grinding machine, the stainless steel grade used was not mentioned. It is obvious that these previous studies did not address the problems from the view point of stainless steel grades, and the machine driven ones are of high speed and power demand. The problems this current study will tackle include engine failure, downtime, size and high cost. This will be enabled by a combination of stainless steel grades and price data analysis for material selection, configuration modification permitting two prime movers to be under the table, and design for low power usage to enhance affordability based on grinder capacity of most small business owners. The purpose of this study/paper is to design a maize grinding machine with a low cost stainless steel and dual energy source for alternative powering using electric motor/internal combustion engine.

MATERIALS AND METHODS

Ethnographic and secondary data collections were considered in the methodology, and data of market survey of materials cost, as well as relevant theories and practice for the design, and analysis was carried out.

Equipment

Data collection which included materials types, powering technologies, dimensions, machine configurations, engine problems etc was carried out from existing grinding machines in the field at Oghara and Ekpoma in Delta and Edo States respectively.

Materials Consideration

Mechanical properties including strength and wear resistance were considered in the design of the maize grinding machine. Other considerations included corrosion resistance, as well as cost.

Procedure

Data collected from existing machines as well as user observations and requirements were assembled. Thereafter, material properties and price survey of five stainless steel types including austenitic (304), austenitic (316), martensitic (410), ferritic (409) and ferritic (430) were analyzed to select a cost effective material type based on user requirement. In the next step, machine configuration was modified to provide two prime movers (electric motor/internal combustion engine) under the table in a compact form. Finally, the machine members were designed using relevant engineering principles.

Design

The design of the main machine members which include the hopper, barrel (throat), conveyor shaft, and belt-pulley systems will be considered under this sub topic, as well as determination of the power requirement.

Hopper

Average bulk density of five varieties of soaked maize at 28^{o}C from the report of Bolaji et al. (2017) was calculated to be $\rho =$ 772.94m^3/kg. Considering a maize need of mass $M =$ 8.5kg; the density is given as

$$\rho = M/V \qquad (1)$$

where $V =$ volume of hopper

$$V = 8.5/772.94 \; = 0.011m^3$$

Hopper Plate Thickness

Assuming distributed loading on each of the faces of the frustum are equal considering the face of area A = ((0.09 + 0.36)/2) 0.2 = 0.045 m^2, and that a maximum load of (8.5kg x 9.81)N will act on each of the inside faces of the hopper when horizontal and simply supported as shown in Figure 1.

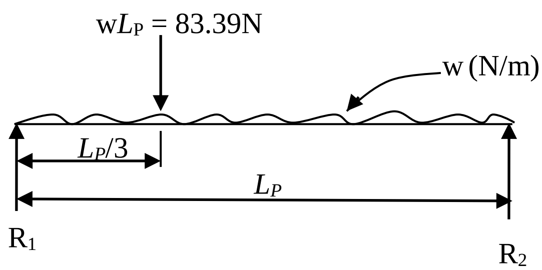

Figure 1: Load on Plate

Taking moment about the reaction R$_2$, reaction R$_1$ can be found for the system with rate of loading w. The equivalent concentrated load of the distributed load is

$$wL_{\mathrm{P}} = 8.5kg(9.81m/s^2) = 83.39N$$

where $L_{\mathrm{P}} =$ length of plate, $w =$ the rate of loading, wL_{P} = load acting on the plate,

$$w(0.2) = 83.39$$

$$w = 416.95N/m$$

$$\sum M_{R2} = 0$$

$$R_1 L_{\mathrm{P}} - wL(2/3)L_{\mathrm{P}} = 0$$

$$R_1 = 55.6 \; N$$

Taking summation of vertical force

$$\sum F_v = 0$$

$R_2 = 27.79N$

Bending moment is

$M_b = Fx_d$

where $F =$ force, $x_d =$ perpendicular distance; and the maximum bending moment is

$M_{maxb} = (R_1)(L_{\mathrm{P}}/3)$

$M_{maxb} = (55.6)(0.2/3) = 3.71Nm$

Considering combined direct and bending load on the plate,

$\sigma_y = \sigma_d + \sigma_b$

$\sigma_{des} = (wL_{\mathrm{P}}/A) + (M_{maxb}y)/I$

where $\sigma_d =$ direct stress, $\sigma_b =$ bending stress; $\sigma_y = 250N/mm^2$ = yield stress of material (stainless steel). Austenitic and ferrite stainless steels have quite low yield strength: 175-300Mpa and 240-260MPa respectively (Tylek and Kuchta, 2014); the predominant structural steel types used for building construction were carbon steel which have nominal yield strength values of approximately 200-300MPa like ASTM A36 (Yu et al., 2019)

