



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

Tukur D. Abdulkadir<sup>1\*</sup>, Muhammad R. Mahadi<sup>1&2</sup>, Aimrun Wayayok<sup>1&2</sup> & Muhamad S.M. Kassim<sup>1&2</sup>.

<sup>1</sup>Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia.

<sup>2</sup>SMART Farming Technology Research Center, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia.

\*Corresponding author E-mail: [dantukuro@gmail.com](mailto:dantukuro@gmail.com)

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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, crank 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 Sclater & 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.

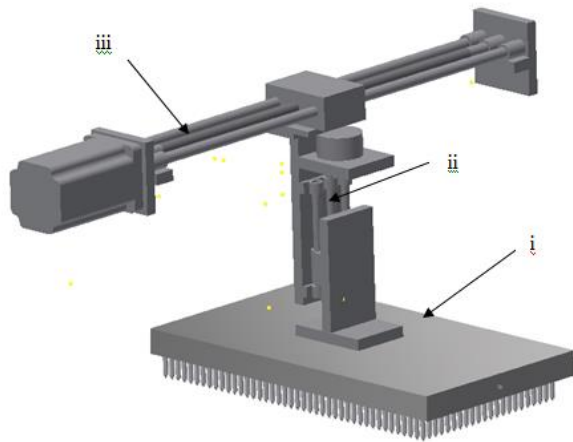


Fig.(1):CAD model of screw based pick and place mechanism

### 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.

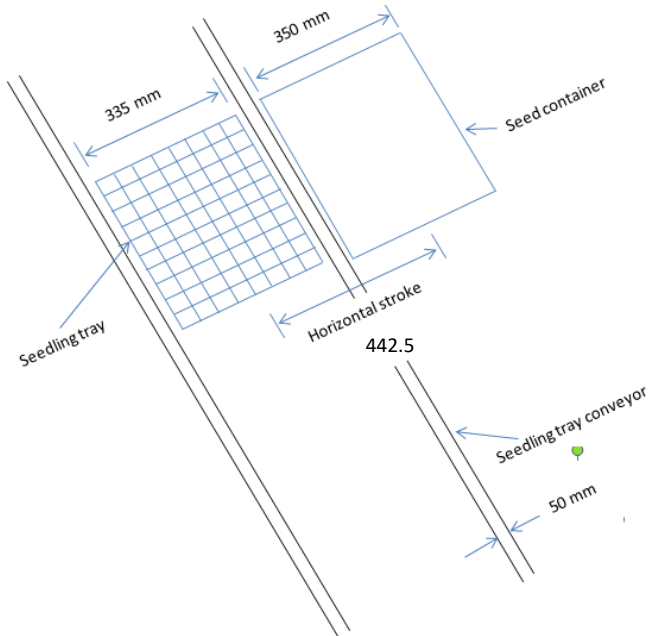
The magnitude of the displacement of B relative to A is given by Equation 1.

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

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

$$V_{B/A} = L\omega_A \quad (\text{Eq.2})$$

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

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

$$(\text{Eq.3}) \quad a_{B/A} = L\alpha_A$$

Where,

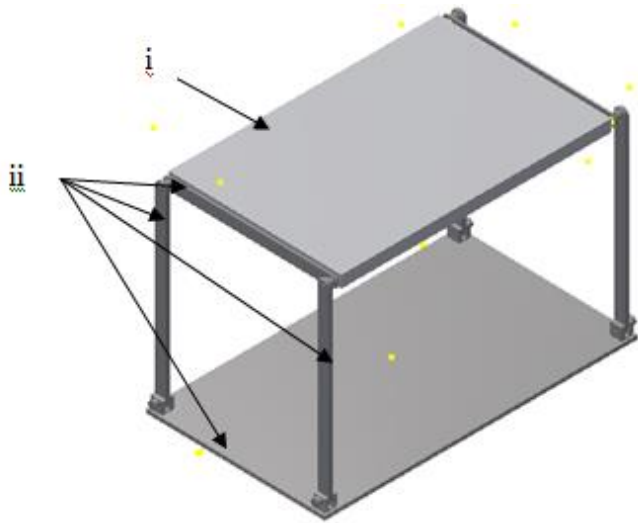
$a_{B/A}$  is the relative acceleration of the translating part,  $\text{m/s}^2$ ,  $\alpha_A$  is the acceleration of the rotating part,  $\text{rps}^{-2}$

### Pick and place crank-rocker seeding mechanism

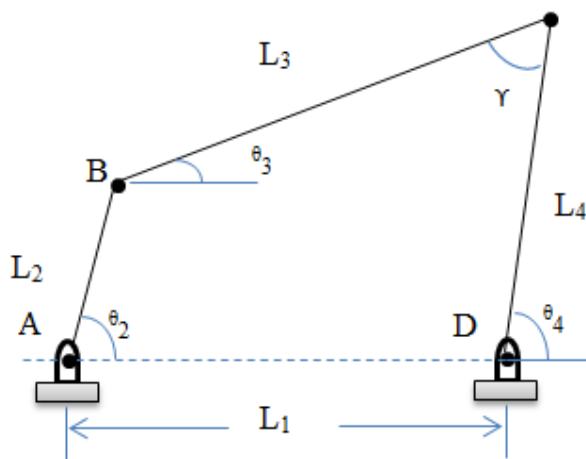
The use of double crank-rocker (parallelogram) mechanism for pick and placement of paddy seeds from seed container to SRI seedling tray was conceived. Configurations of the mechanism were estimated relative to the size of the seeding manifold (Fig. 3 (i)). The manifold contained 924 seeding nozzles. 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.



