Pak. J. Agri. Sci., Vol. 59(3), 329-337 ;2022
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/22.794
http://www.pakjas.com.pk

Reverse design and analysis of gear five-bar planting mechanism based on agronomic requirement

Xu Hongzhen[1], Jiao Haobo[2,*], Liu Jiaodi[1,*] and Niu Zhenhua[1]

[1]College of Mechanical and Control Engineering, Guilin University of Technology, Guilin,541006, China; [2] School of Engineering and Technology, Southwest University, Chongqing, 400716, China
*Corresponding author's e-mail: 15022572215@163.com; shzdxljd@163.com

As crops have different agricultural requirements in pot seedling and the parameters of the planting mechanism need to be repeatedly designed, this paper proposed a reverse design method for the classic gear five-bar planting mechanism based on the agronomic requirements for pot seedling planting. The mathematical model of the planting trajectory of the geared five-bar planting mechanism was constructed through homogeneous coordinate transformation method,; the conditions for the geared five-bar planting mechanism to achieve zero-speed planting were: the gear ratio of the gear pair is -2, and the difference in length between the planetary gear rod and the sun gear rod is equal to the ratio of the planting distance to 2π. Based on the agronomic parameters of pot seedlings (planting depth, planting distance), the parameters of the geared five-bar mechanism were reversed to realize the reverse design of the geared five-bar planting mechanism. Field test results: the average planting depth of tomato pot seedlings is 47mm, the planting distance is 203mm, and the uprightness of pot seedlings is 97.5%, which meets the agronomic requirements of planting tomato pot seedlings. Therefore, the proposed reverse design method of geared five-bar planting mechanism based on agronomic requirements can solve the problem of repeated design of planting mechanism due to different agricultural parameters of most crops, which can greatly reduce the workload of designing various crop planting mechanisms.

Keywords: Reverse design; agricultural requirements; geared five-bar planting mechanism; zero velocity planting; pot seedling.

INTRODUCTION

It is urgent to realize the mechanization of pot seedling planting for China being a large agricultural country (Choi *et al.*, 2002; Yu *et al.*, 2011; Yu *et al.*, 2014). A number of researches were conducted on planting mechanisms. Some of the scholars analyzed the mechanism and optimized the parameters of rice seedling planting mechanisms. The obtained planting trajectory of rice planting helped to improve the quality of rice seedling planting (Bae, 2005; Yu *et al.*, 2012; Jin etal., 2013; Zhou *et al.*,2014; Liu *et al.*,2015; Zhao *et al.*,2016; Xin *et al.*,2017; Xu *et al.*,2020). Other scholars studied the seedling planting of tobacco and vegetables using non-circular geared five-bar mechanism and elliptic geared five-bar mechanism (Wu *et al.*, 2012; Wang *et al.*,2015; Wang *et al.*,2016; Wang *et al.*, 2021). These planting mechanisms are designed for specific planting distance and depth to achieve good planting performances. However, there are different varieties of crops for transplanting with different requirements in planting distance and depth. Therefore, it is important to design a specific planting mechanism with different structures and parameters to realize precise planting of pot seedlings with different requirements in planting distance and depth, which will increase the design workload of the planting mechanism dramatically. Zero-speed transplanting is the main indicator to measure the performance of the planting mechanism, which presents direct effects on the uprightness of the seedlings and the size of the hole (Chen *et al.*, 2011; Liu *et al.*, 2016; Zhao *et al.*, 2020). Geared five-bar planting mechanism as a classic planting mechanism, is widely used in transplanting machines for pot seedlings of rice, vegetables, tobacco, etc., such as the fitting gear five-bar rice pot seedling transplanting mechanism (Zhao *et al.*, 2016; Wang *et al.*, 2021), the deformed elliptical gear-double variable speed crank five-bar Salvia miltiorrhiza transplanting mechanism(Xu *et al.*, 2019), the hybrid-driven five-bar flower potted-seedling transplanting mechanism, etc. (Zhao *et al.*, 2017). This paper takes the classic planting mechanism gear five-bar planting mechanism as the research object, studies the theoretical

Hongzhen, X., J. Haobo, L. Jiaodi and N. Zhenhua. 2022. Reverse design and analysis of gear five-bar planting mechanism based on agronomic requirement. Pakistan Journal of Agricultural Science. 59:329-337.
[Received 7 Jul 2021; Accepted 2 Dec 2021; Published 27 Jun 2022]

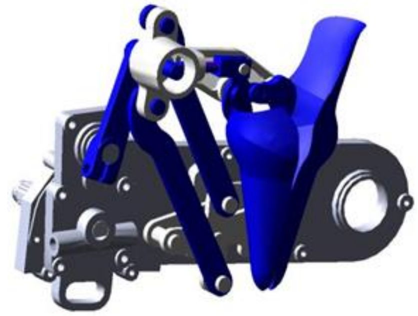
conditions satisfying zero velocity planting trajectory. Under the condition of specific planting distance and depth, the study aims to calculate the structural parameters of geared five-bar planting mechanism and make the design theory of zero velocity planting more generic. A design platform of geared five-bar planting mechanism using Visual Basic software is developed. This platform can solve the problem of redesigning the structural parameters of different planting mechanisms caused by different agronomic requirements in planting and can reduce the workload of designing planting mechanisms for various crops.

