



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(9): 129-137

Received: 27-07-2024

Accepted: 30-08-2024

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Design and development of battery-operated vertical conveyor reaper

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i9b.1456>

Abstract

In India, paddy and wheat are the primary crops, with the country ranking first globally in cultivated area and second in paddy and wheat production. The dwindling agricultural labour force, which declined from 54.6% in 2011-12 to 45.5% in 2021-22, poses a significant challenge, especially during the labour-intensive harvesting season. Harvesting of crops is a critical agricultural operation requiring significant labour, and during the harvesting season, the availability and cost of labour pose serious challenges. Labor shortages and unpredictable weather conditions can lead to substantial losses for farmers. Consequently, adopting mechanical methods to ensure timely harvesting operations is essential.

In recent years, the use of mechanical harvesting devices has increased. However, machines like combine harvesters are very expensive, making them unaffordable for most small and marginal farmers. Although some manually operated reapers have been developed, they have not gained popularity due to the limitations of manual power, such as insufficient power for cutting and conveying crops and difficulties in transporting the machine. Combine harvesters are also in use for this purpose but these machines consume diesel fuel. Price of fossil fuels is hiking day by day. Thus, to ensure efficient and timely harvesting operation walk behind type battery powered reaper was developed, which is very simple in construction, low maintenance and easy to maintain. This study addresses the need for a cost-effective and environmentally friendly harvesting solution tailored for small and marginal farmers. A self-propelled, battery-powered reaper was developed to bridge the gap between manual sickles and expensive mechanical harvesters. This reaper, powered by a 900 W DC motor and four 55 Ah, 12V batteries, was designed to cut and convey paddy and wheat crops efficiently. The reaper's main components include a cutter blade, battery, DC motor, chain conveyor, ground wheel, handle, and transmission system. The weight of the developed reaper with the battery was 121 kg. It was able to cut four rows of paddy and wheat crop placed at 22.5 cm apart.

Keywords: DC motor, battery, serrated type cutter blade, walk behind type and harvesting

Introduction

Agriculture is the primary source of food and is the sole occupation for a vast population in India. It ensures food security and meets the dietary needs of a population expected to reach 1.7 billion by 2050. Agriculture is vital to India's economy, engaging 54.6% of the work force and accounting for 18.6% of India's GVA in 2021-22 (Anonymous, 2021).

India is one of the largest food grain producers globally, supported by a diverse agricultural sector and favorable climate. Major food grains include rice, wheat, maize, millets (sorghum and pearl millet), and pulses (chickpeas, lentils, and beans).

Rice and wheat account for about 30% of global calorie intake, making them essential for billions worldwide. These staples have been cultivated since ancient times and are crucial in many diets. Rice is primarily grown in Asia, Africa, and Latin America, while wheat is predominantly grown in North America, Southern Europe, and Australia. Wheat's adaptability to different climates makes it the most versatile cereal grain, whereas rice is the chief and cheapest carbohydrate source in many developing nations.

Global consumption of rice and wheat is rising due to population growth, necessitating increased production and technological advancements. India holds the second position in rice production only after China. India is also the second largest producer of wheat with a share of around 14.14% of the world's total production in 2020.

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India is also inching towards self-reliance in Pulse production. The production of food grains in the country is estimated at 329.68 million tonnes in 2022-23, which is higher by 1.4 MT than the production of food grains during 2021-22. In which, total production of rice and in the country was 135.29 MT and 110.84 MT in 2022-23 respectively. Total food grain production in Chhattisgarh was 11 MT, in which production of rice and wheat was 105 MT 0.5 MT respectively during 2022-23 (Anonymous, 2022).

India's soil is remarkably productive; with an average land holding of 1.08 hectares, it sustains a population of 1.3 billion. Small and marginal land holdings (< 2.0 ha) make up 86% of total operational holdings and cover 47% of the operated area (Anonymous, 2018a). The share of farm power from draught animals is declining, and agricultural power correlates directly with farm yield. In 2020–21, average farm power availability was 2.76 kW/ha. To meet the growing food grain demand, this must increase to 4.0 kW/ha by 2030 (Tiwari *et al.*, 2019) ^[2].

The availability and prudent use of farm power by farmers has a significant impact on the productivity of agricultural fields. Serious issues facing Indian agriculture include a lack of labour for agricultural work, both during peak working seasons and during off-peak hours. The primary causes of this include the rise in higher-paying non-farm employment possibilities, labour force migration to urban areas, and the poor social standing of agricultural laborers.

The share of workforce employed in the agriculture sector has declined from 70% in 1951 to 42.3% in 2019 and this will further reduce to 25.7% by 2050 (Anonymous, 2018b). Lack of workforce availability and pressing need for improving crop productivity calls for a strong focus on increasing mechanization in agriculture. A substantial increase is found in agriculture mechanization in India. However, the level of farm mechanization is just about 40-45% compared to other countries such as US (95%), Brazil (75%) and China (57%) (Anonymous, 2019).

