Design Of An Automated Millet Milling Machine

Kudzaishe L Mudzingwa
University of Zimbabwe
Department of Mechanical Engineering
Post Office Box MP167
Mount Pleasant Harare
Zimbabwe
kziemudzingwa@gmail.com

Tawanda Mushiri
University of Zimbabwe
Department of Mechanical Engineering
Post Office Box MP167
Mount Pleasant Harare
Zimbabwe
tawanda.mushiri@gmail.com

Abstract

This paper is of design of an automated millet milling machine that targets the small-scale manufacturing. The demand of millet is high in the lowveld region in Zimbabwe and other arid to sub-arid regions in Asia. About 8 million tonnes of millet is produced in India per annum, accumulating to 40% of pearl millet's global production. The existing problem is that millet's demand is increasing due to health and food security reasons yet milling passes through many laborious stages and millet milling machines are relatively expensive to small scale manufacturers in developing countries. Data was collected from published scholarly documents, internet, experts in the field and local companies in the food processing industry. Extreme wearing of the rods with the hammers, development of cracks in neighbourhood of the holes contacting the rods to the hammers, with the likelihood of breakaway fracture and catastrophic results. Also, rolling contact bearings give difficult problems of balance uneven mass distribution and resonance. Numerous analysis of existing machine, use of local cheaper materials and combined mechanisms it was possible to produce a low cost and efficient product. The hammers hit the grains and shatter them before they can pass through the 0.5 mm hole screen surrounding the hammers. Hammer mill size reduction uses impact as the grain hits the projecting hammers, the screen material, and the mill cast iron casing. If this design is implemented, there will be positive benefits through supporting small manufacturing enterprises (SMEs) as stated in the Sustainable Socio-Economic Transformation agenda of Zim-ASSET.

Keywords

Design, millet milling machine, Zimbabwe, size reduction.

1.1 INTRODUCTION

Millets are a group of highly variable small-seeded grasses and referred along with maize and sorghum as coarse cereals (Jaybhaye, 2014). Major species of millet grown in Zimbabwe are pearl and finger millet and this project will focus on these two species. Pearl millet is greatly grown in the semi-arid to arid zones of Africa and Asia where soil temperature can increase to an extent of causing hostile effects on germinating seeds such as less green growth and poor cropping conditions (Singh, et al., 2017). Also, pearl millet has higher efficiency in using available water as compared to sorghum and maize (Singh & Singh, 1995) . Finger millet contains amino acid methionine that lacks in the poor people's diets who feed on staple foods such as rice, plantain, cassava and maize(FAO, 2017) It can be ground and used to produce traditional foods such as puddings and porridge (Kruger, et al., 2016). They are other species such as kodo, barnyard, foxtail, proso and little millet (Bouis, 2000). Of all the types of millet, pearl millet covers above 29 million hectares of cultivated zone but it is geographically distributed, Africa and Asia have areas of 15 million and 11 million respectively as the largest producer (FAO, 2012). Farmers in developing countries tend to grow traditional varieties for family consumption and hybrids for sale in the market (Jambunathan, 1980). Millets are hard and tolerate harsh weather and can grow in areas with low rainfall and low inputs(Ushakumari, et al., 2004). This project will show the natural regions of Zimbabwe and explain where growing of millet is most suitable. As for Zimbabwe, farmers in natural regions IV and V have a comparative advantage in growing small grain crops (FAO, 2006). Ripe millet grains are either prepared for eating as grains or milled to produce meal or flour (Chandrasekara & Shahidi, 2011). Millet flour is a powdery substance made from grinding millet (Wisegeek, 2017). Some of the major products of flour produced are bread, thin porridge (bota) and thick porridge (sadza) in Zimbabwe (Mahati & Michael, 2001). Millet milling is the process in which millet is ground into millet meal. Numerous processes can be done before milling depending on the consumer's desired quality. They include drying, destoning, de-husking, debranning and roasting using ovens or heater (Institution, 2016). However, both pearl and finger millet have no husk layer and are challenging to mill due to their small size and its edible part (endosperm) inside is bound tightly to its seed coat (Sehgal & Kwatra, 2003).

1.2 BACKGROUND

There is an increased demand of millet due to health and food security reasons. The demand is high mostly in the lowveld region in Zimbabwe and other arid to sub-arid regions in Asia. This led to high demand of improved machines to process ripe millet grains.

