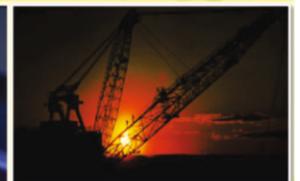# Journal of Engineering and Engineering Technology

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Theoretical Design Of A Plantain Peeling Machine

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A B S T R A C T

Keywords:

Design, Plantain, Electrically-powered, Peeling Machine, Simulation

Peeling of plantain is a major challenge in processing of plantain because of its configuration. Mainly, plantain peeling is still being done manually. This paper presents the conceptual design of an electrically powered plantain peeling machine. The machine consists of four spring-loaded peeling blades and a reciprocating arm that pushes plantain fingers through the peeling blades. The computer aided design (CAD) model of the plantain peeling machine was developed using SolidWorks CAD application software. Suitable materials were selected for the design of the machine. Design analysis of its component parts was then carried out using appropriate design equations and performance evaluation of its frame was carried out using SolidWorks CAD application software. The aim of this study is to design a machine, with 100% local-content material consideration, that will eliminate the manual peeling of plantain. The finite element analysis conducted on the machine showed a maximum stress of $2.195 \times 10^8 \ N/m^2$ and a maximum resultant displacement of 0.6959 mm being experienced at some locations on the frame when a load of 600 N was applied. Also, the minimum factor of safety value obtained was 2.414 and the estimated cost of the machine was ₦69,560. It can therefore be inferred from these results that the stress and displacement values are permissible and negligible for the machine to serve its intended purpose satisfactorily.

1. INTRODUCTION

Plantain (*Musa paradisiaca*), due to its nutritional value, has become an essential source of healthy food in the Nigerian markets today as some people use it for the management of diabetes; and it is fast becoming a sought-after fruit for everyone (Ayodeji, 2016). It has also been reported that plantain is an important world-food crop that is far more important to food security and livelihoods of millions of people in Africa, Asia and South/Central America (Frison and Sharrock, 1998; Babayemi *et al.*, 2010). Unripe plantain is a very rich source of iron, calcium, minerals, vitamins A, C and B group (Usman and Bello, 2017). It is a very reliable source of starch and energy; ensuring food security for millions of people worldwide (Umesh, 2009). It contains 2.3 g of dietary fibre per 100g. Adequate amount of dietary-fibre in the food helps normal bowel movements, thereby reducing constipation problems. Fresh plantain is rich in vitamins and minerals; 100g of plantain provides 499mg of potassium and vitamin B-complex (Umesh, 2009; Fagbohun *et al.*, 2010; Abiodun-Solanke and Falade, 2010). There is an increasing market demand for plantain and its products (Ayodeji, 2016). The increasing market demand for plantain and its products shows that there is a need to design and later develop a machine for peeling plantain effectively in order to meet this market demand and to reduce or eliminate the drudgery involved in the peeling process. Developing this plantain peeling machine will also help to eliminate the hazards involved in the manual peeling of plantain, since, majorly, its peeling is still being manually done. Due to its curvature, effective peeling of plantain with machine is still a major challenge in the world today. Therefore, the objective of this work is to design a machine for peeling plantain and simulate

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the design to ascertain its functionality under normal working conditions when it is fully developed.

2.   MATERIALS AND METHODS

The computer aided design (CAD) model of the plantain peeling machine was developed using SolidWorks CAD application software as shown in Figure 1. Design analysis of its component parts was carried out using appropriate design equations and its design evaluation was done by conducting finite element analysis (FEA) on it, using SolidWorks CAD application software as shown in sections 2.2 to 2.5 and Figures 6 to 8 respectively.
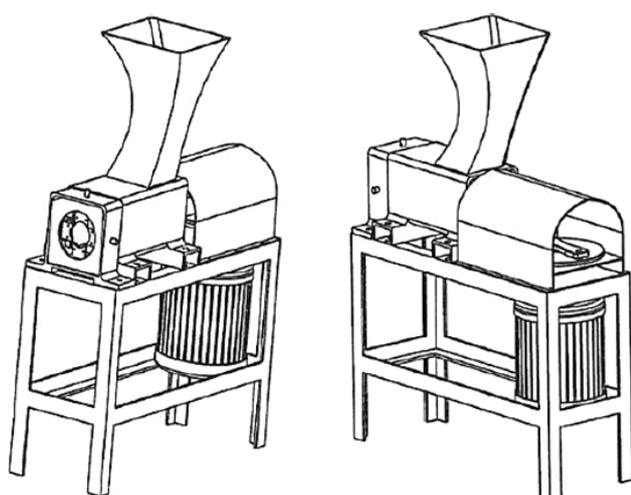

