Design, Fabrication and Testing of a Direct Drive Electric Powered Hammer Mill Machine

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ORIGINAL RESEARCH ARTICLE

Abstract- This research designed, fabricated and tested a direct drive electric powered hammer mill machine. A 3 HP electric motor with speed of 1800 rpm was used to power the mill. The fundamentals of machine design, mechanics of machine and basic workshop technology were applied in manufacturing the mill. The calculated design values for maximum centrifugal force of the beaters mounted on the rotor and the maximum machine shaft diameter of the mill are 27 KN and 12 mm respectively. The working principle of the mill is based on repeated combined hammers (beaters) impacts and collisions of the materials being milled with the housing of the milling compartment. Tests were carried out on the mill using dry maize, dry millet, dry stock fish and the combination of dry maize, dry millet and dry stock fish as samples to determine the mill productivity and milling efficiency. In determining the productivity and milling efficiency of the mill, the initial masses of the samples were made equal. The dry stock fish sample produced the highest mill productivity and milling efficiency. The actual mill productivity of 45.05 kg/h and milling efficiency of 91.12 % were obtained by averaging the mill productivities and milling efficiencies obtained when the samples were tested. From the calculated values of the actual mill productivity and milling efficiency, the mill performance is satisfactory.

Keywords- Electric, Hammer, Machine, Milling, Shaft diameter

1 Introduction

Size reduction is a phenomenon where bigger particles are disintegrated into smaller particles to basically increase their surface area for further processing. Considering the main action of the beaters(hammers) on the processed materials in the milling compartment, reduction mill machines are usually grouped as impact (hammer), attrition, shearing and pressure mills (Bitra et al., 2009). Considering also the orientation of the shaft (rotor) on which the hammers (beaters) are mounted, reduction mills are either horizontal or vertical.

Key particle parameters like geometry, hardness, toughness, size, softening temperature, moisture amount and other milling operating variables like speed and feeding rate are determining factors for decrease in size of particles (Mani et al., 2004 and Tumuluru et al., 2014). In most instances, decrease in the size of particle is usually altered when milling parameters of mills are changed (Workalemahu et al., 2019). Milling actions normally result from impact as well as attrition between lumps or particles of the material being milled, the milling compartment and the milling elements (Nwaigwe et al., 2012). Combined forces of compression and shear are also responsible for decrease in the size of particle (Berk, 2018).

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Hammer mills are the most commonly used feed mills due to their ease of operation and maintenance coupled with the fact that they produce tiny spherical particles at the end of milling process (Kim et al., 2002; Amerah et al., 2007).

2 Brief Review of Related Works

Orisaleye et al. (2022) studied both the simultaneous milling and chopping of a designed small-scale particle size distribution machine and the relationship between the sieve size and particle size distribution. They concluded that milling efficiency is depended on sieve size and decrease in particle size is more effective when milling and chopping are done at the same time. Akporehe et al., (2017) designed an improved hammer mill for milling agricultural products and used solid work to analyse the physical model of the mill. From their analyses, a minimum milling force and power of 8.7 N and 3-5 hp respectively can evenly mill agricultural products for storage.

Mohammed et al., (2015) designed and evaluated a small hammer mill. From the evaluated values, the maximum milling efficiency of the machine is 94.7% and the cumulative weight (C_w) of milled particles is dependent on nominal aperture (N_a) of the screen according to the equation;$C_w(\%) = Aln(N_a) + B, (A, B = constant)$.

3 Materials, Equipment and Methods

3.1 Materials

The body (hopper, discharge, milling compartment, and throat) and rotor assembly (beaters, circular discs) of the mill were fabricated using mild steel plate while the base was fabricated using 90^0 angle mild steel bar. The machine shaft was fabricated using mild steel hollow rod. Other materials are electric motor for powering the mill and


Fig. 1: Dry Maize


Fig. 2: Dry Millet


Fig. 3: Dry Stock Fish

stainless steel for the sieve. The dry maize, dry millet and dry stock fish in figure 1-3 were used as test samples.

3.2 EQUIPMENT

The equipment used for fabricating and testing of the mill are welding machine, bending machine, electrodes, filing machine, hacksaw, drilling machine, weighing balance, scriber, steel rule, centre punch, vernier calliper, divider etc.

3.3 METHODS

The mill was designed and fabricated using the fundamentals of machine design, mechanics of machine and basic workshop/production technology.

3.3.1 Design

Machine design is the development of a new or an improved (modified) machine (Khurmi et al., 2005).

(a) Design Consideration: In designing the mill, several factors were put into consideration for optimal productivity and efficiency. Some of these factors are; safety, material selection, size, cost, assembly and standard.

(b) Design Modification: The mill was modified by eliminating machine elements such as bearing, belt, pulley and also transmission shaft through direct drive system.

