

Design of a Pulverizing and Packaging Machine for Vegetable Powder Production

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Abstract

The design of pulverized and packaging machine is discussed. The pulverizer and packaging machine were designed using appropriate design equations. From design analysis, the speed of the pulverizer shaft, belt velocity, maximum belt tension and power transmitted by the pulverizer belt were 900 rpm, 5.89 m/s, 317.9 N and 1771.2 W respectively. In the same analysis, 102.3 N of centrifugal force was estimated to be acting on the hammers, while the torque acting on the pulverizer pulley and maximum shear stress on the shaft were 18,794.4 Nmm and 2.5 N/mm². The velocity of the conveyor belt and conveyor capacity were 1.07 m/s and 30.3 tons/hr while the effective tension of the conveyor belt and horse power required to drive the conveyor belt were 201.8 N and 1.5 Hp respectively. The design was simulated using ANSYS to check the structural stability and functionality of the system. Simulation results showed that the maximum deformation experienced by the milling mechanism was 7.284 mm while the maximum static and dynamic load was not more than 131 Mpa. The beater mechanism had the maximum deformation of 1.283 x 10⁻⁵ mm while the twisting and bending moment was 25707 pa. The maximum stress imposed by the static and dynamic load on the storage device was 12 Mpa at the deformation of 0.016 mm. Packaging machine component had an average factor of safety of 3.5. The results of the design and simulations showed that the machine is safe for the selected working conditions.

Keywords

Design, Powder, Pulverizing and Packaging Machine, Vegetable

1. Introduction

Vegetables which includes fruits, leaves, fungi, bulbs, tubers, seeds, stems, roots, and flowers, are the edible parts of plant that are consumed as food (Iheanacho *et al.*, 2009). Vegetables are majorly cultivated and consumed by humans in many parts of the world particularly in the view of the fact that it plays significant role in human nutrition and consequentially beneficial to human health (Craig and Beck, 1999). Vegetables are major source of vitamins, dietary fibres, minerals and phytol-chemicals which is strongly associated with overall good health and protects the body by reducing the risk of cancer, heart diseases, anaemia, gastric ulcer, diabetes and other chronic diseases (Prior *et al.*, 2000 and Keatinge *et al.*, 2010).

The perishable nature of vegetables resulting to post-harvest losses has brought the need for further processing so it can easily be packaged and preserved for future usage. However, Vegetable processing is dominated by small-scale producers and this is done traditionally without any standardization. Traditional method of processing vegetables includes; sun drying, grinding with a mortar and pestle and hand sieving and packaging. The problems connected with this method of processing include; poor hygienic, loss of vegetable during grinding and packaging, time wastage during processing and low production rate. The development of a pulverizing and packaging machine will ultimately reduce the aforementioned challenges.

In the wake of the fact that medium scale machines are preferred to full blown ones in rural areas owing to the fact that they possess a better overall energy efficiency utilization. Aderemi *et al.*, (2009) designed and fabricated a medium scale ginger pulverizing machine. In order to produce livestock feeds in large quantity, milling is inevitable but requirements such as; reliable milling machines, uninterrupted power supply, high technical skill is apparently scarce in developing countries. In order to reduce these requirements, Adetola and Oyejide, (2015) developed a hammer mill-type bone milling machine with industrial energy conservation, economic efficiency and high mechanical simplicity. Automation of material handling with bucket elevator and belt conveyor by Ghazi *et al.*, 2014 was geared towards eliminating challenges encountered in industrial machines such as material and time wastage in handling bulk material and packaging.

The design being presented herein consists of two sections; Pulverizing and Packaging units. Based on the design, the electric motor is the source of power to drive all the rotating, translational and essential components as both milling and packaging functions are being carried out simultaneously. The Pulverizer and its unit are designed on the principle of impact and consists of a section where the dried leaves of vegetables are pulverized to powdery form while the packaging section works based on the power transmitted to it by the belt conveyor. The packaging section, which consists of belt conveyor, idler and jars, is responsible for metering, storing and packaging of the pulverized powdered product.

The materials and methods considered for the design of pulverizing and packaging machine are discussed in section 2 and the design results and discussion are presented in section 3. While the conclusion is drawn in section 4.

2. Materials and Methods

2.1 Design and Consideration

The design considerations taken into account in order to design an efficient and effective pulverizing and packaging machine are as follows;

- i. The design was carried out on the basis of the safety of the operator. Some other major hazards which may arise in the course of crushing were properly put into consideration.
- ii. All static and dynamic stresses resulting from direct loading, bending and torsion were considered in the shaft's design.
- iii. To avoid food contamination, corrosion was considered in selecting the choice of material for the design.
- iv. Dried bitter leaf was selected for the design analysis of the machine.

