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Design and Experimental Analysis of New Double-Pitch Rocker-Pin Silent Chain for Conveyors

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Abstract: In order to decrease the lateral fluctuate and implement high speed and smooth conveying and based on the inner-outer compound meshing theory and design method of Hy-Vo silent chain, a new type of double-pitch rocker-pin silent conveyor chain was proposed. The main technical parameters and structure of chain plate were described and its meshing theory and causes of lateral fluctuate were discussed and analyzed. A compared simulation test between the new double-pitch rocker-pin silent conveyor chain and standard round-pin silent conveyor chain about lateral fluctuate had been done to verify the design's advantages. The analysis results show that the lateral fluctuate value generated by the new double-pitch rocker-pin silent conveyor chain was largely smaller than that of the comparison type. And the design could improve the conveying conditions distinctly.

Keywords: Compound meshing, inner-outer, lateral fluctuate, mechanical design, meshing impact, polygon effect, silent conveyor chain,

INTRODUCTION

As the improvement of machinery industry, more and higher requirements about conveyor systems are made by manufacturer, such as high transmission speed, accurate transmission positioning and heavy load, *et al*. But in conveyer systems, traditional double-pitch roller chains has a problems of low transmission speed, serious polygon effect, large impact load and lateral fluctuate (Liu *et al*., 1998; Troedsson *et al*., 2001). Although the use of standard silent conveyor chain ANS (2007) has largely increases the transmission speed and the load ability, the problem of large lateral fluctuate has not been improved (Huang, 2003; Wang *et al*., 2007).

Hy-Vo silent chain is a kind of rocker-pin silent chain which has a smaller polygon effect than round-pin silent chain (Zheng *et al*., 1984; Feng *et al*., 2005). Although it has been invented and manufactured by many companies, there are very few documents published on this topic, and none of them touches Hy-Vo silent chain's design. Some previous papers discussed the kinematics and the dynamic characteristics of the Hy-Vo silent chain meshing with the outside flanks (Bucknor *et al*., 1994; Zhang, 1996; Li, 2008). In recent years, Chinese scholars Meng (2008), Meng *et al.* (2006) and Li (2007) had summarized and presented the inner-outer compound meshing theory, and the design method of the Hy-Vo silent chain with inner-outter compound meshing mechanism in detail. Feng *et al.* (2005), had verified that the lateral fluctuate value produced by Hy-Vo silent chain with inner-outer compound meshing theory much smaller than standard silent chain's (Feng *et al.*, 2005).

Based on the research of Hy-Vo silent chain and the inner-outer compound meshing theory, a new type of double-pitch rocker-pin silent conveyor chain (short for double-pitch silent chain bellow) was designed to decrease the lateral fluctuate value in transmission system. Compared with the same type of standard silent conveyor chain, it not only has the advantages of high transmission speed and heavy load ability, but also has the advantages of lighter weight (per meter 30% lighter than the standard silent chain) and smaller polygon effect which made it produce a small lateral fluctuate value in conveying process.

In this study, we designed the structure of chain plate and the involutes profile sprocket, analyzed the meshing process of the double-pitch silent chain drive, and we also had made a compared simulation test between the new double-pitch silent chain and standard silent chain about lateral fluctuate to verify design's advantage. The analysis results show that the lateral fluctuate value of double-pitch silent chain's was largely smaller than the comparison type's. Therefore the design had a great application value.

STRUCTURE DESIGN

The new type of double-pitch silent chain is a kind of variation structure of Hy-Vo silent chain which has

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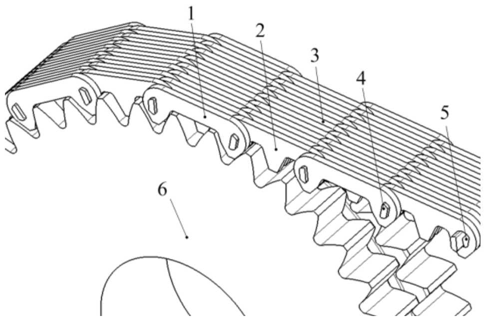

Fig. 1: Transmission sketch of double-pitch rock-pin silent conveyor chain, 1-Reinforcing plate, 2: M-plate, 3: Guide plate, 4: Locating pin, 5: Rolling pin, 6: Involute profile sprocket

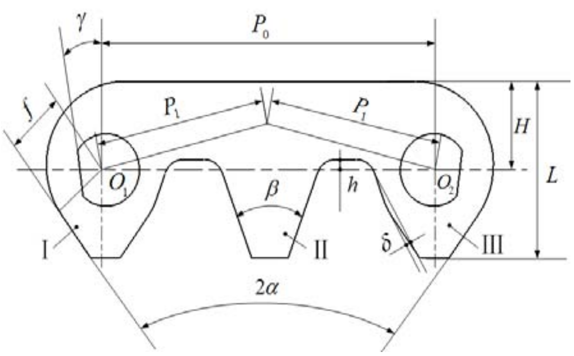

Fig. 2: Parameters schematic of M-plate

approximate twice pitches of standard silent chains. Figure 1 shows double-pitch silent chain's transmission sketch. It can be seen that it is mainly assembled by M-plate, reinforcing plate, guide plate, locating pin, rolling pin and involutes profile sprocket.

