Analytical Comparison between the Speed of Screw and Crank-Rocker Based Pick and Place Mechanisms for Seedling Tray Seeding Machine

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Abstract: In this study the operational speed of screw based pick and place mechanism was compared with that of a crank-rocker based pick and place mechanism analytically for the design of a seeding machine for system of rice intensification (SRI) seedling tray. The configurations of the two types of mechanisms were generated based on their positions relative to a seedling tray conveyor, seed container and size of seeding manifold. The screw based mechanism consists of a vertical screw to which the seeding manifold was mounted and a horizontal screw to which the vertical mechanism was mounted. The vertical screw bearing the seeding manifold reciprocates down to pick seeds from seed container and back to the initial position. The horizontal screw translates horizontally to deliver the vertical screw bearing the seeding manifold to the seedling tray on the conveyor. The crank-rocker based mechanism consists of a pair of crank-rocker carrying a seeding manifold in between them. The mechanism rotates clock wise to pick seed and counter clock wise to drop the seed on the seedling tray. The time required for a complete pick and place circle was computed for both mechanisms using basic mechanics principles. Crank-rocker mechanism with a theoretical pick and place period of 1 second was found to be better than the screw based mechanism with 78.8 second per pick and place circle.

Key words: Seedling tray seeding, screw mechanism, crack rocker mechanism, speed of operation.

Introduction

Economic development and efficiency of agricultural machinery depends on the selection of proper mechanism. Different mechanisms can perform the same task at different speed, capacity and overall efficiency. This study is intended to select a pick and place mechanism with higher operational speed for a seedling tray seeding process. The study is targeted at designing a pick and place mechanism for System of Rice Intensification (SRI) seedling tray developed by Bashar et al. (2015), based on the configuration of a seeding manifold designed by Abdulkadir et al. (2019). The mechanism
in this study could be used on other seedling tray seeding machines or pick and place systems for different applications after little modifications.

The invention and use of screw mechanism can be traced back to the prehistoric and ancient times, where it was used in the form of helicoid pump for lifting water in Egypt (Koutsoyiannis & Angelakis, 2003; Yannopoulos et al., 2015). Though the mechanism in those days was in the form of an auger, the working principles remain the same to the present day screw mechanism, which is using rotary motion to create a translatory motion. Over the centuries, the ancient screw mechanism has evolved in form, sophistication and diversity of usage. The present day screw mechanisms comes in different forms of thread: metric; unified; square and acme, with each having one advantage over the other (Myszka, 2012). The double crank-rocker also called Parallelogram mechanism on the other hand has input and output links of equal lengths; and coupler and frame of equal lengths. In this mechanism the output link is constraint to maintain a parallel orientation with respect to the input link, it has a permanent parallel orientation between frame and coupler. It is used to establish a non-rotational displacement of the coupler of a four bar mechanism with respect to the fixed frame. It is a vital component in the transport and manipulation of end-effector in pick and place devices and other applications. It has numerous applications in automation and robotics.

Screw mechanisms are popular and vital components of many pick and place systems, where they are used in the positioning of end effector as a manipulator for different Cartesian axes (Jain et al., 2015). Screw mechanism was used in the design and development of a hybrid parallel manipulator by Jain et al.(2015). Leadscrew mechanism has been used in gripping devices to grab and release an object at picking and placement positions respectively (Ibrahim et al., 2015; Li et al., 2017; Nishimura et al., 2018). The low efficiency associated with leadscrew mechanism as a result of high friction between mating threads led to the development of other types of screw mechanisms. One of these is the ball screw that reduces contact surface thereby reducing friction between mating parts, resulting in increased efficiency from 20-50% obtained in leadscrew to 90% (Myszka, 2012), though it has associated problems of high cost. The ball screw was discussed and explained in Selater & Chironis (2011). Ball screw is used in the development of high speed pick and placement robot that can be used in production and assembly lines.

