American Journal of Sciences and Engineering Research wwww.iarjournals.com

American Journal of Sciences and Engineering Research

E-ISSN -2348 – 703X, Volume 4, Issue 6, 2021

Design, Fabrication and Determination of Force Analysis on Machine Components of Palm Kernel Nut Cracker

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Abstract: *Several mechanical methods of cracking and separation have been developed for nut cracking processes. The available mechanical crackers include; centrifugal vertical/horizontal-shaft, verticalharmers load and the rotary fluted roller nut crackers. Some of these machine processes have shortcomings, which include high kernel breakage, high production cost, low production rate and highlabour intensity. Therejòre, the design and fabrication of a s-neck horizontal shaft rotary palmkernel cracking machine with Dura, Tenera and their mixture of Dura and Tenera samples wascarried out to overcome the above challenges. The palm kernel cracking machine was powered bydiesel engine and an electric motor. It consists of five different units namely; the transmission,Hopper, cracking chamber, the frame and outlet or discharge units respectively. The transmissionunit consists of two pulleys, bearing, a rotary shaft with beater arm and a v-belt. One pulley of Ø38mm is keyed to a rotary shaft. The cracking chambers measures 100 x 320 mm while the rectangular flat bar (beater arm,) of 5mm thickness is welded at an angle of 1200 each to the shaft.The force analysis of the impeller blade is given as $\frac{2\pi N}{60}$ while the shear stress σ:.rd^2. The area ofthe hub is determined as(4πr^2) = 7rd2 while the breaking force =ord2 Kinetic energy required to crack the kernel during rotation is given as K_E = (Ѡ^2). Hence cracking force required to crack the kernel is given as F_c =p. Vo. Ѡ^{2}r*

Keywords*: Centrifugal, Nut Cracker, Kernel Breakage, Cracking Chamber, Breaking Force.*

I. Introduction

A good number of researches have been carried out on the design fabrication or construction of palm nut cracking machines. Babatunde and Okoli (1988) designed, fabricated and tested a prototype centrifugal palm nut cracker using horizontal-shaft and vertical rotor type in National center for Agricultural Mechanization (NCAM), Ilorin, Nigeria. The design wàs based on centrifugal principlein which the nuts to be cracked were directed to the rotor which hurls the nut and strikes it against a hard beaker plate. Similarly, Ilechie (1985) designed a singled staged nut cracker as an integral component of the small- scale processing equipment in Nigeria Institute for Oil Palm Research, (NIPOR), Benin City, Nigeria. The nut cracker was driven with the same prime mover of the horizontal digester and this was to reduce the cost of power. The researcher further reported that the rotational speed of the centrifugal impact contributed greatly to the poor state of the product after processing. Consequently, Jimoh*et al* (2013) designed an effective automated machine for quality palm production in the Department of Agricultural Engineering, Federal University of Technology Akure. The machine consists of cracking chamber, hopper, metering device, a pair of hammer, transmission

 Received-30-11-2020, Accepted- 11-11-2021

system driving shaft, pulley and main frame. The hopper is calibrated and made from a flat plate of 1mm thickness in a trapezoidal shape with upper dimensions of 400mm^2 and lower dimensions of 200mm^2 while its height is 400mm^2. It formed a feeding chute of the machine, through which nuts are poured into the cracking chamber of the machine. The cracking chamber consists of a pair of hammer with (130 x 80 x 120) mm dimensions made from mild steel, which are arranged at 1 800 to each other. The driving mechanism consists of a vee belt, pulley and a single phase electric motor with power rating of 5KW and speed of 1,840 rpm while the designed power requirement is 429 KW with a speed of 1,718 rpm. The designed shaft diameter is 25.39 mm. However, shaft of 25.00mm diameter was selected. In the same vein Manuwa (1997) designed, fabricated and tested a palm nut cracker. Locally fabricated materials were used in some parts of the machine to reduce the cost and weight of the machine. Maintainability was considered an important factor in design and fabrication of the machine. The machine was tested using local variety of nuts from “wild” palm fruit. The prime mover was an electric motor at a power rating of 2.25 KW, the maximum throughput capacity was 1 .2 ton/hr with a performance efficiency of about 89% and a mechanical damage of 10% at a rotor speed of 5,500 r/mm.Also, Ologunaba (2012) designed and evaluated a Horizontal shaft palm nut cracking machine. The researcher maintained that in view of the problems and global demand of palm kernel and its bye products, efforts have been made towards improved devices from palm kernel extraction. The basic features in the researcher’s designed machine include: hopper, cracking chamber, horizontal shaft with beaters, discharge outlet and prime mover. The hopper is made from 2mm mild steel sheet formed into a pyramidal frustum with top opening of 360mm x 360mm and a bottom opening of 100 x 100mm whose sides are inclined to 60° to help the free flow of the palm nuts into the crackingchamber. Incorporated below the hopper is the metering device into the cracking chamber. The cracking chamber consists of a circular housing made from 40mm steel rod attached with four beaters made of 4mm mild steel flats arranged at intervals of 90° to one another. The circular housing is 350mm diameter with an opening of 100mm x 100m at the upper curvature where the nuts are introduced from the hopper while the lower curvature has an opening of 120mm x 100mm where the cracked nuts escape through the discharge outlet. The machine is powered by 2.25 KW (3 hp) electric motor with the aid of belt and pulley arrangement. The main frame is made from 40mm x 40mm mild steel angle-iron to carry and support machine components.

