Research on torsional vibration modelling and control of printing cylinder based on particle swarm optimization

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Abstract. The torsional oscillation is the dominant vibration form for the impression cylinder of printing machine (printing cylinder for short), directly restricting the printing speed up and reducing the quality of the prints. In order to reduce torsional vibration, the active control method for the printing cylinder is obtained. Taking the excitation force and moment from the cylinder gap and gripper teeth open & closing cam mechanism as variable parameters, authors establish the dynamic mathematical model of torsional vibration for the printing cylinder. The torsional active control method is based on Particle Swarm Optimization (PSO) algorithm to optimize input parameters for the servo motor. Furthermore, the input torque of the printing cylinder is optimized, and then compared with the numerical simulation results. The conclusions are that torsional vibration active control based on PSO is an availability method to the torsional vibration of printing cylinder.

1. Introduction
With the development of materials, electronics, control technology, active control has become a new way in the field of torsional vibration suppression in recent years. It has been noted (Parimal and Catalin, 2013) that a comparative review of modelling and controlling torsional vibrations and experimentation using laboratory setups. Particle Swarm Optimization (PSO) is an artificial intelligence algorithm developed by authors based on the social behavior metaphor (Kennedy and Eberhart, 1995). However, the problem of torsional vibration for impression cylinder of a complicated sheet fed offset printing machine has not yet been solved, so far no PSO application in this field.

Due to the torque on the rotary body and the angular displacement fluctuation changes with time, they lead to the printing cylinder system torsional vibration. The torsional vibration not only affects the printing cylinder in steady state process, but also affects the printing quality. Researchers had made a lot of effort in the printing machine dynamic testing and design. The author (Riese, 2014) has studied the influence of torsional vibration to the printing machine drive motor on overprint, presenting a strategy for compensating existing deviations.

2. Printing cylinder torsional vibration phenomenon and characteristics
The paper studied the characteristics of transmission chain of a certain printing machine. And its printing cylinder structure schematic diagram is shown in Fig.1.
3. Particle Swarm Optimization for printing cylinder

Particle Swarm Optimization (PSO) algorithm known as particle swarm optimization method is a branch of artificial intelligence, which imitates the social behavior of bird flocks searching for feed. Each particle stands for one set of possible solution, and all of them form a swarm. Swarm consists of m particles:

\[
S_{\text{swarm}} = \{x_1, x_2, \ldots, x_m\}
\]  

In the standard PSO algorithm, the d-dimensional neighborhood function of the i-th particle at time \( k \) is calculated by:

\[
v_{id}(t + 1) = wv_{id}(t) + c_1 r_1 (p_{id}(t) - x_{id}(t)) + c_2 r_2 (p_{id}(t) - x_{id}(t))
\]

\[
x_{id}(t + 1) = x_{id}(t) + v_{id}(t + 1)
\]

Combining F(2) and (3), the optimal position \( p_{id}^{k} \) of the individual history is the optimal position of the i-th particle in the previous t generation. The iterative formula is given by

\[
p_{id}(t) = \begin{cases} 
    p_{id}(t-1), f(p_{id}(t)) > f(p_{id}(t-1)) \\
    x_{id}(t), \text{ etc}
\end{cases}
\]

By F. (4), optimal position of the swarm is defined as:

\[
p_{id}(t) = \arg \min \{f(p_{id}(t), i=1,2, \ldots, m)\}
\]

In the above Eqs., \( i=1,2, \ldots, m \).

In order to guarantee the stability of the algorithm in Eq.(5), when the neighborhood function generates new particle velocity, the constraint condition on speed is satisfied:

\[
|v_{id}^{(k)}| \leq V_{\text{max}}
\]

The meaning of each parameter in the F. (6) is shown in Tab.1.

| \( k \) | Inertia weighting factor | \( V_{\text{max}} \) | Velocity vector restricts the constants |
|------|--------------------------|------------------|------------------------------------------|
| \( x_{id}^{(k)} \) | Current position of the particle \( i \) | \( r_1, r_2 \) | A random number between (0,1) |
| \( v_{id}^{(k)} \) | \( i \) Particle velocity | \( m \) | Population number of particles |
| \( p_{id}^{(k)} \) | \( i \) particle individual position optimal value | \( D \) | Search space dimension |
| \( P_{id}^{(k)} \) | Population position optimal value | \( f(\cdot) \) | Fitness (target) function |
Other parameters include the number of iterations, the maximum speed, and population size and so on. Where the swarm size depends on the complexity of the actual problem. For the general problem, the number of 30-40 particles is a good result, in this paper we select swarm size \( m = 50 \); the maximum velocity determines the maximum distance traveled by a particle in a seek cycle, is usually set to \( V_{\text{max}} = 1 \); The number of iterations is set to 60.

4. Realization of active controller simulation
For the parameters selection of the printing cylinder, the more optimization parameters, the better the optimization effect improved, while the difficulty of optimization parameters increases.

4.1 An optimal control model for torsional vibration of printing cylinder
In order to achieve control of torsional vibration for the printing cylinder, the whole system is regarded as a two order coupling with two conjugate poles, and the printing cylinder is simplified as two order system by modal reduction order.

