COMPREHENSION OF FRICTION LAW INSTABILITY: APPLICATION TO WIPER BLADE SQUEAL NOISE

F. Dalzin[1], A. Le Bot[1], D. Mazuyer[1], J. Perret-Liaudet[1] and F. Bretagnol[2]

[1]LTDS-UMR 5513 CNRS-Ecole Centrale de Lyon
36 Avenue Guy de Collongue, 69134 Ecully Cedex, FRANCE
Email: fabien.dalzin@ec-lyon.fr, alain.lebot@ec-lyon.fr, denis.mazuyer@ec-lyon.fr, joel.perret-liaudet@ec-lyon.fr

[2]Valeo Systeme d'essuyage
1 Avenue Pierre et Marie Curie, 63500 Issoire, FRANCE
Email: frederic.bretagnol@valeo.com

ABSTRACT

This paper deals with the squeal noise of a wiper/windscreen contact. This contact consists of a single degree-of-freedom mass-spring-damper oscillator submitted to a velocity-dependent frictional force, which follows the Stribeck law. Using the first Lyapunov method, an instability criterion was defined. Starting from this knowledge, experiments were made to understand the origin of this instability on the tribometer LUG. This tribometer measures the friction coefficient, and allows to see the contact between the elastomer and the glass using a macroscope and optical interferometry. In this paper, a relationship between the instability (apparition of the squeal noise) and the observed contact will be shown.

1 INTRODUCTION

Whereas rubber noise is characterised by its large frequency band, squeal noise is characterised by its narrow frequency band around 1000 Hz. Studies were made to understand the apparition of instability, directly linked to the squeal noise phenomena:

A. Koenen $\&al.$ [1] analysed the major role of the Stribeck curve regarding the instability, and the importance of water and sliding velocity. Le Rouzic $\&al.$ [2] made experiments and built a model starting from their observation on the Stribeck curve.

The aim of this presentation is to understand the relationship between the instability and the evolution of the elastomer contact through the Stribeck curve.

2 INSTABILITY AND STRIBECK CURVE: OBSERVATION

2.1 Stribeck curve

Squeal noise appears only for certain sliding velocities, and a certain quantity of water. Thus, Stribeck curve is a good tools to determinate the instability range.

Stribeck curve represents the evolution of the friction coefficient according to the Sommerfeld number S, depending of the sliding velocity v, as shown in figure 1.

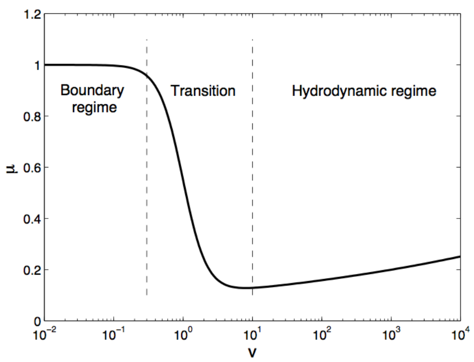

Figure 1. Example of Stribeck curve

There are three regimes in this curve:
- The boundary regime, corresponding to a high friction coefficient.
- The mixed/transition regime, corresponding to a decrease of the friction coefficient.
- The EHD regime, corresponding to a low friction coefficient.

One of the most important interest of using this curve, is that the instability appears only in mixed regime, when there is a strong decrease of the friction coefficient.

2.2 Stribeck curve fitting

Bongaerts $\&al.$ [3] obtained an empirical equation fitting the Stribeck curve:

$$\mu(v) = \left[c * v^q + \frac{1}{1+(\frac{v\eta}{b})^p}(a * v^n - c * v^q) \right] \quad (1)$$

Thus, it is possible to construct an accurate Stribeck curve with only 15 points.
The coefficients a, b, c, n,p, and q could be directly "read" on the curve, and have physical signification.

3 STABILITY ANALYSIS

3.1 Model

Le Rouzic $\&al.$ [2] constructed a model of the contact between the glass and the elastomer. This contact consists of a single degree-of-freedom mass-spring-damper oscillator submitted to a velocity-dependent frictional force, which follows the Stribeck law, see figure 2.

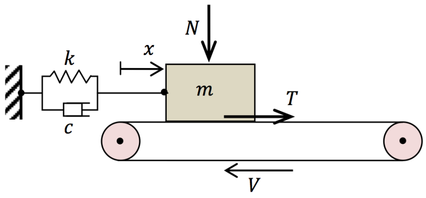

Figure 2. Friction-induced vibration of a mass spring oscillator.

At the natural frequency $\omega^2 = \sqrt{\frac{k}{m}}$, the damping ratio ζ is defined as $\zeta = \frac{c}{2m\omega}$.

