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CONTENTS

Design of a Tractor Operated Carrot Digger

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ABSTRACT: India is the world's second largest producer of vegetables, responsible for nearly 13.3% of global vegetable production. Carrots are one of the most important vegetable crops produced in various parts of the India. Carrot harvesting is a time-consuming and labor-intensive operation that requires 250-300 man-hours per hectare, as well as more time and energy consume. As a result, carrot digging must be mechanized to save time, money, energy, and human drudgery. Therefore, Tractor-operated carrot digger was designed and developed using three types of digging blades (Sweep, Nose and Shovel type).

Key words: Carrot, digger, design, farm machinery

India is the second largest producer of vegetables in the world which accounts for about 13.3 % of the world vegetable production. During recent years, both the production and productivity of vegetables recorded impressive growth. In India, the total area under horticulture production is 25.43 Mha whereas fruits and vegetable are 15.13 and 10.30 Mha, respectively (NHB, 2017-18). The consumption of vegetables in India is 175 g/capita/day which is much less than the vegetable requirement of 285 g/capita/day for a balanced diet (Srivastava *et al*., 2009). Hence for increasing productivity, the cultivation of the vegetables needs to be spread over a large area of cultivable land. Although an annual growth rate of 5.4 % in total vegetable production has been recorded during the last 10 years, the average yield of vegetables in India is still lower than many Asian countries (Attavar, 2000). The main reason for low productivity and quality in vegetable production is low adoption of improved cultivation practices at the grower's level. One of the constraints to increasing both areas under vegetable crops and its productivity is the low level of mechanization. In vegetable farming, agricultural operations like planting, weeding, and harvesting are more labour intensive (Srivastava, 2000).

Carrots are usually sown in the month of October and November with a seed rate of 5 - 6 kg/ha. These are grown on raised beds at a height of 15–20 cm and row to row spacing is about 30–45 cm. Carrot harvesting is a manual and labour-intensive operation. On average, about 250 – 300 man-hours are required for digging and pulling out of carrots in the one-hectare area. Besides the quantum of labour, manual harvesting involves considerable drudgery and human discomfort. The labour has to stoop forward while digging/pulling carrots from the bed and also during picking up. Stooping posture results in a lot of biomechanical stresses in the back and has higher energy consumption as compared to other working positions (Hagen *et al.,* 1993). The labour engaged in harvesting has to squat to move to the next harvesting position. Continuous use of bare hands for pulling out carrots may cause bruises on hands leading to infection. Both stooping and squatting working positions are not ergonomic and, therefore, carrot harvesting operation involves considerable human drudgery. Oxygen consumption during squatting with movement action is 31-35 % of VO2 max and that during bending posture is 70-80 % of VO2 max (Hagen *et al.,* 1993). This results in higher fatigue and reduced work capabilities.

Manual harvesting is not only labour-intensive operation work but also time-consuming and severely increased the cost of labourwhich made the manual digging costly. During harvesting time of carrot, sufficient labours are not available which delays the harvest, hence resulting in the loss of profit. The digging operation of carrot needs to be mechanized for time-saving, reduce human drudgery involved and also to reduce harvesting cost (Chaudhry and Ahmad, 2000). The efforts have been made to develop indigenous mechanized systems for carrot harvesting. Only fewer work on mechanical harvesting of carrots is reported in India. Therefore, present paper takes closer looks on the design of tractor operated carrot digger.

MATERIALS AND METHODS

This part of paper deals with an approach for the designing of the Tractor-operated carrot digger. The carrot was grown in the ridge, which bottom width is 200 mm and the average row to row spacing between was 400 mm.The carrot digger consists of different component like, digging blade, tine, frame and hitching unit.

Design of carrot digger

The main components of carrot digger like tine, frame, digging blade and hitching unit was designed.

