ON THE WET BELT SQUEAL : CHARACTERIZATION OF THE MECHANICAL VIBRATION AND INFLUENCE OF THE MECHANICAL PROPERTIES OF THE BELT ON FRICTION-INDUCED INSTABILITIES

S. GATIGNOL[1,2*] , T. DEMASSOUGNE[2] and A. LE BOT[1]

[1]Laboratoire de Tribologie et de Dynamique des Systemes (LTDS)
Ecole Centrale de Lyon, Ecully, FRANCE
Email: simon.gatignol@doctorant.ec-lyon.fr, alain.le-bot@ec-lyon.fr
[2]HUTCHINSON SNC
Joue-les-Tours, FRANCE

ABSTRACT

Under wet conditions, V-ribbed belts of the Automotive Accessory Belt Drive System might emit a typical squeal noise. A test rig consisting of a static v-ribbed belt in contact with a pulley lubricated with water allow to replicate the phenomenon. Measurements of the belt vibrations suggest that whereas the pulley plays a minor role, the belt vibrations can be directly linked to the squeal emission and it is shown that a single tooth - or single "v"- is sufficient to generate squeal. The source of these vibrations is often considered to be friction-induced vibrations. However, the friction behaviour of the belts is shown unsufficient to explain the outbreak of squeal and the mechanical properties also influence the domain of instability. A characterization of the mechanical properties of the belt has been carried out using DMA experiments and leads to a better understanding of the relation between the different belt structures and their aptitude to generate noise.

1 INDUSTRIAL AND SCIENTIFIC CONTEXT

During the last decades, the global noise emission of vehicles has decreased from 82 to 74 dB. This let emerge parasite noises such as brake or wiper blade squeal. A typical squeal noise can also be emitted by v-ribbed belts in the Automotive Accessory Belt Drive System. Previous studies has allowed the suppression of noise in the case of a dry belt however a solution is still needed in the presence of humidity. The squeal noise that appears on motors between the v-ribbed belt and the alternator pulley has been replicated on a specific test rig presented in section 2. The link between the noise and the mechanical vibrations of both the pulley and the belt is then established in section 3 before the role of friction-induced instabilities features in the occurence of the belt squeal are briefly recalled in section 4. As a more precise understanding is needed, the influence of the mechanical properties of the belt is investigated in section 5.

2 EXPERIMENTAL SETUP

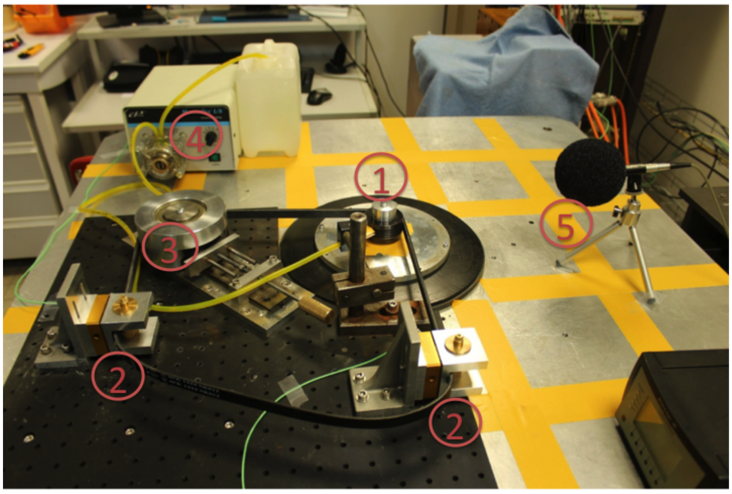

Figure 1: Experimental Setup consisting of: a *pulley* and a *v-ribbed belt* (1) clamped in *2 tension sensors* (2), plus a tensionner(3), a microphon (5) and a peristaltic pump (4)

The test rig used in the following studies is presented in Figure 1. The contact between the v-ribbed belt and the pulley is replicated. The specificity is that the belt remains static so that sliding exist all along the wrap - or contact - angle which is not the case on motors. The rotation of the pulley is controlled so that the sliding velocity is known. The lubrification of the contact is regulated with a peristaltic pump. Sensors measure the evolution of the tensions in both slack and tight free spans. A minimum tension is maintained in slack span thanks to a belt tensioner. The coefficient of friction is computed from the measurement of the tensions using Euler's formula. Measurements of the vibrations of the belt have been carried out with both accelerometers and laser vibrometers. The sound is recorded with a microphon 30 centimeters far from the pulley. Experiments consist in progressively increasing the rotational velocity with a constant supply in water - about 1 mL/s. The belt initial tensions and the ramp of velocity are modified and v-ribbed belts with different coatings are used. The rotational velocity can be stationnary or with a sinusoidal form in order to replicate the phenomenon of acyclism.

3 MECHANICAL VIBRATION AT THE ORIGIN OF THE BELT SQUEAL

Role of the Pulley It is assumed that the contact between the belt and the pulley is necessary for the squeal noise to occur. However, the tests described in section 2 have been carried out with different forms of pulley - plain or empty - without any change on the acoustic signature of the squeal noise. Moreover, the modes of vibrations of the pulley have been investigated using an impact hammer and no likeness has been observed between the natural modes of the pulley and the fundamental mode of the squeal noise.

