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## Design and Development of Four Link Bar Mechanism For Transplanting Wet Rice Seedlings

To cite this article: Marzuki *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **536** 012027

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# Design and Development of Four Link Bar Mechanism For Transplanting Wet Rice Seedlings

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**Abstract.** Indonesia is a great area for the development of sustainable agricultural cultivation technology. Wet rice cultivation management system and method is still done traditionally. These activities are requiring the expertise of a very high order to obtain a uniform spacing and planting. Heterogeneity of plant spacing will have an impact on seed propagation delays planting, the farmer difficult when doing weeding, fertilizing and spraying. Transplanting of seedlings is a labour-intensive operation in the cultivation of rice. There exists a need to mechanize for this operation. This study aims to determine the design parameters of the mechanism design four link bar for modelling mechanism in order to obtain the optimum parameters of the locus of planting. Design tools rice growers using the four-link bar mechanism able to work mechanically to take the rice seedlings from hopper and planted with uniform spacing, closing the planting hole, reducing the time of planting and operational costs. The method used in this research is the design of the prototype and design of functional and structural approaches. Research has produced a prototype component of the combined mechanisms of rice cultivation four link bar mechanism which can move the locus of decision-continuous form of seeds and planting seeds for the six rows.

## 1. Introduction

Rice productivity in Indonesia reached an average of 7 tons per hectare of rice field area in 33 provinces in the Republic of Indonesia. Based on the survey results revealed that the total area of paddy fields from all provinces in the Republic of Indonesia covering an area of 8,132,345.91 hectares. In case in Aceh province has area reaches 397,391 hectares of wet rice fields with rate productivity about 4,648 tons per hectare [1]. This value is very low compared to other provinces in Indonesia has reached 7 tons per ha. Supposedly productivity could be increased if supported by adequate mechanization technology, the use of improved seed, planting a seed that simultaneous and uniform spacing will provide convenience when pest spraying and fertilizing, so it will be able to increase productivity.





Figure1. Traditionally and transplanted GPS rice planting method

Rice planting method is traditionally done by farmers in the province resulted in non-uniform spacing, requires a lot of manpower, a long time and a huge cost (Figure.1). Row spacing uniformity will also have an impact on seed propagation delay, difficult for farmers while doing weeding, fertilizing and spraying [1], [2]. This will certainly have an impact on the decline rice harvest. Rice cultivation manually using human labour will spend about 10 hours / ha with detail 20 workers / ha for planting, 2 /ha uprooting seedlings in the nursery, 2/ ha distribute seeds and 4 / ha for land scratch. The costs required for planting 1 ha reached 1,500,000 IDR.

The use of rice-planting machine (rice transplanted) has been successfully implemented in Japan, Korea, Thailand and China, but cannot be adopted in India and Indonesia because of the limitations of farmer economics ability and culture [2]. The use of rice-planting machines will allow farmers to plant rice because it can save the time; reducing the cost, improve the process of planting rice seedlings, anticipation the lack of manpower in the process of rice planting [2], [3]. Machine able to plant 1 ha within 4 hours with the condition of the plant spacing in the row and column are uniform [4]. Thus, is also able to adjust as desired row spacing variations ranging from 20 x 20 cm, 25 x 25 cm, 22 x 22 cm or 30 x 20 cm.

For wet paddy field system, suitable mechanism in rice-planting machine is four bar linkage mechanism that functions as an arm of seed growers and makers of hoper [4]. Implementation of this mechanism is very complicated, so it requires a depth of kinematic analysis to ensure that this mechanism can work as desired [5]. It is necessary to further study the implementation of the four-link bar mechanism in rice-planting machines.

In this study, the mechanism of four bar linkage is designed for picker mechanism and the planting of rice seedlings. This motion mechanism moves the first speed with of 36 rpm and the second speed of 46 rpm. This motion is then converted into a translational movement of the finger picker and planting seedlings. While the speed of forward movement for the speed of 5 km / h, 10 km / h and 15 km/h. This mechanism is main powered by a unit diesel motor 9.5 HP. The speed ratio between the planting mechanisms adapted to forward speed.

