Research on wire rope deformation distribution of WR-CVT

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Abstract. A wire rope continuously variable transmissions (WR-CVT) has been introduced in the paper, in view of its less research, this paper mainly studied the deformation distribution of 6×7+IWS bending wire rope. The results shown that in the same section, half of the side strands are in a stretched state and half are in a compressed state. When the transmission ratio \(i=2.35\), the maximum deformation and the minimum deformation are decrease when section U1 to U2, U3 transition. Wire deformation distribution when the transmission ratio \(i=0.42\) is similar to that of \(i=0.2.35\). Wire deformation amount and the deformation difference decrease as the transmission ratio decreases, this shows that the increase in the bending radius of the wire will make the wire deformation more uniform, and the reduction of the deformation difference will also reduce the wear. This study provides a basis for the study of fatigue and wears failure of WR-CVT components.

1. Introduction

CVT (Continuously Variable Transmission) as one of the trend of auto technological development, which has the advantages of saving fuel, easier operation, comfortable drive and producing less pollutions\textsuperscript{[1]}. In a comparison of the fuel consumptions of vehicles with different transmission types on the US market for the US Environmental Protection Agency city cycle\textsuperscript{[2]}, it was seen that, generally, vehicles with CVT achieve a higher fuel economy than vehicles with stepped AT. Páczelt, I \textsuperscript{[3]} developed a finite element program that takes into account factors such as nonlinear contact, Poisson effect, friction and wear, which can perform small displacement and deformation analysis of wire ropes in a variety of loads including stretching, torsion and bending. Ma Jun’s \textsuperscript{[4]} research results show that the stress and strain of the wire are higher than that of the core wire. The stress of the steel wire in the different position is spirally distributed in the longitudinal direction. Wu Juan’s \textsuperscript{[5]} research results show that the right by the same twist wire rope steel wire stress, deformation and wire The magnitude of the deformation difference is greater than the right cross twist wire rope. Wire rope CVT (WR-CVT) has been designed in this paper, WR-CVT as shown in Figure 1 and focus on the WR-CVT closed wire rope deformation distribution.

2. Closed wire rope geometry model

The wire rope model has been designed in this paper. 6×7+IWS wire rope contains 1 core strand and 6 side strands, one strand contains a center wire and six side wires. It contains four different geometric forms of wire, they are core strand center wire, core strand side wire, outer strand center wire and outer strand side wire. Core strand center wire is the axis of closed wire rope, core strand side wire and outer strand center wire are single helix, and outer strand side wire is second helix. According to the right-hand rules to establish a Cartesian coordinate system O-xyz as a closed wire rope mathematical
model of the global coordinate system\textsuperscript{[6,7]}, the centerline equation for each wire in a closed wire rope is given\textsuperscript{[8-10]}. The 3D solid model of 6×7+IWS bending wire rope was established by Pro/E. 6×7+IWS wire rope section and 3D solid model is shown in Figure 2.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{WR-CVT.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{6×7+IWS wire rope section and 3D solid model.}
\end{figure}

3. Wire deformation analysis
In order to better observe the change of the wire deformation in the wire along the direction of the core, the local coordinate system along the axis of the cord is established in the bending part of the rope ring. And intercept three sections $U_1$, $U_2$, $U_3$ and $U_1'$, $U_2'$, $U_3'$, Section O-O and O-O' are the reference plane, as shown in Figure 3. In the finite element model of the wire rope, one end applies the surface constraint, restrains all degrees of freedom in three directions, $x$, $y$, $z$, and applies the surface load at the other end. Wire number and path schematic as shown in Figure 4.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Section position}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{Wire number and path schematic.}
\end{figure}
When the transmission ratio $i=2.35$, the deformation of the wire is shown in Figure 5. It can be seen that the cross section of the datum plane is the loading end of the wire rope, and the deformation of the wire closer to the loading end is larger.

In the same section, half of the side strands are in a stretched state and half are in a compressed state. And the amount of deformation of the core strand center wire is substantially the same for the strand 1, 6 and the strand 3, 4. However, the strand 3, 4 deformation are larger than strand 1, 6 which the strand 3, 4 are far greater than the strand 1, 6 of the circular notch.

