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DESIGN AND DEVELOPMENT OF A SECOND-CLASS LEVER FOR MAIZE SHELLING OPERATION

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A B S T R A C T

In this study, a lever was designed for manual shelling of maize. The lever is made up of a 30 mm diameter rod with a 10 mm diameter hole drilled at one end and a 20 mm diameter rod welded vertically to the rod, 400 mm from the other end. The maize ear is placed inside a 70 mm diameter tube before shelling and when the lever is pushed the maize ear is forced through the shelling tube, and in the process the seeds fall off the cob. Explicit Dynamic Analysis of the lever done in Ansys showed that the lever will effectively shell maize ears without damage to both seed and cob. Results of the Analysis gave 0.26485 m and of -9.7419e^{-8} m as maximum and minimum values of directional deformation, 76386 Pa and 0 Pa respectively as maximum and minimum values of equivalent stress, 9,4005e^{-6} m/m and 0 m/m as maximum and minimum values of equivalent strain, 29.507 m/s^2 and 7e^{-2} m/s^2 as maximum and minimum values of total acceleration, and 21085 Pa and -23604 Pa as maximum and minimum values of shear strain respectively. This study therefore develops and new and cost-effective means of shelling maize ears which requires neither electricity nor any sort of fuel to operate.

1. INTRODUCTION

Maize, (which is also known as corn) means that which can sustain life (Malhi et al., 2021; Backer et al., 2018; Ding et al., 2016). Maize is a staple food in many parts of the world, especially in sub-Saharan Africa (Ali *et* al., 2017; Watts et al., 2021; Whitmee et al., 2015). Presently, total maize production worldwide surpasses that of wheat and rice (Wijerathna-Yapa & Pathirana, 2022; Kumar et al., 2019; Wang & Shelomi, 2017). Maize can be consumed directly by humans, used for corn ethanol, animal feed and other products like corn syrup and corn starch (Torres et al, 2016). Maize contains carbohydrate, proteins, iron, vitamin B, and minerals (Amanullah & Fahad, 2018; Hanson et al., 2015; Shewry & Hey, 2015). Small householder farmers are the largest producers of maize in sub-Saharan Africa (Almadani, 2022; Makaruk et al., 2021; Savary et al., 2020).

Maize processing involves the following steps: harvesting, drying, de-husking, shelling, storing, and milling (Manyi-Loh & Lues, 2023; Kn et al., 2023; Chang et al., 2021). Shelling or threshing is one of the most important processing operations done on maize to bring out its quality and increase the shelve life (Alemu

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et al., 2021). Maize shelling is the process of removal of the kernel, leaving only the cob or seed rack (Nwakire et al., 2011). Shelled maize kernels can be used to provide a wide range of food products, such as: cornmeal, corn flour, corn flakes, and other processed maize products (Karlovský et al., 2016; García-Casal et al., 2018; Singh et al., 2019). By shelling maize, the kernels become more accessible for cooking, grinding and further processing, contributing to food security and meeting the nutritional needs of populations (Logan, 2020, Ekpa, 2020; Roosevelt, 2017). Also, shelling reduces the volume of maize, making it easier to store and transport (Harish et al., 2022; Meyer et al., 2020; Tandzi & Mutengwa, 2019). Shelled maize is less prone to spoilage and infestation by pests, as the removal of the protective husk reduces the moisture content and provides less favorable conditions for microbial growth (Hoffmann et al., 2019; Bala, 2016).

