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International Journal Of Modern Engineering Research (IJMER)

Development of a Bone Milling Machine with Safety Hollow and Low Risk of Electrical Damage

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ABSTRACT: *Hammer mills have been one of the cornerstones of agricultural and industrial processing for centuries. Like other industrial machines, bone-milling machine have a number of unique design requirements. In this paper, a hammer mill incorporated with safety hollow for housing hard foreign materials besides milled bones was designed, fabricated and its performance evaluated. The performance evaluation was carried out to determine the efficiency of the machine by comparing its actual milling time with its expected milling time. During operation, the machine was effective in separating hard foreign materials. The test results revealed actual milling times of 4.7, 4.5 and 4.7 min for the three (3) runs analyzed in comparison with the expected milling time of 4 min for 20 kg of cow bone feed to obtain an efficiency of 86.9%.In all, the hammer mill is portable, easy to operate, economically efficient and environmental friendly with less hygiene and electrical hazard and has been designed for the conversion of cow bone into a nutritive supplement in livestock feed.*

Keywords:*Bone, Bone-milling, Efficiency, Nutritive, Portable*

I. INTRODUCTION

Millions of tons of animal by-products are produced annually in Nigeria[1]. A type of waste that is of great concern in both urban and rural areas in Nigeria is abattoir or slaughter-house wastes among whichcow boneis found in large quantity [2]. Survey shows that a total of 289 cows and 382 goats are slaughtered daily in a local abattoir inNigeria. This generates 3.92 ton of blood, 2.9 ton of intestinal content, 4.2 ton of bone and 2.2ton tissues as abattoir waste daily [3]. Oftentimes, cow bone is disposed of in landfill sites and burned in open sites. However, this disposal method poses a serious health risk on the residents of such areas due to its associated environmental hazards [4][5].

Cowbone contains important ingredients which are required in livestock feed as mineral supplements [4]. These can be classified as organic andinorganic materials. The organic material accounts for approximately 20% of the wet weight of bone and about 75% of the dry weight; with 98% calcium, 85% phosphorus and somewhat 50% sodium and magnesium making it beneficial for livestock [6]. In Nigerian livestock industry, slaughter houses are littered with non-meat products and wastes that need to be recycled into useful by-products for further agricultural and industrial uses [7]. Therefore, it is imperative that cow bone be converted into useful materials such as livestock feed supplement.

The most widely used process for recycling these by-products is milling. Milling is the mechanical treatment of materials to produce powder; to change the size or shape of the materials to smaller particles with the aid of mechanical devices and is as old as human history [8]. In the twentieth century, means of milling were developed as an improvement over the old milling machines and emphasis was laid on the means of improving the efficiency of the milling machine and particle size of the product.

Hammer mills are used for pulverizing and disintegration with the hammers operated at high speed [9]. Colloids mill emulsify and disperse liquid media by using high speed rotors with outer serrated surface [10]. Disk attrition mills are a modern fashion of the ancient burrstone mill where the stone are replaced with opposing disk or plate [11]. Dispersion mills have larger gaps which use fine beads within the liquid to enhance the dispersion. It is a size-reduction apparatus that disrupts clusters or agglomerates solids rather than break down individual particles [12]. Pin mills use a rotor with one or more rolls of rods that impact and/or propel particles into stationery pins or surfaces. They fall into the category of high speed rotor pulverizers or disintegrators and produce a finer product than coarse crusher [13].

In Nigeria, the major occupation of residents of rural areas is agriculture[14][15]. The industrial requirements for the use of these milling processessuch as uninterrupted power supply, high technical skill, and reliability of the machines which are often not available to the farmers in most part of the rural areashave made it inconvenient for these farmers to produce livestock feeds in large quantity. There is therefore a need to consider means through which these high industrial requirements can be reduced in the conversion of bone waste into livestock feed supplement. As a result, this work is aimed towards the development of abone milling machine with industrial energy conservation, economic efficiency and high mechanical simplicity.

II. MATERIALS AND METHOD

The materials that were used in this workare mild steel, shaft, bearing, plate sheet, angle bar, bolt and nut, belt, pulley, electric motor, socket, cutting stone and filling stone. Since the machine is expected to be a means by which agricultural workers in the rural area of the country can convert bone waste to feed, the machine has been designed to keep cost low by using materials that are readily available and cheap. Mild steel was chosen as the material to fabricate the bone milling machine due to itsstrength and low medium carbon content which makes it easy to weldand gives it a low weight thus enhancing ease of conveyance.

