University of Banja Luka
Faculty of Mechanical Engineering
Faculty of Electrical Engineering

DEMI 2015

12. International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology

PROCEEDINGS

Banja Luka, 29th - 30th May 2015

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

621.3(082)(0.034.2)
621(082)(0.034.2)
004(082)(0.034.2)

INTERNATIONAL conference on accomplishments in Electrical and Mechanical Engineering and Information Technology (12 ; Banja Luka) (2015)
Proceedings [Elektronski izvor] = Zbornik radova / 12th International conference on accomplishments in Electrical and Mechanical Engineering and Information Technology, Banja Luka, May 2015 ; [editor in chef Vid Jovišević]. - Banja Luka : University of Banja Luka, Faculty of Mechanical Engineering =Univerzitet u Banjoj Luci, Mašinski fakultet, 2015 (Laktaši : Grafomark). - 1 elektronski optički disk (CD-ROM) : tekst, slika ; 12 cm

CD ROM čitač. - Nasl. sa nasl. ekrana. - Bibliografija uz svaki rad.

ISBN 978-99938-39-53-8

COBISS.RS-ID 5049624

University of Banja Luka
Faculty of Mechanical Engineering
Faculty Of Electrical Engineering

PROCEEDINGS

ZBORNIK RADOVA

Banja Luka, May 2015

Print:
Grafomark, Laktaši

Circulation:
200

ISBN:

12TH INTERNATIONAL CONFERENCE ON ACCOMPLISHMENTS IN ELECTRICAL AND MECHANICAL ENGINEERING AND INFORMATION TECHNOLOGY

Supported by:
MINISTRY OF SCIENCE AND TECHNOLOGY OF
THE REPUBLIC OF SRPSKA

Organizer and publisher:
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITY OF BANJA LUKA

Co-organizer:
FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF BANJA LUKA

For publisher:
Prof. Darko Knežević, PhD

Editor in chief:
Prof. Vid Jovišević, PhD

Executive editor:
Biljana Prochaska, MSc

Editorial assistant:
Milivoj Stipanović

ORGANIZATIONAL COMMITTEE

Chairman:

Prof. Vid Jovišević, PhD, Faculty of Mechanical Engineering Banja Luka

Secretary:

Biljana Prochaska, MSc, Faculty of Mechanical Engineering Banja Luka

Members:

Prof. Zdravko Milovanović, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Darko Knežević, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Snežana Petković, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Petar Gvero, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Mladen Todić, PhD, Faculty of Mechanical Engineering Banja Luka
Assist. Prof. Zoran Đurić, PhD, Faculty of Electrical Engineering Banja Luka
Prof. Aleksandar Milašinović, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Mihajlo Stojičić, PhD, Faculty of Mechanical Engineering Banja Luka
Assist. Prof. Zorana Tanasić, PhD, Faculty of Mechanical Engineering Banja Luka
Assist. Prof. Strain Posavljak, PhD, Faculty of Mechanical Engineering Banja Luka
Assist. Prof. Đorđe Čiča, PhD, Faculty of Mechanical Engineering Banja Luka
Biljana Vranješ, MSc, Faculty of Mechanical Engineering Banja Luka
Branislav Sredanović, MSc, Faculty of Mechanical Engineering Banja Luka
Slaviša Todorović, Faculty of Mechanical Engineering Banja Luka
Goran Jotić, Faculty of Mechanical Engineering Banja Luka
Branislav Jovković, University of Banja Luka
Milivoj Stipanović, Faculty of Mechanical Engineering Banja Luka.

PROGRAM AND SCIENTIFIC COMMITTEE

Chairman:

Prof. Ostoja Miletić, PhD, Faculty of Mechanical Engineering Banja Luka, BiH.

Members:

