Application of Self-optimization Closed-Loop Input-shaping with Parameter of Chaotic Particle Swarm in Coaxial Drive Printing System

Xu Bo, Cai Ligang, Yang Jianwu, and Zhang Sen
Beijing University of Technology, Beijing 100124

Abstract—Based on the issue of torsional vibration, this article analyzes the structure of the drive part of coaxial drive printing system, constructs its mathematic model, and explores the mechanism of generation of torsional vibration of press—that is the coupling of inherent frequency between input signal and machine drive system which leads to torsional vibration. In view of this, it adopts the closed loop input-shaping based on chaotic particle swarm to restrain the torsional vibration. In the algorithm, it firstly finds out the optimal control structure by the transfer function based on the structure of three kinds of closed-loop input-shaping and secondly adopts the approach of chaotic particle swarm optimization to make off-line optimization of parameter of input-shaping. Such kind of approach avoids the premature phenomenon existing in traditional particle swarm optimization to some extent. Besides, it enlarges the scope of parameter selection. Finally, it achieves the one-time collection of vibration signal and off-line optimization by the transfer function. This approach can not only avoid system oscillation caused by online optimization but also solve the problem of low precision of pure offline modeling optimization. Meanwhile, it builds multi-mass experimental platforms as well as makes a contrast with site collected data. The data shows that experimental platform proves the system oscillation caused by low frequency vibration point of the drive system of press. It carries out experimental verification by simulation platform and it proves that chaotic particle swarm optimization has fewer iterations and quick convergence compared with traditional particle swarm optimization in the first place. Secondly, after adding chaotic particle swarm optimization, compared with traditional PID control, the closed-loop input-shaping has simple parameter adjustment and obvious effect of vibration restraint. After adopting ITSE evaluation function to evaluate the inhibitory effect, it is found that the vibration damps by 54.4% compared with the fact without adding input-shaping.

Index Terms—Coaxial Drive; Closed-Loop Input-Shaping; Chaotic Particle Swarm

I. INTRODUCTION

Torsional vibration is one of the common vibration modes of shafting. When the torsional vibration occurs, the stress state of axle takes up periodical change, which may cause the fatigue of axle. Even more, It bring about the fracture of the axle, leading to serious and even disastrous accident [1]. Valenzuela [2] and other scholars analyzed the coaxial printer electromechanical coupling of torsional vibration in starting. Chen Yuhua, zhao Jing, etc. [3] design a kind of torsional vibration testing device to collect the vibration signals. Through the signal analysis, the data indicate that that impact disturbance is an important cause of the torsional vibration. Peng Ming, Wang Yi Ming et al [4] proposed that periodic disturbance is also an important reason for the torsional vibration which cause by the gear failure. The torsional vibration seriously affects the printing speed and accuracy of registration [5].

Input shaping technology with simple control realized the fast positioning. At the same time It avoid increase system quality when the damping and stiffness is improving. It’s also avoid to use the complex control algorithm. So It is widely used in precision positioning system to suppressing the residual oscillation.

The basic ideal of the Input shaping technology is using Posicast-control to eliminate the residual vibration based on the principal that two sinusoidal signals separated for half cycle can offset mutually. In recent ten years, especially in the middle of 1990s, since N.C.singer [6] [7] solved the robustness of Posicast-control in a patent; this method has got rapid development. Meanwhile, many scholars also make great contributions to the improvement of the method. Singhose [8], et al put forward highly insensitive method to further improve the robustness of the system. Singer [6], et al try to get the impulse amplitude and time lag of higher-order reshaper, namely increasing the number of impulse in the impulse sequence by establishing multiple constraint equations so as to improve the robustness to the system frequency and damping error. Lucy [9] put forward a kind of design method about mixed input-reshaping based on the known damping of system vibration modal and uncertainty of natural frequency, namely weighting the objective function based on the possible distribution of system parametric variation and the variation range of expected modeling error to system parameter so as to get the nearly optimal residual vibration. Now, the commonly used methods to design the input shaping is based on the Pole-zero cancellation Multimode decomposition Optimal Design Method and so on. In recent years, the closed-loop input shaper are widely studied.
The Pole-zero cancellation method uses the system zero to cancellation pole, so as to avoid the object's dynamic. In that way, it is avoid the unexpect vibrate. Tuttle [10] and Lucy [11] used the Pole-zero cancellation method to design the single input shaping and multiple input system. This method based on directly solving the equation, it is very simple and speeds up the reaction.