Role of the Belt Laser vibrometers have been used to investigate the link between the squeal noise and the vibrations of the belt. A time frequency analysis of the belt velocity or vibrations show that the squeal appear at the same time that strong belt vibrations occur. Moreover, the spectral signature is the same for the belt vibrations and the squeal noise. Therefore, a link between the belt vibrations and the squeal noise exist. Another experiment consist to reach the range of parameters - sliding velocity, tension in free spans, and water supply - at which a stationary noise exist and then to clamp the belt with fingers at proximity of the contact with the pulley. The immediate disappearance of the squeal confirm that the mechanical vibrations of the belt play a key role in the generation of the squeal noise. Similar experiments with the pulley doesn't have any effect.

So the mode of vibrations of the belt has been studied more in detail. On one side, the data of the vibrometers has been completed with measurements using 3D accelerometers detecting belt vibrations in the 3 directions. On another side, belt samples with only one rib have been tested and a squeal noise with the same acoustical signature has been observed as previously. These results highlight that the mode of vibrations of the belts that cause the appearance of the squeal noise doesn't involve the whole structure of the belt but only each tooth separately as mentionned by Dalgarno et al. [1]. However it is difficult to conclude on the excited mode as several directions vibrates.

Therefore, the vibrations of the belt are necessary for the squeal to occur. The conditions that let appear the mechanical vibrations of the belt has been studied The role of friction-induced instabilities is summed up in the next section.

4 FRICTION-INDUCED INSTABILITIES AT THE ORIGIN OF BELT SQUEAL

Friction-induced instability features have been widely used to explain belt squeal both for dry and wet belt. Sheng [2] has highlighted the role of the transition in a mixed lubrication regime and the related negative slope of the friction versus sliding velocity curve as the main feature for the noise to be triggered.

However, recent results show that the correspondance between the level of slope and the appearance of noise is not obvious [3]. The consideration of low velocity sliding highlights that the squeal appears after the strong decrease in friction coefficient, as it can be observed on Figure 2. Moreover the transition from static to dynamic friction - for example the stick-slip motion - is also unsufficient to explain the appearance of squeal [3].

Thus the separated consideration of the friction behaviour is not enough to understand the generation of the instability, a finer understanding of the mechanical properties of the belt is also required.

5 INFLUENCE OF THE BELT MECHANICAL PROPERTIES

The main mechanical properties of the belt are the stiffness of cords in its tension member (back of the belt) and both the stiffness and the damping properties of its teeth. Belts with

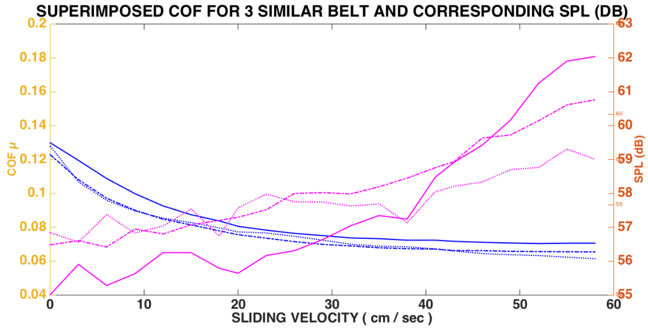

Figure 2: Coefficient of Friction (COF - blue line) and Sound Pressure Level (SPL magenta line) with respect to the sliding velocity for 3 similar belts

modified cords and teeth has been tested as describes in section 2. The results show that the domain where the instability and the noise occur strongly depends on both cords and teeth properties.

That is why the cords stiffness have been measured by traction tests whereas Dynamic Mechanical Analysis (DMA) has been used for the tooth properties. The applicabilty of the Time Temperature Superposition have been checked and the resulting mastercurves show the evolution of the belt tooth properties on a large range of frequencies , as observed on Figure 3. The different belt teeths were distinguishable as a function of their coatings and belt mixtures. Further investigations consist to link the quantitative values reached thanks to the DMA

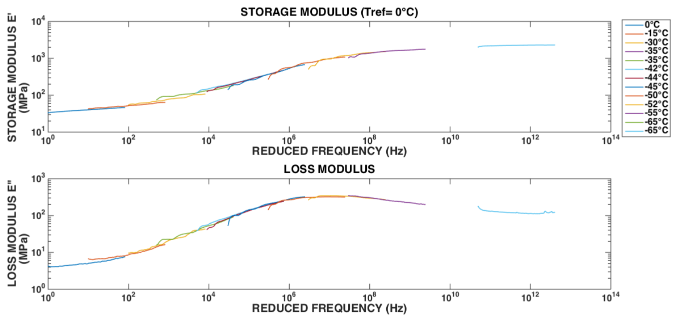

Figure 3. Mastercurves for the storage (top) and the loss (bottom) modulus

experiments with the outbreak of the squeal phenomenon.

REFERENCES

[1] J.E. Connell ,R.A.L. Rorrer. Friction-induced vibration in V-ribbed belt applications. *Proceedings of the ASME conference*, DE-Vol.49(), 75-85, 1992.

[2] G. Sheng et al..Wet belt friction-induced dynamic instability and noise in Automotive Accessory Belt Drive Systems, *Int. J. Vehicle Noise and Vibration*, 2(3), 249-265, 2006.

[3] S. Gatignol, T. Demassougne and A. Le Bot. Detection of friction-induced instabilities at the origin of the squeal of wet poly-V belts, *Proceedings of the conference InterNoise2016*, 7349-7359, 2016.