Prof. Duško Lukač, PhD, University of Applied Science, Köln, /Germany/
Prof. Simo Jokanović, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Miloš Kojić, PhD, Harvard University, /USA/
Prof. Milorad Božić, PhD, Faculty of Electrical Engineering Banja Luka
Prof. Petar Marić, PhD, Faculty of Electrical Engineering Banja Luka
Prof. Bobrek Miroslav, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Ćosić Ilija, PhD, University of Novi Sad, /RS/
Prof. Hadžistević Miodrag, PhD, University of Novi Sad, /RS/
Prof. Soković Mirko, PhD, University of Ljubljana, /SL/
Prof. Milenko Stegić, PhD, University of Zagreb, /RH/
Prof. Ivan Filipović, PhD, University of Wien, /Austria/
Prof. Dušan Gruden, PhD, TU
Prof. Branko Blanuša, PhD, Faculty of Electrical Engineering Banja Luka
Prof. Čedomir Zeljković, PhD, Faculty of Electrical Engineering Banja Luka
Prof. Radivoje Pešić, PhD, University of Kragujevac, /RS/
Prof. Stevan Veinović, PhD, University of Kragujevac, /RS/
Prof. Solvang Björn, PhD, Narvik University, /Norway/
Prof. Ljubiša Papić, PhD, University of Kragujevac, /RS/
Prof. Petar Gvero, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Milan Radovanović, PhD, Society of Thermal Engineers, /RS/
Prof. Vladimir Savić, PhD, University of Novi Sad, /RS/
Prof. Zdravko Milovanović, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Janez Kopač, PhD, University of Ljubljana, /SL/
Prof. Milan Zeljković, PhD, University of Novi Sad, /RS/
Prof. Velimir Todić, PhD, University of Novi Sad, /RS/
Prof. Milentije Stefanović, PhD, University of Kragujevac, /RS/
Prof. Snežana Petković, PhD, Faculty of Mechanical Engineering Banja Luka
Assist. Prof. Strain Posavljak, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Miodrag Manić, PhD, University of Niš, /RS/
Prof. Emilia Assenova, PhD, Technical University of Sofia, /Bulgaria/
Prof. Bogdan Nedić, PhD, University of Kragujevac, /RS/
Prof. Marius Benea Calin, PhD, Faculty of Engineering Hunedoara, /Romania/
Prof. Konstantinos-Dionysios Bouzakis, PhD, AU Thessaloniki, /Greece/
Prof. Dragan Milutinović, PhD, University of Belgrade, /RS/
Prof. Vid Jovišević, PhD, Faculty of Mechanical Engineering Banja Luka
Prof. Ranko Zrilić, PhD, Faculty of Mechanical Engineering Banja Luka

CONTENT

KEYNOTE LECTURES

PRODUCTION AND COMPUTER-AIDED TECHNOLOGIES

ENERGETICS AND THERMAL ENGINEERING

MECHATRONICS AND INFORMATION TECHNOLOGY

AUTOMOTIVE AND TRAFFIC ENGINEERING

QUALITY AND ECOLOGY

MAINTENANCE OF ENGINEERING SYSTEMS AND OCCUPATIONAL SAFETY ENGINEERING

University of Banja Luka
Faculty of Mechanical Engineering

DEMI 2015
12. International Conference
on Accomplishments
in Electrical and
Mechanical Engineering
and Information Technology

METHOD OF DISK BRAKE NOISE ASSESSMENT

Jovanka Lukić[1], Jasna Glišović[2], Danijela Miloradović[3], Slavica Mačužić[4]

Summary: *Widely used method for transient signal assessment were applied on time series of disk brake signal noise. Wavelet Transform (WT), Short Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) were applied on time series signal of disc brake noise in order to get significant data to identify process of appearing of squeal brake noise. Various experimental conditions: pressure, speed etc were varied. Effects of different experimental conditions on disc brake noise were examined.*
Key words: squeal brake noise, wavelet transformation, transient signal, Short Time Fourier Transform

1. INTRODUCTION

Brake squeal is defined as a self-excited and self-sustained unwanted noise in the audible frequency range above 1 kHz. Brake squeal is a nonlinear transient phenomenon and a number of studies using analytical and experimental models of brake systems indicate that it could be treated as a chaotic phenomenon, [4]. Data obtained from a full brake system on a noise dynamometer were examined with nonlinear analysis techniques. The application of recurrence plots reveals chaotic structures even in noisy data from the squealing events.

The Fourier transform provides the spectral content of the function, but it does not provide information on the moment when a component appears or disappears in time. Therefore it is useful for analyzing stationary functions, i.e. those that have spectral components that last infinitely.

The Fourier transform can be used to analyze non-stationary functions only when the frequency content of the function is important, while the duration of certain harmonics is not, [6].