The purpose and objective of this study is to design the mechanism parameters of the four-link bar that can provide the rice planting locus that is appropriate for wet rice fields and modelling the mechanisms which can provide optimum planting locus.

### 1.1 Four Link Bar Mechanism

Thomas (2002) and Guo, LS and Zhang, WJ, (2001) states that the mechanism of rice transplanted machine can using four bar linkage, then Waldron et. all (1999) argued that four bar linkage movement as kinematic chain which is bound to a systems of linkage are coupled together or intersect in a state that allows to move relative to the other link bar. This condition allows the connecting rod is another move to any position as desired [2], [6],[7],[8].

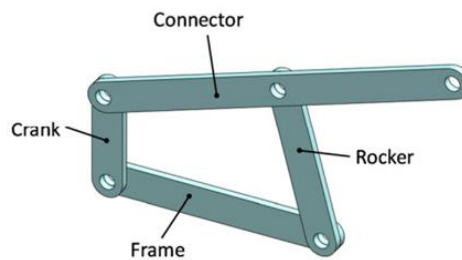


Figure 2. Basic four link bar linkage

Initially, the model of four link bar mechanism consists of frame (link 1), crank (link 2), connector (link 3) and the rocker (link 4). The length of each link bar should be suitable and fit, so would give a smooth movement effect and must be ensured that the crank can be rotatable 360 degree. Figure 2 showed the basic concept four link bar linkage.

The four-bar linkage mechanism is a suitable mechanism that is used in rice planting machines that function as planter arms and take seeds from hopper. The implementation of this mechanism is very complicated, so it requires a depth of kinematic analysis to ensure this mechanism can work as desired [2].

Research conducted by Reis and Forcellini (2002) has identified four basic concepts that must be considered in order to maximize the function of the mechanism of planting, so we get a planting at spacing precision. The concepts include the following; a) How to put seed in the right position, b) Dig a planting hole that is correct, c) feeding procession to hole seed planting, and d) the ability to close the hole again after planting is completed [6].

In a mechanical transplanted the finger which is attaching at the end of connector bar follow a desired trace path of motion. A planar four bar linkage with all revolute pairs is chosen, as this is very simple, a mechanism made of that may be easy to maintain and may cost less to manufacture. The input motion is applied to the crank so that the motion is continuous and rotary. The output motion follows a suitable path in order to meet the requirements of a transplanted which has specified. The mechanism should have one degree of freedom and a connector point that can make a loop may be incorporated. The planting finger will be attached at the end of connector point.

### 1.2 Kinematics Analysis

Kinematics analysis is very important to do; to get the dimension of link bar in other to mechanism can move and rotate smoothly. By using Newton Raphson method that was written with the Jacobian matrix for the connecting bar we can calculate the dimension to determine the length of each four-link bar and analysing [7]. Kinematics diagram also needed (figure 3), as a model to calculate the velocity, acceleration and direction of four link bar mechanism.

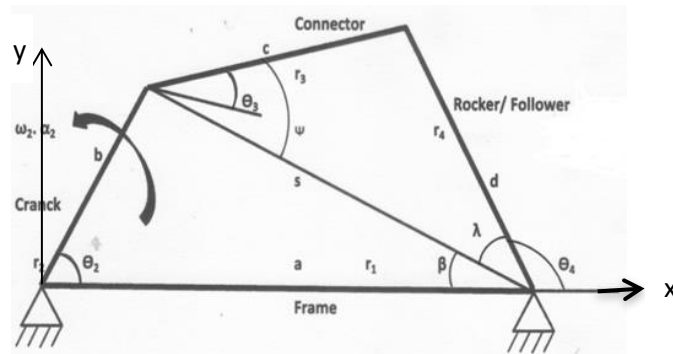


Figure 3. Kinematic Diagram the four link bar mechanism

The linkage parameters according to figure 1 are given;

1. Length of fixed link/frame,  $r_1$ .
2. Length of crank,  $r_2$ .
3. Length of connector,  $r_3$ .
4. Length of rocker,  $r_4$ .
5. Length of connection extension,  $r_F$ .
6. Angle of connection extension,  $\psi$ .
7. Crank angle,  $\theta_2$
8. Connector extension angle,  $\theta_3$
9. Angle of frame with the horizontal,  $\theta_4$ .
10. Crank angular velocity,  $\omega_2$
11. Angle of displacement,  $\beta$
12. Angular acceleration of rocker,  $\alpha_2$
13. Angle between  $s$  and rocker link,  $\lambda$

