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Improvement on the Design,Construction and Testing of Hammer Mill.

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***ABSTRACT**: This paper presents the result of work carried out in improving the design, construction and testing of hammer mill by addressing some lapses associated with the design and construction of the existing ones. These improvement involves redesigning and construction of the hammer mill beater, hammer mill chamber, redesigning and construction of the hammer mill shaft, incorporating a gasoline engine directly to the hammer mill beater thereby providing the means of varying the speed of the hammer mill, replacement of the electric motor with a gasoline engine and (multi-functionality of the improved machine in processing many grains such as maize, millet, guinea corn and even dried cassava.*

***Keywords:** Cereal Miller, Screen Sieve, Beater, Prime Mover and Hopper.*

I. INTRODUCTION

The cereals food consumed is mostly processed through grinding by either iteration or hammering means. It is therefore necessary to have an efficient means of achieving such goals most especially in developing country like ours where Industrial activities are low. The design and construction of hammer mill becomes imperative as that will go a long way in getting processed cereals grains easily within developing nations. Hammer mill (cereal miller) is a device consisting of a rotating head with a free swinging hammer or beater which reduce grains or similar hard dry objects to a predetermine sizes through a perforated screen. As the grains enter the hammer mill, it is pulverized by a combination of hammer blows, particle on particle contact and impact with the walls of the hammer mill. The material remains in the grinding chamber until it is able to pass through the screen covering the discharge area [1]

The perforated metal screen covering the discharge opening of the mill retain coarse materials for further grinding while allowing properly sized materials to pass as finished product. Screen size is determined by the size of the openings in the screen which is also described by inches, millimeters, and microns (one millionth of a meter) while the US mesh i.e. three number of wires running east/west and north/south in one square inch of screen [2]. The appropriate screen size is determined by the desired finish particle size and the properties such as friability and moisture content which a material will breakdown. At such using the same screen to process materials of different properties will result in a range of different finished particle sizes.
Finished particle size is determine by a combination of screen size, motor speed and the size and number of hammer materials which remain in the grinding chamber until it is able to pass through the screen covering the hammer mills discharge opening. Optimal screen size is determined by the desired finished particle size and the properties of the material being processed [3].

Particle size flexibility and the measurement of the perforations in the screen covering the discharge area is the primary factors determining finished particle size. The sizes of these perforations equal to the maximum finished particle size of the materials processed. The ideal particle size range is 650 to 750 microns (µm) can easily and consistently be achieved through proper screen selection. In addition, screen can easily be changed to accommodate the processing goals of a variety of grains using the same hammer mill. The second factor in determining finished particle size is the speed of the hammer mill. When the motor spins, the hammers fail out and impact the materials with great severity causing it to break down. As a result, the higher the motor speeds, the greater the number of hammer mill blows [4]

II. MATERIALS AND METHODS

Materials: The material selected for the construction work were based on the following factors, availability of the material in the market, cost and affordability, durability, malleability, Rigidity and Resistance to wear and corrosion. The materials used are; M.S plate, 90^0 angle iron, selected screen sieve, 5.5HP generating set and Shaft.

2.1 Hammer Mill Design and Configuration

The design and placement of hammer is determined by operating parameters such as motor speed, prime mover in the screen, hammer design and placement that will provide maximum contact with the feed ingredient [5]. Tip speed is the speed of the beater at the tip or edge furthest away from the rotor and is calculated by multiplying the rotational speed of the drive source (shaft rpm) by the circumference of the hammer tips as given by the equation A common range of tip speed seen in hammer mills is commonly in the range 5,000 and 7,000ft/min i.e. 16,000 and 23,000 ft/min is used while the lower value of 16000 ft/min is used for safety and the derive speed is 1800rpm [6]. Due to the improvement in the design and construction of the hammer mill as against the existing ones, a gasoline engine was incorporated and hence the belt drive arrangement as well as its design calculations was skipped.

The hammer diameter is calculated from equation (1) as;

$$V_{tip} = \frac{\pi D + Derive\ speed\ (rpm)}{12in/ft}$$

Where

...1

$\pi = 3.14$

D = diameter in $'mm'$

$$16{,}000 = \frac{3.14D \times 1800rpm}{12in/ft}$$

$$D = 2.83mm$$

Hammer weight determined using the Patton formula:

$W_h = m_n \times g$

…2

Where;

$m_n = mass\ of\ the\ hammer, kg$

The fabricated material was mild steel, density of $7.85g/cm^3$

The centrifugal force exerted by the hammer using the Flavel and Rimmer formula (1981)

$$F = \omega r\sqrt{ms} = \frac{mv}{r}$$

Where;

ω = Rotational speed of the rotor, radians/second

r = Mass of the ore, kg

s = The ore stiffness to breakage, N/m

$$\omega = \frac{2\pi rN}{60}$$

Where;

N = Number of revolutions.

