Mechanism and Machine Theory 86 (2015) 1–14

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Speed losses in V-ribbed belt drives

Berna Balta [a,b], Fazil O. Sonmez [c,*], Abdulkadir Cengiz [d]

[a] Department of Mechanical Engineering, Kocaeli University, Kocaeli, Umuttepe, 41380, Turkiye
[b] Ford Otosan, Product Development Department, Kocaeli, Gebze 41470, Turkiye
[c] Department of Mechanical Engineering, Bogazici University, Istanbul, Bebek, 34342, Turkiye
[d] Mechanical Education Department, Kocaeli University, Kocaeli, Umuttepe, 41380, Turkiye

ARTICLE INFO

Article history:
Received 11 December 2013
Received in revised form 10 November 2014
Accepted 24 November 2014
Available online 12 December 2014

Keywords:
V-ribbed belt drives
Slip
OFAT
RSM
Design optimization
ANOVA

ABSTRACT

One of the concerns in belt drive transmissions is the relative sliding (slip) of the belt with respect to the pulley, which results in speed loss, i.e. decrease in the angular velocity of the driven pulley. In this study, the slip behavior of a V-ribbed belt drive with two equal-sized pulleys is investigated by utilizing several experimental methodologies. The individual effects of belt-drive parameters on speed loss are determined using one-factor-at-a-time (OFAT) test method. The relation between the belt-drive parameters and the speed loss is found using response surface method (RSM). Afterwards, the optimum operating conditions are determined via a design optimization procedure. In order to validate the response surface curve, experiments are conducted with arbitrary operating conditions and the measured and predicted values of speed loss are compared. The predictions of the response surface model are also found to be in good agreement with the empirical results presented in the literature. Furthermore, the predicted model looks reasonably accurate based on the analysis of variance (ANOVA) and the residual analysis. Using the response curve, one may estimate the degree of speed loss for similar belt-drives with operating conditions within the range considered in the present study.

1. Introduction

Belt drives are power transmission systems commonly used in the industry [1]. There are different types of belts like flat belts, V-belts, and V-ribbed belts. Flat belts offer flexibility, while V-belts offer high power transmission capacity. V-ribbed belts, on the other hand, combine these two properties. They are made of a layer of reinforcing cords as tension-carrying members, a protective cushion of rubber that envelopes the cords, a rubber backing, and ribs made of short-fiber-reinforced rubber as shown in Fig. 1.

In comparison to the traditional V-belts, V-ribbed belts have numerous advantages including accommodation to smaller pulleys sizes and belt lengths, backside operation, and relatively longer service life. The ribs on V-ribbed belts guide the belt and make it more stable in comparison to the traditional flat-belts; they also provide increased power transmission capacity by increasing the friction surface and normal pressure.

High efficiency and high performance of V-ribbed belt drives can only be achieved if proper values are chosen for the design parameters. This requires fundamental understanding of the operational characteristics unique to this class of belts and belt drive systems. High efficiency can be achieved by decreasing power losses. In belt drives, power losses occur due to a combination of speed losses and torque losses [1]. Speed losses result from sliding of the belt relative to the pulley, which leads to a decrease in the angular velocity of the driven pulley, and thus in the transmitted power. With a proper design of belt drives, power losses can

* Corresponding author. Tel.: +90 212 359 7196.
E-mail addresses: bguner@ford.com (B. Balta), sonmezfa@boun.edu.tr (F.O. Sonmez), akcengiz@kocaeli.edu.tr (A. Cengiz).

http://dx.doi.org/10.1016/j.mechmachtheory.2014.11.016
0094-114X/

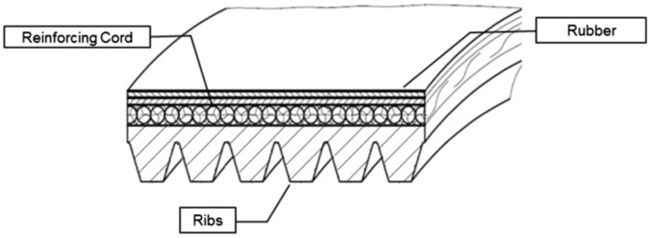

Fig. 1. A scheme for V-ribbed belts.

be decreased and, thus, their efficiency can be increased; but this requires fundamental understanding of the effects of the dominant factors on power loss.

