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Design and kinematic simulation of automated mechanism for shallot planting

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A B S T R A C T

The mechanization-oriented technology for shallot planting is a suitable solution which has a positive impact on changing the style of farming and reducing labor costs and increasing the efficiency in the process of planting shallot. In this research using an automatic planting device, the kinematics of shallot seed feed roller is calculated, designed and surveyed for correct positioning of the shallot in the created hole. This is done by the aid of Autodesk Inventor Professional and Matlab Simulink software. Working principle Diagram of planting shallot device is presented and the design parameters were optimized, and the stability of the suspension system used in the device was investigated.

1. Introduction

Shallot is one of the main agricultural products in some countries in Asia. For example, in the south-western regions of Vietnam (Vinh Chau district, Soc Trang province) the shallots are grown in many places in the area about 5000 to 7000(ha) with an annual output of about 160,000(ton), and such products are exported to some countries such as Indonesia, Malaysia, Thailand, Philippines, India. However, exporting such products has some difficulties mainly due to the low technology of shallot planting in these regions. Indeed, the process of shallot cultivation in addition to soil preparation and layering has been partially mechanized by the farmers. Leftover from the process of planting, the shallot onions are still done manually which requires a lot of labor. Hence there is a need to design and manufacture an agricultural machine for the cultivation of shallot. But till now, there is only a few studies related to the planting process and transplanting mechanism of shallot seeds (Hung et al., 2020; Phi et al., 2021; Cahyaningrum & Widiastuti, 2020; Aziz et al., 2012; Wahyuni et al., 2020) and the main focus had been on preservation and packaging, and production techniques. Astuti et al. (2018) performed a study to determine the impact of storms on productivity and competitiveness of shallot in Brebes (Highlands Java). Nikus and Mulugeta (2010) published research on the technique of planting for a variety of onions including shallot. They described details of the growth and development of the shallot, care techniques and harvest time as well as storage method. The technology of shallot planting in some countries has also been developed but in most cases only a semi-automatic level of planting for the seeds, vegetables and wet rice or placing mechanism of the seeds precisely into the pre-made hole has been utilized (Kumar & Raheman, 2011; Parish 2005). During the design and manufacturing process, it is necessary to check the durability of the kinematic survey through the theoretical basis and displacement analysis of the device.

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The current work illustrates design and displacement analysis of planting devices used for planting shallot mechanism. This research is done with the goal of optimizing the design and improving the labor productivity, quality, reducing the production costs and number of labors and manual tasks during shallot planting. The application of such planting shallot technology with mechanized and automated equipment systems was examined experimentally earlier by the authors in the Southwest Regions of Asia (Hung et al. 2020; Phi et al. 2021). In order to complete the previous works of the authors in this field, the object of this study is the fluctuation of planting shallot device and displacement survey of the device, with the problem of surveying the design and analyzing the kinematics of the feeder mechanism on the parallel plane motion. The lengths of the stages preselected in accordance with the design parameters, number of spindle revolutions, and angular velocity and rotation angle of the links are also defined.

2. Proposed working principle

Based on the research results of Ademe et al. (2012) and others the effect of considering suitable distance between the burrows of shallot on the product and quality of some onions have been investigated. The results show that the two- and three-caves with distance of 10 to 20(cm) results in high shallot production. Through statistical analysis of studies (such as Parish, 2005; Kumar and Raheman, 2011; Ademe et al. 2012) and the field observation of shallot Farmers in Soc Trang province (as shown in Fig. 1), the input parameters for the design of the planting device and the related shallot planting mechanism were chosen as illustrated in Table 1.

Fig. 1. Survey of local farming areas for planting shallot in Vinh Chau district (Vietnam)

Table 1. Input design parameters for shallot planting device

Parameters	Value	Unit
Row distance	12 to 15	cm
Density	4.000 to 4.500	shallot bush /1000m^2
Number of shallots	1 to 2	shallot/hole
Shallot distance	15 to 20	cm

Working principle diagram of the shallot planting device based on the actual needs and solving the problem of mechanization-oriented solution in the planting process of such a product is shown in Fig. 2. Suitable distances between shallots in horizontal and vertical directions are also illustrated in Table 1.

