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TORQUE LOSS MEASUREMENTS ON POLY V-RIBBED BELT DRIVE SYSTEMS

Berna Balta
Ford Otosan
Kocaeli, Turkey

Bülent Balta
Ford Otosan
Kocaeli, Turkey

Abdülkadir Cengiz
Kocaeli University
Kocaeli, Turkey

Fazıl Önder Sönmez
Boğaziçi University
Istanbul, Turkey

Armağan Arıcı
Kocaeli University
Kocaeli, Turkey

ABSTRACT

Efficient belts can provide the same magnitude of energy savings as energy-efficient motors. Therefore, belt drives deserve greater attention, so that their losses should be minimized. The belt drive power losses are a combination of torque losses and speed losses. However, the determination of belt drive behavior in terms of power losses requires extensive experimental investigations. Therefore, in this study, belt slip and torque losses were investigated experimentally with a laboratory constructed test bench. Measurement System Analysis (MSA) was performed in order to investigate the test rig reliability. Special attention was paid for experimental test setup, testing and modeling of torque loss behavior of V-ribbed belt drive systems. Significant design parameters were investigated.

Key words: Power Transmission, Belt Drive Systems, Belt Slip, Torque Loss, Power Loss

INTRODUCTION

Efficient belts can provide the same magnitude of energy savings as energy-efficient motors. Belt drives, thus deserve greater attention and their losses should be minimized. The belt losses are a combination of torque losses and slip losses.

Torque losses include hysteresis losses, friction losses, and idling losses [1].

Slip is a condition that occurs in a belt drive when the load causes the belt to slide out of proper position on the pulley, i.e. creep along the belt, radial compliance, and shear deflection, seating/unseating due to flexural rigidity [2].

Pulley specific slip is defined as the difference of the belt speed and the pulley linear speed.

Most of the experimental work carried out on belt drive systems has taken place before the introduction of V-ribbed belts [3-7]. Therefore, the number of published investigations regarding V-ribbed belt drives is less than V belt and V belt CVT systems. Moreover, experimental investigations for belt drives were mainly focused on slip and losses for V-belts and CVT belts and a few on V-ribbed belt drives [3-4, 7-9]. Torque loss behavior investigations have been limited to V belts and CVT belt drives [3-5, 7].

Two equally sized pulley belt drive test rigs are the basis of these experimental studies. Typically a dynamometer should be constructed with coupled sensors and load cells for power loss measurements. The test rig should then be investigated and modified with Gage R&R studies [10] to reach reliable conclusions about the power loss behavior of belt drives.

The determination of belt drive behavior under several operating conditions and correlation with FE models requires extensive experimental investigations. Therefore, in this study, belt slip and torque losses were concerned and special attention was paid for experimental investigation and modeling of torque loss behavior of a two equally sized pulley V-ribbed belt drive system. Belt slip analysis will be presented on a separate paper.

EXPERIMENTAL TEST SETUP

In order to demonstrate the power loss behavior of V-ribbed belt drives, an experimental test setup was constructed. While designing the test setup, the system parameters were selected as the belt length and belt type, the pulley diameter, the belt pretension, the motor speed, and the braking torque of the driven pulley. In addition, the test setup was instrumented to be able to measure the following system parameters: the angular speeds of the driver and the driven pulleys, driver and braking

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torque on motor and pump respectively; belt pretension, as shown in Figure-1.

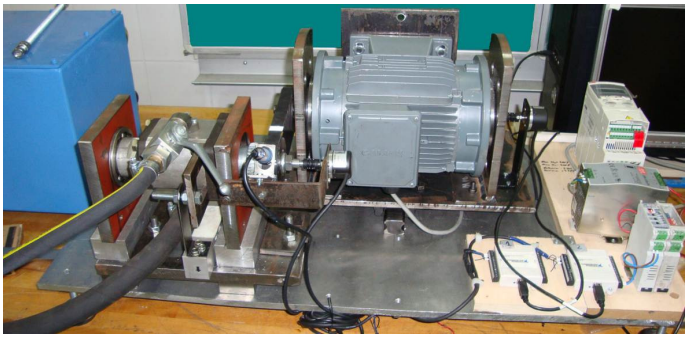

Figure-1. The experimental setup.

