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The Study of Synchronous Belt Transmission Stability with the Influence of Rotation Speed and Tension

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Abstract

The vibration of belt affects the transmission stability, products noise and the life of automotive synchronous belt. The mathematical model of longitudinal vibration was established through analyzing the longitudinal vibration of automotive synchronous belt. The vibration dynamic measurement device was developed based on the laser displacement triangulation measurement principle, aiming at RU style arc teethed synchronous belt transmission process, measured the variety of amplitude over time at the middle of the belt span when rotation speed was 600r/min, 1200r/min, 1800r/min and tensile force was 320N, 480N, 640N, obtained the rules of amplitude and frequency change along with the variation of rotation speed and tensile force. It has significance on improving the transmission stability of arc teeth synchronous belt, reducing the transmission noise and prolonging the service life of belt.

Keywords: *Arc teethed synchronous belt, vibration measurement, transmission stability*

1. Introduction

The synchronous belt is widely used in automobile engine timing driving system because of the simple structure, low price, easy installation, without lubrication, noise reduction and vibration absorption, Automotive synchronous belt can be divided into straight teeth synchronous belt and arc teeth synchronous belt according to the teeth shape Arc teeth synchronous belt , by reason of teeth loads reasonable distribution and effectively reducing the meshing interference, has higher bearing capacity and service life relative to the straight teeth synchronous belt, the current commonly used arc teeth synchronous belt mainly includes types RU and YU, etc.

In order to reduce vibration and noise and improve transmission stability and the life of belt, Scholars at home and abroad are studied and analyzed the vibration and the measurement method of synchronous belt , the natural frequency of the synchronous belt and the vibration by speed of synchronous belt was analyzed by the United States J MOON and Wickert. J. A, the vibration in the process of synchronous belt transmission was measured by the interferometer with 45 degree mirror [1]. M Callegari and others established the dynamic model of synchronous belt transmission by using multi-body dynamics software ADAMS, through the finite element analyzed the vibration in the progress of synchronous belt transmission, and with the help of laser Doppler vibration measured the vibration of the rounds of synchronous belt transmission system [2]. Blaza stojano vic and others analyzed the reasons of noise in the process of transmission and the tooth wear in the progress of synchronous belt transmission by the experimental method [3]. Yuping Yang and others set up static transverse vibration of synchronous belt and longitudinal vibration equation of motion [4]. At the university of North central Yanhua Wang and others analyzed the 469Q gasoline engine timing transverse vibration of synchronous belt, with the DH-10 strain type displacement sensor carried out the synchronous belt transverse amplitude variation measurement experiment [5]. Kunming

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University of science and technology Yanqiang Yao analyzed the contact vibration model of belt drive, and the simulation experiment was carried out [6-8].

The article adopts the theory of the laser triangulation displacement measurement principle developed the measurement device of synchronous belt longitudinal vibration, analyzed the change of speed and tension have the influence to the synchronous belt longitudinal amplitude and the vibration frequency, this has important application value to improve the smoothness of synchronous belt transmission.

2. The Establishment of the Synchronous Belt Longitudinal Vibration Model

The synchronous belt is elastic transmission units, in the transmission process will produce longitudinal vibration and transverse oscillation, as shown in figure 1, the section line with belt and driving wheel on the pitch point of contact for the origin of coordinates O, along the movement direction of the synchronous belt is the X axis, perpendicular to the direction of the synchronous belt surface is the Y axis, along with the axis of the wheel direction is the Z axis, the longitudinal vibration is perpendicular to the direction of the belt surface is Y axis to swing; lateral oscillation is the belt wheel axis direction is X axis to swing.