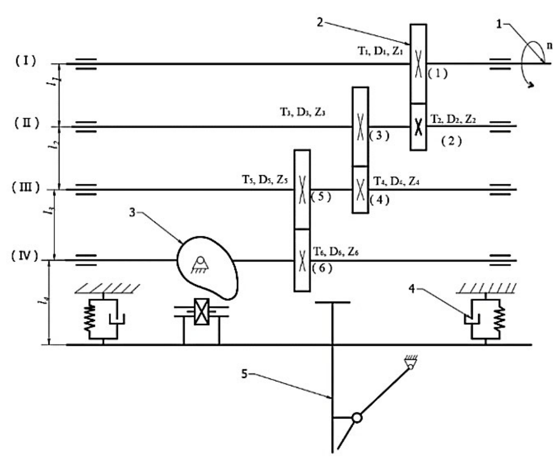


Fig. 2. Working principle diagram of planting shallot device

As seen from Fig. 2, the shallot planting device exerts input power from line (1) transmised from the movement of the tractor, through the transmission gear system (2), with 3 pairs of gears that work together. Then the rotation of cam mechanism and cam follower (3), can rotate the duckbill hole (5) and this device puts shallot in the created hole in the farm. After the cam rotates all the way, the hole-making part is returned to its original position by the elasticity of two suspension systems (4).

2.1. Analysis of kinematic and displacement survey for planting device

After designing a test working principle diagram, kinetic analysis and study of the law of motion is required for the device when the kinematic diagram of the mechanism is known. Analysis of this device consists of three parts of (i) displacement, (ii) velocity and (iii) acceleration and such analysis helps us in determining the law of displacement and change of acceleration or velocity through the stages of the mechanism. Also the results of such analysis can improve the real motion, design calculation and durability of the device.

Fig. 2 shows the working principle diagram of the device. However, in order to simplify the surveying and analyzing, a reduced form of principle diagram shown in Fig. 3 was used. Using this diagram one can see in detail the current status of the design survey connection and calculating device of kinematics by analytical method. As seen from Fig. 3, the coordinate is located at the origin of the axis of rotation of input transmission axis.

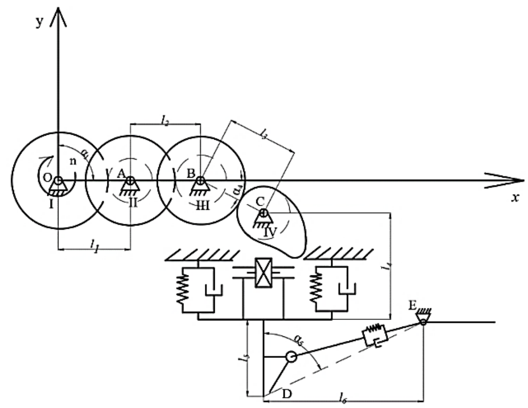


Fig. 3. Working principle diagram of planting shallot device in displacement survey problem.

Planting shallot device works with 3 pairs of transmission gears and duckbill hole-maker device for planting the shallot. Displacement survey is done at positions C, E and D on top of duckbill planting shallot device. The survey position will move on the plane Oxy and the related displacement calculations are shown in Table 2.

Table 2

Definition of displacement survey parameters

Parameters	Explanation of parameters	Unit
l_1, l_2, l_3	Distance between axis I,II,III	mm
l_4	Distance from axis IV center to hole holder bracket	mm
l_5	Distance from bracket to duckbill	mm
l_6	Distance from duckbill to damper bracket device	mm
α_0	The initial angle I axis and *x* axis	deg
$\alpha_1, \alpha_2, \alpha_3$	The angle of I,II,III axis and *x* axis	deg
α_4	The angle of rod BC and *x* axis	deg
α_5	The angle of rod CD with respect to DE	deg
Z_1	Number gear of drive gear	gear
Z_2, Z_3, Z_4, Z_5	Number gear of idler gear driven I,II,III axis	gear
Z_6	Number gear of driven gear IV axis, cam transmission	gear
i_{12}, i_{34}, i_{56}	Ratio of gear mesh in I,II,III,IV axis	gear
w_0, w_1, w_2, w_3	The initial angular velocities Initial and of the axis I,II,III,IV	rad/s

