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Original Research Article

# Design and construction of a wood-based modified yam pounder machine



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## ABSTRACT

This study focused on the design and construction of a wood-based modified yam pounder machine. The high cost of producing yam pounder machine using stainless steel and other metals poses great challenges in terms of efficiency and affordability. In this study, a yam pounder was produced from hardwood obtained from Oak tree which is a locally sourced material with a view to eliminating the tedious and laborious process of preparing pounded yam. The hardwood log of 220 mm long was turned to a diameter of 240 mm using wood lathe machine. Other components were machined to their appropriate sizes based on designed specification before assembling. The designed yam pounder was used to pound 1.034 kg of cooked white yam for three minutes; the same were carried out with the existing yam pounder for three minutes under the same condition. The results obtained from performance tests showed that there was no yam seed from the designed yam pounder but there were few yam seeds in the existing yam pounder. This showed that the designed yam pounder pounds better than the existing one.

*Keywords:* Design and construction; Hardwood; Wood lathe machine, Yam pounder machine

## 1. Introduction

Pounders are machines or devices which apply either torque or reciprocating force on a piece of solid nature for the purpose of changing its form from solid to a semi solid state or paste. Presently, there are two modes of pounding: Rotary (torque) pounding, Impact (reciprocating) pounding. This mode reciprocates in its operation. The mortar and pestle mode of pounding is classified under this mode [1]. The rotary mode of pounding involves the crushing of the boiled yam through the torque rotary force produced from a bowl via pulley and shaft connected to the blade. It is on this principle that the design of this machine and other existing yam pounders are based. Pounded yam is a smooth dough of smashed yam often eaten with a vegetable and fish or meat stew (egusi or ogbonor or Edikaekon or banga soup) [1]. It is a very popular African food especially in the Middle Belt, Eastern and southern Nigeria. It is a highly prestigious meal in these parts of the country. Presenting a dish of pounded yam and ogbonor soup to visitors in Edo land in Nigeria for example is considered a great act of hospitality.

Yam is one of the major staple foods in Nigeria and it is consumed in so many forms apart from being pounded [2], it can be boiled, fried, roasted and eaten as porridge. The various ethnic groups in Nigeria have their unique method of processing yam, the Yorubas process the yam into powdered (dehydrated yam flour) either by sun drying or commercially using desiccating machines [2]. The act of pounding yam has been in existence for a very long time though it is very tedious due to the energy required to produce the smooth texture needed. Traditionally, pounded yam is made by boiling yams in a pot and once cooked; it is placed in a mortar and manually pounded or beaten into a smooth textured dough with a pestle. Until the last few years, the only means of pounding yam was the use of mortar and pestle which is

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quiet strenuous especially when a large number of people have to be served with pounded yam. The noise made by manual method of pounding yam can be unpleasant in a home and house that accommodate several families. Besides the frequent accident that occurs during pounding, it is also not hygienic as a result of the sweat that drops into the yam while pounding [3].

The development of pounding machines has helped to replace human effort in the pounding process. The yam pounding machines have been designed and constructed to ease the preparation of pounded yam. This helps to eliminate the stresses arising from the manual method of using mortar and pestle. So many machines have been designed and fabricated by foreign and local firms, to improve on the condition of pounding [4]. The foreign ones are not readily available because they are expensive. The high cost of production and maintenance are factors that affect the fabrication of yam pounding machines. Having put all these factors into consideration, the need then arose to design a yam pounding machine based on the use of locally sourced raw materials which are readily available and inexpensive. One material which meets these conditions is wood. These woods have high tensile strength, decay resistance and resistance to corrosion and insect attack. Yam pounder have been developed to enhance the hygienic processing of yam for both domestic and commercial consumption, while eliminating the tedious and laborious indigenous process of preparing pounded yam [5]. The cost of yam pounders varies from 80,000 naira to 250,000 naira. Most of this cost is associated with the cost of electric motors, structural materials and machine elements. The structural materials are usually made of stainless steel, aluminum or plastic. The pounding bowl is a critical element. Most local fabricators adopt stainless steel pots obtained from the open market. Others use cast aluminum pots, local use of plastics is not common as the process of production requiring a special mould will make the cost prohibitive [6]. It is known that the traditional method of pounded yam production is by the use of mortar and pestle made of wood. It therefore calls to reason that the pounding bowls and other structural parts of a yam pounder would be made of wood, which is readily available and relatively inexpensive [7]. The problem of this research is to determine the feasibility of using wood as the pounding bowl of yam pounder.