Figure 1: Isometric view of the peeling machine assembly

2.1   Components of the Machine and Selection of Materials

The machine consists of a frame, hopper, the drive unit and the peeling chamber as shown in Figures 1 to 5. The chamber consists of four spring-loaded peeling blades or cutters, whose motion is actuated by the movement of plantain as shown in Figure 3. The body covers the moving part of the machine; in addition to aesthetics, it also provides support and housing for the peeling mechanism. Medium carbon steel was selected for the body cover because of its machinability, hardness and rigidity. The flywheel, attached to the gear reduction box through the frame, should be rigid, hard and machinable. Hence, mild steel was selected for this purpose as the flywheel would be subjected to tension forces from the reciprocating link, as well as torque and speed variations from the electric motor. In addition, the material has to be machinable and withstand the reaction (shearing force) generated when abrasion occurs between the peeling chamber and the plantain, as well as withstand the generated torque. Compressive springs, with adequate stiffness to hold blades in position firmly without crushing the plantain, were selected for the machine. The material

of the springs should have high fatigue strength, high ductility, high resilience and it should be creep resistant. The major considerations here are the spring rate and its free length. Also, it should be able to provide the force required to keep the cutters in contact with the plantain cover or skin during cutting and peeling operations while at the same time accommodate variation in sizes and curvature of plantain fingers. This force should be less than the force exerted on the plantain by the reciprocating hammer but strong enough to withstand unripe plantain and mild in order not to crush the plantain.
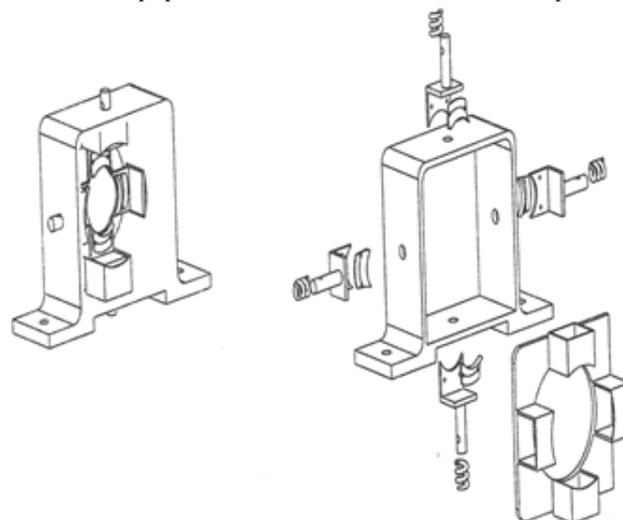

Figure 2: Exploded View of the Peeling Chamber of the Machine
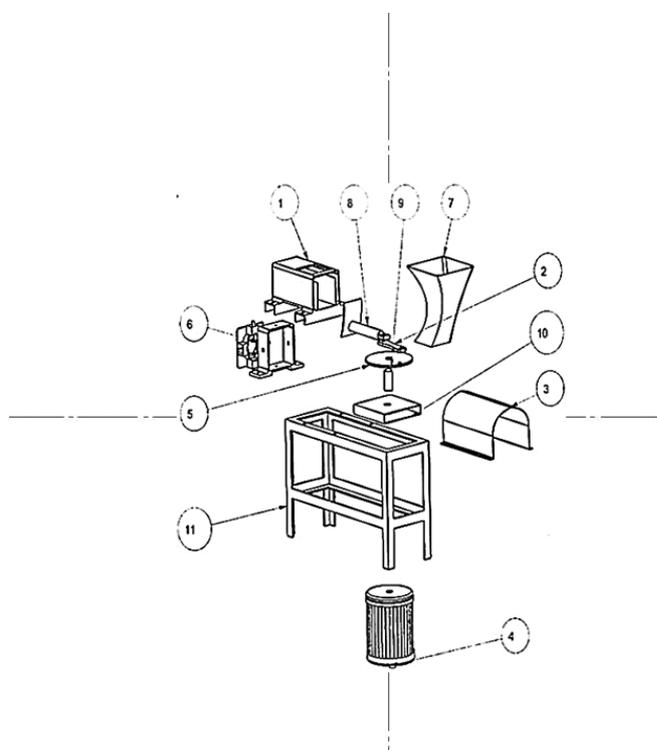