To serve the actual design needs for planting by the shallot device, hole-making part and shallot guiding part, it is necessary to use a pair of intermediate gears and with the same gear ratio for i_{12}, i_{34}, i_{56}.

$$i_{12} = i_{34} = i_{56} = \frac{w_1}{w_2} = \frac{w_3}{w_4} = \frac{w_5}{w_6} = \frac{Z_2}{Z_1} = \frac{Z_3}{Z_4} = \frac{Z_5}{Z_6} = \frac{1}{3} \quad (1)$$

Thus, there is a relationship between the equation of motion and the bond angles as:

$$\alpha_4 = \alpha_0 + w_4 t = \alpha_0 + 3w_4 t = \alpha_0 + 3\alpha_1 \quad (2)$$

$$\alpha_5 = \alpha_4 + w_5 t = 2\alpha_4 = 2\alpha_0 + 6\alpha_1 \quad (3)$$

The parameters affecting the kinematic equation of planting shallot device are described in Table 2. This is a self-contained oscillation stage suitable for the series of oscillations of the mechanism on the plane *Oxy* as written by Eq. 4.

$$\overrightarrow{OD} = \overrightarrow{OC} + \overrightarrow{CD}, \overrightarrow{CE} = \overrightarrow{CD} + \overrightarrow{DE} \quad (4)$$

From the results of analysis and above design rules, the equations of oscillation at the survey points of the device are as following:

Eq. (5) describes the C-point displacement:

$$\begin{cases} x_C = l_1 + l_2 + l_3 . \cos\ \alpha_4 \\ y_C = l_3 . sin\alpha_4 \end{cases} \quad (5)$$

Eq. (6) describes the D-point displacement:

$$\begin{cases} x_D = l_1 + l_2 + l_3 . \cos\ (\alpha_0 + 3\alpha_1) \\ y_D = l_4 + l_5 + l_3 . sin\alpha_4 \end{cases} \quad (6)$$

Eq. (7) describes the E-point displacement:

$$\begin{cases} x_E = l_1 + l_2 + l_6 + l_3 . \cos(\alpha_0 + 3\alpha_1) \\ y_E = l_4 + l_3 . sin\alpha_4 + l_6 . tan(180 - \alpha_5) \end{cases} \quad (7)$$

In order to investigate the acceleration and velocity of the above survey points for planting shallot devices, the method of first and second derivatives of the displacements of the points were used. For example, the velocity and the acceleration equations for the D-point are as follows:

The velocity of D-point expressed in the *x* and *y* directions:

$$\begin{cases} v_{x_D} = \dot{x}_D = -3l_3 . \sin\ (\alpha_0 + 3\alpha_1) \\ v_{y_D} = \dot{y}_D = 3l_3 . cos(\alpha_0 + 3\alpha_1) \end{cases} \quad (8)$$

The acceleration of D-point expressed in the *x* and *y* directions:

$$\begin{cases} a_{x_D} = \ddot{x}_D = -9l_3 . \cos\ (\alpha_0 + 3\alpha_1) \\ a_{y_D} = \ddot{y}_D = -9l_3 . sin(\alpha_0 + 3\alpha_1) \end{cases} \quad (9)$$

2.2. Suspension vibration survey for the planting shallot device

Besides, we studied the vibration of the suspension system used for the design of planting shallot device. By selecting carbon steel and PET materials for designing the shallot planting machine, its total mass M that is sum of $m_1+m_2+m_3$ was obtained equal to about 13 kg, where m_1 is sub-frame mass with specific gravity d_1=7,850(g/cm^3), m_2 is mass of duckbill navigation shallot tuber with specific gravity d_2=7,850(g/cm^3) and m_3 is the mass of duckbill opening and closing part made of plastic PET material with specific gravity of d_3=1,541(g/cm^3). The mass of each part was determined using the Inventor software using "m = d.v" in which d is specific gravity of the device (kg/m^3) and v is the volume of the components contained in the structure under consideration (m^3).

