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STUDIES ABOUT EMISSIVITY VARIATION DEPENDING ON THE TEMPERATURE FOR CAR BRAKE DISC

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Abstract— The temperature control of automotive brake discs during operation is a difficult process because they have shiny metallic surfaces moving rotational contact with fixed brake pads and different temperature gradients. The instrument used for measuring the temperature, in this case is the thermal camera, but requires precise calibration for the emissivity of the material being analyzed and the influence of environment.

The study refers to changes depending on the temperature of thermal emissivity of the material disc brake car, both in static and in dynamic regime and determining analytical relationships to estimate this variation acceptable accuracy.

Keywords— brake disc, emissivity variation, reflectivity, temperature.

I. INTRODUCTION

FAILURE of technical systems is to reduce the operating performance of these systems, and the times at which it breaks systems are used in studies of reliability and maintenance [1],[2]. In recent years have been studies that established the wear of technical systems using fuzzy logic [3]-[4].

The main reasons that cause the damage of the automobile brake discs are excessive wear, vibration and heat stress. Of these, the most difficult to control is thermal stress produced by rapid and uneven disc surface temperature during intense or prolonged braking. They produce deformations of the disc, the occurrence of cracks which accelerate corrosion, rapid wear of the friction material brake pads and uneven distribution of the coefficient of friction on the surface of the disc and ultimately decrease the braking performance of the car.

Since contact thermometers and temperature sensors can't be used to measure the temperature during braking discs, the only possible methods are non-contact. [5]-[6].

By using the thermal camera can easily obtain and store information about the temperature distribution over the entire surface of the disc brake, both in static and in dynamic regime, but to get accurate results are necessary precision settings for emissivity (the ability of object to emit radiation) and reflectivity of the material.

As the brake disc surface is glossy, emissivity is low values and not remains constant during temperature change [7]-[8]. This phenomenon always sized thermal imager parameters so depending on the quality of the disc surface, and depending on its temperature value, if you want to obtain accurate values of the temperatures recorded. [9]-[10].

Another essential parameter influencing the accuracy of the results obtained on the disk surface is the reflected apparent temperature (is an apparent temperature of the objects which is reflected on the target surface). This change particularly, during measurements in dynamic regime. [11].

Making thermal camera calibration parameters simultaneously perform measurements can't be made during operation of disc brakes, because the speed of temperature rise is high and the time available is very short. For this reason it is easier than in the first phase to record images or videos camera and then determine the actual temperature of the brake disc by setting the values of emissivity and reflected temperature using the Flir Research IR software version 3.3 using charts or analytical relationships previously established.

II. EXPERIMENTAL METHODS

The experimental method measuring and recording followed by a thermovision camera of thermal values simultaneously for two points located on the surface of a disc friction brake, one located intro the low and variable emissivity glossy and the other, in the vicinity, located on a black area with high emissivity and constant.

If you use a static regime with the brake disc diameter 247 mm and the thickness of working area is 9.29 mm proper wear of 0.31 mm. A section of it was painted in matt black with a high temperature resistant paint. The disc was uniformly heated over 200 (^{o}C) with a circular heat source power of 1500 (W) and the diameter similar to the disc.

In order to verify the accuracy of the temperature setting of reflected radiation was performed in parallel to a contact measurement, the disk temperature with a digital thermometer.

On the Fig. 1 is represented the infrared picture of the disc brake realized by a thermal camera and analyzed with a Flir R&D software version 3.3.

Fig. 1. The picture of the disc brake viewed with thermovision camera

The Flir SC 640 infrared camera was placed on a tripod at a distance of 1.5 m and angle about 15^{o} from the friction surface of the brake disc, represented in Fig. 2.

Fig. 2. The disc brakes in the static experiment case

To eliminate the possible measurement errors of the temperature disc brake due of currents air influence overheated produced by the heat source, measurements were performed only in its cooling phase.

Were carried out sets of measurements in the temperature range 30 - 230 (^{o}C). For technical reasons the digital thermometer was used only up to 160 (^{o}C).

Initial settings of the emissivity values of the two surfaces of the brake disc were 0.95 for the glossy and for matte black area. Reflectivity value determined by a panel Lambert reflective type radiator has been 22,2 (^{o}C).

During the experiment it was observed that between the actual temperature of the brake disc, measured by contact and matte black zone temperature measured by thermovision camera are not significant differences, which are below 2%. This confirms that the thermovision camera settings were correct, see Fig. 3.

