Creative Design of a Straightline Intermittent Reciprocator

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Abstract

The traditional straightline intermittent reciprocator has only one motion curve. By applying the TRIZ contradiction table to select proper innovative principles, we design a straightline intermittent reciprocator with a polytropic motion curve that possesses the function of variable velocity power source, under the condition of fixed velocity power source. With the Scotch-Yoke as the original mechanism, by modifying its slider and adopting the method of applying the rocker axis of rotation in a set of crank rocker four-link mechanism, we design a straightline reciprocator that possesses such variable motion curves as the variable straightline reciprocating motion, the straightline one-way variable intermittent reciprocating motion, and the straightline two-way variable intermittent reciprocating motion. In addition, by applying the BASIC program language to develop the mechanism design software, we quickly obtain the optimal design plan of the straightline intermittent reciprocator, and by means of the instance design and prototype manufacturing, proves that the achievements of our research may not only provide reference for the design of such mechanisms as the bias cutter, the surface glue cutter, and the punch fast feeder and discharger for the rubber industry, but also be used as the teaching materials and aid for the mechanism creative design.

Keywords: straightline intermittent, reciprocator, TRIZ, contradiction table.

I. Introduction

The straightline intermittent reciprocator is widely used in all kinds of machines, among which are commonly found the following [1-2]: cam, driven follower mechanism as shown in Figure 1, swaying motor, gear and rack combined mechanism as shown in Figure 2, chain and slider drive mechanism as shown in Figure 3. In the literatures about the straightline motion mechanism, Tsai [3] develops cam systems by using the linear motor to produce the straightline motion, since its input signal is periodic, this research makes use of the repetition control theory to design the servo control and improve its feature of output response for the purpose of lowering the steady-state error. Guan and Hsu [4] carries out a discussion on a transmission mechanism that can control the cup action by using the vacuum suction cup to suck both sides of the bag surface, the combination and analysis technology of the bag opening mechanism that can make the straightline motion and reverse motion. Mou [5] explores the creative improvement on the mechanism, efficiency and dimensions of each part of a connector by using the related theories of mechanism design, mechanics and material analysis, and 3D drawing simulation software. Wu *et al.* [6] use the sensor and A/D transducer, display the related time sequence on the PC of the straightline intermittent motion system, straightline reciprocating motion mechanism system, cyclic reciprocating motion mechanism system, straightline reciprocator system, automatic tracking installation system, etc. to help the students understand the actual velocity of the control signal of the mechanism motion and the condition of its displacement variation, and promote the learning effect of the students by showing them the cooperation between different mechanism motions who are learning the automatic machine design. Shih and Ma [7] under the condition of lower cost, apply the fuzzy PWM control method to explore the effective orientation control of the pneumatic cylinder making a straightline motion. Yan [8] applies the connection of N pneumatic cylinders to obtain 2^N methods of the stepping straightline motion orientation, all these are plans that make an effective use of the straightline motion in the field of mechanical design.

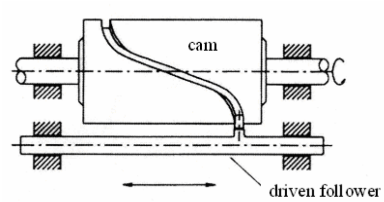

Fig.1　Cam , driven follower mechanism [1]

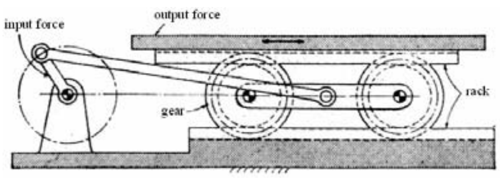

Fig.2　Swaying motor, gear and rack combined mechanism [2, p.150]

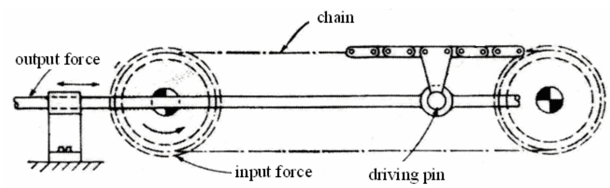

Fig.3　Chain and slider drive mechanism [2, p.77]

With the Scotch-Yoke as the original mechanism [9], as shown in Figure 4, by applying the TRIZ theory to select proper innovative principles, we modify the slider in the Scotch Yoke, and makes use of a set of crank rocker four-link mechanism [10-15], characterized by its rocker axis of rotation with a variable swaying angle displacement and swaying angular velocity, to design a straightline reciprocator that possesses such variable motion curves as the variable straightline reciprocating motion, the straightline one-way variable intermittent reciprocating motion, and the straightline two-way variable intermittent reciprocating motion. In addition, by applying the BASIC program language to develop the mechanism design software, we quickly obtain the optimal design plan of the straightline intermittent reciprocator, and make the plan into a prototype to prove the feasibility and practicability of our research.