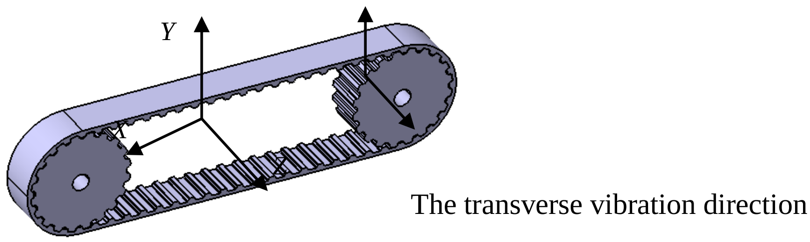

Figure 1. The Vibration Diagram Of Synchronous Belt

In the process of synchronous belt transmission, the longitudinal vibration amplitude is the largest; this is the main factors influencing the stability and noise of transmission, so this article is aimed at longitudinal vibration to study. As shown in figure 2, the equilibrium position of synchronous belt longitudinal vibration is X axis, belt and the pitch circle tangent point of pulley is the origin of coordinates O.

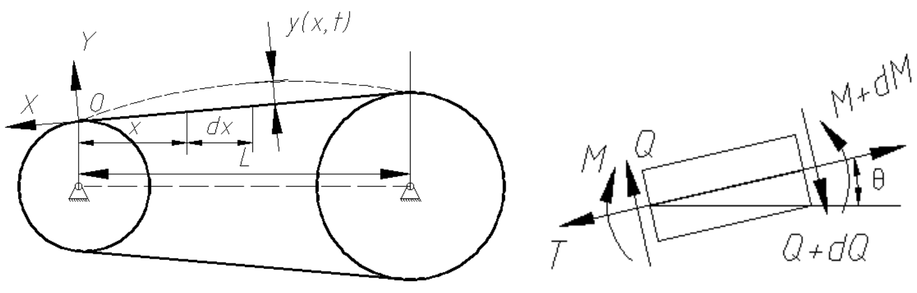

Figure 2. The Longitudinal Vibration Model Of The Belt

Belt tension as T, the quality of belt unit length as ρ, the flexural rigidity of belt cross section as EI, take a infinitesimal belt at a distance from the origin X to analysis, and its length is dx, at both two faces of micro-elements have shear Q, Q+dQ, moment M, M+dM, and tension T, an time t, the force balance equation of y direction and the torque balance equation of the left section midpoint of micro segment as equation (1) and (2):

$$Q\cos\theta(x,t)-(Q+\frac{\partial Q}{\partial x}dx)\cos\theta(x+dx,t)+T\sin\theta(x+dx,t)-T\sin\theta(x,t)=\rho dx\frac{\partial^2 y}{\partial t^2} \quad (1)$$

$$(M+\frac{\partial M}{\partial x}dx)-M-(Q+\frac{\partial Q}{\partial x}dx)dx=0 \quad (2)$$

Because the belt body vibration is minute vibration, so it can be simplified as follows:

$$\sin\theta(x,t)\approx\frac{\partial y(x,t)}{\partial x} \quad (3)$$

$$\sin\theta(x+dx,t)\approx\frac{\partial y(x,t)}{\partial x}+\frac{\partial^2 y(x,t)}{\partial x^2}dx \quad (4)$$

$$\cos\theta(x,t)\approx\cos\theta(x+dx,t)\approx 1 \quad (5)$$

The bending moment M(x, t), flexural rigidity EI, and the deformation y of the beam have the following formula:

$$EI\frac{\partial^2 y(x,t)}{\partial x^2}=M(x,t) \quad (6)$$

Take the formula (3) (4) (5) (6) into equation (1), (2)get the longitudinal free vibration motion equation of synchronous belt transmission, as shown in equation (7):

$$EI\frac{\partial^4 y}{\partial x^4}-T\frac{\partial^2 y}{\partial x^2}+\rho\frac{\partial^2 y}{\partial t^2}=0 \quad (7)$$

The motion and force transmission as constant speed in the process of synchronous belt transmission, so the longitudinal vibration of synchronous belt transmission, in addition to concerned with the span, tension, quality of the belt, but also comes with a change in velocity change, when the belt speed is v, can be obtained with longitudinal vibration y (x, t) derivative of time as follows:

$$\frac{dy}{dt}=\frac{\partial y}{\partial t}+v(t)\frac{\partial y}{\partial x} \quad (8)$$