Structure of chain plate: Figure 2 gives the structure of M-plate and mainly designs parameters. The M-plate has 3 teeth, as shown in Fig. 2, tooth I and III are paper tooth, which mesh with sprocket teeth and transmit power or movement from driving sprocket to driven sprocket. Tooth II does not engage with sprocket and plays a role of decrease the wear between the top toe of chain plate and the track. The inner flank of paper tooth is a piece of arc which makes an extension δ = 0.1 - 0.2 mm to the outer flank of the adjacent M-plate when the link is straightened. And the both sides flanks of tooth II are all straight lines and the angle β should be large as possible to increase the contact area under the case of no interference between the middle tooth and sprocket teeth.

When the standard pitch P_1, sprocket teeth number z and sprocket's pressure angle a_1 are given, the main design parameters: the datum-hole center distance P_0 can be calculated by formula (1), the tooth angle α can be obtained by formula (2) and the distance from hole center to tooth top can be expressed as formula (3):

$$P_0 = 2P_1 \cos \pi/z \tag{1}$$

$$\alpha = \alpha_1 + 180^\circ/z \tag{2}$$

$$H = P_1(\sin(180^\circ/z) + 0.375) \tag{3}$$

The other design parameters such as datum side heart distance f and the offset angle γ, can be determined according to the design principle of Hy-Vo silent chain.

Sprocket profile: Studies have shown that silent chain engaged with Involute profile sprocket could reduce the impact load and noise effectively (Xue *et al*., 2007). But up to now, there is no unified design standard for silent chain sprocket, and most of the silent sprocket wildly used now is straight line tooth profile or there curves and a straight line tooth profile (ANSI, 2007).

The involute profile sprocket is actually a kind of gear with large negative variation coefficient η, and its pressure angle is 30 degree in general. Therefore it is needed to move the sprocket hob's middle line ηm micrometer towards sprocket's center to prevent the undercutting phenomenon between chain tooth profile and sprocket tooth. m is module of the sprocket which can be calculated by formula (4). When the chain type (P_0, f) and sprocket tooth number z are fixed, we can obtain variation coefficient η through formula (5):

$$\mathrm{m} = \frac{P_0}{2\pi \cos \pi/z} \tag{4}$$

$$\eta = \frac{\pi}{4}\left(\sqrt{3} + 2\cot \pi/z - \frac{4f \cos \pi/z}{P_0}\right) - \frac{z}{2} \tag{5}$$

MESHING PROCESS

The new double-pitch silent chain designed using inner-outer compound meshing mechanism was shown in Fig. 2. The inside flank profile of its study tooth is the convex curve instead of concave curve or straight line inside flank which is usually used in standard silent chain's tooth profile. When the chain is straightened,

