DESIGN AND FABRICATION OF AN IMPROVED MOTORIZED MAIZE SHELLER/THRESHING MACHINE

ADEWALE SEDARA[1*], EMMANUEL ODEDIRAN[1], SETH MANUWA[1]

Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, The Federal University of Technology, Akure, Nigeria

Abstract: One major essential operation in processing maize is shelling of maize. Maize shelling is one of the most important processing operations carried out in maize processing since it's among the widely consumed grains all over the world. Shelling bring out good quality of maize which not only prolong its useful life, but also increase the net profit farmers make from its mechanization. Component parts such as: frame, hopper, transmission shaft, cylinder with spikes and blower, concave with sieve, power source, pulley and bearings was designed and fabricated. It can be moved to where it's needed this would encourage farmers to shell their maize grains on the farm.

Keywords: maize grain, fabrication, shelling, motorized

1. INTRODUCTION

Maize (*Zea mays* L.) is among the main cereal grains grown worldwide in a wider range of environments because of its greater adaptability [1]. It is mainly for food source and now has become the most key raw material for animal feed [2]. Corn, popularly known as maize is a major staple food in the globe. It is the third largest cereal produced in the world [3]. It is, after wheat and rice cereal grain in the world. Nigeria is currently the tenth largest producer of maize in the world, and the largest maize producer in Africa [4]. It is estimated that seventy percent of farmers are smallholders accounting for 90 percent of total farm output [5].

Maize crop started as a subsistence crop in Nigeria and has gradually risen to a commercial crop on which many agro-based industries depend on as raw materials [6]. Maize is most productive in the middle and Northern belts of Nigeria, where sunshine is adequate and rainfall is moderate [7]. Maize shelling by hand and simple tools are difficult but also consumes time and energy. Even the existing motorized maize shellers, apart from the fact that they are costly to purchase or hire, they inflict great damage on maize grains during shelling process. The specific objectives of this research are to design and fabricate a motorized maize sheller.

Most sheller used abrasion between a rotating shelling disc and stationary concave compartment to achieve the stripping as reported by [8]. According to [9] the traditional method of maize dehusking was done manually with hand and shelling was done either by beating the dehusked cob of maize with sticks, finger, sickle, etc. This concept of a technology is more appropriate to the needs of developing countries and it's applied equally well to agricultural mechanization. This incurred the cost of transportation between farms to machine industry thereby increase the cost of production.

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2. METHODOLOGY

2.1. Principles of operation

The shelling is accomplished by the shearing by the rotating spikes mounted on the cylinder, which force out the grains from cobs holding them. Different grain crops and varieties have varying characteristics, which require different speeds for achieving the best result of shelling, therefore adjustment of cylinder speed and proper feeding of cobs is essential.

2.2. Design consideration

The following was considered for the machine.

2.2.1. Stability

This factor is a major focus point for improvement in the machine. This is the ability to remain stable and rigid during the shelling operation. The design prototype was put into consideration for balancing the weight of the entire machine. Also, the shelling force must be balance with the sheller.

2.2.2. Sortability

This is another factor in focus upon which improvement was made. It is the ability to separate maize grains into aggregates after shelling process inside the shelling chamber. The whole maize seeds or kernels flow out through the shelled grains outlet while the maize comb or residual shafts simultaneously flow out through another outlet, thereby sorting the aggregates separately.

2.2.3. Transportability

The ability to be moved is a very important factor, since farmer may have farms in different locations. Also, if it is used for commercial purpose, it would be easy to transport from farm to farm. The design therefore gives room for transportability.

2.2.4. Durability

The choice of materials for the machine parts are such that will last longer before replacement of parts begins to be demanded as a result stress and wears undergo from time to time.

2.2.5. Affordability

The machine is fabricated with readily available materials in the locality; thereby no need to settle for highly expensive imported materials that could raise the cost of production of the machine, hence make it unaffordable to farmers.

2.2.6. Strength

Before any construction work could be done on any machine, the behavior of stress action on the machine parts should depend on the load that machine is to carry and this is very essential. The strength solely depends on the materials used in the construction.

2.2.7. Weight

To determine the average weight of cobs was randomly picked and each of their weights was recorded and also cobs without seed (husks) was also weighed with weighing balance.