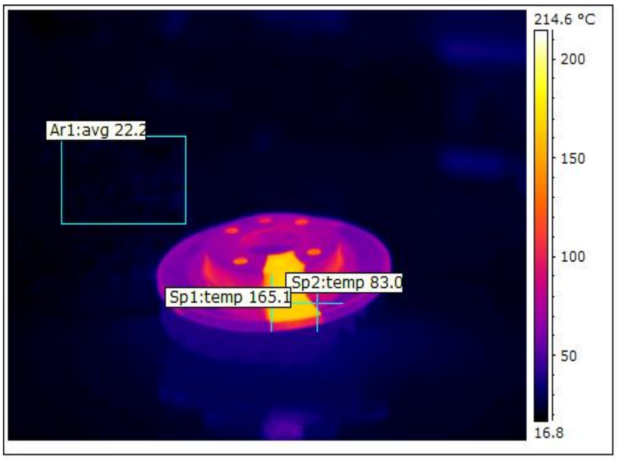

Fig. 3. The disc brakes heated in static regime

Variations in measured temperatures with the thermovision camera in two areas of the brake disc and measured with the contact thermometer are shown in Fig. 4, where T - the surface temperature of brake disc.

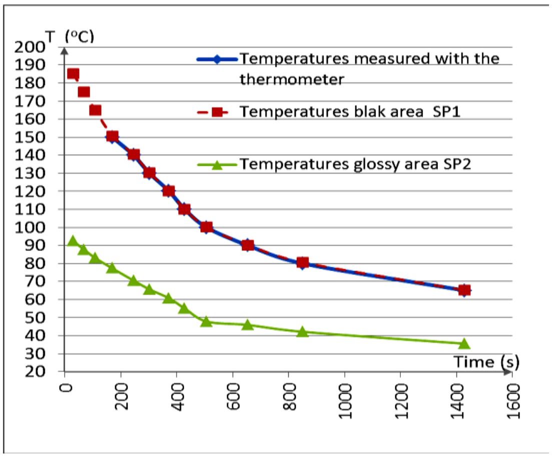

Fig. 4. Variation of recorded temperatures during cooling brake disc in static regime

As the temperatures are higher, the difference between the temperature of glossy zone and black area indicated by thermovision camera is higher. This phenomenon is due to the influence of emissivity glossy brake disc area.

The maximum difference between the two values is 92,7 (^{o}C) and maximum temperature reached 195,1 (^{o}C).

During the experiments was kept constant the ambient temperature and the angle of the brake disc surface and the lens axis of thermovision camera was identical in both regimes. Illumination of space was achieved with diffused light produced by fluorescent lamps to reduce any reflections.

In the experiment in dynamic mode, on the disc brake has painted a circular ring to the boundary of the friction brake pads, the disc was mounted on a stand equipped with 43.5 (kW) heat engine, transmission and hydraulic brake system, and rotated with a speed corresponding to the movement speed of 40 (km /h), represented in Fig. 5.

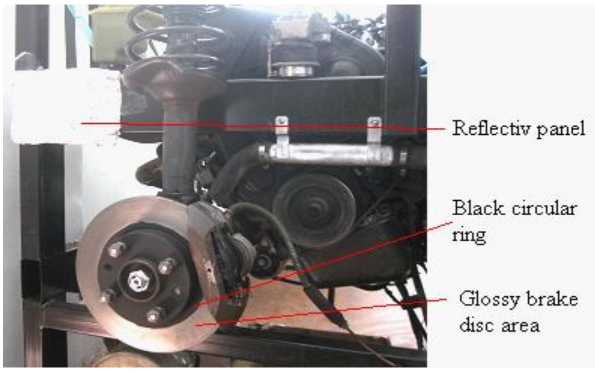

Fig. 5. The disc brake in the dynamic experiment case

The disc was heated to 230 (°C) by operating the braking pressure of 1 (MPa).

Measurements were performed in the cooling phase, with brake system disengaged, while the disc is in rotational motion with constant speed.

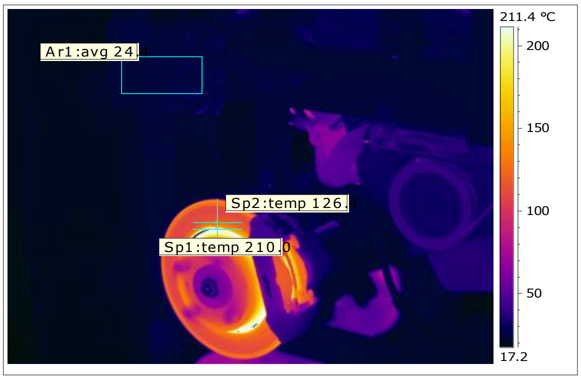

Fig. 6. The picture of disc brakes heated in dynamical regime

The temperature variations measured with the thermovision camera in two areas of the disc brake, are shown in Fig. 7.

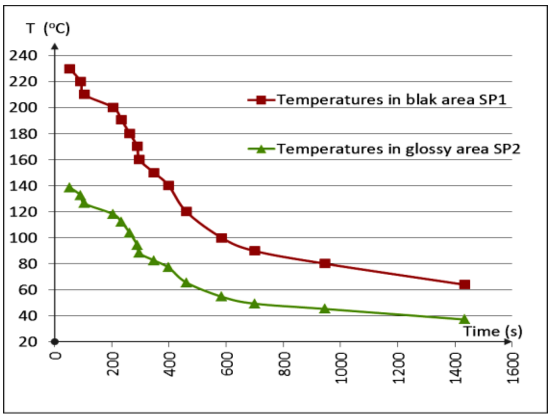

Fig. 7. Variation of temperatures recorded during cooling brake disc in dynamical regime

It was observed that the differences between the values of indicate temperatures by the thermovision camera between the two parts of the brake disc, are similar in the case of the dynamic regime with static regime related.

