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Design, Analysis and Development of Digging and Roller Chain Conveying System for Self-Propelled Onion Harvester

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Abstract: The history of Agriculture in India dates back to Indus Valley Civilisation. India ranks second worldwide in farm outputs. As of 2018, agriculture employed more than 50% of the Indian workforce and contributed 17–18% to the country's GDP. India has the largest net cropped area, followed by the US and China, yet mechanization in farming is comparatively low compared to developed countries. The lack of technological development and unaffordability of new and competent machines for the average farmer are the few of the reasons for this encumbrance. The development of the onion harvester intends that it will provide a reliable and affordable alternative to traditional farming practices. The digging and conveying systems are the integrated part of the onion harvester. The design of the blade and conveyor is made by using CATIA V5 and analysis of the parts are done using ANSYS Workbench. During design and analysis, severe factors are considered such as preventing the damage to onion bulbs, size of bulbs, soil condition, onion leaves at a predetermined height and roots of the crops to penetrate. This paper is intended to discuss the results of the design and analysis of the digging and conveying systems under the guidelines of the SAE TIFAN rulebook [1].
Keywords: Onion Harvester, Blade Design, Conveyor Design, FEA Analysis.

I. INTRODUCTION

TIFAN Stands for "Technology Innovation Forum for Agriculture Nurturing " This competition is targeted to solve the farming challenges and to improve productivity using mechanized solutions. It provides a platform where students come across the real-life challenges of the agricultural sector. Through this program student from engineering colleges across India participate in providing innovative solutions towards product design and overcoming the challenges.

Digging system used to dig out the onion bulbs along with soil mass by loosening the soil. Which lifts the onion bulbs and soil mass onto the conveyor and to the windrowing without damaging the onion. Blades are of different shapes are inverted -V, Rectangular with Sharpe edge, Multi-teeth, V-shaped, Concave shaped, Convex shaped. In our design, we used multi-teeth V-shaped blade because it is efficient in soil loosing and subjected to less draft force.

A Roller chain conveyor is used which consists of a chain, sprockets, bearings, shafts, casing, etc. A conveyor system is designed in such a way that to Convey the maximum number of onions dig out by the digging system to the windrowing system. The conveyor system also acts as the separating unit which separates the onion bulbs from the soil mass. The primary purpose of the separating unit is to convey the onion bulb along with leaves on a vibratory sieve where it will take out some more soil.

II. LITERATURE REVIEW

[2] P.A. Munde, B.P. Sawant and S.A. Sawant (2010), have explained practical aspects of the turmeric harvesting machine in which the bullock-drawn turmeric digger was designed and developed. The rhizome damage was less than 10.7% for the V blade with a 17-degree angle. The digging efficiency was found about an average 86-95 % V blade with a 17-degree angle. The machine has shown better performance for turmeric harvesting in terms of rhizomes damage percentage, digging efficiency, field efficiency, draft requirement over the existing machine and manual methods.

[3] Bendix et al. (2001) studied that mechanical harvester for harvesting, topping and Sacking bulb crops, Such as onions. The harvester extracts the onions from the ground and transports them rearward to a cutting assembly by conveyor Systems that drop out small onions, dirt, rock sand debris. The cutting assembly comprises a Set of elongated cutting blades positioned to co-operatively accept and sever the leaves and roots from the bulb.

[6] Suhas M. Shinde and R.B. Patil, studied onion production all over the world and did a detailed analysis of onion production in India, Maharashtra. He also studied the lifecycle of the crop, its classification of crop depending on colour, size, season, He also understood the conventional steps for onion farming and conventional methods for onion harvesting.

III. DIGGING SYSTEM

The digging system penetrates the surface of the bed to a certain depth and loosens the soil mass, to enable the teeth of the blade to penetrate and slide into the soil without damaging the onion. The three-point mechanism operated by a double-acting actuator is used for lifting and lowering the blade along with the conveyor system. The hydraulic pump is coupled with the engine acts as the source for the actuator. The blade is joined to the base plate by 16 rivet joints of Mild Steel so that blade can be replaced and for ease of serviceability.

