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Research Article

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Development and Performance Evaluation of Improved Hammer Mill

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Abstract This work describes the development of an Improved Hammer Mill utilizing materials that were sourced locally aimed at meeting the demands of the food and animal feed industries. The developed machine is aimed at assisting in the grinding of food and animal feed materials into grain sizes that has the capability of serving the desired demand. The Hammer mill has the ability to accommodate various grain particle sizes as required through the holes of the sieve positioned beneath the hammer assembly. The grinding process is achieved actions of the hammering chamber in beating the material fed into it. The fineness to be achieved depends on the perforated hole size of the detachable screen. This improved hammer mill has a grinding efficiency of 92.6%.It is appreciably dust free and also due to proper air circulation does not destroy the flour produced by overheating which is favourable to food and feed material quality and preservation.

Keywords Hammer mill, Design, Performance test, Shaft speed, Grain particles

Introduction

Hammer mills are widely used in food and feed industries due to its advantages of high productivity and flexibility of grinding a large variety of products [1]. Conventionally, they operate on the principles of impact and pulverization. It consists of a rotor assembly on which swinging hammers are mounted and a screen. The rotor shaft of this mill can be placed vertically or horizontally, but generally horizontal placement is preferred [2-3]. The shaft carries elements known as hammers or beaters. The hammers are constructed in several shapes such as T-shaped element, bars, or rings pivoted to the shaft or to disks fixed to the shaft as preferred. The hammers are allowed to swing freely instead of being rigidly attached so as to absorb shock loads encountered when they come into contact with very hard substances or material. The screen (normally perforated sheet metal) is mounted below, above and/or around the hammers [4]. These screens can be changed intermittently. Hammer mills are operated at high speed to achieve fine pulverization and disintegration of inputted materials. Grinding is achieved through impact and attrition between particles of the material being ground, the housing and the grinding elements [3].

As the material being ground is fed into the grinding chamber, it is initially struck by the rotating hammers and then thrown against perforated plate. Therefore, the material is ground by the repeated impacts of the hammering elements, collisions with the screen and walls of grinding chamber as well as particle on particle impacts [5, 6].As soon as the particle size of material is reduced to the size smaller than that of the holes of the screen, it will pass through the screen and separate out through the outlet of the mill. The fineness of the particles is regulated by the use of sieves of different mesh sizes.

Materials and Methods

The methodology adopted was to examine the most critical defects of conventional hammer mills and make provision in this design that takes care of these observed deficiencies. The defects identified and corresponding solutions proffered are outlined below:

Firstly, as a result of wear and corrosion the sieve screen holes enlarge or burst thereby allowing larger than desired particles to pass through. To take care of this defect, an austenitic stainless steel material which is wear and corrosion resistant was adopted for the screen. Again, after several hours of hammer mill operation, the sieve screen holes are clogged thereby reducing its efficiency and capacity. Also, wet materials become elastic and therefore absorb most of the impact energy of the hammer without breaking. This also reduces the efficiency of the regular hammer mills. Tackling these defects, the introduction of a fan to induce forced convection and rapid drying of material was done. This fan introduction also assists as pressurized air can lift particles of sufficient sizes through great distances thereby causing the particles of the material not to clog on the screen holes. This is observed in tornadoes and cyclones. Furthermore, some of the particles produced by hammer mills are in the form of dust and are lost to the atmosphere which pollutes the environment. They also constitute serious health hazard to the human operators of the 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), et cetera. To a great deal, the introduction of the fan to the milling chamber generates the required suction pressure which limits the quantity of fine particles that escape. Again, a control of the feed was introduced to prevent overloading of the crushing chamber. This was achieved by using a mechanical means to control the periodic opening and closing of the feed hopper gate to the chamber.

Construction Details of Major Parts

The materials for the construction of this hammer mill are: the shaft, pulley, belt, electric motor, the bearings, the stainless steel plates, mild steel angle bars.

Main Shaft: A 34.93mm diameter stainless rod was cut to a 720mm length using power hacksaw. Keyway was cut on it using milling machine for the fixing of the driven pulley.

Hammer Shaft: 20.3mm diameter stainless rod with length of 200mm was used for the hammer shaft. This was cut into 10 pieces.

Hammer: An 8.36mm thick stainless flat bar of 12.5mm length and 4 mm width was cut into 40 pieces. A hole of 21mm was drilled at an end of each hammer, using twist drill, to enable it to be put into position on the hammer shaft.

Hopper: It is pyramidal in shape and it was made from 2.5mm thick stainless plate. The top opening has a dimension of 360mm by 360mm, 200mm by 120mm lower end opening and height of 300mm. The plate was marked, cut to sizes and then welded together.

Stand Frame: The base of the hammer mill was constructed with a 6mm thick mild steel angle bar.