2.2.8. Moisture content

Grain water content should be reduced to 14% or less. It is therefore important to measure before shelling. Moisture increases the deformability of a grain resulting in damage. Hence, more energy is required to break a grain with adequate moisture content than the one with low moisture content.

2.2.9. Strength of grain

Grain hardness is an important property of grains and is of interest to both producers and consumers of grains. Cutting and cracking of grains provides breakage evaluation and consequently threshing efficiency.

2.2.10. Shape and size

These are closely related to physical factors of threshing efficiency in that they influence the shelling capacity and grain loss through sieves. A uniform size distribution enhances the effective uniform concave and separation by sieves.

2.2.11. Density and specific gravity
These factors are important in the separation or cleaning of grains from waste materials (chaff). It determines draft from a blower necessary for an effective cleaning process and grain loss.

2.2.12. Variety of crop
Crop variety affects the threshing efficiency in that the differences in grain length, grain size distribution along the ear, kernel and distance between grain rows might impair a uniform clearance in a sheller/thresher.

2.3. Conceptual design
Figures 1-2 shows the machine designed using AutoCAD 16.

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PROJECT TITLE:DEVELOPMENT OF A MAIZE SHELLER MACHINE

Items	DESCRIPTION	QTY	DIMENSION(cm)	Items	DESCRIPTION	QTY	DIMENSION(cm)
1	HOPPER	1	46x24	10	CONCAVE SIEVE	1	77x30
2	HINGE	2	0.5	11	BELT	1	
3	SHAFT	1	25	12	COB OUTLET	1	14x19
4	FLAT PLATE(FAN)	4	7x15	13	ENGINE SEAT	1	1.5kW
5	BEATERS	20	3x0.7	14	COVERER	1	77x32
6	BLOWER CASING	1	52x15	15	THROAT	1	42x18
7	CLEAN GRAIN OUTLET	1	15x26	16	PULLEY	2	
8	FRAME	1	86x30x19	17	DIESEL ENGINE	1	2hp
9	BEARING	2		18	STOPPER	1	17x25

DRAWN: ODEDIRAN   CHECKED: PROF. S. I. MANUWA
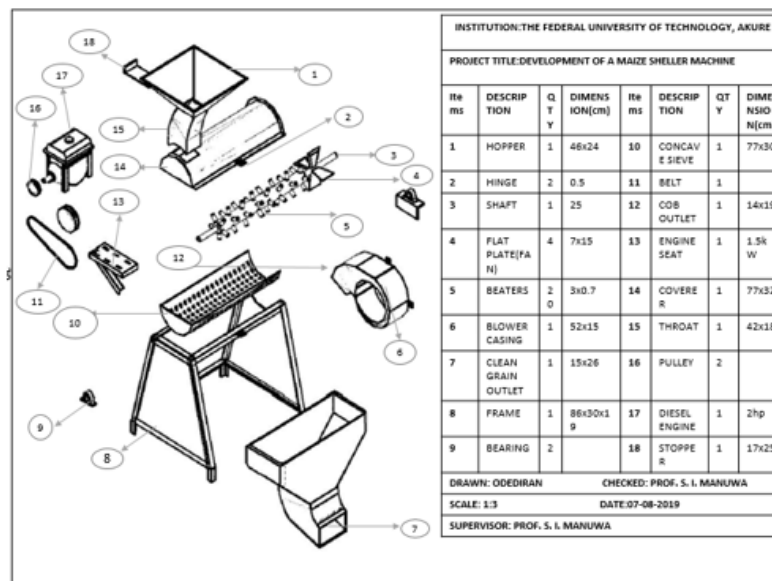SCALE: 1:3   DATE:07-08-2019
SUPERVISOR: PROF. S. I. MANUWA
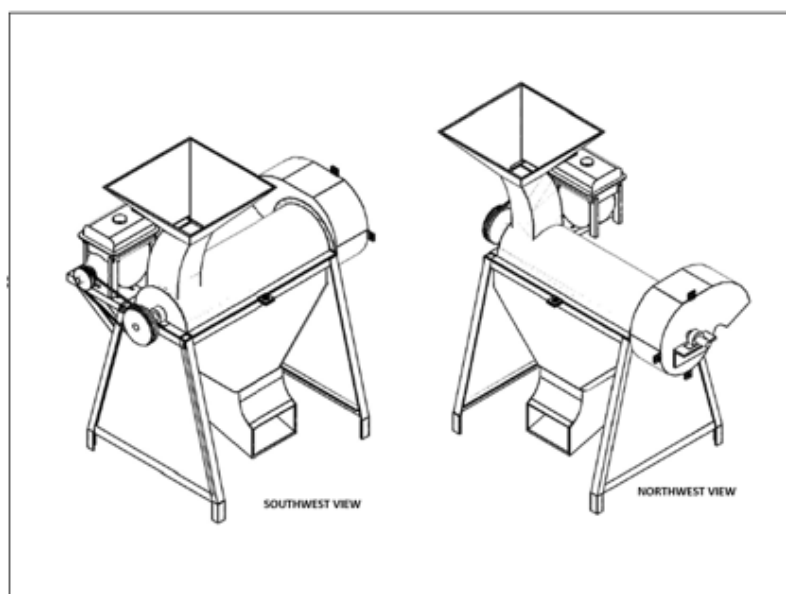
Fig. 1. Exploded view of motorized maize sheller.