Kinematic analysis for four links bar mechanism can calculate using the following equations;

- Displacement analysis

$$s = \sqrt{r_1^2 + r_2^2 - 2r_1r_2 \cos\theta_2} \quad (1)$$

$$\beta = \sin^{-1} \left( \frac{r_2}{s} \sin\theta_2 \right) \quad (2)$$

$$\psi = \cos^{-1} \left( \frac{r_3^2 + s^2 + r_4^2}{2r_3s} \right) \quad (3)$$

$$\lambda = \cos^{-1} \left( \frac{r_4^2 + s^2 - r_3^2}{2r_4s} \right) \quad (4)$$

$$\theta_3 = \psi - \beta \quad (5)$$

$$\theta_4 = \pi - (\beta + \lambda) \quad (6)$$

- Angular velocity

$$\omega_3 = \omega_2 \left( \frac{r_2 \sin(\theta_4 - \theta_2)}{r_3 \sin(\theta_3 - \theta_4)} \right) \quad (7)$$

$$\omega_4 = \omega_2 \left( \frac{r_2 \sin(\theta_3 - \theta_4)}{r_4 \sin(\theta_3 - \theta_4)} \right) \quad (8)$$

$$\alpha_3 = \frac{\omega_3 \cdot \alpha_2}{\omega_2} + \frac{r_4 \cdot \omega_4^2 - r_2 \omega_2^2 \cos(\theta_2 - \theta_4) - r_3 \cdot \omega_3^2 \cos(\theta_3 - \theta_4)}{r_3 \sin(\theta_3 - \theta_4)} \quad (9)$$

$$\alpha_4 = \frac{\omega_4 \cdot \alpha_2}{\omega_2} - \frac{r_3 \omega_3^2 + r_2 \omega_2^2 \cos(\theta_2 - \theta_3) - r_4 \cdot \omega_4^2 \cos(\theta_3 - \theta_4)}{r_3 \sin(\theta_3 - \theta_4)} \quad (10)$$

## 2. Methodology

### 2.1 Formulation of Design Concepts and Analysis

- Determine the design parameters for the four-link mechanism.
- Formulate several design concepts related to the selection of dimensions of the four-link bar.
- Choosing the best concept to proceed to the stage of creating a design project and drawing it with CAD software.
- Computational modeling and simulation to determine the force and analysis of motion analysis in the four-link bar mechanism.

### 2.2 Design Model

The design of the four-links bar mechanism model for the planned construction of the rice planter mechanism as shown;

- The finger takes the rice seedlings from the hopper which also functions to planting the rice seedlings into the ground and moves according to the locus according to the rotary axis of the shaft driven by the power of driving motor.
- The link bars associated with the drive shaft, serves to continue the rotation of the driving motor to rotate the arm of the rice seed picker.
- The frame is directly fixed with the engine frame to ensure movement is performing, so this mechanism can work smoothly.

### 2.3 Design of Mechanism

Thomas E V (2002) argued that four bar linkages should be among the first solutions to motion control problems to be investigated, then four bar mechanism is physically impossible to move if one of the links has a length greater than the sum of the other three. Furthermore, their states that one basic mechanism design problem for which the four-bar chain can provide solutions is that of finding a point of the connector of a four-bar mechanism, which describes a path closely approximating the desired one (figure 4).

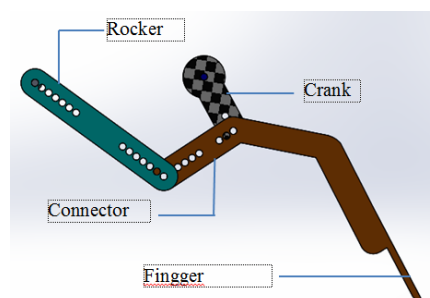


Figure 4. Design Model of four link bar mechanisme

## 2.4 Design of Planting Mechanisms

Four linkage bar mechanism is designed as a planting mechanism consist of four bar mechanism which are crank, connector, frame and rocker. A finger planting, this is part of the connector link mechanism, separating the seeds from the hopper and put them in the ground. The curve traced (locus) by finger planting may have an influence on the stability of the seed is planted. Kinematic analysis of the mechanism of planting are considered important for understanding the operation and further improvements [2].

