

## **Linear and non-linear time series analysis of vibration in friction brakes**

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### **ABSTRACT**

Analysis and predictive modeling of brake squeal is still a challenge in the automotive industry. Large efforts are being made to reduce the squeal propensity. To understand the mechanics behind brake squeal either reduced order tribological and / or structural models or finite element models comprising the complete brake system or even the entire vehicle corner are developed and analyzed. The system is usually investigated with respect to linear stability of the steady sliding state. Although recent research in this field has been able to yield substantial progress (see e.g. [1,2,3]), the limitation of most approaches lies in the restricted representation of the high dimensional phenomena of the friction interface of brake pads and brake disc and often also in neglecting or not considering the effects of the – often even unknown - nonlinearities in the finite amplitude vibration state.

The present study therefore addresses the topic of brake squeal from a different perspective. Instead of analyzing a given numerical model for instability or limit cycles, experimental data of a brake system in non-squealing conditions is subjected to an experimental data analysis. Both techniques of spectral analysis as well as of nonlinear time-series analysis [6] are applied. Although the critical uncomfortable frequencies of brake squeal are of course limited to the audible range, recent findings hint at tribological and structural mechanism at much higher, i.e. ultrasonic, frequencies playing a role in brake squeal (see e.g. [4,5]). The sample rate of the conducted measurements was therefore chosen to allow spectral components of up to about 80 kHz to possibly also reveal particle respectively wear patch dynamics, sized in microscales. To reach a better understanding of the specific mechanisms in the contact interface analyses taking into account the different time-scales are performed.

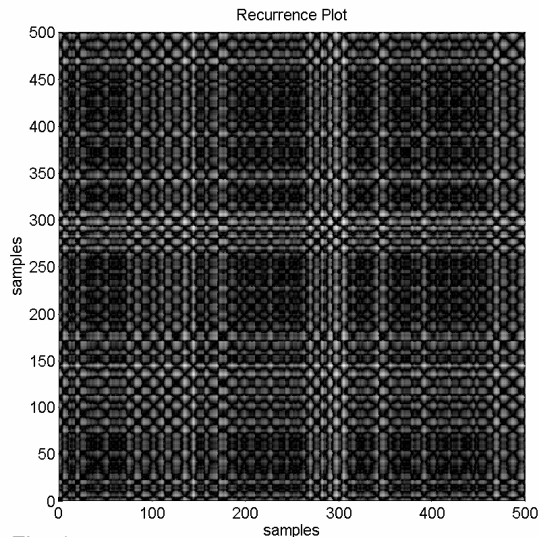


Fig. 1: Detail consisting of 500 samples (~2500 $\mu$ s) of high sampled data. Dark areas represent small dislocations near zero, bright stripes correspond to irregular disruptions thus non-stationarity.

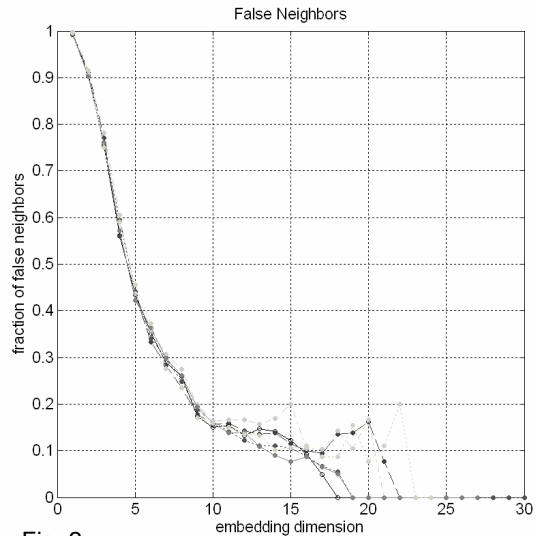


Fig. 2: Phase space reconstruction. The curves represent different data sections within one brake application showing strong decay with increasing embedding dimensions, shading off into ambient noise. The local minimum at 10 dimensions is an indicator for low-dimensional reconstruction.

On the time scale of seconds the spectral analysis based on the broadband friction vibration data shows mainly steady-state behaviour in terms of the short time FFT spectra. Examining the data on the basis of recurrence plots reveals strong disruptions and therefore non-stationarity on short time-scales (Fig. 1). Apparently the irregular microscale motions on these short time-scales leave their footprints in the recurrence analysis while in their entirety they result in a stationary spectrum on slower time scales.

In addition phase space reconstruction techniques have been applied to determine, if the overall dynamics shows signs of low-dimensional deterministic dynamics (Fig. 2).

## REFERENCES

- [1] **Kinkaid** NM, O'Reilly OM, Papanicolaou P, *Automotive disc brake squeal*, JOURNAL OF SOUND AND VIBRATION 267 (1): 105-166 OCT 9 2003
- [2] **Giannini** O, Sestieri A, *Predictive model of squeal noise occurring on a laboratory brake*, JOURNAL OF SOUND AND VIBRATION 296 (3): 583-601 SEP 26 2006
- [3] **von Wagner** U, Hochlenert D, Hagedorn P, *Minimal models for disk brake squeal*, JOURNAL OF SOUND AND VIBRATION 302 (3): 527-539 MAY 8 2007
- [4] **Eriksson** M, Bergman F, Jacobson S, *On the nature of tribological contact in automotive brakes*, WEAR 252 (1-2): 26-36 JAN 2002
- [5] **Ostermeyer** G.P, Müller, M., *New developments of friction models in brake systems*, SAE 2005-01-3942.
- [6] **Kantz** H and Schreiber T, *Nonlinear time series analysis*, 2<sup>nd</sup> Edition, CAMBRIDGE UNIVERSITY PRESS, 2004.
- [7] **Eriksson** M, J. Lord, S. Jacobson, *Wear and contact of brake pads: dynamical in situ studies of pad on glass*, WEAR, Vol. 249, May 2001.