

A Study of Drying-Up Friction and Noise of Automotive Accessory Belt

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ABSTRACT

Multiple-ribbed V belts have been widely used in automotive accessory drive systems to transmit power from crankshaft to power steering pump, alternator, and air conditioning (A/C) compressor. Overload under severe environmental conditions can lead to excessive slippage in the belt pulley interface in poorly designed accessory drive systems. This can lead to undesirable noise that increases warranty cost substantially. The mechanisms of this tribology phenomenon, noise features and system response are of utmost interest to the accessory drive system engineers. As accessory belt systems are usually used in ambient condition, the presence of water or moisture on belt is unavoidable under rainy or highly humid conditions. It has been found that the wet friction with negative coefficient of friction (cof)-velocity slope can lead to self-excited vibrations and squeal noise. In this study, the comprehensive drying-up process of wet belt interface is investigated by using belt-pulley interface test rig and commercially available belts. It is found that after the wet friction corresponding to negative COF-velocity slope and belt self-excited vibrations, the belt exhibits dry friction again during the drying-up process due to its continuous running. But the belt friction is different from the original dry friction. The coefficient of friction of the dried up belt is higher than that of the original belt, which is associated with higher intermittent slip noise. The investigation is expected to give some insight on how to shift the occurrence condition of the slippage and noise out of the operating angular speed range (rpm) of an engine frontend system.

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INTRODUCTION

Automotive multiple v-ribbed belts are key for transmitting power from the engine crankshaft to the automotive accessories. With improvement in quietness of vehicles, it is necessary to reduce the belt noise for higher quality vehicles. The continuous industry emphasis on improving vehicle noise characteristics has resulted in a variety of new belt products intended specifically to inhibit friction-induced vibration and noise. Tighter controls over critical belt drive parameters have helped diminish the occurrence of objectionable belt vibration and noise. These include complex friction materials (composition, geometry), belt construction, drive system dynamics, components and integration, boundary conditions at the friction interface, all of which are subject to temperature and humidity variations, manufacturing and assembly tolerances, wear, non-linearity, viscoelasticity etc.

There are many papers dedicated to the analysis of noise and non-linear belt vibrations. There are some published papers dealing with linear and non-linear transverse/longitudinal belt vibration responses [1-2]. They discussed

models available for analyzing the free and forced axial, transverse and tensional vibrations of belt. The effects of initial tension, transport velocity, bending rigidity, support flexibility, large displacement, belt and pulley imperfections had been discussed. Connell, Rorrer and Meckstroth [3-4] had systematically investigated friction-induced vibration and noise of V-ribbed belts. They characterized basic noise properties by extensive experimentation. Dalgarno et al. [5] discussed the tangential slip noise of V-ribbed belts and attributed the noise from the excitation to the fundamental vibration of belts. Based on the experiments using SAE test rig, researchers [6,7,8] presented mathematical models that unifies previous works. The wet noise has been a critical issue of v-ribbed belts in applications. A typical accessory system consists of transmission belt, crankshaft pulley, tensioner pulley, Idler pulley, air conditioning pulley, compressor pulley, power steering pump pulley, alternator pulley and water pump pulley. All accessory pulleys are driven by the belt. When the load torque of some accessory subsystem is beyond the belt driving torque on its pulley, the belt tangential slippage on the pulley will occur. Intermittent

slip noise, 'chirp' or 'squeak', will occur if friction and slip reaches a threshold level [3,4,5,6,7,8]. However, the slip noise and friction of belt under certain application conditions such as wet belt in dry-up process has not been addressed.

This paper presents an experimental study on noise and friction of wet belts under dry-up conditions. The belt testing is conducted on a belt-pulley test rig. The belt friction is recorded when a wet belt is forced to make slip motion under varied conditions. The belt noise and vibrations are also recorded. The belt friction under dry-up condition is found to have even a higher value than that in wet condition and dry condition. The transient noise and vibration signal exhibits non-stationary and nonlinear properties. The belt noise under dry-up is found to exhibit squeal after intermittent chirp.