In other to get planting mechanism which is suitable as a desired, we need to do modelling and simulation of mechanism by using software like Solidworks. Design begins by creating engineering drawing 2D and 3D. After assembling has been done, we can do simulation to get trace path of planting. Trace path illustrated the real movement of finger planting when it takes the seeds from hopper, putting the seed in to land hole and move continuously to take seed from hopper again (figure 5).

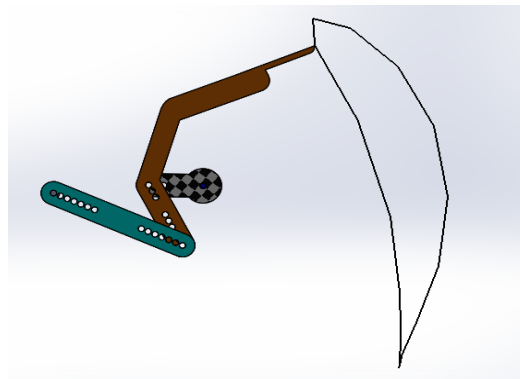


Figure 5. Planting Mechanism Design

## 2.5 Simulation and modelling

Modelling with Solidworks Premium 2015 software must be through the basic introduction of link 1 (Frame), Link 2 (Crank), Link 3 (Connector) and Link 4 (Rocker) as shown in Figure 2. The length of the 4-link bar must have a hole fit, so can give a smooth motion effect and it must be ensured that Link 2 must be able to rotate 360 degrees after the assembly process.

If the modelling is in accordance as desired, then the next step is to determine which components are fixed and moving both rotation and linear. Kinematic analysis for the velocity and acceleration of each connecting link bars can be analysed with Microsoft Excel calculations and by modelling the mechanism using SolidWorks software.

## 3. Result and Discussion

### 3.1 Four link Bar Mechanism Design

The optimum design of four link bar mechanism from various alternative dimensions tested to produce rice planting locus as shown in Figure 6. Figure 6. Explains that the selected mechanism has been tested it can move smoothly according to its functionality for rice planting.

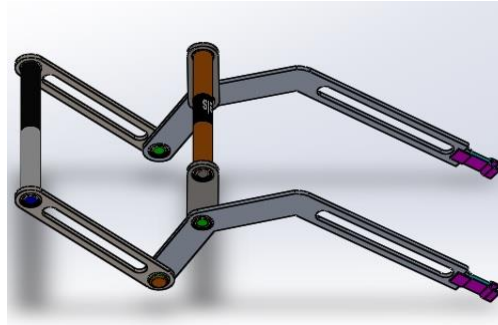


Figure 6. Four link bar mechanism

Crank can move rotation in to 360 degrees which is powered by chain driven which rotate the gears, so the pair connector can move in the same time followed by shaft linkage. Since Crank movement, rocker only can move swinging due to of these links are fixed connection with the frame link (figure7). The mechanism has arranged for three pair mechanisms for the six columns and rows planting purposed.

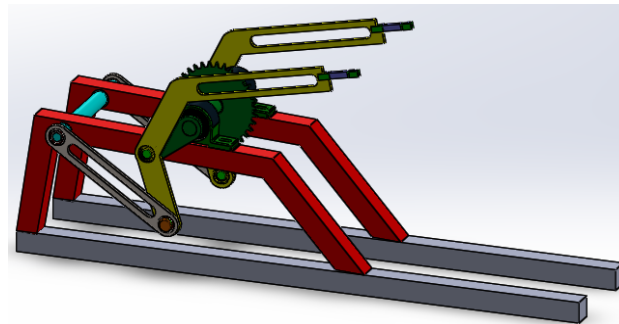


Figure 7. Construction of four link bar mechanism in assembly

Basically, this mechanism can apply in wide area of paddy field planting machine with advanced development based on engine powered and power transfer. This mechanism can be controlled by set up the speed of shaft. The picker finger will move fast if the shaft speed increased. In fact, the picker finger movement will determine the rice planting spacing in columns. One cycle setting is equal to 360 degrees.

