Modern Applied Science
www.ccsenet.org/journal.html
Vol. 2, No. 5
September 2008

A Study of a New Shaped Mechanism of a Ring Spinning Machine Based on Eccentric Cam System Controlled by Microcomputer

Wei Wang, Jiancheng Yang & Zhe Liu
School of Mechanical & Electronic Engineering
Tianjin Polytechnic University
Tianjin 30016, China
E-mail: wangwei120911@yahoo.com.cn

Abstract

This study has for the first time developed a new shaped mechanism of the ring spinning frame based on an eccentric cam system controlled by microcomputer to solve the shortcomings of traditional shaped mechanism of a ring spinning mechanism of a ring spinning machine driven by a plate cam at a constant rotation speed. It has established a model of the shaped mechanism of the ring spinning frame and proposed an optimum control algorithm. The study has theoretically proved that the feasibility of the new shaped mechanism and made simulation experiments. The results of application show that the new shaped mechanism does not only overcome shortcomings of the traditional one, but has much generality.

Keywords: Eccentric cam system, Shaped mechanism, Ring spinning frame, Control

1. Introduction

Ring Spinning Frames are main machines which have been using in the textile industry. And study on their shaped mechanisms has been concerned by both domestic and overseas experts. At present, the shaped mechanisms of ring spinning frames, which have been used in cotton, wool, silk, and flax ring spinning machines, are controlled by constant speed plate cams. Motion regulations of the shaped mechanisms can be obtained just by designing their profile curves of cams. However, these kinds of shaped mechanisms have shortcomings such as: (1) where the profile curve of the cam changes a lot, it is easy to cause pounding or pause, and to lead to the bad reel. Therefore, the yarn quality is affected. (2) It is difficult to manufacture the profile curve of the cam by using common methods. (3) The cam is inflexible, and can satisfy only one kind of motion regulation. Therefore, it is valuable to study the shaped mechanism theoretically and practically.

In recent years, there have been two major approaches to study the shortcomings of the cams mentioned above. On the one hand, an optimum cam profile curve may be designed by some special methods(Yu Q, 1996, p.181-186 & Shen, 1991, p.12-15); on the other hand, the concept of an eccentric cam is introduced(Leslie, 1996, p.39-41), which deferent from traditional cam, it is an actuator which simulates the cam at a constant rotation speed, that is, the cam does not contact driven components, between which there is only electrical relationship. An application to robot is introduced in the paper (Hiroshi, 1999, p.39-40). In paper (Yao, 1999), kinematical and dynamic characteristics of cam driven by servo motor by changing different input functions are studied , which are under the condition of non-changing cam profile curve.

In the light of analyses of the problems existing in the traditional shaped mechanisms of ring spinning frames, a new shaped mechanism has been successfully developed firstly. In particular, an eccentric cam which is programmable is used as a kind of general executive component, by which some desired output regulations can be obtained through changing program without changing the cam profile curves. In addition, there are no needs of considering the problems such as minimum curvature radius and pressure angle and so on.

Obviously, the problems mentioned above can be solved by making use of the new shaped mechanism.

2. Control Rules of Eccentric Cam

2.1 Determining motion laws of angular displacement and angular velocity of eccentric cam

A scheme of the eccentric cam of roller follower and an identical scheme of one are given in Figure 1. (a) and (b), respectively.

Supposing Crank $l_1 = e$ (e is an eccentric distance)

Linkage $l_2 = r + r_1$ (where r is radius of cam ; r_1 is radius of roller follower)

Rock bar $l_3 = l_{\mathrm{AO_f}}$ (the length of frame)

$l_4 = l_{\mathrm{o_c o_f}}$

Given rotation angular of crank is φ ; rotation angular of rock bar is ψ (see Figure 1. (b))

Hence
$$\psi(\varphi) = \delta - \psi_0 \tag{1}$$

Where
$$\psi_0 = \cos^{-1}\frac{l_3^{\ 2} + l_4^{\ 2} - (l_2 - l_1)^2}{2l_3 l_4}$$

