Design, Modeling and structural Analysis of small scale mechanically driven crop harvesting and threshing machine for Ethiopian Condition

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Abstract

This study addresses the need for a cost-effective mechanized system to which harvest and thresh cereal crops in Ethiopia, aiming to improve productivity and reduce reliance on expensive and complex machinery. The research involved a comprehensive literature review, data collection, mechanism synthesis, component design, Modeling, and Structural analysis. The 3D modeling is done using SOLIDWORK software. Also, Structural analysis was conducted using ANSYS software, ensuring the safety and reliability of the design. The proposed machine, operated by human power, demonstrated the ability to harvest and thresh crops across a one-hectare area in 5.83 hours, offering a viable alternative to traditional methods. The findings suggest that this mechanized system presents a practical solution for Ethiopian farmers, reducing labor requirements, eliminating the need for electricity or fuel, and minimizing operational costs. This innovation enhances efficiency, affordability, ease of operation, and ensures the design is safe, making it an appealing option for enhancing agricultural productivity in the country.

Key words: agriculture, threshing, harvesting, cereal crop, Ethiopia, ANSYS software.

1. INTRODUCTION

Agriculture is the backbone of the Ethiopian economy and it contributes about half's of the country's gross domestic product (GDP) and more than 83% of its exports. Furthermore, it is one of the main employment sectors with about more than 80% of the country's population depending on the agricultural sector for their livelihoods. The agricultural sector of Ethiopia is dominated by smallholder farming. Smallholder farms are defined as being smaller than 2 hectares and are mainly managed with family labor. In Ethiopia, about 95% of main crops (e.g., cereals, pulses, oilseeds, vegetables, root crops, fruits, and cash crops) are produced by smallholder farms (Zerssa, 2021; Amar B. Mule, 2018; Terefe, 2017; Gebeyanesh Zerssa, 2021)

In a developing country like Ethiopia, both traditional and modern agricultural practices are utilized for harvesting and threshing crops. At present, the majority of small-scale farmers in Ethiopia opt for traditional methods due to the challenges posed by modern agricultural machinery. These machines are not only expensive but also large, bulky, fuel-intensive, and require skilled operators. However, relying solely on traditional methods also entails certain drawbacks. They demand a substantial amount of manual labor, increase the risk of accidents, result in lower productivity due to outdated harvesting and threshing mechanisms, and prolong the time required to collect the final yield from the farmland (Terefe, 2017; Negalegn Alemu, 2020).

It is important to note that the adoption of modern agricultural machinery can potentially overcome some of these limitations. By introducing more affordable and user-friendly machines specifically tailored for small-scale farmers, the barriers associated with cost, size, weight, and skill requirements can be addressed. This would not only enhance efficiency but also improve safety and productivity in the agricultural sector (Terefe, 2017; Negalegn Alemu, 2020).

Furthermore, the integration of sustainable and environmentally-friendly approaches in agricultural practices should also be considered. Investing in eco-friendly machinery that minimizes fuel consumption and reduces carbon emissions can contribute to a more sustainable future for Ethiopian agriculture.

Therefore, this study aims to address several challenges by designing a new mechanism for machinery used in harvesting and threshing of the cereal crops. The goal is to reduce the need for workers, eliminate the reliance on electricity, minimize fuel consumption, and eliminate the requirement for skilled operators. Instead, the proposed mechanism utilizes human input to develop a harvesting and threshing system that is characterized by simplicity in design, durability, ease of use, and safety, thus minimizing accidents. In addition to that, the designed machine aims to be highly effective while keeping running costs at a minimum.

2. MATERIALS AND METHODS

2.1. General description of the Designed Machine

The designed machine is composed of two main parts: the harvesting part and the threshing part. In the harvesting part, power is generated by the rotation of the rear wheel. The rotational energy is then transmitted to the bevel gear through a belt drive mechanism. As the bevel gear rotates, it drives the camshaft, causing the cutter to move horizontally. This sliding motion facilitates the harvesting of crops. A belt conveyor is employed to transfer the harvested crops to the threshing room. The belt conveyor is powered by a shaft connected to the cross belt, ensuring that the belt rotates in the opposite direction to the power source.

In the threshing room, which constitutes the second part of the machine, the power is also derived from the rotation of the rear wheel through a belt drive. Here, the harvested crops are fed into the machine, and the process of separating the pure seeds or crop from the bran takes place. Finally, the separated crops are stored in a storage tank, while the dust is collected in a designated storage area.