Agricultural mechanization is vital for enhancing food grain production by increasing efficiency and productivity. Mechanized farming methods, such as tractors, harvesters, and irrigation systems, reduce labour-intensive tasks, improve timeliness, and enhance overall farm management. This allows farmers to prepare land, sow seeds, apply fertilizers, control pests, and harvest crops more effectively, leading to higher yields, reduced post-harvest losses, and improved profitability.

Timely harvesting, which involves cutting and gathering crops at the proper ripeness, is crucial to minimize losses and ensure better crop quality. Labour shortages during the harvest season can significantly impact farmers, making mechanical methods essential to ensure timely and efficient harvesting. Manual harvesting, using sickles, is labour-intensive and time-consuming. For example, harvesting paddy and wheat manually requires about 25% of the total labour for these crops, taking approximately 158 to 160 man-hours (Tripathi *et al.*, 2018) ^[3]. Cutting and bundling these crops can take 185-340 man-h/ha (Michael and Ojha, 1987) ^[4], with harvesting alone accounting for a substantial portion of labour needs (Sarker, 2000) ^[5].

Rapid industrialization and urban migration have made labour increasingly scarce and costly, with the farm workforce projected to decline significantly by 2050 (Tiwari *et al.*, 2019) ^[2]. Mechanization is the only viable solution to address this workforce shortage, ensuring timely operations and improved farm profitability.

Mechanical harvesting utilizes power from IC engines and can be categorized into self-propelled and tractor/power tiller-

mounted machines. Self-propelled machines have permanently attached engines, whereas mounted machines can be connected to tractors or power tillers as needed. Although versatile, mounting and detaching is time-consuming. Self-propelled reapers are increasingly used in developing countries, while combine harvesters are common in developed nations. Chhattisgarh is an agrarian state with 70% of its population involved in agriculture. Of the 41.10 lakh farmers, about 82% are small and marginal (Anonymous, 2018b). In Chhattisgarh, there are 4 power reapers and 0.09 combines per 1000 hectares, compared to the national average of 10 reapers and 0.2 combines per 1000 hectares (Singh and Singh, 2019). Combine harvesters and self-propelled reapers are efficient but expensive, posing challenges for small and marginal farmers in India. Custom hiring is an alternative but problematic for small, fragmented lands. Tractor/power tiller-operated reapers have high initial and running costs and contribute to environmental pollution.

Therefore, mechanical harvesters like power tiller operated, tractor operated, self-propelled reapers and combine harvesters are not getting popularity among small and marginal farmers because of its high initial and operating cost which makes them unaffordable. Also, rising of fuel prices day by day, increases the cost of harvesting. Further, non-availability of these machines on custom hiring for small and marginal farmers, force to go for manual harvesting. Manual harvesting by sickle is laborious, costly and time consuming. The efficiency of manual harvesting using sickle is considerably low. It requires about 158–160-man h/ha to harvest paddy and wheat (Tripathi *et al.*, 2018) ^[3].

Reapers are essential for timely harvesting of field crops. Manually operated harvesting equipment is available, using a ground wheel as the power source to operate the cutter bar. However, the available traction force in the ground wheel is insufficient to cut and convey the crop. Additionally, the reapers currently on the market (both self-propelled and tractor-mounted) are high-cost and not eco-friendly. Due to their high initial and operating costs, small and marginal farmers cannot afford to adopt them. Considering all above facts, there is a need of a machine which can fill the gap between sickle and tractor/power tiller/self-propelled reapers for small and marginal farmers and also considerably cheaper and eco-friendly. By using battery as a power source, it can be boon for remote as well as hilly locations. Its battery pack can be use as power grid in remote areas where continuous electricity is a challenge. Battery packs are playing a crucial role in remote areas of Chhattisgarh, addressing the persistent issue of unreliable power supply. In regions where electricity infrastructure is limited or non-existent, battery packs provide a dependable source of energy for various needs, from lighting homes to powering small appliances and mobile devices. Battery technology is helping bridge the energy gap, improve living conditions, and enhance economic opportunities for rural communities.

Materials and Methods

The walk behind type battery-operated vertical conveyor reaper was developed by keeping in a view literature review, farming patterns and personal correspondence. The reaper consisted of cutter blade, battery, DC motor, chain conveyor, ground wheel, handle, and transmission system. The power is transferred from the DC motor to the counter shaft. From the counter shaft, power is then transmitted to the cutter bar through a vertical shaft and conveyor chain. The ground wheel receives power from the counter shaft with the help of a chain and sprocket arrangement. Current flows from battery to power controller and from there it

goes to motor in specific manner. Accelerator and forward reverse button were connected with power controller to regulate the current so the speed of the machine. The methodology adopted for design and development of vertical conveyor reaper is discussed below:

Design of battery-operated vertical conveyor reaper

In machine design process, the physical and engineering characteristics of paddy and wheat crops are taken in to account. Various components of the harvester are engineered to endure any operating condition successfully. Additionally, a field test is conducted to assess the machine's performance.