2.2 Material Selection

Some of the design factors taken into consideration in the choice of material for the design of the pulverizing and packaging machine so as to enhance its reliability, workability, stability, sustainability and efficiency were based on the; availability of material, rigidity and strength, cost of fabrication and overall weight. Since the machine is designed to process consumables, stainless steel was selected for the design of key components such as the; hopper, hammer, hammer shaft, milling case, sieve and metering device. Mild steel was selected for the frame as it is relatively cheap, strong, machine-able and weld-able.

2.3 Design Concept

The pulverizing and packaging machine, which consisted two sections as the name implies, was designed to work simultaneously as a unit machine. The machine components include; the hopper, shaft, metering device, v-belt, conveyor belt, electric motors, bearings, idlers, hammers, bolt and nut, replaceable sieve and mild steel angle bar frame as shown in Fig. 1.

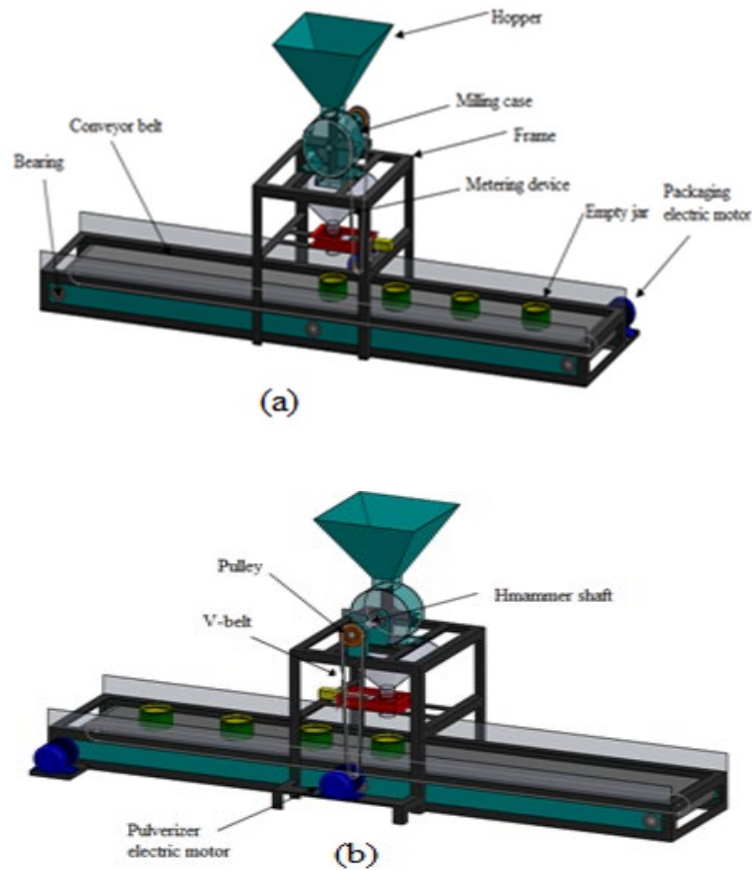


Fig. 1. The pulverizing and packaging machine (a) Front side (b) Back side

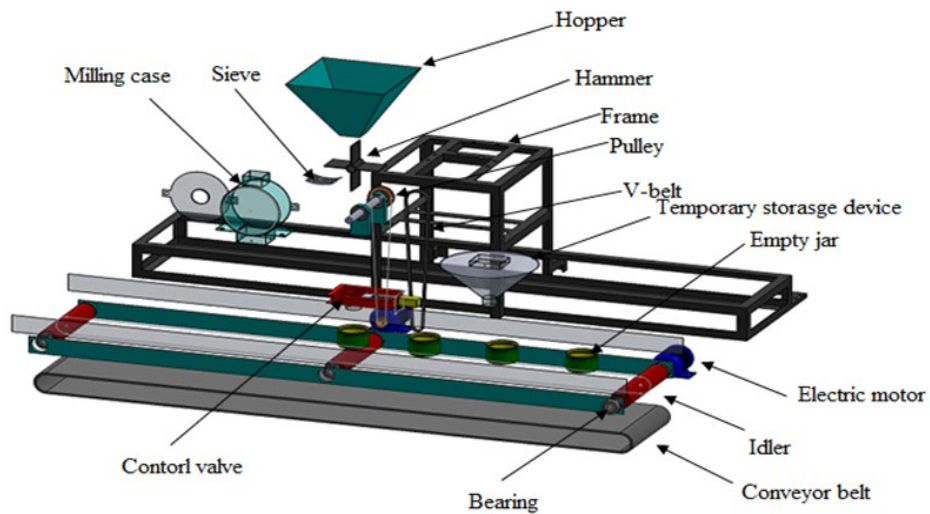


Fig. 2. The exploded view of the pulverizing and packing machine

2.4 Design Calculation of the Pulverizing Unit

The speed of the shaft was determined using (1).