MATERIALS AND METHODS

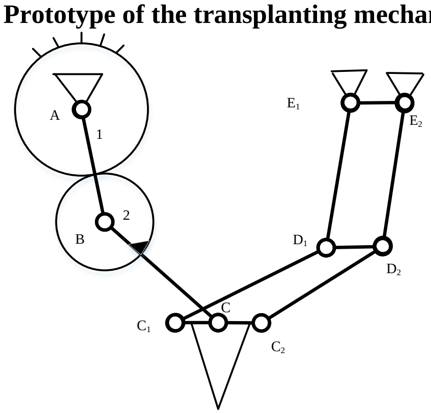
Theoretical analysis: The geared five-bar planting mechanism is a special five-bar mechanism, Fig. 1(a) shows the prototype of the planetary five-bar planting mechanism, and its principle is shown in Fig. 1(b). Sun gear I is fixed in Rack AE to keep the rack still. Planetary gear II is fixed in bar BC. bar AB rotates around Point A. bar BC rotates around Point B by the mesh of Gear I and Gear II. And bar BC drives other bars. As C_1D_1 is in parallel with C_2D_2, and D_1E_1 is in parallel with D_2E_2, C_1D_1 and C_2D_2 can be regarded as one moving part CD, and D_1E_1 and D_2E_2 can be regarded as one moving part DE. Totally the geared five-bar planting mechanism has 4 moving parts, 5 revolute pairs and 1 gear pair. The degree of freedom is 1. However, the degree of freedom of ordinary five-bar mechanism is 2, as shown in Fig. 1 (c). The reason for the difference is that the revolute pair A and revolute pair B of geared five-bar planting mechanism are restricted by gear pair, while ordinary five-bar mechanism doesn't have such restriction. The rotate speed ratio of bar AB to bar BC equals to the gear ratio of planet gear 2 to sun gear 1. Bar AB is called sun gear bar and bar BC is called planet gear bar.

The geared five-bar mechanism drives the planting nozzle to move in a certain trajectory and ensures that the planting nozzle moves in the same plane. Since the planting nozzle is fixed at point C, the movement trajectory of point C is completely consistent with the movement trajectory of the planting nozzle. For convenience, the geared five-bar planting mechanism is set equivalent to the ordinary five-bar mechanism with a linear relation between the rotate speed of Revolute Pair A and rotate speed of Revolute Pair B. The trajectory of point C is taken as the planting trajectory. The mathematical model of the planting trajectory (movement trajectory of point C) is established based on the movement mechanism of ordinary five-bar mechanism.

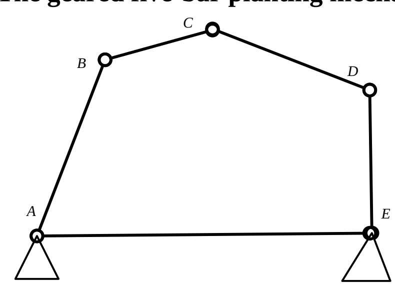
Static trajectory modeling: The bar lengths of sun gear bar AB and planet gear bar BC are concerned with the angular velocity of joint A and joint B, but not concerned with the lengths of bar CD, bar DE and bar AE. Therefore, the ordinary five-bar mechanism is divided into driving links and basic bar group, as shown in Fig. 2.



(a) Prototype of the transplanting mechanism

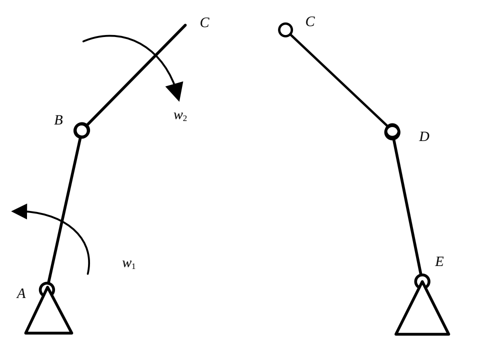


(b) The geared five-bar planting mechanism



(c) The ordinary five-bar mechanism

Figure 1. The principle of the geared five-bar planting mechanism



(a) Driving links **(b)** Basic bar group

Figure 2. Composition of the ordinary five - bar mechanism.

The driving link of ordinary five-bar mechanism is regarded as a mechanical arm with freedom degree of 2. Then, the mathematical model of planting trajectory is built using homogeneous coordinate transformation method. The coordinate system is shown as Fig. 3.