Climate changes, increasing world population, water scarcity, increasing food prices, and other socioeconomic impacts are anticipated to cause a great hazard to food security agriculture worldwide (Saleh, et al., 2013). Millets are measured as food security crop because of their tolerance to harsh weather, hardness and could be grown with low inputs in low rainfall areas (Ushakumari, et al., 2004). In addition, millets have short period of growing seasons, are very resistant to pests and diseases and give better yield in drought prevalent areas as compared to other cereals(Devi, et al., 2011). Millet grains are nutritionally equivalent and even superior to other major cereals in terms of protein, vitamins, energy and minerals (Sehgal & Kwatra, 2003). Millets are richer in minerals, nutraceuticals and dietary fibres than rice and wheat as it contains 9-14% protein, 70-80% carbohydrates. Worldwide, cereals are the largest produced, with 2 500 000 000 tonnes being harvested globally in 2011, with 704 000 000 tonnes of wheat, 723 000 000 tonnes of rice, 883 000 000 tonnes of maize and smaller sums of minor cereals including millets (Lafiandra, et al., 2014). The global production of millet was 762 712 metric tonnes with India leading with a production of 334 500 tonnes in 2010 (FAO, 2012). European and American people now have recognized the importance of millets as component in gluten-free and multigrain cereal foods. However, in numerous African and Asian countries millet is the staple food of the people in millet producing zones and used to prepare beverages, bread, porridges, and snacks (Chandrasekara & Shahidi, 2011). Increasing millet productions in Zimbabwe require use of newer technology in improving existing processing machines bringing advantages such as increase in nutritional content of millet-based products, efficiency and reduction of energy consumption, human labour, costs, pollution and human labour (Gabaza, et al., 2018).

1.3 OBJECTIVES

- To design an automated millet milling machine that can prepare and mill finger and pearl millet.
- To design an automated millet milling machine that can mill at affordable rates to small scale manufacturers in the range of US$500 - $2000.

2 LITERATURE REVIEW

2.1.1 PEARL MILLET'S NUTRITIONAL CHARACTERISTICS

Table 1 Pearl millet nutrients (Badau, et al., 2002)

Protein(g)	**11.8**
Fat(g)	4.8
Ash(g)	2.2
Crude Fibre(g)	2.3
Carbo-hydrates(g)	67
Energy(kcal)	363
Ca (mg)	42
Fe (mg)	11
Thiamine(mg)	0.38
Riboflavin(mg)	0.21
Niacin (mg)	2.8

Pearl millet, in India it is called bajra and mhunga in Zimbabwe and is an important food crop in semi-arid zones of the world and is a food security crop because of its survival at harsh climatic exposure (Sharma, et al., 2014). About 8 million tonnes of millet is produced in India per annum, accumulating to 40% of pearl millet's global production (Sumathi, et al., 2007). Various ways are used to process pearl millet such as traditional pounding, stone grinding and modern milling. Some key processes such as de-hulling and milling are done to produce grits, flour and de-hulled whole grains. Those products are used to prepare foods such as thin and thick porridges (Talukder & Sharma, 2015). In order to get the food's nutritional value, the nutritionists are concerned about the nutritional content of the food products (Badau, et al., 2002).

2.1.2 PEARL MILLET'S PHYSICAL CHARACTERISTICS

The diameters of the grains varied from 2.8 - 3.7 mm and 1.7 - 3.3mm for major and minor diameter respectively. Grain density varied from 1.1 to 1.3 g/ml while grain hardness varied from 30.3 to 68.0N and percent floaters ranged from 48.3 to 95.0%. Grain dimensions are very essential in cleaning and specifically threshing operations. Grain density is a valuable property for transporters, marketers and an indirect method of evaluating grain density, which is also a measure of hardness is percent floaters. Milling quality is affected by grain hardness as harder grains give higher grinding yield (Badau, et al., 2002)