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (1)$$

where:

N_1 is the speed of the motor (rev/min),

N_2 is the speed of the shaft (rev/min),

D_1 is the diameter of the motor pulley (mm),

D_2 is the diameter of the shaft pulley (mm).

The maximum tension in the belt was determined using (2)

$$T = \sigma A \quad (2)$$

where:

T is the maximum tension in N

σ is the allowable stress in N/mm²

A is the cross section area of belt in mm²

The belt velocity was determined using (3).

$$V = \frac{\pi N_1 D_1}{60} \quad (3)$$

where:

V is the belt velocity in m/s

N_1 is the speed of motor in rev/min

D_1 is the diameter of motor pulley in mm.

Equation (4) was used to determine the tension T_1 in the tight side.

$$T_1 = T - T_c \quad (4)$$

where:

T_1 is tension in the tight of the belt in N

T_c is the centrifugal tension in N

T is the maximum tension in N

The tension T_2 in the slack side of the belt was determined using (5)

$$2.3 \log \left[\frac{T_1}{T_2} \right] = \mu \cdot \theta \cdot \operatorname{cosec} \beta \quad (5)$$

where:

T_1 is the tension in the tight side of the belt in N

T_2 is the tension in the slack side of the belt in N

μ is the coefficient of friction between belt and pulley, in radian

θ is the angle of contact on the motor pulley, in radian

β is the groove angle between the pulley in degree.

The power transmitted by the V-belt was determined using (6) (Kunmi and Gupta, 2005).

$$P = (T_1 - T_2)V \quad (6)$$

where:

P is the power transmitted by the V belt in watts (W),

T_1 is the tension in the tight side of the belt in N (N),

T_2 is the tension in the slack side of the belt in N (N),

V is the velocity (ms⁻¹)

The torque on the pulley can be determined using (7) (Kunmi and Gupta, 2005).

$$T = (T_1 - T_2)R \quad (7)$$

where:

T is the twisting moment or torque on the pulley in Nmm

T₁ is the tension in the tight side of the belt in N,

T₂ is the tension in the slack side of the belt in N,

R is the radius of the shaft pulley.

The power developed by the shaft can be determined using (8) (Kunmi and Gupta, 2005).

$$P = \frac{2\pi NT}{60} \quad (8)$$

where:

P is the power developed by the rotating shaft,

N is the speed of the shaft (rev/min)

T is the twisting moment or torque pulley in Nmm

The maximum shear stress on the shaft was determined using (9).

$$\tau(\max) = \frac{16}{\pi d^3} [(\sqrt{M^2 + T^2})] \quad (9)$$

where:

M is the maximum bending moment on the shaft in Nmm,

T is the torque transmitted by the shaft in Nmm,

d is the diameter of the shaft in mm.

The centrifugal force of the hammer is as presented in equation (10) (Hadi *et al.*, 2017).

$$F_c = \frac{mv^2}{R} \quad (10)$$

where:

F_c is the centrifugal force of the hammers in N

m is the mass of the hammer (kg)

V is the velocity of the hammer shaft (ms⁻¹)

R is the radius of the hammer shaft (m)

2.5 Design Calculation of the Packaging Unit

The conveyor belt velocity was determined using (11) as culled from Daniyan *et al.*, (2014).

$$V = \frac{\pi ND}{60} \quad (11)$$

where:

V is the belt velocity in m/s,

D is the diameter of the idler,

N is the speed of the drive in rev/min,

Equation (12) gives the conveyor belt capacity

$$B.C = 3.6 \times A \times \rho \times V \quad (12)$$

where:

B.C is the belt capacity of the conveyor in tons,

A is the belt sectional area in m²,

ρ is the density of the material (bitter leaf powder) to be conveyed,

V is the conveyor belt velocity in m/s.