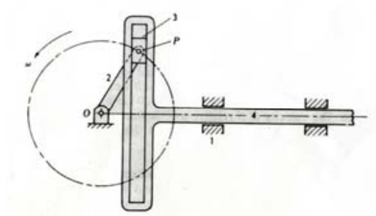

Fig.4 Scotch-Yoke mechanism [9]

II. Design theory

2-1 Creative design principles [16, 17]

In order to achieve the goal of straightline intermittent reciprocator motion under the condition of fixed velocity power source, it must use the Scotch Yoke. Though the Scotch Yoke can provide the straightline reciprocator motion, it may also cause the motion curve to be exclusive. The cause-and-effect linkage graph is shown in Figure 5, and the problem statements are developed as follows:

1a. Find an alternative way of (fixed velocity power source) that provides (the Scotch Yoke).

1b. Find a way to enhance (fixed velocity power source).

2a. Find an alternative way of (Scotch Yoke) that provides (straightline reciprocating motion) under the condition of (fixed velocity power source) that does not cause [motion curve exclusive].

2b. Find a way to enhance (Scotch Yoke).

2c. Find a way to resolve contradiction: (Scotch Yoke) should provide (straightline reciprocating motion), and should not cause [motion curve exclusive].

3a. Find a way to eliminate, reduce or prevent [motion curve exclusive] under the condition of (Scotch Yoke).

3b. Find a way to benefit from [motion curve exclusive].

4a. Find an alternative way of (straightline reciprocating motion) that does not require (Scotch Yoke).

4b. Find a way to enhance (straightline reciprocating motion).

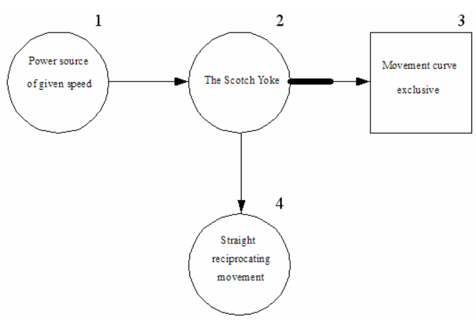

Fig.5 Cause-and-effect linkage graph

The 2nd node in the linkage graph is a contradiction point, according to which we choose 4 groups of proper parameters:

(1) Wanting to improve the velocity of straightline reciprocating motion — parameter 9 (velocity), but not to change the durability of part — parameter 15 (durability of moving object).

(2) Wanting to improve the complexity of straightline intermittent reciprocating motion control — parameter 37 (complexity of control), but not to change the convenience of the mechanism — parameter 33 (convenience of use).

(3) Wanting to improve the complexity of straightline intermittent reciprocating motion — parameter 36 (complexity of device), but not to change the durability of part — parameter 15 (durability of moving object).

(4) Wanting to improve the complexity of straightline intermittent reciprocating motion control — parameter 37 (complexity of control), but not to change the velocity of mechanism power source — parameter 9 (velocity).

By choosing the above 4 groups of parameters, we can obtain the contradiction table, as shown in Figure 6. By means of the contradiction table, the solution principles can be gotten, among which principles 3, 4, 5, and 35 appear most frequently, twice for each. And the following is the discussion on the solution plans of principles 3, 4, 5, and 35:

(1) Principle 3 — Local quality: this principle does not suitable for our problem, so it is not considered in the problem solving.

(2) Principle 4 — Asymmetry: we apply the example of principle 4 of TechOptimizer [18] to work out the problem, by modifying the Scotch Yoke to make its motion not symmetric in motion and thus obtain the straightline intermittent reciprocating motion.

(3) Principle 5 — Combining: we apply the example of principle 5 of TechOptimizer [18] to work out the problem, by combining the crank rocker four-link mechanism and the Scotch Yoke, that is to use the crank rocker four-link mechanism characterized by the variable angular velocity rocker axis of rotation to drive the modified Scotch Yoke to change the motion curve of each stroke of the straightline intermittent reciprocating motion, make the slider driven followers to make different motions to correspond with different design conditions, and thus obtain the better consecutive motion curve for the slider driven followers.