Multimode decomposition method uses empirical mode decomposition to find out the system vibration modal, and eliminate the vibration frequency. Single [12] is the theory of founder, and made great contribution for it.

The optimal input-shaping is by solving a series of constraint equation to get the optimal control input. Robustness, delay time is commonly used to evaluate the optimal performance. Pao [13] and Singhose [14] is the foundation of this method.

This article mainly focuses on the torsional vibration caused by electromechanical coupling in the start-up process of press. It firstly analyzes the reason which is the intercoupling between frequency in the signal and the resonant frequency of mechanical system causes the vibration. Secondly, it adopts the closed-loop Input-shaping to suppress the vibration and compares it with the structure of several kinds of input-shaping. It is proved that input-shaping has the highest efficiency in the former channel. Finally, it points out a kind of parameter self-optimization method based on chaotic particle swarm optimization targeted at the problem that it is hard to adjust the parameter of closed-loop input-shaping as well as improves the optimizing efficiency by simulation. Finally, by simulation and experimental verification, it gets excellent experimental effect.

II. REASONS CAUSING THE TORSIONAL VIBRATION OF DRIVE SYSTEM OF COAXIAL PRESS

The system of typical coaxial drive press is composed by three parts, including motor, speed reducer and transmission shaft (as shown in figure 1).

![Figure 1. Typical coaxial press drive system](image)

Generally, the length of transmissions shaft is between 2.5 and 3.5m. Transmission shaft has long length and thin shaft diameter so that it is always abstracted as an elastic link and the entire system is abstracted as a typical multi-mass spring-damped system, as shown in figure 2.

![Figure 2. Multimass torsional model](image)

Make modeling for the entire system by modal analysis and the mathematical model of the load part is as follows:

\[
\begin{bmatrix}
J_1 & 0 & \cdots & 0 \\
0 & J_2 & \cdots & 0 \\
\vdots & \ddots & \ddots & \vdots \\
0 & \cdots & J_{n-1} & J_n
\end{bmatrix}
\begin{bmatrix}
\theta_1 \\
\theta_2 \\
\vdots \\
\theta_n
\end{bmatrix}
\]

\[
\left(\begin{array}{ccc}
0 & -c_1 & \cdots & -c_n \\
-c_1 & 0 & \cdots & -c_n \\
\vdots & \ddots & \ddots & \vdots \\
-c_n & \cdots & 0 & 0
\end{array}\right)
\begin{bmatrix}
\theta_1 \\
\theta_2 \\
\vdots \\
\theta_n
\end{bmatrix}
\]

\[
\left(\begin{array}{ccc}
k_1+k_2 & -k_2 & \cdots & 0 \\
-k_2 & k_1+k_n-k_n & \cdots & 0 \\
\vdots & \ddots & \ddots & \vdots \\
0 & \cdots & -k_n & k_1+k_n-k_n
\end{array}\right)
\begin{bmatrix}
\theta_1 \\
\theta_2 \\
\vdots \\
\theta_n
\end{bmatrix}
\]

Among which, \( J_n \) refers to the output torque of speed reducer. \( \theta_n \) is the angular displacement of mass block. \( C_n \) is the damping coefficient of the nth location. \( k_n \) is the stiffness coefficient of the nth spring.

Semi-physical experimental platform adopts direct current motor so that modeling motor adopts the model of direct current motor.

\[
L_n \frac{di}{dt} = u_n(t) - R_n i(t) - E_n(t)
\]

\[
E_n(t) = K_e \theta(t)
\]

\[
T_n(t) = K_i J_n(t)
\]

\[
T_n(t) = J \theta(t) + T_0(t)
\]

Among which, \( L_n \) is the armature inductance and \( u_n \) is the armature voltage. \( i \) is the armature current and \( E_n \) is the anti-electrodynamic potential. \( R_n \) is the armature resistance and \( K_e \) is the anti-electrodynamic potential coefficient. \( K_i \) is the electromagnetic torque coefficient of motor and \( T_m \) is the electromagnetic torque of motor. \( T_0 \) is the load torque of motor and \( \theta \) is the angular displacement of motor rotor. \( J \) is the rotational inertia of motor rotor.