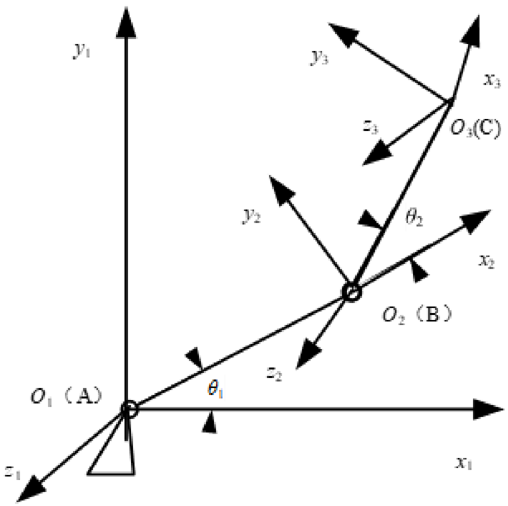


Figure 3. Movement coordinate system of geared five-bar planting mechanism

$O_1x_1y_1z_1$ is the frame coordinate; $O_2x_2y_2z_2$ is the coordinate of sun gear bar; $O_3x_3y_3z_3$ is the coordinate of planet gear bar; θ_1 is the initial angular displacement of sun gear bar AB; θ_2 is the initial angular displacement of planet gear bar BC.

The coordinate from point A to point C is changed into matrix T:

$$T=T_1T_2T_3T_4 \tag{1}$$

Where

$$T_1=\mathrm{Rot}(z_1,\alpha_1)=\begin{bmatrix} \cos\alpha_1 & -\sin\alpha_1 & 0 & 0 \\ \sin\alpha_1 & \cos\alpha_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

α_1 is the included angle between sun gear bar AB and bar AE, $\alpha_1= w_1t+\theta_1$, w_1 is the angular velocity of the revolute pair A, and θ_1 is the initial angular displacement of sun gear bar AB.

$$T_2=Tan\,s\,(l_1,0,0)=\begin{bmatrix} 1 & 0 & 0 & l_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where l_1 is the length of sun gear bar AB.

$$T_3=\mathrm{Rot}(z_2,\alpha_2)=\begin{bmatrix} \cos\alpha_2 & -\sin\alpha_2 & 0 & 0 \\ \sin\alpha_2 & \cos\alpha_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where α_2 is the included angle between sun gear bar AB and planet gear bar BC, $\alpha_2= w_2t+\theta_2$, w_2 is the angular velocity of revolute pair B, θ_2 is the initial angular displacement of planet gear bar BC.

$$T_4=Tan\,s\,(l_2,0,0)=\begin{bmatrix} 1 & 0 & 0 & l_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where l_2 is the length of planet gear bar BC.

The transformation matrix T is obtained through Formula (1).

$$T=\begin{bmatrix} \cos(\alpha_1+\alpha_2) & -\sin(\alpha_1+\alpha_2) & 0 & l_2\cos(\alpha_1+\alpha_2)+l_1\cos\alpha_1 \\ \sin(\alpha_1+\alpha_2) & \cos(\alpha_1+\alpha_2) & 0 & l_2\sin(\alpha_1+\alpha_2)+l_1\sin\alpha_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The coordinate of point C is (x,y,z), and the coordinate of point A is (0,0,0). The coordinate relation between point C and point A is:

$$[x \quad y \quad z \quad 1]^T = T[0 \quad 0 \quad 0 \quad 1]^T \tag{2}$$

Thus the following trajectory equation of point C is obtained according to Formula (1) and (2):

$$\begin{cases} x = l_2\cos(w_1t+w_2t+\theta_1+\theta_2)+l_1\cos(w_1t+\theta_1) \\ y = l_2\sin(w_1t+w_2t+\theta_1+\theta_2)+l_1\sin(w_1t+\theta_1) \\ z = 0 \end{cases} \tag{3}$$

Current researches showed that Y-shaped trajectory can realize zero velocity planting and ensure the upright degree of pot seedlings (Liu *et al.*,2016; Liu *et al.*,2017; Zeng et al.2018; Hu *et al.*,2018). Therefore, Y-shaped trajectory is regarded as the ideal trajectory model for the movement of point C, which is also a combined result of the spindle trajectory of geared five-bar planting mechanism and the linear movement of transplanter. The two focal points of the spindle trajectory are presented on y-axis. The mathematical model of the spindle trajectory is:

$$\begin{cases} x = b\sin\alpha \\ y = a\cos\alpha \end{cases} \tag{4}$$

where, a, b and θ represent the minor axis, the major axis and the angular displacement, respectively. The condition of focal points on y-axis is that the initial angle θ_2=0 and θ_1=π/2, thus Formula (3) is transformed into:

$$\begin{cases} x = -l_2\sin(w_1t+w_2t)-l_1\sin(w_1t) \\ y = l_2\cos(w_1t+w_2t)+l_1\cos(w_1t) \end{cases} \tag{5}$$

After analyzing Formula (4) and (5), the following relation can be obtained:

$$\theta = |w_1t+w_2t| = w_1t,\ \ w_2t=-2w_1t \tag{6}$$

And the following static trajectory model of point C of geared five-bar planting mechanism is obtained through Formula (5) and (6):

$$\begin{cases} x = (l_2-l_1)\sin(w_1t) \\ y = (l_2+l_1)\cos(w_1t) \end{cases} \tag{7}$$

where, $a=l_2- l_1$, $b=l_2+ l_1$. According to Formula (6), the gear ratio of w_2 to w_1 is -2. The static planting trajectory of geared five-bar planting mechanism is shown as Fig. 4.