Some researchers theoretically examined the slip behavior in belt drives. In 1874, Reynolds showed that torque transmissions between pulleys involved speed losses due to belt's elastic creep [2]. Gerbert [3] explained the mechanism of slipping by dividing the arc of contact between belt and pulley into sticking (non-slipping) and slipping regions. The belt was treated as a string and the mechanism of elastic creep of the belt along the pulley was shown to yield a slip arc at the exit region of the pulley, where the entire transition from the high to low tension occurred. In the remaining contact region, commonly referred to as the stick (non-slip) arc, the belt was shown to stick to the pulley without slipping with no change in tension [4]. Although the classical creep theory explains how belt slip occurs to a reasonable extent, speed losses encountered in practice are larger than predicted by extensional creep, particularly for thick flat-belts, V-belts, and V-ribbed belts. Firbank [5] proposed a theory where shear strain in the belt envelope was assumed to be the determining factor on the drive behavior. The difference between the two theories is that the creep theory assumes that belt behavior is governed by the elastic extension and contraction of the belt as opposed to the shear theory. However, both of the assumptions are too strict to explain the slip behavior and the slip regions along the contact region between the belt and the pulley. Firbank claimed that slip occurred only at the exits of the driver and driven pulleys. The remaining region over the entire arc was taken as the real arc of contact as defined by Gerbert [6]. Gerbert [7] proposed an analysis that considered both flexural rigidity and compressibility of the belt and assumed that belt speed differences in the entry and exit regions were observed due to the change in the radius of the curvature of the belt, which meant that belt extensibility was not the only factor to explain the slip behavior. Sorge etal. [8] defined the arc of contact as the power transmitting part of the belt and claimed that there was almost no tension variation in the contact region.

Previous experimental studies on power loss behavior of belt drives usually considered V-belt drives and continuously variable transmission (CVT) belt drives. Researchers basically used belt drive test setups with two equal-sized-pulleys. Peeken and Fischer [9] developed a V-belt drive test setup to determine the efficiency up to 200 Nm torque and 6000 rpm speed with a fixed shaft distance. The belt pre-tension was provided by a pivoted rocking arm. They obtained braking torque vs. slip relation for a single combination of belt tension, belt length, and pulley diameter.

Childs and Cowburn [10] experimentally investigated the effects of mismatch between the wedge angles of pulley grooves and belt ribs on the power loss behavior of V-belt drives. During the tests, they kept the other parameters constant. They [11] also studied the effects of small pulleys on the power loss both theoretically and experimentally. Using pulleys with diameters ranging from 42 mm up to 102 mm, they examined the effect of braking torque on power loss. In the experiments, the same belt length and belt material were used.

Lubarda [12] analytically formulated the variation in the belt force over the arc of contact of flat and V-belts before gross slip occurs. He separated the arc of contact into active and non-active regions, similar to the approach of Gerbert [3] and Johnson [4].

A number of studies were conducted to investigate CVT type belt drives used in motorcycles with the help of two-pulley-belt drive test rigs. Ferrando et al. [13] developed a test setup to determine the effects of the drive parameters on the axial force. A velocity controller was used to maintain its speed. By means of electric motors, the driver pulley was actuated and braking torque was applied to the driven pulley. The belt tension, the input torque, and the total axial force in the belt were measured. With a similar setup, Amijma et al. [14] studied the effects of acceleration or deceleration on the power transmission behavior of a CVT belt drive by measuring the axial force via a load cell at a constant speed (2430 rpm) and a constant braking torque. Chen et al. [15] focused on the efficiency of a rubber V-belt CVT drive. In the test setup, input and output torques were measured by torque transducers and speed was measured by optical encoders. Additionally, they installed laser displacement sensors in order to detect the changes in the pitch radii of CVT pulleys and determined the speed and torque losses under different operating conditions. Akehurst et al. [16–18] investigated the power transmission efficiency of a metal V-belt CVT drive. The belt was constructed from several hundred segments held together by steel band sets. They formulated the torque loss and belt-slip losses and correlated them with the experimental results. Bertini et al. [19] studied the power losses in a rubber V-belt type CVT, both experimentally and analytically. They grouped the power loss contributors as hysteresis losses and frictional losses arising at the entrance and exit regions of the pulleys due to engagement/disengagement of the belt. They validated their model through a test bench, which was capable of measuring the transmitted torques, axial trusts on the pulleys, pulley speeds, and belt tension. However, they did not use different belts and pulley diameters to evaluate their effects. Mantriota [20–22] performed extensive experiments to study the efficiency of power-split CVT (PS-CVT). PS-CVT was obtained by joining a V-belt CVT, a planetary gear train, and a timing belt. Input and output angular speeds and torques were measured by means of torque-tachometers integrated to the driving and driven shafts. A regulation