This is the idea behind the Short Time Fourier Transform (STFT). The shorter the interval the better time and the worse frequency resolution is obtained; and vice versa, an infinite length of an interval matches a standard Fourier transform, providing a perfect frequency resolution. Segmenting the function is performed using a window

[1] PhD, Professor, Serbia, Kragujevac, University of Kragujevac, Faculty of engineering, (lukicj@kg.ac.rs)
[2] PhD, Asistant Professor, University of Kragujevac, Faculty of engineering, (jaca@kg.ac.rs)
[3] PhD, Asistant Professor, University of Kragujevac, Faculty of engineering, (neja@kg.ac.rs)
[4] MSc, ME, PhD student, University of Kragujevac, Faculty of engineering, (macuzicslavica@gmail.com)

function, the width of which is determined according to the length of the interval where the function is nearly stationary. A wavelet is a wave function with a compact support. It is called a wave due to its oscillatory nature, and diminutive is used because of the finite domain where it is difl'erent from zero (the compact support). The use of a continuous wavelet stransform (CWT) is very suitable for the detailed analysis of the transient response. In this paper, the possibilities of coexistence of several instabilities at the same time will be examined, [5,6].

It will be shown that the behavior of the brake can be very complex and cannot be predicted by stability analysis alone.

2. EXPERIMENTAL RESEARCH

2.1 Measurement installation

Brake dynamometer for testing disc brake noise has been developed at the Laboratory for IC engines at the Faculty of Engineering, University of Kragujevac. Since the moment of inertia of the brake disc on rotating drive shaft is equivalent to a linear inertia of the vehicle, it is possible to include the influence of vehicle inertia and thus provide more reliable results in laboratory conditions. The installation consists of several functional units:

- Test bench with the electromotor, power transmission and disc,
- Electric power installation,
- Installation for activation of the disk brake i.e. for generation of the braking torque,
- Measuring equipment.

Electromotor is mounted on the stand that is rigidly connected. The drive block consists of: asynchronous electric motor fed by frequency regulator, friction belt transmission with ratio equal to 1, inertial mass and brake disc. The speed sensor is mounted at the free end of the electromotor's shaft. The inertial mass on the input shaft is made in the form of the disc with diameter of 0.35 m, width of 0.045 m and mass of 35 kg. Mass moment of inertia has value of 0.54 kgm^2 and it corresponds to the kinetic energy of the test vehicle, at low initial speeds, which are critical in terms of the frequent appearance of brake squeal [7].

The components of the measuring chain formed to record the brake fluid pressure in the brake cylinder, p, brake torque, M_k, disk speed, n, and the sound pressure level, *SPL*, during the investigation of the brakes in the laboratory conditions, as well as the connections of individual components are shown in Figure 1 and in the block diagram in Figure 2.

During the experimental research, the two categories of tests were performed: with constant disc rotation speed and for different braking pressures in the disc brake cylinder and with constant brake pressure and varying speeds. Performed tests correspond to braking of the vehicle with disengaged clutch i.e. with interrupted power transmission.

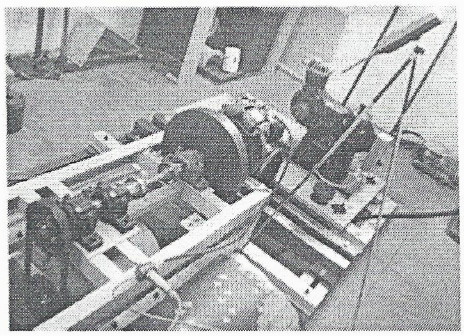

Figure 1 *Photo of designed measuring installation for research of the brake noise [8]*

2.2 Test regimes

Constant disc speed and different brake pressures:

- Constant disc speed in range from 250 to 1000 min^{-1} is applied.
- For every disc speed value, different pressures in range from 0.5 to 3 MPa with increment of Δp = 0.5 MPa are applied.

Constant brake pressure and different disc speeds:

- Constant maximum pressure in the range from 0.5 to 3 MPa is applied.
- For every pressure value, the different disc speeds in the range from 250 to 1000 min^{-1} with increment of Δn = 50 min-1 are applied.

The range of disc speeds at the beginning of the braking process and the corresponding speed of the real vehicle for the tested disk brake with ventilated disc with a diameter of 266 mm and the tire with dynamic radius of 260 mm in are shown in Table 1.

Table 1 *Comparative overview of vehicle's speed and the corresponding disk speeds,* [7]

N	Vehicle speed, km/h	Brake disc speed, min^{-1}
1.	25	255
2.	30	306
3.	35	357
4.	40	408
5.	45	459
6.	50	510
7.	55	561
8.	60	612
9.	65	663
10.	70	714
11.	75	765
12.	80	816

In some braking regimes (e.g. low brake pressure and high initial speed of electromotor), only partial braking exists i.e. reduction of disc speed from the initial speed v_1 to final speed v_2, while in some other cases braking until stopping of the brake disc occurs.