Draft requirement for tines

The tine resembles a cantilever beam was designed by considering the total draft acting on the free end of the tine. The average length of carrot is 146.5 mm so, assume the maximum working depth of digging blade is 200 mm. We have assumed, unit draft for sandy loam soil type was 0.0245 N/mm^2 (Varshney *et al.*, 2009). The draft acting on the tines was calculated as:

Draft per tine (N) = Furrow width (mm) × Furrow depth (mm) × Unit draft (N/mm^2) … (1)

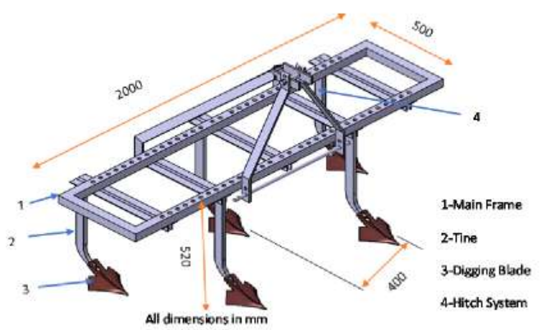

Fig. 1: Isometric View of Developed Carrot digger Design of tine

Total draft = Draft per tine × Number of tines

The total draft acting on the tines was 4.905 kN.

As per average size of tractor, the machine consistsfive tines, two on front and three mounted on the rear frame. The tines were made up of mild steel flat of 520 mm length. The cross-section of the flat was rectangular of width (h) and thickness (b), assuming h = 2.5b. The tines were connected with the frame and the digging blade. Draft acted at the bottom of tine and the bending stress developed in the tine was lesser than the allowable stress for mild steel. The tine consisted of two major components *viz*., foot and leg, those were responsible for the draft requirement. The leg contributed 15-20 % of the draft whereas foot was responsible for the remaining 80-85% draft. Therefore, neglecting the draft due to the shank of tine, the draft was assumed to be acting at the base of the shank. The isometric view of tine is shown in Fig.2. The stress included in the main tine was bending stress (f_b). The bending stress (f_b) induced in the winged tine is expressed as:

$$f_b = \frac{6M}{bh^2} \quad \text{... (2)}$$

Where,

f_b = Bending moment stress for mild steel, kN/mm^2

M = Bending moment, kN-mm

b = Thickness of tine, mm

h = Width of tine, mm.

Bending arm for the tine is 520 mm. Therefore, the

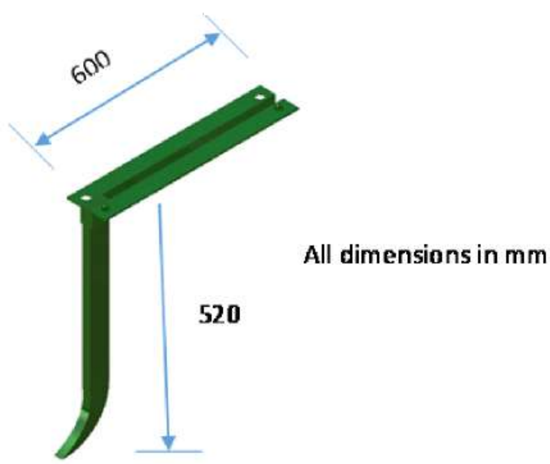

Fig. 2: Isometric View of Tines

effective bending moment (M) was calculated as:

M = Total draft × Bending arm

Substituting the values of bending moment (M) and width (h) in equation 2, bending stress was obtained as follows:

$$f_b = \frac{2448}{b^3} \text{ KN/mm}^2$$

Allowable bending stress of mild steel = 0.175 kN/mm^2 (Varshney *et al.*, 2009). Taking factor of safety = 2, (factor of safety for mild steel).

Design bending stress = Allowable bending stress (f_b) × factor of safety

Equating design bending stress with allowable stress of mild steel, we get

Hence, the dimensions of tine cross section i.e., b = 20 mm and h = 50 mm were selected.

Design of frame

The rectangular frame consisting of two beams of the hollow square section was designed. The frame was fabricated by using the hollow square section of 2000 × 500 × 50 mm. A number of holes were made in the frame and spacing between two holes is 30 mm so that the tine spacing can be adjusted as per the requirement of a row to row spacing for the carrot crop. The spacing between the two tines was kept as 400 mm.

The beam of the frame considered as a fixed beam was subjected to a combination of twisting and bending moment. The cross-section of the beam was taken as a hollow square section with external side 'a' internal side 'b' and thickness 't' which was taken as 5 mm is shown in Fig. 4. Load distribution on the beam was shown in Figure 3.

The torsional shear stress (f_s) developed in the beam is expressed as:

$$f_s = \frac{M_t \text{ X } Y}{J} \quad \text{… (3)}$$

Where,

M_t = torsional moment, kN-mm

Y = Distance from the neutral axis to the stressed fiber, mm and

J = Polar moment of inertia, mm^4.

