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Design and construction of a manual food grinder

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Abstract
In this study, a light weight portable manual food grinder for domestic use was designed and fabricated to meet food grinding needs that arise from erratic power supply in Nigeria. The design analysis for crank lever parameters and conveyor shaft diameter were done. To make the grinder light weight, the body of the machine, the front cover that house the grinding mechanisms and the support stand were printed with Fused deposition modelling 3D printer.The crank lever, conveyour shaft, grinding discs and the adjustment lever were made of cast alumimum metal. The design analysis revealed that an effort force of 600N on the crank lever will inflict maximum twisting moment of 72000 N-mm and 45000 N-mm on the conveyor shaft of the grinder. For the design of crank lever arm, the minimum boss diameter, boss length, boss thickness, lever thickness, lever width, and crank lever diameter were 18.24 mm, 22.9 mm, 3.42 mm, 8.58 mm, 17.36 mm and 14.94 mm respectively. The minimum conveyor shaft diameter was 25.02 mm while the machine required minimum power of 301.59W.

keywords: food, grinder, manual, domestic, design, crank lever, shaft diameter.

1. Introduction

The need for grinding of food substances such as pepper, tomato etc. necessitated the design in this article. The electric blender has not been optimally put into use because of the erratic power supply in Nigeria, most especially in rural areas. This project was designed to tackle this problem and carry out manual grinding of food substances on a larger scale and in an easier manner than the already existing manual grinders. The manual grinding machine is a machine used to grind domestic food substances such as pepper, beans, corn etc in the kitchen 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 by the turning of the crank lever handle. The body of the common manual domestic food grinder and the parts that make direct contact with the food such as the conveyor shaft are made of mild steel while the discs for grinding are made of cast iron. The output of the grinding depends on the distance between the two discs.
Several research projects have been carried out on different grinding machines in both manual and motorized. Sunday and Ndalima [1] designed an efficient machine that has mode of operation that is both motorised and manual that is used for single meat grinding.This was designed for both rural and urban areas. The design shows material selection, arrangement of kinematic forces and parts proportion to ensure maximum functionality and strength of the machine. To prevent the machine failure, The stress (21MN/m2) that the machine is subjected to during operation is kept below its ultimate stress (30MN/m2). Ibrahim et al. [2] designed a manual table-top grinding machine. The mechanism employed were a set of bevel gears intersecting at righ angles with a velocity ratio of 5:1. This is to ease the drudgery encountered when using the existing manual screw grinder. It has advantage over the existing manual screw grinder and electric blender. The power output is five times the power input while it is being manally cranked. Fox [3] designed an efficient machine that mechanically shred breadfruit to best prepare it for the drying process. The shredding technique

used was disc shredder. The disc shredder designed had the ability to shred various agricultural produce at approximately 200 lbs/hr at 60-65 revolution per minutes. Nasir [4] designed and constructed hammer mill from materials that are available locally for grain particles grinding such as guinea corn, millet, maize and other coarse materials of beans, yam tuber, cassava tuber etc. into small size that is enough to pass through the hole of the sieve placed below the assembly of the hammers. During the grinding process, the hammers beat the grains into fine particles that are small enough to pass through the aperture of detachable screen ranging from 87µm to 2 mm. Based on the output shaft speed and power ratingss of the existing grinding machines in the industries like flour mill, one horse-power electric motor is capable to mill effectively when the main shaft speed of 700 rpm is transmitted by belt drive. Odigboh [5] developed a manually operated cassava grating machine prototype. The machine was designed to be easily operated at 30-45 rpm to give the same output and quality as motorised graters at a throughput of 125-185 kg/h. In comparison to the old drudgery and pain-inflicting process involved in the traditional grating method. The prototype grater serves as a powerful alternative. Kevin et al. [6] developed a portable multipurpose machine used for milling and grinding of small work pieces very precisely. He achieved this using 40C carbon steel for the shaft and 12 volt DC motor of 100 revolution per minutes.