In section $U_1$, OIW4-4 wire deformation is the maximum, its value is 0.135mm, OIW1-2 wire deformation is the minimum, its value is 0.04mm, and deformation difference is 0.095mm. In section $U_4$, OIW3-3 wire deformation is the maximum, its value is 0.07mm, OIW6-5 wire deformation is the minimum, its value is 0.018mm, and deformation difference is 0.052mm. In section $U_3$, OIW3-4 wire deformation is the maximum, its value is 0.028mm, OIW6-3 wire deformation is the minimum, its value is 0.011mm, and deformation difference is 0.017mm. Deformation difference is the relative misalignment of the two wires, which will cause the micro-wear of the inner wire, in the load conditions unchanged, the greater the amount of wrong, the more serious wear and tear.

![Figure 5. Wire section deformation ($i=2.35$).](image)

When the transmission ratio $i=0.42$, the deformation of the wire is shown in Figure 6. It can be seen that on the whole distribution of wire deformation is similar to that of $i=0.2.35$, the amount of wire deformation decreases as the transmission ratio decreases, and the difference between the maximum deformation amount and the minimum deformation amount of the wire is also reduced. This shows that the increase in the bending radius of the wire will make the wire deformation more uniform, and the reduction of the deformation difference will also reduce the wear.
4. Conclusion
The wire rope deformation distribution of WR-CVT has been studied in this paper. The 6×7+1WS wire rope geometrical model has been established. The deformation distribution of the wire rope on the three sections is analyzed. The results shown that in the same section, half of the side strands are in a stretched state and half are in a compressed state. When the transmission ratio \(i=2.35\), in section \(U_1\), OIW4-4 wire deformation is the maximum, its value is 0.135mm, OIW1-2 wire deformation is the minimum, its value is 0.04mm, and deformation difference is 0.095mm. The deformation difference between the maximum and the minimum deformation decrease when section \(U_1\) to \(U_2\), \(U_3\) transition. When the transmission ratio \(i=0.42\), wire deformation distribution is similar to that of \(i=0.2.35\), wire deformation amount and the deformation difference decreases as the transmission ratio decreases, this shows that the increase in the bending radius of the wire will make the wire deformation more uniform, and the reduction of the deformation difference will also reduce the wear.

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Nomenclature

| Abbreviation | Description |
|--------------|-------------|
| CVT          | continuously variable transmission |
| WR-CVT       | wire rope CVT |
i 

transmission ratio

DOF

Degrees-of-freedom

(O: x, y, z)

the Cartesian coordinate system

O-O, U₁, U₂, U₃

section

References

[1] Srivastava N, Haque I 2008 Clearance and friction-induced dynamics of chain CVT drives Multibody System Dynamics 19(3) 255-280.

[2] Sluis F V D, Velde A V D, Dongen T V, Spijk G J V, Heeswijk A V 2007 Efficiency optimization of the push belt CVT SAE paper 2007-01-1457.

[3] Páczelt I, Beleznai R 2011 Nonlinear contact-theory for analysis of wire rope strand using high-order approximation in the FEM Computers and Structures 89(11-12) 1004-1025.

[4] Ma J, Ge S R, Zhang D K 2012 Research on Three-dimensional Contact Model and Stress Distribution between Wires of Steel Strand China Mechanical Engineering 23(7) 864-868.

[5] Wu J, Kou Z, Liu Y H, Wu G X 2014 Distribution of equivalent stresses and deformations for 6 strand Warrington seale rope with an independent wire rope core Journal of China Coal Society 39(11) 2340-2347.

[6] Lee W K 1991 An insight into wire rope geometry International Journal of Solids & Structures 28(4) 471-490.

[7] Erdömez C 2013 n-tuple complex helical geometry modeling using parametric equations Engineering with Computers 30(4) 715-726.

[8] Stanova E, Fedorko G, Fabian M, Kmet S 2011 Computer modelling of wire strands and ropes Part I: Theory and computer implementation Advances in Engineering Software 42(6) 305-315.

[9] Stanova E, Fedorko G, Fabian M, Kmet S 2011 Computer modelling of wire strands and ropes Part II: Finite element based applications Advances in Engineering Software 42(6) 322-331.

[10] Guo W, Lu Z X, Zhang W 2015 Geometric modeling theory of bent wire rope based on Pro/E China Mechanical Engineering 26(17) 2363-2368.