TEST SETUP

Typical friction-velocity features and slip noise features of V-ribbed belts can be experimentally characterized by directly using SAE belt friction/slip test rig [6,7,8]. The test rig is used to simulate real belt conditions by circling belts on a driving pulley, driven pulley and idlers. Belt motion is driven by the driving pulley. The driven pulley has a resistant torque controlled with an electric dynamometer. The wrap angle on the driven pulley can be adjusted, and the tension is maintained on the slack-side of the driven pulley by use of weight and cables. During the test, when the resistant torque of the driven pulley increases to a high enough level, the belt will slip, and an associated noise will be generated when the transmitted torque load reaches a certain level. All the testing parameters are recorded by the sensors, data acquisition system and a computer attached to the test rig. In this study, we use a test rig with a belt in sliding contact against a rotating pulley. Fig. 1 shows a picture of the belt-pulley test rig. One end of the belt segment was connected with a force transducer attached to a fixed board. The other end of the belt segment was hung with a dead-load of 5 lbs. The diameter of the commercially available pulley was 163 mm. During testing, the pulley was driven by a DC electric motor powered by a 12V battery with a speed controller. The pulley shaft rpm was measured using an optical tachometer. The running speed range was from 0 to 100 rpm. The force sensor monitors the force transmitted in the belt during testing. The relationship between the forces of the tightened side and the relaxed side (dead-load side) of the belt segment is established by Euler's formula. A force sensor and a data acquisition system were used in the belt-pulley rig to record the force history when the system was running. A load cell system (LC-105-500, Aluminum S beam load cell, PSU-93 power supply) from Omega Company was used for force measurements, and a digital transmitter (D1521 input modules A/D converter) was used for outputting digital signals. The Labview vi system was used for data acquisition. Labview software was also used to communicate with the load cell package of Omega and to read the output signals according to the VI (Virtual Instrumentation) diagram. The

measurement was conducted at room temperature of 21°C. A set of vibration and sound testing system was used to record the belt acceleration and noise signal associated with the interface dry-up running. The accelerometer was mounted on the belt surface 30 mm from the interface. The microphone was installed 1 meter away from the interface and 1.5 meters above floor ground.

In order to investigate the friction due to the rubber pulley contact, commercially available rubber V-ribbed belts and a commercially available pulley were used. Both the belts and the pulley are purchased from automotive parts dealers, Napa Auto Parts and Sears. Prior to the testing, the belt was undergone a dry break-in running for a hundred times to attain a stable coefficient of friction, which is about 1.3.

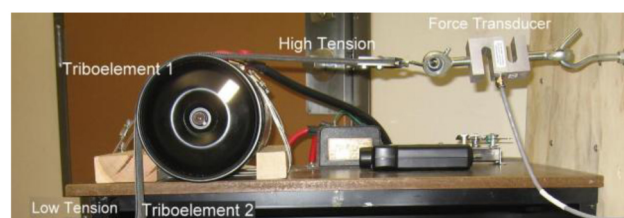


Fig. 1. Test setup

EXPERIMENTAL RESULTS

The purpose of this experiment is to replicate an initially wet belt which is continuously running till the interface turns dry. For this experiment, the belt-pulley interface was initially wet and a series of experimental runs were conducted with brief intervals of time between each run. The interface was not altered in any way once the experiment started. A total of 16 runs were executed over a period of 24 hours with certain intervals extending to several hours while other intervals being as small as 2 minutes. This was done in order to replicate a real time scenario where the belt is run only for short intervals of time but multiple numbers of times of a long time period. The results for run 1, 7, 8, 14, 15 are shown in Figs. 2,3,4,5,6. Initial runs show results similar to wet friction results, a stiction peak followed by a level off friction. However, it is worth noting that as the runs proceed, for the initial 5 runs, the peak values remain the same but a steady increase in the level off value is observed. The next batch of runs was conducted with an interval of 3 hours between 5th and 6th runs and a significant change can be seen. The peak value shown indicates a significant increase from previous results whereas the level off value shows no change. The peaks are still seen due to the interface not being completely dry (there appears to be some water left in the interface - showing certain wet friction characteristics). However, the difference between the peak values and level off values is significantly higher in runs 5-8 when compared to runs 1-4. In the final 4 runs, it is observed that stiction effect is still visible. However the level off value is observed to be alarmingly high compared to what is usually observed