International Journal of Non-Linear Mechanics 80 (2016) 132–143

Contents lists available at ScienceDirect

International Journal of Non-Linear Mechanics

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

Dynamics of windscreen wiper blades: Squeal noise, reversal noise and chattering

Giovanni Lancioni [a,*], Stefano Lenci [a], Ugo Galvanetto [b]

[a] Dipartimento di Ingegneria Civile, Edile e Architettura, Università Politecnica delle Marche, Via Brecce Bianche 1, 60131 Ancona, Italy
[b] Dipartimento di Ingegneria Industriale, Università di Padova, Via Venezia 1, 35131 Padova, Italy

ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
29 June 2015
Accepted 2 October 2015
Available online 23 October 2015

Keywords:
Wiper blade vibration
Friction-induced oscillation
Non-smooth dynamics
Squeal noise
Chattering

ABSTRACT

The motion of a windshield wiper blade is modelled by a mass-spring-damper system on a moving frictional surface. The system dynamics is time-varying, since three different regimes of motion, characterized by different degrees of freedom, are possible. Indeed the system, which schematizes a blade cross-section, can experience stick and slip motions when it is in contact with the glass surface, and free-flight motion when it is detached. The contact between the system and the surface is governed by Stribeck's friction law and Poisson's impact law, which make the dynamics non-smooth. The model is numerically implemented in an event-driven code, and simulations are performed which reproduce the three basic classes of undesired oscillations observed in the motion of real windscreen wipers, i.e., squeal, reversal and chattering noises. Attention is focused on the causes of these vibrations, and remedies for reducing or avoiding them are proposed.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Squeal, reversal and chattering noises represent the three basic undesired oscillations observed in the motion of automotive windscreen wipers. They manifest in different forms, and they are due to different causes.

The *Squeal noise* is a self-excited slip or stick-slip oscillation which occurs at frequency of 500–1000 Hz, when the windshield glass is wet. In wet condition, the friction between the blade tip and the glass depends on the sliding velocity, according to the so-called Stribeck curve [1]. The friction coefficient attains large values for velocities close to zero (boundary regime), while it assumed that low values for large velocities (hydrodynamic regime). In the transition phase between boundary and hydrodynamic regimes, the gradient of the friction coefficient, said *speed characteristic*, assumes large negative values which induce instability of the blade slipping motion, leading to squeal vibrations. Since the transition regime happens at low slip velocities (around 0.1 m/s), vibrations are observed before and after the wiper reversal.

Friction-induced vibrations have been the object of many studies, since they are observed in several engineering applications. We refer to [2–4] for detailed overviews, oriented to industry applications and modelling studies, respectively. Regarding the squeal noise occurring in windscreen wipers, different models have been developed. A simple one degree of freedom (dof) system has been proposed in [5], consisting of a moving mass on a frictional surface, constrained by a spring and a dashpot. The range of sliding velocities at which equilibrium solutions are unstable has been determined by Lyapunov stability analysis, and its close correspondence with the ranges found in experiments has confirmed that the squeal noise is a friction-induced vibration due to the steep gradient of the friction in the static-to-hydrodynamic transition phase. In [6], the lip cross-section of a wiper has been schematizes by a rigid bar constrained by springs to a fixed support, which slides on a moving surface. The system dynamics is governed by a one-dof equation, whose viscous coefficient depends on the friction speed characteristic. For sufficiently large negative speed characteristics, the viscous coefficient becomes negative, and the solution is a self-excited vibration, which reproduces the squeal noise. Self-excited stick-slip oscillations are also studied by means of basic one-dof models in [7,8] or by multi-dof models in [9].

Chattering or *Beep noise* is a low frequency oscillation (<100 Hz) mostly occurring in the slip-stick mode. The main cause of this vibration is geometrical, and it lies in the inappropriate bent configuration often assumed by the wiper blade with respect to the normal to the glass surface. This inclination is measured by the so-called *attack angle*, which is defined as the angle between the symmetry axis of the blade cross-section and the vector normal to the outer glass surface. Sloped configurations

* Corresponding author.
E-mail addresses: g.lancioni@univpm.it (G. Lancioni), lenci@univpm.it (S. Lenci), ugo.galvanetto@unipd.it (U. Galvanetto).

http://dx.doi.org/10.1016/j.ijnonlinmec.2015.10.003
0020-7462/© 2015 Elsevier Ltd. All rights reserved.

can be due also to permanent plastic deformations in the blade lip. This vibration happens only when the wiping motion has the direction pointed by the blade projection on the surface.

In [10,11], finite element modal analysis has shown that chattering occurs when the first bending mode exhibits a flutter instability. In particular, in [11], the influence on the instability of both the attack angle and the normal force applied by the arm to the blade has been investigated. An analogous parametric investigation has been conducted in [12] by a simplified four-dof model. Flutter instabilities induced by the sliding of a rubber waist seal on a glass window have been investigated in [13] through a finite element model accounting for large deformations. Finite element analyses of the dynamics of the whole wiper system have been reported in [14], and they have been used to develop a passive vibration controller. In [15], stick-slip chattering noise in the entire wiper system including two blades has been reproduced through a simple two-dof model.