The aim of this project is to design and construct a yam pounder machine in which the pounding bowl and other structural parts are made of wood as much as possible.

## 2. Materials and Method

### 2.1. Market survey

This is carried out by using a questionnaire (Appendix A). A questionnaire was designed to find out the interest rate of people on the use of yam pounders. It was carried out with respondents randomly chosen from homes, restaurants and hotels in Ikpoba Okha and Oredo Local Government Area of Edo State.

The existing project was also considered with the following factors in view.

- Availability of parts and materials
- Reliability of existing pounders
- Maintenance cost required
- Market requirement and desirability of the machine.

With the above in mind, a specification was then arrived at which guided the design of a yam pounder. Based on the design, appropriate materials and parts for various components of the machine were selected [8, 9].

### 2.2. Selection of materials

The materials for this design were selected while taking into consideration the following factors

i. Strength and rigidity, whether such material have enough strength or is rigid enough to withstand bending or twist.
ii. Resistance to fatigue and variable loading
iii. Resistance to wear and corrosion in components exposed to contact-shading or rotating and atmospheric air.

Materials with low friction coefficient.

### 2.3. Design

This study helps to redress the short comings in the existing yam pounders, and introduce new methods of delivering enough energy to pound in the bowl. This was achieved by introducing a wooden bowl and a large speed reduction pulley into the pounding machine. The result is a better texture of pounded yam.

### 2.4. Construction

The yam pounding machine was constructed using the appropriate materials. Hardwood (Oak) was used in making the pounding bowl. The blades or beaters are made of stainless steel and are horizontally fixed to the shaft at right angle to each other in the bowl. The lower blade is pitched while the upper one is flat. The upper blades crushed the cooked yam and also protect the yam from falling off from the pounding chamber, while the twisting action which breaks the yam grains was achieved by the lower blade [10].

#### 2.4.1. Major components

The major components of this machine includes: The shaft, the bearing, the pulleys, the belt, frame, body casing, pounding bowl, yam beater (kneader) [11].

### 2.5. Purchased items

These are components bought and they form parts of the machine. They are electric motor, bearings, pulley-belt, plywood, cover disc and angle iron.

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**2.5.1. Body casing**
The body casing of the machine measured 665 mm x 430 mm x 430 mm is made of plywood fitted to the angle iron with the help of screws.

**2.5.2. Angle iron**
The inside body frame is made of angle iron measured 665 mm x 40 mm x 2 mm; 430 mm x 40 mm x 2 m and 430 mm x 40 mm x 2 mm respectively. The electric motor is fitted to the body frame with the help of bolts and nuts.

**2.5.3. Electric motor**
The electric motor of one (1) horse power was also purchased. It is the prime mover that provides the motion that is transmitted to the beaters.

**2.5.4. Bearings**
Two sealed SKF deep groove bearings were also purchased and fitted on the shaft covered by the bearing housing.

**2.6. Components designed**

**2.6.1. Pounding bowl**
The bowl was made by cutting a fully seasoned hardwood log (oak red) 220 mm long. The bark was removed, its top and bottom was cut nice and level. A knife was used to make-a small depression in the center of the top surface [9, 12]. Hot coals were then placed on this depression to burn the wood. The coals were kept blowing until a good depressive level was achieved. After that, the wood was then taken to a wood lathe machine to increase the bowl diameter to 240 mm and also to carry out other surface finishing operations.

**2.6.2. Shaft**
A shaft of 300 mm long was machined to the specified diameters. The first shaft was machined to a diameter of 30 mm where the first bearing is fixed. The next one is the pulley diameter of 28 mm followed by the second bearing diameter of 30 mm, the next diameter is the part of the shaft occupied by the thickness of the wooden bowl at the base. The next is the pitched kneader diameter of 28 mm which is then followed by another diameter of 25 mm between the pitched kneader and the flat kneader where the flat kneader has a diameter of 23 mm.

**2.6.3. Yam beaters**
A stainless steel pipe of internal diameter of 25 mm and thickness of 10 mm and height 30 mm was cut. A flat bar made of stainless steel 40 mm wide and 110 mm long was also cut, filed and machined to achieve flatness. This flat bar was welded to both sides of the pipe to form the yam beater or blade.

**2.6.4. Base Plate**
A mild steel plate material measured 350 x 330 x 5 mm was cut and a hole of 80 mm diameter was bore at the center of the plate where the wooden bowl base is fixed or rest on.

