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Design of an Efficient Low Cost Poultry Feather Plucker Machine

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ABSTRACT

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The study aimed at designing an efficient low cost poultry feather plucker with the main objective of ensuring that the machine improves the hygiene, food safety and defeathering processes in poultry meat production. The machine is made up of four main parts viz: the frame, prime mover, plucker drum, and plucker fingers. The study reveals that for the aim to be realized, an electric motor of 0.5hp with 2300rpm is needed to transmit a torque of 1226.25Nmm through a mild steel shaft of 10mm diameter to a plucker drum of mass 2.5kg which has 24 polypropylene plucker fingers mounted on it. The study estimated the cost of producing the machine to be \$98 and considers the design safe since the FoS of the drum has a minimum value of 8 and a maximum value of 56; shear strength of the drum falls below the shear stress of Aluminum.

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Introduction

Protein is a daily requirement in food diet as it is essential for multiple functions in our body which includes building tissues, cells, muscles, as well as making hormones and anti-bodies. This class of food is gotten from plant and animal sources alike. Animal sources of protein include poultry meat and eggs, beef, fish, pork, milk, etc. The World Health Organization (WHO) recommends that the daily intake of protein (mainly leucine) should be 39 mg/kg per day [1]. Leucine is the most abundant amino acid in tissue and food proteins, and it is contained in poultry and lean meat. In a bid to observe this recommendation, people often find themselves patronizing various slaughterhouses.

Most of these slaughterhouses in Nigeria are faced with public health requirements and environmental problems. These slaughter operations are carried out in unregulated manner without recourse to the safety of the food. According to [2], unsafe food poses global health threats, endangering everyone. Infants, young children, pregnant women, the elderly and those with an underlying illness are particularly vulnerable. Every year, 220 million children contact diarrhoea diseases and 96000 die.

It is against this backdrop that this study intends to develop an efficient low cost poultry feather plucker machine that will ensure an improvement in the hygiene, food safety and poultry defeathering processes involved in poultry meat production.

Methodology

The machine is made up of the following main parts:

- The frame
- The prime mover
- The plucker drum;
- The plucker fingers.

The Frame:

The frame is made up of steel angle ASTM A36 material with a size of 2" X 2" x $\frac{1}{4}$ ". The prime mover and plucker compartment is covered with stainless steel plate ASTM A240M which is less than 5mm thick. The machine

framework has a dimension of 800mm as height, 700mm as length, and 400mm as width.



Figure 1. 3D model of Poultry plucker machine frame. *The Prime mover*:

This is made up of a single phase AC electric motor. It provides the torque needed to rotate the plucker drum. *The Plucker Drum*:

It consists of 24 holes which serves as footings for the plucker fingers. These holes on the surface have a diameter of 18mm and are widened to 23mm at a distance of 2mm below the surface. This 2mm constriction is meant to secure the plucker finger within the plucker drum to avoid it from detaching during its operation. The plucker drum is hollow with a diameter of 100mm and a thickness of 20mm; a length of 330mm. The drum is made of Aluminium and produced through a permanent mould casting technique.



Figure 2a. 3D model view of plucker drum. Figure 2b. Sectioned view of plucker drum.



Figure 3. Plucker drum dimensions. *The Plucker Fingers:*

The plucker finger is made up of polypropylene plastic. It is mounted on the plucker drum. Its function is to pick on the poultry feathers, then as the drum rotates, it exerts a shear force on the poultry bird causing the feathers to be plucked.



Figure 4a. 3D model of plucker finger. Figure 4b. Section view of plucker finger.





Part	Function	Material/	Reason	
		Machine		
Framework	Acts as the	Mild steel	Strength	
	supporting			
	structure of			
	the machine			
Prime	Provides	AC electric	Provision	
mover	needed torque	motor	of torque	
	for			
	defeathering			
	action			
Shaft	Transfer	Mild steel	Torsional	
	torque from		strength	
	AC motor to			
	plucker drum			
Plucker	Holds the	Aluminum	Light	
drum	fingers in		weight,	
	place and		cost	
	ensures rotary		savings,	
	contact is		food safe	
	made with the		material.	
	poultry bird			
Plucker	Picks the	Polypropylene	Food safe	
fingers	feathers		plastic.	