Fig. 2. Isometric view of motorized maize sheller.

2.3.1. Design analysis and calculations

Machine component parts are subjected to external forces such as torque, friction, inertial forces, internal forces (as a result of temperature difference), pressure and both normal and shear stresses. Machine components should be able to withstand these forces so as not to fail. To design such a machine as to be capable of withstanding these forces, proper sizing and careful selection of materials for the various component parts is required.

The design analysis was carried out to evaluate the necessary design parameters, strength and size of materials. The design of various component parts of shelling unit is governed by physical properties, mechanical properties and engineering properties of maize. Others are the mechanism of rotating shaft over the concave at a specific clearance for the downward movement of the shelled grains.

The following are the design analysis and calculations for major component parts.

2.3.2. Hopper

Hopper design is founded upon a common criterion for it to function. The criterion is known as the "angle of repose". This type of hopper is a gravity discharge one and the recommended angle for agricultural materials is 80 or more and maize repose angle is 270 [10]. The hopper was designed to be a frustum, trapezoidal in shape and has the following dimensions that were chosen based on proportionality and aesthetics. The larger part is a square of 465 mm by 465 mm while the smaller part is also 108 mm by 108 mm with height of 235 mm. To the vertical is 490 which is the measured angle of friction of maize. The minimum angle of inclination was calculated to be 850. Hence, since 490 is greater than the repose angle of maize plus 80; the hopper will do the required job. The volumetric and gravimetric capacities of the hopper were determined. The volumetric capacity of the hopper, Vh was determined from the equation (1) by [11].

$$V_h = \frac{h}{3} \cdot \left(A_1 + A_2 + \sqrt{A_1 A_2} \right) \tag{1}$$

where A_1 are area of the hopper top = 0.216 m^2, A_2 are area of the hopper bottom = 0.0117 m^2, h are hopper height = 0.235 m.

Therefore: V_h = 0.04749 m^3.

The gravimetric capacity of the hopper, G_h is related to the volumetric capacity of the hopper, V_h using the equation (2).

$$G_h = \rho V_h \tag{2}$$

where ρ are maize density = 415 kg/m^3, V_h are volume of hopper = 0.04749 m^3.

$$G_h = 19.7 \text{ kg} = 193.26 \text{ N}$$

2.3.3. Design of shaft

It is a cylindrical solid rod for transmitting motion through a set of load carried on it. The shaft uses for the threshing is loaded by spikes, bearings, pulley, fan and belt tension. The design is based on fluctuating torque, bending moment and shearing force (Figure 3). For proper designing there is need to determine the shaft diameter, equation (3) was adopted:

$$d^3 = \frac{16}{\pi \delta sy} \left[(K_b M_b)^2 + (K_t M_t)^2 \right]^{\frac{1}{2}} \tag{3}$$

where d are diameter of shaft (mm), Kb are bending moment fatigue and shock, Kt are fatigue and combined factor for torsional moment, Mb are resultant bending moment (Nm), Mt are resultant torsional moment (Nm), δsy are allowable bending stress (MN m^{-2}), π are constant, 3.142.
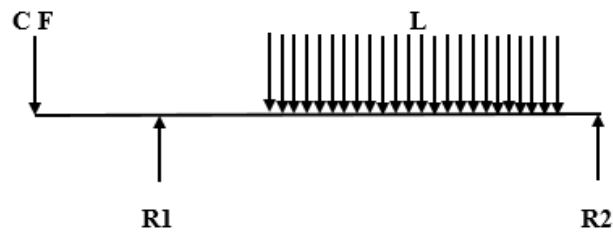
Fig. 3. Representation of the forces: CF – centrifugal force due to flywheel load (N); L – force due to load exerted by cobs of maize and the spikes on the cylinder (N); R1 and R2 – reactions from the two bearings (N).