The open-loop transfer function of system is:

![Figure 3. Transfer function of multimass torsional model](image)
After decoupling and simplification, the transfer function of the entire system is simplified as:

\[ G_2(s) = \frac{J_2K_2s}{J_2s(s-K_2C_2) + K_2} \]  \hspace{1cm} (3)

Without consideration of damping, the transfer function is:

\[ G_2(s) = \frac{J_2K_2s}{J_2s^2 + K_2} \]  \hspace{1cm} (4)

From the equation (3), it can be found that it will increase a pair of poles in the imaginary axis after increasing a section of load for each time, as shown in figure 6. Meanwhile, a transfer function which is same to the equation (3) will act on the former transfer function, which lowers the vibration frequency of original pole.

III. CLOSED-LOOP INPUT-SHAPING ALGORITHM

Input-shaping was firstly put forward by Singer and Seering in 1990s [15] [16]. Its basic idea is that in the time domain, it generates a series of signal which are opposite to the vibration of system by impulse order and offsets with each other by signal so as to avoid vibration. In terms of the frequency domain, it adopts zero pole cancellation to suppress the vibration generated in the pole by configuring zero.

A. Basic Principle of Open Loop Input-Shaping

Open loop input-reshaping system is as shown in figure 7.

\[ A_0(\xi) + \sum_{i=1}^{n} A_0(\xi-\omega_i) \]  \hspace{1cm} (5)

\[ \omega_i^2 = \omega_k^2 + 2\zeta \omega_k S + \omega_k^2 \]  \hspace{1cm} (6)

In the equation, C(s) is the standard model of command shaper.

When \( \sum_{i=1}^{n} A_i e^{-\xi} = 0 \), the entire open-loop system will generate \( 2n \) zero. When the open loop offsets mutually with the pole in \( \sum_{i=1}^{n} A_i \) with \( \omega_k^2 \), the system vibration will be suppressed.
B. Basic Principle of Closed-Loop Input-Shaping

Closed-loop input-shaping is a kind of input-shaping which is studied mostly. It mainly has the following three structures:

- **Input-shaping in forward channel input channel**
- **Input-shaping in feedback channel**

![Position of closed-loop input-shaping](image)

Take second-order system as an example. Its transfer function is:

\[
K_i = \exp\left(\frac{-\frac{\pi}{2}}{\sqrt{1 - \frac{\pi^2}{4}}}\right)
\]  

(7)

\[
C(s) = \sum_{i=1}^{n} A_i e^{-t_i/s}
\]  

(8)

\[
\frac{X_s(s)}{X_s(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}
\]  

(9)

The command shaper is:

\[
Z = \sum_{i=1}^{n} A_i e^{-t_i/s}
\]  

(10)

When the system adopts the structure of closed-loop transfer function as shown in figure 9-1, the transfer function is:

\[
\frac{\omega_n^2 Z}{s^2 + 2\zeta\omega_n S + \omega_n^2 + Z\omega_n^2}
\]

After the conversion of transfer function, input-shaping Z is not in the numerator, which cannot eliminate the pole of system but will damage the control performance. When adopting the structure shown in figure 9-2, the transfer function is:

\[
\frac{\omega_n^2 Z}{s^2 + 2\zeta\omega_n S + \omega_n^2 + Z\omega_n^2}
\]

In case of adopting the cancellation of zero poles and the numerator and denominator make intercoupling, it is hard to solve the equation. Only when adopting the structure shown in figure 9-3, the transfer function of system is simplified as:

\[
\frac{\omega_n^2 Z}{s^2 + 2\zeta\omega_n S + 2\omega_n^2}
\]

When the Z generated in input-shaping can completely cancel out pole, the vibration of the entire system will be suppressed. Thus, the structure shown in figure 9-3 is the most effective control structure with the most extensive application. However, in order to correctly choose the parameter \(A_{i,j}\) and \(t_{i,j}\) in the input-shaping of equation (5) and (6), it needs to make modeling for the controlled object. In case the model is not correct, the system cannot well suppress the system vibration. Based on the structure shown in figure 11, this article puts forward a kind of PID algorithm with input-shaping based on particle swarm optimization. Meanwhile, as for the premature phenomenon existing in traditional particle swarm optimization, it adopts the method in chaos control to make optimization. Such kind of method can achieve accuracy control and at the same time well suppress the system vibration. The parameter adjustment is simple and input-shaping achieves the offline self-optimization of parameter and the effect of vibration suppression is obvious as well as overcomes the defect of traditional online adjustment method that it is easy to arouse system vibration.

