Design for manufacture and assembly of a mini combine wheat harvester: Case of a developing nation - Zimbabwe.

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Abstract

The Zimbabwean Fast Track Land Reform Programme (FTLRP) (2000) resulted in the creation of smaller land pieces which, although beneficiary in that land was indigenised, were however not suitable for farming most cereal crops, particularly wheat. This is because the available machines used for the harvesting processes are mostly designed and economical for large pieces of land. In order to serve those small scale A2 wheat farmers who have resorted to time consuming and laborious manual harvesting methods, and to encourage those who have abandoned wheat farming completely, this paper was done to design a mini combine harvester machine that is both affordable and economical for these farmers. Design specifications and drawings were developed for the machine. Information for the manufacture and assembly of the mini combine harvester was also provided, and material selection was done focusing on the locally available and affordable materials in the country. Manufacture of this mini combine harvester will result in profitable wheat farming by small scale farmers and will also boost the gradually declining wheat grain production. For most practical industrial applications, a transmission shaft with span length L (distance between two adjacent bearings), the maximum deflection δ lies in the range of $0.001L<\delta<0.003L$. In the design process, reaping and threshing systems were designed through the use of the crop requirements. These include the mechanical and physical properties of the wheat kernel and straw properties. The mechanical and physical properties used have been obtained from various studies carried out on determining them, focusing mainly on the varieties being grown in Zimbabwe. The researchers scaled down other systems, that is reduce them in size to cater for the mini combine harvester. The von Mises stresses were done using SolidWorks and they were in range and the weakest point was determined.

Keywords
A2; Wheat; Mini Combine Harvester; Mechanical Properties; von Mises Stress

1. Introduction

1.1 Background

Wheat, a cereal crop, contributes immensely to the food security of Zimbabwe and most nations. Zimbabwe, for example, needs approximately 500,000 tons of wheat annually (Gono, 2008). The crop has high carbohydrates content (80%), 12% protein and about 5% fats. The wheat stalks and chaff obtained after the harvesting process can also be used for animal feed. Lack of machinery also includes lack of proper harvesting machinery.

1.2 Problem statement and objective

As a result of the continued use of inefficient, strenuous, time-consuming and laborious traditional wheat harvesting methods by small scale farmers in Zimbabwe and most developing nations, this research paper aims to design an affordable, efficient and maintainable mini combine harvester machine. The machine should be locally manufactured with locally available materials.

Figure 1. Manual Wheat Harvesting

2. Literature review

Being among the 'big three' cereal crops in the world, over 600 million tonnes are produced annually in the world. For example, the year 2007saw the production of 607 million tonnes compared with 65 million tonnes of rice and 785 million tonnes of maize (FAO, 2015). The wheat harvesting process consists of cutting, threshing, winnowing and collecting the cleaned grain. Methods of harvesting vary depending mostly on the size of the land. They also pointed out that, "When harvest is delayed, shatter loss is the most-often mentioned cause of losses. Estimates of harvest losses range from 5 to 16% for wheat and 8 to 18% for a range of different cereal crops." (Paulsen M, et al., 2015).

The sickle and scythe have been in use for grain cutting for a thousand of years, and are still being used today in most developing nations. However, this process is very time consuming and labour intensive, it results in significant grain losses and is inadequate in allowing small scale farmers to meet the increased demand of grain crops (Boyle, et al., 2012).

The reaper, first developed in 1830 by a Virginia farmer, Cyrus McCormick, cuts the wheat at a specific height and leaves the cut stalk in rows beside the bed. Men then follow gathering the bundles into sheaves (reaper-windrower), or the reaper bundles the sheaves itself (reaper-binder) (Dvorak, 2009). Depending on their construction features (adjustability of height, width of cutter, whether self-propelled or tractor mounted), the work capacity of these machines vary from 3-20 h/ha with grain losses lower than 2 percent. The thresher basically separates the grains from the straws. The first stage involves putting the bundles of stalk into the feeder, which controls the feeding rate of the machine to prevent overloading. The combine harvester, being the most common and efficient machine for harvesting crops, is capable of doing the three basic harvest operations (cutting, threshing and winnowing) all in one, hence the name combine harvester. The basic units for the design of a combine harvester are the cutting, conveying and threshing units (Raisbeck, 2004).

