OPTIMIZATION AND PERFORMANCE EVALUATION OF BLENDER-HAMMER MILL
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Abstract
The principle of design by analysis was adopted for the design of this project. The methodology used was to scrutinize the common critical defects of conventional hammer mills and proffer possible solutions. The foremost components of the new blender-hammer mill were enumerated. The initial tests carried out on the new blender- hammer mill revealed that the mill is capable of performing same function that industrial huge hammer mills and the conventional hammer mills can perform in production of course, medium and fine particles .The results obtained after testing, showed that the crushing efficiency was between 83% to 96%, for dry maize and wheat respectively, which is quite satisfactory. Production of fine grains was achieved but coarse, medium and fine particles were still produced for further re-run for finer particle.

Keywords: Optimization; Blender; Harmer mill; Production; Machine

1.0 Introduction
Different Hammer mills have been developed overtimes; women employed grinding stone, pestle and mortar to reduce grains to ‘powdery state for baking and for preparation of different meals for easy digestion and assimilation into body system [1]. Commonly produced crops in Africa such as yam, cassava, sorghum, corn (dry maize), millet and guinea corn have been domestically and commercially milled for centuries using mortar and pestle shaped from suitable tree stumps, branches or stones [2]. Around mid- nineteenth century, the inventions of electric motors used in high speed grinding machines equipped with hammer and plate mills replaced traditional stone mills. Availability of electricity in many parts of Africa increased the usage of motor-driven mills, thus increasing their importance [3].

However, materials used in most of early mill were mainly cast iron and its alloy grades, steel and steel alloys. Many of these materials are being phased out because of hazard to the user, and because of their low yielding strength[4]. Typical crushing machines are designed to change solid material objects volume into required smaller sizes [5]. Although, both milling and grinding are perhaps the oldest methods of processing biomaterials separately, a very little or no consideration has been given to combination of both systems for optimum use for higher efficiency. Thus, this research project, is a development of a machine that combines hammering and blending together in the same crushing chamber simultaneously. This project also researched into improvement of materials used in mills [6]. The productivity is high as well as the efficiency when compared with the other hammer mills developed. Selection of Fine Crushing Mills Identify classes of different types of fine grinding mills as follows: Impact mill, Roller mill, Ball mediate mill, Air jet mill, other type mills (Shearing attrition mill etc. The tip speed, grading rate, screen size [7], and clearance are factors that influence hammer mill performance. Equipment design and size-reduction needs can influence Hammer tip speeds variation. Nevertheless, tip speeds usually range from 75 m/s to 117 m/s.
They mentioned that tip speeds are usually attained at shaft speeds ranging from 2500 to 4000 rpm [8]. There are connections between hammer tip speed and hammer thickness that affect energy efficacy of the hammer mill. The author also indicated the results obtained showed that thin hammers saved about 13.5% in energy consumption and increased grinding rate by 11.1% for a comparable quality of grain ground. Consequently thin hammers and blending blades of 3 mm thickness were used in this project [9].

2.0 Theoretical Design Consideration
This is carried out on the basis of engineering best practice taking into cognisance safety of operator, customers, and machine. A major safety precaution which may arise while the machine is fully in operation is taken care of. The crushing chamber is made of 10mm thick material, and swinging instead of stiff hammers which enhance flexibility in operation [10].

2.1 Choice of electric motor.
An electric motor with the following specifications was chosen.
1. Power $P = 3.75$ Kw = (5HP)
2. Rotational speed, $N = 1440$ rpm
3. Phase = single
4. Frequency = 50 Hz [11].