2.2. Conceptual Design

Conceptual design is a part of design process in which identify the problem of product by identifying essential problem through abstraction, by establishing functional structure and by search for appropriate solution principle and it is usually expressed as a sketch or as a rough three-dimensional model with some brief description (Dieter, 1991).

2.1.1. Functional Structures

To facilitate the solution of the product machine, it must be establishing the functional structure in order to the product machine will perform its work to achieve the required objective. To perform this design product, it can establish the overall function of a product that have the relationship between the input and output.

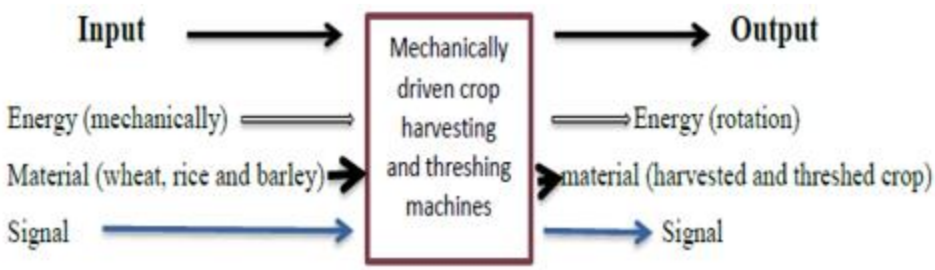


Figure 1: Functional structure

This manual driven machine can be broken down in to sub functions to perform its actions. The sub-functions for the mechanical driven crop harvesting and threshing machine can be either main functions or auxiliary functions. The main functions are functions which serve the overall function directly while the auxiliary functions are functions which serve the overall function indirectly.

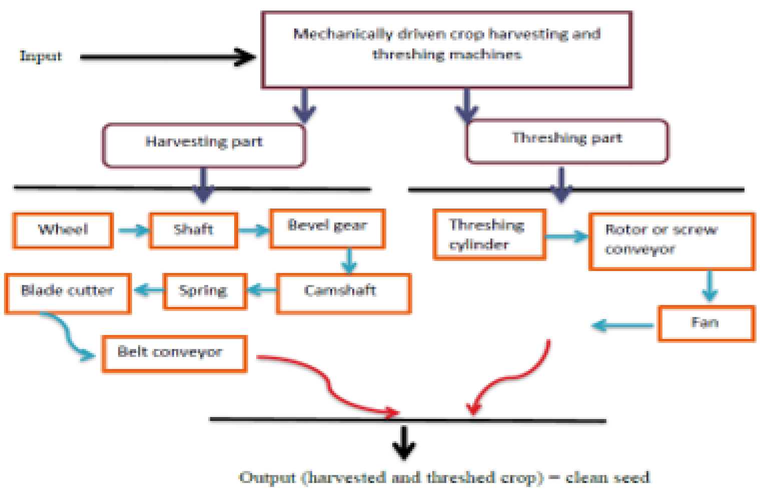


Figure 2: Sub functional structure

To show the relationship between the sub function it can draw the block diagram that show the integration between the sub function to perform the required objective.

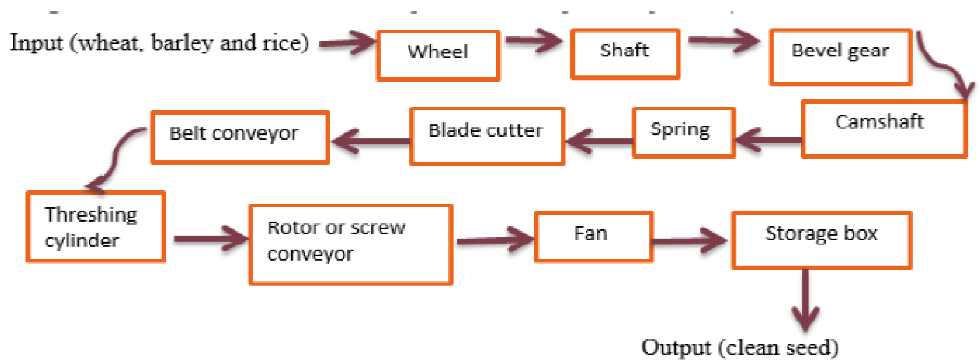


Figure 3: Sub functional structure flows

Inorder to satisfy the main and the sub -function of the above functional structure, one can search for the solution to the main components of the machines using both Internal and External search method. The main or key components that require proper solutions include the power supply, the number of wheels used to drive the machine and enable its function, and the power transmission system from the power supply.

