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Design of a Multi-Purpose Crushing Machine for Processing of Food Grains in Nigeria

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Abstract

Crushing of farm produce for easy storage and consumption is still a problem in most rural areas in Nigeria. Large tons of food crops are lost annually in Nigeria as a result of unavailability of storage facilities. This necessitated the design of a multi-purpose crusher to save crushing energy with minimal grain losses, being the primary aim of this study. The major components of the designed crushing machine consists of a hopper, crushing chamber, shaft, hammers, screen, bearings, discharge outlet and a 2HP electric motor. A number of tests were carried out with the designed crusher using 4.8kg of dry maize and crushing efficiency of 85%, crushing loss of 0.15% and crushing capacity of 65kg/hr. were achieved as optimum performances. From the test results, it was observed that the final crusher design had a higher capacity and efficiency, and this produced finer end products compared to existing ones.

Keywords: Crushing, Food grains, Size reduction, Crushing loss, Design, Fabrication

1. Introduction

The World Health Organization (WHO) on world health dated 7th April 2015 used a slogan; "From farm to plate, make food safe". But before agricultural produce leave the farm to become edible food, tedious processes are involved in making this possible. This process is the transformation of raw ingredients, by physical means into food. The agricultural produce are usually present in range of sizes, often too large to be handle and must be reduced in size for easy handling to aid processing and storage (Agboola,1992; Igbeka and Olumeko,1996).

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Nomenclature	
a	Area (m)
C	Centre distance (mm)
d	Diameter of the shaft
D	Diameter of motor pulley
D_1	The required pitch diameter of the driven pulley
D_2	Pitch diameter of the driver pulley
g	Acceleration due to gravity
h	Height of the cylinder
K_b	Combine shock and fatigue factor applied to bending moment
K_t	Combine shock and fatigue factor applied to torsional moment
N	Speed of motor (rpm)
m_a	Mass after grinding
m_b	Mass before grinding
M_b	Maximum bending moment Nm
M_h	Mass of hammer
M_t	Torsional shear stress Nm
N_1	Rotational Speed of the driven pulley
N_2	Rotational Speed of the driver pulley
P	Power transmitted to the shaft
r	Radius of the smaller pulley (mm)
r_1	Radius of the driving pulley
r_c	Radius of the cylinder
R	Radius of the large pulley (mm)
T_1	The tension in the tight side of belt (N)
T_2	The tension in the slack side of belt (N)
V	Velocity of the belt (m/s)
W_h	Weight of hammer
α_1	Angle of wrap for the smaller pulley (^{0}C)
α_2	Angle of wrap for the larger pulley (^{0}C)
σ	Allowable tensile stress (N/M)

The general term "size reduction" includes cutting, crushing, grinding and milling. The reduction in size is brought about by mechanical means without change in chemical properties of the material, and uniformity in size and shape of the individual grains or units of the end product is usually desired but seldom attained. The processes such as cutting of fruit or vegetables for canning, shredding sweet potatoes for drying, chopping corn fodder, grinding grains for livestock feed, and milling flour are classified under size reduction and can be achieved through the use of a crushing machine. Crushing machines are usually used to reduce the size and shape of materials so that they can be efficiently used for the purpose intended for (Orhorhoro et al., 2016). Crushing as a matter of fact remains the oldest technique in reducing solid materials into smaller particles. During early civilization, grinding of food grains was dominantly practiced by women; it was carried out mainly in two fashions;

- By pounding the grains (mortar and pestle) and secondly,
- By grinding done by crushing the grains between two grinding stone (Paris, 1988).

The method pestle and mortar is widely used in the west-African sub region. The traditional grinding stones used to grind whole or decorticated grain into flour, primarily consists of a flat large stone which is placed on the ground and a smaller stone held by the person to perform grinding, by smashing grains between the two stones (Okafor, 2014). In other words, the operating principles of a crushing machine is by holding the material between two parallel or tangent solid surfaces, and in the process sufficient force is apply to bring the surfaces together to generate enough energy within the material being crushed (Orhorhoro et al., 2016). By so doing, the grains are reduced to smaller particles. Though using grinding stones are effective in grinding for domestic purpose, it may also prove to be very cumbersome if it is considered on a commercial scale, because it will be time-consuming and toilsome.