The design and selection of appropriate reaper component involves following steps:

1. Power requirement
2. Power source
3. Power transmission unit
4. Crop cutting unit
5. Crop conveying unit and,
6. Machine transporting unit e.g., Ground wheel and handle
7. Frame

1. Power requirement

The power requirement for cutting the crop using serrated type cutter blade was taken as 0.53 hp/m length of cutter bar and power required for conveying cut crop as 50% of the cutting power. Cutting width of the developed reaper was taken 1000 mm. Hence, the total power requirement for cutting and conveying unit was taken as 0.77 hp.

Again power required to propel the machine is estimated by using following equation

$$\text{Power (Wr)} = \frac{R_r \times F_s}{75}, \text{hp}$$

Where

R_r = Rolling resistance,

F_s = Forward speed of the machine, 2.3 km/h e.g., 0.63 m/s

R_r = Coefficient of rolling resistance $\times$ weight of machine

Let the assume coefficient of rolling resistance be 0.2 (for agricultural soil) and weight of the machine was 121 kg.

$$\text{Power (Wr)} = \frac{121 \times 0.2 \times 0.63}{75}$$

$$\text{Power (Wr)} = 0.20 \text{ hp or } 0.15 \text{ kW}$$

Assuming 90% power transmission efficiency, so requirement for propelling the machine is 0.22 hp or 0.16 kW.

Total power required

$$P = 0.77 + 0.20$$

$$P = 0.99 \text{ hp} = 745 \text{ Watt}$$

Assuming 90% of the power transmission efficiency.

$$P = 745/0.9$$

$$P = 827.8 \text{ Watt}$$

Thus, a DC motor of above 827.8 W should be used.

2. Power source

Power source include electric power i.e., battery and DC motor.

2.1 BLDC motor served as the machine's main engine. It uses

electrical energy to produce mechanical power. For the development of the prototype reaper, a DC motor with a 900 W rating was chosen based on calculations and market availability. It operates at 480 rpm with a full current supply and 48 V potential variations. Table 1 provides the technical information of the DC motor, and Fig. 1 shows the DC motor and Fig. 2 displays the circuit schematic.

Table 1: Technical information of BLDC motor

S. No.	Specification	Value
1.	Model	Commercial make
2.	Type	BLDC motor
3.	Voltage	48 V
4.	Output power	900 W
5.	Output rpm	480 rpm



Fig 1: View of BLDC motor with controller

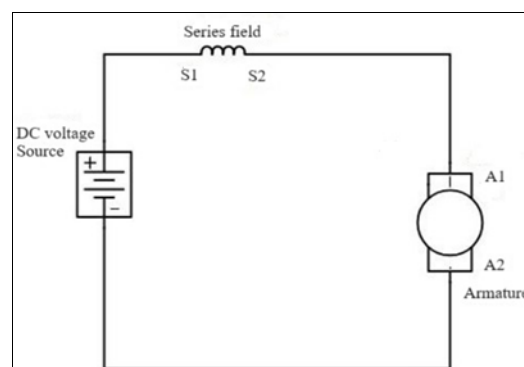


Fig 2: Circuit diagram of BLDC motor

2.2 Battery pack

The battery pack is a crucial component of battery-operated reaper, providing the necessary power for the operation. It typically consists of multiple individual battery cells connected together in series configurations to achieve the desired voltage, capacity, and power output. To make the reaper environment friendly and to reduce the harvesting cost, battery was used as power source. Battery pack is the motive source in electric vehicles. Designing of battery pack is one of the important sections in electric vehicle designing and battery pack calculation depends on several factors. Normally range of the vehicle and motor specifications directly influences the battery pack capacity.

Calculation for size of battery pack

After the selecting the motor, decided the range of the reaper, and here we were aiming maximum speed 2.3 km/h for 2 hours of field working of E-prime mover it means designing a battery pack for a range of 10 km/h and current drawn by the motor in

this speed is calculated below:

$$\text{Motor capacity, kW} = V \times \frac{\text{Ah}}{1000} \quad \dots (1)$$

$$\text{Ah} = 0.9 \times \frac{1000}{48}$$

$$\text{Ah} = 18.75 \text{ A}$$

After finding the current drawn by the motor, we need to consider acceleration current. While accelerating motor draws more current and in deceleration draws less. So, in this condition some current loss will be there and we take that loss as acceleration current. Here we take it 5%, then

$$= 15.625 \times 1.05$$

$$= 19.68 \text{ A}$$

Then we know that,

$$P = V \times I \quad \dots (2)$$

P = Power required at 2.3 km/h speed is

$$P = 48 \times 19.68$$

$$P = 944.65 \text{ Wh}$$

After finding power, here we were designed battery pack for 4 km range and for that we need to consider a Travel factor.