Mathematical model is derived as follows:

\[
J \ddot{\theta} + K \theta = M
\]

The \( F(7) \) is transformed into a state Eq. in which both sides are simultaneously left multiplied by \( J^{-1} \), and rearranged

\[
\dot{\theta} = J^{-1} K - J^{-1} K \theta
\]

The input torque and output position of the printing cylinder motor are taken as the optimization variables, and they can be expressed as:

\[
X = \begin{bmatrix} J_m, \theta_m \end{bmatrix}
\]

If taking the weighted acceleration RMS values the surface of the printing cylinder of the objective function as the minimum of the target function by \( F(8) \) and(9), it is expressed as:

\[
\min E[X] = \min \left\{ \delta = \left[ \int_{0.5}^{80} v^2(E)H(E)\left| z^{-q}G_y(E)df \right|^2 \right]^{1/2} \right\}
\]

The objective function of the optimal design of the impression cylinder is finally determined as:

\[
\min E[X] = v_1 \delta_\theta^2 + v_2 \delta_j^2
\]

4.2 Control simulation with Simulink
Through the acquisition of the signal of mechanical system, the response parameters are determined in the off-line module.

Select the \( S \)-function module in Simulink, and join the PSO \( S \)-function algorithm programmed in module, finally encapsulate them. Add the encapsulated module into the simulation model to get the simulation model based on PSO algorithm. Analysis of simulation result: After the simulation is completed, the optimized results are compared and analyzed. The contrast results are shown in Fig.2 (red line is parameter not optimized curve, blue line is parameter optimization curve).

![Figure 2](image-url)

Figure 2. Simulation results of printing cylinder speed curve before and after active control

It is proved that the torsional vibration model was optimized by PSO algorithm, the torsional vibration of impression cylinder is controlled effectively, and the sensitivity of the input torque response is improved.
5. Experimental studies on torsional vibration test and active control

After system modeling and simulation of the printing cylinder, method and active control of torsional vibration of the printing machine are verified in printing cylinder experimental platform.

5.1 Experimental system design

The torsional vibration test platform is mainly composed of a four color sheetfed offset press, servo motor drive system, dynamic torque sensor and B&K data acquisition system.

![Torsional vibration test platform of printing cylinder](image)

1- servo driver; 2- dynamic torque sensor; 3- servo motor; 4- testing press; 5- B&K acquisition instrument; 6- digital tachometer; 7- software dongle; 8- pulse test system

Figure 3. Torsional vibration test platform of printing cylinder

The experimental platform is divided into driving unit, torsional vibration detection unit and load unit, the driving unit includes servo motor, bracket and elastic coupling. The test system used in the experimental platform is Denmark B&K PULSE vibration testing system. Test principle is that the vibration signals after the sensor acquisition, signal amplification and filtering processing, to achieve the signal processing, the processed data are input to the computer and displayed.

5.2 Torsional vibration test

The torsional vibration test platform is used to simulate the torsional vibration of the printing cylinder under the periodic excitation force, in which the excitation period of the gripper open-closing cam mechanism is determined according to the speed of the motor.

First, adjust the torque sensor to maintain a high degree of coaxial with the drive shaft and load shaft. Then servo motor drive, servo motor speed up to 10000 S/H, respectively, 12000 S/H, and acquisition speed of the system dynamic torque changes. The experiment measured 6 sets of experimental data, Fig.4 is the actual acquisition signal interface, where the ordinate represents the torque, and the abscissa represents the number of points, that is, sampling time.

![Torsional vibration time domain diagram of printing cylinder](image)

(a) 10000 S/H  (b) 12000 S/H

Figure 4. Torsional vibration time domain diagram of printing cylinder

The torque the driving force to change the direction of the whole system to produce the torsional vibration phenomenon is obvious.

5.3 Torsional vibration control experiment

In the steady running of the printing stage, torsional vibration for printing cylinder measurement data is obtained and analyzed. The torsional vibration controllable parameters are optimize and controlled with the built-in motion controller for servo drive system.

Increase the input torque in the angular position of the 6 peaks in a rotating period of the servo motor, and measure the torsional vibration of the cylinder again.
Figure 5. Active vibration control time domain of printing cylinder

In combination with Fig. 5, the torque variation curves of the roller transmission shaft before and after torsional vibration control are compared, shown in Tab. 3.

| Increasing speed range (S/H) | Before control | After control | Amplitude cut off before and after control |
|-----------------------------|----------------|--------------|--------------------------------------------|
|                             | Maximum amplitude of acceleration | Maximum amplitude of acceleration |                                      |
| 8000 Speed up to 10000      | 0.5719         | 0.4609       | 19.4%                                       |
| 10000 Speed up to 12000     | 0.5386         | 0.4131       | 23.7%                                       |
| average                     | 0.5553         | 0.4370       | 21.6%                                       |

After application of the active control strategy with the servo motor, the torsional vibration of the printing cylinder is significantly reduced at the teeth on-off cam mechanism action.

The results show that the experimental platform is suitable for measuring torsional vibration of the impression cylinder at arbitrary speeds. And with the active control to the torsional vibration for the printing machine, the response time of angular velocity and amplitude is improved to realize the optimal control effect of torsional vibration.

6. Conclusion

In view of the common torsional vibration problem of the printing press, the PSO optimization algorithm is used to optimize the input torque of the printing cylinder, which proves the effectiveness of the method in reducing the torsional vibration of the printing cylinder.

Experimental study on active control of the printing cylinder torsional vibration builds the experimental platform for motion and vibration control. The results show that the input torque of the printing machine cylinder optimized the fluctuation of time can effectively reduce the angular velocity and the amplitude of the printing cylinder.

The peak of the torsional amplitude of acceleration is cut down after application of the active control strategy with the servo motor. The conclusions are that torsional vibration active control based on PSO is an availability method to the torsional vibration of printing cylinder.

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