It is a well-known fact that traditional agricultural farming is not sustainable. It requires new engineering advancements and innovations to remain competitive in both local and global markets (Andreoni & Tregenna, 2020; Salvador et al., 2022b; Folke et al., 2021). Agricultural mechanization reduces human labor, increase efficiency and creates a safer working environment. Hence, the development of advanced sensing and intelligent control systems in traditional agricultural operations is expanding immensely due to their economic and environmental benefits. However, automation solutions must consider and focus on technologies tailored to local conditions and the specific needs of farmers with respect to their nation and region (Clarke, 2017; FAO and AUC, 2018; Fielke et al., 2018). For instance, farmers in the rural areas of most developing countries may not have access to stable electricity supply. Also, the prices of fuels which may serve as alternatives to electricity in driving and powering agricultural machines are constantly increasing. This again makes it almost impossible for subsistent farmers to embrace certain automation solutions and technological trends in land cultivation, harvesting, processing and storage of agricultural products. One way of solving this problem is to design agricultural machines that can be manually operated, thereby eliminating the need for electrically powered or fuel driven prime movers. These machines should be capable of performing relatively the same work as their electrically powered or fuel driven counterparts, except for the fact that they will require a human operator which can be exhausting at times, especially when it has been operated for a long time. In the design of such machines, several important factors are considered to ensure their usability, safety and efficiency. One very important factor to consider in such design is ergonomics. The machine must be designed to accommodate the natural movement and range of motion of the human body. Factors such as reach, grip, and posture must be given adequate attention to minimize strain and fatigue on the user. Other factors to be considered include: ease of loading and unloading materials, tool accessibility, safety of operation, etc. One very effective way of controlling or operating manually actuated machines is through the use of a lever (Davis et al., 2021; Guobao et al., 2019).

The aim of this research is to design and develop a second-class lever for maize shelling operation. Specific objectives include:

i. To develop a CAD model of a lever, capable of actuating a maize shelling machine using Solidworks software.
ii. To simulate and conduct explicit dynamic analysis of the developed lever using Ansys software.
iii. To fabricate the lever using optimum parameters derived from the analysis of the model.

2. LITERATURE REVIEW

The lever is a movable bar that hinges on a fulcrum attached to a fixed point. It is a simple machine consisting of a rigid rod pivoted at a fixed hinge, called fulcrum (George, 2017). Levers are used to exert a large force over a small distance at one end by exerting only a small force over a greater distance at the other end (Bibha, 2020; Team, 2017). A lever is divided into three parts: load (output force), effort (input force) and the fulcrum (Mo et al., 2022; Schack, 2021). Levers are classified as first-class, second-class or third-class lever, based on the relative positions of the load, effort and fulcrum (Davidovits, 2008).

3. METHODOLOGY

The materials used in this research work include: 30 mm diameter mild steel rod, 20 mm diameter mild steel rod, 1.5 mm thick stainless-steel plate, rubber pad, Solidworks software, Ansys software, PC, welding machine and accessories, etc.

3.1 Design Methodology and Analysis

3.1.1 Design concept and considerations

The design of the lever was based on the following concept and considerations:

i. The force required for shelling maize will be produced by pushing the lever down.
ii. The force applied on the handle of the lever will be evenly distributed to four steel rods so that four maize ears will be simultaneously shelled, each time the lever is pushed down.

3.1.2 Design of the lever

The free body diagram of the lever is shown in Figure 1.

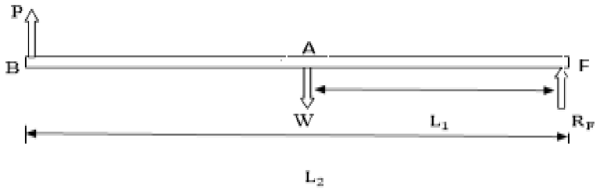

Figure 1. Free body diagram of the lever

The load, W, and the effort, P, act at right angles to the lever at points A and B, respectively. The reaction force, R_F, at point F was determined using Equation (1).

$$R_F = \sqrt{W^2 + P^2 - 2W \times P\cos\theta} \quad (1)$$

Where;

θ = angle of inclination of the lever

The lever being subjected to both bending and twisting moment was designed based on equivalent bending moment as described by (Khurmi & Gupta, 2005; Sharma & Aggarwal, 2006) in equation 2. Hence, diameter of the lever was determined as 28.3 mm. Thus, a standard 30 mm mild steel rod was used in fabricating the lever.