The mass of material loaded on the conveyor was determined using (13)

$$Q = \frac{C}{3.6 \times V} \quad (13)$$

where:

Q is the mass of material in kg,

C is the belt capacity in tons/hr,

V is the belt velocity in m/s,

The effective tension of the belt conveyor was determined using (14) (Dunlop 2004).

$$T_e = T_x + T_y + T_z + T_u \quad (14)$$

where:

T_e is the effective tension in N,

T_x is the tension to move the empty belt in N,

T_y is the tension to move the load horizontally in N,

T_z is the tension to raise or lower the load in N,

T_u is the tension to overcome the resistance of accessories in N.

The horse power required at the drive of the belt conveyor was determined using (15).

$$P_p = \frac{T_e \times V}{33000} \quad (15)$$

where:

P_p is the horse power (hp) required at drive of a belt conveyor,

V is the belt velocity

T_e is the effective tension.

2.6 Principle of Operation

The pulverizing and packaging machine comprises of two sections, that is, the; pulverizing unit (hammer-mill) and packaging unit (belt conveyor system). Both unit are powered by electric motors designed to simultaneously carry out milling and packaging operation respectively. The pulverizing unit (hopper, milling case, hammers, shaft, sieve, pulley, belt, metering device and electric motor) operates on the principle of impact. The packaging unit is a typical belt conveyor which comprises of the belt, idler, jars (spaced at equal interval) and electric motor. Once the dried leaves of the vegetable are fed into the hopper, they go directly into the milling case which houses the hammers, shaft and sieve, and crushed by the high speed rotating hammer until it is fine enough to pass through the sieve aperture. Once the milled leaf comes out of the milling case, it drops into the metering device underneath the milling case which temporarily stores, and controls the flow of the powdered product to the empty jar on the packaging unit. After the needed amount (in gram) has filled the jar, the packaging machine intermittently moves the filled jar away from the loading point for another empty jar to move to the loading point.

3. Results and Discussion

The results of the various designed values for pulverizing and packaging machine components of the machine are as shown in Table 1

The simulation was carried out using the ANSYS, the machine geometry was modelled using SolidWorks design software and the leaf was modelled in ANSYS based on the properties of bitter leaf obtained from literatures. The results of the simulation on the key components are as discussed in the following subsection.

Table 1. The resulting designed parameters of the pulverizing and packaging machine

Parameters	Value
Speed of the pulverizer shaft	900 Rev/min
Maximum tension in the pulverizer belt	317.9 N
Pulverizer belt velocity	5.89 m/s
Tension in the tight side of the pulverizer belt	309.8 N
Tension in the slack side of the pulverizer belt	9.09 N
Power transmitted by the pulverizer belt	1771.2 Watts
Torque on the pulverizer pulley	18,794.4 Nmm
Power developed by the pulverizer shaft	1,771.6 Watts
Maximum shear stress on the pulverizer shaft	2.5 N/mm ²
Centrifugal force of the hammers	102.3 N
Conveyor belt velocity	1.07 m/s
Conveyor belt capacity	30.3 Tons/hr
Mass of material loaded on the conveyor	7.87 Kg
Effective tension of the conveyor belt	201.8 N
Horse power required at the drive of the belt conveyor	1.5 Hp

3.1 Milling Chamber Mechanism

The milling chamber mechanism is a unit comprising the hopper and milling case. Discrete phase analysis was carried out in order to determine the effect of the falling dry leaf at the rate of 0.3kg/s with a distance created at the better position on the milling chamber as well as on the beater mechanism. Fig. 3 shows the result of the discrete phase analysis

As can be seen from Fig. 3, the maximum pressure exerted on the hopper, milling case and the beater mechanism is 101325 Pa. This result was imported to ANSYS in order to carry out structural and dynamic analysis of the milling chamber. These are shown in Fig. 4a and 4b.