2.2 FINGER MILLET

Finger millet is called ragi in India, zviyo and rukweza in Zimbabwe (*Eleusine coracana*). In India finger millet comes after sorghum and pearl millet in importance. Its seed has a brick red seed coat with finely swollen surface (Shobana & Malleshi, 2007). It has a yearly yield of 1.89 million tonnes whilst grown on 1.27 million hectares (FAI, 2011). Its pericarp is thin layered, membranous and loosely attached tissue casing the whole seed and usually detaches during harvesting or through simple abrasion. Bran or seed coat, on the other hand, consists of highly pigmented testa bonded to the aleurone layer, is rigidly attached to the endosperm. (NaturopathyCure, 2017). It is an essential crop of drought-prone regions because of its ability to withstand hostile weather conditions and grow in poor and marginal soils. Finger millet is widely grown as staple food for the traditional consumers and people from the lower socio-economic level in tropical Africa (Eritrea, Ethiopia, Mozambique, Namibia, Zimbabwe), West Africa (Niger, Nigeria and Senegal,), Malaysia, Madagascar, Japan and China (Dass, et al., 2013).

2.2.1 FINGER MILLET'S PHYSICAL CHARACTERISTICS

It is a minute seeded of diameter 1.2 –1.8 mm, if the millet is hydro-treated for decortication to 33 ± 2% content of moisture and steaming for about twenty minutes at atmospheric pressure then drying to 12 ± 2% moisture content boosted the hardness of the millet to 7.1 ± 0.5 from 1.1 ± 0.2 kg/cm^2 (Shobana & Malleshi, 2007).

2.2.2 FINGER MILLET'S NUTRITIONAL CHARACTERISTICS

Table 2 Finger millet nutrients (Shobana & Malleshi, 2007)

Protein(g)	**7.7**
Fat(g)	1.5
Ash(g)	2.6
Crude Fibre(g)	3.6
Carbo-hydrates(g)	72.6
Energy(kcal)	336
Ca (mg)	350
Fe (mg)	3.9
Thiamine(mg)	0.42
Riboflavin(mg)	0.19
Niacin (mg)	1.1

2.2.3 COMBINED GRAIN PHYSICAL CHARACTERISTICS

Table 3 Grain physical properties (Badau, et al., 2002)

DIAMETER(mm)	**Minor 1.7 - 3.3** **Major 2.8 - 3.7**
HARDNESS(N)	30.3 - 68.0
DENSITY(g/ml)	1.1 to 1.3
THICKNESS(mm)	1.4 - 1.9
MOISTURE (%)	12.0 – 12.2

2.3 HAMMER MILL

2.3.1 PRINCIPLES OF OPERATION

Millet grains are loaded into a hopper on top of the hammer mill, and the grains trickle into the grinding chamber through a small regulator gate (Beckmann & Blazek, 2014).. The grains fall into the path of the 1.0 per cent chromium steel hammers, rotating from 2 000 to 4 000 rpm, either through the centre of the front plate or through the top side of the case (Beckmann & Blazek, 2014). The hammers hit the grains and shatter them before they can pass through the 0.5 mm hole screen surrounding the hammers (Clarke & Rottger, 2006). Hammer mill size reduction uses impact as the grain hits the projecting hammers, the screen material, and the mill cast iron casing (indiamart, 2017). The horizontal rotary shaft with hammers is powered by energy source usually an electric motor or diesel engine with capacity of 2 to 150 kW transmitted through V section belts. Common designs have screens or sieves around 180 degrees of the lower periphery to allow easy replacement of screens.

2.3.2 PROBLEMS ENCOUNTERED

Extreme wearing of the rods with the hammers, development of cracks in neighbourhood of the holes contacting the rods to the hammers, with the likelihood of breakaway fracture and catastrophic results (Kosse & Mathew, 2001). Also, rolling contact bearings give difficult problems of balance uneven mass distribution and resonance (Fenchea, 2012).