$$\text{Travel factor} = \frac{\text{Total range (travel)}}{\text{total speed}} \quad \dots (3)$$

$$\text{Travel factor} = \frac{4}{2.3}$$

$$\text{Travel factor} = 1.74$$

This travel factor is to travel 4 km at 2.3 km/h speed constantly. So, total power required = power $\times$ travel factor

$$= 944.65 \times 1.74$$

$$= 1643 \text{ W (1.643 kWh)}$$

Then, we need to consider the efficiency of the battery pack. Lead-acid batteries usually have around 70-75% charging and discharging efficiency. Considering the efficiency of lead-acid battery as 75%.

$$\text{Total power} = 1.643 \text{ kW}$$

$$\text{So, battery pack capacity required} = \frac{1.643}{.75}$$

$$= 2.19 \text{ kWh}$$

Finally, we need to consider the efficiency of BLDC motor and usually it comes around 85-90%. Here we consider DC motor efficiency 85%.

$$\text{So, total battery capacity required} = \frac{2.19}{0.85}$$

$$= 2.576 \text{ kWh}$$

Selection of battery

Lead-acid batteries offer several advantages over lithium-ion batteries in certain applications. They are more cost-effective, with lower initial purchase and replacement costs, making them a practical choice for budget-conscious users. Lead-acid batteries also have a higher tolerance for overcharging and deep discharges, making them suitable for applications where occasional misuse may occur. Additionally, lead-acid batteries are widely available and have a well-established recycling infrastructure, reducing environmental impact. These factors make lead-acid batteries a preferred option for applications such as backup power systems, stationary energy storage, and certain types of vehicles where cost and durability are prioritized over energy density and weight.

Considering the above factor and after finding of required total battery pack capacity, a 48V, 55 Ah lead acid battery was selected to run a motor of 900 W, 48 V. For making a battery pack, four 12V, 55 Ah lead-acid batteries were connected in series to achieving desired battery pack capacity. A single 12V, 55 Ah battery shown in Fig. 3 and detailed specification of lead-acid battery given in Table 2.

Table 2: Technical specification of lead acid battery

S. No.	Particulars	Value
1.	Voltage, V	12
2.	Battery Weight, kg	14
3.	Reusability	Rechargeable
4.	Item Dimension (L $\times$ W $\times$ H), mm	200 $\times$ 200 $\times$ 200
5.	No. of battery required	4



Fig 3: Lead acid battery for battery pack

3. Design of power transmission system

The power transmission system was design to operate the conveyor, cutter bar and ground wheel of the developed prototype reaper. The power is supplied from BLDC motor to conveyor, cutter bar and ground wheel. The power was transmitted with the help of chain and gear drive. The transmission system consists of motor shaft, counter shaft, primary shaft (vertical), secondary reduction shaft and ground wheel shaft. The arrangement of the transmission system is shown in Fig. 4 and 5.

