Design and development of sugarcane harvester for small and marginal farmer

Md. Tahsin Ashraf, DK Roy and RK Naik

Abstract
The shortage of labour during harvesting season and the various types of harvester were available in the market, but they are costly (about 1.2 crore) and has been designed and develop a sugarcane harvester for small and large farmers at an affordable cost. The harvester consisted of main parts main frame, engine (3.73 kW), gear box (20:1), counter shaft, horizontal shaft, vertical shaft, cutter, handle and ground wheel. In sugarcane harvester, power transfer from engine to the cutter and ground wheel through the counter shaft, horizontal, vertical shaft with the help of bevel gear. The weight of the harvester with the engine is 60 kg. It was found that the sugarcane harvester gave 0.1303 ha/h average effective field capacity and 78 per cent field efficiency with minimum labour requirements (5 man-h/ha) as compared to the traditional method of harvesting. The cost of operation was found to be Rs./ha 2067.60/ which was the lowest from traditional (Rs./ha 11200/) with additional saving (Rs./ha 9132/) and total harvesting losses was 2.69 per cent in case of sugarcane harvester.

Keywords: Sugarcane harvester, engine, gear box, bevel gear, cutter, shaft and pulley.

Introduction
Sugarcane, (Saccharum officinarum L.), is one of the several species of tall perennial true grasses of the genus Saccharum. Sugarcane is the source of sugar in all tropical and subtropical countries of the world belongs to family Poaceae. Sugarcane is an important commercial crop (industrial crop), with acreage of about 4 million hectares and production of 300 million tonnes in India. Without the mechanization of the sugarcane harvesting, conventional harvest method is still adopted, which demand very high amount of labour, the labour productivity is low, and the cost of harvest is high.

The purpose of developing single row harvester is to reduce cost and time required for sugarcane harvesting. Sugarcane harvester which is economical, more efficient and cuts the sugarcane and it will be helpful for marginal and small farmers. By using this harvesting machine, we can also solve the problem of labour shortage.

This project work aims to develop sugarcane harvesting machine which is more efficient and having simple mechanism for cutting the sugarcane at a faster rate and should low cost that is affordable by the rural farmers, easy to maintain and less laborious to use. The machine consisted of main parts i.e. engine (petrol, 3.73 kW, 3000 rpm), gear box (20:1), coupling, frame, cutter frame, counter shaft, horizontal shaft, vertical shaft, cutter and ground wheel. All this parts of a machine was mounted on the frame. The wheel was attached to this frame. The petrol engine was mounted on the frame which provides the power to the wheels to move by means of a gear and chain mechanism and it also provides the power to the cutter. Frame was constructed by joining angle of mild steel of rectangular box section members to get rectangular shaped frame of used drilled machine for fixed cutter frame to the main frame by used nut and bolts.

In India agriculture is facing serious challenges like scarcity of agricultural labour, not only in peak working seasons but also in normal time. This is mainly for increased nonfarm job opportunities having higher wage, migration of labour force to cities and low status of agricultural labours in the society. (Jain et al. 2013)[1]

In manual harvesting to cut one acre of sugarcane 15-16 labours are required they take 3 days to cut one acre. By using this machine problem of the labour crises can be reduced. Comparing with manual harvesting only 18% of labours are required, it makes the process faster hence reduces most of the harvesting time and labour required to operate the machine is also less. This machine is helpful for both small and big farmers. (Ratod et al. 2013)[1]. To overcome these problems this project work aims to develop low cost sugarcane harvesting machine which is more efficient and having simple mechanism for cutting the sugarcane at a faster rate.
Materials and Method
This part deals with the design and development of sugarcane harvester for sugarcane crop. A developed sugarcane harvester consists of Frame, engine, gear box, counter shaft, vertical shaft, horizontal shaft, cutter, handle and ground wheel. The various factors involved in the development were operational safety, cost of production and availability of parts and easy of construction. The operation and adjustments were made simple so as to be used by the farmer.