Hammer shaft diameter was calculated using spolt, 1988

$$M_{b\ max} = \frac{L^2W}{8} \quad …3$$

$M_{b\ max}$ = Maximum bending moment, Nm

L = Shaft length, mm

W = Force per unit length, N/m

$$\partial_{s\ (allowable)} = \frac{M_b Y_{max}}{I}$$

Where;

Y_{max} = Distance from neutral axis to outer, m
I = Moment of inertia, m^4
Z = Section modulus, m^3
For round bar;

$$I = \frac{\pi d^4}{64}$$

$$Z = \frac{\pi d^3}{32}$$

Twisting of the rotational shaft is neglected from the torsion calculation. The rotational shaft diameter was calculated using the formula:

$$d^3 = \frac{16}{\pi \delta_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \ldots 4$$

Where:
d = Shaft diameter
σ_s = Shear stress from tables for shafts with keyway
K_b = Combined shock and fatigue factor applied to bending moment
K_t = Combined shock and fatigue factor applied to torsional moment
M_b = Bending moment, Nm
M_t = Torsional moment, Nm

2.2 Determination of Power & Torque Transmitted to the Beater

The main engine drives the milling beater through power transmitted from the shaft of the engine under definite physical specification [7]

The amount of power transmitted is given by equation. (5)

$$P = \frac{2\pi NT}{60} \quad \ldots 5$$

Where T is the transmitting moment or (Torque) acting upon the shaft

$$T = \frac{\pi}{16}\, x\, \tau\, x\, d^3$$

And from this relation

$$\frac{T}{J} = \frac{\tau}{r}$$

Where J = polar moment of inertia of the shaft about the axis of rotation.
τ = Torsional sheer stress
r = Distance from neutral axis to the outer most fiber, that is $\frac{d}{2}$

Where
D = is the diameter of the shaft

We also know that for round solid shaft, polar moment of inertia

$$J = \frac{\pi}{32}\, x\, d^4$$

Substituting equation (5) into equation (4)

$$\frac{T}{\pi/_{32} x\, d^4} = \frac{\tau}{d/_2}$$

2.3 Determination of Centrifuge Force (f_c)

$$Fc = \frac{mv^2}{R}, \quad \ldots 6$$

But $v = wR$

$$And\ w = \frac{2\pi N}{60}$$

N = 1500 rpm (from literature) [6]

$$w = \frac{2\,\pi \times 1500}{60}$$

$= 157.1\ rad/sec$
$R = diameter\ of\ the\ engine\ shaft$
$R = (19mm)$
$V = 157.1 \times (19/1000)$
V = 3.0 m/s

$$\therefore Fc = \frac{0.09 \times 3^3}{0.019}$$
$$= 41.6N$$

2.4 Determination of Maximum Bending Moment of the Beater

Maximum bending moment is determined by the weight (w) and the length (l) as given by;

$$BM_{(max)} = \frac{wl^2}{8} \qquad \ldots 7$$

$$\frac{0.86 \times (0.37)^2}{8}, \quad M_b = 0.0147\text{NM}$$

2.5 Damping Characteristics

Damping characteristic of the machine is determined as below:

The mass of the machine = 45.5kg
The coefficient of damping C = $75\mu/m$
The stiffness of the material k = 750N/m
The natural frequency Wn is

$$w_n = \sqrt{\frac{k}{m}} \qquad \ldots 8$$

The damping factor of the material

$$\eta = \frac{c}{2mwn}$$

$$\frac{750}{2\ x\ 45.56\ x\ 16.46}$$
$$= 0.50$$

$$wd = w_n\sqrt{1 - 2^2}$$
$$wd = 16.46\sqrt{1 - 0.50^2}$$

= 14.252rad/s

The period of oscillation

$$T = 2\pi\sqrt{\frac{m}{R}} \qquad \ldots 9$$

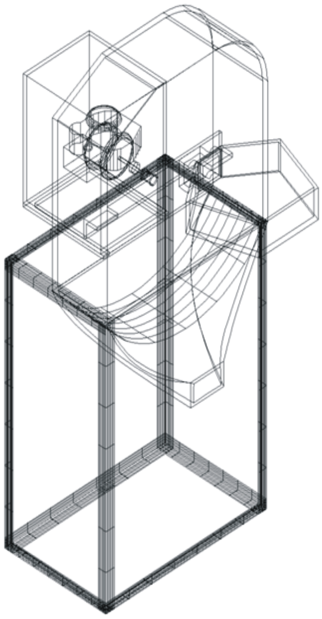

Figure 1; Hammer Mill, 3D view.