So the longitudinal vibration acceleration is as follows:

$$\frac{\partial^2 y}{\partial t^2}=\frac{\partial^2 y}{\partial t^2}+2v\frac{\partial^2 y}{\partial x\partial t}+v^2\frac{\partial^2 y}{\partial x^2}+\frac{dv}{dt}\frac{\partial y}{\partial x} \quad (9)$$

Take equation (9) into equation (7)can be obtained the longitudinal vibration equation of the belt as shown in equation (10):

$$\frac{EI}{\rho}\frac{\partial^4 y}{\partial x^4}+\frac{\partial^2 y}{\partial t^2}+2v\frac{\partial^2 y}{\partial x\partial t}+(v^2-c^2)\frac{\partial^2 y}{\partial x^2}=0 \quad (10)$$

In the formula: $c=\sqrt{T/\rho}$ 。

From equation (10)can be seen that the amount of longitudinal vibration of synchronous belt not only related to the span L, initial tension T, but also with the velocity v of belt.

The main reason causing horizontal swing of the belt is that the tooth error along the direction of synchronous belt toothed the tooth error along the direction of pulley, the axial pulsation of pulley, and the parallelism of the drive shaft and the driven shaft during the transmission. Horizontal swing will cause the synchronous belt occurs traverse along the axial direction of pulley, it will cause the end face of belt contact with the flanges of pulley when serious, resulting in wear, reducing the life of the belt. It was found that the horizontal swing amplitude of synchronous belt transmission process is generally within 0.5mm by experiments, in order to avoid the horizontal swing in transmission process contact with the flanges of pulley resulting in section wear of belt, so in the design of the transmission system of automobile engine, the width of pulley should be wider than the width of the belt about 2 mm.

3. The Measurement Device of the Synchronous Belt Longitudinal Vibration

The longitudinal vibration signal of synchronous belt is a dynamic signal, in order to achieve non-contact dynamic measurement of the synchronous belt longitudinal vibration. A dynamic measurement device of the synchronous belt is developed based on laser triangulation displacement method. this device is mainly consists of a ZX-LD40L laser displacement sensor and a sensor bracket、magnetic table and measuring of analysis software. The measuring range is 10mm, the laser spot size is φ20μm, the measurement accuracy is 2μm, the sampling period is 1ms. The measurement platform can realize the measurement of synchronous belt longitudinal vibration amount, and the belt length is 350-2850mm, drive shaft speed can be adjusted in 50-2000n/min; Tension is applied by using heavy lump, tension can be adjusted in 400-1500N, the measurement device through a magnetic table seat mounted on a test bed frame, adjust the laser light spot irradiation in the middle point A with span, as shown in figure 3, then lock the magnetic table, the test of synchronous belt is 127RU22 type automotive synchronous belt, in the test for the driving pulley and the driven pulley type is RU synchronous belt wheel, its tooth number is Z=26.

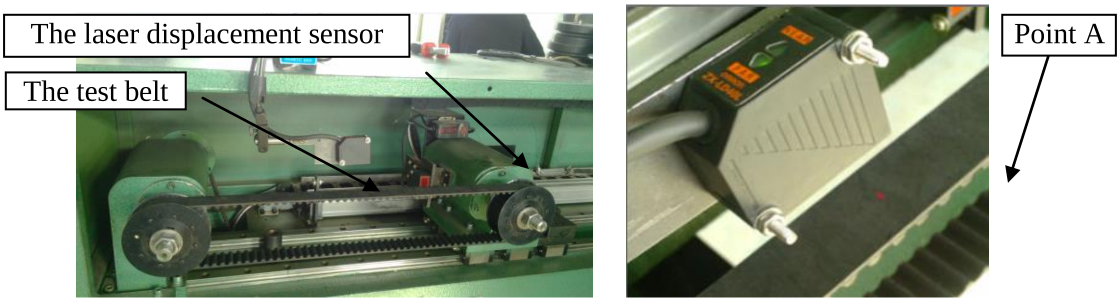

Figure 3. The Installation Drawing Of The Measurement Device

3. Analysis of the Longitudinal Vibration Displacement Results of the Synchronous Belt

Through the theoretical analysis we can see that the speed and the tension of belt and other factors directly affect the amplitude and frequency of the longitudinal vibration of belt, thus influence the stability of belt transmission process, and produce noise, influence the service life of the belt, because in the process of auto synchronous belt transmission, the amplitude of belt at span midpoint A is the largest, therefore, this paper carried out vibration displacement measurements at midpoint A of belt span.