The bone milling machine has been designed so that the shaft and hammers are powered by a three-phase electric motor of 5.5 h.p, running at a speed of 1440 rev/min.The machine is based on the principle of impact and consists of twelve hammers on the driving shaft.The bones are crushed by the rotating hammer at a high velocity of 1152 rev/min. The milled bones then pass through the discharge unit to be stored for use in poultries as mineral supplement in livestock feed. The milling machine was designed in such a way that the hammer milling machine while rotating, separates foreign particles such as stones and metallic particles to the safety hollow.

2.1 Machine Operation

Hammer mills operate on the principles of impact and pulverization [16]. The cow bones were fed into the hammer mill through the feed hopper. The feed hopper was chamfered to facilitate unidirectional flow of the raw material by gravity to the milling chamber. The hammers struck the dried cow bones and broke them into small pieces each time there was a successful hit. The interior part of the machine was designed such that the pulverized material was prevented from leaving the milling chamber until it had been reduced to fine particles. On subsequent impact by the hammers, the larger particles or uncrushed materials were recycled to the crushing chamber. 20 kg of dried cow bones were fed into the chamber through the hopper and the duration of the milling process was recorded.

The hammer mill essentially consists of a number of steel hammers radially and axially spaced on a steel shaft which rotates at a highspeed in a strong housing called base. On the bottom of the housing and close to the tip of the hammers is a sieve. The fine particles passed through the sieve and were collected. The fineness of the particles was controlled by using sieves of different mesh sizes.

2.2 Machine Design

This section attempts to show the basic equations used in the design of the hammer mill and the principles adopted. The major parts designed in this work are the shaft, belt and pulley, and the hopper.

2.2.1 Shaft Design

Shafts are designed on the basis of strength, rigidity or stiffness [17]. On the basis of strength, the cases considered were when the shaft was subjected to:

(i) Shaft subjected to twisting moment or torque only, a length of 0.40m was chosen because shaft length should be short to limit whirling and torsional vibration during operation according to [17], twisting moment is given as

$$\tau = qJ/r \quad (1)$$

[18]noted the following from the compression test carried out on the hardest part of the femur bone of a cow.

$f = 2500$ N $\quad l = 0.40$ m

$$t = fl$$

Using

$$\frac{T}{J} = \frac{q_{max}}{r} \quad (2)$$

$$q_{max} = \frac{Tr}{J} = \frac{T \times \frac{d}{2}}{\frac{\pi d^4}{32}} = \frac{16T}{\pi d^3} \quad (3)$$

$$q_{max} = \frac{16T}{\pi d^3} \leq q_{allow} \quad (4)$$

(ii)For shafts subjected to bending only, the maximum stress (tensile or compressive) given by [17] is as expressed in equation (5)

$M = \frac{\sigma_{bl}}{y}$ (5)

But $I = \pi/64 \times d^4$ for a solid shaft
and
$y = d/2$
Substituting for I and y in equation (2), we have;

$M = \frac{\pi}{32} \times \sigma_b \times d^3$ (6)

But $M = (W \times L)/8$ (7)

Therefore $\sigma_b = \frac{32M}{\pi d^3}$

(iii)When shafts are subjected to combine twisting moment and bending moment according to [17] two theories that are important are maximum shear stress or Guest's theory used for ductile material such as mild steel and maximum normal stress or Rankine's theory which is used for brittle materials such as cast iron. Guest's theory was considered in the design becausethe shaft is a ductile material
According to the maximum shear stress theory, the maximum shear stress in the shaft is given as:

$\lambda_{max} = 2\sqrt{[(\sigma_b)]^2 + 4\tau^2]}$ (8)

Substituting equation 4 and 7 into 8

$$\lambda_{max} = ½\sqrt{[(\frac{32M}{\pi d^3}) + 4(\frac{16T}{\pi d^3})^2]}$$

Therefore, $\lambda_{max} = \frac{16}{\pi d^3}[\sqrt{M^2 + T^2}]$

or where $\sqrt{[M^2 + T^2]} = T_\theta$ (9)

2.2.2 Design of Transmission Shafts for Torsional Rigidity

According to Ghupta and Khurmi (2005), for a solid shaft, the angle of twist can be determined using equation (10). The amount of twist permissible depends on the particular application and varies from 0.3- 3 °/m.