(4) Principle 35 — Transformation of physical and chemical states of an object: this principle does not suitable for our problem, so it is not considered in the problem solving.

	Undesired Result / Feature to Change	1	…	9	15	…	33
		Weight of moving object	…	Speed	Durability of moving object	…	Convenience of use
1	Weight of moving object						
…	…						
9	Speed				3,19 35,5		
…	…						
36	Complexity of device				10,4 28,15		
37	Complexity of control			3,4 16,35			2,5

Fig.6　Contradiction table

2-2 Mechanism design theory

To combine the solution plans of principle 4 and principle 5, we design a straightline reciprocator that is made up of a crank rocker four-link mechanism, an enlarged drive gear set, and the modified Scotch Yoke. The mechanism sketch is shown in Figure 7, where the crank axle O_2 acts as the power source, the rocker axis of rotation O_4 passes the swaying motion to the gear set and enlarges the swaying angle displacement, and, with this swaying motion of the angular velocity, to drive the modified Scotch Yoke, and the straightline intermittent reciprocating motion is also obtained of the slider driven follower making the better motion curve.

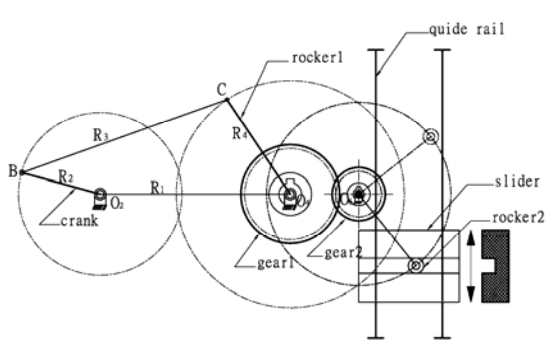

Fig.7　Sketch of the straightline intermittent reciprocator

2-2-1 Crank rocker four-link mechanism

The crank rocker mechanism must attain a particular input relationship, as shown in Figure 8. The crank swaying angle displacement θ, relative position of each link and relationship of each link length are described as follows:

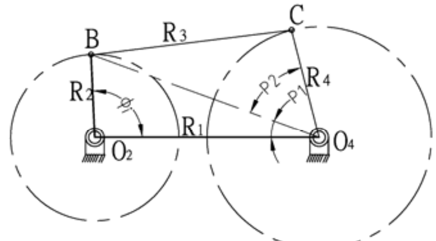

Fig.8　Crank rocker mechanism

Suppose the lengths of fixed link $\overline{O_2O_4}$, crank $\overline{O_2B}$, connected link $\overline{BC}$, and rocker $\overline{CO_4}$ respectively are R_1, R_2, R_3, R_4. And suppose the rocker beginning swaying angle θ_1 and ending swaying angle θ_2 are known, the swaying angle displacement $\theta = \theta_2 - \theta_1$, as shown in Figure 9. Set the lengths of R_1 and R_4 at random, and $C = R_1 / R_4$, then the smaller value C is, the more apparent is the phenomenon of the rocker's quick-return.

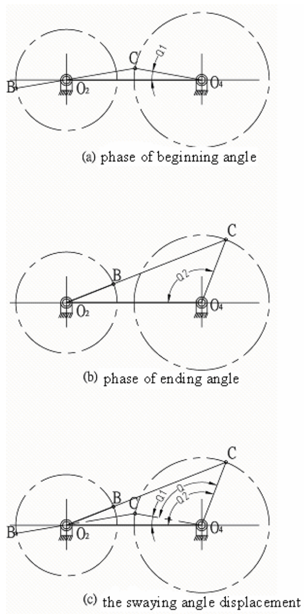

Fig.9 The feature phases of the crank rocker mechanism

From the feature phases of the crank rocker mechanism in Figure 9, and by applying the cosine theorem, we obtain the lengths of R_2, R_3:

$$(R_3 - R_2) = \sqrt{R_1^2 + R_4^2 - 2 \times R_1 \times R_4 \times \cos\theta_1} = A \tag{1}$$

$$(R_2 + R_3) = \sqrt{R_1^2 + R_4^2 - 2 \times R_1 \times R_4 \times \cos\theta_2} = B \tag{2}$$

Add equation (1) to equation (2), and work out the simultaneous equations, we obtain:

$$R_3 = (A + B)/2 \tag{3}$$

$$R_2 = B - [(A + B)/2] \tag{4}$$

Work out the relative motion between crank and rocker:

(a) By applying the cosine theorem to work out the length of the auxiliary line BO_4 in Figure 8, we obtain:

$$BO_4 = \sqrt{R_1^2 + R_2^2 - 2\times R_1 \times R_2 \times \cos\phi_i} \tag{5}$$

Among which ϕ_i is the phase angle of rocker BO_2.