$$d = \frac{16}{\tau\pi}\left[\sqrt{(K_b M_b)^2 + (K_t M_t)^2}\right]^{1/3} \quad (2)$$

Where;

K_b = Combined shock and fatigue factor for bending (1.5)
K_t = Combined shock and fatigue factor for twisting (1)
M_t = Maximum twisting moment
τ = Shear stress due to twisting moment
M_b = Maximum bending moment

3.1.3 Description and operational process of the lever

The lever is designed to produce the force required for shelling maize. It is made up of a 30 mm diameter rod of length 1200 mm.

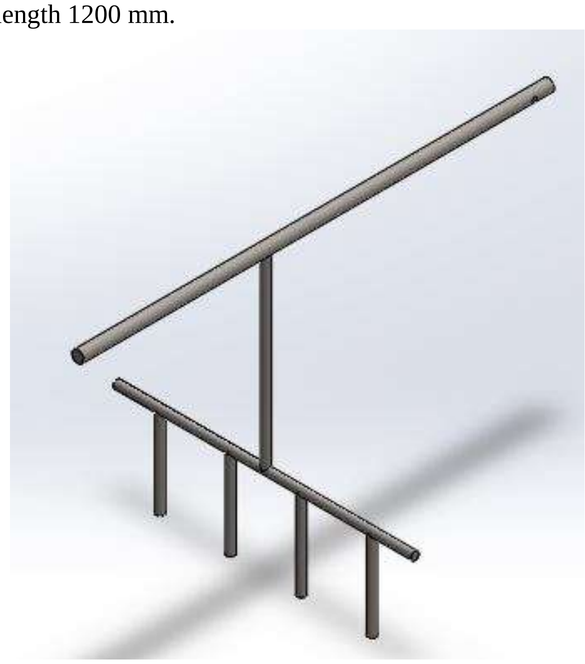

Figure 2. Isometric view of the lever

A 10 mm diameter hole is drilled at one end of the rod while a 20 mm diameter rod is welded vertically to the rod, 400 mm from the other end. Another 20 mm diameter rod with four 220 mm long bars is welded to the lower end of the rod. Figures 2 and 3 show the isometric and orthographic views of the lever respectively.

When the lever is pushed, maize ear is forced through a shelling tube and in the process the seeds fall off the cob. The shelling tube (Figure 4) consists of two tubes of internal diameters 70 mm and 40 mm, joined together. The maize ear is placed inside the 70 mm diameter tube before shelling and after shelling, the cob passes through the 40 mm diameter tube.

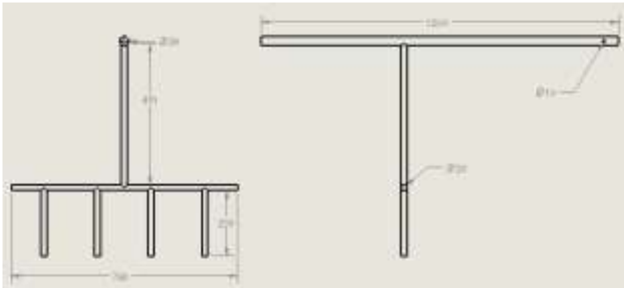

Figure 3. Orthographic view of the lever

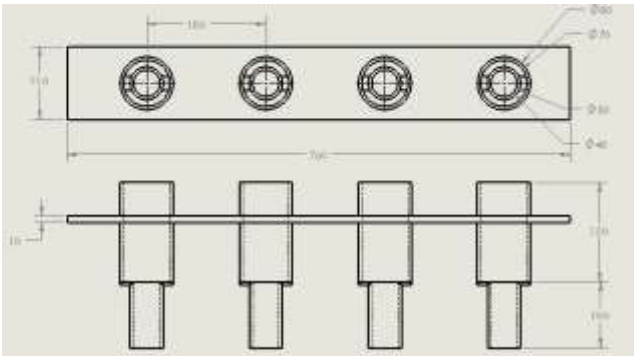

Figure 4. The shelling tube

3.2 Procedure for the Explicit Dynamic Analysis of the Lever using Ansys Software

The lever and shelling tubes were first designed in Solidworks and imported into the Ansys software.