2.4 THEOREMS

2.4.1 DEBRANNING

This is a process of removing the grain's seed coat and can be used as livestock food additive (Koo, et al., 2017). When 3% of water is added and mixed for about five minutes can result in even removal of bran layers. A uniform debranning without deep grooves in the endosperm area was achieved by abrasive surfaces of fine particle size of less than 1000 mesh (Bottega, et al., 2009). Shear force determined experimentally will be used to determine power required for debranning.

$$P_d = Tw$$
$$P_d = FRw$$

P_d – power for debranning

F – shear force for breaking the grain

R – maximum plate radius

w – rotational velocity of plate

2.4.2 GRAIN CONVEYOR

A screw conveyor will be used. Its delivery capacity and total power required from driver will be calculated using below equations.

$$Q = \frac{3600\lambda\pi D^2 tN\rho k}{240}$$

λ – Fill coefficient of the section

D – Screw external diameter

t – Screw pitch

N – screw rotational speed

ρ – Grain bulk density

k – Flux material decrement coefficient

$$P_c = P_H + P_N + P_{St}$$
$$P_c = \frac{c_0 QL}{367} + \frac{DL}{20}$$

P_c – total conveying power

P_H – power to move material horizontally

P_N – power to operate unloaded conveyor

P_{st} – power for an inclined conveyor (zero)

$$P_{TD} = P_c + P_d$$
$$P_{TD} = \frac{c_0 QLg}{367} + \frac{DL}{20} + FRw$$

P_{TD} – Total required conveyor driver power.

2.4.3 DRYING AND ROASTING

Drying and roasting is when the grains are subjected to dry hot air in closed conditions and result in experience weight loss, volume increase and the decrease in density (Berk, 2018).Drier grains cause less sticking problems when grinding (Dijkink & Langelaan, 2002). Heat will be transferred from heating electrical elements to the grains through a stainless drum, stirrers will be rotating at 5 to 20 rpm and insulation with cotton in between is used (Hadzich, et al., 2014). The closing lid will be made of two low emission glasses separated air (Burlon, et al., 2017). Rate of transfer of heat energy will be determined using the equation below and used to size the heating element.

$$Q_d = \frac{m_d C_d \Delta T}{t}$$

$$Q_g = \frac{m_g C_g \Delta T}{t}$$

$$P_{HE} = Q_d + Q_g$$

Q_g – power consumed by heating grains

Q_d – power consumed by heating drum

m_g – mass of grains

m_d – mass of drum

C_g – specific heat capacity of millet grains

C_d – specific heat capacity of drum

T – temperature

P_{HE}- effective power used from heating elements

2.4.4 SIZE REDUCTION

A process of reducing big solid to small unit masses, coarse or fine particles is called size reduction (Sushant & Archana, 2013). In food processing, this process is the most energy consuming one and is typically done by mechanical demolition of huge fragments by compression or impact action in engineering design devices (Berk, 2018). The mechanical characteristics of solid objects have the highest influence on energy of grinding. The energy needed to fracture food is found by its tendency to crack which also depends on the food structure. Harder objects absorb larger values of energy and require a larger fracture creating energy. Moisture content significantly affects foods' mechanical properties evidenced by dry solid foods being brittle and easy to mill and need less grinding energy (Manuwa & Muhammad, 2011). An increase in water content causes an increase in food plasticity, especially when higher energy is required for grinding. In most systems of size reduction all the three forces (compressive, shearing and impact) are experienced, but when a hammer mill is used the impact forces are more significant than shearing, and compression forces are the slightest significant (Dziki, et al., 2012).

Theoretical value of energy needed to grind can be found using following formula

$$dE = \frac{dx}{x^n}$$

- dE - energy required in breaking a unit mass of diameter x about size dx (Chandar, et al., 2016)
- d_1 and d_2 represent the particle size before and after grinding, respectively.
- For Bond n =1.5 is made solution is:

$$\int E = \int_{d_1}^{d_2} \frac{dx}{x^{\frac{3}{2}}}$$

$$E = 2C\left(\frac{1}{\sqrt{d_2}} - \frac{1}{\sqrt{d_1}}\right)$$

$$C = 5E_i$$

$$E = E_i\left(\frac{10}{\sqrt{d_2}} - \frac{10}{\sqrt{d_1}}\right)$$

Bond terms E_i the work index is the sum of energy need to decrease unit mass of an object from an infinite particle size to a size of 100 μm (Chandar, et al., 2016).Taking the range of E_i of maize, 292–1017kJ/kg as that of millet (Velu, et al., 2006).

