ACTIVE CONTROL OF DISK BRAKE SQUEAL

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Summary *Considerable effort is spent in the design and testing of disk brakes of modern passenger cars. This effort can be reduced if refined mathematical-mechanical models are used for studying the dynamics of these brakes before prototypes are available. The present paper is devoted to the modeling of a floating caliper disk brake, special regard being given to the suppression of squeal. The model developed includes the brake rotor, modeled as a flexible rotating plate, housing, piston, yoke, and friction pads. In this nonlinear model all the prominent features of squeal are reproduced, such as e.g. independence of the frequency on the speed, etc. In a test rig built in Darmstadt, the model is validated. In addition, the set-up also permits active control by using "smart pads". Those pads, which include piezoceramic actuators are successfully used for the suppression of squeal.*

Introduction

Automotive brakes have greatly developed during the last decades. Engine power has increased considerably during this period and since the power to be dissipated in a brake can be several times than that of the engine, so did the forces acting at the brake. The geometric space available for the brakes in a car is however rather limited and constrained by the dimensions of the wheel, so that new forms of brake design had to be developed and some of these new designs were more susceptible to generate unwanted noises.

A typical modern floating caliper disk brake is shown in Fig. 1 in an artist's view, together with a mechanical model to be discussed in more detail later. The brake consists of a brake rotor (the *disk*), housing, piston, yoke and friction pads. The braking force is generated by friction between pads and disk. Not only the power but also the expectation for comfort have greatly increased over the last decades. This means that noise levels, and in particular brake noise, which were acceptable 20 or 30 years ago are no longer tolerated by the modern customer.

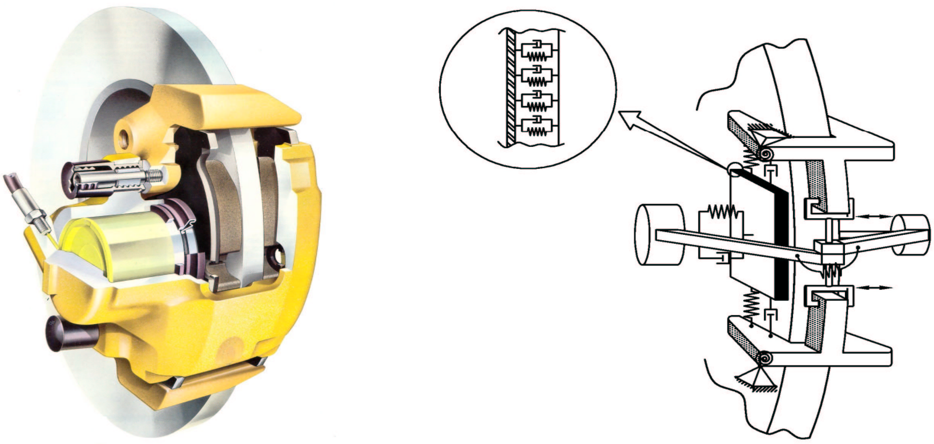

Fig. 1: A typical floating caliper disk brake, a) artist's view, b) dynamic model (schematic).

It should be noted that brake noise in general is exclusively a comfort problem, not affecting the brake function. Although there are some radical developments under way in brakes ('brake by wire'), the noise problem is not affected, as long as the brakes work with energy dissipation by dry friction. The different types of brake noise can be classified with respect to their frequencies and generating mechanisms. Brake noises in the frequency range of 100–1000 Hz are normally known as grind, grunt, moan and groan, etc. and can have different causes. The higher frequency noise in the frequency range between 1-12 kHz is normally termed squeal; it typically occurs at low speeds (0-10 km/h), e.g. during stopping at a traffic light. This paper is exclusively devoted to the modeling of disk brake squeal and the investigation of its suppression.

Modeling

It is commonly accepted by engineers and scientists working in the field, that brake squeal in the disk brake is initiated by an instability due to the friction forces leading to self-excited vibrations. The self-excited brake system then oscillates, reaching a limit cycle. Friction forces are non-conservative restoring forces or follower forces. They result in asymmetric stiffness-matrices, which can produce flutter-type instabilities. This explanation for squeal can be found in the literature (e.g. [1]) and it was used in earlier publications of the authors (e.g. [2]) for several models containing between 4 and 14 degrees of freedom.

The disk is considered as a Kirchhoff plate and discretized using the Galerkin method. Each pad can perform in-plane and out-of-plane motions and is modeled by a rigid plate and a nonlinear deformable layer of negligible inertia. Taking into consideration corresponding vibration modes from experiments, the yoke and the caliper are discretized by multi-degree of freedom models. The models thus obtained exhibit the main properties of the experimentally observed squeal (Darmstadt test rig Fig. 2), e.g. independence of the squealing frequency from the vehicle speed. For the purpose of active control, a simplified 4-dof model is established (Fig. 3) containing also the active piezoceramic elements.