Xin-Jun et al. (2001) used a parallelogram mechanism in the design of a three degree of freedom parallel manipulator for industrial usage. Liu & Wang, (2003) used parallelogram mechanism in the design and development of industrial robot parallel manipulator with 2 to 6 degrees of freedom capability. It was used by Karimi et al. (2018) in the design and development of parallel manipulator for a robotic system. Wang et al.(2010) used a hybrid parallelogram mechanism to develop a remote center of motion mechanism for surgical operations. It was used by Angeles et al. (2000) in the development of robotic manipulator with SCARA motion capability, a popular motion type in precision pick and placement applications, especially in electronic circuit board assembly. Magdy et al. (2016) used parallelogram mechanism in the design of pick and placement applications system with the aid of ADAMS software. Parallelogram
mechanism was used in the development of dexterous micro gripping device by Xiao & Li (2012).

Materials & Methods

Pick and placement screw based seeding mechanism

The use of screw mechanism (Fig. 1) for pick and placement of paddy seeds from seed container to SRI seedling tray was conceived. Configurations of the mechanism were generated relative to the size of the seeding manifold (Fig. 1 (i)) and location of seedling tray. The screw mechanism consists of a vertical screw (Fig. 1 (ii)) that translates vertically for seed picking and horizontal screw (Fig. 1 (iii)) that translates horizontally for transport of seeding manifold from picking to placement positions, and vice versa.

Fig.(1): CAD model of screw based pick and place mechanism

Kinematics of pick and placement screw seeding mechanism

Kinematics of the pick and place screw mechanism was carried out to evaluate the motion and estimate period of operational circle of the mechanism. The estimation of the pick and place time in a pick and placement operation is vital in efficient assembly plant design process. Such time was studied by Ellis et al. (2001); Trinh et al. (2017) and Bharadwaj, et al. (2018). It is based on this time analysis that the mechanism will be adopted for detail design or another option will be considered in the event of longer operational circle period. The lengths of the horizontal and vertical translations required to make a pick and placement circle were estimated based on the position of the seed container and seedling tray. The estimation of the horizontal stroke was described with the aid of fig.(2). The seeding manifold has a width of 350 mm, the seedling tray has a width of 335 mm, the conveyor frame has a width of 50 mm, the seed container (seed container) has a width of 350 mm and the space between seedling tray and conveyor frame plus the space between seed container and conveyor frame is 50 mm. The length of the horizontal translation that the horizontal screw mechanism has to make to deliver the seeding manifold from the picking to the placement positions was 442.5 mm. This length of translation has to be covered twice for pick and placement respectively. The vertical screw mechanism need to make a downward seed picking translation of 50 mm to pick the seeds from the seed container and upward translation of 50 mm.

Displacement, velocity and acceleration analysis of screw mechanism

Assume that in a screw mechanism,

A is the part that is allowed to rotate

B is the other part joined by the screw joint that translates.

The magnitude of the displacement of B relative to A is given by Equation 1.

$$\Delta R_{B/A} = L\Delta \theta_A$$  \hspace{1em} (Eq. 1)

Where,
$R_{B/A}$ is the relative displacement of the translating part.

$L$ is the lead and stands for relative displacement per revolution of the rotating part.

Fig.(2): Top view schematic of horizontal mechanism translation

is the angle moved by the rotating part, rev.$\theta_A$

The first and second differential of the relative displacement magnitude (Equation 1) yields Equations 2 and 3 for the magnitude of velocity and acceleration respectively

$$V_{B/A} = L\omega_A$$  \hspace{1cm} (Eq.2)

is the relative velocity of the translating $V_{B/A}$ part, m/s

is the angular velocity of the rotating part, $\omega_A$ rps

$$a_{B/A} = L\alpha_A$$  \hspace{1cm} (Eq.3)

Where,

$a_{B/A}$ is the relative acceleration of the translating part, m/s$^2$, $\alpha_A$ is the acceleration of the rotating part, rps$^{-2}$

Pick and place crank-rocker seeding mechanism

The use of double crank-rocker (parallelogram) mechanism for pick and placement of paddy seeds from seed container to SRI seedling tray was conceived. Configurations of the mechanism were estimated relative to the size of the seeding manifold (Fig. 3 (i)). The manifold contained 924 seeding nozzles. Four links of the mechanism makes up one crank-rocker mechanism (Fig. 3 (ii)). In operation, the mechanisms flip clockwise and counter clockwise, to pick the seeds and place them in the seedling tray cavities respectively.