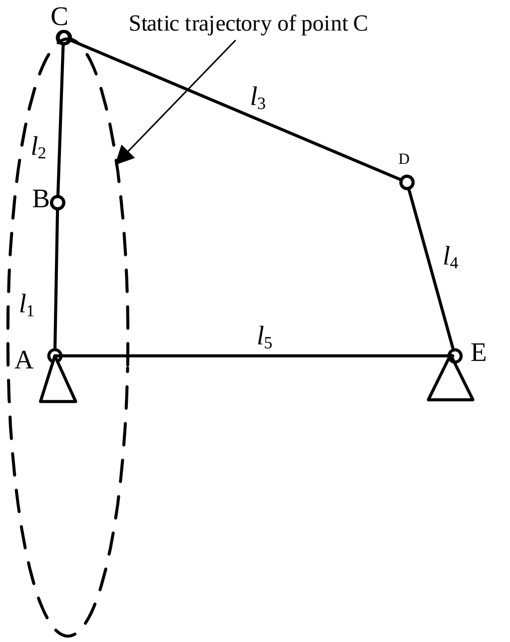


Figure 4. Static movement trajectory of geared five-bar planting mechanism

Movement trajectory modeling: The movement velocity of transplanter is v, so that the transplanter's linear equation is x_0=vt=w_0rt, w_0= $x_0/(rt)$, where r is the radius the forwarding wheel of the transplanter, and w_0 is the rotate speed of the forwarding wheel of the transplanter. The ratio of the forwarding wheel rotate speed of the transplanter to the rotate speed of gear 1 is i_{10}, w_1= $i_{10}w_0$, therefore w_1= i_{10} $x_0/(rt)$. One pot seedling is planted when the geared five-bar planting mechanism finishes one circle. So, when the forwarding wheel of the transplanter finishes one circle, the number of planted seedlings n will satisfy: n= i_{10}=2πr/d, where d is the planting distance. Hence, the movement trajectory equation of the planning mechanism is:

$$\begin{cases} x = (l_2 - l_1)\,sin(\,2\pi x_0/d) + x_0 \\ y = (l_2 + l_1)\,cos(\,2\pi x_0/d) + l_2 + l_1 \end{cases} \tag{8}$$

where, l_1+l_2 is the height of the bar AE from the ground. The lengths of sun gear bar AB and the planet gear bar BC (l_1 and l_2) have influence on the shape of the movement trajectory; l_1+ l_2 decides the height of the movement trajectory; and the planting distance d has influence on the change circle of the movement trajectory.

Theoretical condition of zero velocity planting trajectory: When planting pot seedlings, the planting trajectory should be kept as vertical as possible to the ground to ensure the upright degree of the seedling as the planting head plunges into the hole and pulls out, as shown in Fig. 5.

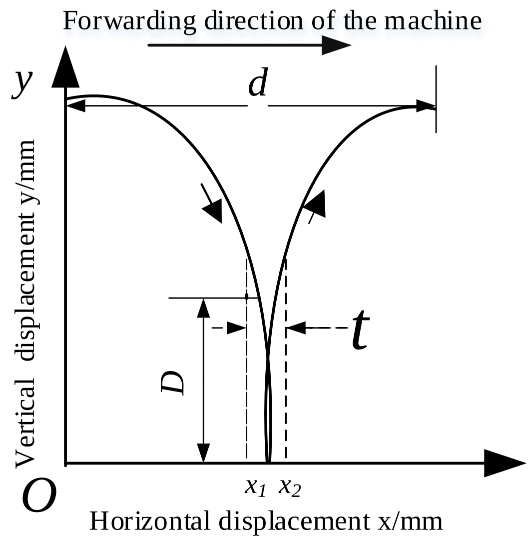


Figure 5. Ideal planting trajectory

D is the planting depth, d is the planting distance, x_1 is the hole entrance, x_2 is the hole exit, and t is the distance between the hole entrance and exit.

According to the movement equation, when y≤D, the planting trajectory should be kept as vertical as possible to the ground. The distance t between the hole entrance and the exit is used as the index of assessing the movement trajectory. The smaller the t, the smaller the diameter of the planting hole will be, which means more vertical planting trajectory, more upright seedlings and more ideal planting trajectory. From a mathematical point of view, the condition to realize zero velocity planting is: the horizontal displacement of the planting trajectory basically keeps unchanged, that is:

$$\lim_{x_0 \to d/2} \Delta x \to 0, dx \to 0 \tag{9}$$

Meanwhile, the vertical displacement changes as fast as possible and the trajectory rapidly moves the lowest level, that is:

$$\lim_{x_0 \to d/2} \Delta y \to \infty, dy \to \infty \tag{10}$$

According to Formula (8) – (10), the movement trajectory during the plunging process satisfies:

$$\lim_{x_0 \to d/2} \frac{dy}{dx} = \frac{dy/dx_0}{dx/dx_0} \to \infty$$

And the following relation can be obtained:

$$l_2 - l_1 = d/2\pi \tag{11}$$

When the planting depth is D, that is y=D, then the distance between the hole entrance and exit t= x_2- x_1. According to Formula (8), we can get:

$$\begin{cases} x_1=(l_2-l_1)\sin(\arccos(1\text{-}\frac{D}{l_2+l_1}))+\left[\pi\text{-}\arccos(1\text{-}\frac{D}{l_2+l_1})\right]\frac{d}{2\pi} \\ x_2=-(l_2-l_1)\sin(\arccos(1\text{-}\frac{D}{l_2+l_1}))+\left[\pi+\arccos(1\text{-}\frac{D}{l_2+l_1})\right]\frac{d}{2\pi} \end{cases}$$

$$t=\frac{d}{6\pi}(\arccos(1\text{-}\frac{D}{l_2+l_1}))^3 \quad (12)$$

Formula (11) has built a relation between planting distance and bar parameters. In order to realize the relation between planting depth and bar parameters of planting mechanism, we assume $t=kD$. The smaller the k, the shorter the distance t between hole entrance and exit will be, and the higher the planting quality will be (Wu *et al.,* 2012; Wang *et al.,*2016; Chen *et al.,* 2011). The designer only needs to establish the mathematical relationship between the agronomic parameters of the pot seedling planting and the parameters of the rods of the planting mechanism according to the agronomic requirements of the pot seedling planting hole and the planting depth. For example, the agricultural requirements of tomato-seedling planting include planting depth of 45mm (Zhao *et al.,* 2020), to realize high-quality planting, we assume $t=0.05D$, the planting hole will not be oversized. According to Formula (12) and l_2- l_1=$d/2\pi$, we can get:

$$l_1=\frac{0.5D}{1-\cos\sqrt[3]{\frac{0.3\pi D}{d}}}-\frac{d}{4\pi}$$

$$l_2=\frac{0.5D}{1-\cos\sqrt[3]{\frac{0.3\pi D}{d}}}+\frac{d}{4\pi}$$

According to the calculation based on the lengths of sun gear bar and planet gear bar, the planting trajectory model of the geared five-bar planting mechanism can be established as Formula (13):

$$\begin{cases} x=\frac{d}{2\pi}\sin(2\pi x_0/d)+x_0 \\ y=\frac{D}{1-\cos\sqrt[3]{\frac{0.3\pi D}{d}}}\left(\cos(2\pi x_0/d)+1\right) \end{cases} \quad (13)$$

Then a generic planting trajectory model of geared five-bar planting mechanism that satisfies zero velocity planting can be established according to the mathematical relation between parameters that satisfy the agricultural requirements of pot seedling planting and the parameters of planting mechanism bars.

Reverse analysis: As shown in Fig. 4, when the geared five-bar planting mechanism moves to the highest point, point A, point C and point E would form a right triangle, then:

$$(l_1+l_2)^2+l_5^2=\mathrm{AE}^2<(l_3+l_4)^2 \quad (14)$$

In order to keep the movement of the geared five-bar planting mechanism away from the mid-gear, the sum of l_3 and l_4 is much larger than the sum of l_1, l_2 and l_5(Li *et al.,* 2005; Fang *et al.,* 2006; Ma *et al.,* 2013; Tao *et al.,* 2014). The process of using Formula (14) to solve the lengths relation is quite complicated, so this paper adopted pantography of the formula to conduct an approximate treatment, as shown in Formula (15).

$$l_1+l_2+l_5<l_3+l_4 \quad (15)$$

By analyzing the above conditions, taking l_1 and l_2 as the basic rod group, to satisfy the above relation, the parameter relation between the five gear bars is constructed as following: l_3=1.4 (l_1+ l_2), l_4=1.5 (l_1+ l_2), l_5=1.3 (l_1+ l_2).

Based on the relation between the five bar and the planting depth and planting distance, the following relation between the bar parameters and the planting depth and distance is obtained, and the parameter design of the geared five-bar mechanism satisfying agricultural requirements is realized.

$$\begin{cases} l_1=\frac{0.5D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}}-\frac{d}{4\pi} \\ l_2=\frac{0.5D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}}+\frac{d}{4\pi} \\ l_3=\frac{1.4D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}} \\ l_4=\frac{1.5D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}} \\ l_5=\frac{1.3D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}} \end{cases}$$

The planting speed can be obtained by taking the derivative of Formula (13) based on bar parameters l_1, l_2, and $x_0=vt$, as shown in Formula (16):

$$\begin{cases} v_x=v\,cos(2\pi vt/d)+v \\ v_y=-\frac{D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}}\frac{2\pi v}{d}sin(2\pi vt/d) \end{cases} \quad 16)$$

Then the planting accelerated velocity can be obtained by taking the derivative of planting trajectory Formula (16), as shown in Formula (17):

$$\begin{cases} a_x=-\frac{2\pi}{d}v^2\,sin(2\pi vt/d) \\ a_y=-\frac{D}{1-cos\sqrt[3]{\frac{0.3\pi D}{d}}}\left(\frac{2\pi v}{d}\right)^2 cos(2\pi vt/d) \end{cases} \quad (17)$$

According to Formula (16) and (17), the movement velocity and accelerated velocity of the geared five-bar planting mechanism are all concerned with the forwarding velocity v of the transplanter. The larger the v, the larger the movement velocity and accelerated velocity will be. Besides, both the planting velocity and the accelerated velocity vary sinusoidally, which can avoid the impact from the movement during the planting process and can improve the stability of the geared five-bar planting mechanism.