Table 1 Material coloction desision table

Mode of Operation:

The electric motor is powered via an electric power source. This electric energy is converted by the electric motor into mechanical energy; delivering the needed torque for the rotation of the drum. The shaft which connects the electric motor to the plucker transmits the torque developed at the spindle of the electric motor to the plucker. As a result of this, the plucker drum begins to rotate causing the plucker fingers which are mounted on the drum, and are in contact with the scalded poultry bird to slide against the scalded bird resulting in the removal of the bird's feathers and scales.

Design Consideration

Power delivered to the plucker drum:

This is considered in order to determine the amount of power needed to de-feather the poultry birds. Since the plucker fingers are attached to the drum, it is assumed that power delivered to the plucker drum equals power needed to de-feather the birds.

(1)

$$\therefore P_{drum} = W_{drum} \times r_{drum} \times \omega_{motor}$$

Where: W= weight, r = radius, $\omega = angular velocity$ *Electric motor power rating*:

The power rating of the electric motor needed to provide the necessary torque for the de-feathering action is expressed as:

$$P_{motor} = \frac{P_{drum}}{\eta_{motor}} \tag{2}$$

Diameter of shaft:

The shaft was designed on the basis of strength. In this design, the shaft was considered to be subjected to combine twisting and bending moments with steady application of load as the shaft rotates.

Hence, the formula used as expressed by [3] is stated below: *for twisting moment*

$$d = \frac{16T_e}{\pi\tau} \tag{3}$$

Where: τ = allowable shear stress of material (mild steel) T_e = equivalent twisting moment

$$\sqrt{(K_{m} \times M)^{2} + (K_{t} \times T)^{2}}$$
(4)
$$T = \text{Torque transmited by shaft}$$

T = Torque transmitted by shaft

=

(5)

(8)

$$=\frac{P\times60}{2\pi N}$$

N = speed of motor, m = maximum bending moment, $K_m =$ combined shock and fatigue factor for bending = 1.5 $K_t =$ combined shock and fatigue factor for torsion = 1.0 *for bending moment*

$$d = \frac{32M_e}{\pi\sigma_c} \tag{6}$$

Where: σ_c = crushing stress

M_e = equivalent twisting moment

$$\frac{1}{2}(K_m \times M + T_{\varepsilon}) \tag{7}$$

Shear stress developed in drum:

This is the stress developed in the drum as a result of the power transmitted for the defeathering of the poultry bird. For the design to be valid, the value for the stress developed in the drum should not exceed the maximum allowable shear stress for the drum material

$$\tau_{drum}$$
 = factor of saftey \times allowable shear stress

 $\therefore \tau_{drum} = F.S \times \tau_{w,s}$ Where: allowable shear stress

 $\tau_{w.s} = \frac{16T_{drum}}{\pi d^3} \tag{9}$

 $T_{drum} = torque on drum = W_{drum} \times r_{drum}$ Design of sunk key:

In designing the sunk key, it is assumed that the forces due to torque transmitted by the shaft acting on the key is uniform, and these forces induce shearing and compressive stresses in the key. Hence, relationship between the shearing and compressive stress induced in the key is expressed by [3] as:

$$\frac{w}{t} = \frac{\sigma_c}{2\tau} \tag{10}$$

Where: w = width of key, t = thickness of key.

Since the key and shaft materials are made up of mild steel, then

$$l = 1.571d [3]$$
 (11)

Bearing selection:

In selecting a bearing that will support the line shaft, the basic dynamic radial load service factor for radial ball bearings and the reliability of the bearing were considered. Since the machine will undergo a uniform and steady loading action, service factor (K_s) for radial ball bearing is unitary, and with an expected reliability of 90%, the dynamic load rating was taken as:

$$B = C \times k$$

$$C = W \left[\frac{L}{10^6} \right]^{1/k}$$
(12)
(13)

Where: L = life of bearing corresponding to a reliability of 90%

$$= a \left[\log_{\theta} \left(\frac{1}{R_{90}} \right) \right]^{1/b}$$

$$L = L_{90} \times 6.84 \left[\log_{\theta} \left(\frac{1}{R_{90}} \right) \right]^{1/1.17}$$
(14)

Where: L_{90} = total life of bearing in revolutions.

 R_{90} = Reliability of bearing K = 3 for ball bearings.