Grinding of foodstuffs can be said to have started many centuries ago. Records however have shown that during the Stone Age (about 6700BC), man ground grains of wheat with rocks to make flour. By 5500 BC came the mill stone which consists of two large individual stones between which the wheat is ground to flour. However, crushing of farm produce after harvesting is one of the major food processing techniques employed by Nigerians to maintain taste, quality and effective food storage (Igbeka and Olumeko, 1996). Despite the tedious efforts involved, non-mechanized system of agriculture continue to exist as the primary means of processing farm produce after harvest in Nigeria, and this subjects handymen employed in this area to painstaking process in attempt to crush farm produce (such as melon, plantain, millet, groundnut maize etc.) into finished products available for sales and consumption. In some parts of Nigeria particularly the rural areas, grinding stone, manual hand grinder or mortar and pestle is mainly used to achieve this purpose which usually consume a lot of time and energy despite the low cost involved.

Crusher mills are the best known equipment used for shredding/grinding, in which the material fragment are subjected to complex forces and then the resulted particles are used in the following operations from the pellet obtaining technology (Nwaigwe et al., 2012). The basic principle in locally made grinding machines is friction. In order to effect size reduction, the two frictional surfaces of the grinding machines have to come together to crush the material between them (Maduako, 2005). Machines are developed to aid quick processing of agricultural materials and products (Hannah and Stephens, 2004), other technologies should be considered and employed to see that existing food machines are sustained for continuous preparation of available meals for the populace. Where necessary, modifications should be made to obsolete machines to ensure proper safeguarding of food items and also improve their reliability, example where carbon steel were used in machine development, they should be upgraded to stainless steel to remove the possibility of food contamination due to material corrosion (Gorham, 1994). In Nigeria, the major occupation of residents of rural areas is agriculture. The industrial requirements for the use of these milling processes such 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 areas have made it inconvenient for these farmers to produce livestock feeds and human food in large quantity. There is therefore a need to consider means through which these high industrial requirements can be reduced by developing a modular machine that will ensure fine crushing of grains, nuts and farm products into tiny shards or granules. As a result, this work is aimed towards the development of crusher mill with economic efficiency and high mechanical simplicity.

1.1 Operation of the Machine

With the power transmitted to the belt drive through the pulleys attached, the shaft in the grinding chamber carrying rectangular hammers attached on it is set into rotation. Agricultural produce which should be dried is introduced into the hopper which directs the movement of the produce via a passage called neck into the grinding chamber. The rotary motion of the hammers provided with a small clearance (20mm) from the wall of the drum allows the striking or beating of the agricultural product against the drum causing the product to shatter into pieces. The grinding continues in the grinding drum as the swinging of the hammers continues to hit the particles of the product against the walls of the drum. The product which has been broken to pieces continues to hit against themselves and the hammers which are positioned such that none of the particles escape being hit. The reduction in size of the grounded pieces continues further as the produce are forced to pass tiny holes (3mm) on the sieve which are at the lower part of the grinding chamber passing through the outlet. The base is rigid enough to support the weight and damp the vibration of the entire unit.

2. Methodology

The machine frame was fabricated using angle bar to give rigidity and stability required to withstand various loads acting on the machine and vibrations resulting from the loading effects. The shaft components were fabricated from mild steel because it can be easily rolled and drawn into shape and it's relatively low cost and availability in the market. It has greater strength giving it undeniable advantages. A number of factors were taken into consideration, some of which include; mechanical properties such as load and stress consideration, strength and rigidity of the design, motion of parts, material selection. Also, ergonomics (designing to suit human use) was carefully considered in the design. However, attention was given to the primary function of the multipurpose crusher, which is grain size reduction. The multi-purpose machine design drawings were developed using AUTOCARD 2015 version.

2.1 Design Parameters

The following parameters were taken into consideration during the design stages of the multi-purpose crushing machine for processing of food grains.

2.1.1 Determination of Shaft Speed

The transmission system used is belt transmission via a pulley (specifically v-belt selection), where the rotating force generated by electric motor serves as the driver. Thus, to calculate the shaft speed, the following parameters were considered;

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \quad (1)$$

$$N_2 = \frac{D_1 N_1}{D_2} \quad (2)$$

2.1.2 Determination of the Belt Contact Angle

The belt contact angle is given by ((Hollowenko et al, 2004))

$$\sin\beta = \frac{R-r}{c} \quad (3)$$

The angles of wrap for the pulleys are given as;

$$\alpha_1 = 180 - 2\sin^{-1}\left(\frac{R-r}{c}\right) \quad (4)$$

$$\alpha_2 = 180 + 2\sin^{-1}\left(\frac{R-r}{c}\right) \quad (5)$$

2.1.3 Determination of Belt Tension

The belt tension can be determined using the relationship below (Khurmi and Gupta, 2008).
Maximum tension in belt

$$T = \sigma \times A \quad (6)$$

Centrifugal tension in belt

$$T_c = mv^2 \quad (7)$$

$$T_1 = T - T_c \quad (8)$$

To get tension in slack side, the relationship shown in Equation (9) can be used

$$2.3\log\frac{T_1}{T_2} = \mu\theta cosec\beta \quad (9)$$

But,

mv^2= centrifugal force acting on the belt.