Development and application of design platform: The parameters, planting static trajectory, movement trajectory, velocity and accelerated velocity of geared five-bar planting mechanism are programmed using Visual Basic software to develop a design platform for the geared five-bar mechanism, as shown in Fig.6.

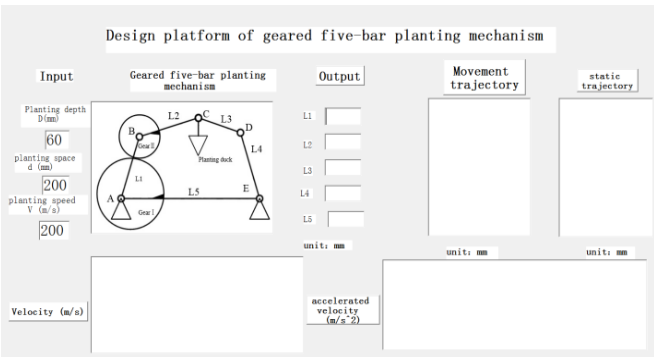


Figure 6. Design platform of geared five-bar planting mechanism

After inputting the planting depth, planting distance, and the forwarding speed of transplanter, the design platform would rapidly output the bar parameters, static trajectory, movement trajectory, velocity variation curve and accelerated variation law of the mechanism. The design platform can effectively improve the efficiency of designing geared five-bar planting mechanism and solve the repeated design problem of parameters of planting mechanisms.

Platform test: This paper took the tomato-seedling planting mechanism as the example to testify the validity of the designing process of the platform. The agricultural requirements of tomato-seedling planting include planting depth of 45mm and planting distance of 200mm.

***High speed photography test*:** These parameters obtained from the platform are used to establish a 3D model for tomato-seedling planting mechanism and a prototype was made. A high-speed photography analysis system (CPL-MS70K, Canada) was used to photograph the movement process of the duckbill tip planted by the gear five-bar planting mechanism, the shooting frequency was 800 frames/s, and the high-speed photography image was analyzed by Blasters MAS.

***Field test*:** Field test was conducted according to the Chinese dryland planting machinery standard (JB/T10291-2013), as shown in Fig.7. The parameters of transplanting experiments in the field were set as Table 1.

Field work

Measuring the uprightness

Measuring the planting depth

Figure 7. The field test

Table 1. Parameters of seedling transplanting experiments in field

Parameters	Values
The variety of tomato seedlings	Shihong 303
Seedling age (d)	50
The moisture content of pot seedling soil (%)	60-72
Seedling average height (mm)	150
The number of transplanted seedlings	512
The forwarding speed of the planting mechanism (km/h)	0.72
the rotate speed of the planting mechanism /min	60

RESULTS

***Platform analysis*:** When inputting the agricultural requirements into the design platform of geared five-bar planting mechanism, the planting trajectory can be obtained through the movement trajectory button and the static trajectory button, and the bar parameters of the geared five-bar planting mechanism can be obtained through the output button. Fig.8 shows that the bar parameters of tomato-seedling geared five-bar planting mechanism are: l_1=114mm, l_2=146mm, l_3=365mm, l_4=391mm, l_5=339mm.

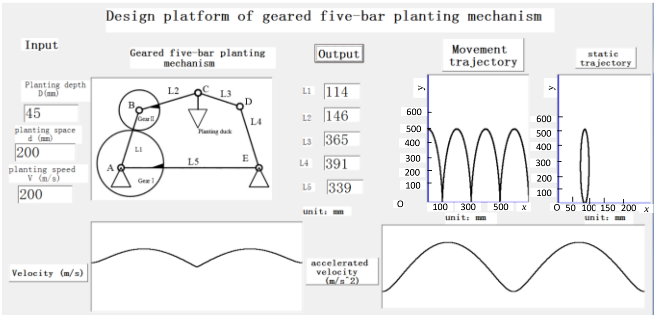


Figure 8. **Design of the tomato-seedling planting mechanism**

***High speed photography analysis*:** Obtained the movement trajectory of the point C of the duckbill tip as shown in the Fig.9, the trajectories of the platform and the high speed photography are basically the same.

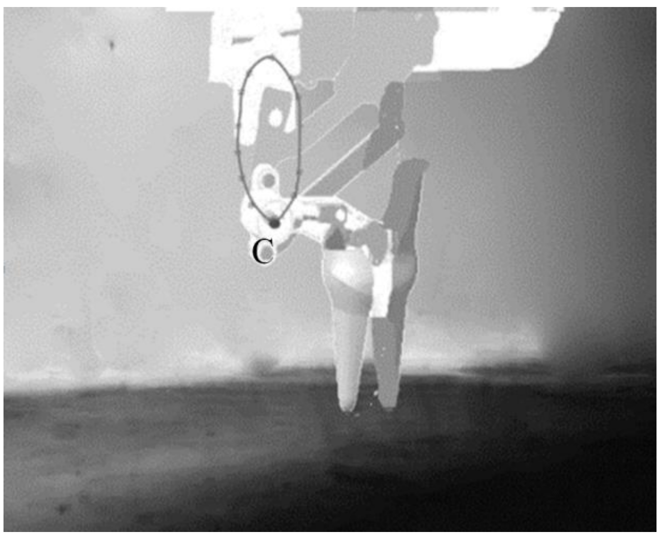


Figure 9. **High speed photography test of the static movement trajectory of the tomato-seedling planting mechanism**

***Field test results*:** The results indicate that the parameters in Table 2 could meet the agronomic requirements. No damage to the pot seedlings was detected. Since the experimental filed was not particularly flat, the planting depth was changeable in a small scope. Besides, the cave diameter was rather small and the seedling perpendicularity can reach up to 97.5%.