Apparatus

In order to extend the experimental studies, which have been developed in the literature, a two equally sized pulley belt drive test system, will be called as dynamometer beyond this point on, was built to measure the speed and torque losses of v-ribbed belt drive systems. The construction of the dynamometer was similar to several other studies [6, 11, and 12].

The driver pulley was actuated with an asynchronous AC electric motor which was driven by a velocity controller, while braking was applied to the driven pulley by a hydraulic pump by means of a valve, permitting different steady state operating conditions of the pump. The pump and motor were placed on bearing housings, each of them were prevented from rotating by means of moment arms, which were linked to individual load cells; where the load cells were mounted on the motor and pump cases; the measured forces through load cells on which were calibrated to give the reaction torques on the motor and pump cases. The rotational speed of each shaft and hence also the slip loss between them was measured through two different optical encoders.

Constant belt pretension was provided by using spring load, applied between ground and the motor case, where the motor was located on a linear bearing rail. The total belt tension in the tight and slack sides was measured by another load cell.

The dynamometer speed range was between 600 rpm to 2500 rpm and the torque range was up to 20 N.m. Pulley diameter range was between 72.5 mm to 97.5 mm. PJ cross sectioned belts and pulleys with belt lengths ranging from 508 mm up to several belt lengths were used. Due to the arrangement of the tensioning mechanism, it was possible to impose various belt tension values to the belt drive system. The ranges of the parameters were selected to represent automotive front end accessory drive belt systems.

Facing motor and pump installation layout was selected to accommodate the shorter belt lengths as shown in Figure-2.

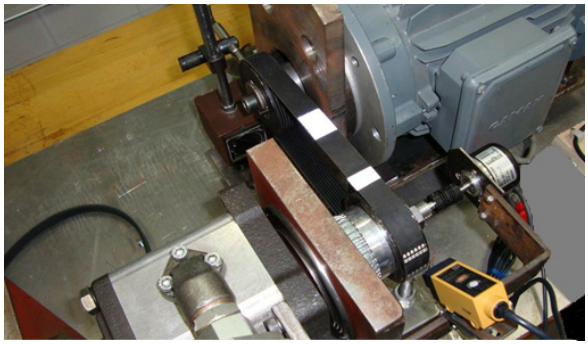

Figure-2. The experimental setup.

For analog to digital data conversion, two microprocessors were used, LabVIEW software was deployed for data acquisition.

Poly v-ribbed J type cross section belts were used for transmitting power between the pulleys as shown in Figure-3 and Figure-4.

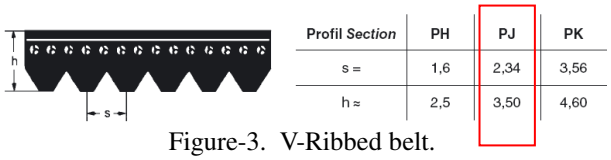

Figure-3. V-Ribbed belt.

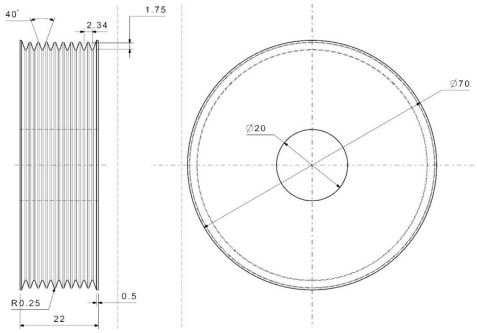

Figure-4. V-Ribbed Pulley Technical Drawing.