As for the design of the shaft with hammers there is use of equivalent torque from:

$$P = Tw$$

$$T_e = \sqrt{K_t T^2}$$

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

3 METHODOLOGY

3.1.1 DESIGN OF SCREW CONVEYOR

Known screw external diameter, $D = 12d_{grain}$, pitch = 0.8D, length, L = 300mm, debranning plates radius, R= 100mm, rotational speed, N = 140rpm. Selected standard motor is 0.25 HP. For screw shaft design material is AISI 304 stainless steel of shear strength 42 MPa. Therefore, taking standard shaft diameter of 25 mm according to IS 3688-1977.

3.2 DESIGN OF THE ROASTER

The drum will be of AISI 304 stainless steel and stirrers rotating at a range of 5 – 20rpm. The internal and external radii are 300mm and 304mm respectively and 900mm length. Calculating heating elements getting rating of 20 kW to compensate heat losses.

3.2.1 DESIGN OF ROASTER MOTOR

Each flight should be able to push maximum capacity which is 50kg. Selected standard motor of 0.5HP

3.3 DESIGN OF THE MILLING SECTION

Selecting standard motor of 20 HP, standard shaft diameter of 40mm and AISI 1020 for grinding shaft

from calculations.

3.4 DRAWINGS

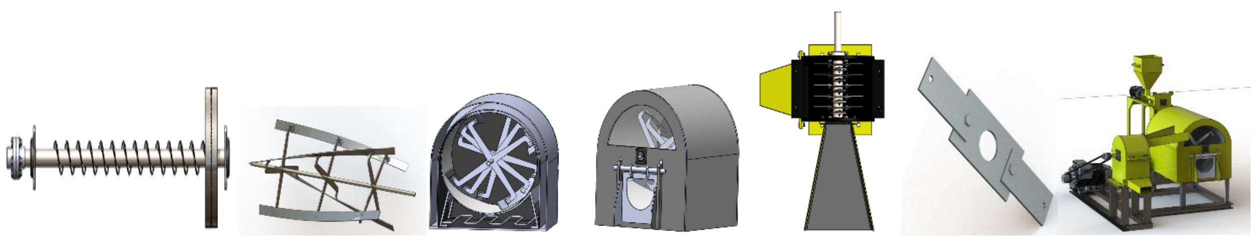
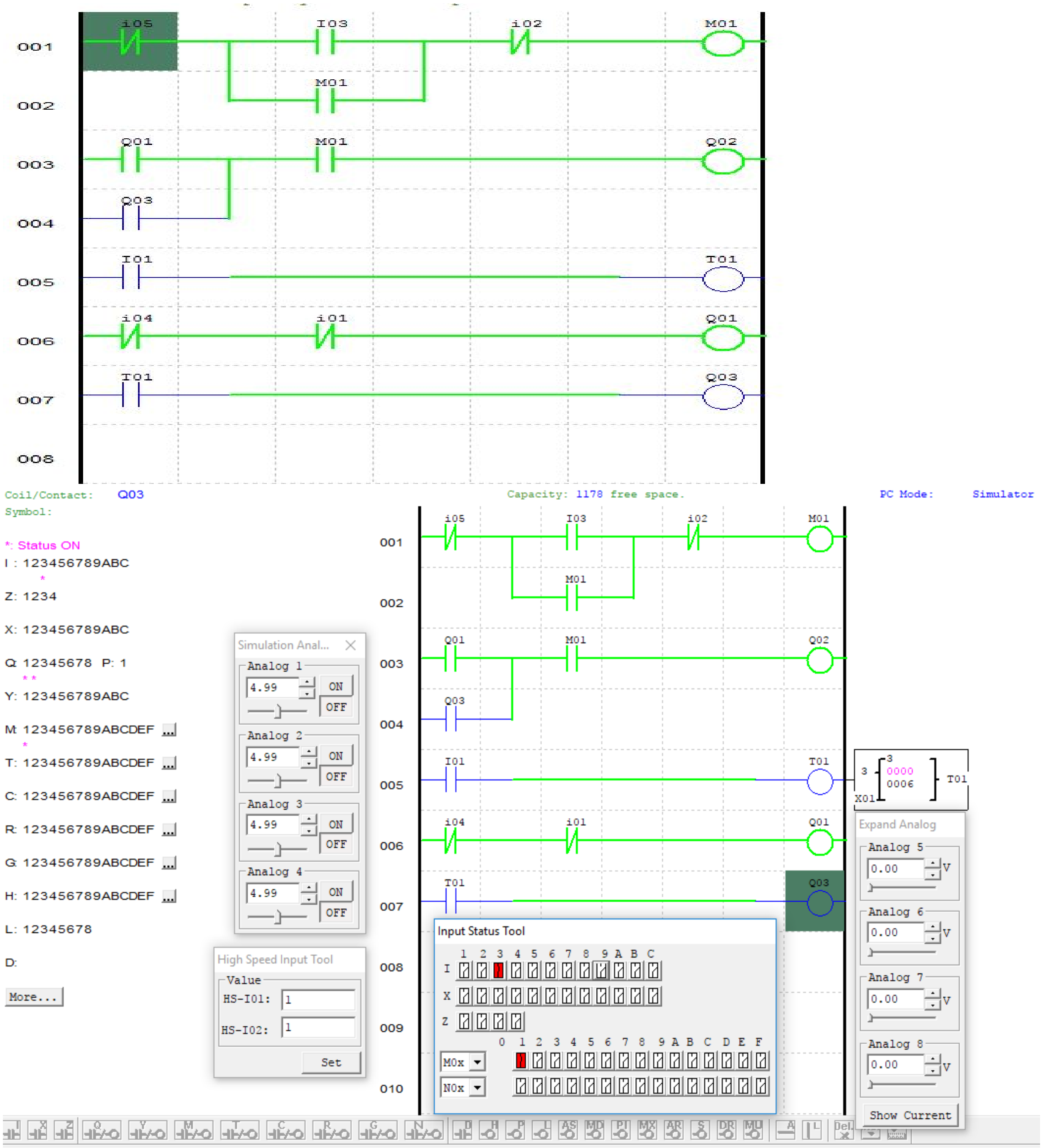