Result Presentation and Discussion

Power delivered to the plucker drum:

Applying equation 1 where the mass of drum is 2.5kg,

 $P_{drum} = 295W$

Electric motor power rating:

Applying the formula stated in equation 2, with $\eta_{motor} = 80\%$

$$P_{motor} = \frac{295}{0.8} = 368.75 \ W \ or \ 0.494 \ hp$$

Hence, a 0.5 hp with a speed of 2300 rpm electric motor can effectively serve as the machine's prime mover.

Diameter of Shaft:

Considering twist moment, taking $\tau = 43$ Mpa shaft diameter as expressed by equation 3 gives:

d = 7.27mm

Considering bending moment, taking $\sigma_c = 56Mpa$, d as expressed by equation 6 gives:

d = 8.14mm

Taking the larger of the two values, we have $d = 8.14mm \ say \ 10mm$

Hence, the diameter of the shaft is 10mm.







Figure 6b. Plucker drum bending moment diagram. Shear stress developed in drum:

Applying equation 9, we obtain a value for the working shear stress to be:

$$\tau_{w.s} = \frac{16 \times 2.5 \times 9.81 \times 50}{\pi \times 10^3} = 6.244 M pa$$

Taking Factor of Safety (FoS) = 2, and applying equation 8, $\therefore \tau_{drum} = 2 \times 6.244 = 12.488Mpa$

[4] states that the shear strength of aluminium to ranges between 50Mpa and 350Mpa. This means that an aluminium material subjected to a shear force during service is expected to fail when the shear stress goes beyond this range.

Hence, this design is considered safe because the working stress falls far below the maximum shear strength of aluminum.

Sunk key design:

In determining the width and thickness of key, the IS: 2292 and 2293-1974 specification on keys is adopted with the key material as mild steel, and diameter of shaft as 10mm. $\therefore w = 4mm$ and t = 4mm

The length of the key was obtained by applying equation 11. $l = 1.571 \times 10 = 15.71mm$

Bearing selection:

With a total life expected of the bearing as 80×10^6 revolutions at a 90% reliability, the life of the bearing as put forward in equation 14 is given as:

 $L = 39.2 \times 10^6$ revolutions.

Therefore, dynamic ratio expressed in equation 13 gives:

$C = 83.3 \, kN$

Comparing the dynamic load rating with values on a standard catalogue, the bearing number 412 having C = 85 kN is selected.



Figure 7a. Isometric view of 3D model showing the prime mover and plucker compartments.



Figure 7b. Top view of 3D model showing the prime mover and plucker compartments.



Figure 8. Isometric view of poultry feather plucker machine.

The specifications of the poultry feather plucker machine are shown in Table 2.

Machine Part	Parameter	Specification
A.C Motor	Power	0.5hp
	Efficiency	80%
	Speed	2300 rpm
Shaft	Diameter	10mm
Plucker Drum	Weight	24.525N
	Length	330mm
	Diameter	100mm
	Torque	1226.25Nmm
	FoS	8(min), 56(max)
	Shear stress	6.244Mpa

Tab	le 2.	Design	Specifica	tion	lS.	
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Sunk Key	Width	4mm
	Thickness	4mm
	Length	15.71mm
Bearing	Reliability	90%
	Total life expectancy	39. 2 × 10⁶ rev
	Load rating	85kN
	Number	412
Frame	Length	700mm
	Width	400mm
	Height	800mm

The Bill of Engineering Measurement and Evaluation (BEME) which gives an insight into the cost of production of the machine is given in table 3.

Table 3. BEME Table.			
S/N	Part	Cost	
1	Framework	\$ 10.00	
2	Prime mover	\$ 35.00	
3	Shaft	\$ 5.00	
4	Plucker drum	\$ 23.00	
5	Plucker fingers	\$ 25.00	
	Total	\$ 98.00	

Conclusion

The study aimed at designing a poultry feather plucker machine. In this study, design of a poultry plucker machine was carried out. The objective of the design is to ensure that the machine improves the hygiene, food safety and defeathering processes in poultry meat production. The machine is made up of four main parts viz: frame, prime mover, plucker drum and plucker fingers. In the design process, factors such as power delivered to the drum, shear stress developed in drum, compressive and shearing stress induced in the sunk key, diameter of shaft and bearing life were put into consideration. The study considers the design safe since the FoS of the drum has a minimum value of 8 and a maximum value of 56; shear strength of the drum falls below the shear stress of aluminium.

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