Planting locus will form on the picker finger which is an extension of the connecting bar (connector). The locus is a trace path of the movement of the picker finger of the grower who takes the seeds from the hopper, carries and sticks the ground rice seeds then moves backwards at the starting position continuously. The shape of the locus is strongly influenced by state positions, the speed and acceleration of the connecting bar in the four-link bar mechanism.

Figure 8. argued that rice-planting machine prototype of the mechanism of the four-links bar mechanism that continuously can take the seeds from hopper and plug the seeds in to the ground at a depth around of 100 mm. Prototype machine uses 9.5 HP diesel engines to drive the prototype and planting mechanism. The prototype is equipped six planting fingers to collect the seeds from hopper, carrying, plug in into the ground and moved mechanically to form the same locus, with spacing in the row with a spacing of 200 x 200 mm and 250 x 250 mm and plant spacing in the column 200 x 200 mm and 250 x 250 mm.



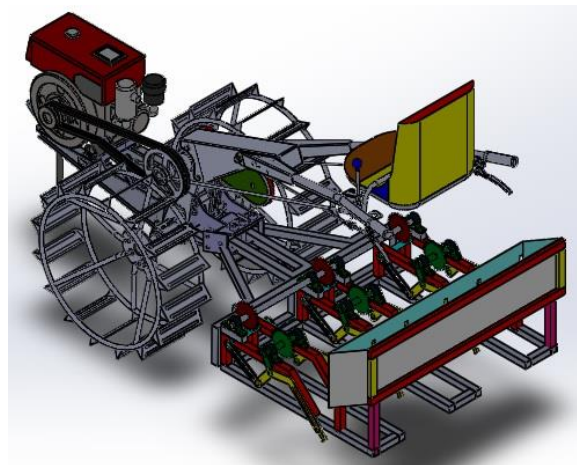


Figure 8. Assembly mechanism for six rows planting seeds

The chain is used as a medium for continue rotation and power from the motor to the planting mechanism. The gears are used to reduce of rotation from high to low rpm and as modifiers rotation clockwise into anti-clockwise. The drive wheel is made based on the similarity with the wheel a hand tractor. Saddle conditioned as seating operator to control the planting mechanism and movement forward, backward and turn the machine. Rotation speed of planting mechanism can vary between 50-300 rpm, while the speed of the prototype consists of three forward speeds and one reverse speed.

### 3.2 Four Link Bar Mechanism Kinematic Analysis

Selection and determined the alternatives variance dimensions of the length of link bar, finally the result is obtained for each linkage bar as follows;

- The length of frame link is 230.87 mm
- The length of crank link is 87.04 mm
- The length of connector link is 117.85 mm
- The length of rocker/follower link is 225.57 mm

Table 1. Displacements calculations in degrees

$\Theta_2$ deg	S	$\beta$ deg	$\Psi$ deg	$\alpha$ deg	$\alpha_2$ deg/s <sup>2</sup>	$\alpha_3$ deg/s <sup>2</sup>	$\alpha_4$ deg/s <sup>2</sup>	$\Theta_2$ deg	$\Theta_3$ deg	$\Theta_4$ deg
0	143.83	0	118.7505	0.475797	0	-6537.7	-1206.58	0	118.7505	152.7388
10	145.9371	5.944638289	117.1487	0.483514	0	-1774.16	2119.348	10	111.204	146.3521
30	161.4667	15.63625923	106.6771	0.524151	0	2714.482	5409.685	30	91.04085	134.3321
60	201.9455	21.91701457	85.43449	0.547784	0	1719.634	3979.235	60	63.51748	126.6973
90	246.7325	20.65687969	65.7517	0.496511	0	1669.004	2212.986	90	45.09482	130.8952
120	284.5555	15.36103054	49.0261	0.405477	0	2275.228	673.0913	120	33.66507	141.4068
150	309.3256	8.087958173	36.39218	0.315169	0	3167.171	-804.388	150	28.30422	153.8542
180	317.91	1.92188E-15	31.2296	0.274303	0	2938.782	-1483.09	180	31.2296	164.2836
210	309.3256	-8.087958173	36.39218	0.315169	0	586.8139	-770.292	210	44.48013	170.0301
240	284.5555	-15.36103054	49.0261	0.405477	0	-986.656	-419.787	240	64.38713	172.1289
270	246.7325	-20.65687969	65.7517	0.496511	0	-1985.96	-659.26	270	86.40858	172.2089
300	201.9455	-21.91701457	85.43449	0.547784	0	-3661.46	-1479.44	300	107.3515	170.5313
330	161.4667	-15.63625923	106.6771	0.524151	0	-7814.52	-3394.13	330	122.3134	165.6046
360	143.83	-8.49593E-15	118.7505	0.475797	0	-6537.7	-1206.58	360	118.7505	152.7388