Figure 1. Assembly

3.5 MACHINE AUTOMATION

The SMT client software was used to code all the controls. All the processes from debranning though roasting up to grinding were automated to reduce human labour, hazards, machine damage and increase accuracy, meal quality and more. If loaded grains in the hoper at the debranning section have foreign objects such as stone, the machine notifies the operator and the inlet to the screw conveyor is automatically kept closed. The operator has to remove the objects. Also, there are mass sensors in this hoper and if the mass of grains reaches 0 the machine gives the operator an allowance time of 5 minutes before it notifies and automatically shut down. There is a grain temperature sensor in the roaster, if the grains reach maximum temperature it means there are ready, the machine notifies and automatically open the oven outlet. If the mass sensor in the roaster reads 0 the roaster automatically shut down after notifying the user. The grinding section has a sensor for foreign objects. If there are these objects in loaded grains, the operator is notified and inlet to hammers is automatically kept closed. Finally, there is a mass sensor in the ejector, if grinding is complete, no meal being ejected and it reads 0, the user is notified before auto-shutdown in 6 minutes. All notification before any control action is for the operator to override the auto-controls.

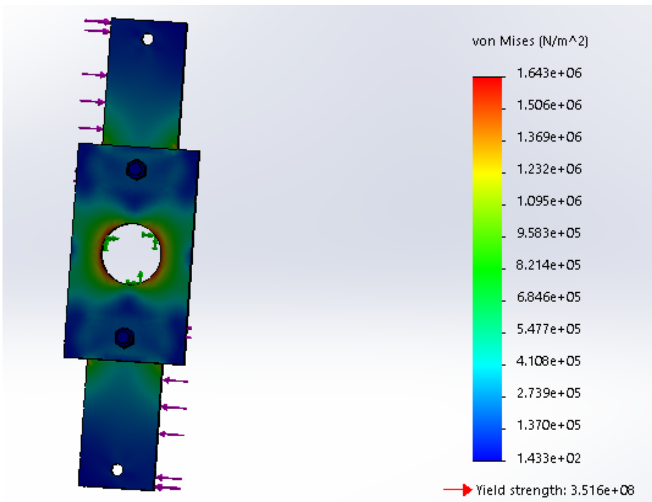


4 RESULTS AND DISCUSSION

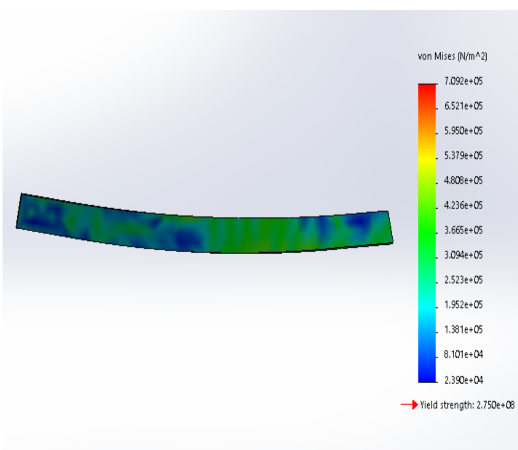
Within the given budget of $500 - $2000 and time, the automated millet milling machine successfully designed. The machine can prepare and mill millet grains into millet meal as stated in the objectives. To keep the cost as low as possible and promote local producers, raw materials were acquired locally. The design project was then successful.