(b) By applying the sine theorem, we obtain:

$$\frac{\sin P_1}{R_2} = \frac{\sin\phi_i}{\overline{BO_4}} \Rightarrow \sin P_1 = \frac{R_2 \times \sin\phi_i}{\overline{BO_4}} \tag{6}$$

Therefore, the instantaneous phase angle P_1 is:

$$P_1 = Sin^{-1}\left(\frac{R_2 \times \sin\phi_i}{\overline{BO_4}}\right) \tag{7}$$

(c) By applying the cosine theorem, we obtain:

$$R_3^2 = \overline{BO_4}^2 + R_4^2 - 2\times \overline{BO_4} + R_4 \times \cos P_2 \tag{8}$$

Therefore, the instantaneous phase angel P_2 is:

$$P_2 = Cos^{-1}\left(\frac{R_4^2 + \overline{BO_4}^2 - R_3^2}{2\times \overline{BO_4} \times R_4}\right) \tag{9}$$

From equation (7) and equation (9), we obtain P_1 and P_2, and after inputting the fixed velocity in different phases, we obtain the rocker instantaneous phase angle of the variable velocity output.

2-2-2 Enlarged drive gear set

As shown in Figure 7, rocker $\overline{CO_4}$ only sways less than 180∘ , and to make the slider obtain the maximum intermittent pause time while moving between two dead point phases, an enlarged gear set must be used, that is gear 1 and gear 2, will enlarge the swaying angle θ_i of the small gear axle O_6, and the largest range of enlarged motion is $180° < \theta_i < 540°$.

2-2-3 Modified Scotch Yoke

In order to make the slider driven follower to make the straightline intermittent reciprocating motion, we modify the Scotch Yoke, whose mechanism sketch is shown in Figure 10. When rocker (part 2) makes the motion of swaying in the upper semicircle, it can drive slider driven follower (part 4) to make the left-to-right straightline reciprocating motion; in the lower semicircle, slider driven follower keeps stationary.

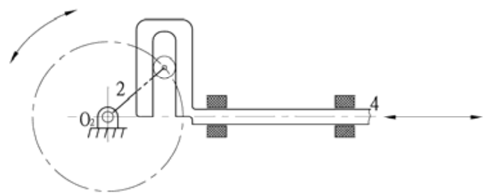

Fig.10　Sketch of the modified Scotch Yoke

III. Computer-aided mechanism design software

With the above stated mechanism design theory, we apply the BASIC software language to develop the mechanism design software, so as to obtain the optimal design plan for the straightline reciprocator. The program contents are included in the appendix, and the program operating steps are as follows:

(1) Input $R_1, R_4, \theta_1, \theta_2$, the program performs the dynamic simulation of the crank rocker four-link mechanism for a round, as shown in Figure 11. Then input the value of 1, and press Enter, the program will perform anew the dynamic simulation for a round. If input Enter, the program will print out the length of each link and the figure of the rocker swaying angle displacement, as shown in Figure 12.

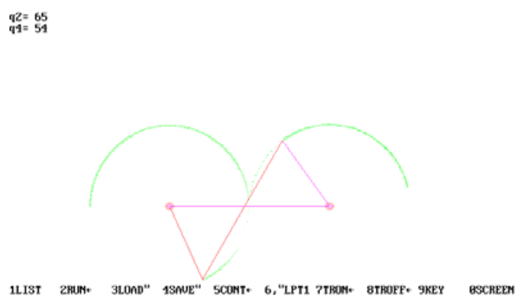

Fig.11　Dynamic simulation of the crank rocker four-link mechanism

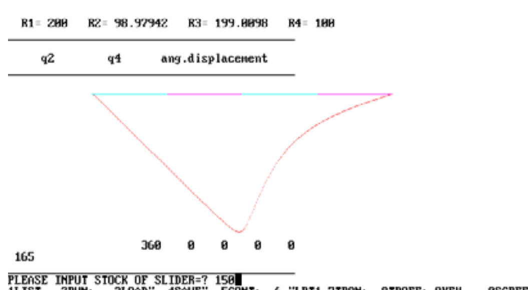

Fig.12　The rocker swaying angle displacement

(2) Input slider motion stroke, the computer will print out the maximum swaying angle displacement of the slider driven follower staying on both ends.