Frame
It constructed by joining angle of mild steel of size 50×50×5 mm in rectangular box section members to get rectangular shaped frame of 1200×500 mm respectively, using drilling machine for fixing cutter frame to the main frame by using nut and bolts shape frame of 1700×200 mm respectively.

Engine
A 5 hp diesel engine running at 3000 rpm was used as prime mover. Engine was source of power in sugarcane harvester transfers power from engine to cutter, through gear box, horizontal shaft and vertical shaft with the help of bevel gear.

Power transmission
a. Selection of power source
The cutting force required to cut one cane is 106.57 N. (Zode et al. 2015) Calculation of power required for sugarcane harvesting is given below;

\[ T = Fr \]  
Where, 
\[ T = \text{Torque of the cutter, N-m} \]
\[ F = \text{Force required to cut sugarcane, N} \]
\[ r = \text{Radius of the cutter, m} \]

\[ T = 13.32 \text{ N-m} \]
\[ P = \frac{2\pi NT}{60} \]

\[ P = 2.77 \text{ kW} \]
Therefore the selected engine gives the power of 3.730 kW but the power required to cut the sugarcane is 2.775 kW. Hence this engine is selected.

b. Design of pulley and belt drive

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Section belt</th>
<th>Power range in, kWs</th>
<th>Top width, mm.</th>
<th>Bottom with, mm.</th>
<th>Thickness, mm.</th>
<th>Weight per meter length in N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B-section</td>
<td>2-15</td>
<td>17</td>
<td>9</td>
<td>11</td>
<td>1.98</td>
</tr>
</tbody>
</table>

Source: Khurmi, 2014

If the power range 1.5 to 15 kW, diameter, it is preffered to use a pulley having 200 mm diameter and B- belt section (Jain et al. (2013))

Diameter of pulley, mm = 200  
(Both, driver and driven pulley)
Bevel gear(No. of teeth) = 16  
(Both, driver and driven gear)
Coefficient of friction = 0.3
Grove angle of pulley 2α (\(^\circ\)) = 40
Power, kW = 3.730
Engine speed, rpm = 3000

Find out the torque on engine sha

\[ P = \frac{2\pi NT}{60} \]

Where,
\[ T_e = \text{Torque on the engine shaft, N-m} \]
\[ N = \text{rpm} \]
\[ T_e = 11.87 \text{ Nm} \]

Velocity of the belt

\[ V = \frac{\pi \times d \times N}{60} \]

Where,
\[ V = \text{Velocity} \]
\[ D = \text{Diameter of pulley; and.} \]
\[ N = \text{Speed of pulley;} \]
\[ V = 31.41 \text{ m/s} \]

According to Indian Standard (IS: 2494 - 1974) dimension of v-belt is if the power is 2-15 kW then length B-section pulley having 17 mm, top width, 9 mm bottom with and 11 mm thickness.

Area of the belt

\[ A = \left[ \frac{\pi \times 11 \times 4^2}{2} \times 2 + 9^2 \right] - - - (4) \]
\[ A=125 \text{ mm}^2 \]

Capacity

\[ \text{Capacity} = e^{\frac{0.27 \times \pi}{20}} \]

Where,
\[ d_1 = d_2 = \text{Diameter of driver or diameter of driven pulley, mm;} \]
\[ \Theta = \pi \text{ radians (D_2=D_2)} \]
\[ \text{Capacity} = 11.942 \]

Constant

\[ K = \frac{\text{Capacity} - 1}{\text{Capacity}} \]

Where,
\[ K = \text{Constant} \]
\[ K = 0.9162 \]

Length of belt

\[ L = 2C + \pi \times (D_1+D_2)/2 + (D_1-D_2)^2/4C - (6) \]
\[ L = 2 \times 50 + 3.14 \times (20+20)/2 \times (20-20)^2/4 \times 50 \]

Where,
\[ L = \text{Length of belt, mm;} \]
\[ D_1 = \text{Diameter of driver pulley, mm;} \]
\[ D_2 = \text{Diameter of driven pulley, mm; and.} \]
\[ C = \text{Centre to centre distance of belt, mm;} \]
\[ L = 1600 \text{ mm} \]
Number of belt required

\[
\text{Number of belt required} = \frac{\text{Total power transmitted (kW)}}{\text{Power transmitted per belt (kW)}} - (7)
\]

\[
= 0.53
\]

Hence the belt required one.