Finally, *Reversal noise* occurs when the wiper reverses the direction of its motion. At reversal, the normal reaction force varies very quickly, acting on the swept surface as an impulsive force, which induces vibrations in a narrow subsequent time interval. A thorough investigation of the reversal noise, both experimental and analytical, has been carried out in [16]. In the analytical study, a one-dof rigid body system has been considered very similar to the system proposed in the present paper.

The objective of this work is to reproduce the above described vibrations by means of a simplified dynamical model, highlighting the causes inducing the noises, and, eventually, suggesting remedies to reduce or avoid them.

The wiper blade cross-section system is schematized by the system drawn in the forthcoming Fig. 1(b). Since the rigidity of the blade lip is higher than that of the neck, the lip is regarded as a rigid pendulum and all its bending deformability is concentrated in the neck through a rotational spring. The pendulum has a mass at its endpoint, it is constrained to a rigid support by a spring and a dashpot, which account for the action of the blade head and wiper arm, and it is in touch with a frictional surface, the motion of which reproduces the wiping motion. The possible impacts of the pendulum tip on the surface are modeled by Poisson's law [17,18], where restitution impulses allow for bounces.

The model is similar to the frictional impact oscillator proposed and studied in [19] and numerically investigated in [20]. They differ for the fact that the frictional impact oscillator has a mass at the hinge, and it has a rotational dashpot in addition to the rotational spring, which are neglected in the present system. Furthermore, the gravitational field considered in [19,20] is ignored here. However, two enrichments are introduced to make the model more realistic. First, two different coefficients of the rotational spring are considered to account for the different stiffness registered when the lip is in contact with the shoulder of the wiper head, and when it is not (see forthcoming Fig. 2). The second new element is the friction coefficient characterizing the contact between the moving surface and the bar tip. It is supposed to depend on the relative horizontal velocity according to the Stribeck curve, which describes friction in condition of wet windscreen [1]. Although the resulting system is based on simplified assumptions, it is capable of capturing the basic features of the complex time-varying dynamics of windscreen wipers, where three different regimes of motions combine (free-flight, slipping and sticking). In such a way, the model succeeds in reproducing the whole variety of noises observed in reality. To the best of the authors' knowledge, the simplified models available in literature [5–8,12,16] describe single specific vibrating phenomena, and they do not posses the descriptive versatility of the proposed model.

Non-smooth systems with impact and/or friction have been the object of intensive studies because of the large variety of nonlinear dynamics phenomena they experience [21–26]. Here we concentrate on the application to windscreen wipers, aiming at capturing their distinguishing vibration phenomena. All the system parameters are related to the specific geometrical and material properties of common windscreen wipers, and then they are properly fixed. Simulations are performed which capture all the three different kinds of motion, and the causes inducing them are

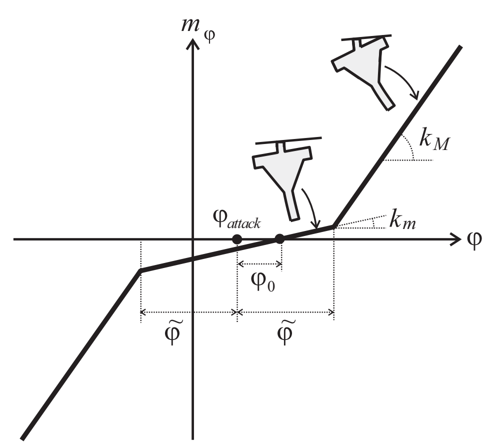

Fig. 2. Graph of the restoring elastic moment $m_\varphi = m_\varphi(\varphi)$.

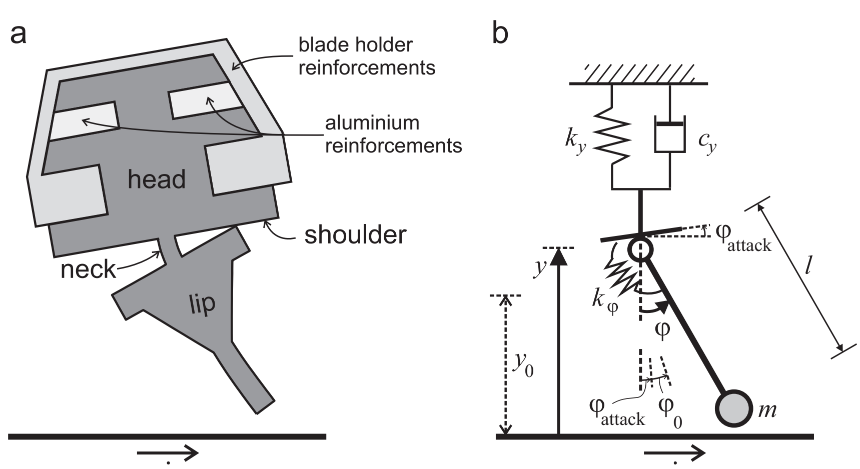

Fig. 1. (a) Windscreen wiper blade section; (b) geometrical scheme of the model.

Download English Version:

https://daneshyari.com/en/article/784911

Download Persian Version:

https://daneshyari.com/article/784911

Daneshyari.com