Also,

$$Z_p = \frac{J}{Y} \quad \text{… (4)}$$

Zp = Polar section modulus, mm^3

Therefore,

$$f_s = \frac{M_t}{Z_p} \quad \text{… (5)}$$

And for hollow square section,

$$Z_p = \frac{2}{9} \frac{a^4 - b^4}{a} \quad \text{… (6)}$$

The torsional moment (M_t) is:

M_t = Total draft × Bending arm length

Now, t = Thickness of section = $\frac{a - b}{2}$ = 5 … (7)

Hence, a = 10 + b

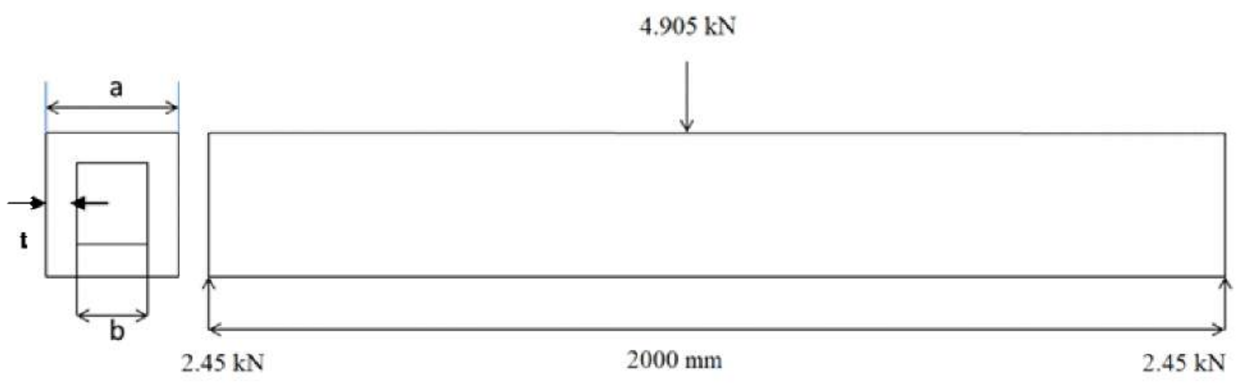

Fig. 3: Load distribution on beam and its cross section

Therefore, the polar section modulus (Z_p) may be given as:

$$Z_p = \frac{2}{9}\,\frac{(10 + b)^4 - b^4}{10 + b}$$

Now, substituting this value in equation 5, fs is given as:

$$f_s = \frac{2550 \times (10 + b)}{\frac{2}{9}((10 + b)^4 - b^4)}$$

Bending stress (f_b) developed in the material is calculated as follows:

$$f_b = \frac{M \times y}{I} \qquad \text{... (8)}$$

Where,

M = bending moment, kN-mm

I = Moment of inertia, $mm^4 = a^4 – b^4/12$

Y = Distance of most distant point of the section from neutral axis, mm = a/2

For the beam with both ends fixed and having load at the centre, the maximum bending moment (M) is given by:

$$M = \frac{W \times L}{4} \qquad \text{... (9)}$$

Where,

W = Total draft and L = Length of frame

Hence, bending moment, M = 2452.5 kN-mm.

Substituting the value in equation 8, the bending stress is obtained as:

$$f_b = \frac{2452.5 \times a/2}{\frac{1}{12}(a^4 - b^4)} = \frac{14715\,(10 + b)}{(10 + b)^4 - b^4}$$

Combined or equivalent stress is expressed as:

$$C_{bf} = \frac{f_b}{2} + \frac{1}{2}\sqrt{fb^2 + 4fs^2} \qquad \text{...(10)}$$

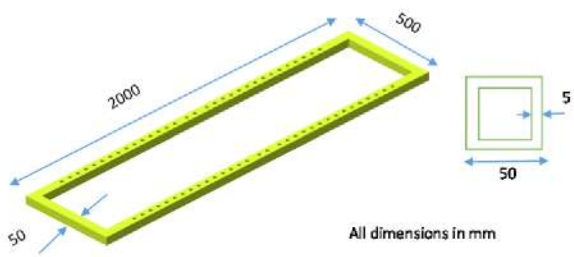

Fig. 4: Isometric view of frame and its cross-section

Allowable bending stress of mild steel = 0.175 kN/mm^2 (Varshney *et al.*, 2009). Taking factor of safety = 1.5 (factor of safety for mild steel).