**2.6.5. Assembly**
The cover disc holds the bearing housing and the wooden bowl firmly with the help of bolts and nuts. The wooden bowl was made to rest on the center hole of the base plate. The shaft is then passed through the bearing housing into the bowl. The pulley is then fixed to the shaft with the help of a key which hold it firmly. The pulley is connected to the electric motor pulley via a V-belt. The electric motor is fixed to the body frame in such a way that the motor pulley and pulley maintain horizontal alignment. The machine is then covered with plywood which is bolted to the body frame. The Yam beaters are attached to the shaft which can also be detached easily.

**2.6.6. Working principle**
The start-up motion is instituted by an electric motor plug to the electricity supply. The power is transmitted via a v-belt to a pulley attached or fixed to the rotary shaft. The shaft then transmits the power to the blades or yam beaters in the bowl which perform the pounding process [9, 13].

**2.7. Parts and assembly drawings**
The assembly drawing of the designed and fabricated machine is shown in Appendix B. The parts lists are shown in appendix C and D. The orthographic projection is shown in appendix E while the exploded drawing in Appendix F. The parts drawings are in appendix G and H.

**2.8. Performance test**
The materials used for the performance test are white yam, water, while the equipment were knife, weighing balance, cooking pot, stopwatch and a pounding machine.

The following procedure was used in carrying out the test at the end of the fabrication of the machine.

A performance test was carried out on the designed and the existing pounder. The existing pounder was used to pound 1.043 kg of cooked white yam for three minutes. The designed machine was also used to pound the same 1.043 kg of white cooked yam for the same three minutes under the same condition.

A quantity of the pounded yam from the existing pounder was measured out into a ø50 mm x 50 mm high container and leveled out.

The procedure was repeated by measuring the same quantity of pounded yam from the designed machine into the same container.

Fifteen persons were asked to rate the texture of the two sample pounded yams.

## 3. Results and Discussion

### 3.1. The modified yam pounder machine design calculation

The design of this yam pounder intends to produce a pounded yam which could be comparable to that produced by using mortar and pestle [14]. This is achieved by using a hardwood (oak red) to make the pounding bowl and the use of a large speed reduction pulley. The kneaders or beaters are horizontally looped, radially fitted to the propelling shaft.

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The lower shaft bears the pitched kneader while the flat blade or kneader is fixed to the upper shaft in the wooden bowl. Wooden bowl just like the native mortar was chosen to make the pounded yam more natural. The wood is cheap and readily available. The machine has the following specifications power input = 220 volts.
The speed of the machine = 290 rpm
Volume of the wooden bowl = 5600571.43 $mm^3$
Height of the wooden bowl = 220 mm.

**3.1.1. Yam beaters**

Let the two kneader or blades be represented by A and B.

Forces acting on blade A, $N_1 = P \times A_1$ (1)

$F_1 = \mu N_1$ (2)

where,
N = Normal force, P = Pressure to crush yam = $18x10^4$ $Nm^{-2}$
A = Area of the blade edges; 1, 2 are points of action,
Coefficient of Friction, μ=1.1
Width of blade A =40 mm and thickness = 8 mm
At point 1, $A_1 = 0.8x4.0x10^{-4} m^2$
From Equation 1, $N_1$ = 57.6 N
From Equation 2, $F_1$ = 63.36 N
At point 2, $A_2 = 0.8x4.0x10^{-4} m^2$
$N_2$ =57.6 N, $F_2$ = 63.36 N
For yam beater B with the blades in transverse position relative to blade A,
Width of blade B = 40 mm thickness =9 mm
At point 3, $A_3 = 0.9x4.0x10^{-4} m^2$, From equations 1 and 2, $N_3$ =64.8 N, $F_3$ =71.28 N
At point 4, $A_4 = 0.9x4.0x10^{-4} m^2$, therefore,
$N_4$ =64.8 N, $F_4$ =71.28 N
$F_3$ and $F_2$ act on both sides of the edges, hence
$2F_2$ = 126.72 N, $2F_3$ =142.56 N
Deflection due to force $F_1$=63.36 N