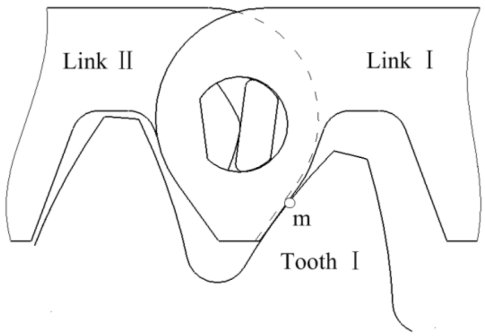

Fig. 3: Inner engagement process

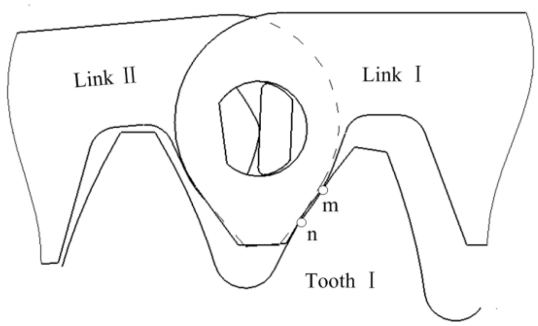

Fig. 4: Inner and outer engagement at the same time

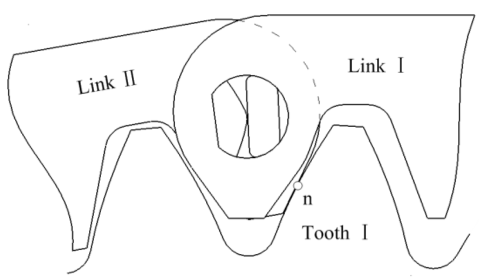

Fig. 5: Outer engagement

there exists an extension δ from inside flank of the M-plate's study tooth to the outside straight flank of the adjacent M-plate's study tooth on the same pin. And because of the special structure of M- plate, the meshing process of double-pitch silent chain and involutes profile sprocket can be divided into three parts: inner engagement process, inner and outer engagement at the same time and outer engagement only, respectively shown in Fig. 3 through Fig. 5.

Let point m is the contact point on the study tooth inside flank of link I and point n is the contact point on the study tooth outside flank of link II. Figure 3 shows that link I begins to contact with tooth I at point m, and at this moment the study tooth outside flank of link II does not contact with tooth I for the extension δ. As the increase of relatively rotate angle between link I and link II, Fig. 4 shows the state of the transmission process from inner engagement to outer engagement in which the outside flank of link II generally gets out from inside flank of link I and contacts with sprocket tooth I at point n, and the inside flank of link I does not separate from tooth I in a short time. In general, point n locates below point m. And then, as shown in Fig. 5, the study tooth's inside flank of link I indent in the study tooth's outside flank of link II and quits the engagement, there is only outside flank of link II contact with tooth I. And when the relatively rotate angle between link I and link II reaches $4\pi/z$, the new silent chain is seated on the teeth of sprocket with the outside flanks of the links.

SIMULATION TEST AND DISCUSSION

Meshing impact and polygon effect which are 2 kinds of inevitable phenomena in chain drive systems are the most important factors causing lateral fluctuate of the conveyor chain. And in high-speed and accurate transmission conditions, the lateral fluctuate value is one of most important indicators for measuring the quality of conveyor chains. So it is necessary for the new double-pitch silent conveyor chain to compare its lateral fluctuate features with standard silent conveyor chains through simulation tests to prove the superiority of the design.

Simulation model: The compared simulation tests about lateral fluctuate used the same simulation model shown in Fig. 6. And the model was assembled by test chains, Driving sprocket, driven sprocket, drive shaft, driven shaft and the base. In order to simplify the model, we made the following 3 assumptions:

- Analyses the tight side chain only, ignored the slack side chain

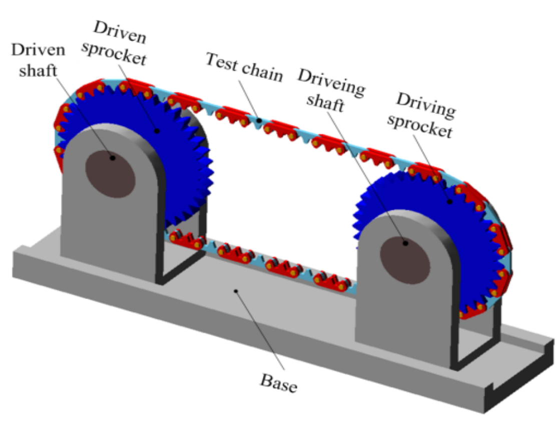

Fig. 6: The simulation model of chain drive system

Table 1: Lateral displacement of gravity centers of M-plates on double pitch silent chain's tight side

	Displacement of y orientation y_i (mm)				
No.	0.36 s	0.37 s	0.38 s	0.39 s	0.40 s
1	77.75	77.99	78.15	78.08	78.06
2	77.72	78.09	78.28	77.88	78.06
3	77.87	78.19	78.25	77.78	78.06
4	78.17	78.09	78.05	77.68	77.96
5	78.25	77.99	78.05	77.88	77.73
6	78.19	77.79	77.65	77.88	77.69
7	78.21	77.79	77.71	78.08	78.06
8	77.92	78.09	77.75	78.18	78.26
9	77.97	78.19	77.95	78.18	78.06
10	77.87	77.79	78.15	78.24	78.16

Table 2: Lateral displacement of gravity centers of chain plates on standard silent chain's tight side

	Displacement of y orientation y_i (mm)				
No.	0.36 s	0.37 s	0.38 s	0.39 s	0.40 s
1	78.96	79.02	78.09	77.69	78.92
2	78.27	79.22	78.59	78.42	79.12
3	78.25	79.12	78.69	78.39	78.92
4	78.56	78.62	78.19	78.59	78.62
5	78.64	78.02	77.89	79.09	78.22
6	78.26	77.72	77.69	79.09	77.62
7	78.06	77.72	78.19	78.39	77.22
8	77.66	77.72	78.59	77.59	77.32
9	77.36	77.52	78.49	77.09	77.62
10	77.46	77.62	77.69	77.19	78.02