Gage R&R Studies

Measurement System Analysis (MSA) has been performed in order to investigate the test rig reliability. Gage Repeatability and Reproducibility (GR&R) is the most common measurement system analysis tool that analyzes the viability of an experimental set-up. Resultant GR&R will indicate overall measurement system variation as a sum of repeatability variation and reproducibility variation. In this study, several MSA iterations were performed and as a result dynamometer was revised to fulfill Gage R&R requirements. Final Gage R&R status is shown in Figure-5.

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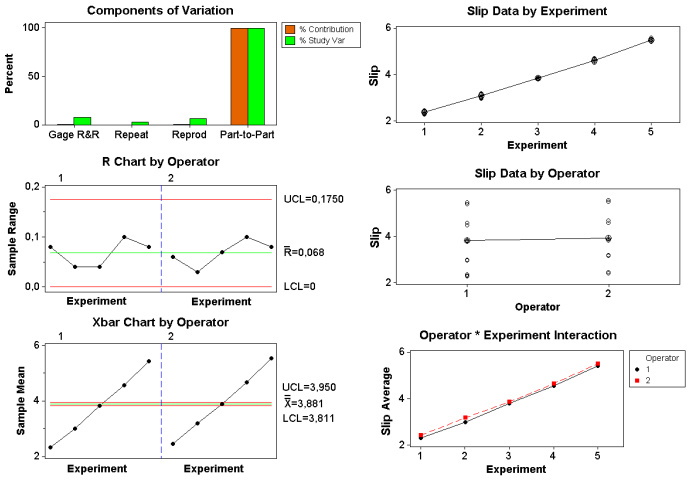

Figure-5. Gage R&R Study.

As shown in Figure-5, Contribution % of Gage R&R was below 1 % and Study Variation % of Gage R&R was below 10 %, and those metrics indicated that the measurement system was valid [10, 13, 14].

Torque Loss Measurements

The power losses are a combination of torque losses and the slip losses. The torque losses include hysteresis losses, friction losses, and idling losses [1].

Hysteresis losses occur due to the belt bending/unbending around the pulleys; therefore reveal at the entrance and exit region. To minimize the hysteresis losses either the belt thickness should be decreased or pulley diameter should be increased to reduce the imposed stresses on the belt material. Increase in driver-pulley speed, significantly increases the hysteresis power losses, which is independent of loading.

Frictional losses are between the side walls of the belt and the inside walls of the pulley. These losses occur whenever the belt enters and leaves the pulley. In v-ribbed belts there are small frictional losses associated with the entrance and the exit of the belt, which grows directly with the speed of the operation and show little variation with the load.

Idling losses are associated with the kinetic energy which is transferred to the surrounding air due to the belt motion. The smoother the belt surface, the smaller these losses will be. Although these losses grow steeply with the belt speed (see Figure-6), they are relatively small losses when compared to the other belt losses. Idling losses are essentially constant as a function of the load.

Air Resistance to Rotation Torque Losses (Idle Torque Loss)

Torque measurements record the total torque acting on the motor and pump casings, respectively. However, total torque on the casings was composed of transmission induced torque, air resistance to rotation induced torque and bearing induced torque. Bearing torque was negligible, but the torque arising from air resistance was not. Therefore, air resistance induced torque was measured and extracted from the total measured torque. To determine the air resistance induced torque, belt was decoupled and the torque was measured for motor speeds from 600 rpm up to 2250 rpm. The fan of the motor was disassembled during the whole experimental study and an outer cooling fan was accompanied to the test rig to minimize the highest fan losses. Thus, the torque measured from the motor speed, when decoupled with the belt, measured only the air resistance to rotation induced torque losses, which is shown in Figure-6.

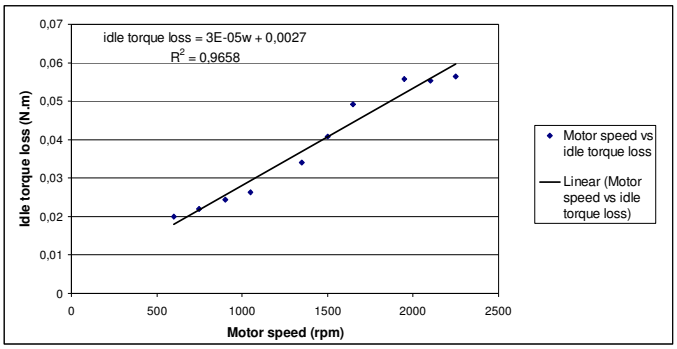

Figure-6. Air Resistance induced torque losses.