2.3. Design Analysis

Detail design is a part of design process in which all dimensions, tolerance, the selection and sizing of the component are finalized (Dieter, 1991). So, in this detail design the main component of the machines is going too selected and designed with specific dimensions of the product machine.

Design specification of this study:

- ✓ Machine Type: Manually driven harvesting and threshing
- ✓ Pushing or operating force :100N to 200N.
- ✓ Average height of the crop (wheat, rice, barely) :1000mm
- ✓ Width of the machine: 1000mm
- ✓ The height of the machine :1500mm (from the ground)
- ✓ Power generation: from the wheel rotations

2.4. Finite element analysis of the Machine frame using ANSYS Software

ANSYS (Analysis system) software is a general-purpose finite element modeling software for numerically solving a wide variety of engineering problems. There are three well-known stages in Finite element modeling and simulation: pre-processing, solution, and post-processing. The frame is first created in Solid work Software and saved as IGE format, then it's exported to the ANSYS software and then the structural analysis was made inorder to determine the strength of the frame under the maximum loading condition.

The frame under analysis has a length of 1930 mm, a height of 1000 mm, and a width of 1000 mm. The weight of the machine alone is 70 kilograms, while the total weight of the machine, including the stored crops and bran, is 100 kilograms. The software analyzes various parameters such as total deformation, equivalent elastic strain, and equivalent stress.

Table 1: summary of the simulation data

Description	Properties
Relevance center	Fine
Analysis type	Static structure
Node	25303
Element	12554
The element type	hexahedral
Material	steel
Yielding Strength	460Mpa
Reference temperate ^{o}C	22

3. RESULT AND DISCUSSION

3.1. Analytical result and discussion

Table 2: Analytical Result

Part	***Parameter and description***	*Result*
Pulley	Effective diameter of pulley to transmit required power	D_2 = 120mm for the first pulley transmit, D_2 = 140mm for the roller shaft, D_2 = 69mm for screw conveyor
Bevel gear	Dynamic tooth load, wear tooth load, static tooth load, module	m =3mm, W_D = 512.3N, W_S = 2029.8N, W_T = 161.6N, W_W = 1201.5KN
Shaft	Bending momentum, shear stress, torsional stress	σ_b =60.37MPa, τ = 18.41MPa τ = 35.35MPa
Cam and follower	The maximum lift or pushing the cutter Maximum acceleration of the cam shaft The maximum force applied	70mm = x a = 37.6m/s^2 F = 94N
Blade cutter	speed of slide blade cutter, the output power used for harvesting, The area of those crops are, area of the blade cutter	V_b = 0.4m/s, P = FV = 37W A_c = 1.539$mm^{2,}$ A_b = 656.6mm^2
Screw conveyor	Hourly capacity, The cross-sectional loading of a screw conveyor	Q = 9.86ton/hr, A = 2.82 × $10^{-3}mm^2$
Selection of fan	Speed of the fan, CFM 5075,	N = 220rpm, 0.35 BHP

The input speed of the machine is $30\ rpm$, and this speed is transmitted through V-belts and gears to another component. By using the velocity ratio, the speed can be increased from $30\ rpm$ to $169\ rpm$. This speed of rpm corresponds to the rotation of the sliding blade cutters used for harvesting crops. The $169\ rpm$ represents the full rotation of the cam applied to the blade cutter, which is responsible for sliding the cutter over the fixed cutters. A return spring is used to bring the sliding cutter back to its original position after the cam completes its full rotations. Therefore, the total number of blade cutters that can cut crops in one minute per revolution is calculated as $169 \times 2 = 338\ rpm$.