3. Methodology

3.1 Cutting unit

To design the reel and cutter bar, the following mechanical properties, obtained from the tensile and bending tests carried out on wheat stalks of 15% moisture content by Chandio A. in the comparison of the mechanical properties of wheat and rice straws (Chandio, et al., 2013) are utilised. According to Persson (1987), the critical speed of a blade, that is the minimum speed required to cut a crop stalk is given by;

$$v_k = \sqrt{[d_{ws}\frac{F_c - F_b}{m}(1 + \frac{z_{cg}}{r_g^2})]}$$

3.2 Threshing unit

Kassa and Abdi (2014) derived the formula for the deflection angle of the crop δ_c with the vertical line as

$$\delta = \frac{h_p\ [Ph_p + 2W(l_c - x_p)}{2EI}$$

Where P is the force to be applied by the reel. According to Kepner (2001), $Q = Q_0 Ln$

Where $Q_0 = permissible\ feed\ rate$ for the threshing drum.

3.3 Power transmission unit

Assuming that the shafts are loaded with suddenly applied loads and minor shocks (K_b=2 and K_t=1.5), the following method is used to design the shaft diameter.

For shear $d^3 = \frac{16}{\pi\tau_{max}}\sqrt{[(K_b M)^2 + (K_t T)^2]}$

For bending

$d^3 = \frac{16}{\pi\sigma_{max}}0.5K_b M\sqrt{[(K_b M)^2 + (K_t T)^2]}$ (Khurmi & Gupta, 2005).

The minimum number of teeth on the bevel gear pinion is

$$T_p = \frac{2A_w}{G[\sqrt{\left[1 + \frac{1}{G}\left(\frac{1}{G} + 2\right) sin^2\Phi\right]} - 1}$$

3.4 Stress analysis

The Simple Elastic Bending and Simple Torsion theories were used in the calculations of the principal stresses, which were then used to obtain the von Mises Stresses.

$Simple\ Elastic\ Bending\ Theory$:

$$\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$$

Therefore, $\boldsymbol{\sigma} = \frac{\mathbf{4M}}{\boldsymbol{\pi}\mathbf{R^3}}$

$Simple\ Torsion\ Theory$: $\frac{T}{J} = \frac{\tau}{R} = \frac{G\theta}{L}$

Therefore, $\boldsymbol{\tau} = \frac{\mathbf{2T}}{\boldsymbol{\pi}\mathbf{R^3}}$