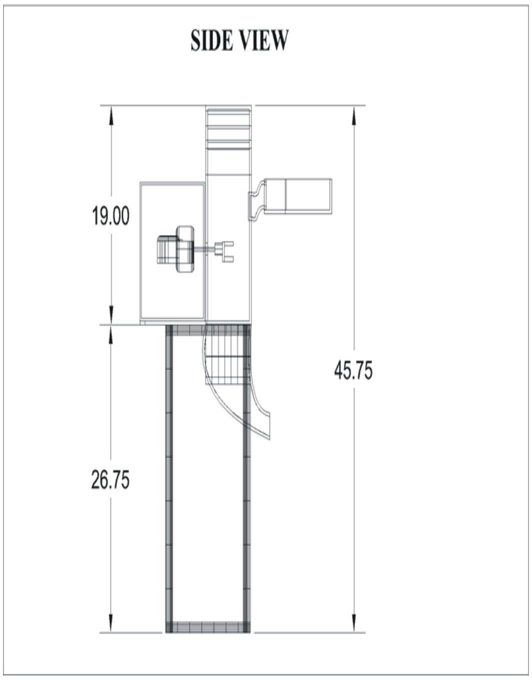

Figure 2; Hammer Mill, Side view

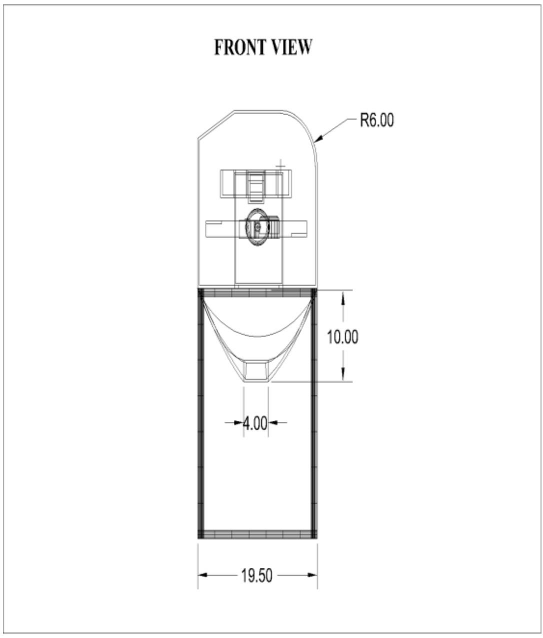

Figure 3; Hammer Mill, Front view

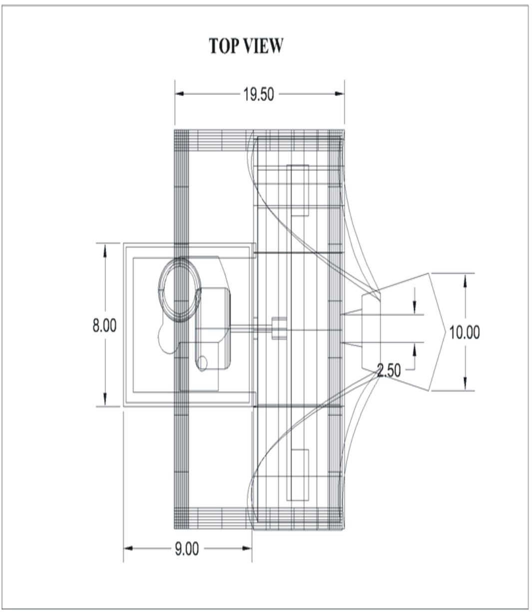

Figure 4; Hammer Mill, Top view

Figure 5a; Hammer Mill

Figure 5b; Hammer Mill

III. RESULTS AND DISCUSSIONS

Table I: Results Obtained from the Calculation

S/No	PARAMETERS	SYMBOL	VALUE	UNIT
1	Speed of shaft	N	1500	rpm
2	Torque Transmitted to the shaft	T	20.363	Nm
3	Power Transmitted to the shaft	P	3198	Nm
4	Beater mass	B_{mass}	0.9	kg
5	Centrifugal force	C_f	41.6	N
6	Maximum B. M.	$M_{b\ max}$	0.02	Nm
7	Natural Frequency	f_N	0.50	*Hz*
8	Damping Factor	D_f	14.25	ω
9	Damping Natural Frequency	f_N	0.65	ω