Table 1. Mechanical and chemical properties of maize cob and seed

Property	Cob	Seed
Young's Modulus (Pa)	$2.1e^{+9}$	$7.3e^{+9}$
Poisson'sRatio	0.127	0.4
Bulk Modulus	$1.14e^{+10}$	$3.5e^{+10}$
Shear Modulus (Pa)		$1.36e^{+8}$
Tensile Ultimate Strength (Pa)	$1.7e^{+7}$	$1.22e^{+8}$
Isotropic Thermal Conductivity	0.052	0.125
Specific Heat Constant Pressure (J/kgk)		2800
Flexural Modulus (Pa)	$3.5e^{+9}$	

Meshing of the lever and tube was done using triangular elements, and the total mesh elements obtained was

32694. The shelling tube was fixed while the lever was given a downward velocity of 2 m/s (this was derived experimentally). The analysis was run for 0.07 seconds. The parameters investigated include: directional deformation, equivalent stress, equivalent strain, total acceleration and shear stress. Mechanical and chemical properties of the maize cob and seed analyzed are summarized in table 1.

4. RESULTS AND DISCUSION

The results of the explicit dynamic analysis conducted on the designed lever and tube are discussed below.

4.1 Directional Deformation

Due to the application of the shelling force, the lever, shelling tube and the shelled maize cob experienced a directional deformation in direction of the applied force. This is shown in figures 5 and 6.

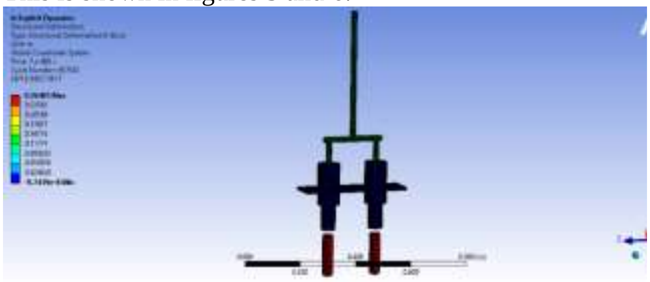

Figure 5. Directional deformation result

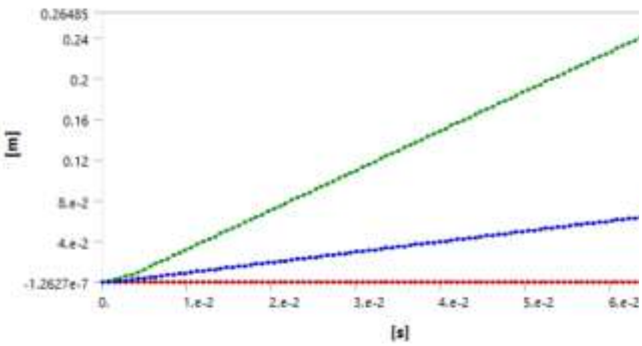

Figure 6. Directional deformation graph

igures 5 and 6 show the directional deformation experienced by the lever, shelling tube and shelled maize cob respectively. The maize cob had the highest value of 0.26485 m while the shelling tube had the least value of -9.7419e^{-8}. This is because the shelling tube is fixed at both ends while the maize cob falls freely inside the tube once the seeds have been removed.

4.2 Equivalent Stress (Von-Mises)

The stress induced on the lever, shelling tube and the shelled maize cob during shelling operation is show in figures 7 and 8.