(c) Design Calculation: In designing the machine, the maximum centrifugal force of the beaters mounted on the rotor and the maximum machine shaft diameter were considered.

(i) Centrifugal force exerted by the beaters: The centrifugal force (C_f) was calculated using the formula;

$$C_f = nmrw^2 \quad (1)$$

Where;

n = Number of beaters = 12

m = Mass of one beater = 0.1 Kg

r = Radius of the machine shaft = 0.008575 m and

w = Angular velocity in rad/s

$$w = 2\pi rN/60 \quad (2)$$

N = Shaft speed = 1800 rpm

(ii) Determination of shaft diameter: The load on the machine shaft is considered to be uniformly distributed along the length of the shaft fixed (supported) at one end. Therefore, the shaft is a cantilever.

The shaft is subjected to both twisting due to turning effect and bending caused by the load (beaters) on the shaft. The machine was designed based on strength. Diameter of the shaft (d) was calculated from;

$$d = \sqrt[3]{\left(\frac{16}{\pi\tau_{max}}\left[\sqrt{(M^2 + T^2)}\right]\right)} \quad (3)$$

Where;

M = Maximum bending moment, calculated from;

$$M = \frac{w_l L^2}{2} \quad (4)$$

w_l = Total weight per unit length

L = Length of the shaft = 0.06 m, and

T = Twisting moment, calculated from;

$$T = \frac{60P}{2\pi N} \quad (5)$$

P = Power transmitted to the shaft = 2.22 KW

N = Shaft speed = 1800 rpm

3.3.2 Fabrication of the Designed Mill

The operations performed during the fabrication of the mill are measurement, marking out, cutting, grinding, drilling, joining/assembly and finishing (painting) operation etc.

(a) Description of Main Parts of the Designed and Fabricated Mill: The designed and fabricated hammer mill parts in figure 4 are described below;

(i) The milling compartment casing: It is made up of front cover, back cover, two side plates and top cover. The entire milling compartment casing is fabricated using mild steel plate of 3 mm thickness.

(ii) Discharge: The discharge is made of 1.5 mm thick mild steel plate. It is a funnel-like system with holes for bolting to the milling compartment.

(iii) Base: The base is made of mild steel angle bar (35 mm by 35 mm by 4 mm) with an overall height of 620 mm and a top width of 185 mm parallel to a base width of 385 mm and a length of 450 mm.

(iv) Electric motor seat: It is triangular in shape and is made of mild steel angle bar of 3 mm thickness. It has a height of 75 mm, length of 220 mm and diagonal support of 232 mm.

(v) Rotor assembly: This is an arrangement of two circular discs of 171.5 mm outer diameter, eight rods of 12 mm diameter and 76 mm length separating the two discs, 12 beaters with 3 beaters evenly spaced on six of the outer rods and a machine shaft of designed internal diameter of 12 mm and thickness of 10 mm as shown in figure 5. The entire assembly is made of mild steel.

(vi) Beaters: The beaters are components of the rotor assembly as shown in figure 5. They are rectangular shaped 3 mm thick mild steel plate. It is 95.25 x 25.4 mm

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in dimension with a drill hole of 12 mm at 12.7 mm interval from each other.

(vii) Machine shaft (Rotor): The machine shaft shown in figure 5 is a hollow shaft made of mild steel. It has a designed internal diameter of 12 mm. The machine shaft which is firmly fixed to the shaft of the electric motor holds the entire rotor assembly. The hollow shaft is welded in a hole drilled at the middle of one of the circular disc.

(viii) Sieve holder: The sieve holder in figure 6 is made of 2 mm thick mild steel plate cut to a dimension of 152 mm by 101.6 mm. It is rolled to form an arc and fixed at the top of the milling compartment with the help of two M8 bolts welded at the concaving surface such that the bolts pass through the holes drilled in the top cover of the milling compartment.

Fig. 4: The Designed and Fabricated Hammer Mill

Fig. 5: Rotor Assembly

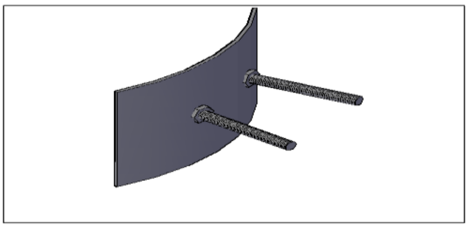

Fig. 6: Sieve Holder

3.3.3 Test

Tests were carried out on the mill. The tests were aimed at determining the mill performance and also expose the areas where improvement on the mill is required. Four samples were used to obtain the milling efficiency and productivity of the mill. Table 1 shows the samples compositions by weight.