Furthermore, Nwankojike (2012) designed, fabricated and evaluated a palm nut pulp consisting of a cake breaker, angular separator, the hopper (3 hp) electric motor, the frame, the separating unit, palm nut pulp discharging chute. The frame is made from 2.5mm thick angle plate. Other component of the machine is mounted on the frame. Again, Oke (2007) designed an indigenous dual kernel cracking/processing machine. The machine according to the researcher has two distinct parts namely; (a) Cracking Unit and (b) Separating unit. The cracking unit is made up of feed hopper, impeller shaft, cracking drum, impeller blade. The nut falls by gravity through the hopper channel into a cracking drum where the cracking process takes place with the help of impeller blade that flaps the palm kernel nut against the walls of the cylindrical cracking drum. The three blades are welded at 120° to each other and the blades have a clearance of 15mm from cracking drum. This is based on the size of the nut and design calculation. The impellers are made of high carbon steel and are removable to ensure adequate maintenance and replacement in case of wear and tears of beaters. According to this researcher, the following factors were considered in determining the design and material selection and construction of the machine. The impinge velocity of palm nut with which it strikes the drum, size of nut, moisture content and shaft clearance (John and Owonicho, 2004).

Therefore, Design parameters and force analysis in the cracking unit according to Oke (2007)

$\omega = 2\pi N/60$ where ω= angular speed of the disk

N = number of rotation

$\pi = 3.14/22$

Force required to crack the kernel nut,

F = Ax S where A= Area of palm nut cracking and S share strength

Furthermore, Jimoh*et al.*(2013) maintained that the sharing force of the machine is obtained from the expressions.

$$f_h = \frac{\pi}{8L} t^3 \delta_s f_s$$

wheref_h= Sharing force in Newton (N)

t Thickness

δ_s= allowable stress in Nm^{-2}

L= Dimension of pressure exerted during sharing in (m)

f_s= Compressive force in (N)

Similarly, various studies have been done on nut impact energy (Antia, 2011); Dienagha and Ibanichuka (1991); (Aseogwu, 1995; Babatunde and Okoli, 1998). From all these work it has been established that nut impact energy ($k_{e(rms)}$) required to crack nut in mechanically operated nut cracker could be evaluated using static impact method. The nut impact energy is given by (Aseogwu, 1995; Dienagha and lbanichukwa. 1991) as;

Ee_{term}= mgh½ mv^2

Where M = mass of hammer (kg)

g = acceleration due to gravity in (m/s^2)

h= length of hammer from the stationary plate for which the nut is placed before impact in (m).

II. MATERIALS AND HANDLING

The design, fabrication and determination of force analysis of a horizontal- shaft rotary palm kernel cracking machine with Dura, Tenera and mixture of Dura and Tenera as input materials was carried out with the aim of increasing the cracking efficiency and increase in productivity, reduce kernel breakage and high production cost which is characterized by most mechanical nut crackers. The horizontal- shaft rotary palm kernel cracking machine involves five different stages namely; the transmission, hopper, cracking chamber, the frame and the outlet units. The transmission unit consists of two pulleys, bearings, rotary shaft with beater arms or blade and a v-belt. This unit transmits the required velocity and power to crack the palm nut. One pulley of 38mm diameter is keyed to a rotating shaft of the electric motor as the driver while the driven pulley is of 100mm diameter. As the driver rotates, it revolves the belt due to the grip between the surfaces of drive and driven pulleys. The cracking Unit is the component of the machine that breaks the nut. It consists of a beater arm or blade inside the cracking chamber of loo x 320mm diameter. The beater arm is made up of three rectangular flat bar of 10mm thick, welded to a shaft at an angle of 1200 each. The blades makes a rotary movement and the nuts that pours into the chamber are flinged by the beater to the casing or rigid chamber where the breaking of the nut takes place. The hopper takes the shape of cone which measures 450mm x 225mm respectively with S-neck mounted on a rigid frame which enables the nut to naturally fall freely from the Hopper to the cracking beater before cracking occurs and finally discharged through the outlet.