4. Results

4.1 Reel dimensions

The number of tine bars **= 6bars**

Therefore, the angular displacement of the successive tine bars is **60°.**

Force to be applied = **0.1N**

Diameter of reel = **800mm**

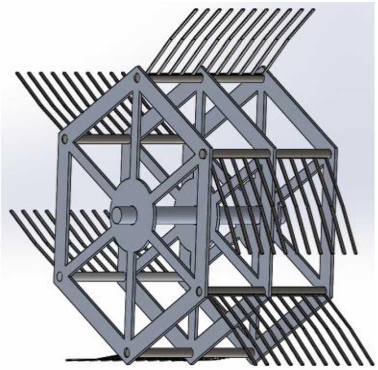

Figure 2. Reel assembly

4.2 Cutter bar

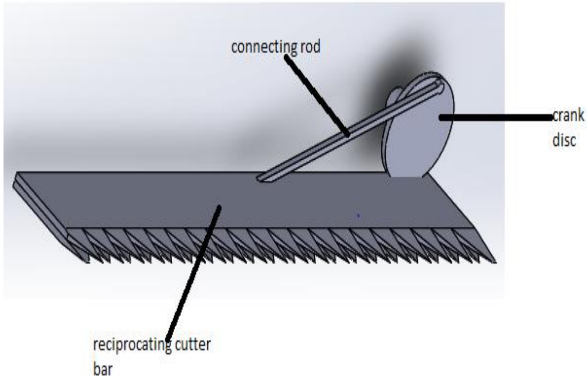

Figure 3. Reciprocating Cutter bar with Slider Crank Mechanism

4.3 Threshing drum and concave

Number of beater rows n = **6 rows**

Length of drum $L \cong \mathbf{600}\boldsymbol{mm}$

Diameter D = **300mm**

Assume a rotational speed of **N=600rpm**

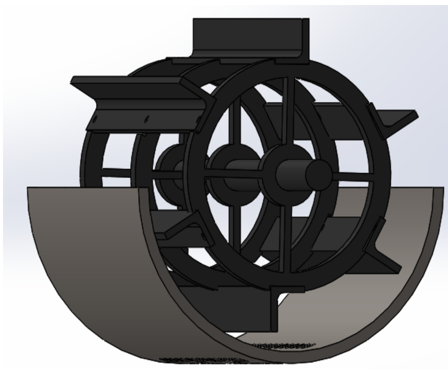

Figure 4. Drum and Concave Assembly

Diameter of concave $d_c = \mathbf{420}\boldsymbol{mm}$

Length of concave $l_c = \mathbf{610}\boldsymbol{mm}$

Thickness of plate t **= 15mm**

4.3 Component Stress analysis

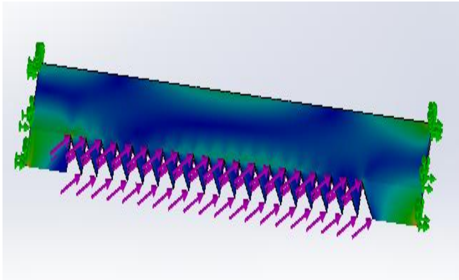

Figure 5. Cutter bar

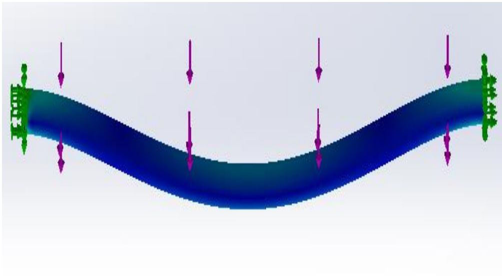

Figure 6. Distribution of von Mises Stresses in Conveyor Shaft

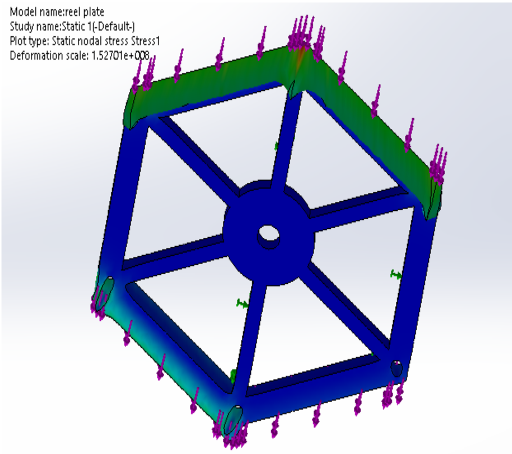

Figure 7. Reel Plate

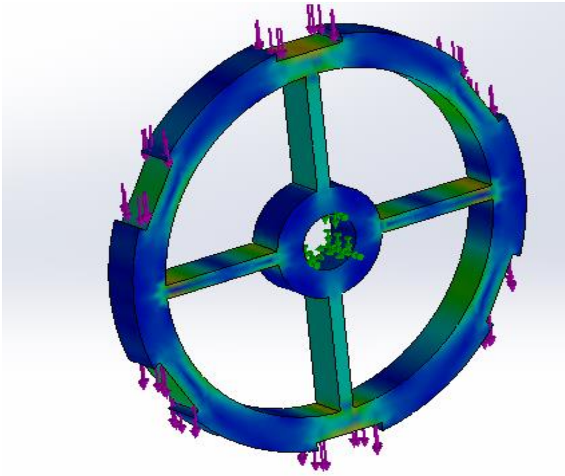

Figure 8. Drum Plate von Mises Stress Distribution

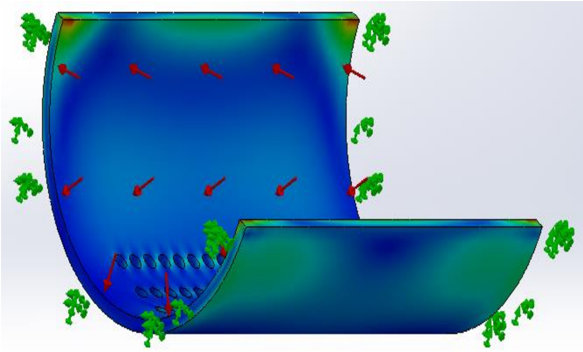

Figure 9. Concave von Mises Stress Distribution

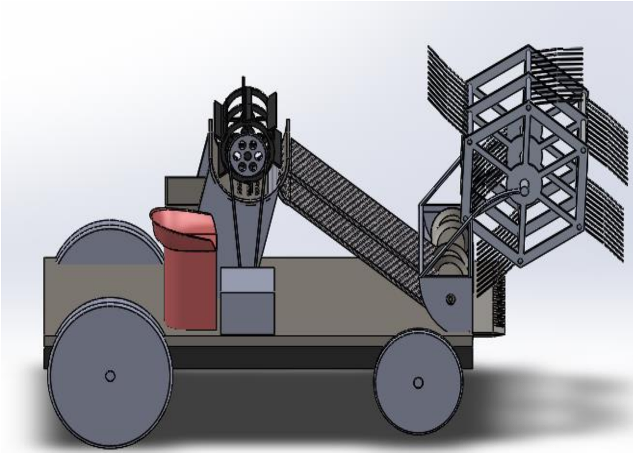

Figure 10. Final Machine Assembly

Conclusion

The mini combine harvester will result in a fast harvesting method for small scale farmers; reduce labour and the respective costs associated with hiring labour; and give the small scale farmers enough time to focus on other operations at the farm. The mini harvester will be more convenient for the operator, and most importantly, reduce postharvest losses due to traditional methods' use. This will increase the productivity and quality of the crops produced, allowing small scale farmers to contribute more to the nation's development to a greater extent. It can also provide an alternative way for cereal crop harvesting to all farmers, preventing the loss of cereal crops due to early rains or animals, birds in the case of cereal crops, destroying the crops.