$$Y_{ma} = \frac{FL^3}{3EI} \quad (3)$$

where
F = applied load = 63.36 N
L = Length of cantilever = 0.11 m
E = Modulus of elasticity for steel = $206.82x10^9$ $Nm^{-2}$
I = Second moment of Area ($m^4$) = $7.03x10^{-3}$ $m^4$
$Y_{ma} = 1.933x10^{-11}$ m, therefore
Total deflection on blade A = $3.866x10^{-11}$ m = $3.866x10^{-8}$ mm
The value is insignificant, hence 8 mm thickness is suitable for blade A.
Deflection on blade B, $Y_{mb} = 1.9334x10^{-11}$ m, total deflection on blade B = $3.868x10^{-11}$ m. The value is insignificant, hence 9 mm thickness is suitable for blade B.
Torque on blade A
At point 1, $F_1$ = 63.36 N, $d_1$ = 0.09 m,
Torque, $T_1 = F_1 \times d_1$ (4)
where $d_1$ = Distance from force to center of the blade,
=63.36 x 0.093
=5.9 Nm
At point 2, $F_2$ = 63.36 N, $d_2$ = 0.093 m
$T_2 = F_2 \times d_2$
$T_2$ = 63.36 x 0.093
=5.9 Nm
Total torque acting on blade A is given by
$T_a = T_1 + T_2$ =5.9 + 5.9
=11.8 Nm
At point 3,
Torque acting, $T_3 = F_3 \times d_3$ = 71.28 x 0.093 =6.63 Nm
At point 4,
Torque acting, $T_4 = F_4 \times d_4$ = 71.28 x 0.093 =6.63 Nm
Total torque acting on blade B is given by
$T_b = T_3 + T_4$ = 13.26 Nm
Total torque acting on the yam beaters =25.06 Nm
Total force acting on the yam beaters
= 126.72 + 142.56 = 269.28 N

**3.1.2. Pounding bowl**

The wood oak red has the following properties
Shear strength parallel to grain; 1780 $Ib/in^2$
Tensile strength perpendicular to grain 800 $Ib/in^2$
Maximum crushing strength parallel to grain =6760 $Ib/in^2$
Modulus of elasticity =1820 ksi
The force needed to pound yam is calculated as follows:
Mass of the yam beaters = 0.41kg x 2 = 0.82 kg
The length of the beater = 200 mm = 0.2 m
The length of one arm = radius of the beater
= 100 mm = 0.1 m
Mass of the cooked yam 4 kg

$$n = \frac{d_1}{d_2} N \quad (5)$$

where $d_1$ = diameter of motor pulley = 50 mm
$d_2$ = diameter of shaft pulley = 250 mm
Speed ratio of transmission = 5:1

$$n = \frac{50}{250} = 290\ rpm$$

Angular velocity, $2\pi \frac{n}{60} = 30\ rad/s$

Total mass = mass of the beaters + mass of cooked yams
= 0.82 kg + 4 kg = 4.82 kg
V = rω = 0.1(30.4) = 3.04 m/s
Pounding force is given by, F = ma = $m\omega^2 r$
= 4.82 $(30.4)^2$ 0.1
= 445.45 N
Power for pounding is given by
Power = force x velocity
= 445.45 x 3.04
= 1354.17 W
The power requires for pounding is therefore 13543.17W
745W = 1 hp

1354.17 W = 2 hp
2.0 horse power motor is then selected for the machine.
The stress produced in the bowl during pounding is σ = F/A, where F = Force, A = area occupied by the rotating blades
σ = 714.37/0.380 = 18799 $Nm^{-2}$
Shear strength of the wood = 1780 $Ib/in^2$ =12272667.5 $Nm^{-2}$ so the shear stress calculated is less than the shear strength of the wood. Therefore, the wood is suitable for the design of the bowl. The diameter was calculated from the above stress and force as 220mm.
Let the maximum volume of yam pounded be $V_{yp}$, $V_{yp} = V_b - V_k$ where $V_b$ = volume of the wooden bowl $V_k$ = volume occupied by the yam beaters.

$$V_b = \frac{\pi D_b^2 H}{4} - \frac{\pi d_b^2}{4} \quad (6)$$

where $D_b$ = 300mm, $d_b$ = 240mm, H = h = 220mm
$V_{yp}$ = 4270106.94$mm^3$

**3.1.3. Pulley and belt arrangement**

$$\text{Speed ratio, } \frac{n_1}{n_2} = \frac{d_2}{d_1} = \frac{250}{50} = 5 \quad (7)$$

**3.1.4. The Pulley System**

In order to reduce the motor speed to the desired speed, we may select, bearing in mind the weight and size of the machine.

i. Speed ratio of transmission = 5:1
ii. Nature of belt = V- belt
iii. Type of belt = rubber impregnated with textile with a coefficient of friction 0.35
iv. Groove angle of pulley, Θ = $40^0$
v. Diameter of motor pulley $d_1$ = 50 mm