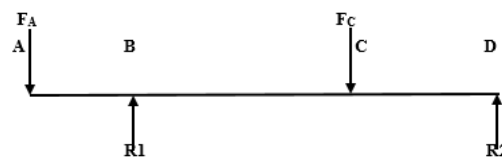The uniformly distributed loads (Figure 4) are turned into a point load.

Fig. 4. Representation of loads.

Calculations:

$$\text{Weight of pulley} = 2.3\text{kg}$$

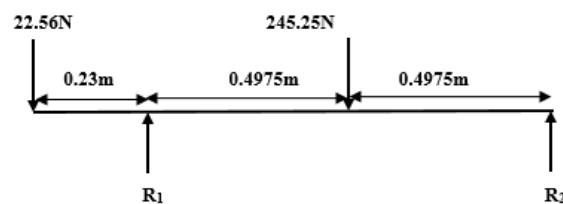$$F_A = 2.3\text{kg} \times 9.81 = 22.56\text{N}$$

Fig. 5. Reactions at point 1 and 2.

Taking moment about R_1 (Figure 5):

$$-22.56\text{N} \times 0.23\text{m} - R_2 \times 0.995\text{m} + 245.25\text{N} \times 0.4975\text{m} = 0$$

$$-5.1888\text{Nm} - 0.995R_2 + 122.011875\text{Nm} = 0$$

$$-0.995R_2 + 122.011875\text{Nm} - 5.1888\text{Nm} = 0$$

$$-0.995R_2 + 116.823075 = 0$$

$$-0.995R_2 = -116.823075$$

$$R_2 = \frac{-116.823075}{-0.995} = 117.41 \text{ N}$$

$$R_2 = 117.41\text{N}$$

$$\text{But, } R_1 + R_2 = 22.56\text{N} + 245.25 \text{ N}$$

$$R_1 + 117.41\text{N} = 267.81 \text{ N}$$

$$R_1 = 267.81 - 117.41 = R_1 = 150.40 \text{ N}$$

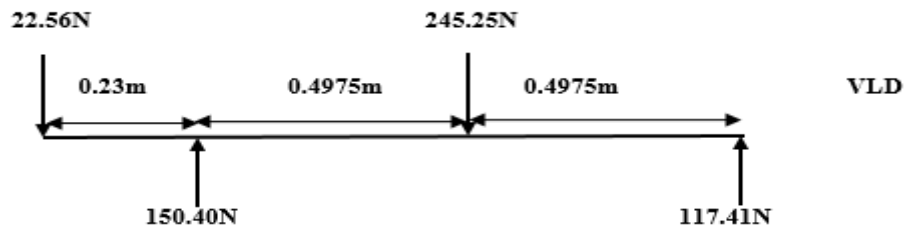Figure 6 present vertical loading diagram.

Fig. 6. Vertical loading diagram.
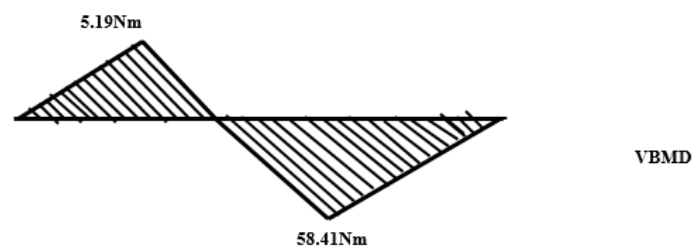
Figure 7 present vertical bending moment diagram.