The vibration differential equation of the damping system can be written as:

$$13\ddot{x} + 150\dot{x} + 388{,}7x = 0{,}15(t) \quad (10)$$

Vibration damping coefficient of spring $C = 150$ (N/m) and spring constant $K = 388{,}7$ (N/m) were determined from Eq. (14) and Eq. (15). The external force acting over time on the suspension system $F = 0{,}15$(N) was determined from the torque applied by the tractor through the spur gear drive system (as stated by Phi et al. (2022)). Thus actual design needs such traction is transmitted through 3 gears with gear ratio of i=1:3 which transmit the motion to the camshaft with torque $T_6 \approx 2{,}146$ (N.m) as calculated in Fig. 4.

$$C = 2.\psi.C_k.\mathrm{M} \tag{11}$$

Ψ: oscillating quenching coefficient ($\Psi = 0{,}15$ to $0{,}3$), select $\Psi = 0{,}2$
C_k: suspension stiffness (N/m)
M: mass suspended on one wheel (kg)

$$K = \frac{G.d^4}{F.D^3.n} \tag{12}$$

G: Elastic module, $G = 20.10^4 (MPa)$
F: external applied force
d: spring wire diameter
D: spring mean diameter
n: number of working cycles

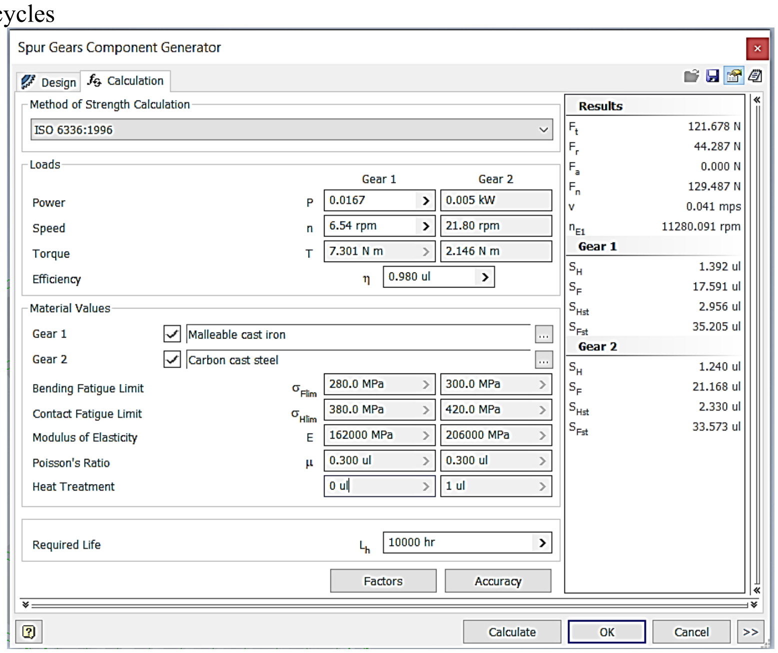


Fig. 4. Kinematics and gear mesh dynamicsZ_5, Z_6

In addition, power input parameter is $P_5 = 0{,}016\ (kW)$, number of spindle revolutions are $n_5 \approx 6{,}54$ (rpm) (as defined by Eq. (13)) and torque is $T_5 \approx 7{,}169$ (Nm). The space is designed for a length of an shallot plantation row with $L = 25\ (m)$, and velocity of $v = \frac{1}{240}$ (m/s).