(a) Machine Productivity and Crushing Efficiency: In carrying out the tests, the mass of dry maize sample was measured before milling and the sample was fed slowly into the hopper which funnelled it into the milling compartment to prevent clogging on the sieve. The time (t) taken for the milling was recorded and the mass after milling was measured. The above process was repeated thrice and the average masses before and after milling were calculated. The average time of milling was also calculated. The same test procedures were repeated for the other samples by applying the same masses before milling for each of the samples. The productivity of the mill (P_m) was obtained from the equation;

$$P_m = \frac{W_2}{t} \quad (6)$$

Where; P_m is the productivity of the mill in Kg/m, W_2 is the mass of the sample after milling in Kg and t is the milling time in h.

The efficiency of the mill was obtained from the equation;

$$\eta_c = \frac{W_2}{W_1} \times 100 \quad (7)$$

Where; η_c is the efficiency of the mill in %, W_1 is the mass of the sample before milling in Kg and W_2 is the mass of the sample after milling in Kg.

The percentage loss of the sample was obtained from the equation;

$$L = 100 - \eta_c \quad (8)$$

Where; L is the percentage loss in % and η_c milling efficiency in %.

4 Results and Discussion

4.1 Results

The milled samples are shown in figure 7-10. Tables 2-5 show the various calculated values obtained from the designed, fabricated and tested mill.

Fig. 7: Milled Maize

Fig. 8: Milled Millet

Fig. 9: Milled Fish

Fig. 10: Milled Maize+ Millet+ Fish

Table 1. The Samples Compositions by Weight

Samples/Compositions	Dry Maize (g)	Dry Millet (g)	Dry Stock Fish (g)	Total (g)
Dry Maize	1050	-	-	1050
Dry Millet	-	1050	-	1050
Dry Stock Fish			1050	1050
Dry Maize + Dry Millet + Dry Stock Fish	350	350	350	1050

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Table 2. Calculated Design Values

S/No	Parameters	Symbols	Values	Units
1	Total weight of beaters	W_T	11.772	N
2	Angular velocity	w	1.62	rad/s
3	Centrifugal force	C_f	0.027	N
4	Bending moment	M	0.35316	Nm
5	Twisting moment	T	11.867	Nm
6	Diameter of the machine shaft	d	12	mm

Table 3. Masses before and after Milling of the Samples and Time of Milling

Samples	Mass before milling (kg)	Mass after milling (kg)	Time taken (mins)
Dry Maize	1.05	0.955	1.28
Dry Millet	1.05	0.960	1.26
Dry Stock Fish	1.05	0.962	1.24
Dry Maize + Dry Millet + Dry Stock Fish	1.05	0.950	1.31

Table 4. Mill Productivity

Samples	Mill Productivity (Kg/h)
Dry Maize	44.84
Dry Millet	45.71
Dry Stock Fish	46.47
Dry Maize + Dry Millet + Dry Stock Fish	43.18
Actual Mill Productivity	45.05

Table 5. Milling Efficiency

Samples	Milling Efficiency (%)
Dry Maize	90.95
Dry Millet	91.43
Dry Stock Fish	91.62
Dry Maize + Dry Millet + Dry Stock Fish	90.48
Actual Milling Efficiency	91.12

4.2 Discussion of Results

From table 2, the calculated diameter (12 mm) of the machine shaft indicates that the fabricated mill is portable because milling machines are classified according to their size based on the diameter of the machine shaft. The portability of the mill makes it limited to small scale milling of materials. The calculated centrifugal force (0.027 N) shows that the force exerted by the beaters away from the axis of rotation of the machine shaft has a negligible effect on the shaft.

From the tests results in tables 3 and 4, the dry stock fish sample produced the highest mill productivity of 46.47Kg/h, highest efficiency of 91.62 % and minimum milling time of 1.24 mins. The different values of mill productivity, milling efficiency and milling time obtained when milling the samples may be due to the differences in the size and hardness of the samples, and the clogging of powdery particles on the parts of the milling compartment (Adekomaya, 2014).
The actual mill productivity and actual milling efficiency of the mill are 45.05Kg/h and 91.12 % respectively. It therefore means that it will take the mill an hour to mill 45.05 kg at loss of 8.88 %.

5 Conclusions

The conclusion from the designed, fabricated and tested direct drive hammer mill machine are that the designed shaft diameter of 12 mm is suitable for the mill. The mill is limited to small scale milling of materials because of its size. Also, the centrifugal force of 0.027 N exerted by the beaters has a negligible effect on the shaft. The values of the mill productivity (45.05 Kg/h) and efficiency (91.12 %) indicate that the hammer mill is a high-performance machine which can be commercialised. The mill productivity is dependent on the efficiency of the mill. Lastly, the weight, vibration, manufacturing cost and maintenance of the mill is low compared to the commercially used mill due to absence of machine elements such as pulleys, transmission shaft, bearings, belts etc.

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