Centrifugal stress

\[
\sigma_c = \frac{W}{g} \times V^2 \times 10^6 - - - (8)
\]

Where,
\[
\sigma_c = \text{Centrifugal stress};
\]
\[
W = \text{weight of belt};
\]
\[
g = \text{Acceleration due to gravity};
\]
\[
V = \text{Velocity of belt}
\]

\[
\sigma_c = 1.006 \text{N/mm}^2
\]

Centrifugal tension

\[
T_c = \text{Centrifugal stress} \times \text{Area of cross section of belt.}
\]

Where,
\[
T_c = \text{Centrifugal tension};
\]
\[
= \sigma_c \times A
\]
\[
= 1.006 \times 125
\]
\[
T_c = 125.75 \text{N}
\]

Power transmitted per belt

\[
P = \frac{(T_1 - T_2)kv}{1000} - - - (9)
\]

Where,
\[
k = \text{constant}
\]
\[
v = \text{velocity of the belt}
\]
\[
T_1 = \text{Tension in tight side, N;}
\]
\[
T_c = \text{Centrifugal tension, N;}
\]
\[
K = \text{Constant;}
\]

Hence, power transmitted per belt=3.73
\[
T_1 = 255.35 \text{N}
\]
\[
\sigma_1 = \frac{T_1}{A}
\]
\[
\sigma_1 = 255.35 \div 125
\]
\[
\sigma_1 = 2.04 \text{N/mm}^2.
\]

Initial tension (T_0)

\[
2\sqrt{T_0} = \sqrt{T_1} + \sqrt{T_2} - - - (10)
\]

Where,
\[
T_0 = \text{Initial tension in belt;}
\]
\[
T_1 = \text{Tension in tight side;}
\]
\[
\text{and T}_2 = \text{Tension slack side;}
\]
\[
\frac{\sigma_1 - \sigma_c}{\sigma_2 - \sigma_c} = e^{\frac{\mu \varphi}{\sin \alpha}} - - - (11)
\]

Where,
\[\theta = \mu, \text{radian;}
\]
\[\alpha = \text{Grove angle of pulley, 20}^\circ;
\]
\[\mu = \text{Coefficient of friction, 27;}
\]
\[
\frac{2.04 - 1.006}{\sigma_2 - 1.006} = 11.94
\]
\[
\sigma_2 = 1.09 \text{N/mm}^2
\]

\[
T_2 = \sigma_2 \times A
\]

Where,
\[
T_2 = \text{Tension in slack side;}
\]
\[
A = \text{Area of belt;}
\]
\[
\text{and.}
\]
\[
\sigma_2 = \text{Tensile stress;}
\]
\[
T_2 = 136.51 \text{N}
\]

1. Gear box

The gear box was used to increase torque and reduced the speed of a prime mover shaft. This means that the output shaft of gear box rotates at as lower than the input shaft. The gear box has gear ratio20:1.it reduces the engine speed at the ground wheel.