In order to analyze the influence of speed and the tension on the vibration, in this paper, the synchronous belt vibration displacement measurement device was used to measure the variety of the driving pulley is 600r/min, 800r/min, 1000r/min, 1200 r/min, 1400r/min, 1600r/min, 1800r/min, when the tensioning force is 320N, 400N, 480N, 560N, 640N, obtained the rules of the amplitude of synchronous belt span midpoint A change along with time.

3.1. Analysis of Effect of Rotation Speed on the Longitudinal Vibration of Synchronous Belt

When the tension is 540N, the rotation speed of the driving pulley are respectively n=600r/min、1200r/min and 1800r/min, the curve of the amplitude of point A change along with time as shown in figure 4.

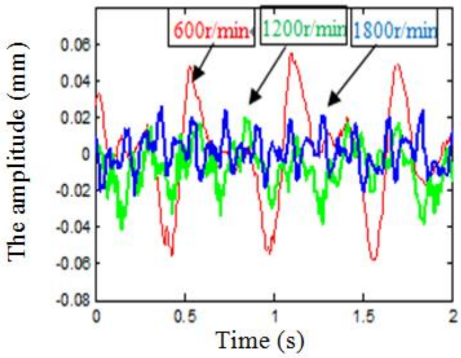

Figure 4. The Curve Of The Longitudinal Vibration Displacement Changes With Time

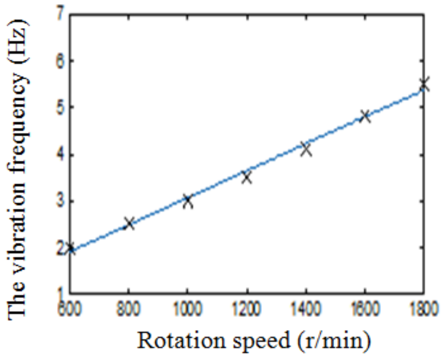

Figure 5. The Curve Of The Longitudinal Vibration Frequency Changes With The Rotation Speed

When the rotation speed of the driving pulley is n=600r/min, the maximum longitudinal amplitude of point A is 0.051mm, the time domain signal of point A was processed by the fast Fourier transform, obtained the vibration frequency of point A is 2Hz; When the rotation speed of driving pulley is n=1200 r/min, the maximum longitudinal amplitude of point A is 0.039mm, obtained the vibration frequency of point A is 3.5Hz; When the rotation speed of the driving pulley is n=1800r/min, the maximum longitudinal amplitude of point A is 0.029mm, obtained the vibration frequency of point A is 5.5Hz.

It can be seen that under the condition of invariable tension, the longitudinal vibration frequency of point A increases with the increase of the driving wheel speed, as shown in figure 5. The longitudinal vibration amplitude of point A decreases with the increase of the driving wheel speed, as shown in Figure 6.

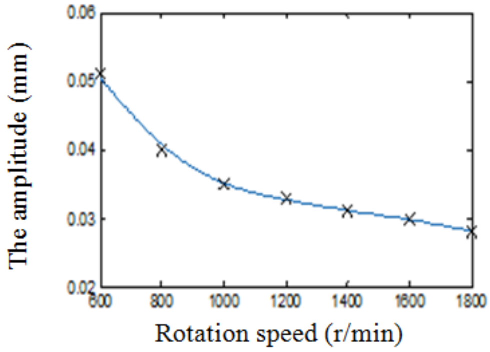

Figure 6. The Curve Of The Longitudinal Vibration Amplitude With The Rotation Speed Diaplacement