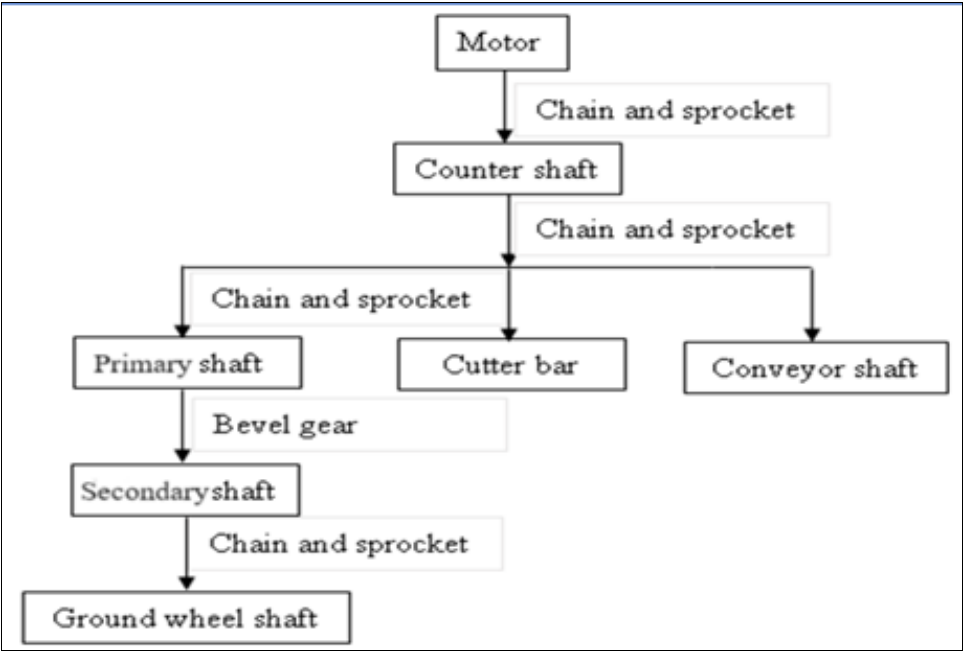


Fig 4: Power flow diagram of power transmission system of developed reaper

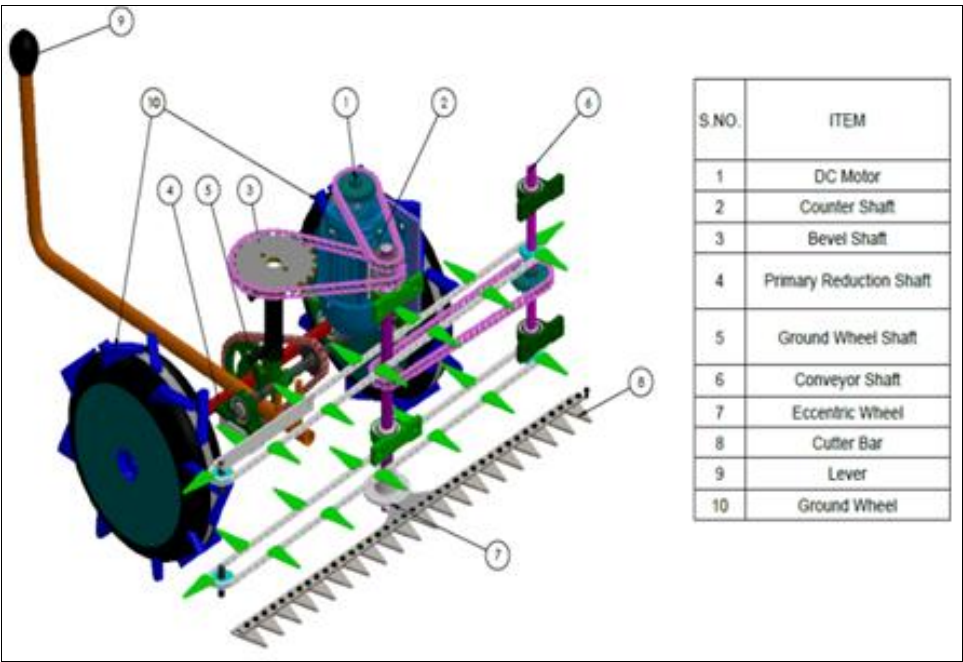


Fig 5: Arrangement of power transmission system

4. Design/selection of crop cutting unit

Wheat and paddy harvester's cutting blade are an important component. Small cutting resistance and low energy consumption requirements of the cutting blade are greatly beneficial and contribute to total energy consumption reduction for a harvester machine, as the cutting process requires significantly large amounts of energy for harvesting. Wheat and paddy harvesters employ reciprocating type of blade in modern harvesters. A reaper employs a reciprocating knife-type cutter bar to harvest cereal crops, which cuts and separates the crop from uncut sections. This cutter bar, also known as a sickle cutter bar, comes in two types: single knife and double knife. Due to market availability a double knife type cutter bar having standard knife section of 48 mm stroke length and two cuts per stroke was selected. The length of cutter bar (L_c) was selected on

the basis of the condition that $L_c = 1-3$ m as less than 1 m size cutter bar creates hindrance in collection and bundling of crop. So, a length of cutter bar 1 m was selected. The double knife cutter bar and their cad model is shown in Fig. 6 and 7.

5. Selection of crop dividers and lifters

The crop divider guides the machine to insert the lifter in the crop smoothly for proper cutting or harvesting of crop. The crop dividers are shown in Fig 3.18. Star wheel type crop lifter was used for lifting the crop. Star wheel for each row is driven by the lugs attached to the vertical conveyor chain thus guiding the plant to the cutter bar. The speed of star wheels is depending upon the forward speed of the machine as they handle the plants to be cut. Star wheel and lugged on conveyor chain do the job similar to that of a reel in case of conventional header unit.