Figure 3: Exploded View of the Peeling Machine; (1) Cutting chamber; (2) Connecting rod; (3) Drive cover; (4) Electric motor; (5) Flywheel; (6) Cutter; (7) Hopper; (8) Push rod; (9) Pin; (10) Roll box; and (11) Machine stand or support.
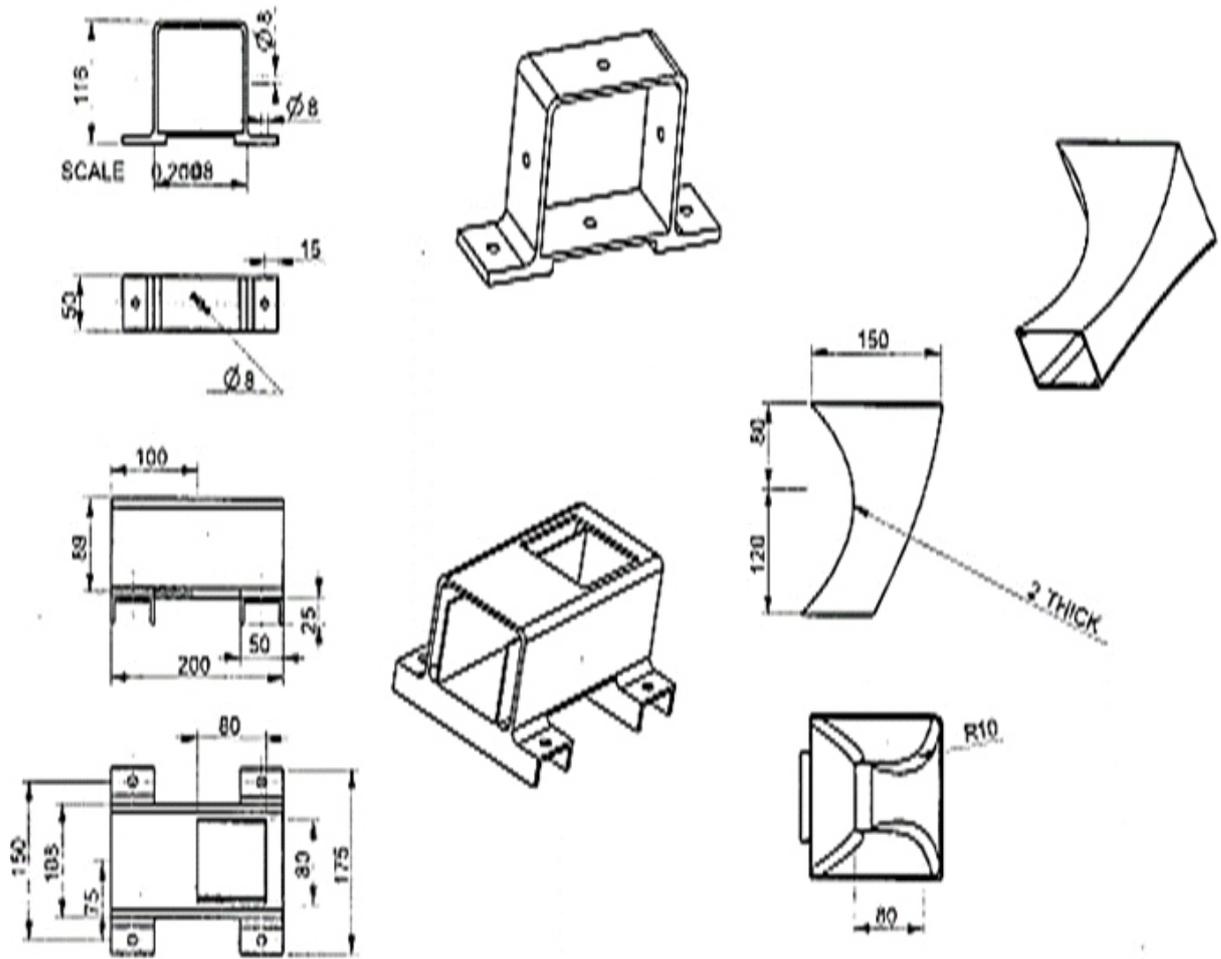
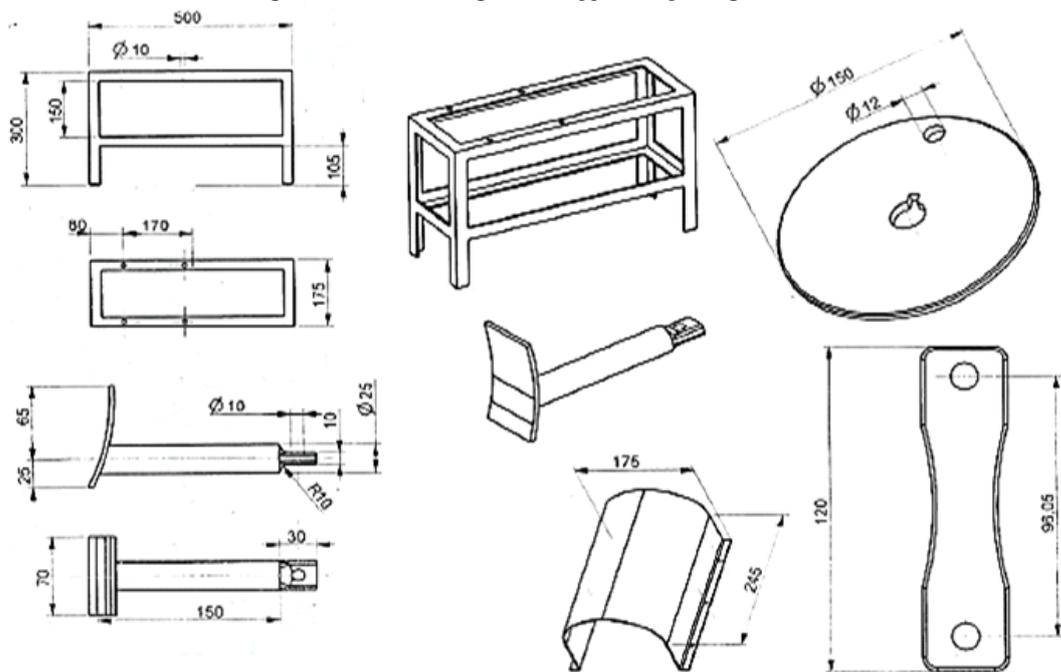Figure 4: Detail drawing of the hopper and peeling chamber