From speed ratio,
$d_2 = 5d_1$
$d_2$ = 5x50 = 250 mm
where $d_2$ is the diameter of the larger pulley and $d_1$ is the diameter of the smaller pulley. The center distance C between the two pulleys is taken as the larger of the value between $\left(\frac{5d_1}{2} + \frac{d_2}{2}\right)$ and C = $d_2$ as recommended by Dutchman [14, 15]

$$C = max\left(\frac{5d_1}{2} + \frac{d_2}{2}\right) \quad (8)$$

$$= max\left(\frac{5(50)}{2} + \frac{250}{2} or 250\right)$$

C = (250 or 250) = 250 mm
Angle of wrap
For smaller pulley, $d_1$

$$Ø_1 = 180^0 - 2\sin^{-1}\frac{\frac{d_2+d_1}{2}}{C}$$

$$(9) = 180^0 - 2\sin^{-1}\frac{d_2+d_1}{2C}$$

$$= 180^0 - 2\sin^{-1}\frac{250-50}{2x250}$$

= $180^0 - 47.2^0 = 132.8^0$ (2.32 radians)
Similarly, for the larger pulley

$$Ø_2 = 180 + 2\sin^{-1}\frac{\frac{d_2+d_1}{2}}{C} \quad (10)$$

$$180^0 + 2\sin^{-1}\frac{d_2+d_1}{2C}$$

$$180^0 + 2\sin^{-1}\frac{250-50}{2x250}$$

= $180^0 + 47.2^0 = 227.2^0$ = (3.97 radians)
To examine the load carrying capacity of the two pulleys, substitute the values of $Θ_1$ and $Θ_2$ respectively into the expression below to know the one with the smaller value.

$$e^{\mu\phi_1 sin^1/_2\theta} = e^{\frac{0.35x2.32}{\frac{sin40}{2}}} = e^{2.37426} = 10.74 \quad (11)$$

Similarly, for the larger pulley

$$e^{\mu\phi_2 sin^1/_2\theta} = e^{\frac{0.35x3.97}{0.342}} = 58.14$$

The load carrying capacity of a pair of pulleys is determined for a V = belt by the one that has the smallest value.
Hence the smaller governs the design. This implies that the smaller pulley is transmitting its maximum power with the belt even at the point of slip while larger pulley is not developing its maximum capacity.

$$\text{But velocity, } V = \frac{\pi d_1 N}{60} \quad (12)$$

Where N = motor speed = 14500 rpm

$$V = \frac{\pi x50x10^{-3}x1450}{60} = 3.79\ m/s$$

Power delivered by the motor is given by:
P = $(T_2 - T_1)$V where
P = power delivered by motor
$T_1$ = Tension at the slack side of the belt
$T_2$ = Tension at the tight side of the belt

$$T_2 - T_1 = \frac{0.75x10^3}{V} = \frac{0.75x10^3}{3.79} = 197.8$$

The table for V – belt dimension for various classes of V – belt is given below [13]

**Table 1.** Dimension of various belt

| Cross section symbol | Nominal top width b (mm) | Nominal thickness t(mm) |
|---|---|---|
| Y | 6.5 | 4 |
| Z | 10 | 6 |
| A | 13 | 8 |
| B | 17 | 11 |
| C | 22 | 14 |
| D | 32 | 19 |

For durability, the class A section is recommended for this design
$b_1$ = 13 mm, t = 8 mm
Mass density of leather belt = 207 $kg/m^3$
M = *lxbxt*= $13x10^{-3}x8x10^{-3}x270$
= 0.0281xkg/m
Allowable stress for the belt is 1.7mpa
$S_1 = 1.7x10^6$pa
The stress on the slack side of the belt is obtained from

$\frac{T_1-mv^2}{T_2-mv^2} = \exp(\mu\phi/sin\ {}^1/_2\ \theta$ (13)

where $S_1$ = stress on the tight side of the belt

$S_2$ = stress on the slack side of the belt

V = velocity of the belt

$\phi$= angle of wrap

θ= Groove angle

$$\frac{S_1 - MV^2}{S_2 - MV^2} = \frac{1.7x10^6 - 0.028x3.79^2}{S_2 - 0.028x3.79^2}$$

$S_2 = 1.37x10^5$

But the cross sectional area of the belt is obtained from

$\frac{T_1-T_2}{T_1-S_2} = A$ (14)

$\frac{197.8}{1.7x10^6-1.37x10^5} = 1.266x10^{-4}m^2$

A = $1.266x10^{-4}m^2$

Allowable belt tension, $T_2 = S_1xA$

= $1.76x10^6x1.266x10^{-4}$

=222.8 N

But $T_2 - T_1$ = 197.8

$T_1$ = 222.8-197.8

=25 N

The full length $L_b$ of the belt is obtained from

$L_{b1} = 2c + 1.57 (d_1+d_2) + (d_2-d_1) + \frac{d_2-d_1}{4d_2}$ (15)