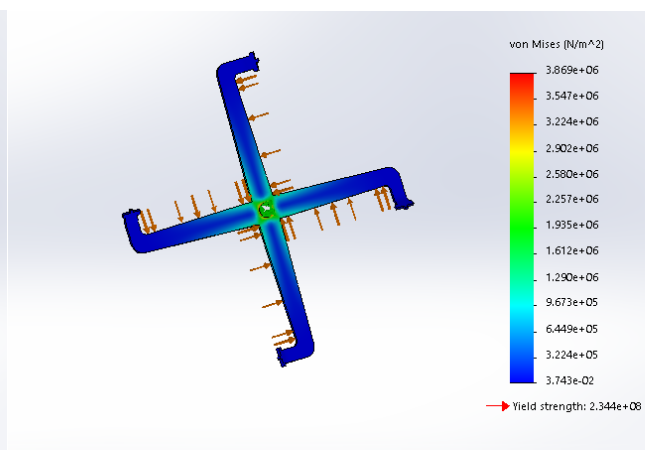
4.1 VON MISSES STRESS ANALYSIS

4.1.1 HAMMERS

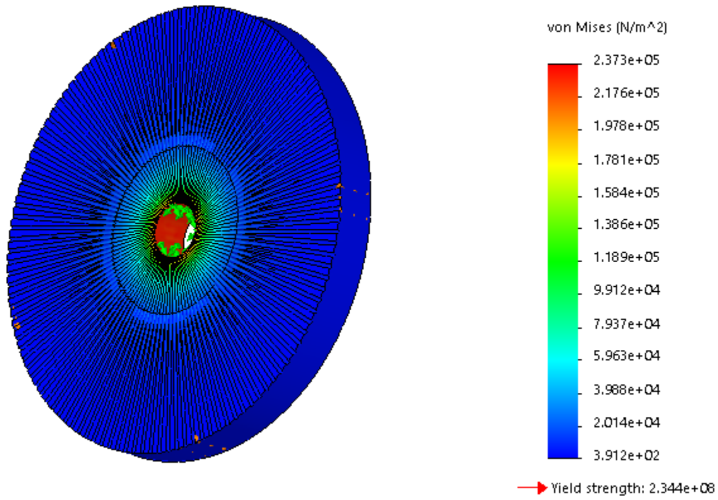


4.1.2 STIRRER FLIGHTS



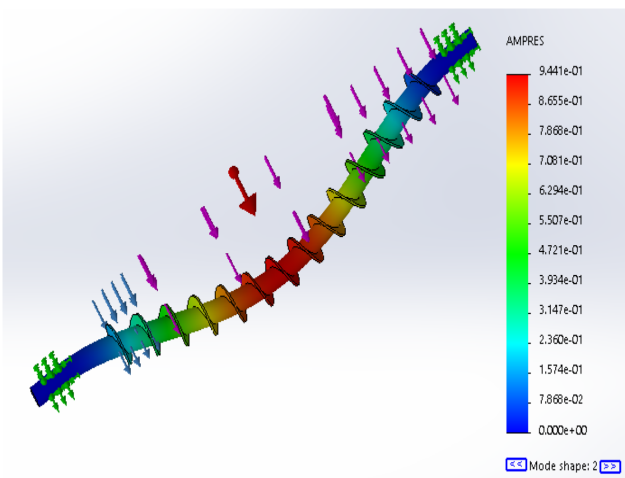


4.1.3 DEBRANNING PLATES



4.2 MODAL ANALYSIS

4.2.1 SCREW CONVEYOR

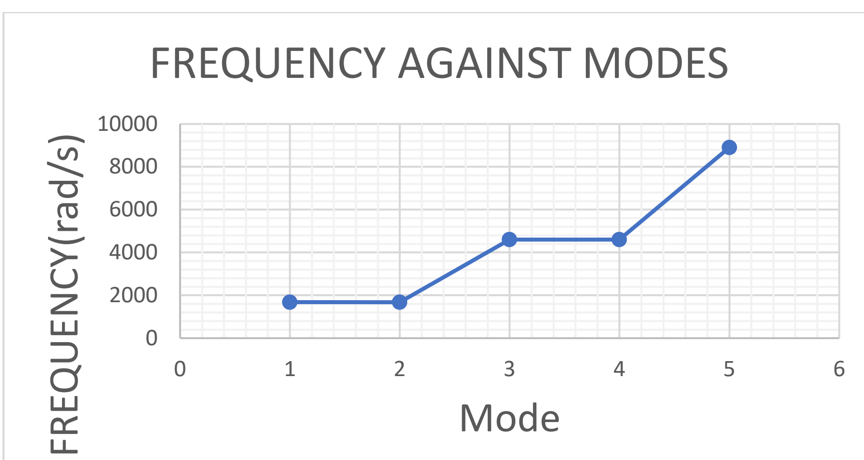


Mode List

Frequency Number	Rad/sec	Hertz	Seconds
1	1682.9	267.84	0.0037336
2	1683.6	267.95	0.003732
3	4598	731.8	0.0013665
4	4600	732.1	0.0013659
5	8904.9	1417.3	0.00070559

Mass Participation (Normalized)

Mode Number	Frequency(Hertz)	X direction	Y direction	Z direction
1	267.84	0.60631	5.7325e-09	0.020072
2	267.95	0.020067	6.7649e-11	0.60619
3	731.8	1.2187e-05	2.5668e-07	5.4182e-07
4	732.1	4.7386e-07	4.3041e-09	1.2248e-05
5	1417.3	0.11085	6.7178e-09	0.0060707
		Sum X = 0.73724	Sum Y = 2.735e-07	Sum Z = 0.63234



4.3 RECOMMENDATIONS

- Bran from the grains fall of through a sieve which connects the debranning section to the roaster. To keep the working space clean and to benefit the local livestock, the bran can be collected under the sieve.
- Unsafe acts and conditions can be absolutely avoided.
- These devices stop the machine immediately in times of emergency and should be accessible to the operator as easy as possible. They should be marked in red and checked frequently if they are working.
- Maximum temperature of grains from is too high for human to feel. The operator is recommended to wear gloves during manual cooling of grains and also collect grains using high density plastic or metal containers.
- The machine uses high voltage which is dangerous to any human or livestock. The operator is recommended to check if there are any loose or naked electric wires.