IV. CHAOTIC PARTICLE OPTIMIZATION OF INPUT-SHAPING

A. Algorithm Flow Chart

In order to solve the problem of complicated modeling of vibration signal, this article adopts a kind of chaotic particle swarm algorithm based on the traditional PID control combing the order reshaping algorithm to optimize three parameters, \(A_1,A_2,t\) in the input-shaping.

The online optimization control structure of traditional input-shaping is as shown in figure 10.

![Block diagram of online swarm optimization input-shaping algorithm](image)

After passing through the input-shaping, the input signal \(u(t)\) enters the control system and the control system controls the actuator to operate. Use the encoder to test the speed operation curve of actuator. Meanwhile, the speed value enters evaluation module to evaluate the operating state. The evaluation result is reported to particle swarm optimizer. The particle swarm optimizer reads the parameter in input-shaping and makes optimization as well as gradually amends the parameter in input-shaping, which makes the system vibration to the minimum. However, traditional true time control parameter is easy to arouse the system vibration and even damage the mechanical structure.

This article tries to make the signal enter the mechanical system, collects the signal and then enters the input-shaping by transforming the flow chart and exchanging mechanical system and the sequence of input-shaping transfer function, as shown in figure 11.

![System of offline swarm optimization closed-loop input-shaping](image)
After the conversion of transfer function, the system is divided into online part and offline part. Thus, by collecting the signal of mechanical system for one time, it can analyze and determine the parameter of input-shaping by offline module. The specific execution steps are as follows:

1) Simply adjust PID parameter and make the system reach the basic response speed and control precision.
2) Set input signal to simulate mechanical system.
3) Collect vibration signal.
4) Input vibration signal to simulation system as the input signal.
5) Adopt chaotic particle swarm optimization to automatically optimize the parameter.
6) Add the optimal input -shaping to the system shown in figure 11.

The equation of input -shaping is:

$$C(s) = \sum_{i=1}^{n} A_i e^{-sT_i}$$  \hspace{1cm} (11)

The evaluation function adapts traditional ITSE function, namely

$$ITSE = \int_0^T te^2(t)dt$$  \hspace{1cm} (12)

Under the ITSE criterion, the obtained controller parameter can make the system have small overshoot under the step response. Meanwhile, rapid transient response can correctly evaluate the performance of system.

B. Chaotic Particle Swarm Optimization:

1) Particle Swarm Optimization (PSO):

PSO is a kind of new swarm intelligent optimization and a kind of bionic optimization firstly put forward by Kennedy and Eberhart in 1995, which is similar to genetic algorithm. It focuses on random solution to seek the optimal solution with iteration and evaluates the quality of solution by fitness. But it is simpler than the rules of genetic algorithm. This algorithm is easy to be carried out, with high precision and quick convergence so that it is widely applied. The flow chart of the algorithm is shown in figure 12.

![Flow chart of particle swarm optimization](image)

Figure 12. Block diagram of particle swarm optimization

However, prematurity of algorithm is a core problem of particle swarm algorithm, which makes algorithm in local minimum and seriously affects the precision of algorithm.

2) Chaotic particle swarm

As for the prematurity of particle swarm optimization, this article adopts chaotic algorithm (CLS) to improve traditional particle swarm optimization. By the ergodic process of chaotic trajectory, it avoids algorithm in local minimum.

Chaotic particle algorithm involves chaotic search algorithm and the steps are as follows:

1) Set K=0, take decision variable $x_j^k, j=1,2,...,n$ to map the chaotic variables between 0 and 1 based on the following equation, $\frac{x_j^k}{x_j^k - x_{\min,j}} = x_j^k, j=1,2,...,n$. Among it, $x_{\max,j}$ and $x_{\min,j}$ are the search upper and lower bound of the $j^{th}$ dimension variable.

2) Calculate the chaotic variable $s_{j+1} = 4s_j(1-s_j), j=1,2,3,...n$ in next iteration.

3) Convert the chaotic variable, $x_{j+1}$ to the decision variable $x_{j+1} = x_{\min,j} + s_{j+1}(x_{\max,j} - x_{\min,j}), j=1,2,3,...,n$.