2. Counter shaft

a. Design of Counter shaft

A 5 hp engine running at 3000 rpm was used as prime mover. The Counter shaft has 3000 rpm, because same teeth of driver and driven gear. Hence, the torque transmitted to the counter shaft will be same of engine shaft.

\[
\frac{N_1}{N_2} = \frac{T_2}{T_1} - - - (12)
\]

Where:
\[
N_1 = \text{Speed of driver gear;}
\]
\[
N_2 = \text{Speed of driven gear;}
\]
\[
T_1 = \text{No. of teeth of driver gear;}
\]
\[
T_2 = \text{No. of teeth of driven gear;}
\]
\[
N_2 = 3000 \text{ rpm}
\]

b. Transmission ratio

\[
= \frac{T_2}{T_1} = \frac{N_1}{N_2} = 1
\]

c. Torque on the Counter shaft

\[
T_c = T_c \times 1 - - (13)
\]

Where,
\[
T_c = \text{Torque on counter shaft, Nm;}
\]
\[
T_c = \text{Torque on engine shaft, Nm;}
\]
\[
T_c = 11.87 \text{Nm}
\]

4. Horizontal shaft

a. Design of horizontal shaft

The horizontal shaft has 3000 rpm, because same diameter of driver and driven pulley. Hence, the torque transmitted to the counter shaft will be same of counter shaft.

\[
\frac{N_2}{N_3} = \frac{D_2}{D_1} - - - (14)
\]

\[
\text{~ 121 ~}
\]
Where:
\( N_2 \) = Revolution of driver pulley;
\( N_3 \) = Revolution of driven pulley;
\( D_1 \) = Diameter of driver pulley; and
\( D_2 \) = Diameter of driven pulley.
Hence, \( N_3 = 3000 \text{ rpm} \)

a. Transmission ratio
Transmission ratio = 1

b. Torque on the horizontal shaft.
\( T_h = T_c \times \text{Transmission ratio} \)
\( T_h = T_c \times 1 \)
Where,
\( T_h \) = Torque on horizontal shaft, Nm; and
\( T_c \) = Torque on counter shaft.
\( T_h = 11.87 \text{ Nm} \)

c. Design for diameter of horizontal shaft
\( T_1 + T_2 + W_P = - (15) \)
Where,
\( T_1 \) = Tension on Tight side
\( T_2 \) = Tension on slack side
\( W_P \) = Weight of pulley
\( = 255.35+136.51+(2 \times 9.81) \)
\( = 411.48 \text{ N} \)

Moment at A
\( 411.48 \times 740 = R_C \times 890 \)
\( R_C = 342.12 \text{ N} \)
\( R_A + R_C = 411.48 \)
\( R_A = 411.48 - 321.23 \)
\( R_A = 69.36 \text{ N} \)

Bending moment at A
\( M_b = 0 \)

Bending moment at B,
\( M_b = 69.36 \times 740 \)
\( M_b = 51326.4 \text{ N-mm} \)

Bending moment at C
\( M_b = 0 \)

\[ D_h = \frac{16}{\pi \zeta_{ed}} \times [K_t M_t] \] (16)
Where,
\( D_h \) = Diameter of shaft, mm;
\( \zeta_{ed} = \text{allowable stress}, \text{ MPa}; \)
\( K_t \) = Equivalent torque, Nm; and
\( M_t \) = Equivalent bending moment, Nm.

According to ASME code, \( \zeta_{ed} = 55 \text{ N/mm}^2 \) without keyway
\( D_h = \frac{[16/\pi \times 55]}{[1.5 \times 51326.40]} \)
\( D_h = 21.56 \text{ mm} \)

Vertical shaft
The horizontal shaft was the shaft, which intersects the vertical shaft with the help of Bevel gear, which transmits the power from the horizontal shaft to a vertical shaft at 90\(^\circ\) with the help of bevel gear. The bevel gear is used to transmit the power between two shafts, which are non-parallel or intersecting, but coplanar.