Fig 6: View of double knife cutter bar

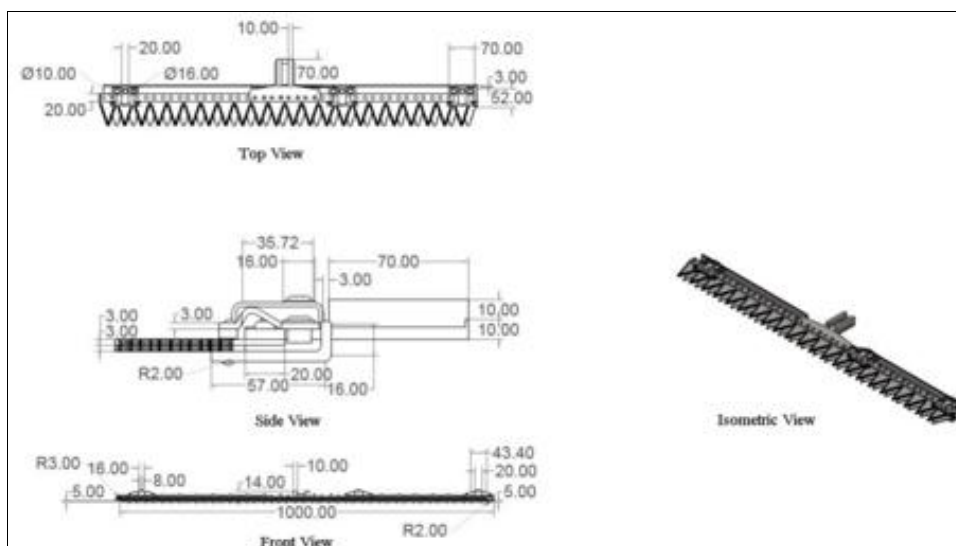


Fig 7: Isometric view of double knife cutter bar

For lifting and conveying crop to cutter bar, the size of crop lifter = 300 mm.

$$\text{So, number of crop star wheel type crop lifter} = \frac{\text{Size of cutter bar}}{\text{Size of star wheel}} = \frac{1000}{300} = 3$$

Therefore, three number of crop star wheel type crop lifters was used.



Fig 8: Star wheel

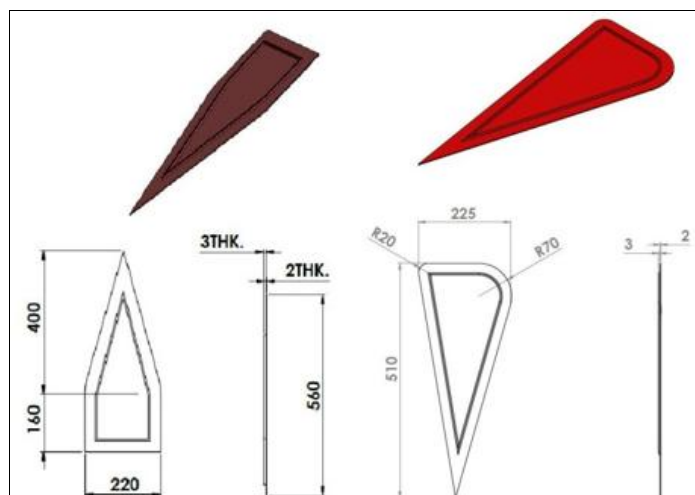


Fig 9: Crop divider and lifter

6. Design of crop conveying unit

The crop cut by the cutting unit of developed harvester is conveyed to one side by the lugged chain conveyor at an angle of 90° for easy collection and bundling. This arrangement facilitated the facile accumulation and bundling of the harvested crop. The crop conveying mechanism comprised a dual conveyor chain system, each equipped with lugs for conveying purposes. One chain was positioned at an elevation of 100 mm above the cutter bar, while the other resided at a vertical distance of 200 mm relative to the former. These two conveyor chains were strategically configured to ensure the harvested crop maintained a vertical orientation during transit, ultimately

directing it towards the machine's right side.

The upper and lower conveyor chains were mounted on 4 different sprockets of 20 teeth and driven by the counter shaft sprocket (11 teeth) through chain drive. The centre-to-centre distance between the lower conveyor chain sprockets was 840 mm and the upper conveyor chain sprocket was 810 mm. The length of chain was selected for the above purpose was calculated by equation 3.7 (Khurmi and Gupta, 2005).

Number of chain links on upper chain conveyor

$$L_n = \{(N_1 + N_2)/2\} + (2c/p) + \{(N_2 - N_1)/2\pi\}^2 \times (p/c) \dots (3.18)$$

Where

L_n = Number of chain links

N_1 = Number of teeth on pinion sprocket (20 for the selected sprocket)

N_2 = Number of teeth on sprocket (20 for the selected sprocket)

p = Pitch on the chain, mm (30 mm for chain selected)

c = Center distance between the shafts, mm (840 mm as per above)

$$L_n = \{(20+20)/2\} + (2 \times 840/30) + \{(20-20/2\pi)\}^2 \times (30/840) \\ = 20 + 56 + 0 \\ = 76$$

Length of upper chain conveyor = $L_n \times p = 76 \times 30$

$$= 2280 \text{ mm}$$

Similarly, number of chain links on lower chain conveyor was calculated by using equation 3.5 = 74, so, length of chain was = 2220 mm.

7. Ground wheel

Two pneumatic wheels of size 100×200 mm and 400 mm diameter were used as transportation wheels to make easy movement of machine in the field. Each wheel was fastened to a 25 mm shaft. With the help of bearings and shaft, the ground wheels were mounted at the centre of frame, as shown in Fig. 3.19. To make self-propelled, the ground wheel shaft received power from motor shaft through three reduction units.