The design stress can be determined from applying a safety factor *Fs*, to the yield stress,

$\sigma_{des} = \sigma_y/F_s$

where $= 0.045m^2$, $y = t/2$, $t =$ thickness of plate, $I = bt^3/12 =$ second moment of (4) area considering a rectangular section, $b = (l_1 + l_2)/2 =$ (0.09+0.36)/2 = 0.23m = average width of plate.

Using a safety factor of 2, and solving for t,

$t = 0.0009m = 1mm$

Mass of Maize in Barrel

Ignoring the cut-out part being loading opening and external volume of shaft passing through the throat; and taking a throat (barrel) of 75mm (0.075m) internal (5) diameter *d* and length of 130mm (0.130), the volume is

$$V_b = \pi r^2 L_b \quad (7)$$

where V_b = volume of barrel, $r =$ radius of barrel, L_b =length of barrel; putting values in equation (7)

$V_b = 0.00057m^3$

using equation (1), the mass of maize in the barrel at a time is

$M_b = 0.46kg$

Barrel Plate Thickness

Considering the unfolded plate of the throat with length L_b, width πd and thickness t as indicated in Figure 2.

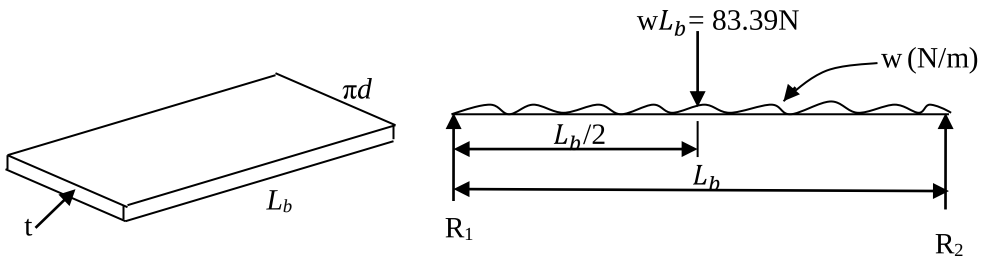

Figure 2: Left: Unfolded Barrel Plate; Right: Loaded Barrel

The width of the plate is equal to circumference of the circle πd and the area is

Area = $(L_b)(\pi d)$ = (0.13)π(0.75) = 0.24m^2

Assuming load wL_b = 83.39N, then the reactions at the supports are equal as $wL_P/2 = R_1 = R_1 = (83.39/2)$N. The maximum bending moment is

$M_{maxb} = (R_1)(/2) = (wL_P/2)(L_P/2)$

$M_{maxb} = 2.71$Nm

Using equation (5) gives t = 0.0013m (or 2mm)

Torque and Power

For a rotating shaft through the throat, the angular velocity is

$\omega = 2\pi N/60$

where $N = 300$ rpm= rotational speed, $\omega =$ angular velocity

$\omega = 31.42 rad/s$

The torque is given as

$Ʈ = M_b r^2 \omega^2$

$Ʈ = 0.66 Nm$

Power is

$P_o = Ʈ\omega$

$P_o = 20.74W$

$0.46kg = 20.74W$

$1kg = 20.74/0.46 = 45.09W$

$8.5\ kg = 383.27W$

Power loss is

$P_l = P_o(1 - PF)$ (8)

where $PF = 0.7 =$ power factor; and putting values in equation (10)

$P_l = 114.98W$

Electric motor power,

$P_e = P_o + P_l$ (11)