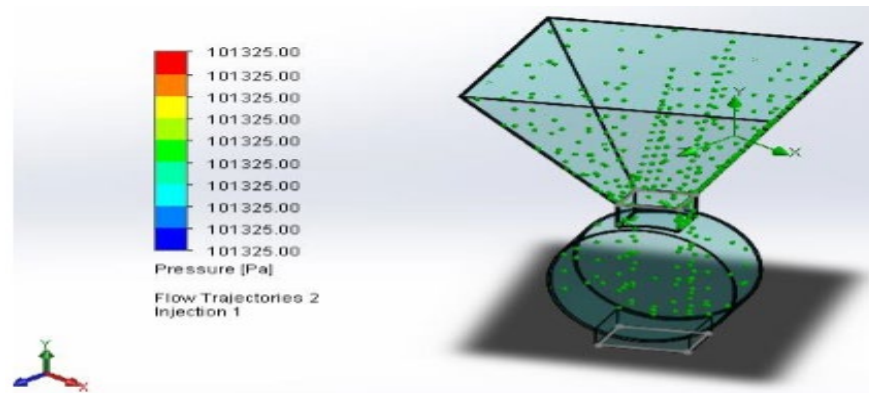


Fig. 3. Pressure exerted on the milling chamber mechanism

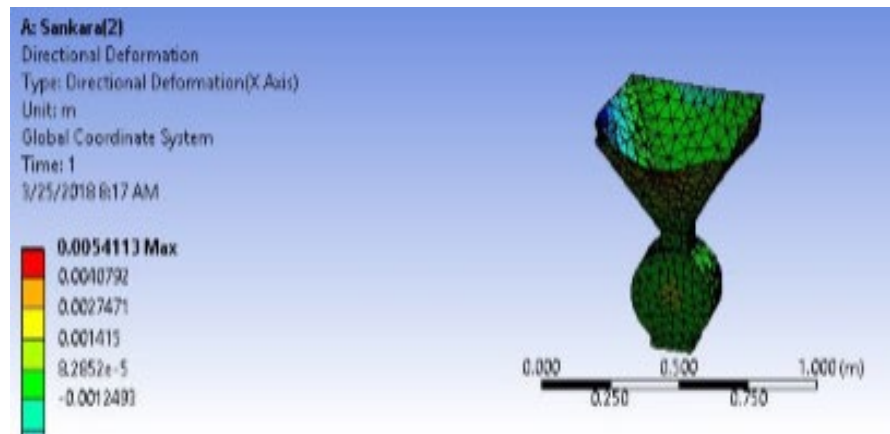


Fig. 4(a). Maximum deformation experienced by the milling chamber

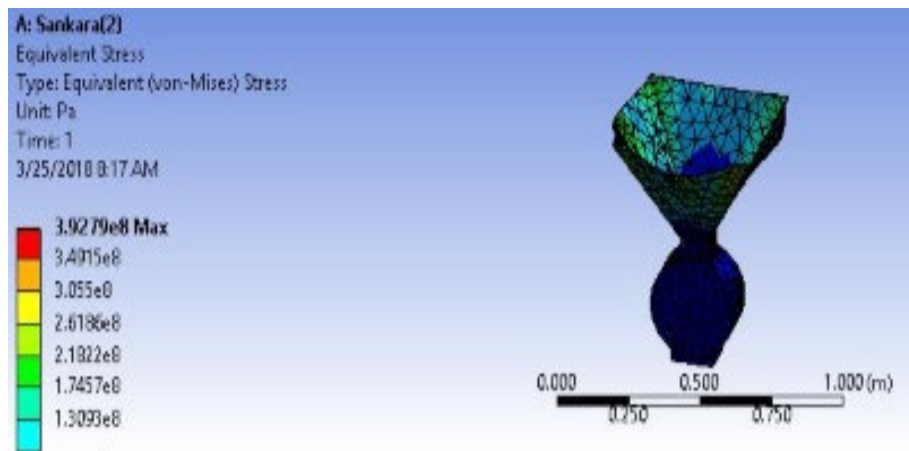


Fig. 4(b). Maximum stress imposed by static and dynamic load on the milling chamber mechanism

Inferring from Fig. 4a, the maximum deformation experienced by the milling chamber mechanism is 0.007284 m (yellow portion) which is infinitesimally small i.e., it does not affect the stability of the system and the maximum stress imposed by the static and dynamic load is on the milling chamber mechanism is predominantly not more than 131 MPa as shown in Fig 4(b). This is below the yield stress of stainless steel and it implies that the milling case can withstand the vibration it experiences due to the falling leaf at 0.03 kg/s as well as the rotation of the beater mechanism.

3.2 Beater Mechanism

The beater mechanism comprises of them hammer, shaft and pulley. One end of the beater was fixed (boundary condition) while the beater was subjected to a rotation of 900 rpm with the bearing load applied to it as well as the effect of the falling dry leaf on the beater. The result is shown in Fig. 5a and 5b.

Maximum deformation experienced by the beater is 1.2831e-8 m which is infinitesimally small as shown in Fig. 5a, i.e., it does not affect the stability of the system. Also, from Fig. 5(b), the maximum stress imposed on the beater due to twisting and bending load is predominantly not more than 25707 Pa. which is below the yield stress of stainless steel. This implies that the beater can withstand the twisting and bending load is it subjected to. This indicates that the beater is capable of beating the dry leaf until it is reduced to the size of the sieve aperture.