a. Speed calculation of horizontal shaft
\( N_1 = \frac{T_2}{T_1} \)
\( N_2 = \frac{T_2}{T_1} \)
Where:
\( N_1 \) = Revolution of driver gear;
\( N_2 \) = Revolution of driven gear;
\( T_1 \) = No. of teeth of driver gear; and
\( T_2 \) = No. of teeth of driven gear.
\( N_2 = 3200 \text{ rpm} \)

b. Transmission ratio
Transmission ratio = 1

c. Torque on the vertical shaft:
\( T_v = 8.89 \text{ N-m} \)
Where,
\( T_v \) = Torque on vertical shaft

d. Design for diameter of vertical shaft
Moment at A
\( (537.16 \times 300) + (147.3 \times 700) = 0 \)
\( 172940.8 = (R_C \times 300) \)
\( R_C = 576.4693 \text{ N} \)
\( R_A + R_C = 537.16+147.3 \)
\( R_A = 107.99 \text{ N} \)

Bending moment at A
\( M_b = 0 \)

Fig 1: Horizontal shaft

Fig 2: Vertical Shaft
Bending moment at B
\[ M_B = 107.99 \times 130 \]
\[ M_B = 14038.7 \text{ N-mm} \]
Bending moment at C
\[ M_B = 147.3 \times 400 \]
\[ M_B = 58920 \text{ N-mm} \]
Bending moment at D
\[ M_B = 0 \]
Diameter of the shaft
\[ D_V = \left[ \frac{16}{\pi \zeta_{ed}} \right] \times \left[ K_t M_t \right] \] ... (17)

Where,
- \( D_h \) = Diameter of shaft, mm;
- \( \zeta_{ed} = \) allowable stress, MPa;
- \( K_t \) = Equivalent torque, Nm; and
- \( M_t \) = Equivalent bending moment, Nm.

According to ASME code
\[ \zeta_{ed} = 55 \text{ N/mm}^2 \] Without keyway
\[ D_v = \left[ \frac{16}{\pi \times 55} \right] \times \left[ 1.5 \times 58920 \right] \]
\[ D_v = 20.1521 \text{ mm} \]

4. Cutter
The output shaft of the engine which connects to the gear box with the help of coupler and gear box has two output shaft one for speed reducing and other output shaft (same engine speed) for transmitting power from the horizontal shaft to the vertical shaft with the help of bevel gear. The cutter was mounted at the bottom of the vertical shaft. Bevel gear was used transfer the power from the horizontal to the vertical shaft of the cutter assembly.

a. Calculation for speed of cutter
Shear force required to cut the wood is found to be 450 N and shear force required to cut the sugarcane is 106.57 N. (Zode et al. 2015) \[ 23 \]. So, shear force required to cut sugarcane is less than the wood cutting.

Pulley is mounted to the output shaft of the engine and through the belt drives the power is transferred to the horizontal shaft of the cutter assembly. Bevel gear is used transfer the power from horizontal to the vertical shaft of the cutter assembly.

\[ \text{Gear ratio} = \frac{n_1}{n_2} = \frac{Z_2}{Z_1} \] ... (18)

Where,
- \( Z_d \) = Bevel gear, driver pinion = 16;
- \( Z_2 \) = Driven gear, driven pinion = 10;
- \( n_1 \) = Speed at vertical shaft of = 3000 rpm.; and
- \( n_2 \) = speed of cutter = 4800 rpm.

5. Handle height
Handle height (position) in working task have been standardized by many research workers. Chaffin et al. (1983) are commended the minimum height 800-900 mm for Indian workers. Therefore machine handle height was kept at 900 mm.

6. Ground wheel
Transportation wheel or ground wheel was the main component of the single row sugarcane harvester, which were touches on ground surface. We select two 830×30 size rubber tube tyre wheels. This facilitates easy movement of the harvester in the field.

a. Speed of ground Wheels
The output shaft of the engine was keep that 3000 rpm for the 1st gear ratio raising 20:1 So, the speed of the output of the gear box is 150 rpm

\[ \text{Gear ratio of gear box} = \frac{N_1}{N_g} \]

Where,
- \( N_1 \) = Engine speed, rpm;
- \( N_g \) = Speed of output of gear box;
- Gear ratio was 20:1

Then apply above equation.
\[ N_g = 150 \text{ rpm} \]