$P_e = 383.27 + 114.98 = 498.25W\ (0.5kW)$

$\mathrm{w}x = 83.39N$

Shaft Design

The equivalent concentrated load of the distributed load in Figure 3 is

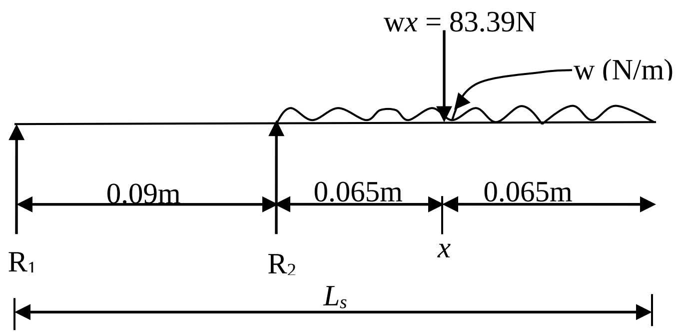

Figure 3: Shaft Loading

$w(0.13) = 83.39$

$w = 641.46N/m$

For the whole beam of length L_s, taking moment about R_1, gives R_2 = 143.62N, and from summation of the vertical forces R_1 = 60.23N. When moment of the force wx is taken about R_1, then the maximum bending moment will be

$M_{maxb} = (83.39)(0.155) = 12.93Nm$

The shaft diameter can be obtained using equation (12)

$d_s = (32\, n_s\, (M_{maxb}^2 + T^2)^{\frac{1}{2}}/\pi S_y)^{1/3}$ (12)

where = n_1 x n_2 = 3 x 3, S_y = 250N/mm^2 = yield strength of stainless steel; and substituting

$d_s = 0.01708m(17.1mm)$, use $18mm$

Belt-Pulley

Pulley diameters and speed relation can be gotten from (Ujevwerume and Ayadju, 2023; Ayadju and Otomewo, 2020) as

$d_2/d_1 = d_2/d_3 = N_1/N_2 = N_3/N_2$

where $d_1 = 0.03m =$ diameter of driver pulley (internal combustion engine) = d_3 = that of electric motor, $d_2 =$ diameter of driven pulley, $N_1 =$ speed of driver pulley (internal combustion engine) = $N_3 =$ that of electric motor , $N_2 = 300$ rpm = speed of driven pulley

For a transmission or speed ratio of 5

$d_2/d_1 = 5$

$d_2 = 0.150m$

Putting values in equation (13) then $N_1 = 1500rpm$,

length of belt l_b, angle of contact θ (also called angle of wrap, or angle of lap) of belt with smaller pulley, angle of contact θ of belt with bigger pulley are given in equations (14), (15) and (16) respectively

$l_b = (2c + \pi(d_1 + d_2)/2 + (d_2 - d_1)^2/4c$

$\theta = 180 - 2\beta$

$\theta = 180 + 2\beta$

β can be determined from equation (17)

$\beta = sin^{-1}(d_2 - d_1)/2c$

where c is centre to centre distance of the belt-pulley system, and the relation of the tight side tension T_1 and slack side tension T_2 shown in Figure 4 is given in equation (18)

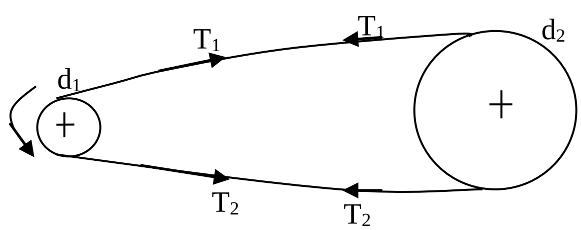

Figure 4: Pulley-Belt System

$T_1/T_2 = e^{\mu\theta}$ (18)

where μ = 0.3 = coefficient of friction between belt and pulley

Velocity can be determined from equation (19)

$v = 2\pi N r_1/60$ (19)

wnere $r_1 = 0.015m$ = radius of pulley 1, c = 0.47m for the internal combustion engine; putting values in equations (14), (17), (15), (16) and (19) then l_{b1} = 1.23m = length of belt 1, $\beta = 7.33^o$, $\theta = 165.34^o$ = 2.89 rad, $\theta = 194.66^o$ = 3.4 rad and $v = 0.94m/s$

Power requirement is related to tension and velocity as

$P_e = (T_1 - T_2)v$

Using equations (18) and (20), and $\theta =$ 3.4 rad, then

$T_1 = 829.51N$ and $T_2 = 299.46N$

For the electric motor, c = 0.42m for the electric motor; putting values in equations (14), (17), (15), (16) and (19) then $l_{b2} =$ 1.19m (20) = length of belt 2, $\beta = 8.21^o$, $\theta = 163.58^o = 2.86$ rad, $\theta = 196.42^o =$ 3.43 rad.. Applying equations (18) and (20), and $\theta = 3.43$ rad, then

$T_1 = 824.52N$ and $T_2 = 294.47N$

The grinder, internal combustion engine and electric motor pulleys arrangement is shown in Figure 5; 1, 2 and 3 being pulleys on shafts of internal combustion engine, grinder and electric motor respectively. Slots are provided at the top for belt passage, and a sliding top each that moves outward at the ends over the internal combustion engine and electric motor. The dimensions are in millimeters.