A. Design Parameter

1) *Crop Parameter:* The standard row to row spacing of onion plants, planted in 5 rows on each bed, is 15 cm. An onion will be planted 10 cm apart in each row. The approximate diameter of onion varies from 3 to 6.5 cm and the weight of onion 70-80 gm per bulb. The maximum length of leaves ranges from 60 to 65 cm - partially lodged from the neck of the onion bulb.
2) *Cultivation Parameter:* The cultivation of onion will be done using the Bed Furrow Bed method. Each bed will be 75 cm wide separated by a 37.5 cm wide-furrow from the adjacent bed and the bed will extend up to 16m in length.
3) *Soil Parameter:* There could be a variety of types of soil present depending upon the location, however below mentioned values pertaining to the worst-case scenario for their designs. Type of soil considered for calculations is Black cotton and resistance of the soil is 0.7 Kg/cm².

B. Calculation

1) *Assumptions*

Average bulk density of soil=1.45g/cm3
Centre of resistance = z1=0.2 (measured from cutting edge)
Factor of Safety=1.1

2) *Draft Calculation:* The draft of shear was calculated by using general soil mechanics equation suggested by Numerical solutions for the dimensionless factors that have been developed by Sokolovski (1965), Hettiarachi et al. (1966) and Hettiarachi and Reece (1974) to cover a range of values for the angle of internal friction, angle of soil–metal friction and rake angle for blade deformation in the soil in two dimensions. This equation takes into account different soil properties and tool geometry.

$$P_p = \gamma z_1^2 N_\gamma + c z_1 N_c + c_a z_1 N_{ca} = q z_1 N_q$$

Where,
P_p= Passive resistance of soil acting at an angle of soil metal friction with the normal to interface (kg/m)
γ = bulk density of soil (kg/m2)
z_1 = depth of operation (m)
c_a = soil interaction adhesion (kg/m2)
q = Surcharge pressure on soil from surface above the failure plane (kg/m2)
N_γ, N_c, N_{ca} and $N_q$are the dimensionless less factor.

N_γ / N_c =1.83/1.68

$P_p = \gamma z_1^2 N_\gamma + c z_1^2 N_c$

P_p = (1.45 × 10³) × (0.2²) × 1.68 + (710) × (0.2²) × 1.68

P_p = 145.82 kg/m

The component parallel to blade plate,

$P||$ = P_p × sin(20)

$P||$ = 145.82 × sin(20)

$P||$ = 49.87 kg/m

Component perpendicular to blade plate,

$P \perp$= P_p × cosγ

$P \perp$= 145.82 × cos(20)

$P \perp$= 137.02 kg/m

Here, Blade is supported at 160 mm by nuts and bolts.
Distance between centre of resistance & point of support=160-33.13 =126.9mm=12.69cm
Bending Moment due to perpendicular = 137.03×12.69=1738.78 kg.cm

Bending stress,

$$\sigma_b = \frac{6 \times BM}{b \times t^2}$$

$$\sigma_b = \frac{6 \times 1738.78}{30 \times t^2} = \frac{347.7}{t^2}$$

Direct stress,

$$\sigma_d = \frac{P||}{b \times t}$$

$$\sigma_d = \frac{49.87}{30 \times t} = \frac{1.66}{t}$$

Total stress is given as,

$$\sigma_t = \sigma_b + \sigma_d$$

Safe stress of Spring steel = 970 kg/cm^2

$$\sigma_t = \frac{970}{1.12}$$

$$863.3 = \frac{347.7}{t^2} + \frac{1.66}{t}$$

$$863.3t^2 - 1.66t - 347.7 = 0$$

$$t = 0.6\, cm = 6\, mm$$

C. Material Selection and Specification

As per our design and by considering the forces on the blade, wear and tear, and the life of the blade, we selected EN42J as the material of the blade. The criteria of selecting the material must include technical inspection which satisfied sufficient bending stiffness, bending strength and it should be readily available at optimum cost.