The Linear velocity (V) of the belt is given as

$$V = \frac{\pi dN}{60} \quad (10)$$

2.1.4 Determination of the Torque and Power Transmitted to the shaft

Power transmitted to the shaft is given by

$$P = (T_1 - T_2)V \quad (11)$$

The torque exerted on the driving pulley is given by

$$T = (T_1 - T_2)\, r_1 \quad (12)$$

2.1.5 Determination of the Hammer weight

From the equation,

$$W_h = m_h g \quad (13)$$

2.1.6 Determination of the Centrifugal Force Exerted by the Hammer

Centrifugal force exerted by the hammer can be calculated as given by:

$$F = \frac{mv}{r} \quad (14)$$

The angular velocity of the hammer is given by

$$\omega = \frac{2\pi rN}{60} \quad (15)$$

2.1.7 Shaft Design

The design of power transmitting shaft basically consists of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity, during its operation under various loading and working conditions. Shafts are usually circular in cross-section, and may either be hollow or solid.

The following are considered during shaft design;

- The diameter of the shaft
- Length of the shaft.
- Reaction on bearing resting on shafts.
- Size bearings.
- Bending and Tensional Moments.

2.1.8 Shaft Design Parameters

Shafting is usually subjected to torsion, bending and axial loads. For torsional loads, the torsional stress T_{xy} is;

$$T_{xy} = \frac{M_{tf}}{J} = \frac{16M_t}{\pi d^3} \quad (16)$$

For bending loads, the bending stress (tension or compression) is given as;

$$S_S = \frac{M_b}{I} = \frac{32M_b}{\pi d^3} \quad (17)$$

Equation (16) and Equation (17) are for solid shaft (Budynas and Nisbett, 2008)

For a solid shaft having little or no axial loading, equation (18) can be used

$$d^3 = \frac{16}{\pi\sigma_s}\sqrt{(k_b M_b)^2 + (k_t M_t)^2} \quad (18)$$

2.1.8 Bending and Torsional Moments

One of the first steps in shaft design is to draw the bending moment diagram for the loaded shaft or the combined bending moment diagram if the loads acting on the shaft are in more than one axial plane (Khurmi and Gupta, 2008). From the bending moment diagram, the tensional moment acting on the shaft can be determined from;

$$M_t = (T_1 - T_2)\,R \qquad (19)$$

2.1.9 Grinding Drum Design

The drum has a cylindrical shape and the volume of a cylinder is given as;

$$\text{Volume of cylinder} = \pi r^2 h \qquad (20)$$

3. Performance Test and Results

The performance test of the machine was carried out after the fabrication was completed in order to know if it is functioning according to the detailed design specifications. Dry maize was obtained weighed using weight balance scale. The machine was operated for three minutes to allow speed to stabilize. The dry maize was introduced into it through the hopper for another five minutes to check for vibration, misalignment in the shaft connection, other irregularities of the machine and finally the performance of the machine. The stop watch was used to monitor the time. Series test were conducted with the machine, and the crushed maize was collected into a scale, weighed and recorded using the weight balance scale.

3.1 Test using Dry Maize

A 4.8 kg of dry maize was fed into the hopper and the maize was slowly fed into the grinding chamber to prevent clogging on the screen. The time taken for grinding was noted and also the mass of the recovered maize after grinding was recorded. As shown in Table 1, this was repeated five times and the average time and mass values were used for calculation.

Table 1: Crusher Mill Test Results using Maize

Trial	Mass of maize before grinding (kg)	Mass of maize after grinding (kg)	Time taken (minutes)
1	4.80	4.08	4.80
2	4.80	4.04	5.12
3	4.80	4.00	5.04
4	4.80	4.12	5.00
5	4.80	4.08	5.04
Average	4.80	4.06	5.00

Average mass of the dry maize before grinding = 4.8 kg
Average mass of the dry maize after grinding = 4.016 kg
Average time taken = 1.25 min

$$\text{Crushing Efficiency Ceff} = \frac{\text{mass of recovered material}}{\text{mass of input material}} \times 100 \qquad (21)$$

$$\text{Crushing Efficiency Ceff} = \frac{4.064}{4.8} \times 10 = 85\%$$

$$Losses = \frac{m_b - m_a}{m_b}$$

$$Losses\ \frac{4.8 - 4.064}{4.8} = 0.15\%$$

This paper outlined the design of food grain crushing machine to improve its efficiency and usage. The performance tests conducted indicated that high value of crushing efficiency is attainable. Series of test were conducted with 4.8kg of dry maize and the crushing efficiency was found to be 85%, crushing loss of 0.15% and crushing capacity of 65kg/hr. From the test result, it was observed that the modified crusher has a higher capacity and efficiency.