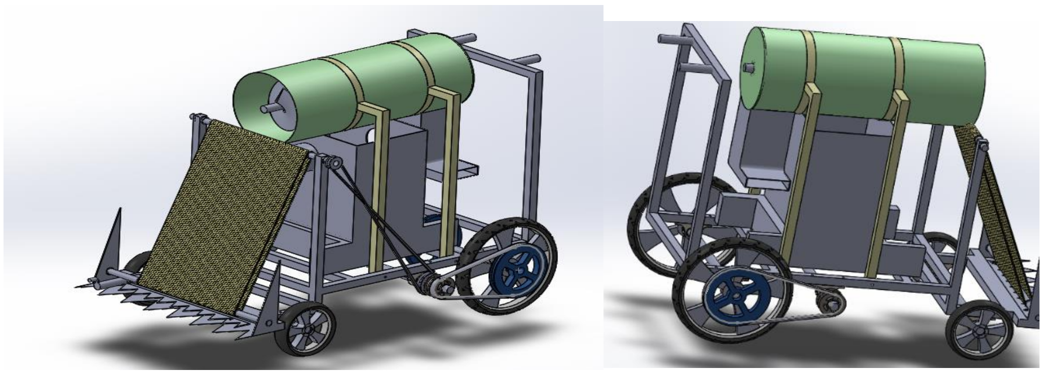


Figure 4:3D model of the designed machine

In addition to that, this input speed ($30\ rpm$) is also transmitted through the V-belt to the screw conveyor, which is used for threshing purposes and discharging the bran into the bran storage tanker. By using the velocity ratio, the speed of the screw conveyor can be increased to $130\ rpm$ This rpm of the screw shaft represents the speed at which the screw conveyor threshes the crops through rubbing action between the cylinders and the screw, as well as separates the bran from the seed by applying air blowing into the sieve.

When comparing this machine with the traditional harvesting and threshing crop system, it proves to be more efficient than human effort. In the Ethiopian context, it takes the effort of 10 people approximately 16 hours to harvest one hectare of crops. This 16-hour duration becomes the only time available for harvesting, potentially leading to decreased productivity for farmers.

In contrast, this machine significantly improves efficiency by reducing the time required for simultaneous harvesting and threshing to around 6 hours. Furthermore, when compared to modern mechanized machines, this machine has the advantage of lower initial and running costs. It can operate effectively by harnessing human pushing force to power its functions.

4.2. ANSYS Software Result and Discussion

4.2.1. Total Deformation of the Fame

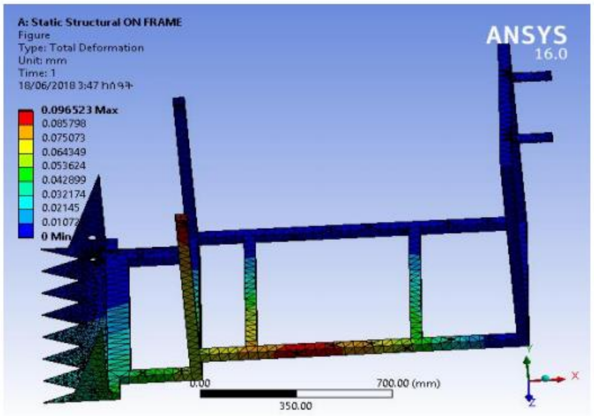
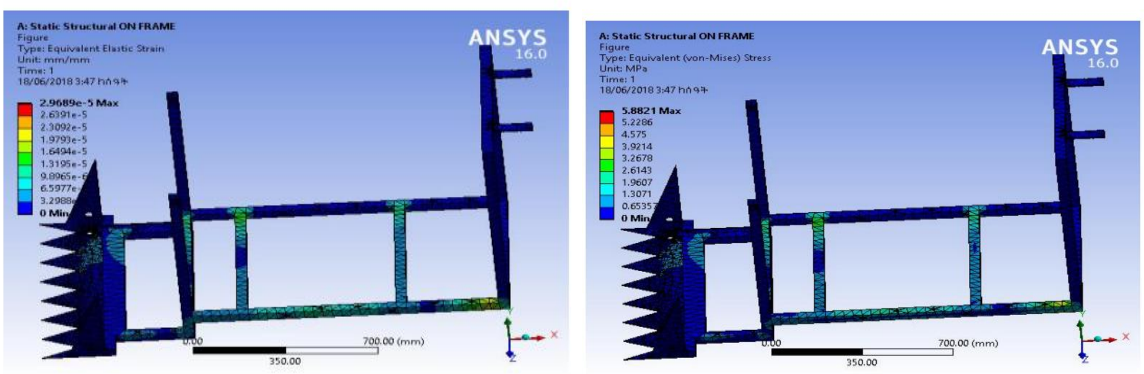


Figure 5: Total deformation of the frame

As shown in Figure 5, the maximum total deformation of the frame is found in the lower section, indicated by the red color, with a value of 0.09652mm. This value indicates that the design of the frame is safe and capable of carrying a load of 100 Kg without experiencing any permanent failure.

4.2.2. The equivalent elastic strain and stress



a. Equivalent elastic strain b. Equivalent elastic stress

Figure 6: The equivalent elastic strain and stress of the frame

Equivalent stress and strains are among the criteria used to assess material failures in the designed structure. As depicted in Figure 6(a), the equivalent elastic strain value is recorded as 2.9689e-5. This number indicates that the elastic strain of the frame is approximately 0. When the elastic strain value is approximately 0, it signifies that the design is considered safe.