$\delta = \angle \mathrm{O_c} O_\mathrm{f} \mathrm{A}_1$

According to geometrical knowledge, the following result can be obtained
$$\delta = \mathrm{tg}^{-1}\frac{A}{B} - \sin^{-1}\frac{C}{\sqrt{A^2 + B^2}} \tag{2}$$

Where
$$A = \frac{l_4}{l_1} + \cos(\varphi_0 + \varphi)$$

$$B = \sin(\varphi_0 + \varphi)$$

$$C = \frac{l_3^{\ 2} + l_4^{\ 2} + l_1^{\ 2} - l_2^{\ 2} + 2l_1 l_4 \cos(\varphi_0 + \varphi)}{2l_1 l_3}$$

$$\varphi_0 = \sin^{-1}[\frac{l_3}{l_2 - l_1}\sin\psi_0]$$

The regulation of driven member is presented as follows:
$$\psi = \psi(t) \tag{3}$$

Angular velocity can be obtained by the first derivation of angular displacement with respect to time
$$\dot{\psi} = \frac{\mathrm{d}\psi(t)}{\mathrm{d}t} = \frac{\mathrm{d}\psi(\varphi)}{\mathrm{d}\varphi} \times \frac{\mathrm{d}\varphi}{\mathrm{d}t}$$

Rewriting the formula above leads to
$$\dot{\varphi} = \frac{\mathrm{d}\varphi}{\mathrm{d}t} = \dot{\psi} \Big/ \frac{\mathrm{d}\psi(\varphi)}{\mathrm{d}\varphi} \tag{4}$$

where $\frac{\mathrm{d}\psi(\varphi)}{\mathrm{d}\varphi}$ is hold according to Eq. (1)

Angular displacement of the eccentric cam is obtained based on Eq. (4).
$$\varphi(t) = \int_0^t \frac{\dot{\psi}}{\frac{\mathbf{d}\psi(\varphi)}{\mathbf{d}\varphi}}\mathbf{d}t \tag{5}$$

2.2 Optimum calculus of control instructions of angular displacement of the eccentric cam

It is only suitable to solve several values of some points with calculus to solve angular displacement of the eccentric cam by Eq. (5).

Considering continuous conditions, it is suitable to adopt spline function to approach function φ(t) by steps.

2.2.1 Simulation with the 5th order spline function

Two factors should be considered when proceeding curve simulation is done. Firstly, fewer inserting values in keeping simulating accuracy should be chosen under the condition of equal distribution of insert points. Secondly, when changing the distribution of insert points to meet the needs of simulation accuracy in order to obtain optimum simulation curve with third derivation, the best simulation curve can be reduced to the following optimum design.

$$\phi(x_j) = \min\left\{ \max_{j=2,3\ldots,n_{j-1}} (\Delta y(x_j)) \right\} \quad (6)$$

Subject to:

$$\Delta y = y_j(x_i) - \overline{Y}_j(x_i) \le \varepsilon$$

2.2.2 Optimum design of curve simulation by steps with 5th order spline function.

We can adopt the 5th order spline function to replace Eq.(5) by steps, if cam angular displacement and angular velocity of every section of beginning and end are given

$$\sum_{i=1}^{n} [\varphi(t)_i - \hat{\varphi}(t)_i]^2 \le \varepsilon, \quad i = 2,3,\ldots,n-1$$

Note that, it should be to considered that $\sum_{i=1}^{n} [\varphi(t)_i - \hat{\varphi}(t)_i]^2 \le \varepsilon$,(i =2,3,…,n-1) is among the middle value of section the control law $\hat{\varphi}$（KT）（K=1,2,….)of angular displacement of eccentric cam can be obtained according to adoptive sample T. Control rules $\hat{\varphi}$（KT）（K=1, 2…) of eccentric cam can be obtained according to adoptive sample T after spline $\hat{\varphi}(t)$ of every section function is given.

