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Research Article

The Design and Lateral Fluctuate Analysis of a New Double-Pitch Silent Chain for Conveyors

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Abstract: In order to reduce the lateral fluctuate in the conveying process of double-pitch roller chain for conveyors and implement smooth and steady conveying and based on the engagement theory and design method of silent chain, a new type of double-pitch silent chain for conveyors was proposed. Its chain plate was designed and analyzed its time-shared meshing theory and the reason of lateral fluctuates. and when rotating speed ω = 400 r/min, rotational resisting moment T = 20 Nm, a compared simulation tests between the new double pitch silent chains for conveyors and traditional double pitch roller chains for conveyors about lateral fluctuate values had been done. The analysis results show that the lateral fluctuate value of double pitch silent chain was largely smaller than the double-pitch roller chain's and the design could improve the conveying conditions distinctly. Therefore, the design of double-pitch silent chain for conveyors has value of application.

Keywords: Double-pitch silent chain, lateral fluctuate, meshing impact, polygon effect, time-shared meshing

INTRODUCTION

Chain for conveyor is a kind of chain driving systems which are wildly used in machinery manufacturing, agricultural machinery, metallurgy and other fields to transport parts, goods or materials. And double-pitch roller chain is the most wildly used conveyor chain (Zheng *et al*., 1984). But in conveying process, since the serious polygon effect and impact, the Lateral fluctuate is very large (Troedsson and Vedmar, 1999; Liu *et al*., 1998; Qin, 2010), which result in conveying error and increase the rejection rate.

Silent chain has been design, manufactured and improved since inverted in 1885. But there are few of study discuss about the design method of silent chains except some national standards, production manuals and patents. In recent years, some scholars make a series of deep researches on design methods (Meng *et al*., 2007; Liu, 2011), meshing theory (Meng, 2008; Xue *et al*., 2007; Meng *et al*., 2009), kinematics and the dynamic characteristics (Feng *et al*., 2005; Wang *et al*., 2007) and other sides researches about silent chain, which greatly enriched the types of silent chain and expanded its application range.

Although the use of standard silent conveyor chain. ANSI B29.2M (2007) has largely increases the transmission speed and the load ability, the problems of serious impact, bad wear and large lateral fluctuate have not been improved for its heavy weight per meter. Based on the previous studies of silent chain, we proposed a type of double-pitch silent chain to improve the problems existed in the conveyor with double-pitch roller chain. The double-pitch silent chain not only has the advantages of it not only has the advantages of high transmission speed and heavy load, but also has the advantages of lighter weight.

In this study, we designed the structure of chain plate, analyzed the time-shared meshing process, analyzed the reason of lateral fluctuate and we also had made a compared simulation test between the new double-pitch silent chain and double-pitch roller chain about lateral fluctuate to verify design's advantage. The analysis results show that the design of double-pitch silent chain produce a largely smaller lateral fluctuate than double-pitch roller chains. 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 standard silent chain which is mainly assembled by M-plate, reinforcing plate, guide plate and round pin. The M-plate and round pin and guide plate and round pin use clearance fit, the reinforcing plate and round pin use interference fit. And involutes sprocket is used in the chain drive system. Figure 1 shows double-pitch silent chain's transmission sketch.

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Table 1: Parameters and their formulas of M-plate

Parameter	Symbol	Design formula
Hole center distance/(mm)	P_0	$P_0 = 2P1 \cos 180°/z$, z-sprocket tooth number P-standard pitch
Tooth angle/(°)	2α	$2\alpha = 2\alpha_1+360/z$, α_1 = tooth angle of hoop
Side heart distance/(mm)	f	$f = 0.375P_1$
Distance from hole center to tooth top/(mm)	H	$H = P_1(\sin(180º/z) +0.375$
Distance from hole center to crotch/(mm)	h	$h = 0.06P_1$
Tooth angle of mid-tooth/(°)	β	$\beta = 40º46º$

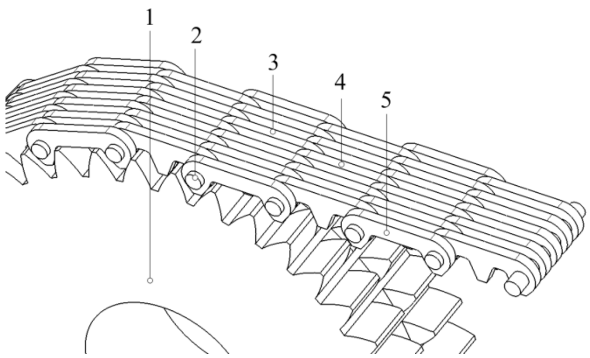


Fig. 1: Structure of double-pitch silent chain drive; 1- Sprocket, 2- Round pin, 3- M-plate, 4-Guide plate and 5- Reinforcing plate