The best fitting equation for idling loss is:

$$T_i = 3e-5 * w + 0.0027$$

where, T_i is in N.m.

The amount of inherent loss at the pump body was assumed to be in the same magnitude of the motor inherent loss and the measured braking torque was extracted from the resistance losses in the same amount.

Net Torque Loss Measurements Results and Discussions

As shown in Figure-6, torque losses were measured when driver pulley was idle. Those losses were taken into account while calculating the net torque losses. In Figure (7a) and Figure (7b) net torque losses were evaluated as a function of driver pulley speed. As shown on these graphs, torque losses were nearly constant along the various pulley speeds. Figure (7a) investigates the net torque losses as a function of pretension, whereas Figure (7b) demonstrates the effect of braking torque increase on net torque loss. In Figure-7b, the results show that at low drive torques (for a given belt pre-tension) the net torque loss is relatively high and so the drive efficiency is low.

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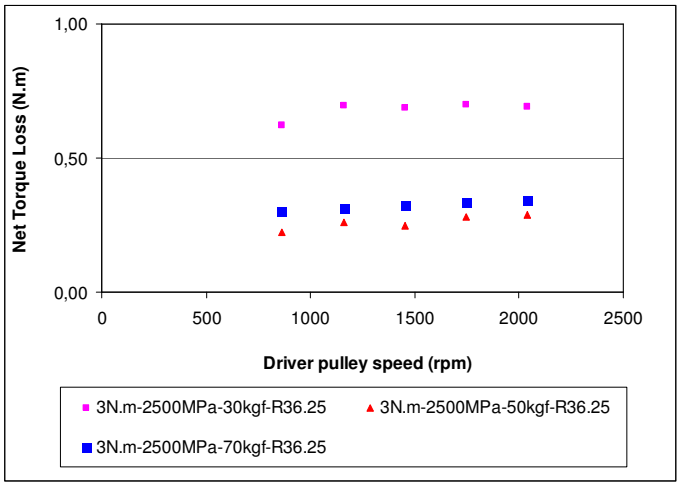

Figure (7a). Net torque losses as a function of driver pulley speed for different tension values.

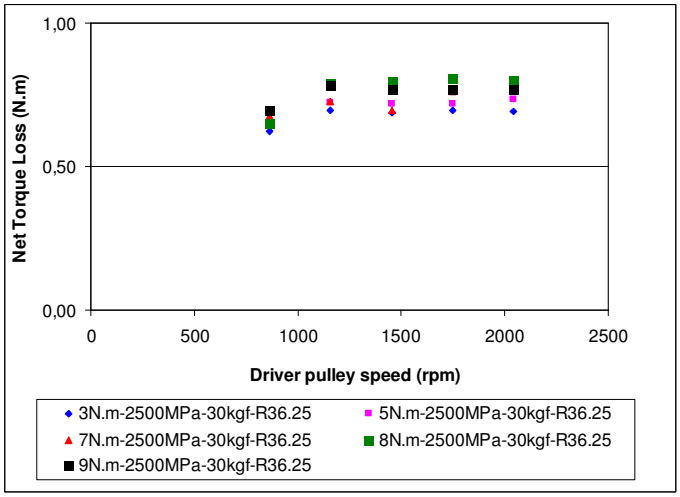

Figure (7b). Net torque losses as a function of pulley speed for different braking torque values.

In Figure-8, net torque losses were evaluated as a function of braking torque. When the braking torque reaches a higher threshold, then there begins to be belt slip and the net torque losses increases dramatically, as shown in Figure-8.

In Figure-9, net torque losses were evaluated as a function of pre-tension. When the pre-tension reaches a lower threshold, then the pre-tension is not enough and there is slippage which results in higher torque losses, as shown in Figure-9.