2.2 Transmission drives Selection:
Belt and pulley system was adopted for the power transmission drives of the machine.

![Fig 1. The belt profile](image)

Where
- $b$ – Top width of belt
- $t$ – Belt thickness
- $x$ – Belt base thickness [12]

2.3 Pulley or sheave design.
The pulley diameter for the rotor was selected using the equation for speed ratio shown in Eq. (1):

$$D_r = \frac{D_m N_m}{N_r}$$

Where,
- $N_m = $ Electric motor rotational speed = 1440 rpm
- $D_m = $ Motor’s pulley diameter of = 200mm
- $D_r = $ Diameter of rotor = 100 mm
Therefore \( N_r = 2880 \text{ rpm} \)
The speed of the shaft can be only gotten when slip condition of the belt over the pulley is zero. However, the speed value reduces by about 4% when there is slip or creep [13].

### 3.0 Evaluation of length of the belt, \( L \)

\[
L_b = 2L + \frac{\pi}{2}(D_2 + D_1) + \frac{(D_1 + D_2)}{4C}
\]

\( L_b = 1471.39\text{mm} \approx 1475\text{mm} \)
\( L_b = 1475\text{mm} \) was adopted
Where
- \( L_b \) = length of the belt, mm
- \( L \) = center to center distance the between larger and the smaller pulley, mm

According to V belt standard design, a two V belts, type B60 was selected, width \( b = 16.7\text{mm} \) and thickness \( t = 10.3\text{mm} \) [14].

Centre to Centre distance,

\[
L_{\text{min}} = 0.55(D_1 + D_2) + T \quad \text{Patton, 1980}
\]

\( L_{\text{min}} = 175.3\text{mm} \approx 175.3\text{mm} \)

\( L = 2(D_1 + D_2) = 2 \times 300 = 600\text{mm} \)

Centre to centre distance.
\( L \) ranges between 175mm to 600mm.
Consequently \( L = 500\text{mm} \) was adopted
Where;
- \( T \) = belt thickness
- \( D_1 \) = Driven pulley diameter
- \( D_2 \) = Driving pulley diameter

### 3.1 Calculation of blender hammer shaft diameter

The bending moment of the blender hammer can be calculated by equation 4.[15]

\[
M_{b(\text{max})} = \frac{Wl^2}{g}
\]

Where
- \( M_{b(\text{max})} \) = Maximum bending moment, N/m
- \( l \) = length of the shaft
- \( W \) = Force per unit length, N/m

\[
\sigma_{s(\text{allowable})} = \frac{M_{b(\text{max})}Y_{\text{max}}}{l} \quad \text{(5)}
\]

\[
\frac{l}{Y_{\text{max}}} = Z \quad \rightarrow \quad \sigma_{s(\text{allowable})} = \frac{M_b}{Z} \quad \text{(6)}
\]

Where
- \( Y_{\text{max}} \) = Distance from neutral axis to outer fibers
- \( l \) = Moment of inertia
- \( Z \) = Section modulus

For solid shaft;
\[
l = \frac{\pi d^4}{64}
\]

\[
Z = \frac{\pi d^4}{32}
\]

3.2 **The maximum bending moment of the main shaft.**

The position of the electric motor in relation to main shaft is such as \( T_1 \) and \( T_2 \) act parallel to each other [16].

Therefore \( F_1 + F_2 = 481.63 \text{N} + 234.96 \text{N} = 716.59 \text{N} \)

The overall loading system on the shaft is shown in the Fig. 2

From the shear force, it is obvious that \( b \) is the point of maximum bending moment [17].

3.3 **Determination of the shaft Diameter**

The ASME code equation for a solid shaft with little or no axial loading is;

\[
d^3 = \frac{16}{\pi \sigma_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2}
\]

Where

\( d \) = shaft diameter;
\( \sigma_s \) = shear stress from tables of shaft and key way;
\( K_b \) = combine shock and (0) fatigue factor applied to bending moment;
\( K_t \) = combine shock and fatigue factor applied to torsional moment;
\( M_b \) = bending moment, N. m;
\( M_t \) = torsional moment, N.m

3.4 **Shaft Component Generator**

With the calculated Torque, Power, belts Tension and the material adopted inputted into the Auto card system above the following results were obtained [18].

