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Experimental Investigation of Sprocket Tooth Form Effect on Dynamic Tension of Silent Chain

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Abstract: The study's aim was to get ANSI sprocket tooth profile and involute sprocket tooth profile for effects on dynamic tension of chains in the silent chain drive, and analyse and compare the advantages and disadvantages of the different tooth profiles to choose more practical tooth profile from the two sprockets. Current collector was used to test the dynamic tension when straight sprocket and involute sprocket engaged with the same silent chain. And experimental data measured were analyzed in the amplitude domain and frequency domain. Test results indicate that the probability of tension appearing in the different numerical size and power spectral densities of load in the different frequencies of the involute tooth form are better than of straight tooth form, which show that the involute sprocket has been good working properties. In addition, taking the advantages of involute tooth profile into account in the process, the involute tooth form is recommended in universal sprocket tooth form of the actual use.

Key words: Current collector, dynamic tension, silent chain drive, sprocket tooth form

INTRODUCTION

Sprocket is an important basic part in a silent chain drive system, and it has a direct impact on the working performance of the entire transmission system. General silent chain drive system is non-conjugated transmission (Zhengzhi *et al*., 1984; Liu *et al*., 1997), the feature of which is not high to the accuracy of the sprocket, and not strictly require the curve of a particular tooth form. Standards of silent chain sprocket mainly were: (ANSI B29.2M, 2007; DIN 8191, 1998). The ANSI B29.2M of which provided that working tooth profile of silent chain sprocket was a straight line, and the DIN8191 provides that working tooth profile of silent chain sprocket was involute. So far, there were yet no unified ISO standards of silent chain sprocket, national standards of transmission silent chain and sprocket were most the same as using the American standard ANSI B29.2M and were established in principle(ANSI B29.2M, 2007; DIN 8191, 1998; ISO606, 2004).

Chain tension and its changing laws were a comprehensive reflection of the force condition in work processes of the silent chain drive. A complete wave curve of chain tension could clearly show the Start-up shock of chain drive, tension change of slack/tight span, meshing impact, and dynamic loads and abnormal changes of loads caused by polygon effect (Calvo *et al*., 2006; Soviero and Lavagna, 1997; Wang *et al*., 1992). Such a curve with the corresponding frequency and amplitude of a variety of loads could be drawn by spectral processing. Figure 1 shows the typical change curve of silent chain tension (Zhengzhi *et al*., 1984).

Many scholars (Meng, 2008; Liu, 1994; Wada *et al*., 1999; Ward and Dwyer-Joyce, 2001) for the sprocket tooth profile did the theoretical analysis and experimental research, but qualitative research was basically used for some meshing characteristic of sprocket tooth profile, lack of quantitative analysis and comparison, In particular, experimental comparative analysis of the different sprocket tooth profile for effects on dynamic tension of silent chain in the chain drive. Therefore, under existing conditions, current collector was used to test the dynamic tension of chains which ANSI sprocket and involute sprocket engaged with, and the experimental results were analyzed and compared to get the advantages and disadvantages of the two tooth profiles, then choose more practical tooth profile from the two sprockets. Meanwhile, to promote the improvement of chain drive technology and develop universal standards of sprocket cutters, experimental verification report was provided.

EXPERIMENTAL METHODOLOGY

Figure 2 shows block diagram of the dynamic measurement system of current collector. When the dynamic tension of chains was measured, Chain rotated along a closed loop (rotation frequency f = V / L), this required rotor of current collector at the speed of n = 60 f synchronously operated with chain. And a flexible whip-wire was used to connect the strain gauge sensor and the

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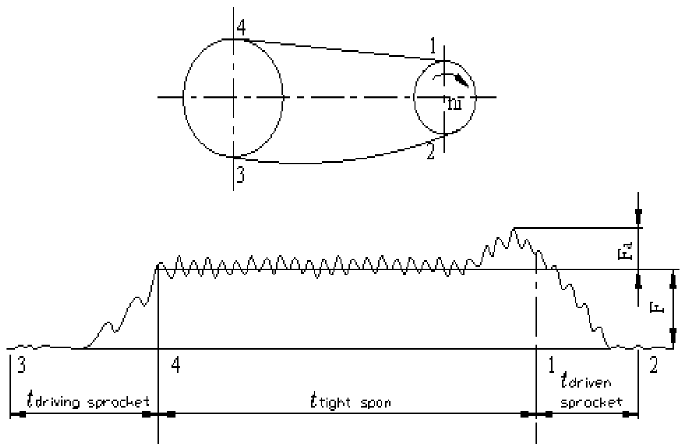


