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Petr LITOŠ*, Milan HONNER, Jan ŠROUB***, Vladislav LANG******

THE SYSTEM FOR THE MEASUREMENT OF THERMO-MECHANICAL INSTABILITIES OF DISC BRAKES

SYSTÉM PRO MĚŘENÍ TERMOMECHANICKÝCH NESTABILIT KOTOUČOVÝCH BRZD

Abstract

The contribution deals with the introduction of the measuring system for the application in the research of thermo-mechanical instabilities of disc brakes. The first part is devoted to the description of the system for fast measurement of the brake disc surface temperature field during braking, which is the main part of the measuring system. The second part is focussed on the principles of evaluation of the brake disc surface temperature field. The third part deals with applications of the system on dynamometer testing rigs and cars. It demonstrates capabilities of the measuring system to be used in the experimental research of disc brakes.

Abstrakt

V příspěvku je představen měřicí systém pro použití ve výzkumu termomechanických nestabilit kotoučových brzd. První část je věnována popisu podsystému pro rychlé měření teplotního pole povrchu brzdového kotouče při brzdění, který je hlavní částí měřicího systému. Druhá část příspěvku se zaměřuje na principy vyhodnocení teplotního pole povrchu kotouče. Třetí část příspěvku uvádí aplikace systému na brzdovém stavu a na autě., které dokládají použitelnost měřicího systému v experimentálním výzkumu chování kotoučových brzd.

1 INTRODUCTION

Thermo-mechanical instabilities or thermal judder processes manifest itself in hot spots origination on the brake disc surface and unstable interaction between frictional heating, thermoelastic distortion and elastic contact. It is well known, that the driver experiences brake judder as vibrations in the steering wheel, brake pedal and the floor. In the higher frequency range, the structural vibrations are accompanied by a sound. Brake judder primarily affects the comfort but could, when confronting an inexperienced driver for the first time, lead to faulty reactions and to reduced driving safety. Furthermore the thermal judder can cause permanent distortions or cracking of the brake disc. High temperatures may also cause brake fading and excessive wear especially in places of the hot spots [1], [2].

*Ing., Ph.D., Department of Physics, Faculty of Applied Sciences, University of West Bohemia in Pilsen, Univerzitni 22, 306 14 Plzen , tel. (+420) 377 63 4720, e-mail plitos@kfy.zcu.cz
**Doc. Ing., Ph.D., Department Thermomechanics of Technological Processes, New Technologies Research Center, University of West Bohemia in Pilsen, Univerzitni 8, 306 14 Plzen, tel. (+420) 377 63 4720, e-mail honner@ntc.zcu.cz
***Ing., Department Thermomechanics of Technological Processes, New Technologies Research Center, University of West Bohemia in Pilsen, Univerzitni 8, 306 14 Plzen, tel. (+420) 377 63 4722, e-mail jsroub@ntc.zcu.cz
****Ing., Ph.D., Department Thermomechanics of Technological Processes, New Technologies Research Center, University of West Bohemia in Pilsen, Univerzitni 8, 306 14 Plzen, tel. (+420) 377 63 4717, e-mail vlang@ntc.zcu.cz

Experimental techniques, such as the application of fast infrared cameras [3], play the main role in the thermo-mechanical instabilities investigation. The objective is to clarify the influence of various physical parameters in the macro and micro-scale on the origin, development and consequences of thermo-mechanical instabilities. The results are projected into structural recommendations for designers and into technological recommendations for users of brake systems and technologies.

2 THE SYSTEM FOR THE BRAKE DISC TEMPERATURE FIELD MEASUREMENT

The main part of the measuring system developed at the University of West Bohemia in Pilsen for the experimental research of thermo-mechanical instabilities is a fast sub-system for the measurement of brake disc temperature field. The hardware of the system consists of fast two-colour infrared photon detectors cooled by liquid nitrogen with optical fibers for the measurement of infrared radiation (fiber optic cables transfer the infrared radiation to detectors), an inductive sensor for the measurement of the disc rotational speed and PC data acquisition unit. The experimental set-up is shown in Fig.1.