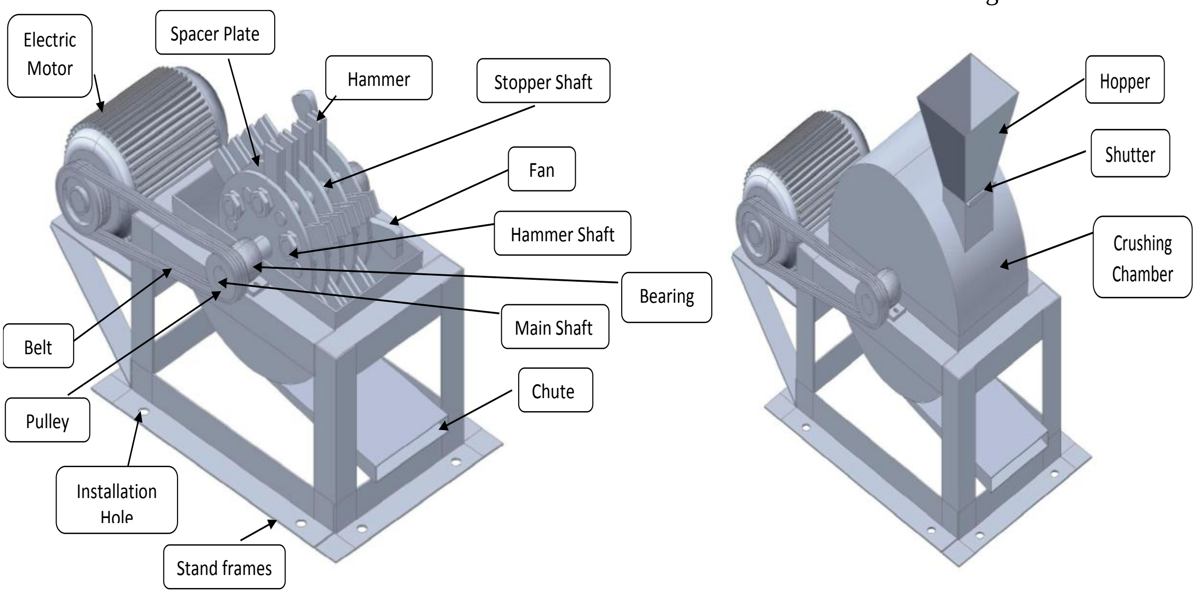

Figure 1: Sectioned and Complete views of the Improved Hammer mill

Design Consideration

This section attempts to show the basic equations used in the design of the hammer mill and the principles adopted. The major components of the machine include the hammers, shaft, bearing, fan, casing and electric motor.

Power Required by Machine

The power required by the hammer mill, P_h, is given by

$P_h = T\omega$ …………………………………...................................... (1)

Where, P_h= power, T = torque and ω= angular velocity

Design of Shaft: A shaft is the rotating machine element which transmits power from one place to another [7]. The shaft of the hammer mill which is rotating the hammers and fan will be subjected to twisting moment only. For a shaft subjected to twisting moment only, the diameter of the shaft was obtained by using the torsion equation given as

$T = \frac{\pi}{16}\tau d^3$ …………………………………………… (2)

where, T = Twisting moment/Torque (Nm)

τ = Torsional shear stress (N/m^2) = 42 MPa [7] and d = Diameter of shaft (m)

Also, an equation for determination of Turning/Twisting moment (T) on the pulley is as shown:

$T = (T_1 - T_2) R$ ……………………………………......... (3)

where; T_1 = Tight side tension (N), T_2 = Slack side tension (N) and R = Radius of pulley (m)

Determination of shaft and pulley speed: To calculate the shaft speed, this equation is used:

$\frac{D_1}{D_2} = \frac{N_2}{N_1}$………………………………… (4) [3]

where:

D_1 and N_1 =Diameter (m) and revolution of the smaller pulley (rpm) respectively.

D_2 and N_2 = Diameter (m) and revolution of the larger pulley (rpm) respectively.

To obtain the speed of the driving and driven shafts and pulleys:

$V_1 = \frac{\pi D_1 N_1}{60}$ and $V_2 = \frac{\pi D_2 N_2}{60}$ ………………………. (5) and (6)

where:

V_1 and V_2 are the speeds (m/s) of the driving and driven shafts and pulleys respectively.

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value is reduced by 4% [8].

Table 1: Dimensions of standard V-belts [7]

Types of belt	Power ranges in kw	Minimum pitch diameter of pulley (D) mm	Top width (b) mm	Thickness (t) mm
A	0.7-3.7	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

Design for belt:

Selection of belt type: Based on the power transmitted (3.7 kw or 5hp) and according to the Indian standards (IS: 2494-1974), belt type B was selected considering the specifications from Table 1.