8. Handle

The handle of the machine was designed on the basis of the working position of the operator easy working and shoe/floor friction and subject to anthropometrics. The co-efficient of friction (μ) between operators' shoe and the soil surface was 0.3. The person with large reach and high body weight can achieve high working force if also provided with high traction surtaxes and enough space to lean.

To operate, guide and balance the forces during operation of developed reaper two side arms was made up of MS round pipe of 25 mm diameter. The handle was attached at the rear side of the machine which was connected with the frame through the nut bolts. Handle height (position) in working task have been standardized by many research workers. Ayoub and Daniel (1974) and Chaffin *et al.* (1983) have recommended the minimum height 800-900 mm for Indian workers. Therefore, machine handle height was kept 880 mm. View of the handle as shown in Fig. 11.

9. Design of frame

It was a structural configuration, founded on the arrangement

and placement of diverse constituents within the machine. A structural framework was devised to accommodate all the parts of the developed reaper, as depicted in Fig. 12. The material selection was of paramount significance to endure the full operational load. A mild steel square frame of 1000 x 840 mm² was constructed using MS square pipe of 35×35×3 mm to accommodate various components of the machine-like battery, d. c. motor, gear box, transportation wheels, handle, crop cutting, and conveyor and ground wheel.

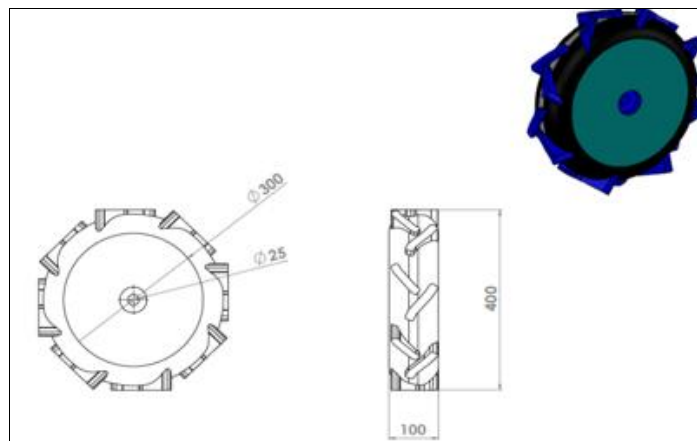


Fig 10: Dimension of ground wheel

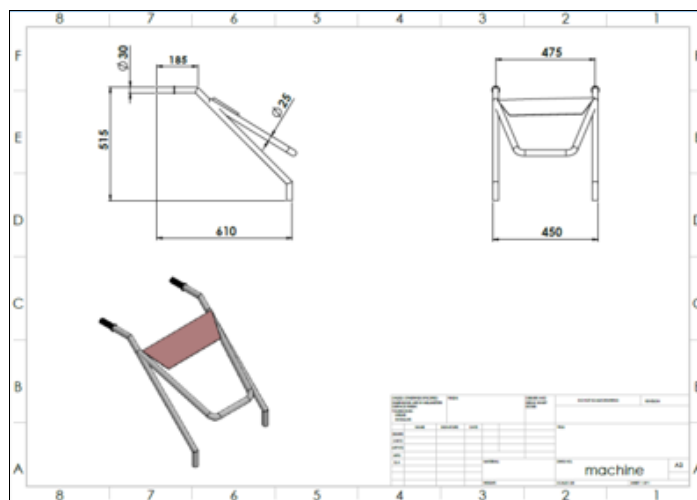


Fig 11: Isometric view of handle

Fabrication of battery-operated vertical conveyor reaper

After design calculation and consideration of components a 3-D model was developed by using Solid work to visualize the designed developed reaper. The final design of the reaper was achieved after a 3-D model was created and all of the components were attached in the proper positions. Developed reaper was designed to reduce time consumption and drudgery involve in harvesting of wheat and paddy crop.

Development of Battery-Operated Vertical Conveyor Reaper

A battery-operated reaper was designed and fabricated. The developed harvester was consisting of various parts i.e., main frame, DC motor, battery, cutter bar unit, conveyor unit, handle, crop lifter and divider, star wheel, ground wheel and power transmission system. The schematic conceptual drawing of the developed harvester was done using Solid work and the different components of developed machine are shown in Fig. 12 and 13. The developed reaper is depicted in Fig. 14.