$$\text{Input velocity: } n_5 = \frac{1000.v}{\pi.\mathrm{d}} \tag{13}$$

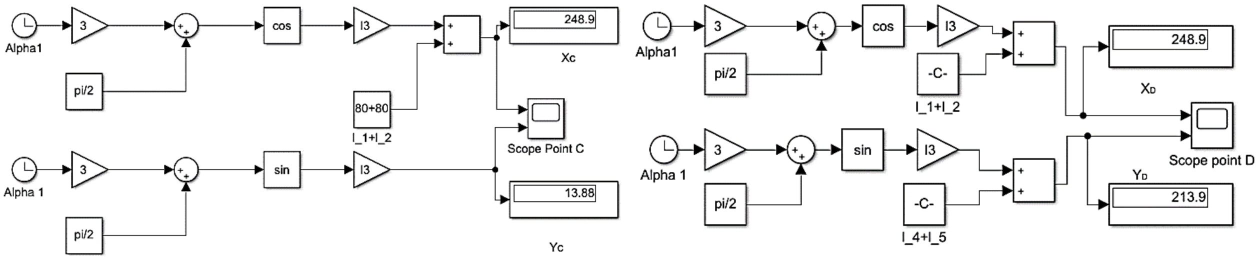
$$\text{Output power : } \mathrm{P}_6 = \mathrm{P}_5.\eta \tag{14}$$

$$\text{Output velocity: } n_6 = \frac{n_5}{i} \tag{15}$$

Kinematics of the problem when motion is transmitted from the gear shaft Z_5 (Gear 1) through each gear Z_5 (Gear 2) contains the camshaft that transmits the motion and the force exerted by the torque T_6 as defined in Fig. 4.

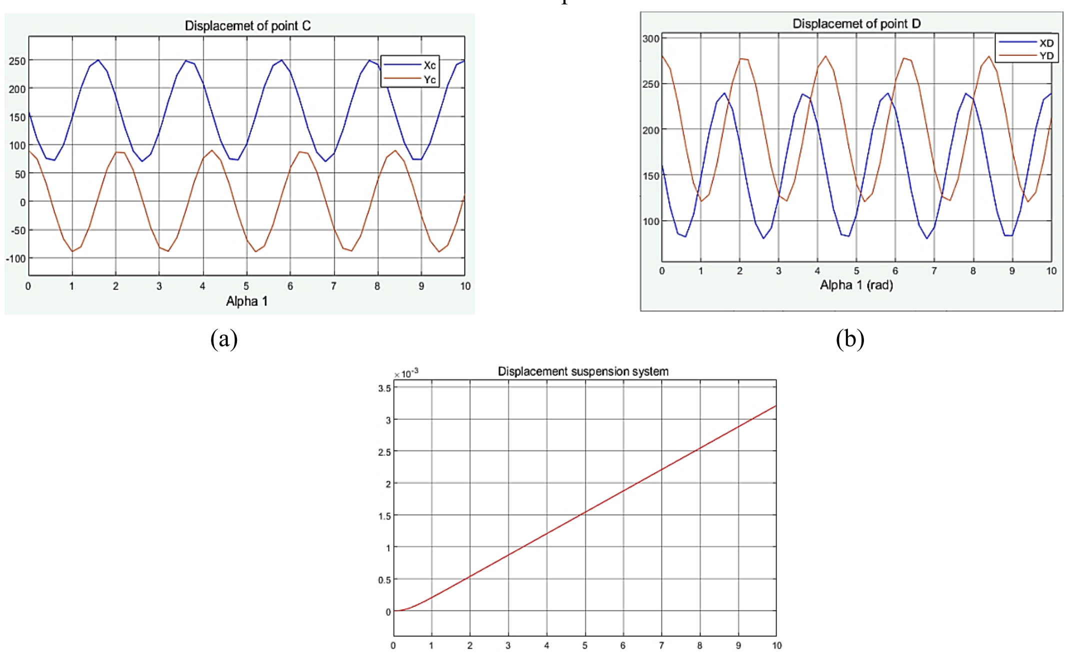
3. Results and discussion

From Eqs. (5-6) and by using the Simulink tool in Matlab and via oscilloscope survey block diagrams such as those shown in Fig. 5 for C-point and D-point, it is found that the oscillation of the suspension drum system is negligible. After surveying on the software, we get the results through the oscillation chart by adjusting the parameters of the mechanism affecting their motion trajectories. Through simulation on the block diagram, the results presented in the form of graphs of Fig. 6a and 6b were obtained. Fig. 6c also shows the suspension system displacement on the planting shallot device.



