Modeling and Testing of a Novel Continuously Variable Transmission for Heavy-duty Vehicles

by

Chan Ka U

MSc in Electromechanical Engineering

2012

Faculty of Science and Technology

University of Macau

Modeling and Testing of a Novel Continuously Variable Transmission for Heavy-duty Vehicles

by

Chan Ka U

M-A5-6533-1

A thesis submitted in partial fulfillment of the requirements for the degree of

MSc in Electromechanical Engineering

Faculty of Science and Technology
University of Macau

2012

Approved by ______________________________
Supervisor

____

____

Program Authorized
to Offer Degree ______________________________

Date ______________________________

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at the University of Macau, I agree that the Library and the Faculty of Science and Technology shall make its copies freely available for inspection. However, reproduction of this thesis for any purposes or by any means shall not be allowed without my written permission. Authorization is sought by contacting the author at

Address: Estrada do cemiterio, No 3, Macau
Telephone: (853)66643794
E-mail: chankau@iacm.gov.mo

Signature ________________________

Date ____________________________

University of Macau

Abstract

Modeling and Testing of a Novel Continuously Variable Transmission for Heavy-duty Vehicles

by Chan Ka U

M-A5-6533-1

Thesis Supervisor: Prof. Wong Pak Kin

Department of Electromechanical Engineering, Faculty of Science and Technology

Continuously Variable Transmissions (CVT) are becoming increasingly popular in automotive applications. It is believed that CVT will dominate the automotive transmissions in the future. A wide range of transmission ratio helps with reducing the engine speeds, which makes driving more comfortable and increases fuel economy. The most popular design is the Van Doorne's CVT with single metal V-belt. However, it is applicable to light-duty vehicle and scooters only due to low torque capacity. This thesis studies a novel dual-belt CVT (DBCVT) system, in order to eliminate the limitations on the traditional single-belt CVT, so that it can be applicable to heavy-duty vehicles. This thesis is the first attempt at developing the analytical model for a novel dual-belt CVT system with experimental validation. Based on the model built, dynamic analysis of transmission process is also performed. Simulation and experimental results show that the model developed is valid and the use of dual-belt CVT can really improve the torque capacity and transmission efficiency as compared to traditional single-belt CVT.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

a	Center-to-center distance
C_e	Mass of steel element per unit length
C_r	Mass of steel ring per unit length
d_b	Bearing mean diameter
ε	Slip ratio
$E_A=E_p(0)=E_s(0)$	Extrusion force at the exit of driving pulley or extrusion force at the entry of driven pulley
$E_p=E_p(\beta)$	Distribution of extrusion force of steel element on driving pulley
$E_s=E_s(\beta)$	Distribution of extrusion force of steel element on driven pulley
$F_A=F_p(0)=F_s(0)$	Tensile force at the exit of driving pulley or tensile force at the entry of driven pulley
$F_B=F_p(\beta_p)=F_s(\beta_s)$	Tensile force at the entry of driving pulley or tensile force at the exit of driven pulley
$F_p=F_p(\beta)$	Distribution of tensile force of steel ring on driving pulley
F_{rp}	Radial friction between steel element and driving pulley
F_{rs}	Radial friction between steel element and driven pulley
$F_s=F_s(\beta)$	Distribution of tensile force of steel ring on driven pulley
F_{spring}	Spring force
F_{tp}	Tangential friction between steel element and driving pulley
F_{ts}	Tangential friction between steel element and driven pulley
f_b	Bearing torque loss factor
h	Radial distance between contact surface and rocking edge in steel element

h_e	Thickness of steel element
h_r	Thickness of each layer in steel ring
i	Transmission ratio
i_{max}	Maximum transmission ratio
i_{min}	Minimum transmission ratio
K	Experimental constant
k_p	Experimental constant for driving pulley
k_s	Experimental constant for driven pulley
L	Length of metal belt
m_e	Mass of steel element
n	Number of belts
n_i	Input speed
n_o	Output speed
N_p	Pressure between steel element and driving pulley
N_r	Number of layers in steel ring
N_s	Pressure between steel element and driven pulley
P_1	Power loss due to radial friction between steel element and pulley
P_2	Power loss due to tangential friction between steel element and pulley
P_3	Power loss due to friction between inner layer of steel ring and contact surface of steel element
P_4	Kinetic energy loss of steel elements
P_5	Bearing loss of input shaft
P_6	Bearing loss of output shaft
P_p	Pressure between steel ring and steel element on driving pulley
P_s	Pressure between steel ring and steel element on driven pulley

Q_p	Axial clamping force of driving pulley
Q_s	Axial clamping force of driven pulley
r_p	Working radius of driving pulley
r_{pi}	Effective radius at the entry of driving pulley
$r_{pmax}=r_{smax}$	Maximum working radius of pulley
$r_{pmin}=r_{smin}$	Minimum working radius of pulley
r_{po}	Effective radius at the exit of driving pulley
r_s	Working radius of driven pulley
r_{si}	Effective radius at the entry of driven pulley
r_{so}	Effective radius at the exit of driven pulley
t	Working radius difference between band and element
T	Torque capacity
T_i	Input torque
V_e	Velocity of steel element on straight part in DBCVT
V_{ep}	Linear velocity of steel element on driving pulley
V_{es}	Linear velocity of steel element on driven pulley
v_p	Linear velocity of driving pulley
V_{rp}	Linear velocity of steel ring on driving pulley
V_{rs}	Linear velocity of steel ring on driven pulley
v_b	Kinematic viscosity
v_s	Linear velocity of driven pulley
α	Angle between the vertical centerline of the shafts and the tangent point of metal belt
β_{0p}	Angle of increase or decrease in E_p
β_{0s}	Angle of increase or decrease in E_s
β_p	Contact angle of driving pulley

β_s	Contact angle of driven pulley
γ	Slip angle
η	Power transmission efficiency
θ_p	Angle of groove of driving pulley
θ_s	Angle of groove of driven pulley
μ_{ep}	Friction coefficient between steel element and pulley
μ_{re}	Friction coefficient between steel ring and steel element
ω_p	Angular velocity of driving pulley
ω_s	Angular velocity of driven pulley