An approach of FEM analysis of the influence of pretension on the transverse vibration of belt drive

Wenting Nie and Dayu Zheng
Mechanical Design and Theory, Harbin University of Commerce, Harbin, Heilongjiang Province, 150000, China
*Corresponding author’s e-mail: zhengdayu2000@126.com

Abstract. Belt drive has been widely used in various types of mechanical transmission. Because the belt is sensitive to the pretension, the tension force directly affects the vibration characteristics of the belt, in order to reduce the impact of the pretension on the belt drive, the finite element software is used to simulate the belt, the effect of the change in pretension on the frequency and amplitude of the transverse vibration in the belt drive is obtained. Reasonable selection of the pretension can reduce the vibration amplitude of the belt, reduce the transmission noise and improve the service life of the belt. This method can provide reference for vibration characteristics analysis and system design optimization of the belt drive structure.

1. Introduction
Belt drives play a vital role in power transmission in many applications. Because the belt drive has the advantages of mitigating impact, absorbing vibration, less noise, low cost, convenient maintenance, etc., and can be used for transmissions with large spacing between the two shafts, the belt drive is applied to more and more fields [1-2]. Since the belt drive is sensitive to pretension, too much or too little pretension will have a certain impact on the movement of the belt drive, if the pretension is too low, it will cause sliding in the flat belt and V-belt drive and the jump teeth in the synchronous belt drive; excessive pretension can cause premature failure of the belt due to shearing or wear, and excessive wear of the belt bearings, therefore, the reasonable selection of the pretension is very important in the belt drive [3-5]. Since the magnitude of the pretension directly affects the vibration characteristics of the belt, this paper analyzes the influence of the change of the pretension on the vibration process of the belt drive.

In the belt drive system, there are mainly three types of vibration, one is the vibration of the transmission system along the center line of the two pulleys, that is the longitudinal transmission of the belt drive; the other is the vibration perpendicular to the direction of the belt surface, that is the transverse vibration of the belt drive; the third is the torsional vibration of the belt drive [6-7]. These three forms of vibration will have effect on the transmission characteristics of the belt drive. Many factors in the belt drive system can cause system vibrations, such as the magnitude of the pretension, the speed of movement, and other unstable factors, so reducing or avoiding vibrations must also start with these factors. A variety of vibrations are present in the travel belt drive, but since the transverse vibration is the main form of vibration in the belt drive structure, its vibration amplitude is the largest, and in the belt drive system, excessive transverse vibration may not only cause belts and pulleys slipping, but also reduce the transmission efficiency of the belt drive system; at the same time, transverse vibration is also the main factor of noise generation [8-9]. Therefore, this paper mainly studies the transverse vibration in the belt drive.
In this paper, the finite element model of belt drive is established by finite element software, the vibration pattern of the transverse vibration of the transmission belt is obtained, the influence of different pretension on the vibration frequency and amplitude of the belt under the condition of uniform motion is analyzed. This method can provide a reference for the study of the vibration characteristics of the belt.

2. Transverse free vibration equation of belt drive
When obtaining the transverse free vibration equation of the belt drive, it is assumed that the bending stiffness of the belt is negligible, the belt has a uniform mass distribution and does not need to consider gravity. Assume that the pretension $F$ and the moving speed $v$ of the belt are uniform, the free vibration model of the belt drive is shown in figure 1.

Figure 1. Transverse free vibration model of belt drive.

According to reference [10], the transverse free vibration mathematical model of the belt can be expressed as:

$$\frac{\partial^2 y}{\partial t^2} + 2v \frac{\partial^2 y}{\partial t \partial x} + \left( v^2 - c^2 \right) \frac{\partial^2 y}{\partial x^2} + \frac{\beta}{q} y = 0$$

(1)

Where: $v$—motion velocity, m/s; $y$—transverse displacement, m; $c$—wave velocity, m/s; $eta$—belt transverse vibration damping; $q$—mass distribution coefficient.

Under the condition that the damping $\beta$ is neglected and the initial conditions and the boundary between the two ends are considered, the solution of the equation (1) is:

$$y_i(x,t) = \hat{y} \sin \left[ \alpha_i \left( t + \frac{v}{c^2 - v^2} x \right) \right] \sin \left( \frac{k\pi x}{l_0} \right)$$

(2)

The natural frequency of the conveyor belt during transverse vibration is:

$$f_k = \frac{k}{2l_0} \frac{F - qv^2}{\sqrt{Fq}}, k = 1, 2, 3...$$

(3)

Where: $F$—pretension, N; $l_0$—the span of the belt is length, m.