That is

$$\hat{\varphi}(t) = \sum_{k=0}^{5} a_k (t - t_1)^k \quad (7)$$

Boundary conditions:

$$\varphi(t_1) = \varphi_1,\ \varphi(t_n) = \varphi_n;\ \dot{\varphi}(t_1) = \omega_1,\ \dot{\varphi}(t_n) = \omega_n;\ \ddot{\varphi}(t_1) = \varepsilon_1,\ \ddot{\varphi}(t_n) = \varepsilon_n. \quad (8)$$

where φ_1 and φ_n — Angular displacement of beginning and end points, respectively

ω_1 and ω_n —Angular velocity of beginning and end points, respectively

ε_1 and ε_n —Angular acceleration of beginning and end points, respectively

t_1 and t_n —time of beginning and end points, respectively

3. Design of Control System

3.1 System model of variable frequency and adjusting speed

The block figure of control system of changing frequency and adjusting speed is shown in Figure 2.

$V(t)$ — Changing frequency sign which is sent into frequency converter; $\omega(t)$ — Regular velocity of motor spindle on the basis of frequency; $V_D(t)$—Sign which is sent by computer; $V(t)$—Simulation sign which comes from D/A converter; $M(t)$— Motor torque.

Transfer function is expressed as follows:

$$\frac{\omega(s)}{M(s)} = \frac{1}{Js + c} \quad (9)$$

Where J — The moment of inertia

c — The damping coefficient

If frequency converge is taken as inertia system, its transfer function is $\frac{k_1}{\tau_1 s + 1}$;

Where k_1 — Defined as increasing rate of frequency controller (v/s)

If D/A controller is taken as keeper of 0 order, its transfer function is taken as $\frac{1-e^{Ts}}{s}$. Therefore, transfer function of the system based on D/A controller is shown in Figure 3.

Considering sign delay, the transfer function of the cam system is

$$HGp(z) = \frac{K(b_1 z^{-(d+1)} + b_2 z^{-(d+2)})}{1 - a_1 z^{-1} - a_2 z^{-2}} \tag{10}$$

Where

$$a_1 = e^{-\frac{T}{\tau_1}} + e^{-\frac{T}{\tau_2}}$$

$$a_2 = e^{-\frac{T}{\tau_1}-\frac{T}{\tau_2}}$$

$$b_1 = 1 + \frac{\tau_1 e^{-\frac{T}{\tau_1}} - \tau_2 e^{-\frac{T}{\tau_2}}}{\tau_2 - \tau_1}$$

$$d = {\tau_d}/{T}$$

$$b_2 = e^{\frac{-T}{\tau_1}-\frac{T}{\tau_2}} + \frac{\tau_1 e^{\frac{-T}{\tau_2}} - \tau_2 e^{\frac{-T}{\tau_1}}}{\tau_2 - \tau_1}$$

(d and b_2 are whole numbers, and τ_d is delay time)

$$k = \frac{k_1 k_D}{c}, \quad \tau_2 = \frac{J}{c}$$

3.2 Design of control approach

Here, the control method of increment may be chosen, which consists of the front feedback and the hind feedback, that is, combinations of open loop and closed loop as shown in Figure 4, because the cam may pursue after any position sign without error in theory.

3.2.1 Design of front feedback and hind feedback

The block figure on the basis of Figure 4. is expressed in Figure 5, in which the part depicted as dotted line is composition controller realized by computer program.

Where $\Delta X(z)$ — Theoretic angular displacement increment of the eccentric cam in theory

$\Delta Y(z)$ —Actual angular displacement increment

$\Delta E(z) = \Delta X(z) - \Delta Y(z)$ —Error value

$M_1(z)$ and $M_2(z)$ — Feedback positive number and front feedback positive number

$M(z) = M_1(z) + M_2(z)$ — The total correct value

In the light of Figure 5, transfer function scheme is expressed as follows:

$$\frac{\Delta Y(z)}{\Delta X(z)} = \frac{G_F(z)HG_P(z) + G_C(z)HG_P(z)}{1 + G_C(z)HG_P(z)} \tag{11}$$

If $G_F(z)HG_P(Z) = 1, \Delta Y(z)/\Delta X(z) = 1$, the theoretic transfer function of pursuing input sign without output sign is obtained.