2. Materials and methods

The design in this work was done to eliminate reliance on electricity for grinding operations, make the grinding operation to be easily done and also make the machine portable and of less weight so it can be moved easily from place to place. The parts that make direct contact with the food such as the conveyor shaft and the discs for grinding, the handle for turning the shaft and the disc adjustment lever are made of cast aluminum material to eliminate the poisonous nature of cast-iron being used for both manual and motorised grinding machine in Nigeria. The body of the machine was made of PLA plastic printed with 3D printer that used Fused Deposition Modelling technology (FDM). This is to make the machine of light weight.

2.1 Machine description

The machine primarily consists of a hopper, body, shaft, crank lever, front cover and an adjustment lever Figure 1(a). The dimesions of the manual food grinder was 260 x 300 x 400 mm. The hopper was made up of PLA plastic. The larger upper opening is for introducing the food into the machine. The hopper is oval in shape. The upper opening has a diameter of 150 mm and a thickness of 5mm while the bottom opening has a diameter of 40 mm. The body of the machine was also made of PLA plastic. It houses the other parts of the machine that are made of metallic materials. The food drops directly from the hopper into the body. It has a total length of 193 mm. The conveyor shaft was made up of two parts, the worm and shaft. They were both made of aluminum materials. The shaft conveys the food to the two discs for grinding operation. There are two grinding discs made of cast aluminum material. One is stationary and attached to the body while the other one is rotating and attached to the shaft. The discs do the grinding of the food. The crank lever was attached to the shaft and by screw and was used to power the machine manually for grinding operation. The front cover was used to cover the front of the machine and serves as the grinding chamber where the two grinding plates rub each other to perform grinding operation. The adjustment lever was made of aluminum and was used to adjust the distance between the two discs. There is an iron ball between the end of adjustment lever and the end of the conveyor shaft. The stand that support the entire machine was made of plastic. The picture of the fabricated machine is shown in Figure 1(b).

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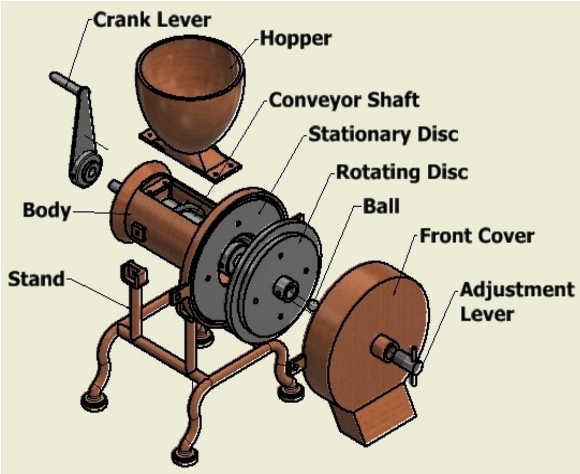

Figure 1(a): Manual food grinding machine diagram

Figure 1(b): Manual food grinder

2.2 Machine operation

The machine grinds the food by the action of two aluminium discs. The first disc is stationary and was attached to the body of the machine while the second disc was attached to the shaft. The second disc rotates when the crank handle is turned. The food substance is fed into the machine through the hopper that opens directly into the body of the machine. As the handle rotates, the conveyor shaft conveys the food to the disc. The adjustment lever is used to adjust the distance between the two discs when the food falls in between the discs. The smaller the distance, the finer the output of the grinding process. As the crank handle rotates, the movable disc grinds the food against the stationary disc. The paste flows out of the machine from the discharge chute on the front cover.

2.3 Machine design analysis

2.3.1 Design of diameter of the lever handle (dh)

Figure 2 shows various parameters of the crank lever arm to be designed for. The diameter of the handle (dh) was obtained from bending considerations. It was assumed that the effort (P) applied on the handle acts at (2/3)rd of its length L1. The diameter of the lever handle was calculated below according to Khurmi and Gupta [7].

$$Maximum\ bending\ moment\ on\ the\ handle = P \times \frac{2L1}{3} \quad (1)$$

$$Section\ modulus\ of\ the\ handle = Z = \frac{\pi}{32} \times dh^3 \quad (2)$$

$$\therefore Resisting\ moment = \sigma_b \times Z \quad (3)$$

Where σ_b is permissible bending stress for the material of the handle (Alumimum 6061-T6). This was determined according to Hamrock et al. to be 165 Mpa [8, 9].