TESTING:

3.2 Testing Using Maize (Corn)

5kg maize was fed into the hopper and the hammer mill was switched on. The grinding process was noted. The process was repeated five times and average reading was used for calculation. The same process was carried out using millet, and guinea corn From the hammer mill testing using maize (corn) as discussed; the following result were obtained in table1 to table 3 given the result obtained when the hammer mill was tested with three different types of grains.

Table II: Test Result Using Maize (Corn)

Trial	Mass of maize (corn) before grinding (kg)	Mass of maize corn after grinding (kg)	Time taken (min:sec)
1	5	4.54	4:55
2	5	4.54	4:52
3	5	4.55	4:52
4	5	4.56	4:51
5	5	4.55	4:49

Average mass of the maize (corn) before grinding = $5kg$

Average mass of the maize (corn) after grinding = $4.55kg$

Average time taken = 4min 5sec.

$$crushing\ efficiency = \frac{mass\ of\ output\ material}{mass\ of\ input\ material} \times 100$$

$$\therefore \frac{4.55}{5} \times 100 = 91\%\ efficiency$$

And the losses

$$\frac{M_b - M_a}{M_b}$$

Where

M_b = mass before grinding

M_a = mass after grinding

$$\therefore loss = \frac{5 - 4.55}{5} = 0.09\ in\ \% = 0.09 \times 100 = 9\%$$

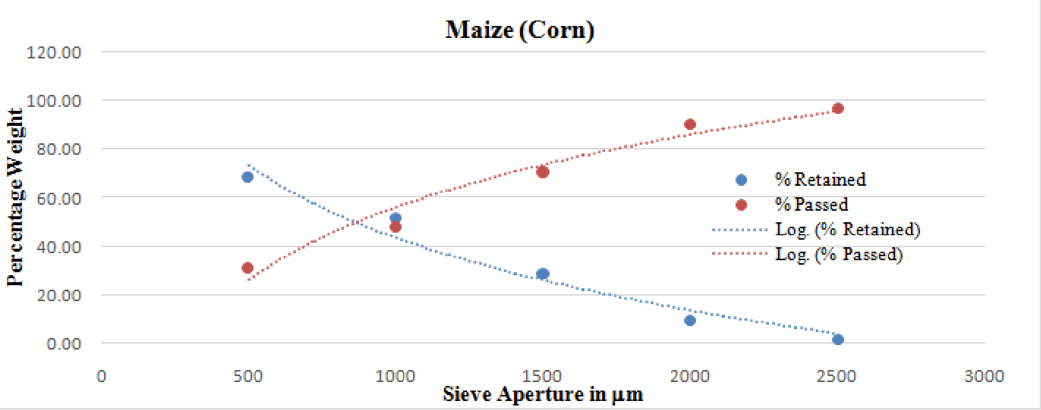

Figure 1: Plot of Percentage weight versus Sieve Aperture

Table III: Test Result Using Millet

Trial	Mass of millet (corn) before grinding (kg)	Mass of millet after grinding (kg)	Time taken (min:sec)
1	5	4.63	5:57
2	5	4.64	5:23
3	5	4.66	5:11
4	5	4.64	5:08
5	5	4.68	5:11

Average mass of millet before grinding = $5kg$
Average mass of millet after grinding = $4.65kg$
Average time taken 5minutes 22 seconds

$$crushing\ efficiency = \frac{mass\ of\ output}{mass\ of\ input}\ x\ 100 = \frac{4.65}{5}\ x\ 100 = 93\%$$

