Design and development of single row power weeder for rice

A. SIRMOUR AND A. VERMA

Department of Farm Machinery and Power Engineering,
Faculty of Agricultural Engineering, I.G.K.V (Raipur)

Received : 12-12-2017 ; Revised : 05-03-2018 ; Accepted : 15-03-2018

ABSTRACT

Weed control is one of the most difficult tasks on an agricultural farm. Weeding by mechanical devices reduces the cost of labour and also saves time. In order to assess the possibility of mechanization of the weeding operation, a power operated single row active weeder were designed and developed in the Faculty of Agricultural Engineering, IGKV, Raipur. From the design point of view- power source (engine), cutting blades shaft were the important components of single row power weeder for rice. Average working speed of operation was found as 2.45 km hr\(^{-1}\). The average fuel consumption of power weeder was found as 0.55 l hr\(^{-1}\). The maximum field capacity was found 0.054 ha hr\(^{-1}\). The working width of the developed machine may be adjustable between 140 mm to 250 mm. The weeding efficiency was observed as 88.62 per cent under single row active power weeder. The saving in cost of weeding was 60 per cent and saving in time was 65 per cent compared to manual weeding.

Keywords: Blade, power weeder, rice, rotor speed, transmission

Weed control is one of the most difficult tasks in agriculture that accounts for a considerable share of the cost involved in agriculture production. Weeds compete with crop plants for nutrients and other growth factors and in the absence of an effective control measure, consume 30 to 40 per cent of applied nutrients resulting in significant yield reduction. In India, about 4.2 billion rupees are spent every year for controlling weeds for production of major crops. Weeding with the use of manual tools requires high labour force. Mechanical weeder are used to complete the weeding operation in due time at less cost. Environmental pollution caused by chemical is also reduced by the use of mechanical weeder.

Pitoyo et al. (2000) reported the development of a power weeder for mechanical control of weeds in the rice field. The machine is driven by two strokes engine 2 hp/6500 rpm. The machine performance was 15 h/ha capacity at travelling speed 1.8 km hr\(^{-1}\), the mass of the machine was 24.5 kg. Victor et al. (2003) reported that a rotary power weeder reduce the drudgery and ensure a comfortable posture of the operator during weeding and increases production as, field capacity and weeding efficiency of the rotary power weeder were 0.0712 ha/h and 73 per cent respectively. In order to assess the possibility of mechanization of the weeding operation, the power operated single row active weeder was designed and developed considering the optimum shape, size and location of cutting blades, evaluation of its performance, optimisation of dimensions of machine for better performance.

MATERIALS AND METHODS

A manually operated power weeder was designed for weeding of mechanical and manual transplanting of rice. From the design point of view- power source (engine), cutting blades shaft were the important components of single row power weeder for rice.

Power requirement

Assumption

Soil resistance has a considerable effect upon the power requirement of weeder. Also, width of cut and speed of operation influences power requirement of weeder. For calculating power requirement of the weeder, maximum soil resistance was taken as 0.5 kgf/cm\(^2\). The speed of operation of the weeder was considered as 0.7 ms\(^{-1}\) to 1.0 ms\(^{-1}\). Total width of coverage of cutting blades was in the range of 12 to 30 cm. The depth of operation was considered as 3 to 8 cm, transmission efficiency is 82 per cent.

\[
P_d = \frac{SR \times d \times w \times v}{75}\ hp
\]

where,

\[
SR = \text{soil resistance, kgf/cm}^2
\]
\[
d = \text{depth of cut, cm}
\]
\[
w = \text{effective width of cut, cm}
\]
\[
v = \text{speed of operation, ms}^{-1}
\]

Hence, power requirement is estimated as

\[
P_d = \frac{0.5 \times 8 \times 30 \times 1}{75}\ hp = 1.6\ hp = 1.26\ kW
\]

Total power required

The total power required is estimated as 1.95 hp as follows

\[
P_t = \frac{P_d}{\eta} = \frac{1.6}{0.82} = 1.95\ hp = 1.56\ kW
\]
Design and development of single row power weeder for rice

where,
\[ P_d = \text{Power required to dig the soil:} \]
\[ \eta = \text{Transmission efficiency.} \]

Thus, a prime mover of 1.49 kW (2 hp) was required for this weeder.