(3) Input the left stay swaying angle displacement of the slider driven follower, then, there will appear the dynamic simulation process of the slider driven follower and its motion displacement diagram, and will print out the 4 time distribution proportions of the slider driven follower staying left, moving from left to right, staying right, and moving from right to left, and the data total 360∘ , which is the value of the motor drive crank rotating for a round, as shown in Figure 13.

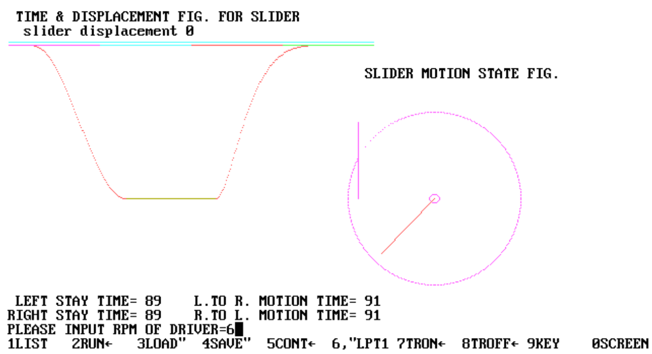

Fig.13 Dynamic simulation of the driven follower

(4) Input RPM of the driver, and print out the motion time of the slider driven follower when crank axle rotating for a round, as shown in Table 1.

Table 1 Time of the slider driven follower

Motion time	**Deg.**
Left stay time = 2.472222 sec	89º
L. to R. motion time = 2.527778 sec	91º
Right stay time = 2.472222 sec	89º
R. to L. motion time = 2.527778 sec	91º

IV. Application instance

4-1 Design requirements

We suppose the design requirements for a slider to become a straightline reciprocator are as followers:

(1) The straightline reciprocating motion stroke is 150 *cm*.

(2) One motion condition of the slider is: the time is equivalent between the four stages of staying left, moving from left to right, staying right, and moving from right to left.

(3) Another motion condition of the slider is: the quick-return straightline

intermittent reciprocating motion that has the same time of staying left and staying right.

4-2 Optimal design plan

According to the above design requirements, perform the software designed in this paper, we obtain the optimal design plan of the straightline reciprocator. The steps are stated as follows:

(1) According to the mechanism design and space requirement, input in order by means of the trail and error approach: $R_1 = 100$, $R_4 = 50$, $\theta_1 = 1$, $\theta_2 = 121$, we obtain the length of each link and the figure of angle displacement, as shown in Figure 14.

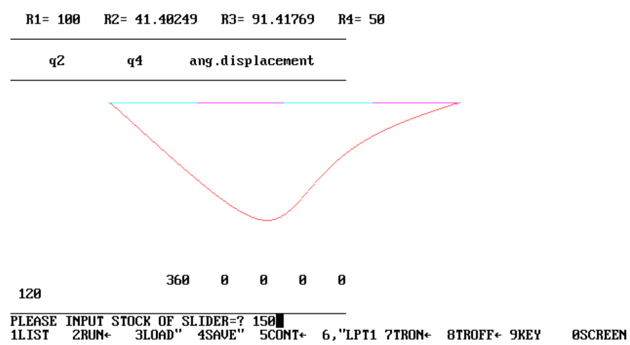

Fig.14 The length of each link and figure of angle displacement

(2) Input slider straightline reciprocating motion stroke, 150 *cm*.

(3) Input the rocker rotation angle 20° for the slider to stay left.

(4) Input RPM of crank axle = 6, we obtain the result as shown in Table 2, but the result does not correspond with the design requirements in the 2nd item, section 4-1 in this paper.

Table 2 Time of the slider driven follower

Motion time	**Deg.**
Left stay time= 1.277778 sec	46°
L.to R. motion time= 2.916667 sec	105°
Right stay time = 2.194445 sec	79°
R. to L. motion time= 3.611111 sec	130°

(5) Let $R_1 = 100$, R_4 respectively is 50, 60, 70, 80, 90, 100, $\theta_1 = 1$, $\theta_2 = 121$, slider motion stroke = 150, the left stay swaying angle displacement of the slider = 20, and RPM of driver = 6. The execution data are shown in Table 3.