Kinematics of crank-rocker mechanism

In a seedling tray seeding process, it is required that when the seeding manifold is at picking or placement positions, it should be perfectly flat. This would enable each of the seeding nozzles to have contact with the seed on the seed container, and each of the seedling cavities to be seeded with a single seed respectively. The kinematic analysis of the seeding mechanism is important in ensuring such a constraint. In the kinematic study of the crank-rocker mechanism, the displacement, velocity and acceleration of the moving links are studied relative to the frame. To study these parameters, consider the four-bar mechanism shown in fig.(4). $L_1$ is the length of the frame (non-moving link), $L_2$ is the length of the input link, $L_3$ is the length of the coupler, $L_4$ is the length of the output link, $\theta_2$ is the crank angle, $\theta_3$ is the coupler angle, $\gamma$ is the transmission angle and $\theta_4$ is the follower angle. The displacement and velocity of each of these links were estimated with the aid of Equations 4 – 9 derived from figure 4.
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Fig. (3): CAD model of Crank-rocker based pick and place mechanism

Fig. (1): A generalized four-bar mechanism

Displacement analysis

The relative displacements of the links of the crank-rocker mechanism were calculated using equations 4, 5, 6 and 7. The angular displacement of the input link was constrained to from 8° to 172° based on relative position of the mechanism, seed container and seedling tray.

\[ BD = \sqrt{(L_1^2 + L_2^2 - 2(L_1)(L_2) \cos (\theta_2))} \]  
(Eq. 4)

\[ y = \cos^{-1}\left[\frac{(L_3^2 - (L_4^2) - (BD)^2)}{2(L_3)(L_4)}\right] \]  
(Eq. 5)

\[ \theta_3 = 2 \tan^{-1}\left[\frac{-L_2 \sin \theta_2 + L_4 \sin \gamma}{L_1 + L_3 - L_2 \cos \theta_2 - L_4 \cos \gamma}\right] \]  
(Eq. 6)

\[ \theta_4 = 2 \tan^{-1}\left[\frac{L_2 \sin \theta_2 - L_3 \sin \gamma}{L_2 \cos \theta_2 + L_4 - L_1 - L_3 \cos \gamma}\right] \]  
(Eq. 7)

Velocity Analysis

The relative velocity of the three moving links, which are link 2, link 3 and link 4 of the mechanism were estimated using Equations 8 and 9. In these analyses the angular velocities of links 3 and 4 were estimated using an assumed constant input angular velocity of 60 rpm from a stepper motor on link 2.

\[ \omega_3 = -\omega_2 \left[\frac{L_2 \sin (\theta_4 - \theta_2)}{L_3 \sin \gamma}\right] \]  
(Eq. 8)

\[ \omega_4 = -\omega_2 \left[\frac{L_2 \sin (\theta_3 - \theta_2)}{L_3 \sin \gamma}\right] \]  
(Eq. 9)

Where, \( \omega_2, \omega_3 \) and \( \omega_4 \) are the angular velocities of the input link, coupler and follower respectively, rad/s

\( \theta_2, \theta_3, \theta_4, \gamma \) are the input, coupler, transmission and follower angles respectively, in degrees

L_2 and L_3 are the lengths of the input link and coupler respectively, mm

Results & Discussion

Speed of screw based seeding mechanism

The period for pick and place circle of the screw based seeding mechanism was estimated by calculating the period for translation of the horizontal and vertical mechanism and summing up the two.