Power transmission system of worm and worm gear

The following table shows the various proportions for worm and worm gear arrangement in term of the axial pitch (\(P_a = 6.08\)) in mm.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Normal pressure angle</td>
<td>14 1/2°</td>
</tr>
<tr>
<td>2.</td>
<td>Outside diameter</td>
<td>(D_g + 1.0135 \text{ Pa} = 71.78\text{mm})</td>
</tr>
<tr>
<td>3.</td>
<td>Throat diameter</td>
<td>(D_g + 0.636 \text{ Pa} = 69.49\text{mm})</td>
</tr>
<tr>
<td>4.</td>
<td>Face width</td>
<td>(2.38 \text{ Pa} + 6.5 = 20.97\text{mm})</td>
</tr>
<tr>
<td>5.</td>
<td>Radius of face gear</td>
<td>0.882 Pa+14</td>
</tr>
<tr>
<td>6.</td>
<td>Radius of gear rim</td>
<td>2.2 Pa +14</td>
</tr>
</tbody>
</table>

Table 1 : Proportion of worm

Table 2 : Proportions for worm gear

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Normal pressure angle</td>
<td>14 1/2°</td>
</tr>
<tr>
<td>2.</td>
<td>Outside diameter</td>
<td>(D_g + 1.0135 \text{ Pa} = 71.78\text{mm})</td>
</tr>
<tr>
<td>3.</td>
<td>Throat diameter</td>
<td>(D_g + 0.636 \text{ Pa} = 69.49\text{mm})</td>
</tr>
<tr>
<td>4.</td>
<td>Face width</td>
<td>(2.38 \text{ Pa} + 6.5 = 20.97\text{mm})</td>
</tr>
<tr>
<td>5.</td>
<td>Radius of face gear</td>
<td>0.882 Pa+14</td>
</tr>
<tr>
<td>6.</td>
<td>Radius of gear rim</td>
<td>2.2 Pa +14</td>
</tr>
</tbody>
</table>

Torque transmitted by the shaft

\[
T = \frac{P \times 60 \times 10^3}{2 \times \pi \times N}
\]

where,
\[ P = \text{power, kW} \]
\[ T = \text{torque transmitted by the shaft, Nm} \]
\[ N = \text{revolutions per minute} \]

Considering engine speed as 6000 rpm and engine power 1.49 kW we get torque as 2.37 Nm.

Diameter of the flexible shaft

For designing the rotor shaft, the maximum tangential force which can be endured by the rotor should be considered. The maximum tangential force occurs at the minimum of blades tangential speed is calculated by the following (Bernacki et al., 1972)

\[
K_s = \frac{C_s \times 75 \times N_c \times \eta_c \times \eta_z}{u}
\]

where,
\[ K_s = \text{Maximum tangential force, kg,} \]
\[ C_s = \text{Reliability factor (1.5 for non-rocky soils and 2 for rocky soils),} \]
\[ N_c = \text{Power of engine, hp,} \]
\[ \eta_c = \text{Traction efficiency for the forward rotation of rotor shaft as 0.9,} \]
\[ \eta_z = \text{Coefficient of reservation of engine power (0.7-0.8),} \]
\[ u = \text{Minimum tangential speed of blades} \]

Tangential peripheral speed, \(u\), can be calculated using the following equation:

\[
u = \frac{2 \times \pi \times N \times R}{6000}
\]

where,
\[ N = \text{Revolution of rotor, rpm, and} \]
\[ R = \text{Radius of rotor, cm} \]

After substituting values for revolution of rotor shaft (176 rpm) and its radius as 16 cm in equation (3.14), tangential peripheral speed was obtained as 2.94 ms\(^{-1}\). Using the tangential peripheral speed and other parameters in equation (1), the maximum tangential force was determined to be 55.10 kg.

The maximum moment on the rotor shaft (\(M_s\)) is calculated through the following:

\[ M_s = K_s \times R \]

With rotor shaft radius of 16 cm, moment acting on it was 881.6 kg-cm.

The yield stress of rotor made from rolled steel (AISI 302) was 520 MPa. The allowable stress on the rotor (\(\sigma_{all}\)) was calculated by the following equation (Mott, 1985):

\[
\sigma_{all} = \frac{0.577 \times k \times x \sigma_y}{f}
\]

where,
\[ \sigma_{all} = \text{Allowable stress on rotor shaft, kg.cm}^{-2}; \]
\[ k = \text{Coefficient of stress concentration (0.75),} \]
\[ f = \text{Coefficient of safety (1.5), and} \]
\[ \sigma_y = \text{Yield stress, 520 MPa} \]

By substituting above values in the following equation, rotor shaft diameter was calculated as:

\[
D = \frac{16 \times M_s}{\tau_{all} \times \pi}
\]

\[ D = 14.3 \text{ mm} \]
Fig. 1: Specification of blade

Fig. 2: Design of handle

Fig. 3: 2-D diagram of the developed machine
Design and development of single row power weeder for rice

Fig. 4: Isometric view of developed power weeder for rice

Fig. 5: Power requirement of power weeder with different blades

Fig. 6: Plant damage per cent of power weeder with different blades
In order to take into account fluctuating load during the operation, diameter of the rotor shaft was selected higher than the calculated value as 16 mm.