= 2(250) +1.57 (50+250) + $\frac{(250-50)^2}{(250)}$

= 500+471 +40

= 1011 mm

**3.1.5 Analyzing the force at pulley**

Force acting on Pulley

$F_n$ = Net force, $F_B$ = Bending force

$F_B = CF_n$

where C = V-belt factor = 1.5 [12]

$F_n = F_1 - F_2 = 2T_B^1/DB^1$ (16)

$D^1_B$ = 250mm = 0.25m where $T_B^1$ = 645 Nm

$F_n = \frac{2x64.5}{0.25} = 444.8\ N\ \approx 445\ N$

$F_B = 1.5F_n$

= 1.5 x 445

= 667.5

= 668 N

**3.1.6. Design of power transmission shaft**

This is aimed at determining the correct shaft diameter that will give satisfactory strength and rigidity. The shaft is subjected to different types of loads such as torsion, axial load or combination of loads as transmits power to various components.

For Ferritic Knealed stainless steel

Tensile strength, $\delta u$= 517 mpa

Yield strength $\delta y$= 276mpa

Ductility = 30%

Endurance limit $\delta n = {}^{\delta u}/_2 = \frac{517}{2} = 285.5\ mpa$ 285.5mpa

Assume 12.5 < D > 50mm [12]

Size factor $C_s$ = 0.85

Load factor $L_f$ = 0.6 (Torsional loading)

Endurance strength $\delta n$= $C_s$ x $L_f$ x$\delta n$ (17)

= 0.85 x0.6 x 285.5

=131.8 mpa

Design safety factor N = 3

Assume 100% efficiency

Speed ratio: $L = \frac{d_1}{d_2} xn$ (18)

$d_1$ = 50mm, $d_2$ = 250 mm

$d_1$ = diameter of pulley

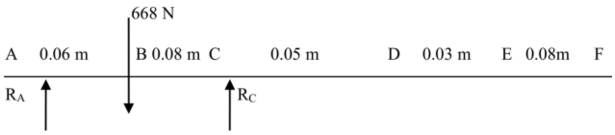
$d_2$ = diameter of shaft pulley

$n = \frac{50}{250} x1450 = 290\ rpm$

$\omega = \frac{2\pi n}{60} = \frac{2\pi 290}{60} = 30.37\ rad/s$

Torque in the shaft, $T = \frac{1960}{30.37} = 64.5\ Nm$

**3.1.7. Analyzing the reactions at supports**




**Shaft showing forces acting**

$\sum M_A = 0$

668 x 0.06 – $R_C$ (0.14) = 0

$R_C = \frac{668x0.06}{0.14}$

$R_C$ = 286.3N

$\sum f_0 = 0$

$R_A = 668 + R_C = 0$

$R_A$ = 668-286.3

= 381.7N

= 382N

**3.1.8. Shaft sizing**

Point A

At this point, we have zero torque and zero bending moment as justified by the bending moment diagram, the shear force at this point is V= 40.08 (vertical). To the left of A, the shaft should be slightly smaller with a well-rounded fillet for easy sliding of the bearing A. Using shear forces analysis we have:

$A = \frac{\pi D^2}{4}\ \ butT = \frac{4V}{3A}$

$$D_1^2 = \frac{16V}{3T\pi} \rightarrow D_1 = \sqrt{\frac{16V}{3T\pi}} \quad (19)$$

Stress t = Sys/N = Sys/2N

= $276x10^6/2x3 = 46.0x10^6$ pa

$$D_1 = \sqrt{\frac{16x38^2}{3x46x10^6x3.142}} = 3.8\ mm$$

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To the right of A, there is a right sharp fillet at the shoulder so as to hold bearing A in place. To the left of pulley B, there is a well rounded fillet, thus $K_t = 1.5$ At the pulley
Torque = 64.5Nm
Moment = 22.9Nm
Using maximum shear stress theory

$$D_2 = 32N/\lambda\sqrt{[(k_t M|\delta n^1)^2 + (T|\delta y)^2]^{\frac{1}{3}}} \qquad (20)$$

$$D_2 = 32x3/\pi\sqrt{\left[\left(\frac{1.5x22.9}{131.8x10^6}\right)^2 + \left(\frac{64.5}{276x10^6}\right)^2\right]^{\frac{1}{3}}} =$$