- The operator should check if there are no obstacles on rotating parts and also the operator should not to wear loose clothing.

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6 BIOGRAPHIES

Kudzaishe L Mudzingwa was born on the 31st of October 1995 at Chiredzi General Hospital, Zimbabwe. He finished his "O" level in 2012 and "A" level in 2014 passing his science subjects and received prices amongst the best students. All that got him to begin to study a BSc. Honours Degree in Mechanical Engineering at the University of Zimbabwe in 2015. Kudzaishe aspires to pursue a career advanced technology in solid mechanics and dynamics. Apart from academics, he enjoys playing cricket and chess.

Dr. Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters in Manufacturing Systems and Operations Management (MSc. MSOM) (2011-2012) from the University of Zimbabwe, Harare, and a Ph.D. from the University of Johannesburg, South Africa (2013-2017). He also obtained a Certificate with Siemens in Programmable Logic Controllers in the year 2013 where he worked with SCADA and PLC Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a Senior Lecturer and Senior Research Associate at the University of Zimbabwe and University of Johannesburg, respectively. In the past (2012-2013), he has also lectured at the Chinhoyi University of Technology, Zimbabwe, lecturing mechatronics courses. He has also been an assistant lecturer for undergraduate students at Chinhoyi University of Technology, tutoring advanced manufacturing technology, robotics and machine mechanisms.