3.2 Stability analysis

Using the first method of Lyapunov, Le Rouzic $\&al.$ [2] shown the model leads to the criterion:

$$\begin{cases} \frac{d\mu}{dv} < -2\zeta : \text{UNSTABLE} \\ \frac{d\mu}{dv} > -2\zeta : \text{STABLE} \end{cases} \tag{2}$$

where v is the relative velocity between glass and elastomer: $v = V - \dot{x}$.
When $\frac{d\mu}{dv} < -2\zeta$, the equilibrium is unstable and leads to a periodical response (limit cycle).This criterion is in adequacy to the observations on the Stribeck curve: the instability occurs in mixed regime, see in figure 3. The vibration velocity was measured with a vibrometer.

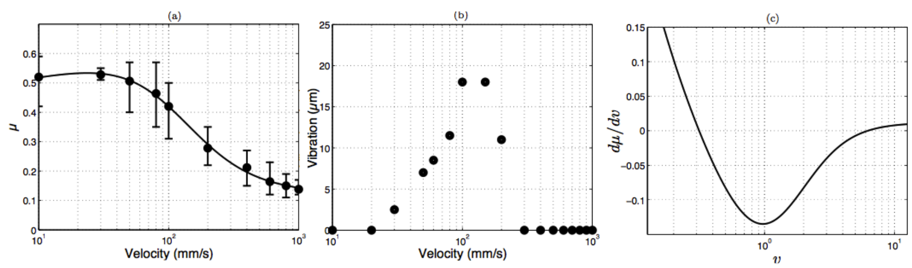

Figure 3: (a) Friction coefficient versus sliding velocity. (b), Vibration amplitude versus velocity. (c), Slope of the empirical fit translated by 2 ζ with $\zeta = 0.006$.

4 OBSERVATION OF THE CONTACT

Deleau $\&al.$ [4] observed the relation between the dynamic of the elastomer/glass contacts, and the Stribeck curve. Following his research, we analysed on the tribometer LUG the interferometry images we get, see figure 4. The tribometer LUG measures the friction coefficient, and allows to see the contact between the elastomer and the glass using a macroscope and optical interferometry.

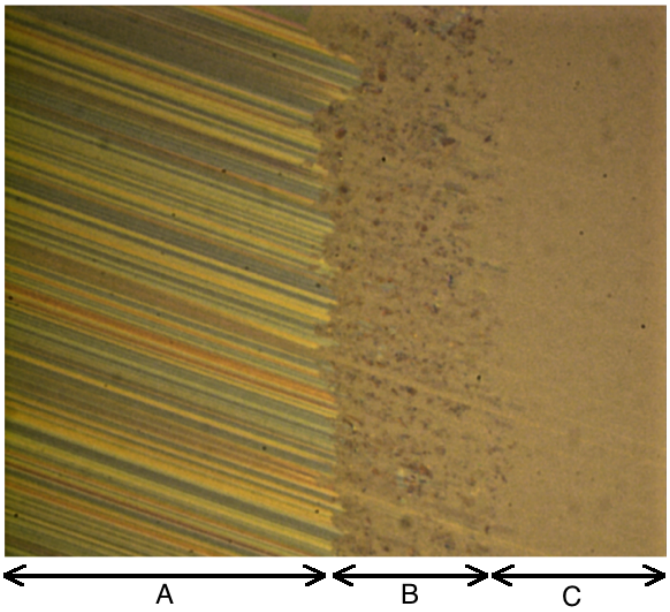

Figure 4. Contact between glass and elastomer.

On the left on the image (A), the different streaked colors correspond to different very thin water thickness.
On the center (B), the contact elastomer/glass can be seen. This contact is composed of a multitude of contact spots. As was mentioned previously, the different colors of these spots correspond to different water thin thickness.
On the right on the image (C), only water is present.

For different sliding velocities, we can see a strong evolution of the spot contact colors, showing an evolution of the ”dry” contacts and the ”wet” contacts. An analysis of this results has been done.

REFERENCES

[1] A. Koenen and A. Sanon. Tribological and vibroacoustic behaviour of a contact between rubber and glass (application to wiper blade). *Tribology International*, 40:1484–1491, 2007.

[2] J. Le Rouzic, J. Perret-Liaudet, A. Carbonelli, A. Le Bot, and D. Mazuyer. Some experimental and analytical results on self-excited vibration of a dynamic sliding system in the case of stribeck law for friction coefficient. In *International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 2011.

[3] J.H.H. Bongaerts, K. Fourtouni, and J.R. Stokes. Soft-tribology lubrification in a compliant pdms-pdms contact. *Tribology International*, 40:1531–1542, 2007.

[4] F. Deleau, D. Mazuyer, and A. Koenen. Sliding friction at elastomer/glass contact: Influence of the wetting conditions and instability analysis. *Tribology International*, 42:149–159, 2009.