= 0.2154m = 215.4mm
At the second point which is the pulley seat, there is a profile key seat $K_t = 2$

$$D_3 = 32x3/\pi\sqrt{\left[\left(\frac{2x22.9}{131.8x10^6}\right)^2 + \left(\frac{64.5}{276x10^6}\right)^2\right]^{\frac{1}{3}}} =$$

= 228.6mm
To the right of the pulley there will be a rounded fillet $D_2 = D_4$ = 215.4mm
Point B
Here there is another bearing with a sharp fillet to the left of the $K_t = 2.5$
Moment M = 0 and Torque = 64.5Nm

$$D_5 = 32x3/\pi\sqrt{\left[\left(2.5x\frac{0}{131.8x10^6}\right)^2 + \left(\frac{64.5}{276x10^6}\right)^2\right]^{\frac{1}{3}}} =$$

= 0.188m =188.2mm
Selection of bearing B
The reaction at A represents the radial load at the point,
$F_A = F_r$ = 382N
There is an axial load generated by the weight of the pulley which is 382N
Assuming rolling bearing A
Rotational factor X = 1, inner rate exponent for life Equation $K_t = 3$, service factor $S_f = 1.4$ (rotating part). If we have the maximum speed 725 rpm. The machine work for 24 years at 12 hours daily. Thus the life before failure is L = 24 x 12 x 725
= 208800 hours.
The basic life in a million revolutions ($L_{10}$) is

$$L_{10} = \frac{60LN}{60} \qquad (21)$$

N = n = 290

$$L_{10} = 60x2\frac{208800x290}{106}$$

$L_{10}$ = 3633.12 hours
$F_t/F = 38/1x382 = 0.102<Q$
$\rightarrow C_r = 1, C_t = 0$
The equivalent dynamic lead rating
$F_L = (C \text{ x } C_rF_r \text{ x } C_tF_t) S_f$ [14]
= (1 x 1 x 382 + 0) 1.4
$F_L$ = 536.2N

The basic dynamic load rating
$C = F_L (L_{10})^{1/k}$
$= 536.2 (3633.12)^{⅓}$
= 8243.0N
From the table of deep grove ball bearing, we selected the bearing with designation [15]
BRN: 16002
D: 15mm
D: 32mm
B: 8mm
Selection of bearing C
$L_{10}$ = 3,633.12 hours
For this bearing there is no axial load
$F_t = 0, F_r = 286.3$N
$F_t/F_r = 0/1 \text{ x } 286.3 = 0 < Q$
$C_t = 0, C_r = 1$
$F_L = (C_rf_r + C_tF_t)$ 1.4
= (1 x 286.3 + 0) 1.4
= 400.82N
Therefore checking the table for deep groove ball bearing
We select the bearing with designation [15]

| | |
|---|---|
| BRN | 16004 |
| D | 20mm |
| D | 42mm |
| B | 11mm |

Point D
At this point, we have the pitch kneader which mix and also displace the pounded yam upward in a vertical motion.
The torque at D = ⅔ of torque generated
$T_D = ⅔ \, T_B^1$
⅔ x 64.5
$T_D$ = 43.0Nm

$$D_6 = 32N/\pi\sqrt{\left[\left(k_t M\middle|\partial n^1\right)^2 + (T|\delta y)^2\right]^{\frac{1}{3}}} \qquad (22)$$

From the shaft design at point D, M = 0

$$D_6 = 32x3/\pi\sqrt{\left[(0)^2 + \left(\frac{43}{276x10^6}\right)^2\right]^{\frac{1}{3}}} =$$

$D_6$ = 0.1644m
= 164.4mm
Point E
In this place, we have the flat kneader, which is responsible for only mixing.
$T_E = ⅓ \, T_B = ⅓ \text{ x } 64.5 = 21.5$Nm

At the point E. the moment if zero ($\sum M_E = 0$)

$$D_7 = 32N/\pi\sqrt{[(k_t M|\delta n^1)^2 + (T|\delta y)^2]^{\frac{1}{3}}}$$

$$D_7 = \frac{32x3}{\pi\sqrt{\left[(0)^2+\left(\frac{215}{276x10^6}\right)^2\right]^{\frac{1}{3}}}} = 130.5mm$$

**Table 2.** Selected Diameters of Shaft

| S/NO | Part | Number | Maximum Diameter | Specified Diameter |
|---|---|---|---|---|
| 1. | Bearing A | $D_1$ | 3.8mm | 30mm |
| 2. | Shoulder | $D_2$ | 215mm | 30mm |
| 3. | Pulley B | $D_3$ | 228.6mm | 28mm |
| 4. | Shoulder | $D_4$ | 128.6mm | 32mm |
| 5. | Bearing B | $D_5$ | 188.2mm | 30mm |
| 6. | Pitch kneader | $D_6$ | 164.4mm | 28mm |
| 7. | Flat kneader | $D_7$ | 130.5mm | 23mm |