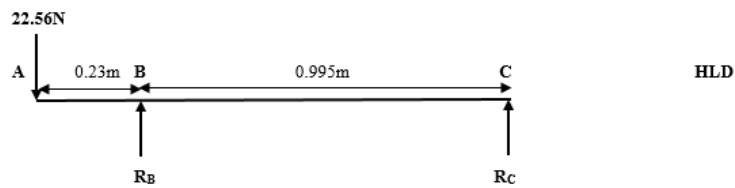Fig. 7. Vertical bending moment diagram.

Fig. 8. Horizontal loading diagram.

From Figure 8, taking moment about R_B:

$$0 = 22.56N \times 0.23m + R_C \times 0.995m; \quad 0 = 5.1888 + 0.995R_C$$

$$R_C = \frac{-5.1888}{0.995}$$

$$R_C = -5.21N$$

$$R_B + R_C = 22.56N; \quad R_B - 5.21N = 22.56N; \quad R_B = 27.77\ N$$

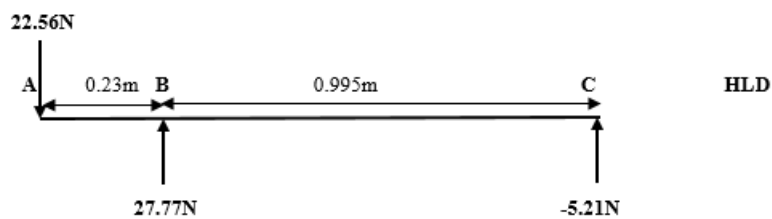Figures 9 and 10 present horizontal loading force diagram and horizontal bending moment diagram.

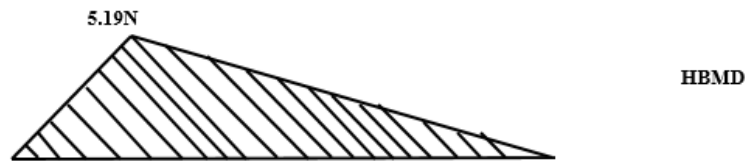Fig. 9. Horizontal loading force diagram.

Fig. 10. Horizontal bending moment diagram.

At A, MBH =0

At B, when x = 0.23 m

MBH = 22.56 x 0.23 = 5.1888 = 5.2 Nm

At C, when x = 1.225 m

MBH = (22.56 x 1.225) – (27.77 x 0.995) = (27.636 - 26.775) Nm

MBH = 0.861 Nm

Calculation of torsional moment:

$$Mt = \frac{p}{2\pi N} \tag{4}$$

where Mt are torsional moment (Nm), P are power (watts), N are speed (rev/m).

$$Mt = \frac{1492}{2x\Pi x\frac{2500}{60}} \quad = \frac{1492}{261.8} = 5.7 \text{ Nm}$$

Calculation of maximum bending moment:

$$Mb = \sqrt{(MBV)^2 - (MBH)^2} \tag{5}$$

where Mb are maximum bending moment (Nm), MBV are maximum vertical bending moment (Nm), MBH are maximum horizontal bending moments (Nm).

Therefore:

$$Mb = \sqrt{(58.41)^2 - (5.19)^2} \quad = \sqrt{3411.7281 - 26.9361} = \sqrt{3384.792}$$

Mb = 58.18 Nm.

2.3.3.1. Determination of shaft diameter
The required diameter for a solid shaft is calculated using equation (3) [12].

Assumption:

$$\delta s = 47 \text{ x } 10^6 \text{ N/m}$$

$$Kt = Kb = 1.5$$

$$d^3 = \frac{16}{\pi \delta s} \sqrt{(kbmb)^2 + (ktmt)^2}$$

$$d^3 = \frac{16}{\pi x47x10^6} \sqrt{(1.5x58.18)^2 + (1.5x5.7)^2}$$

$$d^3 = \frac{16}{\pi x47x10^6} x87.69$$

$$d^3 = \frac{1403.04}{\pi x 47 x 10^6}; \quad d^3 = 9.5 \text{ X } 10^{-6}$$

$$d \quad = 0.0212 \text{ m} = 21.2 \text{ mm}$$

Therefore, a 25 mm diameter shaft was selected.

2.3.3.2. Design of shelling cylinder
The number of spikes on the shelling cylinder is given by equation (6):

$$Np = \frac{L_c}{S_{sr}} x \frac{\pi d}{S_{sc}} \tag{6}$$

where Np are shelling cylinder spikes, Lc are length of shelling cylinder = 750 mm, Ssr are spike spacing on row = 90 mm, Ssc are spike spacing on circle = 75 mm, d is shelling cylinder diameter =80 mm.