If the "1/Belt Drive System Efficiency" was defined as "Net Torque Loss" divided by "Braking Torque"; for a given braking torque, an optimum pretension value was observed at a level, which is not too low or too high but within an optimum saddle pre-tension range, as seen in Figure-10.

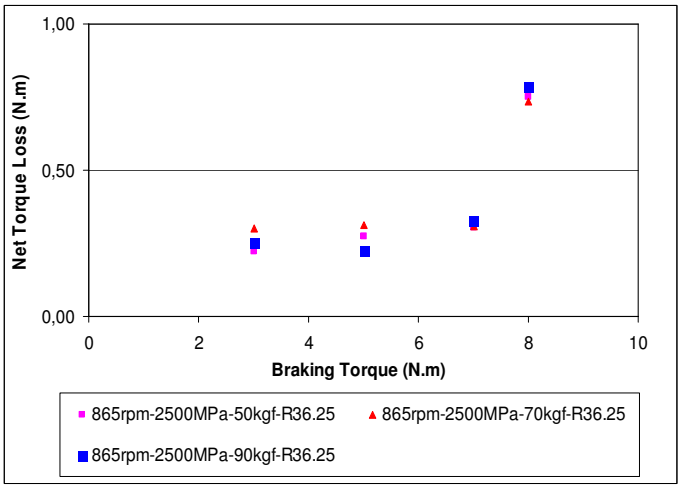

Figure-8. Net torque losses as a function of braking torque.

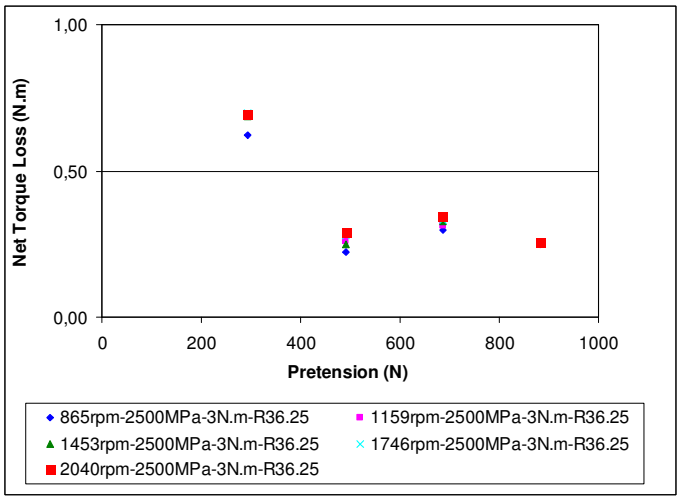

Figure-9. Net torque losses as a function of pretension.

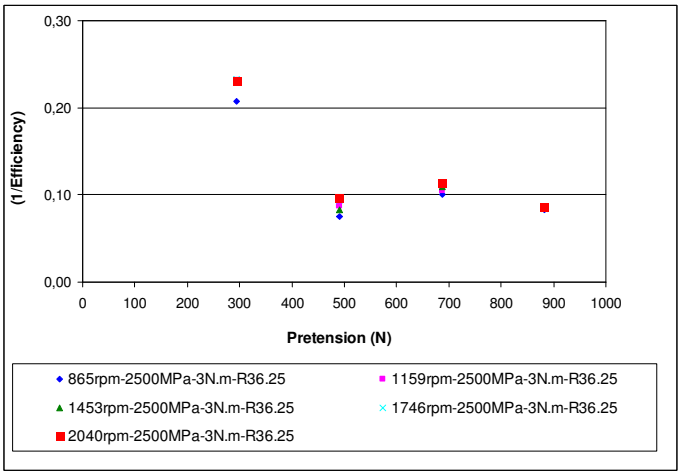

Figure-10. 1/Efficiency as a function of pre-tension at 3N.m braking torque.