Figure 5: Detail drawing of other component parts of the machine

Plantain fingers are fed through the hopper unit into the peeling chamber. A reciprocating arm or rod (which is made of mild steel) helps in pushing plantain finger against the peeler as it passes through the chamber while the peels are collected through the chute to the machine base. The movement of the peeler is actuated by the movement of the plantain and the springs enable the peeler to remain in contact with plantain curvature. The relative motion between the peeler and auger shafts as well as the linear motion of the plantain finger produces the required peeling. The machine frame supports other parts of the plantain peeling machine. The frame is subjected to the direct weight (compressive forces) of the plantain finger and other members of the machine. It is also subjected to torque and vibration from the electric motor and peeling chamber. The desired material should be of high rigidity, hardness, adequate toughness and must possess good machining characteristics. For this purpose, $50 \times 50 \times 3$ mm angle iron (mild steel) was selected.

2.2 Determination of Shearing Force for the Plantain Peel

According to Obeng (2004), the average force required to shear a plantain pulp is 33.15 N. Based on the findings of Asoegwu *et al.* (1998) on mechanical properties of plantain fruit, the shear force required to slit and peel plantain skin (F_p) was assumed to be equal to the average force required to shear or slice a plantain pulp. Moreover, considering the shear strength of the raw plantain peel and the area under shear, the impact force required to shear the raw plantain may be obtained from Equation (1) and the area under shear can be determined using Equation (2). According to Obeng (2004); Ugwuoke *et al.* (2014); Obayopo (2014), the maximum length of plantain is 300 mm and its average diameter is 50 mm.

$$F_p = A_p \times \tau_p \qquad (1)$$

$$A_p = \frac{\pi D_p^2}{4} \qquad (2)$$

Where: F_p is the Force required for shearing the raw plantain peel; A_p is the Area under shear stress, τ_p is shear stress of the raw plantain and D_p is the diameter of the raw plantain.

2.3 Spring Design

By making reference to section 2.1, Equation (3) was used to calculate the spring rate or stiffness of each of the springs that were incorporated into the peeling chamber (Khurmi and Gupta, 2008).

$$k = \frac{W}{\delta} \qquad (3)$$

Where: k is the spring stiffness; W is the average load on spring; and δ is the deflection.

Each spring needs to deflect by 20mm in order to accommodate up to 70mm diameter of plantain finger. The force required in the machine will be equal to the force resisted by the blades or the average load on spring (W), which was assumed to be taken up equally by the four blades as expressed by Equation (4).

$$\therefore W = \frac{F_p}{n} \qquad (4)$$

Where: F_p is 33.15 N as stated in section 2.2 and n is the number of springs in the machine, which is 4.

$$\therefore W = \frac{33.15}{4} \approx 8.3 \ N$$

From Equation (3), $k = 8.3/20 = 0.415$ N/mm

2.4 Motor Required.

According to Ugwuoke *et al.* (2014), a 0.37 HP gear motor, with speed 144 rpm, was selected because of its low speed and low cost. According to Khurmi and Gupta (2008), Equation (5) can be used to determine the speed of the reciprocating arm, (V_p).

$$V_p = \frac{2LN'}{60} \qquad (5)$$

Where: L is the distance covered by forward stroke of the link, which is equal to the length of the longest plantain finger (i.e. 0.3 m or 300 mm); and N is number of revolutions per minute of the gear motor.

$$\therefore Vp = \frac{2 \times 0.3 \times 144'}{60} = 1.44 \text{m/s}$$

According to Khurmi and Gupta (2008), to determine the torque produced by the motor, Equation (6) was used.

$$T = \frac{P \times 60}{2 \pi N} \qquad (6)$$

Where: P is 0.37 HP or 276 W.

$$\therefore T = \frac{276 \times 60}{2 \times \pi \times 144} = 18.3 \text{ Nm}$$

2.5 Connecting Rod Design

According to Rajput (2013), the maximum compressive force exerted on the connecting rod is equal to the force (F_p) required to slit and peel the plantain skin, which is 33.15 N, as stated earlier. To determine the crippling load, F_{cr} of the connecting rod, Equations (7) and (8) were used.

$$F_{cr} = \frac{\pi EI}{L^2} \qquad (7)$$

$$I = \frac{db^3}{12} \qquad (8)$$

Where: L is the length of the rod which is equal the maximum length of plantain (300 mm) as earlier stated; E is young modulus of elasticity, which is 200 GPa for mild steel; I is the moment of inertia of the cross-sectional area of the rod; d is the thickness of the material, which is 12 mm and b is the width, which is 20mm.

$$\text{Hence, I} = \frac{12 \times 20^3}{12} = 8 \times 10^3 \text{ mm}^4$$

$$\therefore F_{cr} = \frac{3.142 \times 200 \times 10^3 \times 8 \times 10^3}{300^2} = 56 \text{KN}$$

2.6   Factor of Safety of the Design

There is a need to establish the integrity or functionality of the machine frame by ensuring that factor of safety (FOS) is above 1 in order to prevent structural failure of the frame (Khurmi and Gupta, 2008; Farayibi, 2017). Equation (9) was used to determine the factor of safety by inputting values from Figure 6.

$$FOS = \frac{YS}{DS} \qquad (9)$$

Where: YS is the yield strength of the material selected for the frame and DS is the design or working stress.