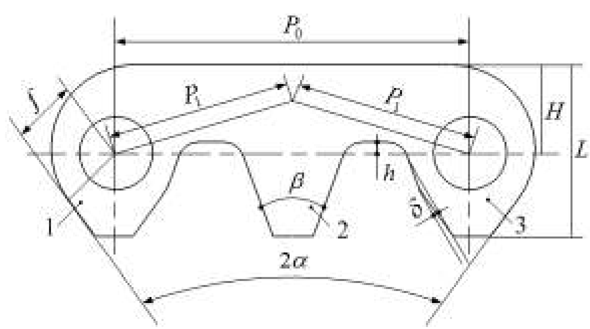


Fig. 2: Parameters schematic of chain plate

Figure 2 gives the structure of M-plate. The M-plate has 3 teeth, as shown in Fig. 2, tooth 1 and 3 are work tooth, which mesh with sprocket teeth and transmit power or movement from driving sprocket to driven sprocket. Tooth 2 does not engage with sprocket and plays a role of decrease the wear between the top toe of chain plate and the track. its mainly designs parameters contain Hole center distance P_0, Tooth angle 2α, Side heart distance f, Distance from hole center to tooth top H, Distance from hole center to crotch h, tooth angle of mid-tooth β and extension δ, *et al*. Table 1 gives the design formula of the designs parameters.

TIME-SHARED MESHING PROCESS

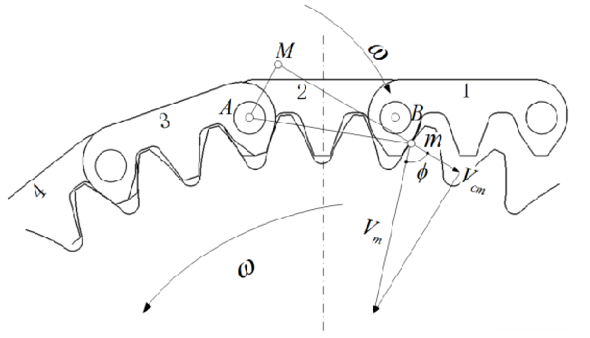
The new double-pitch silent chain designed using time-shared meshing mechanism was shown in Fig. 2. The inside flank profile of its study tooth is convex curve instead of concave curve or straight line inside flank which is usually used in standard silent chain's tooth profile. When the chain is straightened, there exists an extension δ from inside flank of the M-plate's work tooth to the outside straight flank of the adjacent M-plate's work tooth on the same round pin. And because of the special structure of M- plate, the inside convex curve flank contact with the sprocket tooth first and then as the relative rotation between the adjacent chain links, the inside flank separated with sprocket tooth and outside straight flank begins to mesh with sprocket tooth. Thus realize the time-shared mesh process. And when the relative angle between the adjacent chains links reach to $4\pi/z$, the outside straight flank of study tooth positioned on the sprocket.

LATERAL FLUCTUATE INCENTIVE

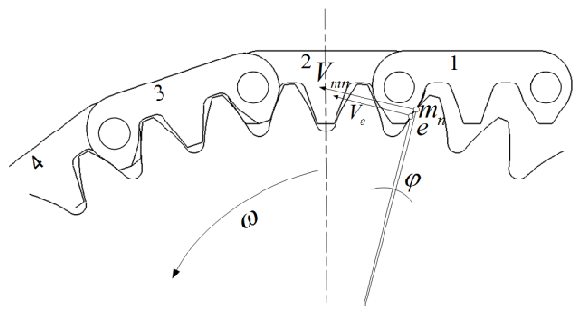
In the process of double-pitch silent chain drive, the slack side tension is much less than the tight side tension, so the influence of the slack side tension to sprocket acceleration can be neglected (Zheng *et al*., 1984). And when manufacturing errors and chain wear are also neglected, meshing impact between tight side and sprocket tooth and the polygon effect are the main incentive for the lateral fluctuation in double-pitch silent chain drive.

Meshing impact incentive: Due to the speed of first meshing point is not equal to the speed of chain link before engaging with sprocket tooth, it results in meshing impact. The influence of meshing in impact to lateral fluctuation is decided by the vertical component of normal impact between chain and sprocket. It is different from the outside engagement silent chain that the engagement process of double-pitch silent chain with time-shared meshing theory should be divided into two parts: inner engagement process and outer engagement process.