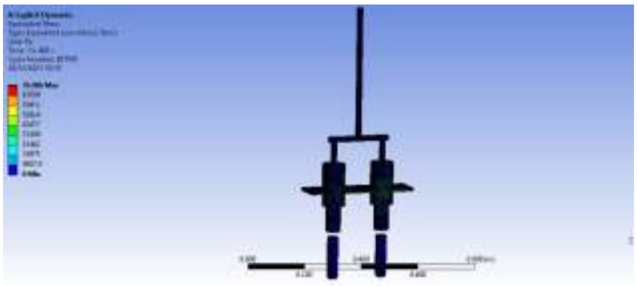

Figure 7. Equivalent stress result

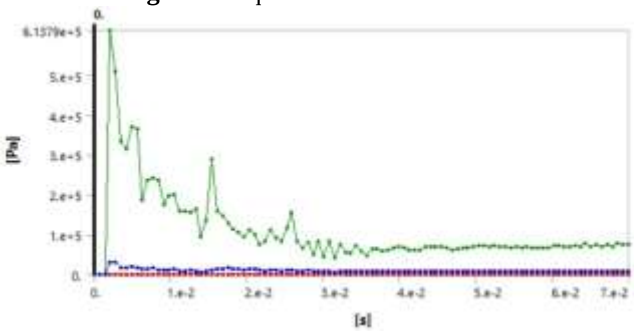

Figure 8. Equivalent stress graph

From figures 7 and 8, stresses on the lever, shelling tube and maize cob were obtained as 7943.6 Pa, 76386 Pa and 0 Pa respectively. Also, figure 8 shows that stress on the tube fluctuated between 0-4e^{-2} s before becoming fairly constant.

4.3 Equivalent Strain

Stress causes a material to deform (strain). Hence, equivalent strain results are shown in figures 9 and 10.

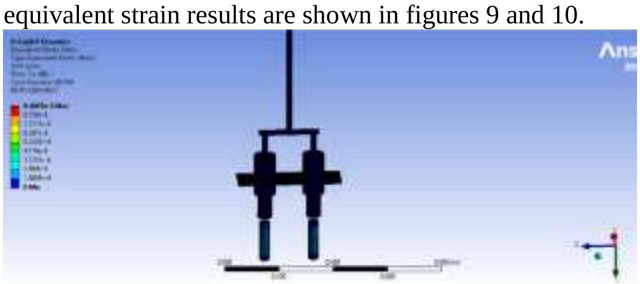

Figure 9. Equivalent strain result

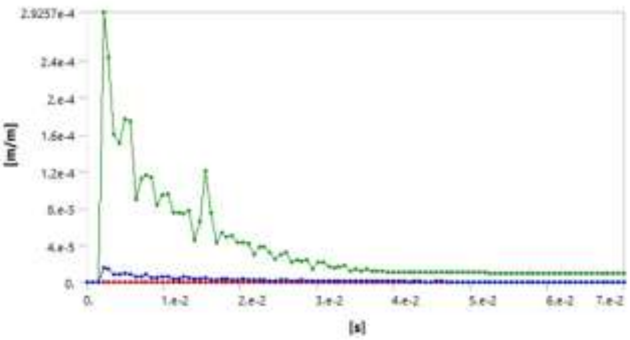

Figure 10. Equivalent strain graph

Equivalent strain recorded for the lever, shelling tube and maize cob were 3.5836e-7 m/m, 0 m/m and 9,4005e^{-6} m/m.