Fig. 1: Change curve of silent chain tension

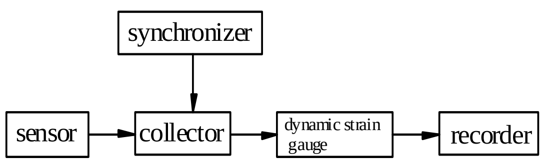


Fig. 2: Block diagrams of the dynamic measurement system of current collector

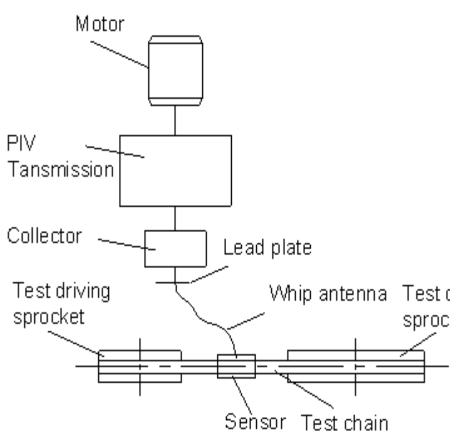


Fig. 3: The stepless adjustment synchronizer

rotor to lead the output signals of sensor. If the rotation speed of chain and one of the rotor of current collector were not synchronized, which made the whip - wire wrapped, even broken. Therefore, the rotor of current collector needed to be stepless speed to achieve synchronous operation. Figure 3 shows a stepless adjustment Synchronizer, PIV continuously variable transmission and AC adjustable speed motor were used by the device, so very wide range of stepless adjustment could be obtained.

Experimental Instruments and Equipments:

Component parameters of the chain drive: To contrast the change of sprocket tooth form influencing on the chain tension under the same experimental conditions, therefore, the relevant experimental conditions (such as processing and installation of sprockets, chain tension, etc.) to the two profile was kept consistent. Test objects were straight sprocket and involute sprocket. And test parameters pitch P = 15.875 mm, chain link number L_p = 122, sprocket tooth number $Z_1 = Z_2 = 26$. Test chain were pre-running 10 min, and oil - spray lubrication method was used.

Measuring point, arrangement and bridge connection: Figure 4 shows the experimental schematic diagram of arrangement and bridge connection of strain gauge. As the chain structure and size limits, it was difficult to symmetrically post strain gauge at both sides of the outer plate to eliminate the influence of bending deformation when the chain was forced, thus, this experiment only at the outside of the outer plate attached two strain gauge. In order to improve placement accuracy and efficiency, T - type strain rosette was used, the strain rosette employed foil strain gages with sensitive grid of which effective area of 2×1 mm^2. Full-bridge circuit shown in Fig. 4 was consisted of strain rosette and two standard resistors.

Test calibration: Because the measure was not the purpose of determining the point of stress, but was to determine the force acting on the chain. Therefore, direct calibration method of force was made use of to test chain tension. The method not only could simplify the calibration work, and could improve the measurement accuracy. Gradual loading, unloading, read of force values and record corresponding strain values were scheduled when the calibration was done, and the calibration curve of force was plotted based on the force and strain values corresponding. From the calibration

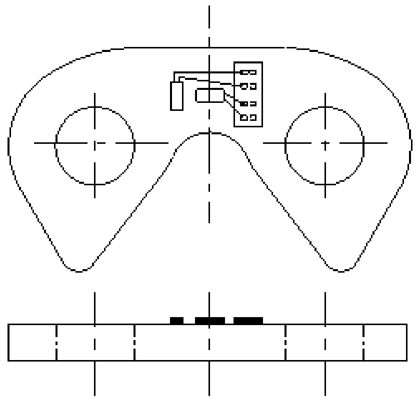


Fig. 4: Arrangement and bridge connection of strain gauge on the plate

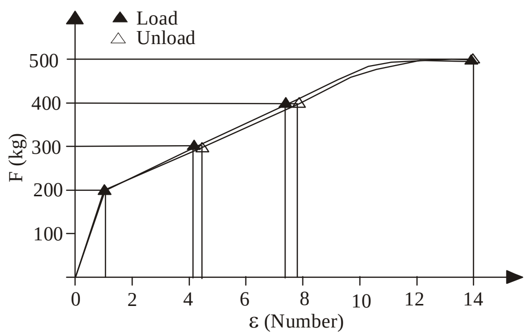


Fig. 5: Calibration curve of the tested chain

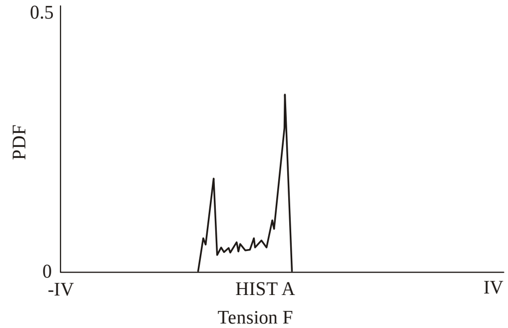
curve shown in Fig. 5, under the given test specifications, test system was essentially linear State, so the test could be prepared for.