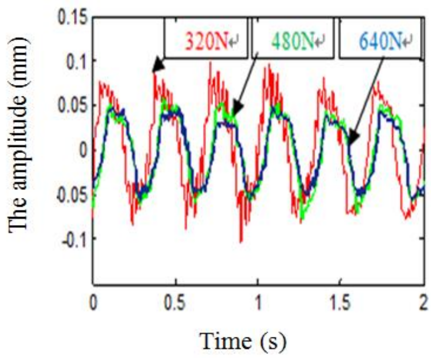

Figure 7. The Curve Of The Longitudinal Vibration Changes With Time

3.2. Analysis of Tension on the Effect of the Longitudinal Vibration of Synchronous Belt

When the rotation speed of the driving pulley is n=1000r/min, the tensioning force are respectively T=320N, 480N, 640N, the change curve of the amplitude of point A with time as shown in figure 7. When the tensioning force is 320N, the maximum longitudinal amplitude of point A is 0.085mm; when the tensioning force is 480N, the maximum longitudinal amplitude of point A is 0.051mm; when the tensioning force is 640N, the maximum longitudinal amplitude of point A is 0.044mm.It can be seen in the case of driving wheel speed is constant, the longitudinal vibration frequency of point A remain unchanged, the amplitude of point A decreases with the increase of the tension, as shown in Figure 8:

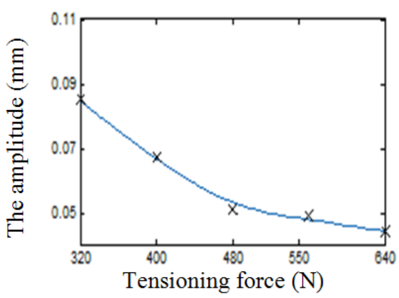

Figure 8. The Curve Of The Longitudinal Vibration Amplitude With The Tension Force

In the automobile engine transmission system, the longitudinal vibration of the synchronous belt is the main reason for the noise, when the tension of the engine transmission system is fixed, with the speed of the driving wheel increases, the longitudinal vibration amplitude of the belt reduce gradually, at the same time, the loudness of the noise also gradually reduced, but with the speed increases, the longitudinal vibration amplitude of the belt increase gradually, the tone of the noise gradually increased; When the speed of the driving wheel is fixed, with the tension increases, the longitudinal vibration amplitude decreases gradually, the tone of the noise reduced gradually, and the frequency of the noise keeps constant.

Because of the longitudinal vibration of the synchronous belt, in the synchronous belt teeth meshing into with the pulley meshing out parts, due to vibration and produce meshing interfere, so that the gear tooth top of the pulley in contact with the tooth root of the belt and that causes friction, cause the tooth root of the belt wear, with the increase of wear can further produce tooth loss, thus affect the service life of the automobile engine drive system. Therefore, in the design of the automobile engine transmission system, in order to minimize the longitudinal vibration amplitude of the synchronous belt should be appropriate to increase the longitudinal stiffness of the belt, and reduce the span of the belt, and make the longitudinal vibration frequency avoid the natural frequency of the synchronous belt transmission system.

4. Conclusions

(1) This paper analyzes the longitudinal vibration in the process of the arc tooth synchronous belt transmission, through using the method of synchronous belt was simplified to a vibrating string fixed at both ends, The mathematical model of the arc tooth synchronous belt longitudinal vibration was established;

(2) A non-contact belt longitudinal vibration measuring device was developed by the laser triangulation displacement measurement principle, that measurement accuracy is 2μm , measurement cycle is 1ms, And the longitudinal vibration of the belt was real time measured during the process of transmission, measurement accuracy can be achieved 2μm, measurement cycle is 1ms;

(3) Measured the curve of amplitude changes over time at the middle point A of synchronous belt span when rotation speed respectively was 600r/min, 1200r/min, 1800r/min and tensioning force was 320N, through the analysis can be seen, when the tension force is fixed, the longitudinal vibration amplitude of synchronous belt decreases with the increase of the rotation speed, the vibration frequency increases with the increase of the rotation speed.

(4) Measured the curve of amplitude changes over time at the middle point A of synchronous belt span when rotation speed was 1000r/min and tensioning force respectively was 320N, 480N, 640N, through the analysis can be seen, when the tension force is fixed, the longitudinal vibration amplitude of synchronous belt decreases with the increase of the tensioning force, and the vibration frequency basically keeps constant.

Acknowledgements

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