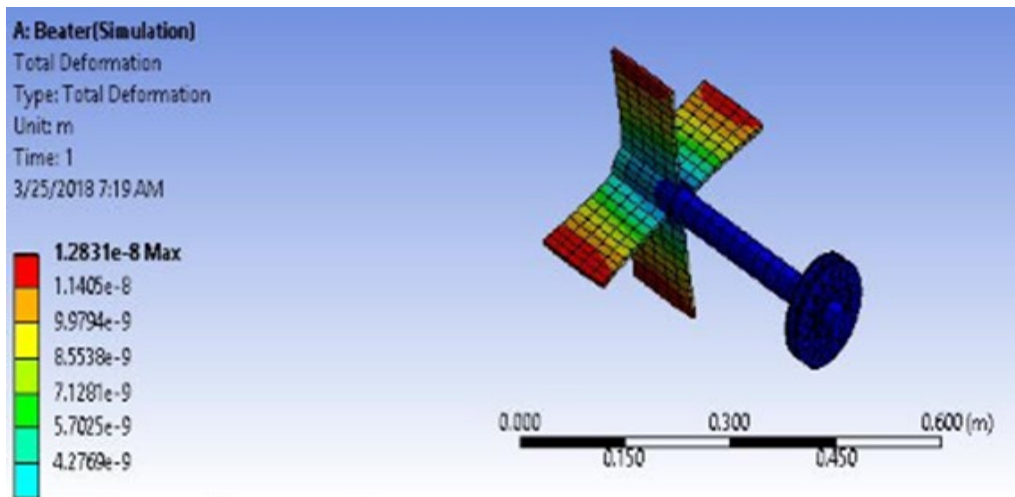


Fig. 5(a): Maximum deformation experienced by the beater mechanism

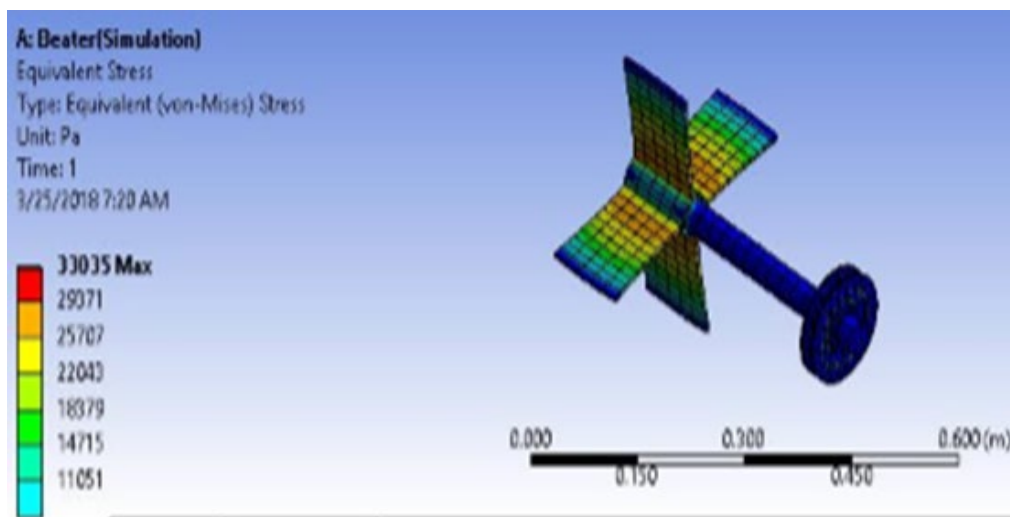


Fig. 5(b). Maximum stress imposed on the beater mechanism

3.3 Temporary Storage Device

The temporary storage was filled with the milled leaf dropping from the milling case. Discrete phase analysis was carried out in order to determine the pressure exerted on the temporary storage device by the milled leaf. The result is shown in Fig. 6.