Therefore, an increase in harvest mechanization was seen to be very important in order to harvest crops in a fast way with minimum losses. For most small scale farmers (A1 and A2), there is therefore a need for the design of harvest machinery that is economical for them, as most of them do not afford the machinery already present, or acquire the machinery way past the harvesting period.

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Authors Biographies

Rumbidzai Prosper Jera was born in Harare, Zimbabwe in 1994. She is currently a student at the University of Zimbabwe, Harare, studying for a Bachelor of Science Honors Degree in Mechanical Engineering. She did her Advanced and Ordinary level studies at St Mary's High School in Chitungwiza, Harare, where she was involved in a number of engineering and science programs. In the year 2011, she was the secretary for the Science Education in Teacher Training (SEITT) school science club, and later on went to hold the vice-presidency for the club in the years 2012-2013. In 2016, she joined the Zimbabwe Institute of Engineers as a student member. Her current research involves material science, solid mechanics and Finite Element Analysis. Other areas of interest in research and design include aerodynamics, fluid mechanics and manufacturing and engineering management systems.

Dr. Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters (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 Link Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a 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 and machine mechanisms.

Professor Charles Mbohwa is an NRF-rated established researcher and professor in the field of sustainability engineering and energy focusing on green technology, energy and systems. In January 2012 he was confirmed as an established researcher making significant contribution to the developing fields of sustainability and life cycle assessment. He has contributed a chapter to a state-of-the-art book by experts in energy efficiency. In addition he has produced high quality body of research work on Southern Africa. Since 2012 he has worked on sustainability engineering with emphasis on integration of other soft aspects like humanitarian logistics and health care systems. The work also encompasses and integrates energy systems, life cycle assessment and bio-energy/fuel feasibility and renewable energy.