III. RESULTS

Since the two points that were measured the temperatures on the surface of the brake disc are considered very close to the same temperature.

By changing the emissivity in thermovision camera settings were equalized the temperatures indicated by the point located in the glossy area with the points in the black area, obtaining the image of emissivity variation depending on the temperature, both static regime and dynamic are represented in Fig. 8, where E - the surface emissivity of brake disc.

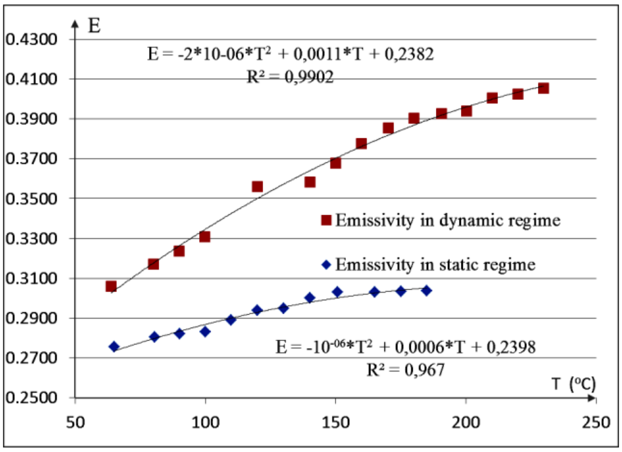

Fig. 8. The emissivity variation of glossy surface for brake disc in static and dynamic regime

It was observed that the values of brake disc material emissivity measured in static regime differs from the dynamic regime.

Based on experimental data recorded by statistical processing using regression procedure were determined mathematical relationships for variation of the material emissivity for the disc brake with friction brake pads, depending on the temperature in static and dynamic regime.

In the case of the static regime the relationship obtained is a polynomial function of second degree (1)

$$\mathbf{E = -10^{-6} * T^2 + 0{,}0006 * T + 0{,}2398} \qquad (1)$$

In this case the coefficient of determination R^2 established using regression procedure in Excel programme is: $R^2 = 0{,}967$

In the dynamic regime case the relationship obtained is also a second degree polynomial function (2).

$$\mathbf{E = -2 * 10^{-6} * T^2 + 0{,}0011 * T + 0{,}2382} \qquad (2)$$

In this case the coefficient of determination R^2 established using regression procedure in Excel programme is: $R^2 = 0{,}9902$

To validate the above relationships, the emissivity values determined analytically was compared with those determined experimentally, and the results obtained with the related errors are shown in Table I for static regime, respectively in Table II for dynamic regime.

TABLE I
VARIATION OF EMISSIVITY IN STATIC REGIME

The temperature of brake disk (degrees C)	The emissivity experimentally determined	The emissivity analytically determined	The error
165,10	0,3030	0,3116	2,84%
150,70	0,3030	0,3075	1,49%
140,30	0,3000	0,3043	1,43%
130,20	0,2950	0,3010	2,02%
120,00	0,2940	0,2974	1,16%
110,00	0,2890	0,2937	1,63%
100,10	0,2830	0,2898	2,42%
90,20	0,2820	0,2858	1,34%
80,60	0,2805	0,2817	0,41%
65,10	0,2755	0,2746	0,32%

TABLE II
VARIATION OF EMISSIVITY IN DYNAMIC REGIME

The temperature of brake disk (degrees C)	The emissivity experimentally determined	The emissivity analytically determined	The error
230,00	0,4056	0,3854	4,98%
220,00	0,4025	0,3834	4,75%
210,20	0,4005	0,3811	4,86%
200,20	0,3940	0,3783	3,99%
190,60	0,3928	0,3752	4,48%
180,10	0,3905	0,3714	4,88%
170,30	0,3854	0,3675	4,64%
160,00	0,3776	0,3630	3,87%
150,10	0,3677	0,3582	2,57%
140,10	0,3582	0,3531	1,44%

We observe that the differences between the analytical results do not exceed by more than 5% of the values obtained experimentally.

IV. CONCLUSION

The emissivity of brake disc increases together with temperature increasing in both its static and dynamic regime.

The emissivity of brake disc material while in motion differs from the idle, higher values being recorded in dynamic regime case.

In both cases, the relationships for calculating the emissivity depending on the temperature which can be estimated with good accuracy by a second-degree polynomial functions whose coefficients can be determined using the regression method.

These types of relationships can be further used in other studies on heat stress of disc brakes and its influence on the performance of the brakes, wear or operational safety when using thermovision camera, because through the correct emissivity setting is ensure a greater accuracy of measured temperature values.

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