TABLE I. Material composition of the blade

Property	Value
Spring steel	EN42J
Carbon	0.75 to 0.85%
Mn	0.60 to 0.90%
Silicon	0.10 to 0.35%

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TABLE II. Overall Technical Specification

Sr. No.	Specification	Value
1.	Blade Geometry	$750*265*6\ mm^3$
2.	Draft Calculations	145.82 Kg/m
3.	Rake Angle	18°
4.	Width of Blade	265 mm
5.	Thickness of Blade	6 mm
6.	Throat Clearance	180 mm

D. CAD model and FEA Results

1) CAD Model

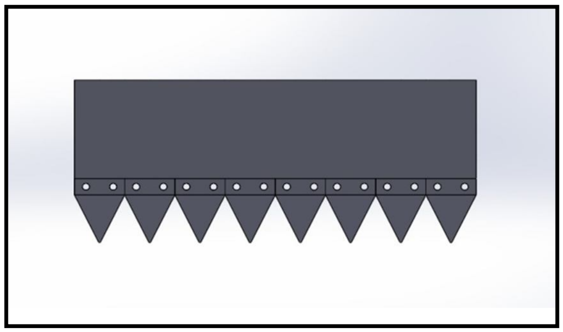

Fig. 1 CAD Model of the Blade.

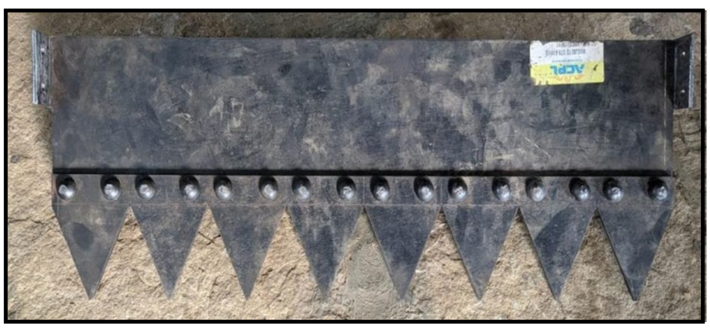

Fig. 2 Photo of the actual Blade

2) *Analysis of The Blade:* The FEA analysis of the model is carried out to optimize the design by analysing the reaction of blade under the loading conditions. As per the design calculations, the thickness of the blade is 6 mm and it is tested under the draft forces acting on the blade. The boundary condition is considered as the zero displacements of the side end of the blade at top corners as shown in Fig.2, which will be joined to the conveying system. The mesh size is 60 divisions per line and is optimized at critical areas for getting the best analysis result. The ANSYS solver is used for analysis. The forces applied on each tip of the blade and the resulting total deformation and equivalent (von-mises) stress has been verified and ascertained to be safe.