**Design of cutting blades**

Different parameters used in the study and have been in consideration to give safe strength and bending values for manufactured blades during weeding operation. The calculation and assumptions are based on standard handbook of machine design were followed (Shigley et al., 2004). Assumption was made as follows; Number of blades in one working set = 4; Length of blade = 11.3 cm; Width of blade = 4 cm. To calculate the design strength of blade; revolution per minute of rotor shaft (N) = 176 r.p.m; radius of engine output rotor (R) = 16 cm.

The soil force acting on the blade (Ke) was calculated by the following equation:

\[ K_e = \frac{K_s \times C_p}{i \times Z_e \times n_e} \]

Where,

- \( K_s \) = Maximum tangential force, kg,
- \( C_p \) = Coefficient of tangential force as 0.8,
- \( i \) = Number of flanges is 2,
- \( Z_e \) = Number of blades on each side of the flanges is 4 and
- \( n_e \) = Number of blades which act jointly on the soil by total number of blades.

By solving eqn. 3, the soil force acting on the blade (Ke) was determined as 55.1 kg.

The dimensions of the blades are given in Fig. 1. The values of be, he, S, S and S1 were equal to 0.2 cm, 2.0 cm, 4.0 cm, 8.0 cm and 1.0 cm respectively.

Considering the shape of the blades, the bending stress (\( \sigma_{bz} \)), shear stress (\( \tau_{skt} \)), and equivalent stress (\( \sigma_{eq} \)) can be calculated by the following equations (Bernacki et al., 1972):

\[ \sigma_{bz} = \frac{6 \times K_e \times S}{b_e \times h_e^2} \]

\[ \tau_{skt} = \frac{3 \times K_e \times S}{\left(\frac{h_e}{b_e} - 0.63\right) \times b_e^3} \]

\[ \sigma_{eq} = \sqrt{\sigma_{bz}^2 + 4\tau_{skt}^2} \]

Where,

- \( \sigma_{bz} \) = bending stress, MPa,
- \( \tau_{skt} \) = shear stress, MPa, and
- \( \sigma_{eq} \) = equivalent stress, MPa.

The bending stress, shear stress and equivalent stress were determined as 324.20 MPa, 216.25 MPa and 540.52 MPa, respectively.

**Determining the blade width (W)**

It was assumed that most of the tilled soil mass is in the first half of the blade working depth and maximum working depth should be assumed 6 cm for power weeder so that the minimum blade width (W) can be determined.

\[ W = \frac{H_h}{\sin \beta} \]

and

\[ \beta = 90^\circ + \gamma - \alpha \]

Where,

- \( H_h \) = half of maximum working depth, m
- \( \alpha \) = angle of blade rotation from the horizontal, degree
- \( \beta \) = angle of inclination of the blade from horizontal, degree
- \( \gamma \) = cutting angle, 23.8°

Inclination angle (\( \beta \)) was calculated, angle \( \alpha \) was determined as:

\[ \alpha = \sin^{-1}\left(\frac{H - H_h + R}{R}\right) \]

where,

- \( H \) = maximum working depth
- \( R \) = radius of rotor

The cutting angle \( \gamma \) was determined as 23.8°. By substituting above calculated values of angles \( \gamma \) and \( \alpha \) in Eq. 3.19, inclination angle \( \beta \) was calculated as:

\[ \beta = 90^\circ + \gamma - \alpha = 90^\circ + 23.8^\circ - 54.34^\circ = 59.46^\circ \]

According to Eq. 3.18, the calculated minimum blade width W was 3.48 cm.

**Maximum force required to cut the soil for each blade (P):**

\[ P = pA = 6.49 \text{ kg/each blade} \]

Where:

- \( p \) = Maximum specific resistance of soil = 0.50 kg/cm²
- \( A \) = Area to be disturbed,
- \( a \) = edge length of the blade, 2.2 cm.
- \( l \) = length of blade, 11.3 cm

If we have maximum four blades but only one can cut and disturb the soil, and 3 sets in the power rotor, so the maximum force required to cut the soil by the weeder.
Design and development of single row power weeder for rice

\[ P_{\text{max}} = 6.49 \times 3 = 19.47 \text{ kg} \]

Cutting force per unit length of blade

\[ P_c = \frac{P_{\text{max}}}{1} = 1.72 \text{ kg cm}^{-1} \]

Taking this as beam (cantilever) with uniformly distributed load, both maximum bending load and moment of inertia can be calculated as below:

Maximum bending load = \( \frac{P_a \times I^3}{2} \) = 109.81 kg cm

Moment of inertia (I) = \( \frac{1}{12} \times b \times S_s^3 \) = 1.066 cm\(^4\)

Where;
\( S_s \) is width of blade edge, 2 cm; and
\( b \) is maximum thickness of blade edge, 0.2 cm.