So transfer function of front feedback control may be written as:

$$G_p(z) = \frac{M_2(z)}{\Delta X(z)} = \frac{1}{HG_p(z)} = \frac{1 - az^{-1}}{bz^{-d-1}} \tag{12}$$

Front feedback positive number is

$$M_2(z) = \frac{1 - aZ^{-1}}{bZ^{-d-1}} \Delta X(z) = \frac{1}{b}[Z^{d+1}\Delta X(z) - aZ^d \Delta X(z)] \tag{13}$$

Thus, the recurrence formula of front feedback is expressed as follows:

$$M_2(k) = K_F[\Delta x(k+d) - a\Delta x(k+d)] \tag{14}$$

In order to decrease the calculation time of practical control program, this paper calculates the front feedback error value in advanced, and produce a table of front feedback for testing. The controller $G_c(z)$ of closed feedback can adapt the simple PID controller. Considering the dynamic characteristic of frequency converter, it is suitable to choose PI controller, and its error value is defined as

$$m_1(t) = K_P \Delta e(t) + K_I \int_0^1 \Delta e(t) dt \quad (15)$$

The formula of feedback error value can be obtained by discrediting Eq.15.

$$M_1(k) = K_P \Delta E(k) + K_I E(k) \quad (16)$$

3.2.2 Design of PI controller parameters

In order to obtain K_p of PI controller and K_I of PID controller, calculate K_p and k_I on the basis of experiential formulas. After an initial result is obtained, modify it by experiential method.

According to PID formulas, several formulates are obtained as follows:

$$K_P = 0.45 K_{PU} \quad (17)$$

$$K_I = K_P / (0.83 T_U) \quad (18)$$

Where K_{PU} ——PI controller increment

T_U ——Oscillation period

To obtain K_{PU} and T_U, make pulse transfer function HGP(Z) restore continuous transfer function, and it can be expressed as follows:

$$G_P(s) = \frac{K e^{-\tau_d s}}{\tau s + 1} \quad (19)$$

where $K = 1.274$, $\tau = 0.068$, $\tau_d = 0.11$

According to Nyquist criterion, and considering function GK(jω), several results, which are obtained by solving equation (19), can be obtained as follows:

$\omega_\psi = 19.2921$

$K_{PU} = 0.7851$

So $$T_U = 2\pi / \omega_U = 0.3257$$

Substituting K_{PU} and T_U to Eqs. (17) and (18), the initial numerical value can be obtained as follows:

$K_{PU} = 0.3533$

$T_U = 1.3158$

Choosing PI controller parameters depends on the formulas, which is applied to experiment and modified. Considering that the total error amount consists of front feedback error and feedback error, it is suitable to adopt front feedback error and to pursue the slope wave input. A diagram with slope wave $x(k)$ =20, 10 (responsibility to 600r/min and 300r/min.) and $K_p = K_I = 0.34$ is depicted in Figure 7.

From Figure 6, we can come to the conclusions that stable errors are zero, without surpass, but transition time is too long. When rotation speed is 600r/min. adjustment time is 0.94s; when 300r.p.m, 0.49s. If K_p and K_I are increased, there are surpass or saturation.

On the basis of analyses mentioned above, it is reasonable to choose $K_p = 0.3533$, $K_I = 1.3138$.

4. Experiment of Cam Mechanism

On the basis of theoretical study and simulation mentioned above, a new shaped mechanism of ring spinning frame based on eccentric cam system controlled by microcomputer is developed firstly as shown in Figure 7. This system consists of single chip computer, frequency converter, A.C. motor, gear reducer, shift encoder and mechanism of eccentric cam with roller follower and so on, which is illustrated in Figure 8. in broken line.