Table 2. Results of field test.

Testing index	Avg. planting depth (mm)	Avg. planting distance (mm)	Vertical rate (%)
Index value	47	203	97.5%

DISCUSSION

The lengths of sun gear bar AB and the planet gear bar BC (l_1 and l_2) have influence on the shape of the movement trajectory; $l_1 + l_2$ decides the height of the movement trajectory; and the planting distance d has influence on the change circle of the movement trajectory.

This paper reversely calculated the parameters of geared five-bar mechanism, given the planting distance t and depth D the known condition. During the calculation, the relation between hole entrance and exit positions and the planting depth were constructed, $t = kD$, which made it possible for reverse calculation.

The movement velocity and accelerated velocity of the geared five-bar planting mechanism are all positively concerned with the forwarding velocity v of the transplanter. Besides, both the planting velocity and the accelerated velocity vary sinusoidally, which can avoid the impact from the movement during the planting process and can improve the stability of the geared five-bar planting mechanism.

After inputting the planting depth, planting distance, and the forwarding speed of transplanter, the design platform would rapidly output the bar parameters, static trajectory, movement trajectory, velocity variation curve and accelerated variation law of the mechanism. The design platform can effectively improve the efficiency of designing geared five-bar planting mechanism and solve the repeated design problem of parameters of planting mechanisms.

During the field test of the planting mechanism designed by the platform, when the hole size cannot satisfy the designing requirement, the planting depth and the installation height of the planting mechanism to the ground can be increased to reduce the hole size.

The time that the transplanter moves forward to finish planting a pot seedling is the same as the movement cycle of the gear five-bar planting mechanism, i.e. the relation between the rotate speed w_1 of the sun gear bar AB and the forward velocity v of the transplanter is: $v=d/(2\pi)w_1$. This relation can help to solve the low matching degree problem between rotate speed of planting mechanism and the forwarding velocity of transplanter.

***Conclusion*:** The conditions for geared five-bar mechanism to realize zero velocity planting were: the transmission ratio of gear pair is -2; the planet gear bar l_2, sun gear bar l_1 and planting distance d satisfy $l_2 - l_1 = d/2\pi$. Under the condition of Y-shaped planting trajectory, the relationship between the hole entrance and exit and the planting depth was established to narrow the hole size and reduce the seedling exposure rate. The parameters of the geared five-bar mechanism was obtained through the agronomic parameters (planting depth and planting distance) of the seedlings to realize the, reverse design of the bar parameters of the geared five-bar planting mechanism.

The developed parameter design platform can shorten the reverse solution of the parameters of the gear five-bar planting mechanism and solve the problem of repeated design of the planting mechanism due to different agronomic requirements of crop planting, thus realizing the rapid design of planting mechanism to satisfy different agronomic requirements.

The field tests of the gear five-bar planting mechanism based on tomato planting agronomic parameters reverse design showed that the average planting depth of tomato pot seedlings was 47 mm, and the planting distance was 203 mm, which met the agronomic requirements for planting tomato pot seedlings. The pot seedlings' uprightness reached 97.5% and the exposed seedling rate was only 0.3%. Insufficient flatness of the test field was the main reason for the exposed seedlings.

***Authors Contributions statement*:** All authors contributable equally.

Conflict of interest: No

***Acknowledgement*:** This work was supported by the National Natural Science Foundation of China (Grant No.51565048), the Natural Science Foundation of Guangxi province (No. 2021JJA160046), and the Middle-aged and Young Teachers' Basic Ability Promotion Project of Guangxi (No. 2020KY06020) The authors thank the anonymous reviewers for their constructive suggestions on the paper.

REFERENCES

Bae, K.Y. 2005. Design of a rice transplanting mechanism with noncircular planetary-gear-train system. J. Korean Soc. Prec. Eng. 22:108-116.

Choi, W.C., D.C. Kim and I.H. Ryu. 2002. Development of a seedling pick-up device for vegetable transplanters. Transactions of the ASAE. 45:13-19.

Chen, J.N., B.H. Wang, X. Zhang, G. Y. Ren and X. Zhao. 2011. Kinematics modeling and characteristic analysis of multi-linkage transplanting mechanism of pot seeding transplanter with zero speed. Transactions of the CSAE. 27: 7-12.

Fang, F. 2006. System of path generator for gear five-bar mechanism. Mach. Man. Res.35:59-61.

Hu, J.P., J. Pan, C.D. Zhang, S.W. Zhang, W.Z. Fei and H.R. Pan. 2018. Motion analysis and experiment planting mechanism with planetary gears of transplanting machine. Transactions of the CSAM.49:78-86.