The measurement of the temperature at the midpoint of the brake disc surface is important in order to avoid the overheating. If the system is cold, the working temperature should be raised to 80 - 90°C. This is achieved by braking with lower pressure and with engaged electric motor.

Measuring signals are then led from sensors to the data acquisition system NI USB-6341 produced by National Instruments that, in interface with the software LabVIEW 2010, acquires, analyses and presents real-time data and stores the measurement results. The sound pressure level is the measuring signal with the highest frequency, so it sets the sampling rate during experimental research. Digitization of data is achieved in the 131072 points, with step of $2*10^{-5}$ sec, which enabled the reliability of data processing in the area from 0.381 Hz to 25000 Hz (this includes a relevant area of frequency of vibration and noise in motor vehicles [7]).

3 RESULTS OF RESEARCH IN TIME DOMAIN

For illustration, measured parameters that define the braking process - brake pressure, *p*, disc speed, *n*, braking torque, M_k and the sound pressure level, SPL, are displayed in Figures 3 to 6. Although the measurements in the case of maximum braking pressures from 0.5 MPa to 3.0 with step Δp=0.5 MPa are performed, only regimes related to limit values of pressure variation interval and to initial disc speed corresponding to the vehicle initial speed of 75 km/h are shown. Diagrams of measured parameters in other regimes are similar to the described limit ones and will not be shown here.

Since a new friction couple (disc - brake pads) is used in research, a low friction on the friction surface in the brake assembly is present, even when the brake is not activated. This can be noticed in the diagram that shows the variation of the braking torque where braking torque values of 5÷7 Nm exist before and after the braking process (braking pressure greater than zero), independently of the brake pressure and disc speed value applied.

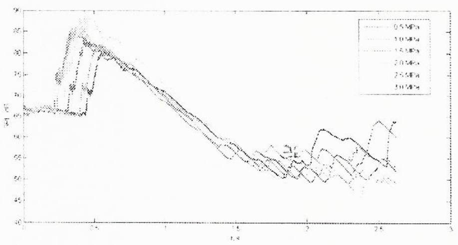

Figure 2 *Variation of the SPL for the initial disc speed of 765 min⁻¹ (v=75 km/h)*

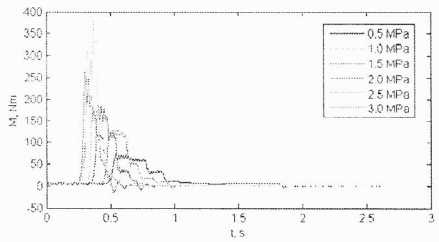

Figure 3 *Variation of the braking torque for the initial disc speed of 765 min^{-1} (v=75 km/h)*

The sound pressure level, SPL, is the most important quantity for estimation of the occurrence of brake squeal. With the variation of the maximum braking torque, the expected increase in noise level is present and it exceeds the threshold of 70 dB in all regimes (Figure 32). In the regime of the highest test pressure of 3.0 MPa, the intensive variations which correspond to squeal noise are observed. This is better evaluated in the frequency domain by analysis of the power spectra of the sound pressure levels.

The influence of different regimes of maximum brake pressure on the braking torque variation during braking is shown in Figure 23. It is clear that the braking torque follows to a large degree the form of changes in the brake pressure, and when maximum pressure is low (0.5 and 1.0 MPa) the residual braking torque is shown (partially activated brakes), [7,8].

4 ANALYSIS OF TRANSFORMATION METHODS

Method of DWT is perfomed with haar transformation coefficient. Coefficients of DWT transformation of SPL signal is given in in figures 4 and 5.

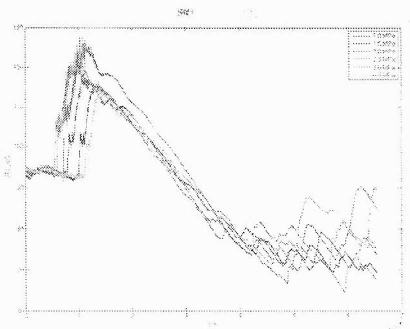

Figure 4 *Coefficient of DWT transformation of SPL*

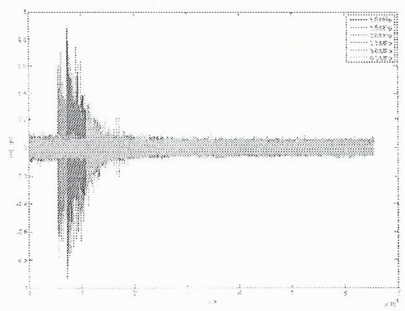

Figure 5 *Coefficient of DWT transformation of SPL*

DWT method is covinient for SPL transformation. As well as in following analysis of transformatin *Haar* wavelets were applied. Scale was 64.