3.2 Installing and operating guidelines

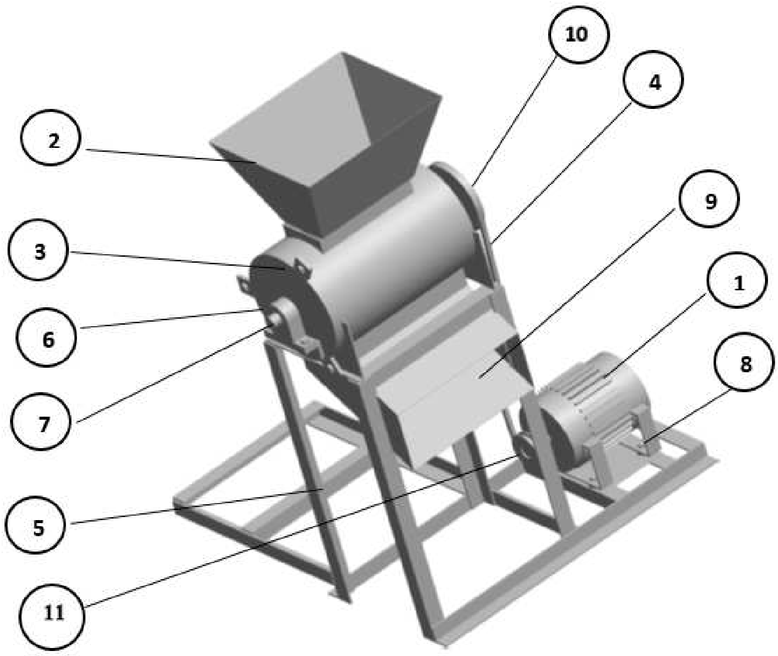
The following points should be considered during the installation of the machine

- Machine should be installed on level ground
- Machine should be installed at a well- ventilated spot
- Machine should be installed near a source of natural light
- Machine should be observed carefully before operation
- Plug wire to socket and switch on the power supply

3.3 Care and Maintenance

- Change the belt when it has less tension.
- Clean machine after each use.
- Ensure that all bolts on machine are tightened properly.
- Lubricate all rotating parts before use to avoid wear of the machine parts.

Figure 1 shows the isometric view of the multi-purpose crushing machine while Figure 2 shows the assembly drawing of the multi-purpose crushing machine.



Parts List	
1	Electric Motor
2	Feed Hopper
3	Grinding Chamber
4	Transmission Belt
5	Machine Frame
6	Bearing
7	Shaft
8	Bolt, Nut and Washer
9	Product Outlet Tray
10	Driven Pulley
11	Drive Pulley

