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Design of Cereal Crops Crushing Machine

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Abstract **Original Research Article**

Cereal crops are the major dietary energy supplier in Africa especially in Nigeria. In most Africa countries, cereals supply estimated 80% of the energy requirements. Major categories of cereals produced in Nigeria include rice, sorghum, maize, etc. It is mostly grown in the savannah ecological zone of the country. Processing and storage of the products are the major factors that limit its commercialization in Nigeria. However, crushing of the products to smaller sizes for storage can help for its easy package and preservation, thus this research work. This research work is aimed at designing of cereal crops crushing machine. The machine consists mainly of feed hopper, electric motor, shaft, bearing, V-belt, pulley, etc. Detail design was carried out to know the value of required parameters and components for operation**.** The outcome of the results obtained show that torque of 15.05 Nm, shaft diameter of 20mm, crushing force and power of 650N, and 2hp were required for efficient operation of the machine.
Keywords: Design, cereals, crushing, machine, power, torque.

INTRODUCTION

Cereals belong to the grass family *Poeceace* [1]. It is grown for their fruit, the caryopsis, which have been the most important sources of world's food for the last 10,000 years [2]. Their cultivation and history are traced back to the fertile crescent of Mesopotamia some 10,000 years ago, and this region now include parts of Turkey, Syria, Iraq and Iran [2]. The major cereal crops produced in Nigeria are rice, maize, sorghum, wheat, pearl, millet, sugar cane with rice ranking as the sixth major crop in terms of the land area while sorghum account for 50% of the total cereal production and occupies about 45% of the total land area devoted to cereal production in Nigeria [3]. The role of cereals to modern society is related to its importance as food crop generally consumed throughout the world. In some parts of Asia and Africa, cereals products comprise 80% or more of the average diet, in central and western Europe, as much as 50% and in the United State, between 20-25% [2].

Cereals crops are the major dietary energy suppliers and provide significant amount of protein, minerals (potassium and calcium) and vitamins (vitamin A and C) [4]. Cereals are consumed in a variety of forms, including pastes, noodles, cakes, breads, drinks etc. depending on the ethnic or religious affiliation. However, the processing and preservation of cereal crops required crushing. Crushing is carried out to reduce the sizes of cereals for storage. Also, for easy processing and preservation for future used. The bran, husk, plant parts and other residues (after processing) are useful as animal feeds and in the culture of micro-organism. Wax syrup and gum are extracted from cereals for industrial purposes. Several Nigeria ethnic groups use cereal crops residues for different purposes. More than 70% of the working adult populations in Nigeria are employed in the Agricultural sector directly or indirectly and over 90% of Nigeria's Agricultural output comes from peasant farmers who dwell in the rural areas where 60% of the population live. Majority of these farmers have limited access to modern machinery and equipment and other productive resources are unlikely to have access to pesticides, fertilizers, hybrid seeds and irrigation without some form of public sector intervention [5]. Some of major problems militating cereals commercialization in Nigeria are processing and storage facilities. The rate of growth of Nigeria's food production is 2.5% per annum in recent years, while food demand has been growing at the rate of more than 3.5% per annum due to high rate of population growth of 2.83% [6].

A crushing machine is mainly used to reduce large solid material objects into a smaller volume, or smaller pieces so that it can be efficiently used for the purpose intended to [7]. Crushing can be defined as the process of transferring a force amplified by mechanical

advantage through a material made of molecules that bond together more strongly, and resist deformation more, than those in the material being crushed do [8,9]. The crushing materials selected must possess a better strength and toughness than the materials to be crushed [10]. Crushing machines work by mainly 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 so that its molecules fracture, or change alignment in relation to (deformation), each other [11-13]. In this present research work, a cereal crushing machine was designed.

MATERIALS AND METHODS

The durability, safety and most importantly the performance of a machine depends on the material used. For a better design to be achieve, good materials at possible lowest cost most be used. The machine consists mainly of feed hopper, electric motor, shaft, bearing, V-belt, pulley, etc. The V-belt attached to the pulley to drive the shaft connected to the electric motor. To ensure that a perfect crushing machine with good crushing efficiency and performance is achieve, the power require to crush the cereals, length of V-belt, speed of driver and driven pulley, belt tension, torque transmitted by electric motor, and force require to crush the cereals were all calculated for.