In figures 4 and 5, CWT transformation coefficiens of SPL under 3 MPa inital brake pressure are given.

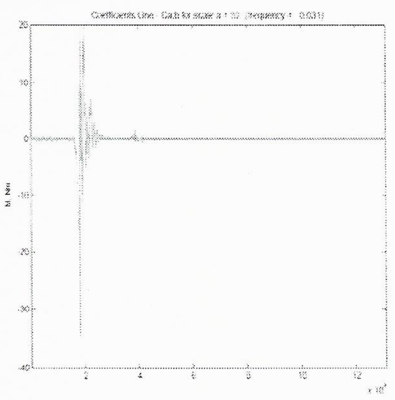

Figure 6 *CWT coefficient line of the braking torque for the initial brake pressure 3. MPa*

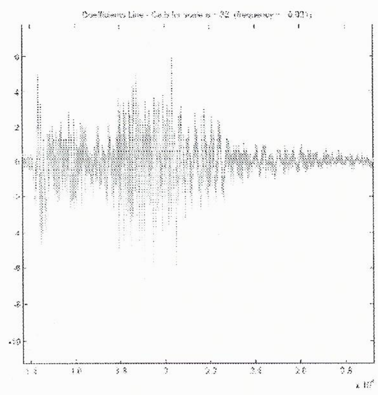

Figure 7 *CWT coefficient line of the SPL for the initial brake pressure 3. MPa*

Signals of SPL and brake torque are transformed by CWT and results are given in figures 6 and 7. Performed analysis showed that CWT is more suitable for brake moment analysis than SPL analysis. Method CWT is suitable for denoising signal and determination of discontinuities.

In the following research particular DWT wavelet decomposition will be performed by lowpass and highpass filters.

3. CONCLUSION

Discrete Wavelet Transformation is suitable method of statistical analysis applicable in NVH analyse of transient signals. Method DWT is convinient for denoising signals.

Continous Wavelet Transformation is more suitable for brake torque analysis and brake pressure than for anlaysis of SPL.

Method CWT is suitable for determination of discontinuities of signals.

AKNOWLEDGEMENT

The paper is a result of the research within the project TR 35041 financed by the Ministry of Education, Science and Technological Development, Republic of Serbia.

REFERENCES

[1] Papinniemi, A., Laia, J.C.S., Zhaob, J., Loader, L. (2002), Brake squeal: a literature review, *Applied Acoustics,* vol. 63, no. 4, pp. 391–400.

[2] Vitanov,N., K., Hoffmann N., P., Wernitz, B. (2014), Nonlinear time series analysis of vibration data from a friction brake: SSA, PCA, and MFDFA, *Chaos, Solitons & Fractals*, vol. 69, pp. 90-99.

[3] Chandrika U.,K., Kim, J., H., (2010), Development of analgorithm for automatic detection and rating of squeak and rattle events, *Journal of Sound and Vibration*, vol. 329, pp. 4567–4577

[4] Oberst, S., Lai, J. C. S., (2011),Chaos in brake squeal noise, *Journal of Sound and Vibration*, vol. 330, pp. 955–975

[5] Trapp, M, Chen, F (2012), *Automotive Buzz, Squeak and Rattle, Mechanisms, Analysis, Evaluation and Prevention.* Butterworth-Heinemann, Elsevier,Oxford

[6] Radunović, D. (2009), *Wavelets – from math to practice*, Springer Verlag, Berlin Heidelberg

[7] Glišović, J. *Theoretical and experimental research of high-frequency noise of disc brakes*, (2012), PhD Thesis (in Serbian), University of Kragujevac, Kragujevac

[8] Glišović, J., *et. all.*, (2014), A contribution to research of some physical characteristics of disc brakes in laboratory conditions, *Mobility and Vehicle Mechanics*, vol.40, no 4, pp. 29-46

530577-TEMPUS-1-2012-1-RS-TEMPUS-JPCR

Improvement of Product Development Studies in Serbia and Bosnia and Herzegovina