The use of equations 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 is the initial step that is carried out to test the

displacements, velocity and accelerations of the four link bars whether it can move according to the desired or not. The suitability of this kinematic movement can be seen from the calculation results and then analysed with a graph so that it will provide an initial description of mechanism that will be formed. Table 1. Illustrate the kinematic calculations result of four link bar displacement in degrees and Table 2. Shows the kinematic calculations result of four link bar Angular velocity calculations in degrees. The tables illustrate the kinematic analysis of the four links bar which is calculated based on mathematical equations using Microsoft Excel software.

**Table 2.** Angular velocity calculations in degrees

$\Theta 2$	$\omega 2$	$\omega 3$	$\omega 4$	$\alpha$	$\alpha 2$	$\alpha 3$	$\alpha 4$
deg	deg/sec	deg/sec	deg/sec	deg	deg/s <sup>2</sup>	deg/s <sup>2</sup>	deg/s <sup>2</sup>
0	572.958	-346.731	221.0855	0.475797	0	-6537.7	-1206.58
10	572.958	-507.357	221.0855	0.483514	0	-1774.16	2119.348
30	572.958	-597.919	221.0855	0.524151	0	2714.482	5409.685
60	572.958	-435.496	221.0855	0.547784	0	1719.634	3979.235
90	572.958	-277.784	221.0855	0.496511	0	1669.004	2212.986
120	572.958	-162.163	221.0855	0.405477	0	2275.228	673.0913
150	572.958	-34.9608	221.0855	0.315169	0	3167.171	-804.388
180	572.958	156.8691	221.0855	0.274303	0	2938.782	-1483.09
210	572.958	334.1118	221.0855	0.315169	0	586.8139	-770.292
240	572.958	411.5707	221.0855	0.405477	0	-986.656	-419.787
270	572.958	420.3898	221.0855	0.496511	0	-1985.96	-659.26
300	572.958	366.0506	221.0855	0.547784	0	-3661.46	-1479.44
330	572.958	166.0051	221.0855	0.524151	0	-7814.52	-3394.13
360	572.958	-346.731	221.0855	0.475797	0	-6537.7	-1206.58

The results of the kinematic analysis of angular velocity ( $\alpha$ ), and the acceleration of the angle ( $\omega$ ) as shown in Figure 9. Figure 9 is a graph showing the dynamic analysis four links bar mechanism displacement and velocity which has been created based on data from table 1 and table 2. The figure informs the change in the amount of angular velocity and accelerations in time against the displacement of the link bar. Figure also provides information that the mechanism can synergize between the four-interconnected links bar and can move simultaneously according each degree of freedom.