3.   RESULTS AND DISCUSSION

3.1   Simulation of the Machine Frame Model

The machine frame model was simulated by conducting finite element analysis (FEA) on it in order to evaluate the design performance of the plantain peeling machine. The results of the evaluation are as shown in Figures 6, 7 and 8. The machine frame model was discretized into 340 elements and 348 nodes in order to generate its solid mesh; and a load of 600 N was evenly distributed on the frame. Figure 6, which is the finite element model (FEM) of the stress distribution within the machine frame members, shows a maximum and minimum stresses of 2.195×10^8 N/m^2 and 5.858×10^6 N/m^2 respectively being experienced at some locations indicated on the frame model. Obviously, the maximum stress was found to be lower than the yield strength of the selected frame material as indicated in Table 1. Also, a maximum and minimum resultant displacements of 0.6959 mm and 0.001 mm respectively were observed from the assessment result of the resultant displacement of the machine frame members under the influence of load as seen in Figure 7. Finally, Figure 8 shows the factor of safety distribution among the machine frame members, from where a minimum FOS of 2.414 as well as a maximum FOS of 90.48 was observed.

Table 1: Properties of the material selected for the machine frame

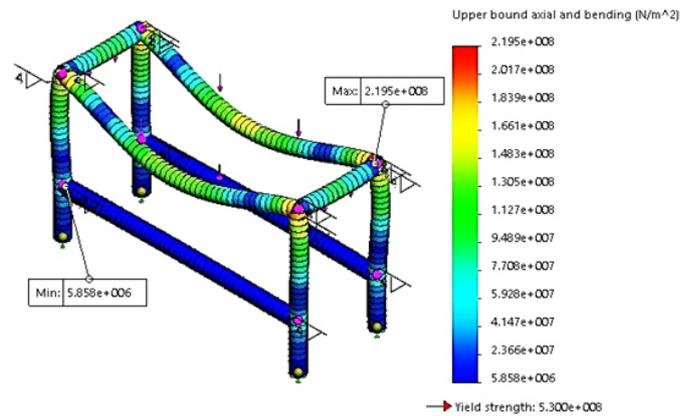| S/N	Properties	Numeric value
1	Yield strength	5.3×10^8 N/m^2
2	Tensile strength	6.25×10^8 N/m^2
3	Elastic modulus	2.05×10^{11} N/m^2
4	Poisson's ratio	0.29
5	Mass density	7850 kg/m^3
6	Shear modulus	8.0×10^{11} N/m^2
7	Thermal expansion coefficient	1.2×10^{-5} K^{-1}

Figure 6: Finite element model of stress distribution within the machine frame

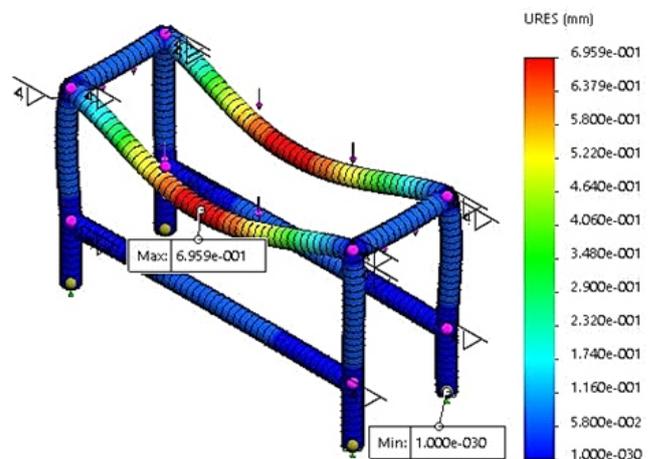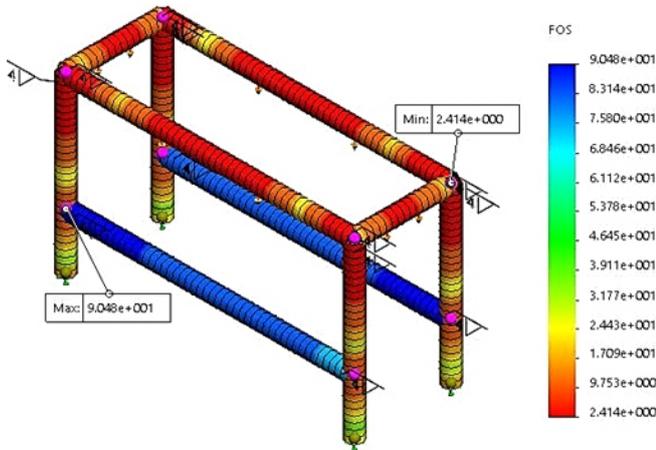Figure 7: FEM of resultant displacement of the machine frame members