Equating the resisting moment to maximum bending moment and making dh subject of formular gives an expression for the diameter of the handle.

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$$dh = \sqrt[3]{\frac{64 \times P \times L1}{3\pi\sigma_b}} \tag{4}$$

According to Khurmi and Gupta [7], One operator can apply a force of 400N. Using an overload factor of 1.5, the maximum force P applied by the operator is 600N. The length of the crank lever arm L (Figure 2) was 120mm. The length L1 of the lever handle was 60mm. Substituting these value into equation (4) gave the minimum value of dh to be 11.4 mm. Therefore 15mm diameter was used in the design for the handle diameter.

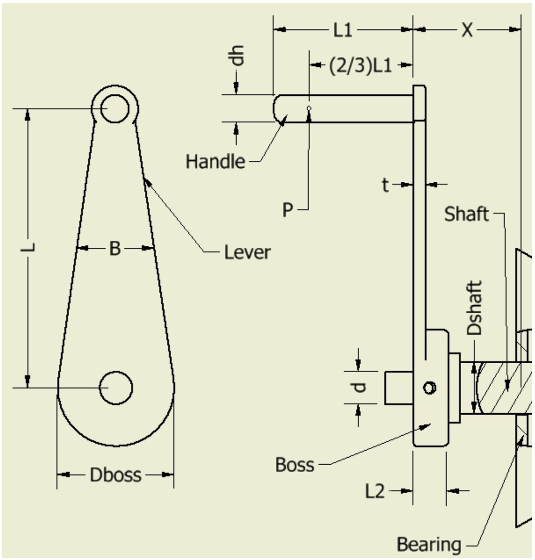

Figure 2: Crank Lever of the machine

2.3.2 Design of the boss for crank lever

The design of the boss for the crank lever entails three things. They are diameter of the boss (Dboss), thickness of the boss (t_b) and length of the boss (L2).

The diameter of the boss (Dboss) and thickness of the boss (t_b) are given by Khurmi and Gupta as

$$Dboss = 1.6\ dh \tag{5}$$

$$t_b = 0.3\ dh \tag{6}$$

The length of boss (L2) can be obtained by equating twisting moment and moment of resistance to tearing which is parallel to axis. Therefore we get,

$$P \times L = L2 \times t_b \times \tau_{all} \times \left(\frac{dh + t_b}{2}\right)$$

$$L2 = \frac{2P \times L}{t_b \times \sigma_t} \times \left(\frac{1}{dh + t_b}\right) \tag{7}$$

Where σ_t is permissible tensile stress for the material of the crank lever (Alumimum 6061-T6). This was determined according to Hamrock et al. to be 124 Mpa [8, 9]. Using equations (5), (6) and (7), the minimum values of the boss diameter (Dboss), thickness of the boss (t_b) and length of the boss (L2) were obtained to be 18.24 mm, 3.42 mm and 22.9 mm respectively.

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2.3.3 Design of the lever

The design of the lever has to do with the determination of the thickness and width of the lever. The cross section of the lever near the boss can be determined by considering the lever in bending. It is assumed that the lever extend to the center of the shaft which result in the stronger section of the lever. Bending moment is given by equation (8), bending stress is given by equation (9) and section modulus of the lever is given by equation (10).

$$M = PL \quad (8)$$

$$\sigma_b = M / Z \quad (9)$$

$$Z = \frac{1}{6} \times t \times B^2 \quad (10)$$

Substituting these equations into one another give bending stress equation (11) which leads to equation (12) for lever thickness calculation.

$$\sigma_b = \frac{6P \times L}{t \times B^2} \quad (11)$$

$$t = \frac{6P \times L}{\sigma_b \times B^2} \quad (12)$$

According to Khurmi and Gupta, the width of the lever arm B near the boss is taken to be twice the thickness of the lever. i.e.

$$B = 2t \quad (13)$$

Using equation (13) and the value of permissible bending stress (165 MPa) in equation (12), the minimum value of lever thickness was obtained to be 8.68 mm. This makes the minimum width of the lever (B) near the boss to be 17.36 mm.