Calculation of belt length, L: The equation for calculation of belt length is as shown [7]:

$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D_1 + D_2)^2}{4C}$ …………………………………… (7)

where, L = Length of belt (mm), D_1= Smaller pulley diameter (mm), D_2= Larger pulley diameter (mm), C = Centre distance of pulleys (mm).

Power transmitted by belt: The power transmitted by the belt, P, is given by

$P = (T_1 - T_2) V$ …………………………………… (8)

Where, P = power transmitted, T_1 = tension on tight side of belt, T_2 = tension on slack side of belt, V = linear velocity of belt.

The Hammers

The centrifugal force on the hammers, F_h, is given by

$F_h = N_h\ m_h\ r_h\ \omega_h$ ………………………………………………………. (9)

Where, F_h = centrifugal force, N_h = number of hammers , m_h = mass of each hammer, r_h = radius of hammer, ω_h= angular velocity of hammer

Assuming inelastic impact between the hammers and material, the velocity of material, Vm, given by

$$V_m = \sqrt{\frac{2F_hR_h}{M_mN_m}} \quad \ldots\ldots\ldots\ldots \text{(10)}$$

Where, V_m = velocity of material being milled , M_m = mass of material being milled, N_m = number of material impacted

The minimum width of hammer, W_h, to withstand the centrifugal force at impact is given by

$$w_h = d_h + \frac{F_h}{t_{h\sigma_h}} \ldots\ldots\ldots \text{(11) [8]}$$

Where, W_h = width of hammer, d_h = diameter of hammer, t_h = thickness of hammer, σ_h = working stress on hammer

Number of belts required, n.: The number of beltsrequired to transmit 3.7 kw power from electric motor was calculated using the given equation:

$$n = \frac{Motor\ power}{power\ per\ belt} \quad \ldots\ldots\ldots \text{(12)}$$

Selection of bearing: Ball rolling contact bearing of standard designation 307 was selected for the machine. This selection was based on the type of load the bearing will support when at rest and during operation and also based on the diameter of the shaft. The designation 307 signifies medium series bearing with bore (inside diameter) of 35 mm [7].

Result and Discussion

Testing is a vital step in the process of machine development. After design and construction, testing is necessary in order to determine the performance efficiency of the machine, and afterwards, point out areas of possible improvement where necessary. Based on the design, a prototype was fabricated, as shown in the Figure 1. In order to evaluate its performance, two parameters were tested: Product Output Rate and Product Temperature.

The experimental material was dry maize grains and screen sieve hole is 2mm in diameter. The productivity test was performed under rated condition of motor, each test lasted for 15min and three times were iterated. The amount of product at each test was weighed with a digital balance and the averaged value for the three tests was used as the final productivity.

The temperature of product at the grinder outlet, taking as the final product temperature, was detected with a mercury thermometer. At the end of each test, the temperature increase of the product was calculated by subtracting initial temperature of material from the final temperature. The tested performance of the prototype was tabulated and is shown in Tables 2 and 3.The power source of the hammer mill is a three phase electric motor with a power capacity of 3.73kW and a rotational speed of 3000r.p.m.

Test Procedure

A 5 kg of dry maize grain was fed into the hopper and the Hammer mill was switched on. The grinding time for each run was recorded with the aid of a stop watch. This was repeated for three times and the mean value recorded and used for calculation. The output rate is recorded as well as the output material temperature.

$$Grinding\ efficiency = \frac{Mass\ of\ output\ material}{Mass\ of\ input\ material} \times 100\%$$

Table 2: Hammer mill productivity performance test result

Experimental runs	Mass before operation (kg)	Mass after operation (kg)	Time taken (min)
1	5	4.6	13.3
2	5	4.8	13.5
3	5	4.5	13.1
AVERAGE	5	4.63	13.3

Table 3: Temperature test performance result

Experimental runs	Temperature before (°C)	Temperature after (°C)	Time taken (min)	Temperature increase of product (°C)
1	32	34.5	13.3	2.5
2	32	35.6	13.5	3.6
3	32	35.2	13.1	3.2
AVERAGE	32	35.1	13.3	3.1

Conclusion

Based on the performance test conducted on the improved Hammer mill operated by an electric motor of 3.7 KW and a rotor speed of 3000 rpm, a grinding efficiency of 92.6% was obtained. During the performance test, the product input-output ratio stood at 5:4.63 average mass value. For the increase in temperature of the milled product, a temperature difference of 3.1°C was obtained. It can be seen that the Hammer mill has a good performance in productivity and energy consumption, especially with the low product temperature increase, this will be favorable to the quality of milled materials and there storage.

Figure 2: Pictorial view of Improved Hammer mill

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