Figure 8: FEM of Factor of safety distribution on the machine frame members

S/N	Description	Material and Sizes	Quantity	Rate (?)	Cost (?)
1	Stainless steel plate	1220 × 610 × 3 mm	1	30,000	30,000
2	Angle Iron	50 × 50 × 3 mm mild steel	1	2,500	5,000
3	Electric Motor	0.37 kW	1	15,000	15,000
4	Electric Cable	1.5 × 3cores	3 yards	120	360
5	Bolts & Nuts	Steel M10 1.25	30	10	300
6	Sprocket	60mm × 14teeth	1	300	300
7	Electrode	Gauge 12	1 packet	1,300	1,300
8	Cutting Disk		2	250	500
9	Chain		1	500	500
10	Paint	4 liters	1	1,300	1,300
11	Workmanship			11,000	11,000
12	Miscellaneous	-	-	4,000	4,000
				Total	69,560

3.2   Discussion

It can be seen from the simulation results obtained for stress and resultant displacement distributions within the machine frame members that some points on the frame were actually subjected to maximum stress and displacement. Although the maximum stress experienced by the frame is far below the yield strength of the material selected for it, these points are areas where failure may probably start under normal working conditions after a long time of usage. This failure may not likely occur since the minimum FOS obtained is 2.414. This FOS value is observed to be sufficient enough to prevent the machine from experiencing structural failure under normal working conditions. It can therefore be inferred from these results that the stress and displacement values are permissible and negligible for the machine to serve its intended purpose satisfactorily. Hence, the design concept of the machine shows a greater chance of getting the desired result if properly developed.

3.3   Bill of Engineering Measurement and Evaluation

The bill of engineering measurement and evaluation (BEME) for the machine is as presented in Table 2. The fully developed machine is expected to be achieved with very low cost of production as shown in Table 2.

Table 2: Bill of Engineering Measurement and Evaluation for peeling machine

4.   Conclusion

The conceptual design and simulation of plantain peeling machine have been successfully done in this study. The machine was designed to consist of a frame, cutting chamber, four cutters, connecting rod, drive cover, electric motor, flywheel, hopper, push rod, pin and roll box. The results obtained from the simulation of the machine frame showed: a maximum stress of 2.195×10^8 N/m^2, which is lower than the yield strength of the selected frame material; a maximum resultant displacement of 0.6959 mm; and a minimum FOS of 2.414. It can be inferred from the developed model of the machine and from its design analysis as well as from the results obtained from the simulation of the machine frame in Figures 6, 7 and 8 that the machine will serve its intended design purpose satisfactorily when fully developed and evaluated. Moreover, in the design of the machine, timely processing of fresh plantain, labour impact reduction and increased production capacity were given due consideration.

The machine is expected to be hygienic, very simple and safe to operate. It will be very good for small scale and large scale production of plantain products if fully developed. The development of the machine is also expected to offer a sustainable approach for processing and consumption of plantain products in developing countries like Nigeria. The design of the plantain peeling machine is a work in progress, which is expected to perform with satisfactory efficiency and design capacity if fully developed.

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