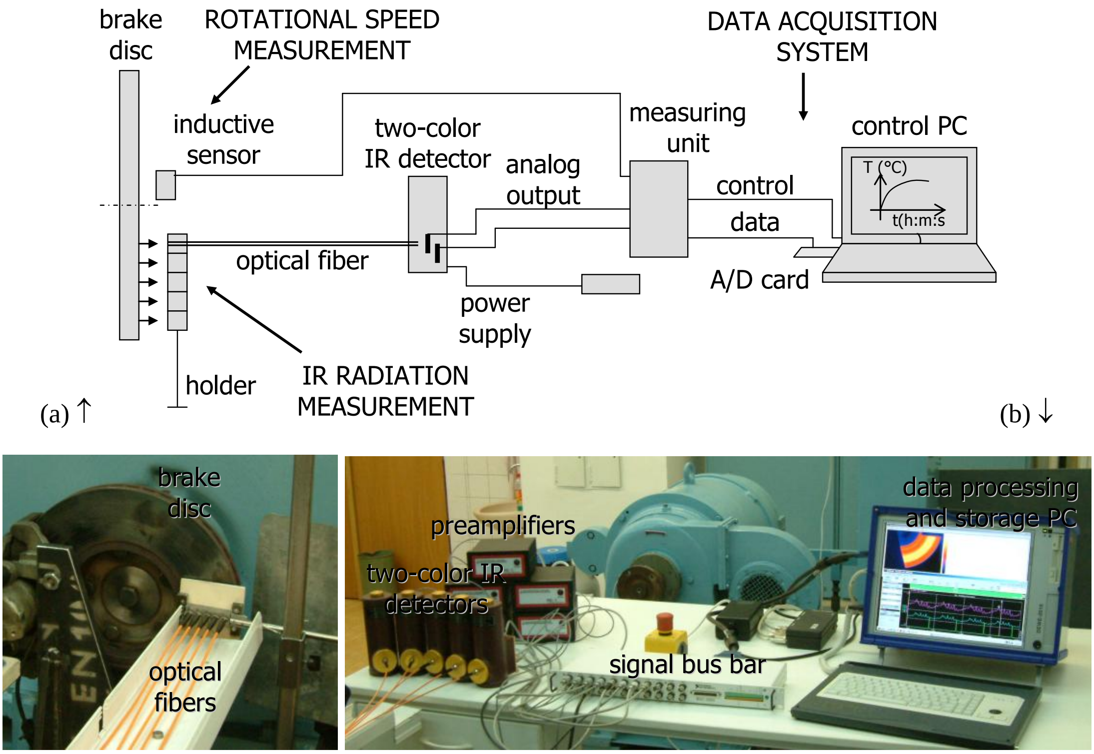

Fig. 1 System for the brake disc temperature field measurement – (a) simplified scheme, (b) experimental set-up

The two-colour infrared detector consists of two layers. The upper one, InSb detector, is sensitive to short infrared wavelengths while the bottom layer, HgCdTe detector, is sensitive to longer wavelengths. The two-colour detectors are designed such that only one infrared input is needed because InSb detector acts as a radiation filter for the bottom HgCdTe detector and hence the response curves do not overlap. Moreover spectral transmission of optical fibers has to correspond with the infrared detector relative spectral response to achieve minimum losses of the optical signal.

3 TEMPERATURE FIELD EVALUATION

One-colour method (radiation intensity) or two-colour method (ratio of radiation intensities of two adjacent wavelengths or wavebands) together with calibration system can be used for the quantitative evaluation of surface temperatures.

The electrical signal produced by the photon detector can be obtained as [4], [5]:

$$f_{1-C}(T) = A_{\mathrm{det}} \cdot RVF \cdot R_{peak} \cdot \int_{\lambda_1}^{\lambda_2} \varepsilon(\lambda,T)\, R(\lambda)\, U(\lambda)\, M_{\lambda}(\lambda,T)\, d\lambda\ , \tag{1}$$

where λ_1, λ_2 (μm) are the minimum and maximum detectable wavelength, A_{det} (cm^2) active detector area, RVF (-) radiation view factor, ε(λ,T) (-) emissivity of the measured surface, R_{peak} (V/W) responsivity in peak of the spectral response curve, R(λ) (-) spectral response function of the infrared photon detector, U(λ) (-) transfer function of the optical system, $M_{\lambda}(\lambda,T)$ ($W/cm^2.\mu m$) spectral radiant emittance.

The major advantage of the two-colour method is based on the reduction of the emissivity influence on the temperature measurement process by means of the two different infrared signals bands detection. The ratio of the two signals is proportional only to the surface temperature in the case of grey body (emissivity in both bands is equal). Then the surface temperature is expressed as:

$$f_{2-C}(T) = \frac{\varepsilon \cdot A_{\mathrm{det}1} \cdot RVF \cdot R_{1peak} \cdot \int_{\lambda_1}^{\lambda_2} R_1(\lambda)\, U(\lambda)\, M_{\lambda}(\lambda,T)\, d\lambda}{\varepsilon \cdot A_{\mathrm{det}2} \cdot RVF \cdot R_{2peak} \int_{\lambda_2}^{\lambda_3} R_2(\lambda)\, U(\lambda)\, M_{\lambda}(\lambda,T)\, d\lambda}\ , \tag{2}$$

where ε is the emissivity of the grey body.