Hence the speed \( N_g = 150 \text{ rpm} \) was found that the output of gearbox

Now using formula for find the rpm of ground wheel
\[ \frac{N_s}{N_w} = \frac{Z_2}{Z_1} \]

Where:
- \( Z_d \) = Small sprocket teeth;
- \( Z_2 \) = Larger sprocket teeth;
- \( N_s \) = speed of the ground wheel shaft; and
- \( N_w \) = Speed of the ground wheel.

\[ \frac{150}{45} = \frac{45}{15} \]

\[ N_w = 50 \text{ rpm} \]

Hence, found that the speed of ground wheel 50 rpm

Table 2: Selection of material for light weight engine operated sugarcane harvester

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Particular</th>
<th>Material</th>
<th>Size</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diesel engine (kW)</td>
<td>2.982</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gear box</td>
<td>Mild steel</td>
<td>20:1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Cutter(mm)</td>
<td>Steel alloy</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Bevel gear</td>
<td>Steel alloy</td>
<td>16 &amp; 10</td>
<td>1 &amp; 1</td>
</tr>
<tr>
<td>5</td>
<td>Bearing</td>
<td>UCP205</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UCP206</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Main frame, mm</td>
<td>Mild steel</td>
<td>900×500×50</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Cutter frame, mm</td>
<td>Mild steel</td>
<td>600×260×50</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Horizontal shaft, mm</td>
<td>Mild steel</td>
<td>350×25</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Vertical shaft, mm</td>
<td>Mild steel</td>
<td>900×25</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Ground wheel shaft, mm</td>
<td>Mild steel</td>
<td>830×30</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Handle, hollow pipe, mm</td>
<td>Mild steel</td>
<td>550×270×35</td>
<td>2</td>
</tr>
</tbody>
</table>
**Result and Discussion**

The sugarcane harvester was designed and fabricated. After testing this harvesting machine in the field it was found that the effective field capacity of sugarcane harvester was 0.1303 ha/h at operating speed of 1.03 km/h and found field efficiency was 78%. The cost of harvesting machine was 50,000. The cost of operation found 2067.60 Rs/ha.

The purpose of developing this paper was to develop a machine to reduce the cost and time required for sugarcane harvesting. We were also solving the problem of labour shortage.

**Table 3: Comparison of field capacity**

<table>
<thead>
<tr>
<th>Harvesting implements/methods</th>
<th>EFC, ha/h</th>
<th>Time req., H</th>
<th>Man day per ha</th>
<th>Cost, Rs/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed harvester</td>
<td>0.1303</td>
<td>0.198</td>
<td>5</td>
<td>2067.60</td>
</tr>
<tr>
<td>Gadasa</td>
<td>0.0168</td>
<td>59</td>
<td>30</td>
<td>10500</td>
</tr>
<tr>
<td>Local cutting equipment</td>
<td>0.0134</td>
<td>74.12</td>
<td>30</td>
<td>11200</td>
</tr>
</tbody>
</table>

**Conclusion**

Design and development of sugarcane harvester to reduce the cost and time required for sugarcane harvesting. The sugarcane harvesting machine, which were economical, more efficient and cut the sugarcane at a faster rate and it was helpful for small scale farmers and unskilled labours can also be operated without difficulties by using this harvesting machine. Thus, on the basis of information obtained through the study, the following conclusion could be inferred:

1. The developed harvesting machine having two row cutters gave a better field performance compared to the traditional method.
2. The mode of power transmission and speed for ground wheel and cutter were found satisfactory.
3. Engine power found adequate for the designed width (100cm) of cut.
4. It is recommended that use of the harvester at an average forward speed of 1.03 km/h to harvest the sugarcane crop.
5. The performance of developed harvester was found satisfactory. It gave field capacity 0.1303 ha/h with 5 men-h/ha.
6. The fabrication cost of the machine came around Rs. 50,000/
7. Comparatively found economical (harvesting cost 2067.60 Rs/ha) than that of traditional (Rs/ha 10500)

**Reference**