**Table 1. Shaft Loads**

| Index | Location (mm) | Radial Force | Torque (Nm) | Deflection Y(10\(^{-3}\)m) | Deflection X(10\(^{-3}\)m) |
|-------|---------------|--------------|-------------|----------------------------|----------------------------|
| 1     | 0             | 716.590 N    | 716.590 N   | -186.081                   | 186.081                    |
| 2     | 0             |              | 12.333      | -186.081                   | 186.081                    |
| 3     | 400           | 22.148 N     | 22.148 N    | -38.604                    | 38.604                     |
| 4     | 400           |              | -12.333     | -38.604                    | 38.604                     |

The shaft was loaded as indicated above with radial force on X and Y axis and Torque, while the Deflection sizes and direction on the axes are indicted. The deflection angle is very small and negligible.
Table 2. Shaft Supports

| Index | Type  | Location (mm) | Reaction Force | Deflection | Deflection Angle |
|-------|-------|---------------|----------------|------------|-----------------|
| Y (N) | X (N) | Y (10^3 m) | X | Size | Direction Angle (°) |
| 1 | Fixed | 150 | 1769.38 | 1769.38 | 0.000 | 180 | 0.03 |
| 2 | Free | 250 | 1008.38 | 1008.38 | -0.000 | 180 | 0.01 |

The supports (two ball bearings 100mm apart) were at the 150mm and 250mm from the ends of the 400mm step shaft, forming an overhanging beam with uniformly distributed load (UDL) of 100mm at the center.

3.5 EVALUATION OF THE MACHINETHROUGHPUT/CAPACITY.

Throughput/ capacity: This is the maximum rate of production i.e. quantity of material that could be processed per unit time. It may be either volumetric or gravimetric. The volumetric throughput/capacity was calculated by equation 10 below [19].

\[ Q = VAK \]

3.6 Calculation of area of flow

This was calculated by equation below.

\[ A_f = B/4[\left( \frac{d_2^2}{d_1^2} \right) + \frac{d_2^2}{d_2^2}] n \ (L) \]

Where, [20].

D = Milling chamber diameter, \( d_1 \) = Disk diameter of the
\( d_2 \) = Diameter of the fan  n = number of hammer blades
L = Length of the hammer blade. T = Hammer thickness.

Fig.2: The shear force and bending moment analysis.

4.0 Result and Discussion
The maximum ideal diameter for the shaft stands at 28.08 mm as indicated above on first support 150mm from the pulley, and about 13mm at the other end of the shaft where the hammers and the blender are installed. In these project diameters 40mm and 25mm were adopted respectively. Though an over design, but this is good for the stability and durability of the machine. The scope of this project is limited to grinding of soft materials such as food items like grains, legumes cocoa or coffee dry beans, pharmaceutical products and laboratory samples. It is not designed to crush stones, metals and other hard materials [20]. The design is such that there is minimal friction among the grinding components in the grinding chamber. This eliminates issue of metal particles resulting from friction among the grinding components. Combination of double action of blending and hammering enhances higher productivity and efficiency. All lubrications systems are located within the bearing housing outside the grinding chamber [21].

Two types of testing that were carried out on any new designed and manufactured machine to ascertain its safety in operation of the machine, performance evaluation, to detect defects for possible improvement and to evaluate the achievement level of the research. Idle testing or running was used in operating the machine without load at low speed first, then at increased speed for about 30 minutes to 1 hour to detect unusual noise and also the level of vibration. This is operating the machine with the designed loads or specimen to evaluate the performance, which is the work ability and efficiency of the machine [22]. The materials are dried cassava, corn beans and genuine corn of various weights, while the testing apparatus are stop watch, weighing balance and set of sieve. 1/2kg of each sample was fed into the machine and the reads was taken.

Idle and load tests were carried out and found to be capable of pulverizing to milling efficiency of 89%.....99% which shows that the performance of the machine compares favorably with the performances of the other mills developed. The machine can be powered either by electric motor or fuel powered engines of the same capacity to achieve the same efficiency and effectiveness.

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