The calibration is the basis for the temperature evaluation. The calibration procedure consists of the following steps, heating the brake disc sample at known temperatures, reading the signal from all detectors by the measurement system which is used during testing, reconstruction of the calibration curve for each detector. This curve is then used in temperature evaluation process, see Fig.2. Each change of the experimental system arrangement requires performing recalibration.

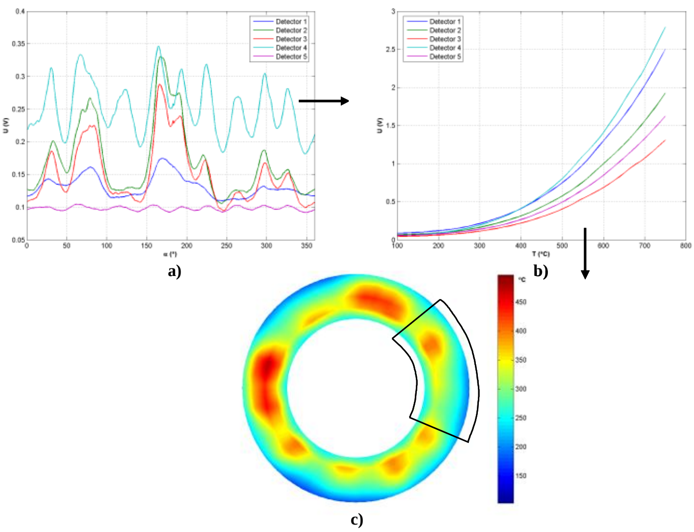

Fig. 2 Example of temperature evaluation in non-contact measurement: a) signal from all five infrared detectors for one disc revolution, b) the calibration curves, c) appropriate surface temperature field.

4 APPLICATIONS OF THE MEASURING SYSTEM

The measuring system has been applied on the dynamometer brake testing rig in order to investigate the effects of individual parameters of brake discs and pads. The system has been also applied on cars in order to investigate the effects induced by the car aerodynamics, etc. The Fig.3 shows the measurement in the wind channel with the measuring system completely installed inside the car. It creates prerequisites for the application of the system in real conditions on roads.

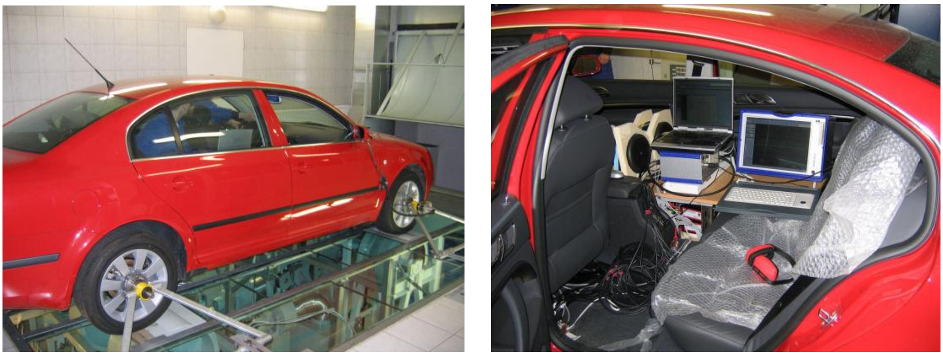

Fig 3 Photo from the experimental research of thermomechanical instabilities of car disc brakes in wind channel using the application of the measuring system inside the car.

5 CONCLUSIONS

This paper introduces system that has been developed for the experimental investigation of the disc brake dynamic behaviour. The system is convenient for the installation on a brake testing bench and also for the installation on a car. The measuring system provides observation of temperature field evolution. The results can be used in the research of correlations between the temperature field and pressure, vibrations, temperature of the disc caliper, etc. The major advantages of the applied infrared detectors with optical fibers compared to fast infrared camera are the possibility to measure temperatures on small areas, targets hard to reach and out of the direct line of sight (measurement on the real car), data post processing and various analyses with raw data from infrared detectors, two-colour detectors and appropriate calibration provides more accurate temperature measurements. On contrary one of the major advantages of IR camera is instant visualization and real time feedback [3].

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Reviewer: doc. MSc. Mojmír VRTEK, Ph.D., VŠB - Technical University of Ostrava