Similarly Ologunaba (2012); Manuwa (1997); Obiakor and Babatunde (1999); and Adebayo (2004) identified the cracking devices as roller, Hammer impact and centrifugal-impact crackers. Consequently, Ndukwu et al (2010) carried out a study on the functional performance of a vertical-shaft centrifugal nut cracker. They maintained that cracking takes place when the vertical shaft makes a force impact on the nut thereby shattering the shell and leaving the kernel. Subsequently, Nwankwojike (2012) designed, fabricated and evaluated a palm nut-pulp consisting of a cake breaker, angular separator, the hopper, 3Hp electric motor, the frame, the separating unit and palm nut and pulp discharging units. Also, Elechi et al (2010) designed and fabricated a palm nut horizontal-shaft rotary cracker to improve on the efficient performance of palm nut processes. In the same vein, Oke (2007) designed a dual kernel cracking/processing machine with the following distinct parts; (i) Cracking Unit and (ii) Separating Unit. According to the researcher, the cracking unit comprises; the feed hopper, Impeller shaft, cracking drum and impeller blade. The nut fall by gravity through the hopper to the cracking chamber where the cracking process takes place with theaid of the cracking beater which flaps the palm nut against the cylindrical cracking & drum. The cracking blades are welded at 1200 to each other with a clearance of 15mm away from the drum. Therefore, the separating unit is made of camshaft, returning spring and separating tray, which is inclined at angle of 1200 less the angle of responses of shell but is far greater than that of the kernel. This is to ensure free fall of the kernel. The tray according to this researcher has two sections: The first section of the tray is, shell screener, which is made 10mm iron rods lined at equidistant of 9.00mm. This section separates the shell from the kernel. The second section is kernel screener that separates cracked from uncracked palm kernel which is made of a tray perforated with l6mm diameter based on the average of nut size. The tray is subjected to vibration with the three camshaft powered by 4 hp electric motor and three returning spring. Both the cracking and separating units are powered by 4 hp with 2500 rev/mm with two pulleys. One of the vee pulleys is connected to the cracking unit and the other to the separating unit.

Fig. I: Pictorial view of an S-neck palm nut cracker

FORCE ANALYSIS OF COMPONENT PARTS

Striking force, i.e. force delivered by the impeller blades. Force required to crack the kernel F_a = Force developed by the rotating blades (beater arm) F_b

Beater arm force = centrifugal force developed by the rotating blade.

:. $F_b = F_a$ = m. linear acceleration

$m.\omega^2 r$ (1)

$F_c = p.V0.\ \omega^2 r$ (2)

Where m = mass of blade, w = $2\pi N/60$ = angular velocity

p = density of mild steel

V_o = volume of blade

r = radius / height

F_c = cracking force.

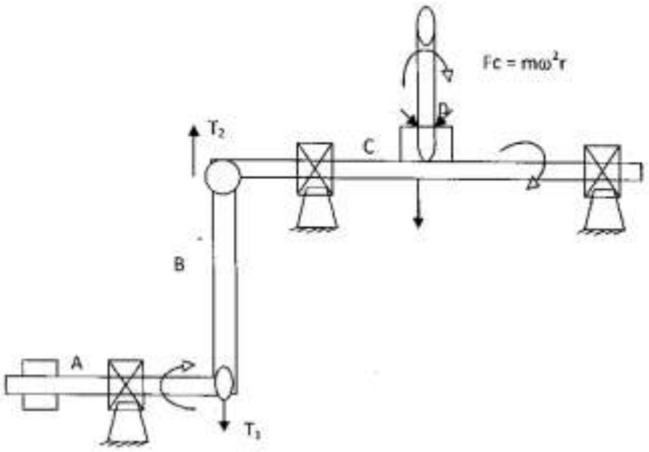

Fig 2: Schematic Diagram of shaft and the various components

Where as
A = Shaft from Electric motor
B = belt Joining electric motor pulley to main shaft
C = Main Horizontal shaft
D Beater arm blade and Hub on the main shaft.
T_1, T_2 = electric motor pulleys
The maximum kinetic energy of impact with which the beater arm (blade) strikes the palm nut is given by
K_{EK} = ½ MV^2 (3)
Where
K_{EK} = Kinetic Energy of kernel
M = mass of kernel

V = Velocity of kernel

Assume the velocity of the kernel velocity of the blade.