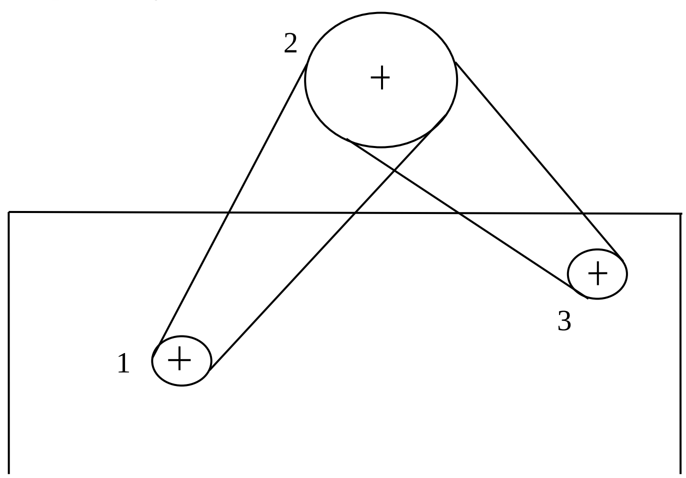

Figure 5: Grinder, Internal Combustion Engine and Electric Motor Pulleys Arrangement

RESULTS AND DISCUSSION

Table 1: Design Results

Hopper	
Material	Ferritic Stainless Steel
Volume (m^3)	0.011
Mass of Corn (kg)	8.5
Sheet Thickness (mm)	1
Throat	
Material	Ferritic Stainless Steel
Diameter (mm)	75
Length (mm)	130
Volume (m^3)	0.00057
Sheet Thickness (mm)	2
Shaft	
Material	Ferritic Stainless Steel
Diameter (mm)	18
Length (mm)	155
Pulley	
Driver Pulley Diameter (mm)	30
Driven Pulley Diameter (mm)	150
Driver Pulley Speed (rpm)	1500
Driven Pulley Speed (rpm)	300
Belt Length l_{b1} (mm)	1230
Belt Length l_{b2} (mm)	1190
Power	
Technology	Electric Motor/Internal Combustion Engine
Power (kW)	0.5
Table Height (mm)	441.4
Height from Table to Centre of Grinder Pulley (mm)	200
Table Length (mm)	800

8.5kg of maize needed a hopper capacity of 0.011m^3 with a sheet thickness of 1mm as seen in Table 1. Throat section of the maize grinding machine was also predicted to be made of 2mm thick sheet with a capacity of 0.00057m^3. The shaft diameter was calculated to be 18mm ferritic stainless material. 0.5kW was determined to power the machine using a belt and pulley system with driver and driven pulley diameters of

30mm and 150mm respectively, and driver and driven pulley speeds of 1500rpm and 300rpm accordingly, and belt length of 1230mm and 1190mm for engine-grinder pulleys and the electric motor-grinder pulleys respectively. Moreover, the alternative electric motor powering used would enhance availability and abate the effect of engine failure and downtime on operations. The arrangement offered a compact machine when compared from measurement from an existing machine with modified table height, height from table to centre of grinder pulley, and table length of 441.4mm, 200mm and 800mm accordingly

CONCLUSION

The modified machine to grind 8.5kg of maize was found to have a hopper and a barrel volume of 0.011m^3 and 0.00057m^3 with sheet thickness of 1mm and 2mm respectively. It was also predicted to have a conveyor shaft of 18mm in diameter, and pulleys of 30mm and 150mm in diameters and 1500rpm and 300rpm in speeds at driver and driven ends accordingly. A power of 0.5kW was determined to drive the machine with transmission belt length of 1230mm for the engine belt-pulley system and 1190mm for that of the electric motor, while the table height, height from table to centre of grinder pulley and table length were 441.4mm, 200mm, and 800mm respectively.

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