Basic Component of the Machine

The machine is expected to have the following component:

Main Frame

The main frame was designed with angle Iron bar. Strength and rigidity were the main reason for selection of angle Iron bar.

Feed Hopper

The feed hopper is the receptacle through which cereals is admitted into the machine for crushing.

Crushing Chamber

This unit consists of the shaft, crushing blades, perforated mesh, etc.

Electric Motor and Pulley System

An electric motor is used to power the machine. A reduction pulley system is used to transmit power to the crushing chamber at reduced speed and increased torque.

Shafts Design

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is transmitted by some tangential force and the resultant torque (or twisting moment) set up within the shafts permits the power to transferred to various machine or its elements linked up to the shaft. To transfer the power from the shaft, the various members such as pulleys, bearings, etc. are mounted on it.

Bearings

Bearings are precision design used to support the shaft and permit relative motion between the contact surfaces of the members while carrying load.

Speed Reducers

The function of speed reducers is as follow:

- To deliver the power at lower speed to the presser mechanism.
- To transmit power through the machine element that reduces the rotational speed.
- To receiver power from the input source (engine) through a rotating shaft.

Operating Principles of the Crushing Machine

The whole unit is powered by electric motor of 2hp with a speed of 1440rpm. Cereals are fed into the machine through the feed hopper into the crushing chamber. The cereals settle down at the crushing chamber where it makes contact with the crushing blades and the crushing chamber vessel. When the engine is switch on, the shaft is rotated by a V-belt attached to the pulley to drive the shaft impeded with the crushing blades, thus crushing the cereals. The design has been well considered by the authors with the view of addressing the problem of repeated crushing to refine the sizes and texture of the cereals. The driven shaft is also used to drive a speed reducer which in turns is used to drive the shaft that turns the crank.

Design Requirement

Establishing design requirements is one of the most important elements in the design process and this task is normally performed at the same time as the feasibility analysis. The design requirements control the design of the project throughout the design process. The following design requirements were drawn:

- Estimation of power required by the crushing machine (watts)
- Determination of approximate length of the belt (m)
- Determination of load on shaft pulley and belt tensions (N)
- Determination of speed of driver and driven pulley
- Determination of torque transmitted by electric motor
- Determination of force require to crush the cereals
- Selection of bearing for shaft

Design Consideration

The design considerations phase is where you make a list of factors that need to be considered in broad terms. To achieve optimum function for this machine, proper considerations were made to specify and identify some problems which could hindered effective performance of the machines, and effort was

put to identify the factors and constraints as put together.

- Functionality
- Reliability
- Durability
- Materials and labour use
- Simplicity
- Portability and space
- Operational procedure
- Power supplier
- Usability
- Maintenance
- Cost
- Safety

Detailed Design

Design calculation was carried out to know the detailed design of the required parameters and components**.** This phase builds on the already developed concept, aiming to further elaborate each aspect of the project by complete description through solid modeling, mathematical modeling, working drawing as well as specifications.

Determination of Crushing Force

The crushing force of the cereals can be calculated as follow:

$$W = M_T \times g \quad (1)$$

where;

M_T = Total Mass

g = Acceleration due to gravity = 9.81m/sec^2

Determination of Volume of Crushing Chamber

Volume of the crushing chamber is calculated as follows:

$$V_C = V_P - V_{CB} - V_B \quad (2)$$

where

V_C = Volume of crushing chamber

V_P = Volume of truncated pyramid

V_{CB}= Volume occupied by crushing blades

V_B = Volume of bearing housing

Volume of Feed Hopper

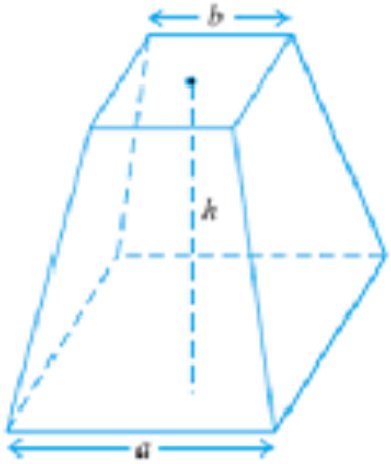

Fig-1: Show the feed hopper with the dimensions

The volume of the feed hopper can be calculated as follows:

$$V_P = \frac{1}{3}(a^2 + ab + b^2)h \quad (3)$$

Volume Occupied by Crushing Blades

The Occupied by the crushing blades is given by Equation (4);

$$V_{CB} = LBH \quad (4)$$

where,

L = Length of crushing blade

H = Height of the blade

B = Breadth of crushing blade

Volume of Bearing Housing

The volume of bearing housing may be determined from the following equation:

$$V_B = \pi r^2 h \quad (5)$$

where,

r = Radius of bearing housing

h = Height of bearing housing

Density of Cereals

The density ρ_C of the cereal is determined as;

$$M_T = \rho_C \times V_C \quad (6)$$

Therefore Density,

$$\rho_C = \frac{M_T}{V_C}$$

Design for Speed Ratio of Belt Drive

Velocity ratio for belt drive is the ratio between the velocity of the driver and the follower (driven). It may be expressed mathematically as:

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad (7)$$

where,
D_1 = diameter of the driver
D_2 = diameter of the driven
That is,
N_1 = speed of the driver
N_2 = speed of the follower

Power Required

$P = FV$ (8)

Where,
P = Power required to turn the shaft
V = Speed
F= Force

$$V = \frac{\pi DN}{60} \quad (9)$$

where,
V= Speed
D= Diameter
N= Speed in revolution per minute
Therefore,

$$P = \frac{Ma\pi DN}{60} \quad (10)$$

A safety factor of 1.5 for optimum performance, reliability and durability was used.

Distance between Driven and Driving Pulley

The centre to centre distance between driver and driven pulley is given as:

$$C = 2D_1 + D_2 \quad (11)$$

Where;
D_1 = Diameter of the driver
D_2 = Diameter of the driving
C= Centre to centre distance between driving pulley and driven pulley

Determination of Belt Length

The belt length can be obtained as follow:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1+D_2}{4C} \quad (12)$$

Determination of Lap Angle

The equation is expressed as follow:

$$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right) \quad (13)$$

Where,
α_1 = Angle of lap for driving pulley (rad)
α_2 = Angle of lap for driven pulley
C = Centre to centre distance between driving pulley and driven pulley
However, for open belt, angle of lap is given as

$$\alpha = 180 - 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right)$$

Determination of Torque

The torque is obtained from the equation as follow:

$T = FR$ (14)

where;
T = Torque
F = Force

Determination of Belt Tension

The belt tension can be calculated as follow:

$$2.3log\left(\frac{T_1}{T_2}\right) = \mu\alpha \quad (15)$$

where,
α = angle of wrap of an open belt
μ= coefficient of friction = 0.4 (Appendix 1)
T_1= Tension in the tight side of the belt
T_2= tension in the slack side of the belt
Also;

$P = (T_1 - T_2)V$ (16)

where,
P = Belt power (watts)
V = Belt speed (m/sec)
T_1 and T_2 are tension on the tight and slack sides respectively (N)

Design of Shaft

$$T_d = \frac{60PK_L}{2\pi N} \quad (17)$$

T_D= Design torque
K_L= Load factor=1.75 for line shaft
Thus, for diameter of shaft

$$d^3 = \frac{16}{\pi S_S}\sqrt{(K_bM)^2 + (K_tT_d)^2} \quad (18)$$

where,
M=Bending moment
For suddenly applied load (heavy shock), the following values are recommended for K_b and K_t
K_b= 2 to 3
K_t= 1.5 to 3
Selecting material of shaft SAE 1030
S_{ut}= 527MPa
S_{yt}=296MPa