EXPERIMENTAL RESULTS AND ANALYSIS

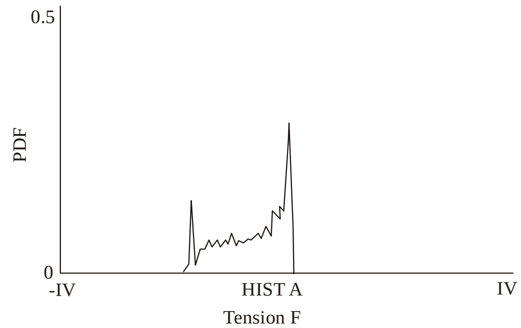
Tension signal was picked up by the dynamic strain gauge, recorded on the tape recorder, and then fed to the FFT dual-channel dynamic signal analyzers. Experimental data measured were respectively processed in the amplitude domain and frequency domain. Analysis results were as follows:

Amplitude domain analysis: Figure 6 shows the experimental probability density curve of the chain tension. The horizontal axis represented the tension in the figure, and the vertical axis represented the probability of tension appearing in the different numerical size. From the figure could be seen visually the distribution of the silent chain tension under the same experimental conditions.

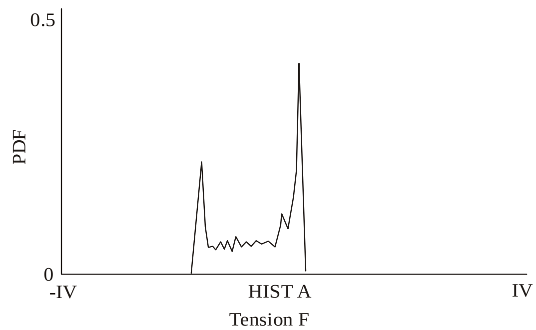
The difference between the probability of the larger chain tension appearing and that of smaller one for involute tooth form was smaller than that for straight tooth form, which indicated that the chain meshing with



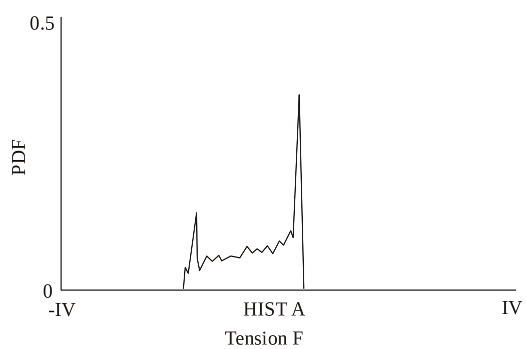
(a) Straight tooth from, n_1 = 300 rpm



(b) Involute tooth from, n_1 = 300 rpm

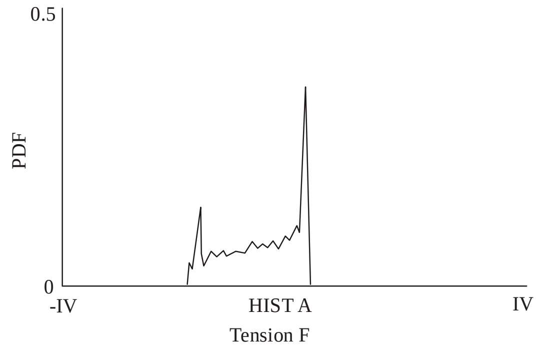


(c) Straight tooth from, n_2 = 500 rpm

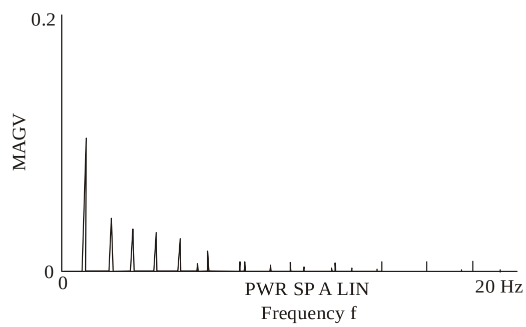


(d) Involute tooth from, n_2 = 500 rpm

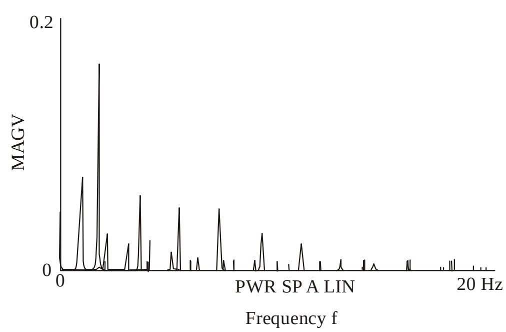
Fig. 6: Probability density curve of the silent chain tension