The ring spinning frame may be selected as an experimental device (see Figure 7.). The prototype is shown in Figure 7. Here, choosing. a =15(mm); b =93(mm); c =400(mm) (see Figure 8.).

Solving Eqs. (1) ~ (15) leads to the law of movement, just as shown in Figure 9.

As shown above, some results are obtained. Firstly, the time is about the same with the two kinds of cam. Secondly, the shock is about the same by two kinds of cam. Thirdly, the curves between two cams drivers are about the same.

There, however, is a little pause when curve is in changing direction, whose main causes are the response speed of motor is lower at the corner of changing speed, so that the ring board moves behind.

Output motion regulations can be obtained illustrated in Figure 10. When constant speed law is input.

The new shaped mechanism is characteristic by the eccentric cam that is simple contracture and easily manufacturing and every output law of roller follower can be obtained by changing program. The experimental results show that it is obvious that the new shaped cam mechanisms can overcome the disadvantages of the traditional ones. Therefore, this kind of shaped mechanism has more practical effect.

5. Conclusions

(1)A new shaped mechanism is put forward, and it proves theoretically and practically that this mechanism works effectively.

(2) The optimum control instructions can be obtained by Optimum design of curve simulation by steps with 5th order spline function.

(3) Errors can be decreased by using the front feedback and the hind feedback.

(4) The old shaped mechanisms of ring spinning frames, which have been used in cotton, wool, silk, and flax ring spinning machines, may be replaced by the new shaped mechanism developed by this study.

References

Gu, Ningxi & Wang, Shuigen. (1991). Analyzing and Improvement of Building cam shock in spinning Frame. *Journal of Textile Research*, 12(7), 13-13.

Hiroshi, Makino. (1999). Smart cam application to robot Control. *Assembly Automation*, 19(1), 39-40.

Jan, van Gerwen. (1999). Electronic cam and gear. *Assembly Automation*, 19(1), 35-38.

Leslie, Langnau. (1996). Using electronic cams for motion control. Power Transmission Design, 2(6), 39-41.

Shen, Shide & Lv, Shiyuan. (1991). New Method for Designing Textile Cam. *Journal of Textile Research*, 12(1), 12-15.

Yu, Q. (1996). Optimum design of cam mechanisms with oscillating flat-face followers. *Mechanics Research Communications*, 23(2), 181-186.

Yao, Yan'an. (1999). Active Control for Cam Mechanism. Ph. D thesis, Tianjin University, Tianjin, China.