Where the lost

$$= \frac{mb - ma}{mb} = \frac{5 - 4.65}{5} = 0.07\ in\ 5 = 0.07\ x\ 100 = 7\%$$

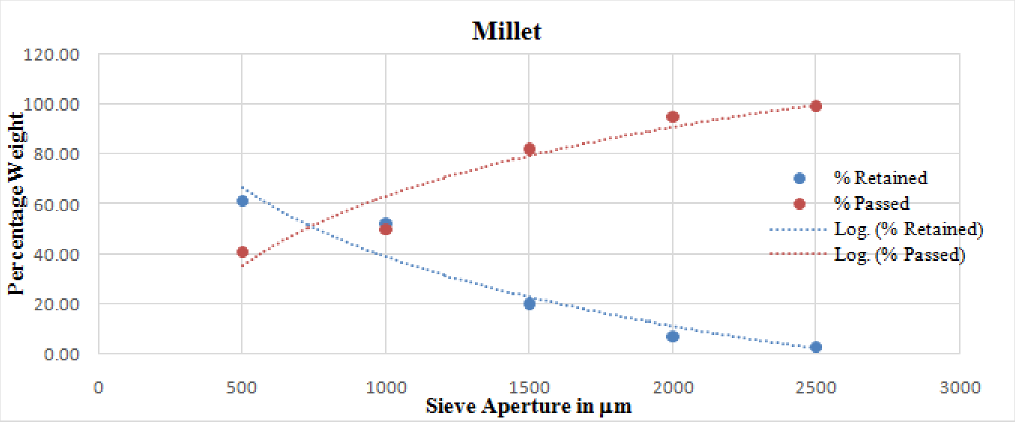

Figure 2: Plot of Percentage weight versus Sieve Aperture.

Table 4: Test Result Using Guinea – Corn

Trial	Mass of guinea corn before grinding (kg)	Mass of guinea – corn after grinding (kg)	Time taken (min:sec)
1	5	4.68	5:43
2	5	4.68	5:06
3	5	4.67	5:08
4	5	4.64	5:12
5	5	4.68	5:38

Average mass of guinea corn before grinding = 5kg
Average mass of guinea corn after grinding = 4.67kg
Average time taken 5minutes:21 seconds

$$crushing\ efficiency = \frac{mass\ of\ output}{mass\ of\ input}\ x\ 100 = \frac{4.67}{5}\ x\ 100 = 93.4\%$$

And the last % $= \frac{mb-ma}{mb} = \frac{5-4.67}{5}\ x\ 100 = 6.6\%$

Note
Mb = mass before grinding
Ma = mass after grinding

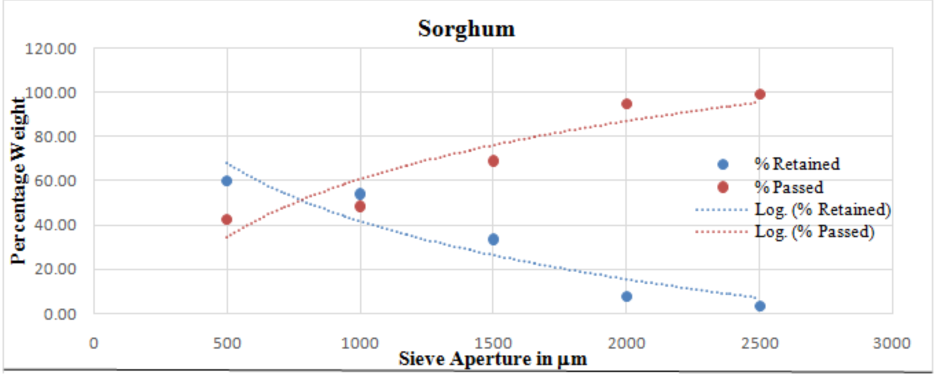

Figure 3: Plot of Percentage weight versus Sieve Aperture

IV. CONCLUSIONS

Based on the results obtained, the following conclusions were drawn The existing literature shows that the efficiency of the hammer mill was found to be 54% [8]. From the result of the test carried out and mentioned above the crushing efficiency of the improved machine was found to be 91, 93 and 93.4% after taken average of the efficiencies, the efficiency of the machine becomes 92.47%. It is clear that the crushing capacity and efficiency of the improved machine shows that the performance of the machine is satisfactory, while the slight loss obtained was due to the sticking of the powdery materials to the wall of the crushing hammer known as hammering chamber and some strains that pass through the screen due to size[9] The following objectives can be said to be achieved; redesigning the hammer mill, redesigning hammer mill chamber shape, directly incorporating the variable speed engine to the hammer mills shaft, improving cereal grinding operation for both human, birds and animals feed, alleviating the physical sufferings associated with the conventional grinding machine and improving the economic condition of rural populace.[10]

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