$\tau_{max \le 0.30 S_{yt}}$

$\tau_{max \le 0.18 S_{ut}}$

Where,
S_{ut}= Ultimate yield strength

RESULTS AND DISCUSSION

In this present research work, cereals crushing machine was successfully designed (Fig. 2 and Fig. 3). Main analysis and concern about the design considerations, design requirement, and material selection were evaluated. The major components of the machine are; shaft, bearings, feed hopper, pulley, crushing chamber, V-belt, and electric motor. To ensure that an efficient machine was design for performance, the following parameters were designed for; shaft diameter, required force and power, torque, etc. The results obtained from detailed design show that torque of 15.05 Nm, shaft diameter of 20mm, crushing force and power of 650N, and 2hp were required for efficient operation of the machine.

Table-1: Results of Detailed Design

S/N	Parameters	Unit	Calculated Data
1	Required Force	N	650
2	Torque Required	Nm	15.05
3	Power Required	Hp	2
4	Shaft diameter	mm	20

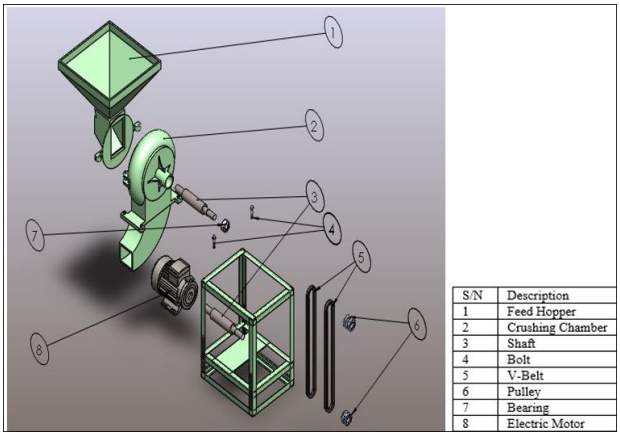

Fig-1: Exploded View of Cereal Crushing Machine

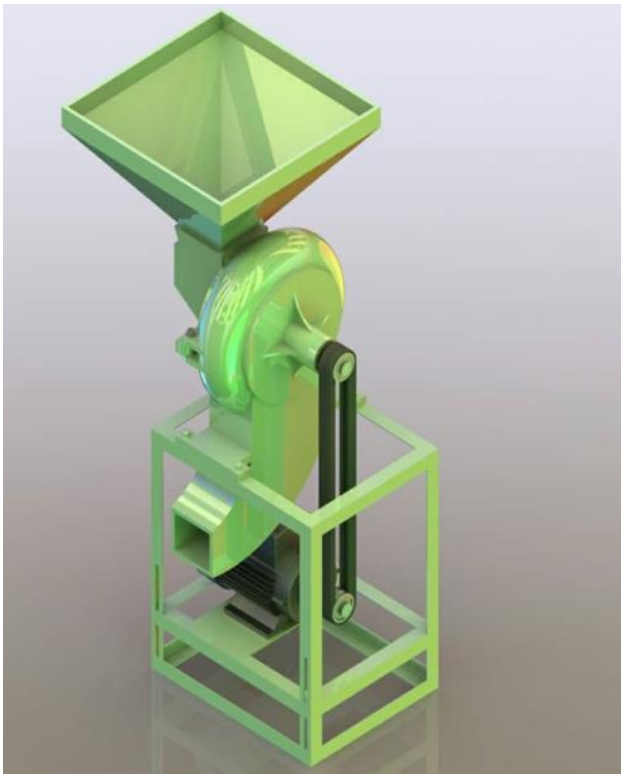

Fig-2: Isometric Model View of Cereal Crushing Machine

CONCLUSION

Cereals are consumed in a variety of forms, including pastes, noodles, cakes, breads, drinks etc. depending on the ethnic or religious affiliation. However, the processing and preservation of cereal crops required crushing. In this research work, cereal crushing machine was successfully design and this was aimed at solving problem of cereal processing and storage. The out of the results obtained reveal that a minimum crushing force and power is required by the machine. For all cereal crops crushing, the conceptual design developed from this model will greatly enhance production speed, product integrity, quality and availability at minimum cost.

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