Mechanism and Machine Theory 116 (2017) 220–233

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

Research on modeling and bending stress distribution of a new metal belt continuously variable transmission

Wu Zhang, Chuanwei Zhang*, Wei Guo, Xiaobin Xu, Zhengxiong Lu

School of Mechanical Engineering, Xi'an University of Science and Technology, Xi'an, Shaanxi, 710054, China

ARTICLE INFO

Article history:
Received 9 February 2017
Revised 12 May 2017
Accepted 30 May 2017
Available online 7 June 2017

Keywords:
Continuously variable transmission
Metal belt
Wire rope
Stress

ABSTRACT

A wire-rope continuously variable transmission (WR-CVT) obtained by modifying a metal-belt continuously variable transmission (MB-CVT) is proposed. From a comparative analysis of the WR-CVT metal ring and the MB-CVT closed wire rope, the WR-CVT is found in preliminary findings to operate normally. Experiments on a WR-CVT prototype demonstrate the transmission principle confirming the finding. A geometric model of the closed wire rope with its distinctive strand pattern was developed using Pro/Engineer software. Using the finite element method, wire stress was analyzed with the results indicating that stress is less in the core strand than in the six outer strands. Each of the six outer strands has a side wire in contact with the semi-circular notch of the metal block. Stress is significantly higher in these two side wires than in the other side wires. The stress distribution in the WR-CVT closed wire rope is different from that of a wire rope in continuous sheave contact, indicating that the former with its discrete contact points with the metal blocks exhibits "stress stepping" different from that reported in previous studies.

1. Introduction

Over the past three decades, continuously variable transmission (CVT) has aroused a great deal of interest for their use in agricultural vehicles, motor-cycles, and especially in automobiles [1]. The metal belt CVT (MB-CVT) has been a popular development trend in the automotive technology offering advantages that include comfortable drive, ease of operation, better acceleration, fuel savings, and reduced emissions of pollutants. The MB-CVT occupies an important position in the modern era of the car industry. In the basic MB-CVT structure (Fig. 1) [2–4], both the driving pulley and the driven pulley consist of a fixed half-pulley and a moving half-pulley. The belt contains about 400 metal blocks supported by two sets of bands, every band has 8–11 layers, and each layer is 0.2-mm thick. These metal blocks contact the surfaces of both the driving and driven pulleys, and a torque is transmitted via friction between the pulleys. In principle, an infinite number of transmission ratios is achievable using the pressure regulating devices of the moving half-pulleys [5–7].

In a previous study [8], the elastic deformation of the pulley sheaves was found to affect significantly the transmission ratio and the slip behavior of the metal belt subassembly, as well as the CVT's transmission efficiency. The varying pulley groove angle and the local elastic axial deformation of the pulley in this model were described with simple trigonometric functions. Nilabh and Imtiaz [9] focused on understanding the influence of pulley flexibility and friction characteristics on the MB-CVT dynamic performance. In a previous paper [10], the particular shape of the deformed pulley was described

* Corresponding author.
E-mail address: zhangchuanwei999@163.com (C. Zhang).

http://dx.doi.org/10.1016/j.mechmachtheory.2017.05.022
0094-114X/

Nomenclature

CVT	continuously variable transmission
MB-CVT	metal belt CVT
WR-CVT	wire rope CVT
DOF	degrees-of-freedom
$6 \times 7 + \mathrm{IWS}$	"6" indicates number of strand, "7" indicates number of wire in every strand, "IWS" indicates core strand is steel core.
FEM	finite element method
i	transmission ratio
Pro/E	Pro/Engineer
$(O: x, y, z)$	Cartesian coordinate system
S	core strand center wire centerline to point S as a starting point
γ	angle at which each wire centerline rotates counterclockwise about the x axis ($0 \le \gamma \le 2\pi$)(°)
P	a starting point which core strand center wire centerline
ξ_n	core strand side wire initial phase, for n = 1, 2,..., 6, ξ_n=(n-1)60° (°)
θ	winding angle of core strand side wire/ outer strand center wire (°)
φ	winding angle of outer strand side wire (°)
R_1	radius of closed wire rope (mm)
R_{cs}	helical radius of core strand side wire (mm)
R_s	helical radius of outer strand center wire (mm)
R_w	helical radius of outer strand side wire (mm)
β_{cs}	helix angle of core strand center wire (°)
β_s	helix angle of core strand side wire/ outer strand center wire (°)
β_w	helix angle of outer strand side wire (°)
T_{cs}	lay length of core strand center wire (mm)
T_s	lay length of core strand side wire or outer strand center wire (mm)
T_w	lay length of outer strand side wire (mm)
d_{cc}	diameter of core strand center wire (mm)
d_{cs}	diameter of core strand side wire (mm)
d_{oc}	diameter of outer strand center wire (mm)
d_{os}	diameter of outer strand side wire (mm)
L	circumference of closed wire rope (mm)
E	modulus of elasticity (Pa)
μ	Poisson ratio
G	Shear modulus (Pa)
σ_s	Yield limit (Pa)
f	coefficient of friction
F	force on tangential direction of closed wire rope (N)
O-O'	loaded end of FEM model
O-O''	fixed end of FEM model
A_1	section located in the 1st metal block end when $i = 2.35$
A_2	section located in the middle of the 2nd metal block when $i = 2.35$
B_1	section located in the 1st metal block end when $i = 0.42$
B_2	section located in the middle of the 2nd metal block when $i = 0.42$
σ_{max}	maximum stress of closed wire rope (MPa)
σ_{min}	minimum stress of closed wire rope (MPa)
CW	core strand center wire
IWm	number of the core strand side wire, m is the number, m = 1, 2, 3, 4, 5 and 6
OCWm	number of the outer strand center wire, m is the number, m = 1, 2, 3, 4, 5 and 6
OIWm-k	number of the outer strand side wire, m and k are the number, m, k = 1, 2, 3, 4, 5 and 6

based on the Sattler model [2] showing that the variation in groove angle and in the local groove width of the pulley was easily described using simple trigonometric formulas. The former shows that the characteristic behavior of the transmission during slow shifting maneuvers, referred to as "creep mode", is caused by the bending of the pulleys. Narita [11] analyzed the influence of metal–metal friction characteristics on the efficiency using a commercial CVT unit, and recognized friction losses through slipping between the belt segments and pulley, between the segments and band, and between bands. In a previous paper [12], the authors presented an experimental study of the MB-CVT dynamics., establishing a very good agreement between experimental data and their theory data. They also proposed a relatively simple differential equation to