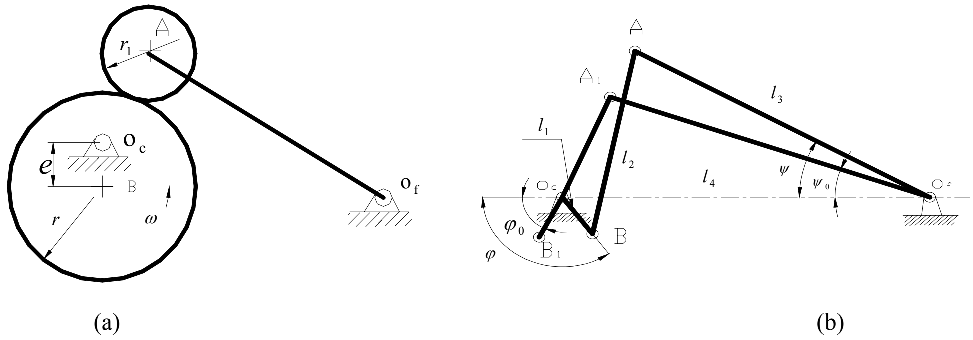


Figure 1. Scheme and identical scheme of an eccentric cam of roller follower

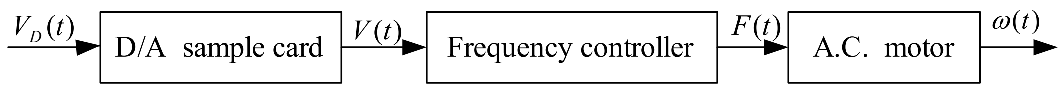


Figure 2. Scheme of changing frequency and adjusting speed

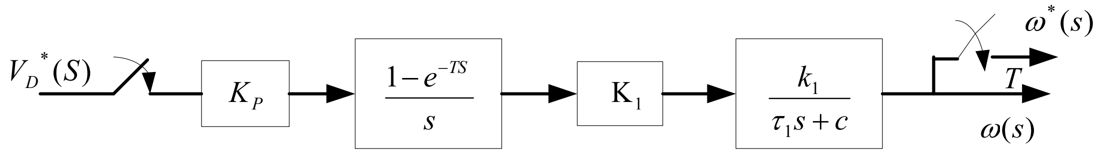


Figure 3. Block figure of transfer function of controlled system

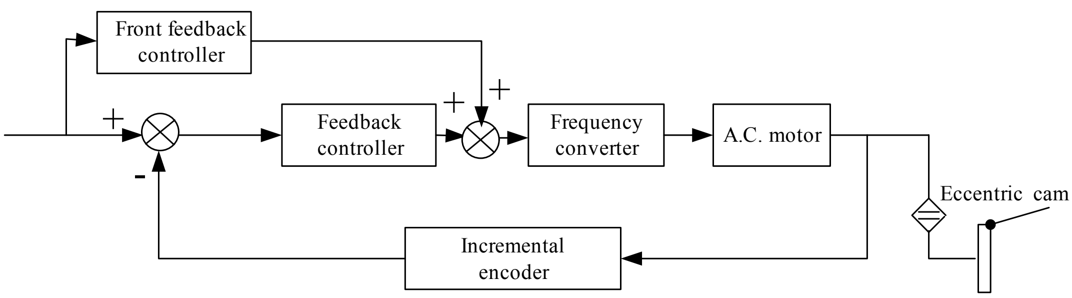


Figure 4. Scheme of control system

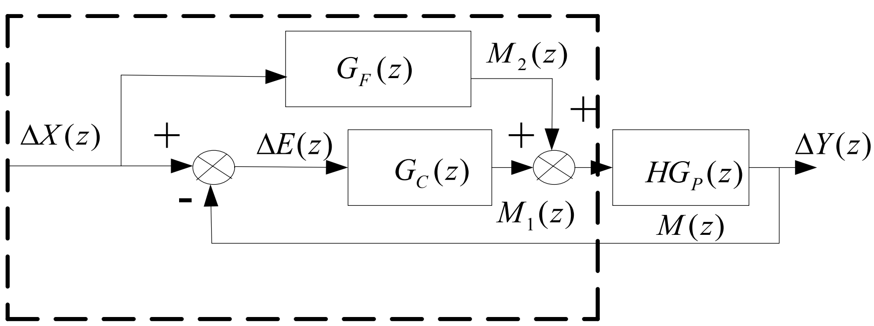
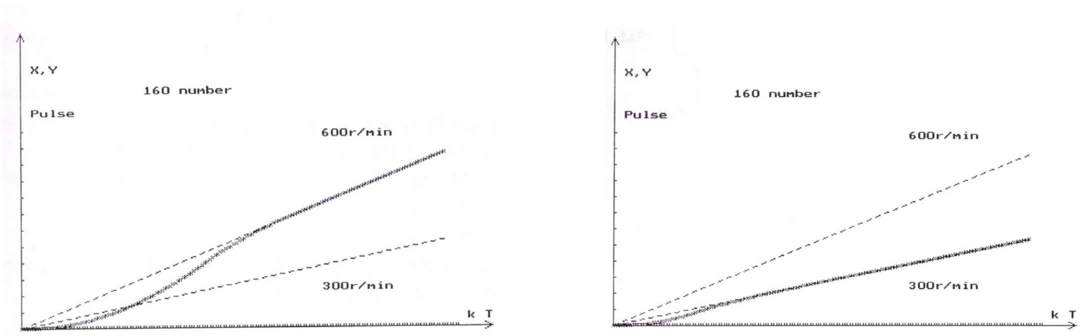