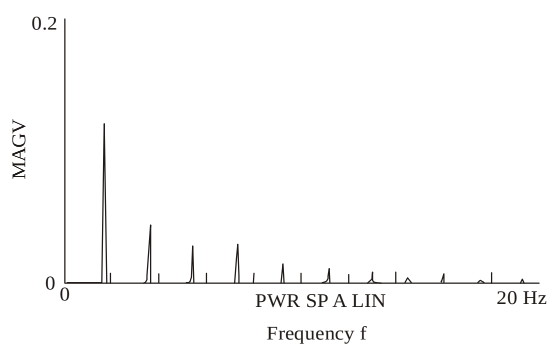
(a) Straight tooth from, n_1 = 300 rpm



(b) Involute tooth from, n_1 = 300 rpm



(c) Straight tooth from, n_2 = 500 rpm



(d) Involute tooth from, n_2 = 500 rpm

Fig. 7: Power spectral density curves of the silent chain tension

involute tooth form was better than that with straight tooth form in the capacity of resistance to fatigue failure. This was because in the loop operation of the chain, constantly undergoing repeated effect of the larger tight side tension and smaller slack side tension, chain plate was under varying load, after a certain number of cycles, fatigue failure in the stress concentration zone on both sides of the plate hole would occur.

Frequency domain analysis: Figure 7 respectively shows the experimental power spectral density curves Horizontal axis represented different frequencies in the figure, and the vertical axis represented the power spectral density. The values quantitatively reflected the distribution conditions of various loads in different frequencies.

- The figure shows frequency structure of the experimental curve to the two tooth profile was consistent under the same experimental conditions. Frequencies Under different peak were multiples of the first peak frequency (Basically equivalent to rotation frequency under the two speed conditions, where: n_1 = 300 rpm, f = 1.07 Hz; n_2 = 500 rpm, f = 1.78 Hz).
- Two tooth forms compared against amplitude (voltage value) at the same frequency, on the whole, the values of straight tooth form was larger than that of involute tooth profile, in particular, under the first peak.
- From amplitude corresponds to the first peak frequency caused by a higher wheel speed of view, straight tooth form was greater than involute tooth form. In other words, with the speed increase of the driving sprocket, dynamic load of chain transmission composed of straight tooth form was higher than that of involute tooth form when chain and sprocket meshed. The amplitude corresponding to the first peak was equal to that of dynamic load under rotation frequency of chains, and it could reflect the tension of tight span of chains meshing sprocket in work processes of the chain drive. The value for wear and fatigue of the silent chain was of great significance.

CONCLUSION

By the above analysis, judged from the difference of sprocket tooth profile effects on dynamic tension of silent chain, involute tooth form was better than straight tooth form. If the processing of tooth profile were further considered, for straight tooth form as sprocket tooth profile, supplementary information of US standard ANSI

B29.2M provided that each pitch silent chain sprocket (z = 17 to 150) requires seven sprocket hobs to hob respectively, thereby which increased the number of tools and made processing property poor. While for involute tooth profile as tooth profile of sprocket, the German standard DIN 8191 (1998) provided hobs were the straight tooth form, and the tooth top section and working segment of sprocket being cut were completely involute. And using a hob could process different tooth number of sprockets for a specification of the chain, which made manufacturing technology of sprocket hob simplified greatly, could directly reference a method of manufacturing gear hob to reduce manufacturing costs, made processing property improved greatly, and had obvious advantages. Therefore, involute tooth profile should be selected to universal sprocket tooth form in silent chain drive.

NOMENCLATURE

AC	= Alternating current
ANSI	= American National Standards Institute
DIN	= German Industrial standards
f	= Rotation frequency, Hz
F	= Effective circle force, N
FFT	= Fast Fourier Transform Algorithm
F_d	= Dynamic load, N
ISO	= International Standardization Organization
L	= Entire chain length, mm
L_p	= Chain link number
n_1	= Driving sprocket speed,rpm
n_2	= Driving sprocket speed,rpm
P	= Pitch, mm
PIV	= Positive infinitely variable drives
t	= Time, s
V	= Chain speed, m / s
Z_1	= Driving sprocket tooth number
Z_2	= Driven sprocket tooth number

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