- The datum-hole centers of plates distributed on the pitch cycle, when the chain plates sated on the sprocket
- All parts are rigid body; ignored the elastic deformation of the parts

The test chains were the new type of double-pitch silent chain and standard silent chain. The pitch of double pitch silent chain was P = 25.4 mm and the number of chain link was Lp = 40, and the pitch of standard silent chain was P = 12.7 mm, and chain link number Lp = 80, the drive sprocket and driven sprocket had the same tooth number $z_1 = z_2 = 39$, rotate speed of driving shaft was $\omega = 500$ r / min , rotational resisting moment of the driven shaft was T = 20 Nm, simulation time was t = 0.5 s.

After the simulations was done, we selected ten gravity centers of chain plates on tight side of test chains as research objects respectively at time 0.36, 0.37, 0.38, 0.39 and 0.40 s. And then we extracted their displacement of y orientation. The data were listed in Table 1 and 2.

The lateral fluctuate value of test chains can be divided into two parts: one is lateral fluctuate value caused by polygon effect λ_p which can be expressed by Eq. (6) and the other is lateral fluctuate value caused by meshing impact λ_{im}, which can be obtained through using formula (7) to process the date in Table 1 and 2:

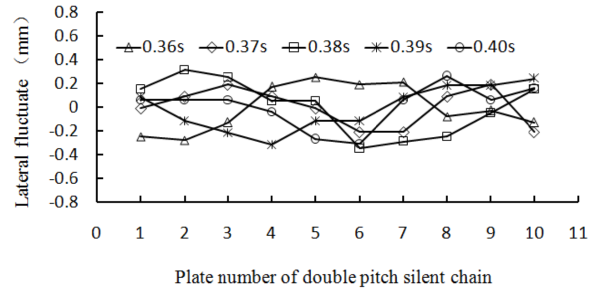

Fig. 7: Lateral fluctuate curves double pitch silent chain

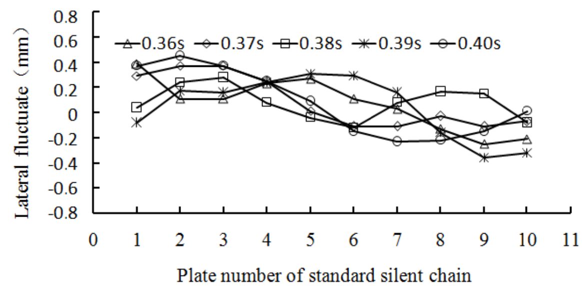

Fig. 8: Lateral fluctuate curves of standard silent chain

$$\lambda_{\rm p} = r(1-\cos\omega t) - \Delta \tag{6}$$

$$\lambda_{\rm im} = y_i - r - \lambda_{\rm p} \tag{7}$$

where r is the radius of pitch cycle.

And then we could draw the curves of lateral fluctuate value caused by meshing impact as shown in Fig. 7 and 8. The zero line expressed centre line of the tight side of test chains.

Compared Fig. 7 with Fig. 8, it can be seen that among the lateral fluctuate curves caused by meshing impact from 0.36 to 0.40 s, the maximum absolute value produced by standard silent chain was 0.57 mm, while that produced by double-pitch silent chain was only 0.28 mm. and the lateral fluctuate of the former was approximately 1.035 times larger than that of the latter.

The reasons of smaller lateral fluctuate of the new type of double-pitch silent chain can be summarized as follows: on the one hand, the use of rock-pin structure had effectively decreased the lateral fluctuate caused by polygon effect. On the other hand, the lighter weight per meter, the use of inner-outer compound meshing theory and the use of involutes sprocket in the drive system made the double-pitch silent chain system decreased the meshing impact distinctly.

CONCLUSION

The research on the conveyor chains for lateral fluctuate reduction started from changing the structures of standard silent chain, and a new type of double-pitch silent chain for conveyors was designed. Though analysis and simulations tests we can conclude that:

- The proposing of design method and main parameters of double-pitch rock-pin silent chain could accelerate the development and application of high-speed and heavy load conveyor chains. And it could provide guide for future designs and research.
- The polygon effect and meshing impact are the main reasons of lateral fluctuations for conveyor chain.
- Due to the lighter weight per meter and the use of inner-outer compound meshing theory, the double-pitch silent chain greatly reduced the lateral fluctuation caused by the meshing impact.
- Due to the rock-pin structure, the double-pitch silent chain greatly reduced the lateral fluctuation caused by the polygon effect.

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