In the meshing process, firstly, the study tooth's inside convex curve flank contact with the sprocket tooth and as sprocket rotation, the contact point m move from m_0 to m_n along the tooth profile direction to the base circle and at this process, the impact speed decreases gradually. As shown in Fig. 3a, the normal impact speed of point m could be expressed as:



(a) Inner engagement process



(b) Outer engagement process

Fig. 3: Meshing impact of double pitch silent chain and involutes sprocket

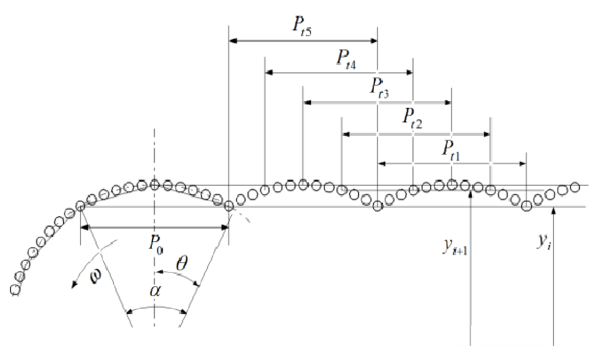


Fig. 4: Polygon effect's influence on lateral fluctuate of double pitch silent chain

$$\begin{aligned} V_{cm} &= V_m \cos\phi \\ &= \omega\overline{AM}\cos\phi = \omega\overline{AM}\cos\angle mAM \end{aligned} \tag{1}$$

When the contact point between work tooth's inside flank of link 1 and sprocket tooth is point m_n, if the relative angle between link 1 and link 2 continually increase, the inside flank get separated from sprocket tooth and work tooth's outside flank of link2 begin to contact with sprocket tooth at point, as shown in Fig. 3b and at this time the normal impact speed of contact point e can be expressed as below:

$$V_{ce} = V_e \cos(\phi_e - \varphi) - V_{mn}\cos\phi_{mn} \tag{2}$$

where, $V_e = \dfrac{\omega r_b}{cos\phi_e}$

$V_{mn} = \dfrac{\omega r_b}{cos\phi_{mn}}$

r_b = Base circle radius
ϕ_e = Pressure angle at point e
ϕ_{mn} = Pressure angle at point m_n

Polygon effect incentive: The polygon effect in double-pitch silent chain drive causes the uneven of transmission speed V and the change of the vertical instantaneous speed is one of the main reason for lateral fluctuate in chain drive.

Figure 4 shows the sketch of tight-side chain's lateral fluctuates caused by polygon effect in double-pitch silent chain drive. And in Fig. 4, the circles represent round pin of tight-side chain; P_{ti} is the place of round pin at time t_i; y_i is the distance between round pin and centerline. And thus we can get the lateral speed V_{yi} of tight-side chain caused by polygon effect through formula (3):

$$V_{yi} = \lim_{t_i \to t_{i+1}} \frac{y_i - y_{i+1}}{t_i - t_{i+1}} = r\omega\sin\left[\omega t - X\left(\frac{4\pi}{z}\right)\right] \tag{3}$$

Where X = Round function, $X = \left[\frac{\omega Zt}{4\pi}\right]$
r = Sprocket pitch circle radius
ω = Sprocket angular speed

Lateral acceleration of tight-side chain a_i can be expressed as below:

$$a_i = \lim_{t_i \to t_{i+1}} \frac{V_{yi} - V_{yi+1}}{t_i - t_{i+1}} = \frac{\mathrm{d}V_{yi}}{\mathrm{d}t} \tag{4}$$

And according to Newton's second law, lateral dynamic load acting on tight-side chain can be calculated:

$$F_i = ma_i \tag{5}$$

DYNAMICS SIMULATION

In high-speed transportation process, the transverse fluctuations of the conveyor chain will reduce the transmission accuracy, therefore, the simulation and analysis about transverse fluctuations of double pitch silent chain drive has important practical significance.