Figure 5. Transfer function figure of control system



(a) $x(k)$ =20 slope wave input (b) $x(k)$ =10 slope wave input

Figure 6. Output scheme of slope wave input

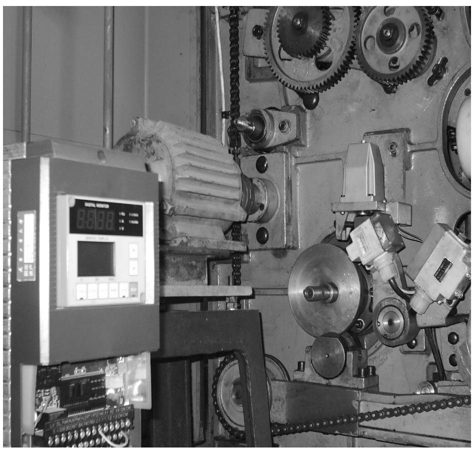


Figure 7. A prototype of the eccentric cam system

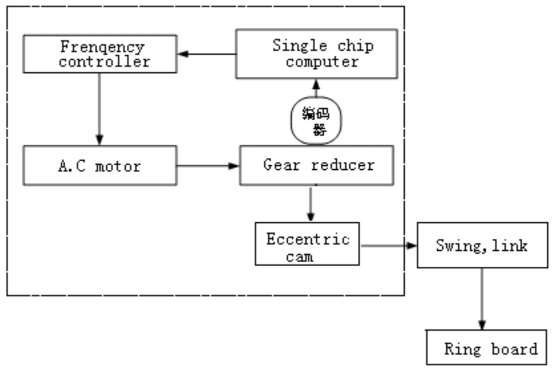


Figure 8. Schematic diagram of the eccentric cam system

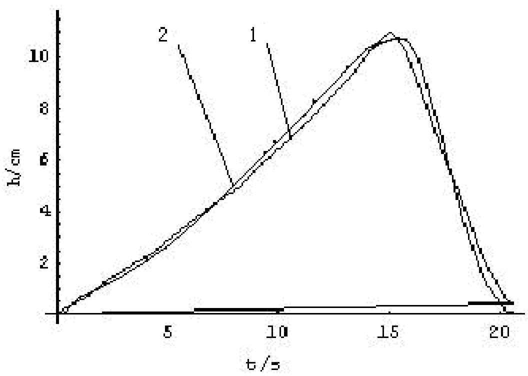


Figure 9. Displacement curve of ring board

1. The law of the old plate cam

2. The law of eccentric cam

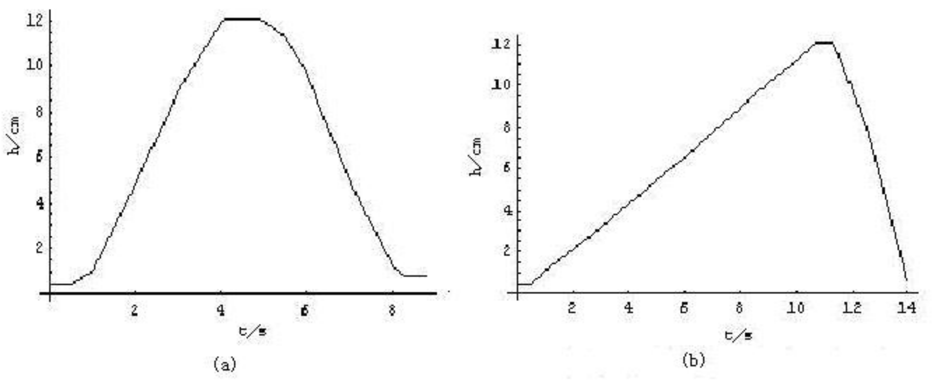


Figure 10. Output motion law scheme of input constant rotation

(a) Input constant rotation at the same rotation

(b) Input constant rotation at the different rotation