3. Simulation analysis process and results

3.1. Establishment of finite element model
Using finite element software can not only analyze product performance, but also find product problems, reduce design cost, shorten design cycle, and improve design success rate [11]. In this paper, the finite element software is used to model the A-type V-belt. Since the conveyor belt is composed of anisotropic materials, its transverse and longitudinal characteristics are very different, but in the vibration process, the transverse vibration is mainly affected, so the conveyor belt is simplified to a simple elastomer, which is further simplified by the analytical model [12]. Define the material properties of the belt, set the belt density to $1.11 \times 10^3$ kg/m$^3$, the elastic modulus to $E=3.0 \times 10^5$ Mpa, the Poisson’s ratio to 0.48, and the belt length to 1.6 m. Since the frame is very rigid relative to other parts, it is assumed that its...
deformation and motion are zero, and it is simplified as a rigid body as a shaft. For the driving wheel and the driven wheel, because the axis is fixed, it can be simplified by the rigid body constraint method to a cylindrical rigid body rotating around a fixed point [13]. In the model established in this paper, the driving wheel and the driven wheel are equal in size, the diameter $d$ is 132mm, and the elastic modulus $E=2.0\times 10^5$Mpa, the Poisson's ratio is 0.2, and the density is $7.8\times 10^3$kg/m$^3$, this completes the establishment of the belt finite element model. After the model is established, the structure is meshed by regular hexahedral elements, and the belt and pulley are divided into 5580 units and 6964 nodes. The obtained finite element model is shown in figure 2.

Figure 2. V-belt drive finite element model.

The contact pair is used to construct the contact pair, because the belt is defined as a whole, it is only necessary to add a face-face contact pair between the belt and the two pulleys, so that the structure transmits the motion by friction [14-15]. Apply a concentrated force to one of the pulleys to give the system a certain pretension. Next, apply the speed to the system, the analysis results obtained under these conditions are equivalent to the simulation of the belt system under no-load motion under uniform motion.

Adding a speed of 1000 rpm to the belt drive system while applying a pretension of 500 N, the first-order and second-order modes of the transverse vibration of the belt are obtained by simulation as shown in figure 3 and figure 4, respectively. Since the simulation analysis analyzes the geometric model of the entire belt, it is equivalent to dividing the whole model into two parts: the tight side and the loose side, therefore, the average value of the vibration frequency of the loose side and the tight side is taken as the first-order frequency value, and the same simulation method is used to simulate the different pretension conditions.

Figure 3. First-order mode shape.

Figure 4. Second-order mode shape.

3.2. Simulation results

In order to analyze the influence of pretension on the vibration characteristics of transverse vibration during belt drive, in this paper, the variation of transverse vibration characteristics under the condition of 100N increment is obtained when the pretension is from 100N to 1000N at 1000rpm. Since the above simulation results show that the maximum amplitude generally occurs at the midpoint of the belt span, in order to analyze the influence of the pretension on the transverse vibration of the system, the midpoint with the tight edge is selected as the research object.

From the simulation results, it can be seen that when the pretension is 100N, the first-order vibration frequency is 18.454Hz, and the maximum vibration amplitude is 26.982mm; when the pretension is 500N, the vibration frequency is 18.456Hz, and the maximum vibration amplitude is 25.579mm; when the pretension is 1000N, the vibration frequency is 18.465Hz, and the maximum vibration amplitude is
24.031mm; with the change of the pretension value, the transverse vibration frequency of the belt transmission is maintained at about 18.45 Hz, which remains basically unchanged. However, the maximum amplitude of the transverse vibration gradually decreases as the pretension increases, the maximum amplitude when the amplitude is from 26.982mm at a pretension of 100N to 1000N pretension is 24.031mm, the effects of the change in pretension on the transverse vibration characteristics of the belt drive can be seen very intuitively from figure 5 and figure 6. Figure 5 is a plot of frequency versus pretension and figure 6 is a plot of maximum amplitude as a function of pretension.

4. Conclusion
1) The following results are obtained by finite element analysis of the transverse vibration of the belt drive system: as the pretension of the belt continues to increase, the frequency of the transverse vibration of the belt drive remains substantially unchanged, the maximum amplitude of the transverse vibration decreases as the pretension increases. Therefore, when using the belt drive system, the size of the pretension should be reasonably selected, which can not only reduce the vibration amplitude of the belt, but also reduce the transmission noise and adjust the service life of the belt.

2) In the study of this paper, it is assumed that the strip material is linearly elastic and the influence of damping on it is ignored. However, glass fiber, aramid fiber and polymer materials are usually added to the belt, most of these materials have inherent viscoelastic behavior, therefore, the experimental results in this paper will have some errors. In the future research, the viscosity should be introduced, elastic parameters allow the experiment to achieve better simulation results.

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