So, equating the combined stress with allowable shear stress, the following is obtained:

Therefore, the value of b was calculated 40 mm. Now, substituting b = 40 mm and t = 5 mm in equation 7, a = 50 mm is obtained.

Hence the external side of the hollow section of the frame, a = 50 mm and internal side of the hollow section of the frame, b = 40 mm and length of frame 2000 mm was selected, as per availability in the market.

Design of digging blades

The function of the digging blade was to loosen the soil around the carrot and pull it out on the upper surface. The digging blade was designed based on the draft acting on it digging of carrot. The efficient implement design for the low draft, high digging efficiency and better soil loosening should have rake angle of about 30° (McKeyes and Maswaure, 1997). The working depth of carrot mainly depends upon the length of the carrot. Three different types of digging blades (Sweep, Nose and Shovel type) were selected whose rake angle was about 30°. The width of sweep and nose is 200 mm and width of the shovel was 60 mm. The complete dimension of all digging blade is shown in Table 4. The isometric view of all three types of digging blade and Fig. 6-8 are the line diagram of all digging blade with dimension.

Design of hitch system

The hitching system of the developed machine was subjected to normal loads. Therefore, the hitch point was made by welding two plates with the beam at a spacing of 329.5 mm from the centre of the beam. The size of these plates was 200 × 100 × 25 mm with a hole size of 28 mm drilled at 50 mm from the front end to connect the upper hitch plates and the hitch pin together. The hitch point span of 685 mm was selected, which is recommended for the second category.

Implements of a special type. Hitch assembly was designed as per recommendation of IS Standard (**IS-4468 – 1997)** and specification of hitch assembly is shown in Table 3

Table 3: Specifications of the hitch assembly

Description	Dimensions (mm)
Upper hitch attachments	
Diameter of hitch pin hole	28
Width between inner face of yoke	60
Width between outer face of yoke	89
Lower hitch point	
Diameter of hitch pin	28
Linch pin hole distance,	75
Lower hitch point span	685
Other dimensions	
Diameter for linch pin for upper hitch pin,	
for lower hitch pin,	1212
Mast height	610

Fig. 5: Digging blades used in designed carrot digger

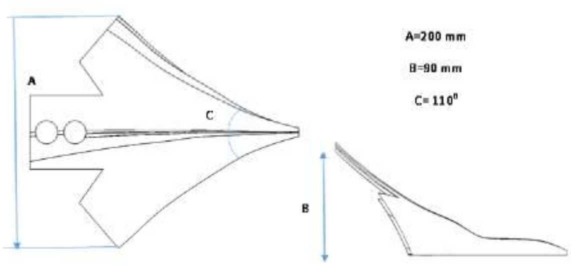

Fig. 6: Line diagram of sweep type blade

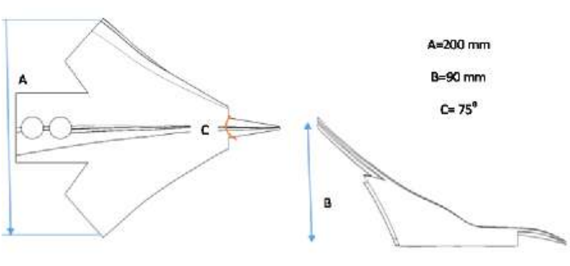

Fig. 7: Line diagram of nose type blade

Table 4: Specifications of the digging unit

S. No.	Digging blade	Width (mm)	Rake angle (°)	Thickness (mm)	Material
1	Sweep type	200	30	4	Carbon Steel
2	Nose type	200	30	4	Carbon Steel
3	Shovel type	60	30	4	Carbon Steel

Performance evaluation of Carrot Digger

The designed Carrot digger was evaluated for its performance digging efficiency, Damage Percentage, field capacity, field efficiency and draft requirement.