Therefore Np = 28.

The total number of spikes on the shelling cylinder, Np = 28.

2.3.3.3. Determination of pulley or flywheel diameter of cylinder shaft
The diameter, D_2 is given by the formula:

$$D_2 = \frac{N_1 D_1}{N_2} \tag{7}$$

where N_1 are petrol engine motor speed = 1440 rpm, D_1 are petrol engine pulley diameter = 80 mm, D_2 are diameter of driven pulley = 170 mm, N_2 are shelling speed = 551 rpm, $N_2 = \frac{N_1 D_1}{D_2}$; N $_2$ = 551 rpm.

Pulley diameter of blower shaft is kept constant to get the constant blowing speed as calculated using equation (7):

$$N_2 = \frac{N_1 D_1}{D_2}$$

2.3.3.4. Design of perforated concave screen
Total area of sieve:

$$A = \frac{2\pi L}{2} = \pi r L \tag{8}$$

where r = 112.5 mm, L = 765 mm and A = 270408.375 mm² or 0.27 m², Diameter of each hole = 15 mm, area of each hole in a column (circular).

$$A = \pi r L$$

where r = 7.5 mm and A = 176.74 mm² = 1.767375 x 10⁻⁴ m ²

Total numbers of column = 20

Total area of column = 20×1.327×10² = 2.65×10³ mm²

Area of sieve under stress = Total area of sieve - minus total area of column

Area of sieve under stress = 0.29− 2.65×10³ = 307000 mm² or 0.307 m²

Area of sieve A = 307000 mm² or 0.307 m²

Fg = 0.319 N

$$\text{Stress on sieve} = 1.039 \text{ N/m}^2$$

2.4. Materials selection

2.4.1. V-belt selection
Belt depends on power to be transmitted at a required tension. The equation (9):

$$P = (T_1 - T_2) V \tag{9}$$

where P are the power in (watt), T_1 are the belt tension in tight side (μ), T_2 are the belt tension in loose side (μ), V are the belt speed (m/s) $= \frac{D\Pi N}{60}$, smaller pulley diameter are D (m), N are the belt speed (m/s)

2.4.2. Length of belt
Here, the belt was considered as an open drive. This type of belt drive was employed when the two parallel shafts have to rotate. Belt length was obtained by using equation (10).

$$L = \frac{2C + \frac{\pi}{2}x(d_1 + d_2) + (d_1 + d_2)^2}{4C} \tag{10}$$

where C are length of central distance (cm), putting the values of d_1 and d_2.

Therefore, L= 1.732 m

2.4.3. Bearing selection and location
The bearing is selected based on the load carrying capacity, life expectancy, and reliability. The shelling force is either by impact loading as seen in cylindrical beaters, or shearing force as seen in hand-threshing.

2.4.4. Power source and Horsepower requirement of motorized maize sheller
According to [13], the power delivered by a shaft is given by equation (11):

$$P = F \times V \tag{11}$$

where P are power (Nms^{-1}), F are force of shelling (N), V are velocity (m/s).

Force required to thresh the maize is given by:

$$F = m\omega^2 r \tag{12}$$

where F are force required to thresh maize, m is mass of threshing bars, ω are angular velocity of shaft, r is shaft radius.

The angular velocity ω is determined by the equation:

$$\omega = \frac{2N}{60} \tag{13}$$

where N are threshing speed which is in revolutions per minute.

The power delivered is given by:

$$P = F\omega r \text{ or } P = Fv \tag{14}$$

Appropriate power of motor is determined or selected when the total power requirement for shelling is determined at an appropriate shelling speed. According to [14], the threshing speed that will give very low mechanical damage, but high threshing output is within the range of 300 - 650 revolutions per minute.

The relationship between speed and torque of the prime mover is given by equation (14):

$$N_1 T_1 = N_2 T_2 \tag{15}$$

The Torque developed is given by the relation:

$$T = F \times r \tag{16}$$

2.4.5. Power requirement
As the torque transmitted by the shaft was known, the horsepower was calculated by using equation (17):

$$HP = \frac{2\pi NT}{4500} \qquad \text{or} \qquad P = \frac{2\pi NT}{4500} \text{ [HP]} \tag{17}$$

where P are power [HP], N are speed (rpm) = 956 rpm, T are torque (kg m) = 1.18 kg m= 1.5753 HP (1.1747 kW).