**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)

$$\gamma = \cos^{-1} \left[ \frac{(L_3^2) + (L_4^2) - (BD)^2}{2(L_3)(L_4)} \right]$$

(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

seeding manifold from the seed picking to the seed placement position, and vice versa.

### Displacement of horizontal screw mechanism

In this section of the screw mechanism analysis, the screw displacement was studied based on screw features

$$\begin{aligned} &\text{Using Equation 1} \\ &= 442.5 \text{ mm } R_{B/A} \end{aligned}$$

The proposed screw mechanism was assumed to have a horizontal screw of M20×2.5 type. The 2.5 is the pitch (mm) of the thread. Therefore, L = Pitch = 2.5 mm

What need to be found is  $\Delta\theta_A$  that will result in 442.5 mm screw translation.

Substituting

$$\begin{aligned} 442.5 \text{ mm} &= 2.5 \times \Delta\theta_A \\ &= 177 \text{ rev} \qquad \Delta\theta_A \end{aligned}$$

to achieve 442.5 mm translation the screw need to make 177 revolution

For a full circle of pick and placement, the screw needs to translate twice, to and fro.

### Velocity of horizontal screw mechanism

The velocity of the horizontal screw mechanism was studied using Equation 2. With the same thread features as in displacement analysis above, assuming 300 rpm for the rotating part, from a stepper motor.

$$L = \text{Pitch} = 2.5 \text{ mm}$$

$$\text{Assume } \omega_A = 300 \text{ rpm} = 5 \text{ rps}$$

$V_{B/A}$  is what needs to be found

$$V_{B/A} = 2.5 \times 5 = 12.5 \text{ mm/s.}$$

### Translation time of horizontal screw

The time required to translate the horizontal screw mechanism for each of the pick and

placement circles was calculated using Equation 10, by multiplying one horizontal translation period by two  $V_{B/A} = \frac{D_t}{T_t}$  (Eq.10)

Where,

$D_t$  is the translation distance = 442.5 mm

$T_t$  is the translation time to be found

$$T_t = \frac{442.5}{12.5} = 35.4 \text{ s.}$$

The total time for a full pick and placement circle translation is obtained by multiplying the single stroke time by 2.

$$= 70.8 \text{ s.}$$

Now let us study the translation time of the vertical screw.

### Vertical screw

In the proposed pick and place screw mechanism, the vertical screw needs to make a vertical translation of 50 mm to pick the seed and translate upward 50 mm to horizontal translation level.

### Displacement of the vertical screw

The vertical screw mechanism was analyzed as it was done to the horizontal screw mechanism. The displacement of the vertical screw mechanism was calculated using Equation 1.

$$R_{B/A} = 50 \text{ mm}$$

The vertical screw was assumed to be of M20×2.5 type. The 2.5 is the pitch (mm),

$$\text{Therefore } L = \text{Pitch} = 2.5 \text{ mm}$$

What need to be found is  $\Delta\theta_A$  that will results in 50 mm translation of the vertical screw.

Substituting the known values into the equation yield

$$\Delta\theta_A = 20 \text{ rev}$$

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.

$$L = \text{Pitch} = 2.5 \text{ mm}$$

$$\text{Assume } \omega_A = 300 \text{ rpm} = 5 \text{ rps}$$

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

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

### 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  $70.8 + 8 = 78.8\text{s}$ . 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  $164^\circ$ , starting at  $8^\circ$  from the seed container position, and ending at  $172^\circ$  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.

$L_1, L_2, L_3,$  and  $L_4$  are lengths of link 1, 2, 3 and 4 of the crank-rocker mechanism respectively.

$\theta_2, \theta_3, \theta_4, \gamma,$  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  $8^\circ$  input angle

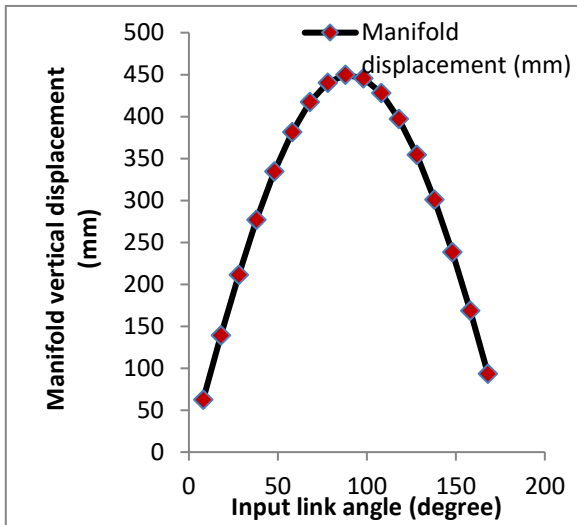
to 90°, and decreased from 90° input angle to

172°.

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

<b>L<sub>1</sub></b> <b>(mm)</b>	<b>L<sub>2</sub></b> <b>(mm)</b>	<b>L<sub>3</sub></b> <b>(mm)</b>	<b>L<sub>4</sub></b> <b>(mm)</b>	<b>θ<sub>2</sub></b> <b>(degree)</b>	<b>BD</b> <b>(mm)</b>	<b>θ<sub>3</sub></b> <b>(degree)</b>	<b>θ<sub>4</sub></b> <b>(degree)</b>	<b>Υ</b> <b>(degree)</b>
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





**Fig.(5): Seeding manifold displacement curve.**

**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  $164^\circ$  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.

$$\omega = \frac{\theta}{t} \quad (\text{Eq. 11})$$

Where,

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

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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