$\theta = TL/GJ \times 180/\pi$ (10)

$$= \frac{584TL}{Gd^4}$$

The value of twist used in this design is 2.6°/m which was determined by substitution of values into equation (10)

2.2.3 Belt and Pulley

Allowable stress for rubber is from 1.0 - 1.7mPa. Rubber density, $\rho = 1.250 kg/m^3$,
The arrangement of belt and pulley was designed to facilitate the transmission of motion between shafts.
According to [17], belt design analyses are carried out using the following equations.

Power, $P = (T_1 - T_2) V$ (11)

Belt tension ratio $= \frac{T_1 - mv^2}{T_2 - mv^2}$ (12)

$= e^{\wedge}f\alpha cosec\theta$

Where $m = b\ t\ p\ \sin\beta = \frac{D-d}{2C}$

$\alpha_1 = 180° - 2\beta$

$= 180° - 2\sin^{-1}\frac{D-d}{2C}$

$\alpha_2 = 180° + 2\beta$

$= 180° + 2\sin^{-1}\frac{D-d}{2C}$

The centrifugal tension is given by:

$f_c = m_b\ v_b$ [19] (13)

and the belt length was determined by equation (14)

$L = [\sqrt{4C^2} - (D_1 - d_1)^2] + ½(\alpha_1 d_1 + \alpha_2 D_1)$ (14)

2.2.4 The Hopper

The bone milling machine was designed to grind 20kg of dried bone in 4min.Fig. 1 shows the assembly drawimg of the bone milling machine. The volume of the feeding hopper was determined thus:

$V = m/d$ (15)

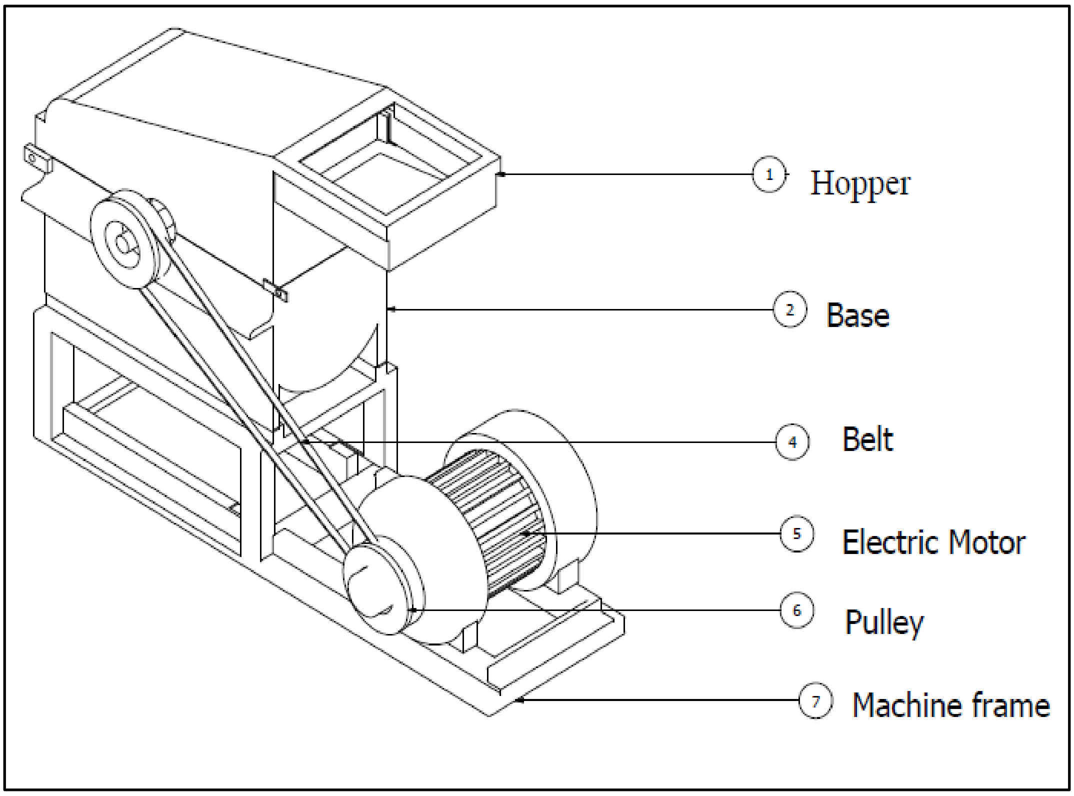

Figure 1: Assembly drawimg of the bone milling machine

2.2.5 Designs For Whirling

$F_0 = m(r+e)w^2$

F_0 must be resisted by the inertia force on the shaft, which is Kr.