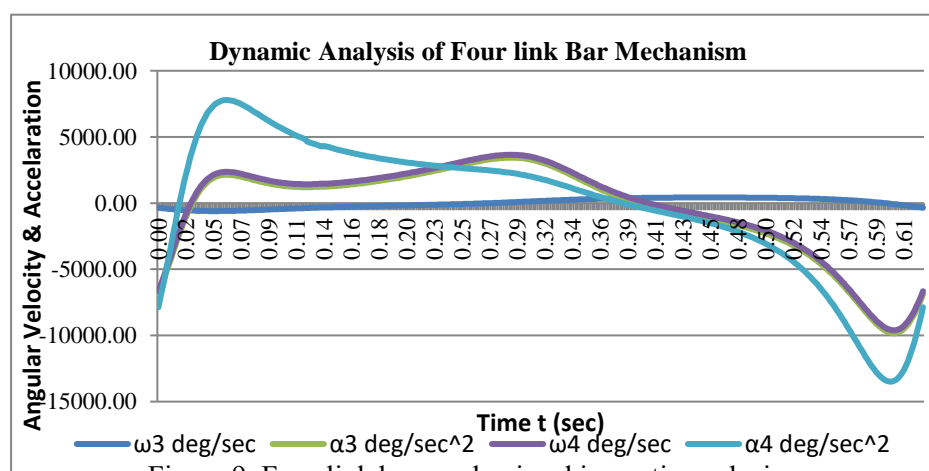


Figure 9. Four-link bar mechanism kinematic analysis

### 3.3 Motion Analysis

Motion analysis is performing to make sure if the mechanism exactly can move and motion follow by the degree of freedoms. This study using the Solidworks software to create the three dimensions drawing component, continuing by assembly process and modelling the mechanism in motion analysis. In the motion analysis, motor selection always becomes the first consideration. Motor rpm, the wise of motor motion (clock wise or counter clock wise) and time determination also needed.

Initially, the mechanism is designed as follow rank (L2) rotating moving in 360 degrees as a source power to rotate the mechanism. The movement of the L2 carries the link bar L3 (connector) so that it rotates 360 degrees. The rotation motion of the L3 is arranged and is limited by the L4 link bar which moves linear interpolation (swinging). While the link bar L1 (frame) only remains as a support for the stability of the movement.

In motion analysis, each of link displacement can be analyse by graph and data. The movement data can manually save into the table. The data also we can create the trace path of the motion of each link, but in motion analysis the trace path automatically generated by software.

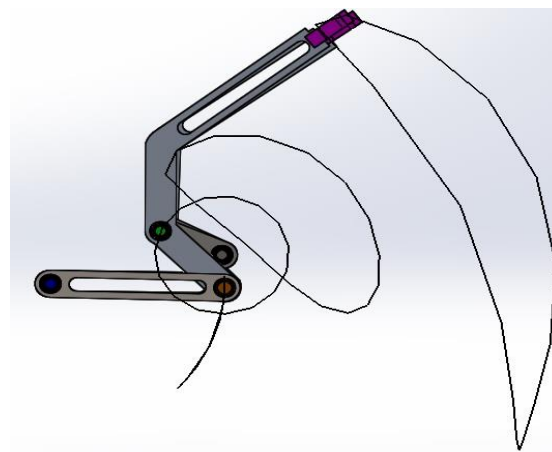


Figure 10. The trace path of each movement

Figure 10, shows the trace path of each link bar movement in to mechanism. The shape of the pattern shows the movement performance of each link bars. The trace path of crank (L2) is round (circular) 360°, and then the link bar moves in a circle according to the reference point of the axis. The trace path of connector (L3) is almost a half of circular. The trace path of rocker/follower (L4) is like bowstring, it means link bar moves according to the trajectory.

### 3.4 Planting Locus

The planting finger of the seedling will move according to the degree of freedom given by the combined mechanism of the four link bars. The planting locus must be ensured its performance to be able to pick up seeds from the hopper, carry and plug the seed into the soil with a certain depth. Furthermore, it moves backwards to its initial position without damaging the rice seeds that have been plugged in. This movement must be the same for each step forward and backward.

Figure 11 describes the planting locus is formed from the height of the lift from the planter's finger in a step forward, the step of the movement of taking the seedlings on the hopper, the step of planting the rice seedlings into the soil and returning.