2.3.4 Design of diameter of the Crank lever (d)

The diameter of the crank lever shaft (d) was considered to act under pure torsion.

$$The\ twisting\ moment\ on\ the\ crank\ lever\ shaft = T = P \times L \quad (14)$$

$$\therefore The\ resisting\ torque = T = \frac{\pi}{16} \times \tau_{all} \times d^3 \quad (15)$$

Where τ_{all} is the maximum induced shear stress on the crank lever shaft. For the material of the crank lever (Alumimum 6061-T6), this was determined according to Hamrock et al. to be 110 Mpa.

The diameter of the crank lever shaft was obtained from equation (16) by equating equation (14) and (15).

$$d = \sqrt[3]{\frac{16P \times L}{\pi \times \tau_{all}}} \quad (16)$$

Substituting the values into equation (16) gave the minimum value of d to be 14.94 mm. Therefore 20mm diameter was used in the design for the crank lever shaft diameter.

2.3.5 Design of shaft diameter at the center of bearing (Dshaft)

The diameter of shaft at the center of bearing (Dshaft) was calculated by assuming that the shaft is subjected to combine bending and twisting.

The twisting moment is given by equation (14). The bending moment was calculated as shown in Figure 5 by equation (17).

$$M = P\left(\frac{2L1}{3} + X\right) \quad (17)$$

Therefore equivalent twisting moment (T_e) on the shaft at the center of the bearing is given by equation (18) according to Khurmi and Gupta.

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$$T_e = \sqrt{M^2 + T^2} \tag{18}$$

$$T_e = \sqrt{(PL)^2 + (P\left(\frac{2L1}{3} + X\right))^2} = P\sqrt{L^2 + \left(\frac{2L1}{3} + X\right)^2} \tag{19}$$

The length X in figure 5 is 35mm from the design sketch. Substituting the values in equation (19), the equivalent torque T_e was obtained to be 84905.83 N-mm.
The equivalent twisting torque at the center of the bearing is also given by equation (20).

$$T_e = \frac{\pi}{16} \times \tau_{all} \times Dshaft^3 \tag{20}$$

Substituting the value of Te in equation (20), the minimum diameter of the shaft (Dshaft) at the center of bearing was obtained to be 15.78mm.

2.3.6 Design of conveyor shaft diameter

Equations (14) and (17) were used to calculate the twisting moment T and bending moment M acting on the conveyor shaft at bearing center with reaction R1 and the values obtained for them were 72000 N-mm and 45000 N-mm respectively. Equation (21) [10,11,12,13] could be used to obtained the diameter of the conveyour shaft. However, the shaft design analysis was done using Autodesk Inventor Professional software shaft design tool to obtain the minimum conveyor shaft diameter of 25 mm. Figures 6-9 showed the free body diagram, bending moment diagram, torsion stress diagram and ideal diameter diagram of the conveyor shaft as plotted by the software.

$$d^3 = \frac{16}{\pi\tau_{all}} \sqrt{(K_bM)^2 + (K_tT)^2} \tag{21}$$

Where: Kb and Kt are dimensionless constants
The reactions R1 and R2 were obtained to be 184.390 N and -150.790N respectively.