Therefore, $m(r+e)w^2 = kr$ (16)

From equation (15)

$$r = \frac{ew^2}{(k/m) - w^2}$$

where $w = \sqrt{\frac{K}{M}}$ then the axis of rotation becomes wide and whirling will take place

$W_n^{\,2} = K/M$

then, $r/e = \frac{\left(\frac{w}{w_n}\right)^2}{1-\left(\frac{w}{w_n}\right)^2}$

When $\frac{w}{w_n} = 1$

From the American Society of Mechanical Engineering (ASME) code, for no whirling situation,

$\frac{w}{w_n} < 0.707$

where $w = 2\pi N/60$ and $k = \frac{\pi d^4 G}{32L}$ [20]

2.3 Fabrication of the Milling Machine

The mild steel plate was cut to specification to fabricate the hopper, and some other parts were considered to specification so as to fit the design as shown in the TABLE1.

Table 1: Materials used in fabrication and specification

S/N	Material	Specification
1	Mild steel angle iron	76mm × 69mm
2	Mild steel plate	1220mm × 2440mm
3	Mild steel shaft	50mm × 450mm
4	Mild steel flat bar	30mm × 300mm

Flat metal plate was welded to the tip ends of the hopper front: This serves as a channel through which the base will be joined to the hopper using bolts and nuts. Solid shaft of adequate size was selected. The hammer chamber plate was also cut to specification and welded together, six auxiliary shafts were welded to the gaps between the disc and two hammers where inserted on each of the shafts, making twelve hammers all together and the entire component was welded to the stand.

The angle iron bars were welded together to form the support on which the hammer chamber stands. The bearing support was also welded to the side of the hammer chambers in such a way that the bearing fit properly to aid smooth running of the shaft. The mild steel plate was cut into appropriate size and shape to make the hammer. The hammers were heat treated to obtain the required property and strength.Plate 1, 2 and 3 shows the side view of the machine,hammers on the auxiliary shafts,safety hollow opened and safety hollow closed with mild steel, respectively.

Plate 1: side view of the machine

Plate 2: hammers on the auxiliary shafts

Plate 3: safety hollow opened

Plate 4: safety hollow closed with mild steel

III. RESULT AND DISCUSSION

The procedure was repeated thrice for consistency and the efficiency was determined. Khurmi and Ghupta, 2005 reported that a bone milling machine milled 100kg of bone in 20minutes and while in this paper it milled 20 kg in 4 minutes which implies that the two are operating with the same efficiency.The output efficiency of the bone milling machine are shown in Table 2.

Table 2: The output efficiency of the bone milling machine

S/N	Sample	Mass (kg)	Expected milling time (min)	Weight of bone after milling (Kg)	Actual milling time (min)
1	a	20	4	18	4.7
2	b	20	4	19	4.5
3	c	20	4	18	4.7

$\mu = 20\text{kg}$

$\lambda_e = (4 + 4 + 4)/3 = 12/3 = 4 \text{ min}$

$\lambda_t = (4.7 + 4.5 + 4.7)/3 = 13.9/3 = 4.6 \text{ min}$

$w_e = m/At = 20/4 = 5 \text{ kg/min}$

$w_r = m/Aat = 20/4.6 = 4.35 \text{ kg/min}$

$\eta_m = \frac{w_r}{w_e} \times 100 = 4.35/5 \times 100 = 0.869 \times 100 = 86.9\ \%$

Thus, the output efficiency of the bone milling machine is 86.9 %.