Therefore, actual horsepower required was 1.5753 HP. The calculated horsepower was 1.5753 HP; the motor efficiency and belt efficiency were calculated as 70% and 75%, respectively. The recommended horsepower of machine was calculated by using the formula:

$$\text{Required HP} = \frac{\text{actual hp}}{\text{motor efficiency} \times \text{belt efficiency}} \tag{18}$$

The horsepower of machine was 2 HP.

2.5. Description and working principle
The machine is to be powered from the petrol engine mounted. The power supply moves through the belt connecting rotary pulleys. The same pulley gives rotation to the shelling cylinder located in the shelling chamber. Motion of the pulleys provide the discs velocity which pull and shell by friction and shearing action against the spikes of iron rod projected on the shelling drum. The empty cobs will pass out through the cobs outlet opening directed from the blower chamber and are thrown out by rotation of the blower blades as well as the air generated by the blower, while the dust and chaff are blown off by blower located near the shelling cylinder. The maize grains pass through the concave screen or sieve and then to the grain outlet chute from where clean maize grains are collected.

3. RESULTS AND DISCUSSION

Hopper design
The hopper of the sheller was fabricated in trapezoidal shape using mild steel sheet of 2 mm thickness. It is of dimension 465×465 mm at the top and 108×108 mm at the bottom. It designed as to aid conveyance, reduce the labour of constant feed and allows for continuous feeding.

Transmission shaft
This is a rod of 30 mm diameter, machined to 25 mm diameter and was used as shaft. The operations carried out was mainly facing and turning it was held between centers on the lathe machine.

Shelling cylinder
An I.S steel of 65 mm x 750 mm rotated along the cylinder and separated grains from the cobs. However, cylinders with beaters are easy for manufacturing and are economical.

Blower casing
Steel plate of 2.5 mm thickness was used instead of wood and a thin sheet casing.

Concave screen
The concave steel plate of 6 mm thickness. The length of concave was 750 mm with slotted holes 10 mm diameter by considering average dimensions.

Outer cover
Sheet of diameter 18 cm, incorporated with the hopper and was hinged and bolted to give protection to the cylinder and avoid grains spilling out. A hinge joint attached and bolt was to facilitate cleaning of inner cylinder.

Rotor Shaft
Key components of the sheller was the rotor shaft; other parts such as flats of cylinders, blower and bearings were mounted. The standard size and length were selected considering the shaft design. The pulley was attached to give drive to shaft from motor.

Outlet
The outlet for separated grains was made at the bottom of the shelling cylinder. A metal sheet was used to collect grains without being shattered outside.

Frame
The whole sheller dimension was 77 cm x 42.5 cm x 128 cm.

Cob outlet
The concave screen was inclined to $5\text{-}10^0$ to allow the shelled cobs to flow easily to the blower compartment from where it is blown through the outlet.

Power supply
The power supply to the machine is sourced from 2hp petrol engine. This is in conformation to the calculated required energy to run the machine. The rotational energy dissipated by the engine is transmitted through the belt and consequently to the shelling drum.

3.1. Machine Testing
The motorized maize sheller was tested for a variety for one (1) minutes and four trails were recorded. The highest throughput capacity of the sheller was 701.42 kg/h at 2 kg/h feed rate; the highest shelling rate obtained was 630.32 kg/h with feed rate of 120 kg/h and it was observed that the highest machine efficiency obtained was 94.98%.

4. CONCLUSIONS

Since most maize shelling and threshing are done manually, this has proven to be stressful and not effective, therefore there is a need to improve the technology used in shelling maize. A motorized maize sheller machine has been designed and fabricated with locally available materials. The machine was powered with a diesel engine with design considerations to make the machine affordable and efficient. The machine was tested and found to satisfactory to shell maize with throughput capacity of 701.42 kg/h, shelling rate of 630.32 kg/h and machine efficiency of 94.98%. The machine designed if adopted by fabricators and commercial farmers can improve productivity and reduce post-harvest losses.

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