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CONCLUSION

In order to extend the experimental studies in the literature, a dynamometer was built to measure the slip and torque losses for a two equally sized pulley of v-ribbed belt drive system.

The torque losses include hysteresis losses, friction losses, and idling losses. Hysteresis losses and friction losses are determined by belt drive. Even when no torque is being transmitted to the pulleys there is still a drive torque, and hence power loss, requirement just to rotate the drive at a constant speed, which corresponds to idling torque loss. Thus, net torque loss is calculated as the measured torque loss subtracted by idling torque losses. Net torque losses are almost constant along the various pulley speeds.

Energy is dissipated due to longitudinal stretching and shearing of the belt as the belt tension changes around a given pulley due to torque transmission. Pre-tension is also dominant and optimum pretension level should be selected according to the application. Net torque losses decrease with the increased pretension force. Net torque losses increase with the increased braking torque. In addition to those conclusions above, stiffer belts and larger pulley sizes are also useful.

FUTURE WORK

"Slip loss measurements on poly v-ribbed belt drive systems" will be presented on a separate paper.

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REFERENCES

[1] Almeida, A., Greenberg, S. Technology Assessment: Energy-efficient Belt Transmissions. Energy and Buildings. 1995:22(3):245-253.

[2] Gerbert, G. Belt Slip-A Unified Approach. Journal of Mechanical Design Transactions of ASME. 1996:118:432-438.

[3] Peeken, H., Fischer, F. Experimental Investigation of Power Loss and Operating Conditions of Statically Loaded Belt Drives. Proceedings of the 1989 International Power Transmission and Gearing Conference. 1989:15-24. Illinois.

[4] Childs, T.H.C. and Cowburn, D. Power Transmission losses in V-belt drives, Part 1: Mismatched Belt and Pulley Groove Wedge Angle Effects, Part 2: Effects of Small Pulley Radii. Proc. Instn. Mech. Engrs. 1987:201(D1):33-53.

[5] Ferrando, F., Martin, F., Riba, C. Axial Force Test and Modeling of the V-Belt Continuously Variable Transmission for Mopeds. Journal of Mechanical Design. Transactions of ASME. 1996:118:266-273.

[6] Amijima, S., Fujii, T., Matuoka, H., and Ikeda, E. Study on Axial Force and its Distribution for a Newly Developed Block-Type CVT Belt. Int. J. of Vehicle Design. 1991:12:324-335.

[7] Chen, T.F., Lee, D.W., and Sung, C.K. An Experimental Study on Transmission Efficiency of a Rubber V-Belt CVT. Mech. Mach. Theory. 1998:33:351-363.

[8] Dalgarno, K.W., Moore, R.B, Day, A.J. Tangential Slip Noise of V-Ribbed Belts. Proc. Instn. Mech. Engrs. 1999:213(C):741-749.

[9] Yu, D., Childs, T.H.C., Dalgarno, K.W. V-Ribbed Belt Design, Wear and Traction Capacity. Proceedings of the Institution of Mechanical Engineers. 1998:212(D):333-344.

[10] Balta, B., Sonmez, F.Ö., Cengiz, A., "Gage Repeatability and Reproducibility Investigations of a Test Rig Using ANOVA/Xbar-R Method", IMECE 62130, ASME Conference on Mechanical Engineering, Denver, Colorado, 11-16 November, 2011.

[11] Castle, J.B, Herrick, T.J., Chandrashekhara, K. Experimental Measurements of V-Ribbed Belt Tracking Lateral Forces. 2000, SAE 2000-01-0912.

[12] Childs, T.H.C. and Cowburn, D. Power Transmission losses in V-belt drives, Part 1: Mismatched Belt and Pulley Groove Wedge Angle Effects. Proc. Instn. Mech. Engrs. 1987:201(D1):33-40.

[13] Forrest, W., Breyfogle III, "Implementing Six Sigma, Smarter Solutions Using Statistical Methods", Wiley, 2nd Edition, 2003.

[14] The Black Belt Memory Jogger, First Edition, GOAL/QPC and Six Sigma Academy, 2000.

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