Horizontal screw

The horizontal screw mechanism needs a relative translation of 442.5 mm to deliver the
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This means for the vertical screw to translate 50 mm and pick the seed, it requires 20 revolutions.

**Velocity of the vertical screw**

The velocity of the vertical screw mechanism was calculated using Equation 2. With the same thread features as in displacement analysis above, assuming 300 rpm for the rotating part, from the power source.

\[ L = \text{Pitch} = 2.5 \text{ mm} \]

Assume \( \omega_A = 300 \text{ rpm} = 5 \text{ rps} \)

\[ V_{B/A} = \text{what needs to be found} \]

\[ V_{B/A} = 2.5 \times 5 = 12.5 \text{ mm/s} \]

**Translation time of vertical screw**

The time required to transport the manifold on the vertical screw mechanism for seed picking was calculated using Equation 10.

\[ T_t = \frac{50}{12.5} \times 2 = 8 \text{ sec} \]

**Operational period of screw based seeding mechanism**

The total translation time of both horizontal and vertical screw mechanisms for one full pick and placement cycle is 70.8 + 8 = 78.8s. This period for the cycle of pick and place in a seedling tray seeding machine can be considered high. Screw mechanism was also reported to result in loss of substantial amount of energy due to the high friction involved in motion transfer. The efficiency in a threaded screw was reported to be in the range of 20 – 50 % by Lokhande et al. (2012); Repcic et al.(2012). These two problems compelled the search for alternative with perceived high operational speed and efficiency. The second option considered is the crank-rocker mechanism.

**Speed of crank-rocker based seeding mechanism**

The time required for the pick and place crank-rocker seeding mechanism to transport the seeding manifold from the seedling tray position to the seed container position and back to the seedling tray position was estimated. This is the time for full circle of pick and placement. The mechanism was constrained to rotate a total of 164°, starting at 8° from the seed container position, and ending at 172° at the seedling tray position, and vice versa. The mechanism makes clockwise and counter clockwise rotations for picking and placement respectively.

**Displacement analysis**

Result of the displacement analysis of the three moving links of the proposed crank-rocker pick and place mechanism is presented in table (1). In the counterclockwise motion of the input link, the distance BD increase with increase in rotation angle, and the reverse is the case in the clockwise seed picking rotation of the input link. The coupler bearing the manifold was found to maintain a horizontal orientation due to the parallel nature of the links.

\[ L_1, L_2, L_3, \text{ and } L_4 \] are lengths of link 1, 2, 3 and 4 of the crank-rocker mechanism respectively.

\[ \theta_2, \theta_3, \theta_4, \gamma, \text{ and } BD \] are crank angle, angle between coupler \((L_3)\) and horizontal, rocker angle and transmission angle respectively.

The displacement and trajectory of the seeding manifold from the frame in relation to input angle is shown in fig.(5). A smooth curve representing the manifold displacement was observed. The displacement curve has shown that the vertical displacement of the seeding manifold increase from 8° input angle...
to 90°, and decreased from 90° input angle to 172°.

Table (1): Displacement relationship of the four links in pick and placement mechanism.