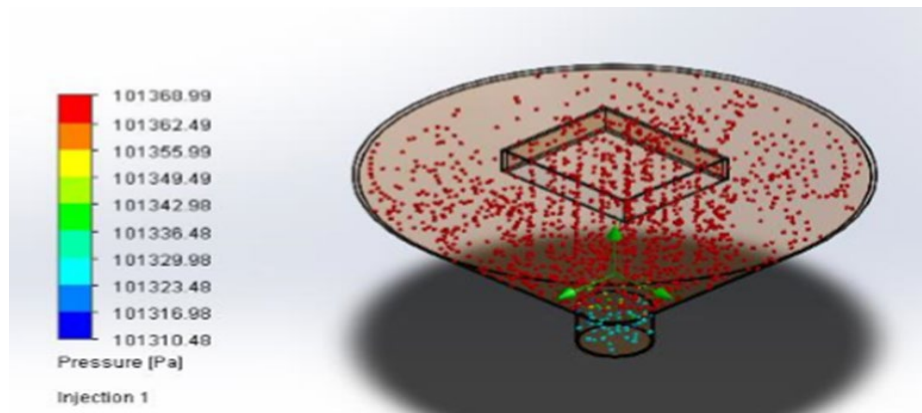


Fig. 6. Pressure exerted on the temporary storage device

The maximum pressure exerted on the temporary storage device is 10136899 Pa as shown in Fig. 6. This result was later imported into ANSYS in order to carry out structural and dynamic analysis of the temporary device when the valve was closed as shown in Fig. 7.

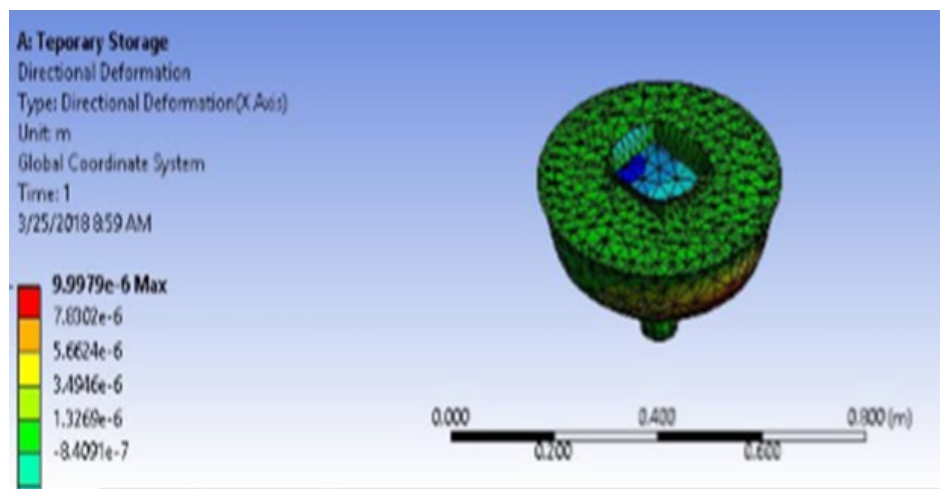


Fig.7(a). Maximum deformation experienced by the temporary storage device

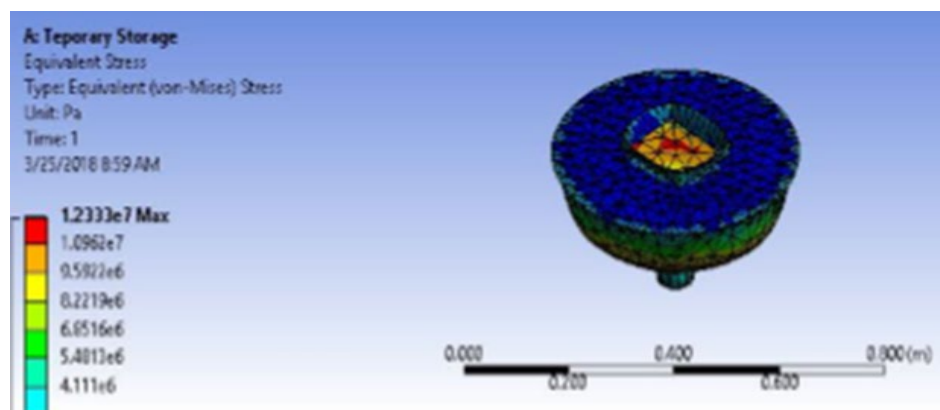


Fig. 7(b). Maximum stress imposed on the temporary storage device

The maximum deformation experienced by the temporary storage device (Fig. 7a) when the valve was closed is 1.5815×10^{-5} m (red portion) which is not enough to affect the stability of the system and from Fig. 7(b), the maximum stress imposed by the static and dynamic load is 12 MPa which is far below the yield stress of stainless steel. This implies that the temporary storage device can withstand the stress imposed on it and the valve is capable of preventing the flow of the milled leaf after the milled leaf has completely filled the jar on the packaging machine.

3.4 Packaging Machine Components with the Machine Frame Simulation (PMCMF)

The PMCMF mechanism was subjected to both static and dynamic load as well as the result of the discrete phase analysis earlier carried out. The conveyor roller was subjected to a rotation of 200 rpm and the conveyor belt was loaded with load equivalent of ten (10) filled jar of 500g/Jar. The result is as shown in Fig. 8.