4) Make evaluation on the new solution based on the decision variable $j=1,2,3,...,n$. In case the new solution is superior to initial solution $x^{(k)}=[x_1^{(k)}, x_2^{(k)}, x_3^{(k)}, ... x_n^{(k)}]$ or the chaotic search has reached the maximum number of iteration, take the new solution as the search result of CLS. Otherwise, set $k = k + 1$, convert 2).

Chaotic particle swarm is extremely sensitive to initial value and the number of iteration is large so that it combines particle swarm optimization and chaotic algorithm. PSO is mainly used for global search and CLS is used for local search based on the result of PSO. Thus, it gets chaotic particle swarm. The steps of algorithm are as follows:

1) Initialize the position and speed of various particles in swarm randomly.

2) Evaluate the adaption of every particle and store the position and adaptive value of each particle in the pbest of each particle and store the position and the adaptive value of the individual with the optimal adaptive value in pbest in gbest.

3) Update the speed and position of each particle;

4) Calculate the objective function value of each particle and keep 20% of particle with the best adaptive function value in the swarm.

5) Carry out chaotic local search to the best particle in the swarm and update its pbest and gbest of the swarm.

6) In case of meeting with the condition of suspension (It is generally the presupposed operational precision or number of iteration), stop searching and output the result. Otherwise, convert 7.

7) Shrink the search area by the following equation:

$$x_{\min,j} = \max\{x_{\min,j}, x_j - \rho x (x_{\max,j} - x_{\min,j})\}, 0 < \rho < 1$$

$$x_{\max,j} = \min\{x_{\max,j}, x_j - \rho x (x_{\max,j} - x_{\min,j})\}, 0 < \rho < 1$$

Among which, $x_j$ refers to the value of the $j^{th}$ dimension variable in current pbest.

8) Randomly generate the rest of 80% particles in the space after shrinking and convert 2.

© 2014 ACADEMY PUBLISHER
In the process of above chaotic search algorithm, in order to maintain the diversity of swarm and enhance the dispersibility of search, when maintaining a certain number of excellent particles, the algorithm shrinks the area based on the dynamic state of the best position of the swarm and randomly generates particles in the contractive area to replace particles with poor performance.

C. Optimization Method of Chaotic Particle Swarm Optimization to Parameter of Input - Shaping

(1) Optimizing design flow

The optimization of chaotic particle swarm optimization to the design is the core link of the optimization and the process is shown in figure 13. The particle is the bridge which connects particle swarm optimization and simulink model, which is $A_1$, $A_2$, $t$ in the equation (11). Its optimization process is as follows: chaotic PSO generates the particle swarm and assigns particles in the particle swarm to parameter $A_1$, $t$ in input—shaping successively and then operates simulink model of control system and gets the performance index of the set of parameter. The performance index is transferred to chaotic PSO as the adaptive value of the set of particle and finally judges whether to quit the optimization or not.

![Figure 13. PSO process](image)

**V. Verification of Test Results**

A. Collection and Analysis of Site Apparatus Signal

It collects the online speed signal of business four-color form press BF-4400B of Beirenfushi, as shown in figure 14.

![Figure 14. BF-4400B press](image)

The whole set achieves the closed-loop control in PLC by signal from control encoder. Use the control encoder to collect signal and test the speed by M/T method as well as adopts first order inertial element to make filtering. The operation curve is shown in figure 15.

![Figure 15. Site test of torsional vibration](image)

Parameters selected in the test process are shown in table 1.

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inertia time constant T</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>Resolution ratio of encoder</td>
<td>228000 pulse/rad</td>
</tr>
<tr>
<td>3</td>
<td>Sampling period of monitoring PLC</td>
<td>1ms</td>
</tr>
</tbody>
</table>

In the running state with high speed, torsional vibration is obvious. After fft, it is found that there is a low frequency vibration point at 5 Hz, which leads to torsional vibration.

B. Introduction to Test Platform

In order to simulate the start-up procedure of press, it constructs multi-mass rotational platform which is composed by control system, actuator and detector. Master control system adopts X20 series of PLC of B&R and its sampling period can be 400us. Mechanical structure is composed by motor, speed reducer, mass block and spring. Specific parameters are shown in table 2.