### 3.1.9. Base plate

For a square base plate with all the edges firmly fixed and uniform load over a small area at the centre of the plate. Let W = total load on the plate in Newton.

t= thickness of plate in mm

δ= maximum tensile stress in plate $N/mm^2$

d= maximum deflection of plate

E= modulus of Elasticity in $N/mm^2$

$r_0$= radius of the centre area to which load is applied

$$\text{Then } S = 0.62w/t^2 \text{ Log } (½r_0) \quad (23)$$

$d = 0.0568WL^2/Et^2$

Allowing for a hole of Area, $A_h$ at the centre of the plat, the equations are modified to:

$$δ = 0.62W/t^2 \text{ Log } (½r_0) - W/A_h \quad (24)$$

$d=0.0568W (L^2+A_h)/Et^3$

for the base plate,

L=478mm, W=14gN, $r_o$=80mm, $r_h$=50mm

$A_h=1150mm^2$, $E=200{,}000N/mm^2$

Assume t=5mm,

Then

$δ= 0.62x14x9.81/(5^2)loge(478/100)-0.0175$

$= 1.40N/mm^2$

$d=0.0568x14x9.81x (478^2 + 1150^2)/200{,}000x5^3$

d=0.015mm

The maximum stress is far within limit of mild steel if 5mm plate is used. The deflection is also within tolerable for the alignment of the pulleys.

### 3.2 Result of the Performance Test Carried Out

The pounded yam obtained from the existing yam pounder was smooth and starchy but few yam seeds were found. While the pounded yam obtained from the designed machine was also smooth and starchy and no yam seed was found. The result from the fifteen respondents is shown in Table 3. The product from the existing yam pounding machine was fairly good since they found some yam seeds in the pounded yam sample. The comment obtained from the designed yam pounder was excellent since they found no seed in the pounded yam.

**Table 3.** Result of the performance test carried out [5, 7, 8]

| Respondent | No of Seeds | Texture and quality of the Pounded yam from existing pounder (Comment) | No of Seeds | Texture and quality of the pounded yam from designed pounder (Comment) |
|---|---|---|---|---|
| 1. | 3 | Seeds found | Nil | Smooth & starchy |
| 2. | Nil | Smooth & starchy | Nil | Smooth & starchy |
| 3. | Nil | Smooth & starchy | Nil | Smooth & starchy Smooth & starchy Smooth & |
| 4. | Nil | Smooth & starchy | Nil | starchy Smooth & starchy Smooth & starchy |
| 5. | 1 | Seed found | Nil | Smooth & starchy Smooth & starchy Smooth & |
| 6. | Nil | Smooth & starchy | Nil | starchy Smooth & starchy |
| 7. | Nil | Smooth & starchy | Nil | |
| 8. | Nil | Smooth & starchy | Nil | Smooth & starchy Smooth & starchy Smooth & |
| 9. | Nil | Smooth & starchy | Nil | starchy |
| 10. | 1 | Seed found | Nil | Smooth & starchy |
| 11. | Nil | Smooth & starchy | Nil | |
| 12. | 2 | Seeds found | Nil | |
| 13. | Nil | Smooth & starchy | Nil | |
| 14. | Nil | Smooth & starchy | Nil | |
| 15. | Nil | Smooth & starchy | Nil | |

## 4. Conclusion

The design and construction of a wood-based modified yam pounder machine had been achieved. This study eliminates the tedious, noisy and laborious indigenous process of preparing pounded yam. Optimal possible values were used in the design and construction of the machine. Indigenous technology was employed in this study by using mortar made from hardwood (Oak tree) as the pounding bowl whichmakes the pounded yam more natural. The performance test carried out show that the pounding speed of the machine is quite adequate with fine texture for the pounded yam compared with other yam pounder machines. This Shows that the machine is efficient, reliable and affordable with cost of 123,000 naira per machine, hence it is recommended for household and commercial use.

### Conflict of interest

The contribution of the authors is equal. All authors reviewed the results and approved the final version of the manuscript.

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**Authorship contribution statement for Contributor Roles Taxonomy**

Engr. Aghawegbehe Kingsley and Dr. Dıckson Davıd Olodu designed and fabricated the machine. The article was written and reviewed by Engr. Aghawegbehe Kingsley and Dr. Dıckson Davıd Olodu. Both authors were involved in the coordination, planning and execution of the experimental design.

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