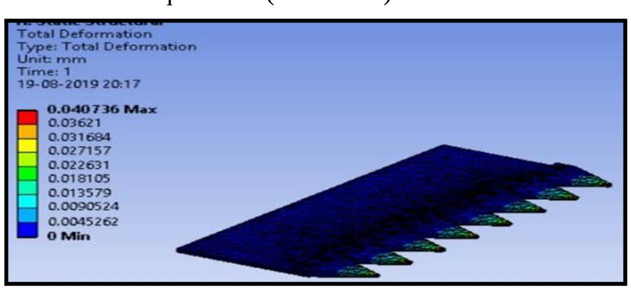

Fig. 3 Total Deformation Subject

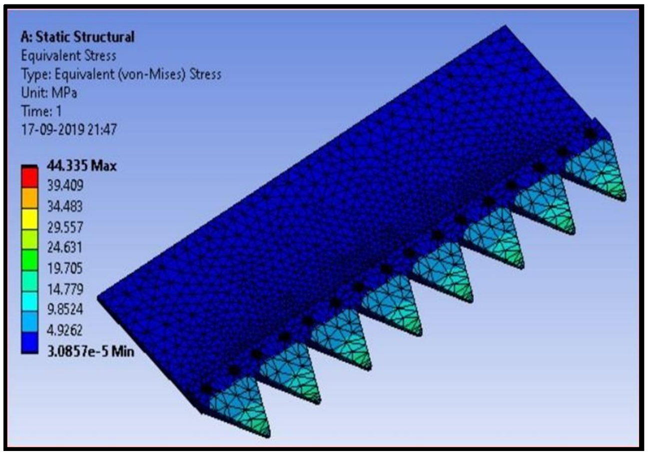

Fig. 4 Equivalent Von Mises stress

IV. CONVEYING SYSTEM

The main goal of the separating unit is to convey the onion bulb along with the leaves on the vibrating conveyor where it will take out some more soil and thus clean it. The conveyor is needed to be designed as a separating unit of the harvester. The type of conveying system is roller chain type. The four-bearing pressed-on rectangular block on which two shafts are mounted. The rods are brassed on the roller chain while maintaining the required spacing. The rear shaft is coupled with the hydraulic motor via a direction control valve and it is run by the pump. For designing the hydraulic motor, the RPM and the required torque are calculated.

A. Calculation

Dimensions of Conveyor: 800 mm×700 mm×140mm
Pipes of 12mm OD and 10mm ID of 730mm length are used to separate soil.
Diameter of a drive shaft of conveyor = 30mm
The Diameter of the driven shaft of the conveyor=25mm
Spacing between two pipes = 28mm
Weight on the conveyor during working = 127.15Kg
Total weight of pipes mounted on chain= 6kg
Weight of conveyor= 40 Kg
Keeping linear velocity of conveyor = 1.13m/s

$$V = \frac{\pi \times Diameter\ of\ Sprocket \times N}{60 \times 10^3}$$

$$1.13 = \frac{\pi \times 86.39 \times N}{60 \times 10^3}$$

$$N = 249.81\ rpm$$

Thus, the power shaft of the conveyor should be rotated at 250 rpm

$$\text{Rotary Power required} = Force \times Velocity$$
$$\text{Force} = mg = 105.54 \times 9.81 \times 0.7$$
$$\text{Force} = 724.74N$$

$$\text{Rotary Power required} = 724.74 \times 1.13 = 818.95\ W$$

Thus, Rotary Power required is 1.11hp.

Mass flow rate of the conveyor = Bulk density × Area covered × Velocity of vehicle + yield of onion × width × speed × form factor

$$= 1450 \times 0.7 \times 0.1 \times 1.025 + 210 \times 0.7 \times 1.025 \times 0.01$$
$$= 104.0375 + 1.5$$
$$= 105.54 \ \mathrm{kg/s}$$

During the working conditions, the total mass on the conveyor depends upon the speed of the conveyor. (As we are supplying constant speed to the conveyor by hydraulic motor, we assume the speed to be 1.13 m/s)

By considering the load on the conveyor, speed of the shaft, the diameter of both the shafts of conveyor is 30 mm.

Torque on the shaft:

$$\text{Power} = \text{Torque} \times \text{Rotational Velocity}$$

$$818.95 = \frac{\text{Torque} \times 2\pi \times 250}{60}$$

$$\text{Torque} = 31.28 \ \mathrm{N.m}$$

B. Material selection and Specification

The conveyor consists of a chain, sprockets, bearings, shafts, casing, etc. based on requirements, design and calculations, components of the conveyor are as follows:

TABLE III. Technical Specification and Material

Sr. No.	Element	Material	Dimension	Quantity
1	Roller Chain (10B1)	C.I	Length=3794mm Pitch=15.875mm	1
2	Rear Shaft	EN8	Diameter=30mm Length=1000mm	1
3	Front Shaft	EN8	Diameter=25mm Length=850mm	1
4	Sprockets	C.I	Tip diameter=94.6mm Bore diameter=30mm Pitch Diameter=86.39mm	4
5	Ball Bearing	MS	Internal Diameter=30mm	2
6	Pedestal Bearing	MS	Internal Diameter=30mm	2
7	Pipes	MS	Outer Diameter=10mm Internal Diameter=7mm Length: 740mm	30
8	Casing	MS	946mm*140mm*8mm	2