Simulation model: The compared simulation tests about lateral fluctuate used the same simulation model shown in Fig. 5. And the model was assembled by test

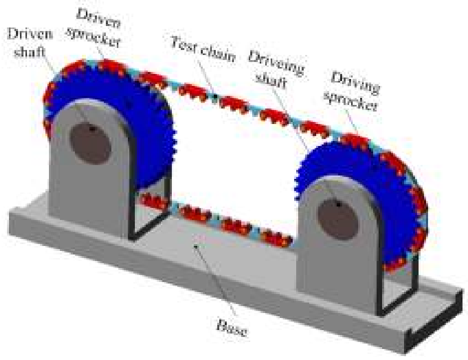


Fig. 5: The simulation model of chains for conveyor

Table 2: Lateral displacement of pins on double pitch roller chain's tight side

	Lateral displacement y_i (mm)				
No.	0.36s	0.37s	0.38s	0.39s	0.40s
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

Table 3: Lateral displacement of pins on double-pitch silent chain's tight side

	Lateral displacement y_i (mm)				
No.	0.36s	0.37s	0.38s	0.39s	0.40s
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

chains, Driving sprocket, driven sprocket, drive shaft, driven shaft and the base.

Simulation conditions: The test chains were the new type of double-pitch silent chain and double-pitch silent chain. The pitch of test chain was P = 25.4 mm and the number of chain link was Lp = 40, the drive sprocket and driven sprocket had the same tooth number $z_1 = z_2 = 39$, rotate speed of driving shaft was ω = 400 r/min, rotational resisting moment of the driven shaft was T = 20, simulation time was t = 0.5S.

Simulation result and analysis: When simulation finished, ten round pin of tight-side of test chains were selected as research objects respectively at time ti = 0.35 s, 0.37 s, 0.38 s, 0.39 s, 0.40 s and we extracted

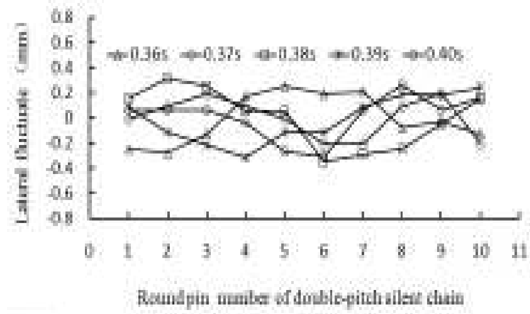


Fig. 6: Lateral fluctuate curves of pins on the new double pitch silent chain drive's tight strand

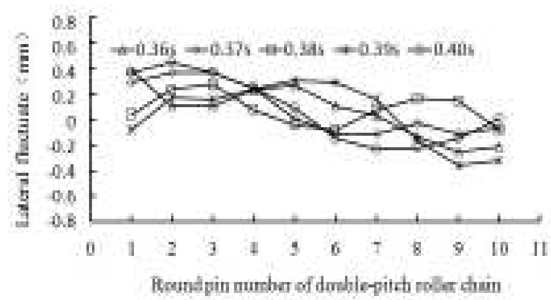


Fig. 7: Lateral fluctuate curves of pins on double pitch roller chain drive's tight strand

their y orientation displacement. The data were listed in Table 2 and 3.

And through the analysis of Lateral fluctuate incentive, the Lateral fluctuates value λ_i can mainly divide into two parts: λ_{im} the lateral fluctuates caused by polygon effect and λ_{ip} lateral fluctuate caused by impact. By using formula (6), (7), (8) to process the data, we drawn the lateral fluctuate curves of pin caused by impact shown in Fig. 6 and 7 and zero line expressed the centerline of tight-side of test chains:

$$\lambda_i = y_i - r \tag{6}$$

$$\lambda_{ip} = r(1-\cos \omega t) \tag{7}$$

$$\lambda_{im} = y_i - r - \lambda_{ip} \tag{8}$$

As shown in Fig. 6 and 7, the maximum lateral fluctuate value produced by double-pitch roller chain was 1.22 mm from the time 0.36 s and 0.40 s, but that produced by double-pitch silent chain was only 0.27 mm. It could be seen that the lateral fluctuate of the former was approximately 3.5 times larger than that of the latter.

And we also used standard deviation (formula (9) to analyze the data's dispersion (Jia, 2006). The results shown that standard deviation lateral fluctuate of double pitch roller chain was 0.593, while that of double- pitch silent chain was only 0.184. It could be gotten that transmission use double -pitch silent chain more smooth than transmission use double-pitch roller chain:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{9}$$

The reason of why double-pitch silent chain transmission much smoother than double-pitch roller chain is that the impact between double-pitch silent chain's work tooth and sprocket tooth is meshing impact which is more smaller than the normal impact between rollers of double-pitch roller chain and sprocket tooth, the use of time-shared meshing theory divide one impact process into two process which reduce the impact further.

CONCLUSION

- The proposing of design method and main parameters of double-pitch 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
- Due to the use of time-shared meshing theory, the double-pitch silent chain greatly reduced additional load caused by speed change, So that its lateral fluctuation significantly smaller than the double-pitch roller conveyor chain

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