:. $V_{\omega}r$ (4)

but K_{EK} = ½ m $(\omega r)^2$ 0.5m $\omega^2 r^2$ or 0.5 p. Vo. $\omega^2 r^2$ (5)

VELOCITY OF IMPELLERS/BLADE

ωr (6)

Volume of blade = Total volume — Volume of the offcut

= l x b x t - 2 (Area of triangular side x t)

Where 1 = length, b = breadth, t = thickness.

F_k=AxS (7)

$\sigma = F/A$ (8)

WhereF_k = force required to crack the kernel, A = Average area of the kernel, σ= shear stress.

THE HUB

The area of the Hub is spherical

Therefore the Area of a sphere is ($4\pi r^2$) or $=4\pi\left(\frac{d^2}{2}\right)^2 = \pi r^2$

Breaking force = σ. πd^2 (9)

For a rotating system, (Norton 1999)

ENERGY OF THE IMPELLER/BLADE AND TUE KERNEL DURING ROTATION

KE = ½ (ω^2)
K_{EMI} =½ (mv^2) (11)

Where K kinetic Energy, I = length, w = angular velocity

K_{EMI} = Kinetic energy of mass of impact

Exit velocity = (2gh) (12)
Average Time of cracking each kernel
h= ut—¼gt
$\left(\frac{2h}{g}\right)^{\frac{1}{2}}$ (13)
Where g = mass of cracking chamber casing
h = Average height of fall from Hopper before the nut hits the impellers
t = time of fall
Also s = ut + ½ gt2 where s = height of fall, u = initial velocity, t = time of fall and g = acceleration due to gravity.

Striking velocity of kernel i.e. fall velocity given as

$V^2 = u^2 + 2as$ (13)
$= 2gh$
$V = \sqrt{(2gh)} = (2gh)^{1/2}$ (14)
$= \sqrt{2 \times 9.81 \times 0.13} = \sqrt{2.5506} = 1.6 m/s$
Where as
u = initial velocity = o
a = acceleration due to gravity = 9.81 m/s^2
s = distance = height of fall 130mm = 0.13m

Force required to crack the kernel = force development from the rotating impellers

Force required to crack is given as

F = Ma (15)

M. ω^2r…………

Fc = p.vo. ω^2r

Where M = mass of impeller

w	=	$2\frac{2\pi N}{60}$ = angular velocity
Vo	=	volume of impeller blade
r	=	radius/height
Fc	=	cracking force
p	=	density ofmild steel

Kinetic energy of impeller i.e. the striking velocity

= ½ mv2

= acceleration of impeller, a = $\frac{v.u}{t}$ (16)

Moment of Inertia

I_1 = ½ ml^2.3

Where	I	=	moment of inertia
	m	=	mass of impeller
	L	=	Full length of impeller
	F	=	Iα = $I\omega^2 r$

Where I = moment of inertia

α = angular acceleration w2r

Impulse of impeller

= I_ix α x t = $I_i\omega$r (17)

= fxt

Moment of impeller before impact

V_1	=	linear level of speed motor
M_1	=	mass of impeller
Ms	=	mass of shaft
Δm	=	(M_1 — Ms) — (V_1 - Vs)
Mo	=	M1 -V1 = Mv (18)

Change of momentum of the various impellers after impact for the various operations.

Impeller Torgue= at various speeds T_1 = 3 [F_ixCL_i + ds + ts]fr

Where	Ft_i	=	force delivered by impeller
	L_i	=	length of impeller
	ds	=	diameter of shaft
	ts	=	thickens of impeller sleeve

Power delivered by Impeller at no level power = $T\omega$

T_i	=	power delivered by impeller
ω	=	angular velocity of the impeller

MASS OF SHAFT

$M_s = V_l$ x p

π^2hxp (19)

$W_s = M_s x g$
Where M_s = Mass of shaft
V_l = Volume of shaft
p = Density of mild steel
r = radius of shaft
h = height of shaft
W_s = weight of shaft
Volume of cylinder

$V_c = \pi r^2 h$
$= \pi(R^2 - r^2)\ h$
$\pi R2h - \pi r^2$ (20)
Volume of Hub
VR=mh(R2—r2) (21)
Where: V_c = Volume of cylinder, R = outer Radius, r= inner radius, V = volume of Hub, h = height of hub.

TOTAL AXIAL LOAD ON SHAFT
= wt. of shaft ± wt. of blade and hub (22)
$\frac{Axialload}{2}$ (23)
Total Radial load = centripetal force due to rotating blades and shaft (24)
:. Radial load on each bearing
$= \frac{Radialload}{2}$ (25)

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