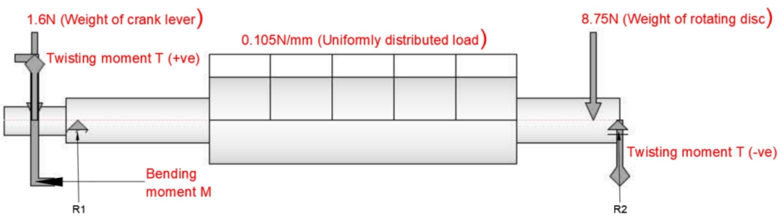

Figure 3: Free body diagram for conveyor shaft

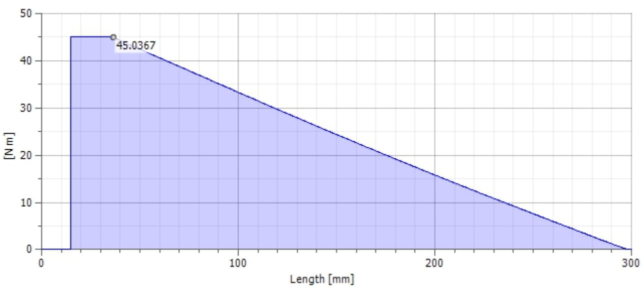

Figure 4: Bending moment diagram for conveyor shaft

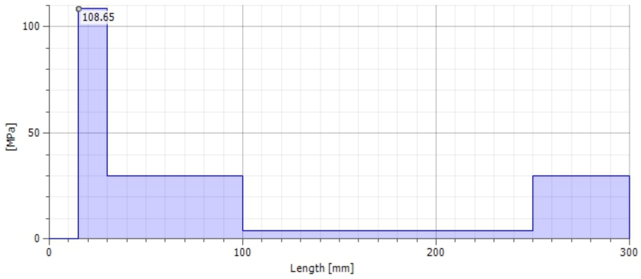

Figure 5: Torsion stress diagram for conveyor shaft

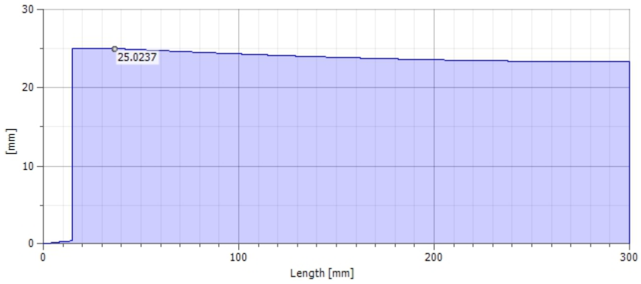

Figure 6: Ideal diameter diagram for conveyor shaft

2.3.7 Power required to turn the crank lever

Equation (22) [2] was used to obtain the minimum power (P_w) required to turn the crank lever.

$$P_w = \frac{2\pi NT}{60} \tag{22}$$

The result obtained for minimum power (assuming crank lever turning speed of 40 rpm [2]) was obtained to be 301.59W.

3. Results and discussion

Table 4.1 presents the design details of machine parts for the manual food grinding machine. An average person uses maximum force of 400 N to operate a lever [7]. The design used a safety factor of 1.5 and design the grinder for maximum force of 600 N. The table showed different design parameters calculated for the crank lever arm and the conveyor shaft diameter. The maximum twisting moment of 72000 N-mm and bending moment of 45000 N-mm were inflicted on the conveyor shaft at the center of the bearing close to the crank lever arm. The minimum diameter of the lever handle was obtained to be 11.4 mm. The boss of the crank lever arm were designed to have minimum boss diameter, thickness and length of 18.24 mm, 3.42 mm and 22.9 mm respectively. The lever thickness and the lever width near the boss were obtained to be 8.68 mm and 17.36 mm respectively. The crank lever shaft diameter was 14.94 mm. Shaft diameter at the center of bearing was 15.78 mm. The minimum conveyor shaft diameter was obtained to be 25.02 mm. The reactions at the two bearing were 184.390 N and -150.790 N. The machine required minimum power of 301.59 W.

Table1: Design Detail of Manual Food Grinder

S/N	Deaign Parameter for the grinding machine	Value
1	Crank force	600 N
2	Lever handle diameter	11.4 mm
3	Boss diameter	18.24 mm
4	Boss thickness	3.42 mm
5	Boss Length	22.9 mm
6	Lever thickness	8.68 mm
7	Lever width near the boss	17.36 mm
8	Crank lever shaft diameter	14.94 mm
9	Shaft diameter at the center of bearing	15.78 mm
10	Maximum Bending Moment on the shaft	45000 N-mm
11	Maximum Twisting Moment on the shaft	72000 N-mm
12	Reaction (R1)	184.390 N
13	Reaction (R2)	-150.790 N
16	Minimum diameter of conveyor shaft	25.02 mm
17	Minimum power	301.59 W

4. Conclusion
The manual pepper grinding machine has been designed and fabricated. It required maximum effort force of 600N. The machine required a minimum conveyor shaft diameter 25 mm and minimum power of 301.59W. The machine is handy, light weight and manual. This is considered an important innovation that will serve a good purpose for domestic use, especially those who are living in rural areas and those who live in urban cities where there is epileptic power supply.

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