To check for bending:

Deflection for cantilever beam = \( \frac{P_{\text{max}} \times I^3}{3EI} \)

Where;
\( E = 2.1 \times 106 \text{ kg cm}^{-2} \) for mild steel.
The value will be 4.18 \( \times 10^{-3} \). It is almost negligible and for safe design deflection should be < a/1200 (4.18 \( \times 10^{-3} < 5 \times 10^{-3} \)), so, it is safe.

Description of machine components

Based on design values of different components, an engine operated rice weeder was fabricated in the workshop of Faculty of Agricultural Engineering, IGKV, Raipur. The technical specifications of the engine are shown in Table 3.3.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of cylinder</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Engine maximum power</td>
<td>2 hp</td>
</tr>
<tr>
<td>3</td>
<td>Weeding width</td>
<td>140 mm to 250 mm</td>
</tr>
<tr>
<td>4</td>
<td>No. of Blades</td>
<td>4,6,8 as per field condition</td>
</tr>
<tr>
<td>5</td>
<td>Rotor speed</td>
<td>176 rpm</td>
</tr>
<tr>
<td>6</td>
<td>Weeding depth</td>
<td>3 - 8 cm</td>
</tr>
<tr>
<td>7</td>
<td>Power transmission</td>
<td>Light weight aluminium gear box</td>
</tr>
<tr>
<td>8</td>
<td>Fuel tank capacity</td>
<td>1.1 Lts</td>
</tr>
<tr>
<td>9</td>
<td>Fuel</td>
<td>Petrol mixed with lub.oil(1Lts of petrol with 40 ml of oil)</td>
</tr>
<tr>
<td>10</td>
<td>Material of blade</td>
<td>Mild steel-L type blade</td>
</tr>
<tr>
<td>11</td>
<td>Overall dimension</td>
<td>1345.8 x 573 x 1020 mm</td>
</tr>
<tr>
<td>12</td>
<td>Total weight</td>
<td>14.5 kg</td>
</tr>
</tbody>
</table>

J. Crop and Weed, 14(1)
Where,

\( W_1 \) = Number of weeds counted per unit area before weeding operation

\( W_2 \) = Number of weeds counted in same unit area after weeding operation

**Field capacity**

Field capacity (ha/h) was computed by recording the area weeded during each trial run in a given time interval. With the help of stopwatch, time was recorded for respective trial run along with area covered.

**Plant damaged**

It is the ratio of the number of plants damaged after operation in a row to the number of plants present in that row before operation. It is expressed in percentage.

\[
\text{plant damage (\%)} = \left( 1 - \frac{q}{p} \right) \times 100
\]

Where,

\( p \) = Number of plants in a 10 m row length of field before weeding.

\( q \) = Number of plants in a 10 m row length of field after weeding

**Fuel consumption**

The fuel tank was filled to full capacity before the testing at levelled surface. After completion of test operation, amount of fuel required to top fill again is the fuel consumption for the test duration.

**RESULTS AND DISCUSSION**

**Operation speed**

The speed of operation was found as 0.69 m/sec by using 4 blades in power weeder followed by 0.61 m/sec on using of 6 blades.

**Power requirement**

The power requirement at 15 DAS with 22 cm of width is maximum found in 8 blades as 0.51 hp followed by 0.42 hp in 6 blade and then 0.39 hp in 4 blades.

The testing was carried out to assess the technical and economic performance of the developed power weeder. It was tested on the basis of field capacity, field efficiency, weeding efficiency, performance index, energy consumption and cost of operation. Thus, the following conclusions could be drawn. The performance of paddy weeder was found excellently on wet condition, the working width of the developed machine should be adjustable between 140 to 250 mm, forward speed 2.48 km/h and depth of operation ranged from 3- 4.2 cm, with fuel consumption of 0.55 l/h. The effective field capacity was 0.054 ha/h. The weeding efficiency as 82.92 per cent, the operating cost of the rotary paddy weeder was Rs.980/ha compared to Rs. 2300/ha for manual weeding. The saving in cost of weeding was 60 per cent and saving in time was 65 per cent compared to manual weeding.

**REFERENCES**