| L₁ (mm) | L₂ (mm) | L₃ (mm) | L₄ (mm) | θ₂ (degree) | BD (mm) | θ₃ (degree) | θ₄ (degree) | Y (degree) |
|--------|--------|--------|--------|-------------|--------|-------------|-------------|-----------|
| 400    | 450    | 400    | 450    | 8           | 77.48  | 0           | 8           | 8         |
| 400    | 450    | 400    | 450    | 18          | 141.84 | 0           | 18          | 18        |
| 400    | 450    | 400    | 450    | 28          | 211.28 | 0           | 28          | 28        |
| 400    | 450    | 400    | 450    | 38          | 280.74 | 0           | 38          | 38        |
| 400    | 450    | 400    | 450    | 48          | 348.73 | 0           | 48          | 48        |
| 400    | 450    | 400    | 450    | 58          | 414.40 | 0           | 58          | 58        |
| 400    | 450    | 400    | 450    | 68          | 477.12 | 0           | 68          | 68        |
| 400    | 450    | 400    | 450    | 78          | 536.33 | 0           | 78          | 78        |
| 400    | 450    | 400    | 450    | 88          | 591.55 | 0           | 88          | 88        |
| 400    | 450    | 400    | 450    | 98          | 642.34 | 0           | 98          | 98        |
| 400    | 450    | 400    | 450    | 108         | 688.29 | 0           | 108         | 108       |
| 400    | 450    | 400    | 450    | 118         | 729.05 | 0           | 118         | 118       |
| 400    | 450    | 400    | 450    | 128         | 764.29 | 0           | 128         | 128       |
| 400    | 450    | 400    | 450    | 138         | 793.75 | 0           | 138         | 138       |
| 400    | 450    | 400    | 450    | 148         | 817.19 | 0           | 148         | 148       |
| 400    | 450    | 400    | 450    | 158         | 834.44 | 0           | 158         | 158       |
| 400    | 450    | 400    | 450    | 168         | 845.36 | 0           | 168         | 168       |

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Velocity analysis

The angular velocity relationship between the input link ($\omega_2$), coupler ($\omega_3$), follower ($\omega_4$) and linear velocity of point b and c, which are the edges of the manifold, is presented in table (2).

The angular velocity of the input link which is decided and set on the motor was constant. The angular velocity of the coupler is zero, this implied that the manifold is translating in a flat pattern without rotational motion involved. The angular velocity of the follower is the same as the angular velocity of the input link. This implied that there was no relative acceleration among the links of the crank-rocker seeding mechanism, hence acceleration is zero and there is no need for conducting acceleration analysis of the mechanism.

Table (2): Velocity relationship among the four links of pick and placement mechanism

| $\omega_2$ (rpm) | $\omega_3$ (rpm) | $\omega_4$ (rpm) | $V_b = V_a$ (mm/s) |
|------------------|------------------|------------------|-------------------|
| 60               | 0                | 60.00            | 2827.44           |

Where,

$\omega_2$, $\omega_3$, $\omega_4$, are angular velocities of input link, coupler and follower respectively.

$V_b$ and $V_a$ are linear velocities of points a and b respectively.

Operational period of crank-rocker seeding mechanism

The time required for the input link to rotate 164° at 60 rpm angular speed was calculated using Equation 11. This is the time for one way rotation, the full two ways rotation period was double the one way rotation time.

$$\omega = \frac{\theta}{t}$$  \hspace{1cm} (Eq. 11)

Where,

$\omega$ is the angular velocity of the input link, $\omega$ rad/sec.

$\theta$ is the angle of full forward or $\theta$ backward stroke of the input link, rad.

$t$ is the time for a full forward or backward stroke of the mechanism, sec.

The time for one-way stroke of the mechanism

$$t = \frac{2.86234}{6.2832} \approx 0.5 \text{ sec}$$

Time for the pick and placement cycle (1 sec) was obtained by multiplying one stroke period by 2.

The 1 sec pick and placement period calculated above for the double four bar pick and place seeding mechanism was compared
with the 78.8 sec calculated for the full pick and placement circle in the pick and placement screw mechanism. On the basis of operation time, the four bar seed placement mechanism has a greater advantage over the screw seed placement mechanism. Hence, it is adopted for detail design.

Conclusion

Based on the analysis carried out to compare speed of operations of screw mechanism and crank-rocker mechanism for seeding of SRI seedling tray, in comparison to screw based pick and place mechanism, crank-rocker based pick and place mechanism requires few components with the advantage of low cost of development. On the basis of speed of operation, crank-rocker based pick and place mechanism with one sec per pick and place circle period is faster than screw based pick and place mechanism with 78.8 sec per pick and place circle. The crank-rocker seeding mechanism has the potential to achieve higher efficiency than the conventional seedling tray seeding mechanisms.

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