Table 3 Data of the program

Input \ Item Data	1	2	3	4	5	6	modify - 1	modify -2
R_4	50	60	70	80	90	100	80	80
R_1	100	100	100	100	100	100	100	100
θ_1	1	1	1	1	1	1	1	50
θ_2	121	121	121	121	121	121	170	171
left stay time	1.28	1.56	2	2.67	3.78	5.03	2.44	1.61
left motion time	2.92	2.89	2.86	2.83	2.86	2.97	2.50	4.42
right stay time	2.19	2.03	1.9	1.78	1.64	1.56	2.53	1.61
right motion time	3.61	3.53	3.25	2.72	1.72	0.44	2.53	2.36
R_2	41.4	50.3	59.31	68.43	77.63	86.14	79.63	50.64
R_3	91.4	90.3	89.34	88.49	87.76	87.88	99.69	128.80
left stay angle	20	20	20	20	20	20	18	6

We choose the execution result of the 4th item in Table 3 as basis, which is the closest to the slider left-to-right straightline motion time, to enlarge the swaying angle of the rocker, to accelerate the straightline motion velocity of the slider, and increase the staying time between the two dead points, so there are modifications as follows: $\theta_1 = 1, \theta_2 = 170$, the left stay angle of slider = 18 , as shown item modify-1 in Table 3, and the execution results are shown in Table 4, which correspond with the design requirement in the 2nd item, section 4-1 in this paper. Then on the basis of the execution results in the 4th item in Table 3, make these modifications, $\theta_1 = 50, \theta_2 = 171$, and reduce the swaying angle of the rocker of the slider staying on two dead points, so as to prolong staying time, that is the modification: left stay angle of slider = 6 , as shown item modify-2 in Table 2, and the execution result is shown in Table 5, which correspond with the design requirement in the 3rd item, section 4-1 in this paper. The prototype of the straightline reciprocator is shown in Figure 15.

Table 4 The average motion time of the slider driven follower

Average motion time	**Deg.**
Left stay time= 2.444445 sec	88º
L.to R. motion time= 2.5 sec	90º

Right stay time= 2.527778 sec	91°
R. to L. motion time= 2.527778 sec	91°

Table 5 The quick-return motion time of the slider driven follower

Quick-return motion time	**Deg.**
Left stay time = 1.611111 sec	58°
L.to R. motion time = 4.416667 sec	159°
Right stay time = 1.611111 sec	58°
R. to L. motion time = 2.361111 sec	85°

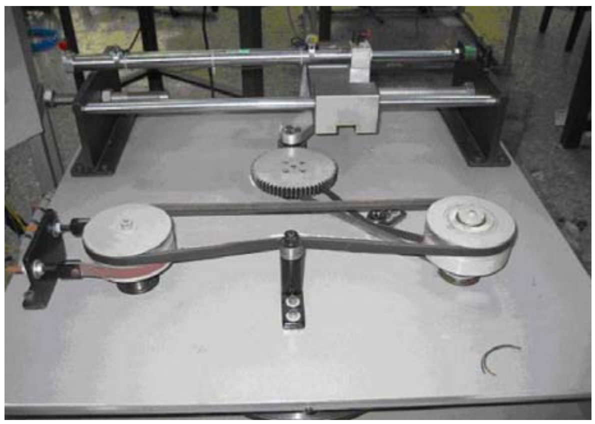

Fig.15 Prototype of the straightline intermittent reciprocator

V. Conclusion

By applying the TRIZ contradiction table to select proper innovative principles, we make use of the crank rocker four-link mechanism characterized by a variable angle velocity rocker axis of rotation, to drive the modified Scotch Yoke to change the motion curve of each stroke of the straightline intermittent reciprocating motion, to make the slider driven followers to make different motions, to correspond with the design conditions for different motions, and thus to obtain the motion curve for the slider driven followers to make the better required consecutive motion. This research makes the following conclusions: (1) the efficiency of variable velocity may be obtained with the fixed velocity power source, (2) if the swaying angle of rocker is less than 180°, the slider that can make the straightline one-way and two-way intermittent reciprocating motions can also make the straightline reciprocating motion, (3) the slider stroke and the time of staying between two ends may be changed by adjusting the phase of rocker, (4) the slider displacement, velocity and acceleration curve being consecutive obtained by selecting proper input parameters, (5) the development of mechanism design software can quickly complete the optimal design of the straightline intermittent reciprocating motion. These research achievements may not only provide reference for the design of such mechanisms as the bias cutter, the tread skiver for the rubber industry, and the fast feeder for press machine, but also be used as the teaching materials and aids for the mechanism creative design.

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