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motor</td>
<td>20W</td>
</tr>
<tr>
<td>2</td>
<td>Speed reducer</td>
<td>Reduction ratio: 14:1</td>
</tr>
<tr>
<td>3</td>
<td>Mass block 1</td>
<td>Rotational inertia 1.5865*10^(-5)</td>
</tr>
<tr>
<td>4</td>
<td>Mass block 2</td>
<td>Rotational inertia 4.6630*10^(-5)</td>
</tr>
<tr>
<td>5</td>
<td>Spring stiffness</td>
<td>2.42x10^-7~2.58x10^-7 Nm/rad</td>
</tr>
<tr>
<td>6</td>
<td>Resolution ratio of encoder</td>
<td>1000 pulse/rad</td>
</tr>
<tr>
<td>7</td>
<td>Master control PLC</td>
<td>X20 series of PLC or B&amp;R</td>
</tr>
<tr>
<td>8</td>
<td>Sampling period</td>
<td>1ms</td>
</tr>
</tbody>
</table>

The position signal is reported back to master control PLC by encoder and then composes the closed-loop system. The gridding precision of encoder is 1000 lines/circle. PLC sampling module subdivides it into four and the precision of subdivision is 4000 lines/circle.
Adopt multi-mass transmission platform to simulate the torsional vibration of press in the transmission process and make open loop test and closed loop test with $P=0.5, I=0, D=0.001$. The test results are shown in figure 17.

Compared with the actually collected signal, torsional vibration of simulation experimental platform is more obvious in the start-up process. It can completely simulate the start-up process of press in engineering practice.

### C. Simulation Optimization

Adopt the sampled data in figure 17 as the input signal. The objective value is set as 8500Puls/s. In matlab, respectively adopt traditional particle swarm optimization and chaotic particle swarm optimization to make offline optimization to $A_1$ and $t$. The specific parameters are shown in the following table.

After optimization of PSO, $A_1=0.4962, A_2=1-A_1=0.5038, t=0.1000$. The optimization process of PSO order shaper is shown in figure 14.

Compared with traditional PSO, it can be seen that the adaptive value of chaotic optimization becomes basically stable after iteration for three times. But traditional particle swarm will be stable for five times. Parameter optimization particle swarm has no change after six times but traditional optimization needs eight times. As for the optimization result, in terms of traditional optimization, $A_1=0.4964, t=0.1$; in terms of chaotic optimization, $A_1=0.4962, t=0.1$. The difference can be ignored. The simulation result is shown in the figure.

Compared with the curve in figure 19, the torsional vibration caused by electromechanical coupling can be basically eliminated.

### D. Platform Experiment

Bring the optimization parameter to the experimental system and collect signal, as shown in the figure:
After adopting input-shaping, closed loop system adopts ITSE function to calculate the adaptive value, which decreases from ITSE=15478.7 to 7051.9. Compared with the situation without addition of input-shaping, the vibration damps by half.

VI. Conclusion

(1) This article firstly analyzes reasons leading to the system vibration of coaxial drive press, which is that input signal stimulates the pole near the imaginary axis leading to the torsional vibration of system in the start-up process.

(2) Secondly, by analyzing the mathematical model of press system, based on the site data collection, it constructs multi-mass transmission platform and studies the start-stop vibration of press.

(3) As for torsional vibration, it firstly puts forward the structure of optimal closed loop input-shaping and constructs the chaotic particle swarm optimization to carry out automatic optimization for the parameter of input-shaping. The newly constructed structure converts the transfer function and achieves one-time online optimization compared with traditional structure, which avoids the system vibration caused by online optimization and avoids the poor precision caused by inappropriate modeling in the process of pure offline optimization.

(4) It makes a comparison between chaotic particle swarm optimization and traditional particle swarm optimization. After verification of simulation experiment, it can be found that chaotic particle swarm has faster speed of convergence than traditional particle swarm optimization.

(5) After verification of physical experiment platform, it adopts the PID controller of closed loop input-shaping, which has sound effect of vibration suppression on the torsional vibration caused by pole coupling in the secondary flexible connection structure in the transmission structure of coaxial drive press. It adopts ITSE function to evaluate vibration value, which decreases from ITSE=15478.7 without the addition of input-shaping to ITSE=7051.9, with the decrement for 54.4%.

ACKNOWLEDGEMENT

National Scientific and Technological Supporting Projects Innovation Application Demonstration Project of the First Generation CNC Mechanical Products (2012BAF13B00)

REFERENCES