The machine has been designed and fabricated so as to separate foreign materials which may get into the feed during the milling process. The hammers while rotating at high speed, screens out any material or object stronger than bone into the safety hollow at the backend of the machine, this will elongate the useful life of the hammer and aid operational safety. It was observed that fineness of the milled material increases from the first to the last test. Also the weight of the bone before and after milling remained relatively the same. This means that there is a limited loss of materials during the milling process. Some of the particles produced by hammer mills are in the form of dust and are lost into the atmosphere during the process of collecting. The relative lost in weight was due to the safety hollow at the backend of the bone milling machine which houses hard particles, and some raw materials which may have been feed with the bone through the hopper. The minimum loss of dust is an advantage as it can help reduce serious health hazard to the human operators ofthe hammer mills as they enter the lungs (which can lead to cancer) and ears (which can lead to hearing loss), eyes (which can lead to blindness).

The machine efficiency was due to the ratio of the actual milling time to the expected milling time. The difference in milling time was from operators delay in the different feeding process. The number of hammers on the rotating shaft as well as the power of the electric motor has a direct influence on the milling time and hence the efficiency of the machine. The higher the hammers the higher the impact, and the higher the electric motor power the higher the speed of rotation.It was observedfrom the test that for proper maintenance and operation of the machine, over feeding of dried bones into the machine (> 20 kg) should be avoided and the bearing should be properly greased by removing the seal. A vibration damper was incorporated into the foundation of the bone-milling machine to reduce the noise and vibration of the machine.The hammer carrier was also designed to prevent the electric motor from getting burnt from wrong connection of the cable into the electric motor; it operates such that the pulleys rotate in an anti-clockwise direction indicating that the cable connection is wrong. The unmilled and milled cow bone are shown in Fig. 2 and Fig. 3.

Figure 2: Sample of the dried un-milled cow bone

Figure 3: Sample of the milled cow bone

IV. CONCLUSION

This paper was aimed at the design, fabrication and performance evaluation of a bone mill with a special attribute of separating foreign particles into the safety hollow. The machine was majorly constructed using locally available materials with preference for local utilization. Its major components are feeding hopper, shaft, hammers, frame, base, bearing,electric-motor, cutting and filling stone.The hammers have been designed to rotate in an anti-clock wise direction manner in case of wrong electrical connection, thereby rendering assurance to the electric motor. From the performance evaluation of the machine, a reasonably high efficiency was achieved for bone milling. Its portability is also a benefit in that it can be conveniently be conveyed to other places within the area or beyond for use.

The adverse effects of smoke and noise have been substantially reduced by this new machine making it advantageous in rural areas where measures for determining consequent environmental impact are not usually available. With the location of application in mind, this machine has been designed to cater for inadequate technicality on the part of local operators.The machine is economically feasible with high mechanical simplicity. In order to aid the growth of local livestockfeed production, it is recommended that this machine be developed capacity-wise and commercialized.

NOMENCLATURE

T	Twisting moment (or torque) acting upon the shaft	Nm
F	Applied force	N
J	Polar moment of inertia of the shaft about the axis of rotation	M^4
q	Torsional shear stress	
r	Distance from neutral axis to the outermost fiber	m
M	Bending moment	Nm
V	Volume	cm^3
I	Moment of inertia about the axis of rotation	
σ_b	Bending stress	Nm
y	Distance from the neutral axis to the outermost fiber	m
L	Length of shaft	m
m	Mass	kg
k	shaft stiffness	
G	Polar moment	Gpa
P	Power transmitted	Watts
T_1	Belt tension on tight side	N
T_2	Belt tension on loose side	N
f	Coefficient of friction between belt and pulley	
α	Angle of wrap	degree
θ	Groove angle for v-belt	degree
β	Belt width	mm
t	Belt thickness	mm
ρ	Belt density	kg/m^3
D	Outside diameter of large pulley	mm

d	Outside diameter of small pulley	mm
C	Centre distance between the driving and driven pulley	mm
α_1	Motor Pulley wrap angle	degree
α_2	Shaft pulley wrap angle	degree
l	Length	m
b	Breadth	m
h	Height	m
r	Radius	mm
π	3.142	constant
ρ	Density	kg/m^3
λ	Shear stress due to twisting moment	
v	Velocity	m/s
ω	Angular velocity	
μ	Average input	kg
λ_e	Average expected milling time	s
λ_t	Average actual milling time	s
w_e	Expected working rate	kg/m
w_r	Actual working rate	kg/m
η_m	Output efficiency of the machine	%

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