In addition to that as shown in Figure 6(b), the value of the equivalent stress is 5.882Mpa which is less than the yielding strength of the material (460Mpa), this induce that the design is safe, and it can carry the load of the whole machines, the final crops and the branes with out any failure.

4.3. Manufucturing and Assembly Method

4.3.1. Manufucturing Steps of the Designed Component

1. *Pulley*
- ✓ Step 1: cut the ingot with help of hacksaw
- ✓ Step 2: machining processes take place such as turning boring to gate the final dimension of these pulley based on its dimensions
- ✓ Step 3: make the ‘v’ section on the lath machines

2. *Measuring devices for pulley*
- ✓ Scriber
- ✓ Measuring scale
- ✓ Vernal caliper

3. *Wheel*
- ✓ Step 1: cut the metal simple bar used for making wheel
- ✓ Step 2: making the roll on the rolling machines, up to the required diameter of the wheel is obtained.
- ✓ Step 3: cut the arm for the wheel by using grinder.
- ✓ Step 4: by using welding to fix the arm with the wheel.
- ✓ Step 5: Tighten with the lower frame by using bolt.

4. *Shaft*
- ✓ Step 1: cut the shaft with required diameter and its length
- ✓ Step 2: tighten on lathe machines and reduce its diameter in order to easy to assembly with bearing or others.

5. *Frame*
- ✓ Step 1: preparation of the components by cutting out of larger square cross section bar based on the required dimensions.
- ✓ Step 2: prepare for joining process by using welding machines and bolt.

6. *Storage tankers sheet metal*
- ✓ Step 1: Cut the Sheet metal with required thickness and its length.
- ✓ Step 2: prepare for joining process by using weld with the frame.

7. *Threshing cylinder*
- ✓ Step 1: Cut the Sheet metal with required thickness, diameter and its length.
- ✓ Step 2: roll the sheet metal on rolling machine to get the desired rolled cylinder.
- ✓ Step 3: provide the space for seed and stalk or bran exhausting system.
- ✓ Step 4: provide the sieve holder spaces that used to separate the seed from bran.
- ✓ Step 5: provide air blowing system to the threshing cylinder.

8. *Screw conveyor*
- ✓ Step 1: prepare the screw shaft with its desired dimensions.
- ✓ Step 2: prepare the sheet metal that used as the screw, with the desired diameters.
- ✓ Step 3: rolling the sheet metal as a screw and winding on the screw shaft.
- ✓ Step 4: weld the screw on the screw shaft.

4.3.2. Assembly process of the Manufactured component

The following are the machine assembly procedure after the manufacturing process to produce the required product.

1. Prepare all the required parts or machine components.
2. Set the frame on the level ground.
3. Tighten the wheels with the rear axle shaft with the frame and lock the required pulleys on the axle shaft which my used for transmitting power.
4. Inserting the second shaft and lock the bevel gear and the next pulley on the shafts.
5. Tighten the cam shaft and spring on the frame.
6. Holding the blade cutter between the cam shaft and spring.
7. Tight a belt conveyor between the blade cutter and threshing cylinder.
8. Tight the threshing cylinder with the screw conveyor and fix the bran storage tanker with screw conveyor discharge.
9. Holding the sieve between the threshing cylinder and seed storage tanker
10. Fixing the outlet of the fan on the sieve.

5. CONCLUSION

This study aimed to design and analyze a mechanically driven a cereal crop harvesting and threshing machine suitable for Ethiopian conditions, with the goal of reducing problems, improving productivity, and contributing to the country's economic development.

The study encompassed various stages, starting with providing background information about the machine, followed by conceptual design, detail design, manufacturing process, and working principle. During the detail design phase, each component of the machine was analyzed and designed using Solid Work software, and the structural analysis of the machine frame is conducted using ANSYS software. The manufacturing process of the parts and the working principle of the machine, along with assembly and part drawings, were also described.

The designed machine demonstrates several advantages over existing large-scale mechanized machines and traditional methods. It offers a lower initial cost, reduces farmer work fatigue, saves time, eliminates running costs, and provides the ability to efficiently harvest and thresh crops on one hectare of land within 5.83 hours. These features contribute to improved economic viability and productivity when compared to other methods of harvesting and threshing machines.

Overall, the designed machine proves to be ergonomically safe and presents a favorable alternative for crop harvesting in Ethiopian agricultural settings. It combines cost-effectiveness, reduced labor requirements, time efficiency, and enhanced productivity, thereby benefiting both farmers and the country's economy.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest described in this article.

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