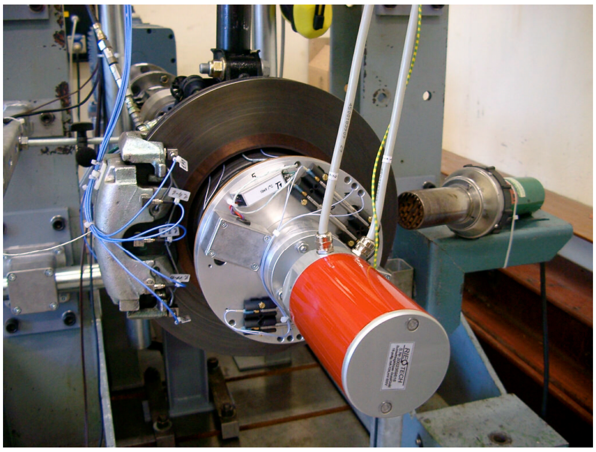

Fig. 2: Darmstadt brake test rig

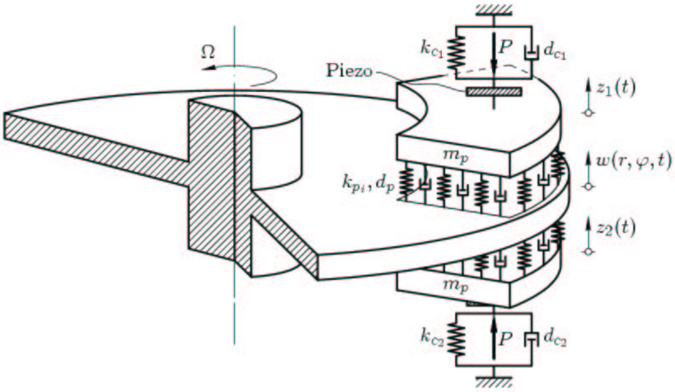

Fig. 3: Simplified model for brake squeal control

Active control

To suppress actively brake squeal, “smart pads” (Fig.4) were designed and manufactured. Those pads contain piezoceramic staple actuators, which can be independently driven at both pads and within the pads. Based on the model shown in Fig. 3, the method of optimal control is established. An observer is used to calculate the state vector from accelerometer measurements. This method was successfully applied in experiments for the active suppression of squeal.

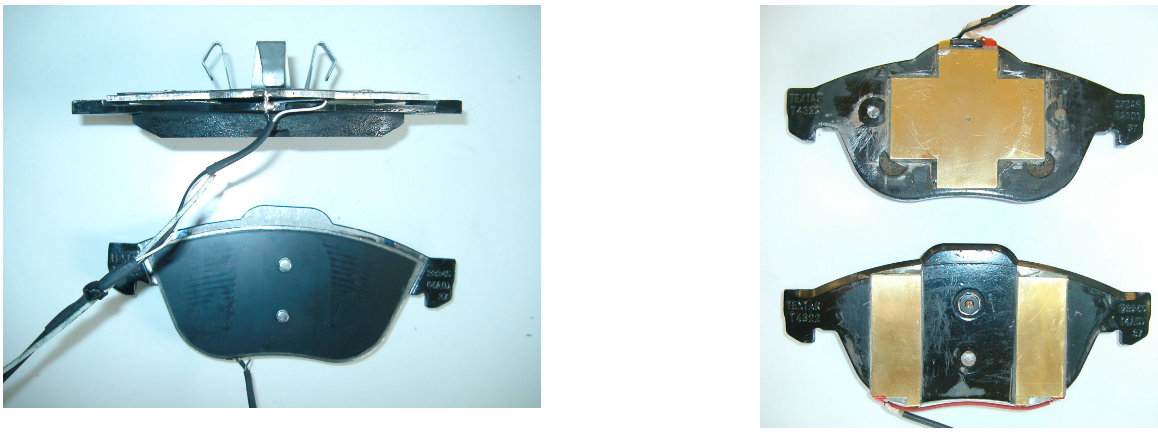

Fig. 4: Prototypes of “smart pads”

Conclusions

A model was developed for a floating caliper disk brake, with particular attention being paid to modeling the self-excitation leading to brake squeal. Suppression of the self-excitation via active control has been studied.

Active control of squeal presently is not envisaged as a technique to suppress squeal in the brake of a passenger car, but rather as a possible tool to be used in industrial laboratories to shorten the time for optimizing new brake designs, with high potential saving benefits. The development and laboratory implementation of the active squeal control goes along with a more profound understanding of brake squeal and a better modeling of the phenomena, ultimately leading to improvements in the design of disk brakes.

References

[1] Popp K., Rudolph, M.: Brake Squeal. In “Detection, Utilization and Avoidance of Nonlinear Dynamical Effects in Engineering Applications”, Shaker-Verlag, 197-225, 2001.

[2] von Wagner U., Jearsiripongkul T., Vomstein T., Chakraborty G., Hagedorn P.: Brake Squeal: Modeling and Experiments. VDI-Report 1749, 173-186, 2003.