Figure 1: Isometric view of the Multi-Purpose Crushing Machine

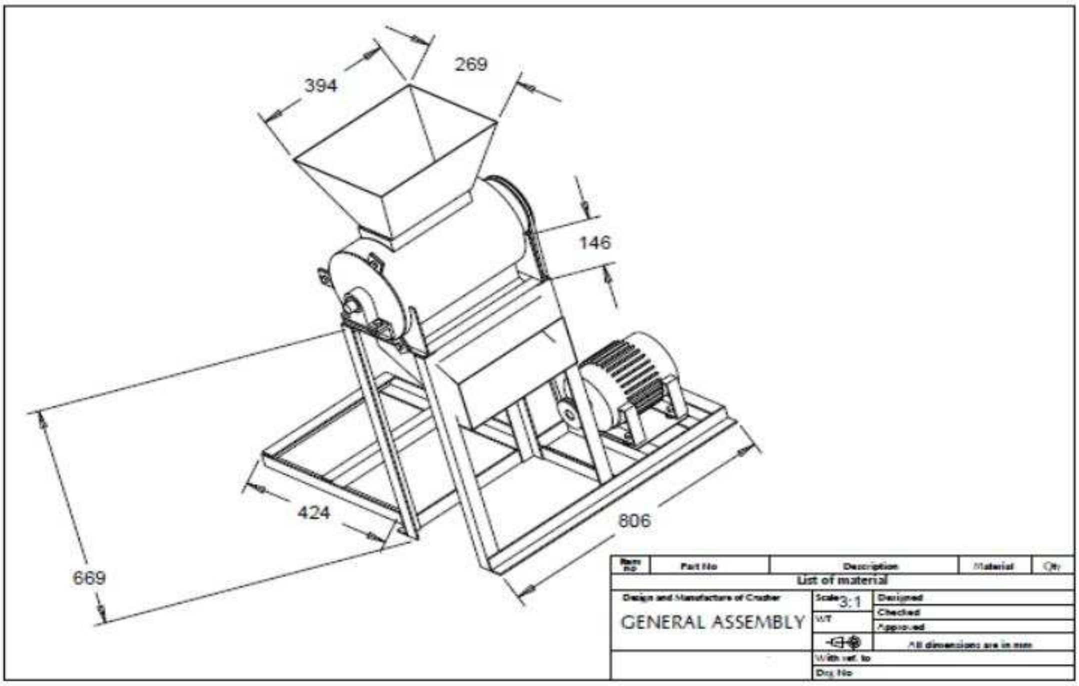


Figure: Aassembly drawing of the multi-purpose crushing machine

4. Conclusion

The designed multi-purpose crushing machine reduced processing losses, produce flour with longer shelf life (dry flour), enhance greater consumer choice, ensure new markets for domestic cereals and legume crops, and reflect a more effective response to changing market requirements and increase food security for Nigeria. The major components of the machine are shaft, hammers, bearing, cracking chambers and electric motor. From the design consideration and analysis portability, reliability, safety, serviceability and cost of construction were given due considerations. Most components were fabricated using locally sourced materials. The preliminary tests carried out on the operated crushing machine confirm that it operates satisfactory. The screen is stationary but the hammers are the adjustable types, making it possible to mill grains small enough to pass through the stationary screens with an aperture size of 3mm. The environmental pollution associated with the use of conventional hammer mills is eliminated. Thus there is no health hazard experienced by the operator of the new machine. It is hoped that the commercialization and wide spread application of the multipurpose crushing machine will contribute significantly to the growth of the agricultural and solid mineral processing industry in Nigeria.

References

Agboola, S., 1992. Technologies for Small-scale Storage of Grains in Nigeria,. proceedings of 3rd CODRI seminar on Food Storage, Processing and Utilization. CODRI 1(1), p.22-27

Basil O., 2014. Developing a Yam Flour Processing System, International Journal of Engineering and Technology Volume 4

Budynas, R. G. and Nisbett, J. K., 2008. Shigley"s Mechanical Engineering Design. Eighth Edition, McGraw-Hill, 2008, ISBN: 978-007-126896-7

Gorham, J.R., 1994. Metal particles in Food as a cause of injury and disease, A Review Handbook. Marcel (Edition), N.Y. USA, p. 615 – 636

Hannah, J. and Stephens, R., 2004. Advanced Theory and Examples in Mechanics of Machines. Edward Arnold Ltd,New Delhi, Ist Edition, p. 677-819

Hollowenko, 2004. A textbook on Theory and Problem of Machine Design. Tata Mc, Gram Hill Edition

Igbeka, J. and Olumeko, D., 1996. An Appraisal of Village Level Grain Storage Practices in Nigeria, Journal of Agricultural Mechanisation in Asia, Africa and Latin America, 27(1), p.29-33

Maduako, J.N., 2005. Agricultural products storage II. A lecture note. Federal University of Technology Yola. Adamawa State, Nigeria.

Khurmi, R.S. and J.K. Gupta, (2008). Shaft, v – belt and Rope Drives: A Textbook of machine Design. 13th Edition, S. Chad and Co. Ltd. New Delhi, p. 456 – 498, p.657 –659

Nwaigwe, K.N, Nzediegwu C; and Ugwuoke P.E., 2012. Design, construction and performance evaluation of a modified cassava milling machine Research Journal of Applied sciences, Engineering and Technology, 4(18), p. 3354 – 3362

Orhorhoro, E.K., Ikpe, A.E., and Tamuno, R.I., 2016. Performance Analysis of Locally Design Plastic Crushing Machinefor Domestic and Industrial Use in Nigeria. EJERS, European Journal of Engineering Research and Science, 1(2), p.26-30

Paris M.G., 1988. Grinding using mortar and pestle and using wheel mill. Collle point surles technologies, ISBN 2-86-844029-11, p.279