4.4 Total Acceleration

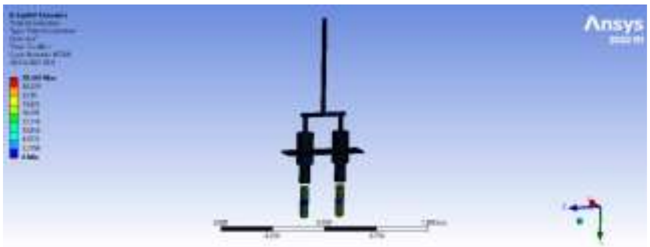

Figure 11. Total acceleration result

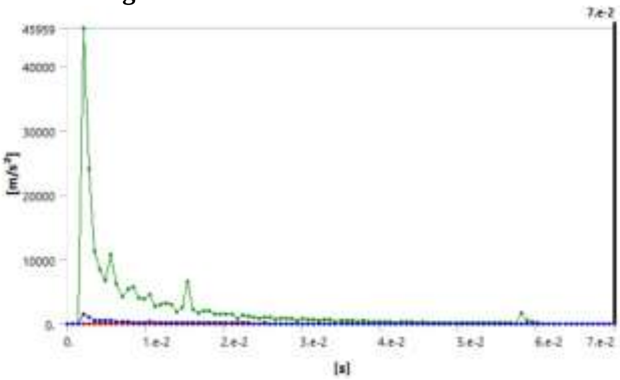

Figure 12. Total acceleration graph

Figures 11 and 12 show total acceleration values of the lever, shelling tube and shelled maize cob as 4.8334 m/s^2, 7e^{-2} m/s^2 and 29.507 m/s^2 respectively.

4.5 Shear Stress

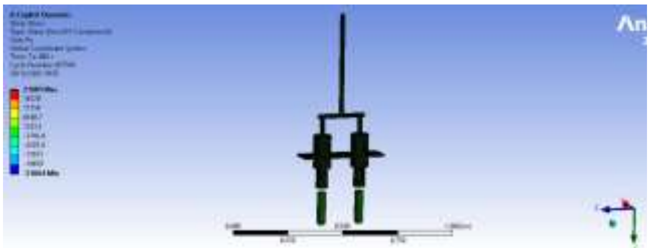

Figure 13. Shear stress result

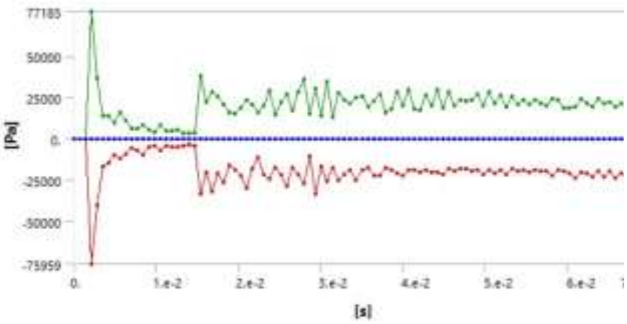

Figure 14. Shear stress graph

Shear stress values obtained for the lever, shelling tube and shelled maize cob were -23604 Pa, 0.9483 Pa and 21085 Pa respectively (Figures 13 and 14). Figure 14 shows that while the shear force on the tube stays relatively constant throughout the time period, shear force on the lever and maize cob fluctuate.

4.6 Fabrication of a maize shelling machine

Since the results of the analysis conducted in Ansys showed that the lever will effectively and efficiently shell maize plants, the designed lever and shelling tube were

Figure 15. lever-actuated maize shelling machine

thus employed in the fabrication of a lever-actuated maize shelling machine (figure 15).

5. CONCLUSIONS

A second-class lever capable of shelling maize was designed, simulated and developed. The lever and shelling tube (through which the maize cob passes through after shelling) were designed using Solidworks software. Analysis of the designed lever and shelling tube were done using Ansys software and the following conclusions were drawn:

- The lever successfully and effortlessly shells maize without damaging the seeds or breaking the cob.
- Maximum values of stress and strain obtained from the analysis are far below the maximum stress and strain that both the maize cob and seed can withstand (this can be seen in table 1). Hence, both the maize cob and seed will still retain their physical properties after shelling.

This study is particularly beneficial to rural maize farmers who have limited access to stable electricity, and cannot afford other means of power.

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