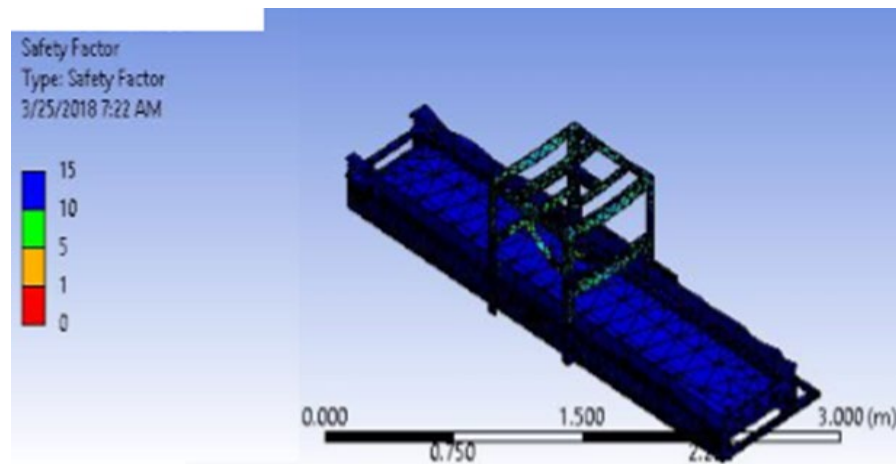


Fig. 8. Packaging Machine Component with The Machine Frame (PMCMF) Simulations

The maximum factor of safety is between 2 and 5 which implies that the system can withstand at least twice the load it is subjected to. This shows that the system will work effectively.

4. Conclusion

A pulverizing and packaging machine for vegetable powder production has been proposed and presented in this paper. The design concept adopted and the design analysis required for reliable production of vegetable powder has been discussed. The simulated results obtained indicate that the system is effective and safe for fabrication. The magnitude of stresses (including bending and twisting) experienced are not enough to impair the conditions of the machine in real life or when being used.

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References

- Iheanacho, K., Udebuani, M. E. and Angela, C., Nutritional composition leafy vegetables consumed in Imo State Nigeria, *Journal of Applied Science and Environmental Management*, vol. 13 no.3: pp. 35-38, 2009.
- Craig, W. and Beck L., Health protective effects, *Canadian Journal of Dietetic Practice and Research*, vol. 60(2), 78-84, 1999.
- Prior, R. L. and Cao, G., Antioxidant phytochemicals in fruit and vegetables, diet and health implications, *Hort Science*, vol. 35, no.4, pp. 588-592, 2000.

- Keatinge J. D. H., Waliyar F., Jammadass R. H., Moustafa A., Andrade M., Drechsel, P., Hughes J. D. A., Kar-divel P. and Luther K., Re-Learning old lessons for food: By bread alone no longer-diversifying diets with fruit and vegetables, *Crop Science*, vol. 50, no. 1, pp. 51-62, 2010.
- Aderemi, B.O, Ndirika V. I. O. and Yerima Y, Design and fabrication of a medium scale ginger pulverizing machine for rural dwellers, *Journal of Basic and Applied Sciences*, vol. 3, no. 2, pp. 389-394, 2009.
- Adetola S. O. and Oyejide A. J., Development of a bone milling machine with safety hollow and low risk of electrical damage, *International Journal of Modern Engineering Research*, vol. 5. No. 6, pp. 52-59, 2015.
- Ghazi A. T., Yousuf, H., Md. Asheke R. and Fahim A. T., Automation of material handling with bucket elevator and belt conveyor, *International Journal of Scientific and Research Publications*, vol. 4, no. 3, pp. 1-13, 2014.
- Daniyan I. A, Adeodu A. O. and Dada O. M., Design of a material handling equipment belt conveyor system for crushed limestone using 3 roll idlers, *Journal of Advancement in Engineering and Technology*, vol. 1, no. 1, pp. 1-7, 2014.
- Kunmi, R. S. and Gupta, J. K., *Machine Design*, Eurasia Publishing House (PVT.) LTD., New Delhi, 2005.
- Hadi M. I., Bawa M. A., Dandakouta, H., Ahmed M. and Kamtu, P. M. Improvement on the design, construction and testing of hammer mill, *American Journal of Engineering Research*, vol. 6, no. 3, pp. 139-146, 2017.
- Dunlop Belting, *Dunlop Conveyor Belt Design Manual*, Source <http://services.eng.uts.au> , 2004.

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