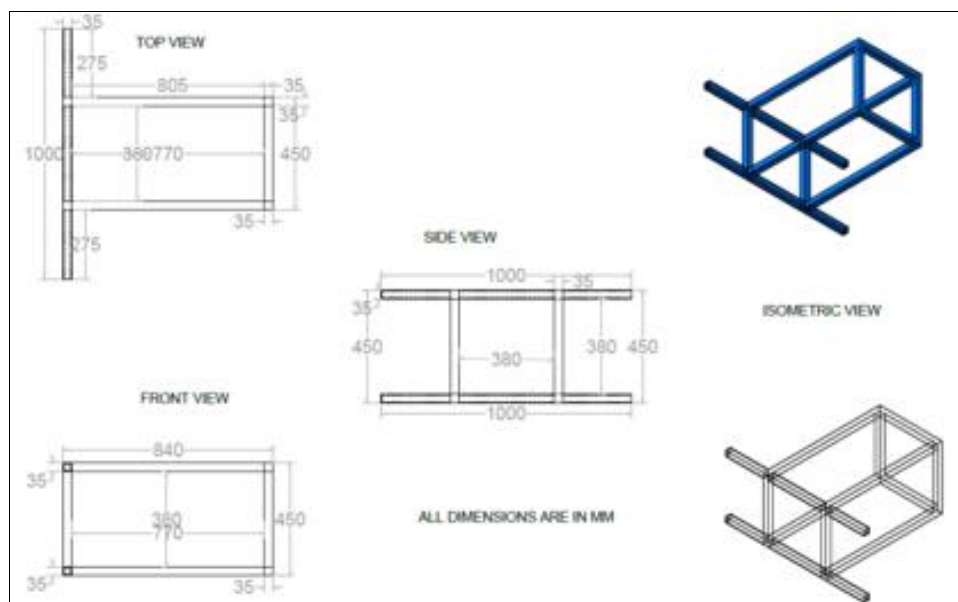


Fig 12: Dimension of frame

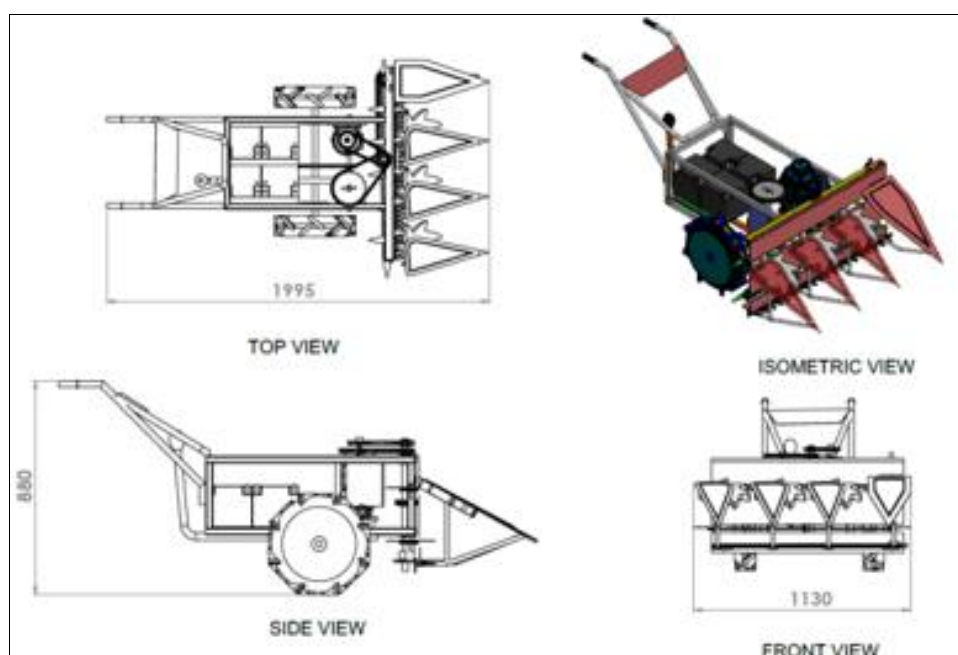


Fig 13: Line diagram of developed reaper



Fig 14: Developed Battery operated reaper

Conclusion

Manual harvesting is done by using sickle and it requires more time and drudgery. Combine harvesters and self-propelled reapers exhibit superior efficiency, requiring less time and delivering high field capacity compared to manual harvesting. However, these machines entail substantial costs and complexity, posing challenges for uneducated farmers. The majority of small and marginal farmers in India face difficulties in procuring these machines due to their high initial costs. While an alternative option is custom hiring, it remains problematic for those with small and fragmented lands. Harvesting through tractor-operated or power tiller-operated reapers incurs significant initial costs, running cost, and contributes to environmental pollution through fuel combustion.

Hence, there is a need which bridges the gap between sickles and tractor/power tiller/self-propelled reapers, specifically tailored for small and marginal farmers, while also being significantly more cost-effective and environmentally friendly. Employing a battery as its power source, this technology could

prove advantageous for both remote and hilly terrains. Furthermore, its battery pack can function as a power grid in remote areas, addressing the persistent challenge of maintaining continuous electricity supply. Therefore, a project was planned to develop a self-propelled battery powered reaper, having cutting and conveying unit powered by battery for paddy and wheat crop which will be within the affordable range of small and marginal farmers. In this era dominated by fossil fuels, battery-powered machinery is being introduced in automobiles. Similarly, in farming, the use of battery-powered equipment can be widely adopted to help reduce the burden of fuel costs for farmers.

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