Jin, X.P., X.L. Wang, E.R, Mao and Z.H. Song. 2013. An expert system for aided design of rice transplanter chassis systems. Adv. Mat. Res. 2300:1710-1713.

Li, X.G., Y.Q. Huang and L.Y. Feng. 2005. Study of the and necessary conditions for existence of double crank of planar five-bar mechanism. Mech. Sci. Tech. 24:51-53.

Liu, J.D., W.B. Cao, D.Y. Tian and H.Z. Zhao. 2017. Kinematic analysis and test on transplanting mechanism with effective zero-speed transplanting on mulch film. J. Mech. Eng.53:76-84.

Liu, J.D., W. B. Cao, D. Y. Tian, H. Y. Tang and H.Z. Zhao. 2016. Kinematic analysis and experiment of planetary five-bar planting mechanism for zero-speed transplanting on mulch film. Int. J. Agric. & Biol. Eng. 9:84-91.

Liu, X.L. 2015. Optimal design and experimental study of rice pot seedling and wide-narrow distance transplanting mechanism. Ph.D. diss., Zhejiang Sci-Tech Univ., Hangzhou, China. 26-29.

Ma, L. and N. Shi. 2013. Gear-5-bar combination mechanism's kinematics characteristic simulation. J. Xi'an Univ. Sci. Tech. 33:727-730.

Tao, J., R. Zhang and C. Liu. 2014. Study on the method of realizing preconceived track by geared five-bar mechanism. Sci. Tech. Innov. Herald. 11:29-31.

Wang, Y., J.N. Chen, X. Zhao and X.C. Sun.2015. Parameter optimization and experiment of planting mechanism driven by planetary non-circular gears. Transactions of the CSAM.46:85-93.

Wang, Y.W., Y.H. Tang, J. Wang and S.M. Chen. 2016. Parameter optimization for dibble-type planting apparatus of vegetable pot seedling transplanter in high-speed condition. Transactions of the CSAE.47:91-100.

Wang, L., L. Sun, H.M. Huang, Y.X. Yu and G.H. Yu. 2021. Design of clamping-pot-type planetary gear train transplanting mechanism for rice wide-narrow-row planting. Int J Agric & Biol Eng. 14:62-71.

Wu, W., S. L. Sun, M.T. Xiao and J. Z. Li. 2012.Optimization design for planter of 2ZY-1 tobacco transplanting machine. Chin. J. Con. Mach. 10:166-170.

Xin, L. , M.L. Zhou, W. Wang, M. Zhou and Y. Zhao, 2017. Optimal design and development of a double-crank potted rice seedling transplanting mechanism. Transactions of the ASABE. 60:31-40.

Xu, G.W., H.X. Liu, A.C. Farman, H.M. Fang, S.C. Jiang and T.F. He. 2019. Design and test of tilted transplanting mechanism on mulch-film of Salvia miltiorrhiza. Transactions of the CSAM. 50:78-89.

Xu, C.L., Y.L. Shan, L. Xin, J.T. Xie, Z. Li and Y. Zhao. 2020. Design and experiment of high-speed rice transplanter with Extensible Mulch Cutting Mechanism in Mulching Cultivation System. Transactions of the CSAM. 51:79-87.

Yu, G.H., C.W. Chen, L. Sun, L.G. Qiu and Y. Zhao. 2012. Design and optimization of backward rotary transplanting mechanism in wide narrow row planting. Transactions of the CSAM. 43:50-56.

Yu, X.G., W.S. Yan and C.Y. Wu. 2011. Research and development status of the oilseed rape transplanter in China and improvement of clip-chain trans-planter. J. Agri. Mech. Res. 33:232-234.

Yu, X.X., Y. Zhao, B.C. Chen, M.L. Zhou, H. Zhang and Z.C. Zhang. 2014. Current situation and prospect of transplanter. Transactions of the CSAM. 45:44-53.

Zeng, B., L.Z. Quan, J. Tong, J. Ye and D. Y. Xue. 2018. A new approach based on central composite design and multi-objective optimization for design of a roller-mill mechanism in a maize stubble harvester. Int. J. Adv. Man. Tech. 94:4329-4342.

Zhao, X., H.Y. Cui, L. Dai, Y.D. Xu, C. Wang and J. Shen. 2017. Optimal design and experiment of hybrid-driven five-bar flower potted-seedling transplanting mechanism. Transactions of the CSAE. 33:34-40.

Zhao, Y., H.X. Zhu, L. Xin, M.L. Zhou, J. Feng and M. Zhang. 2016. Mechanism analysis and experiment of transplanting mechanism with fitting gear five-bar for rice pot seeding. Transactions of the CSAE. 32:12-21.

Zhao, X., J. Ye, M.Y. Chu, L. Dai and J.N. Chen. 2020. Automatic scallion seedling feeding mechanism with an asymmetrical high-order transmission gear train. Chin. J. Mech. Eng. 33:148-161.

Zhou, M., L. Sun, X. Du, Y. Zhao and L. Xin. 2014. Optimal design and experiment of rice pot seedling transplanting mechanism with planetary Bezier gears. Am. Soc. Agric. Biol. Eng. 57:1537-1548.