(a) (b)

Fig. 5. (a) Simulink diagram for surveying displacement for the C- point, (b) simulink diagram for surveying displacement for the D- point.



(a) (b)

(c)

Fig. 6. (a) Displacement survey graph for the C-point, (b) displacement survey graph for the D-point, (c) survey graph of suspension system displacement on the planting shallot device.

Vibration survey to evaluate the displacement of the suspension system on the shallot growing structure can be done using the block diagram of Fig. 7 by means of Matlab Simulink (Tung et al. 2021, Van et al. 2021). The result obtained from the motion differential equation (Eq. 10); shows that the displacement of the suspension system in the interval of $0 < l_{lx} \leq$ 0,0032(mm), has negligible effect on the vibration of the device (Fig. 6c) and the maximum displacement is determined at $l_{lx} \leq 0{,}0032$(mm).

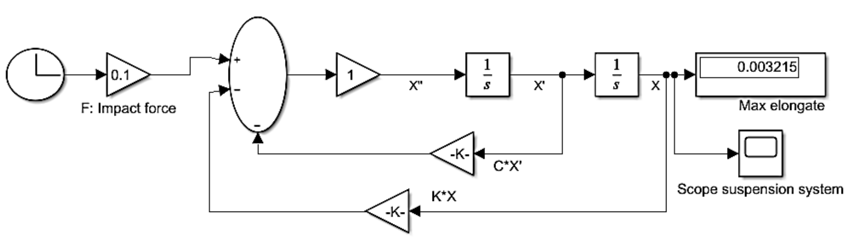


Fig. 7. Simulink diagram to survey the suspension displacement on the planting shallot device.

Through the analysis of optimal design parameters, the following values were used for the survey: l_1=80(mm), l_2=80(mm), l_3=90(mm, l_4=110(mm), l_5=90(mm). Initial survey angle is also selected as $\alpha_0 = \frac{\pi}{2}(deg)$ and angle $\alpha_1 = 10$ (rad) varied over time (*t*). The survey results for C-point with l_{OC} along x direction, $80 \leq l_{OC} \leq 250$(mm) and along y direction, $-80 \leq l_{OC} \leq 90$*(mm)* provides suitable centering of the camshaft and cam components locations that causes eccentric forces to create the required holes for shallot seed planting. The optimal calculation suggests the following values: $x_C \approx 250(mm), y_C \approx 14(mm)$. The D-point is the lowest place in the planting shallot device which is linked to the duckbill part. D-point marks the intersection of the planting trajectory and the structure's return journey. The survey results for the D-point l_{OD} x direction: $(80 \leq l_{OD} \leq 240$(mm)) and y direction: $(130 \leq l_{OD} \leq 280$(mm)) indicates where to place the hole and its guider part. The optimum value for the location of this point in the shallot device mechanism is obtained at $x_D \approx 250$(mm) and$y_D \approx 214$(mm). Such results obtained from the computational analyses provide basic systems to carry out structural design and compliance with the operational requirements of the principle diagram.

4. Conclusions

In order to find a suitable distance for placing the drive gear shafts for a new planting shallot mechanism, a simple and efficient drive system was designed. This mechanism can simulate and perform motion trajectories that guide the seeds into the correct row and correct design holes in the plant. Initially, the study investigated the factors affecting the motion trajectory of the device. Then by applying the dynamic simulations, the distance between the transmission linkage axes of the helical gear system and displacement profiles of some typical points on the structure of planting shallot device were investigated. Using Matlab-Simulink analyses the system of differential equations was derived and solved. Also the vibration of the mechanism and suspension system used in the device during the design process when it is in motion with the external force acting from a tractor was analyzed. The design parameters were finally optimized to obtain a high quality mechanized shallot planting device.

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