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C. CAD model and Analysis Results

1) CAD Model

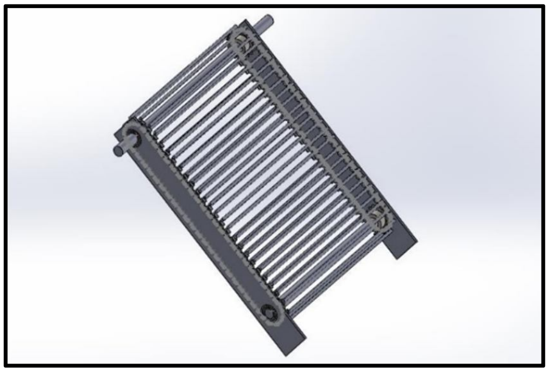

Fig. 5 CAD Model of Conveying System

Fig. 6 Photo of the Actual Conveying system.

2) *Analysis Results for Rear Shaft:* The rear shaft which is coupled to the bidirectional hydraulic motor has to be designed under maximum torque conditions. The torque 31.75 Nm is applied at the centre of the shaft and the boundary condition is given to the end of the shaft to compute the maximum twisting of the shaft.

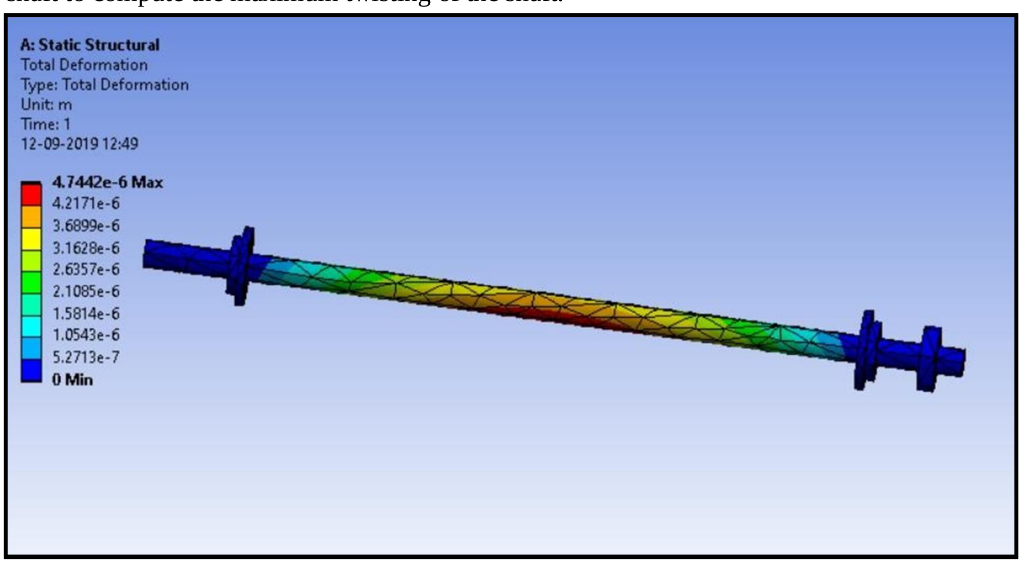

Fig. 7 Total Deformation Subject to Rear Shaft

V. CONCLUSION

The main objective of the system is to give good performance with minimum cost and better fuel economy. All designs and calculations were done to reduce failure criterion with the suitable factor of safety and strength, depends on the result of different harvesting tests performed. Comparative study of digging and conveying systems before initiating actual fabrication, real-time conditions were simulated using ANSYS. The digging blade system was designed to facilitate the interchangeability of blade tips with a hydraulic lifting mechanism. Conveyor system provides with forward and reverses rotating mechanism using bidirectional hydraulic motor which avoids adhering of onion bulk. By designing and developing digging and conveying units, farming productivity can be increased and also expenses can be reduced.

VI. ACKNOWLEDGEMENT

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