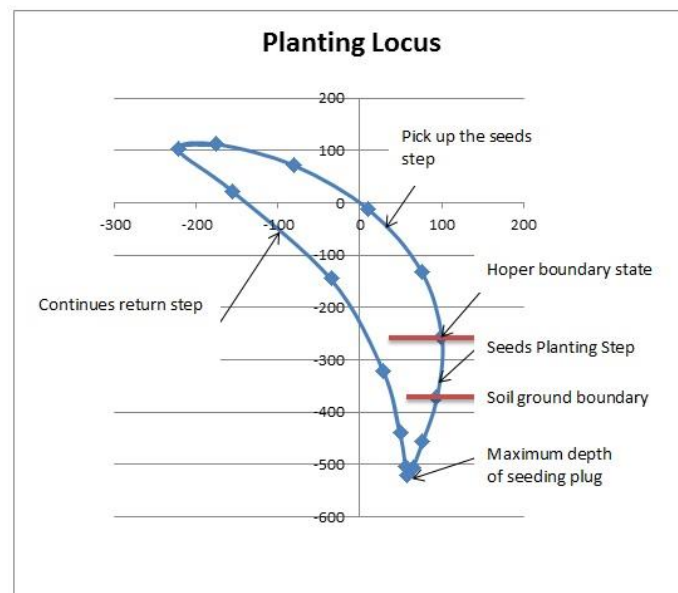


Figure 11 planting locus

Figure 12 shows the X direction displacement about 322.416 mm and Y direction depth of planting around 634.227 mm. The movement of X direction which is almost half of Y direction is very effective to be applied to the machine because there is little space needed to drive this mechanism.

The mechanism prototype that has been designed and simulated in this study has a total lift distance of 634.22 mm in the back step or Y direction, and in the forward step X or total horizontal movement reaches 322.41 mm. The distance to reach the lower limit of the hoper is 371.56 mm; the distance to reach the soil is 484.95 and the depth of the seedling into the ground about 100 mm.

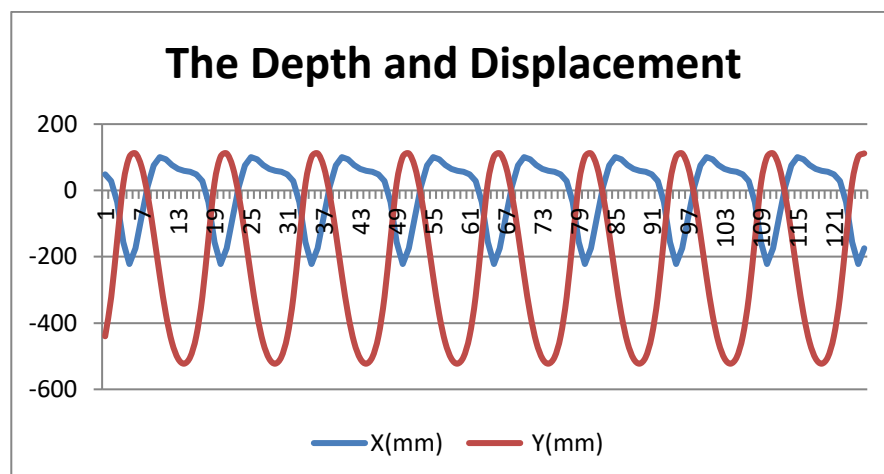


Figure 12 .the depth of planting and displacement of planting finger

#### 4. Conclusion

Determination and selection of alternative link bar dimensions that can provide smooth motion based on mathematical equations using Microsoft Excel software and according to the modelling and simulation with Solidworks Premium 2015 are L1, L2, L3 and L4 are 230.87 mm, 87 mm, 117.85 mm and 225.57 mm respectively. In addition, the motion of mechanism its performance to be able to take seeds from the hoper, carry and plug the aunt into the soil with a certain depth and cautiously moves

backwards to its initial position without damaging the rice seeds that have been plugged in. This movement must be the same for each step forward and backward.

The prototype that has been designed and simulated has a total lift distance of 634.22 mm in the back step or Y direction, and in the forward step X or total horizontal movement reaches 322.41 mm. The distance to reach the lower limit of the hopper is 371.56 mm; the distance to reach the soil is 484.95 and the depth of the seedling into the ground about 100 mm.

The four-link bar mechanism can be applied as a mechanism for rice planters on diesel engines 9.5 HP commonly used as a hand tractor with little modification of power and rotation. The prototype is equipped finger function growers collect the seeds from hopper, carrying, digging seedlings into the ground and moved mechanically to form the same locus with a row plant spacing of 200 x 200 mm and 250 x 250 mm and plant spacing in the column 200 x 200 mm and 250 x 250 mm with six planting fingers.

## 5. Acknowledgments

Appreciation and expression of highest gratitude to P2M leaders of the Lhokseumawe state polytechnic and to all colleagues who have provided support.

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