Digging efficiency

Digging efficiency is the ratio of the number of carrots successfully dug out to the total number of carrots present in the given area.

$$\text{Digging Efficiency (\%)} = \frac{\text{No of carrot successfully dug out}}{\text{Total no. of carrots in the field}} \times 100 \quad \ldots(11)$$

Damage percentage

During digging operation, different types of damage occur to the carrots in the form of cuts, crushes, slices or bruises. Improper depth of operation during digging was one of the main causes for cutting and slicing of carrots. Bruises were caused due to the friction of the carrots with the metal parts of the digger. Damage Percentage was calculated as

$$\text{Damage percentage (\%)} = \frac{\text{No. of Damage carrots}}{\text{Total no of carrots dugout}} \times 100 \quad \ldots(12)$$

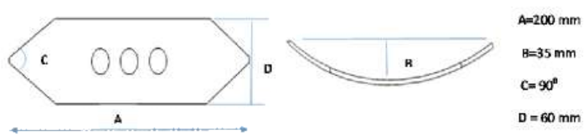

Fig. 8: Line diagram of shovel type blade

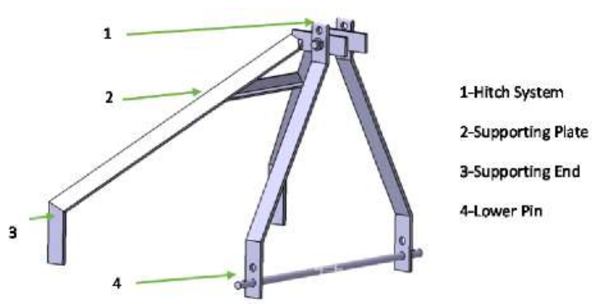

Fig. 9: Hitch assembly of developed machine

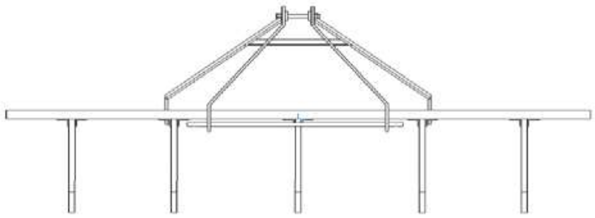

Fig. 10: Front view of developed machine

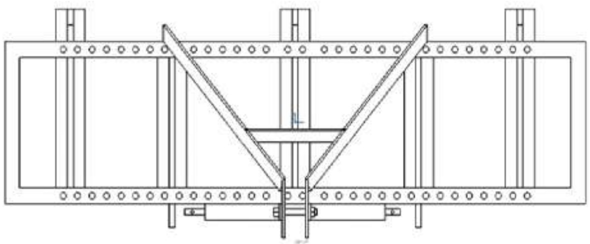

Fig. 11: Top view of developed machine

Actual field capacity

For calculating the actual field capacity, the time required during actual work and the time lost in turning, adjustments etc. were recorded. The actual area covered during this period by the developed machine was also measured. Thereafter, the actual field capacity (AFC) was calculated using the following expression:

$$AFC = \frac{A}{Tp + Tn} \quad \dots (13)$$

Where,

AFC = Actual field capacity, ha/h
Tp = Productive time, h
Tn = Non-productive time, h
A = Area covered, ha

Draft requirement of machine

The Carrot digger is mounted type equipment. The draft for the Carrot digger was measured with a dynamometer and two tractors. The Carrot digger was mounted on Massey Ferguson tractor and was pulled by John Deere tractor through a dynamometer. The dynamometer readings were taken when on Massey Ferguson tractor was in a neutral position, but the Carrot digger in operating conditions and again another reading was taken when the implement was in a raised position. The difference between the two readings would provide the draft requirement for the implement.

Draft power requirement is calculated by the formula:

$$\text{Power (kW)} = \text{Draft (kN)} \times \text{Speed (m/s)} \quad \dots (14)$$

CONCLUSION

Agriculture is an important sector of the Indian economy as it contributes about 17 % of total Gross Domestic Product (GDP) and provides employment to our 60 % of the population. In India, carrot is one of the most important vegetable crops grown in different part of country. Carrot digging is labour intensive operation which require 250-300 man-hours/ha. Manual digging is not only labour intensive but also time consuming which delays the harvest crop resulting its damage. A five-row tractor operated carrot digger was designed for digging of carrot. The carrot digger consists of digging blade, tine, frame and hitching unit. The designing of carrot digger was mainly forces on tine, design of frame, design of digging blade and designing of hitching unit. The width of carrot digger is 2000 mm, spacing between tine is 400 mm and height of tine is 520 mm.

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