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To cite this article: N Stojanovic *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.* **1271** 012024

IOP Conf. Series: Materials Science and Engineering 1271 (2022) 012024 doi:10.1088/1757-899X/1271/1/012024

The determination of the disc brake thermal stresses for different vehicle speeds

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Abstract. From the aspect of traffic safety, the brake system is one of the most important systems. For all exploitation conditions, for which vehicles are projected, and for loads in prescribed boundaries, no matter to the vehicle speed, it is important, for the brake system to be reliable and to provide a very fast stop, or speed adjustment to road conditions. During the stop or during the speed adjustment it comes to the disc brakes temperature increment. So, because of this, the experimental investigations were conducted, in order to determine final values of the temperature for multiple braking processes until stop. In this paper, were conducted two experimental tests for the same vehicle, but for different speeds, which were 60 km/h and 80 km/h, while the other parameters (initial temperature, the mass of the simulated vehicle, number of repetitions) were the same for both tests. The conclusion is that by increment of the speed, rises the necessary time to stop the simulated vehicle, and by this, rises and the stopping distance. Also, rises and the temperature of the disc brake, with the increment of the vehicle speed.

1. Introduction

Besides the steering system, the brake system is one of crucial systems on the vehicle, from the aspect of the traffic safety. The brake system should provide deceleration, that is, the speed adjustment to road conditions. Also, it should provide the vehicle stop, as well as the vehicle maintain in steady state, in the case when the vehicle is parked. In all situations, the brake system should be reliable and to not endanger the safety of the driver, as well as the safety of other traffic participants.

The two main types of brakes which are widely used are disk brakes and drum brakes. In the case of disk brakes, the disk can be solid disc, or a vented disc. However, today the widest application have vented discs [1], and because of this, this type of disc will be analysed in the paper. The vented discs are much more convenient for use, because their ribs provide a much better cooling and heat release into the environment [2]. Thanks to this, it is not endangered the reliability of brake elements during the extreme conditions of exploitation, compare to the solid discs [3]. The only thing, about which should take care, when use the vented disc, is the geometry of ribs [4]. Because, only by correct choice of the shape of ribs, that is, by their modification, the heat release will efficient [5]. The Limpert [6] in his research shown that 60% of heat releases from ribs, while the rest amount of heat, releases into the environment from the contact surface of the brake disc.

During the braking process comes to the increment of the temperature of the brake disk and brake pads [7]. Also, this can cause the reduction of the friction coefficient [8], which further leads to the longer stopping distance, as well as to the longer time, which is necessary to stop the vehicle. In the case, if the heat does not release into the environment, or the heat release is very slow, a hot spots can appear, or even can come to cracks [9, 10]. The temperature field is completely connected with the field of stresses which appear on the contact surface of the brake disc [11], which further results with the damage of the brake disc. Depend from the type of braking, will depend and type of heat stress. During the normal braking, a great heat stresses appear, however, due to the extreme braking, an enormous heat stresses appear [12].

One of main questions is, will a brake system provide safe vehicle stop, no matter to the temperature of the brake disc and brake pads. Also, how much will heat up the brake disc and brake pads, in respect to the vehicle speed. This paper shows, how much are the temperatures for different vehicle speeds, as well as how the speed influences on the temperature increment. Besides these answers, the paper provides and thermographic presentation of temperature distribution on the contact surface of the brake disc.

2. The experimental installation

The test rig for the investigation of disk brakes thermal stresses – BRAKE DYNO 2020, is shown on figures 1 and 2, while the scheme of the test rig is presented by figure 3. The connection between the shaft of the electric motor (1) and flywheel mass (5) is provided by the electromagnetic clutch (2), which turns on and turns off, by brush (14). The position of electric motor by height can be adjusted, by adjusters (23). The control of the speed of the electric motor is achieved by frequency regulator (13). In order to have constant information about the angular speed of the flywheel mass, on the driven part of the clutch is mounted wheel with teeth's (13), where the inductive sensor (17) serve to measure the rotation speed. The rotation speed can be followed during the acceleration, as well as during the braking process. The shaft of the flywheel mass, on both sides lays on two bearings (4) on the support construction of the test rig (22). On the opposite side from the electric motor is the brake disc (6), which by screws is connected with the shaft of the flywheel mass. The brake calliper (27) is connected with the base by carrier (28) and force sensor (19). Inside each brake pad are mounted two temperature sensors (18), for temperature measure on the entering and exiting side of the brake pad, while for the measure of the temperature of brake disk thermal camera is used (8). The brake activates by hydraulic braking installation (12 and 26), while the hydraulic brake installation activates by pneumatic installation (9), which use air from compressor (10). Firstly, rises the air pressure in the pneumatic installation, where the air from the compressor to the pneumatic part comes through the pipe (25). After that, the pneumatic part activates the brake cylinder (12), and by further rise of oil pressure in the hydraulic installation (26), brake pads press the brake disc, where value of the brake pressure rises until the value of the pressure equalizes with the value defined before the measurement. During the measurement, are followed the values of the pressure in the pneumatic installation (21), and in hydraulic installation (20). The control of the test rig is automatized, that is, the commands to the test rig are sending from the computer (11), which receives and sends signals trough A/D converter 6353. During the measurement, all data are collecting and save on the computer memory.

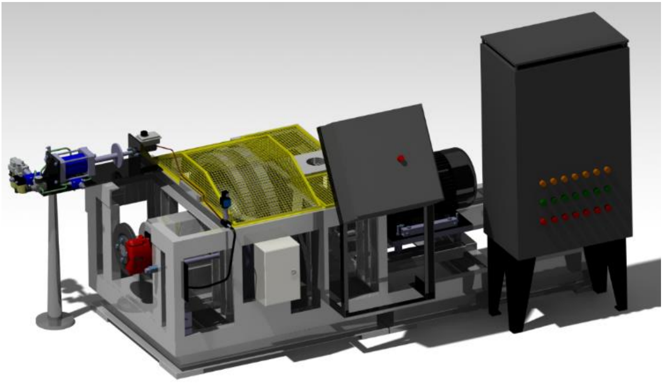

Figure 1. 3D model of the test rig.

Figure 2. The test rig – BRAKE DYNO 2020.

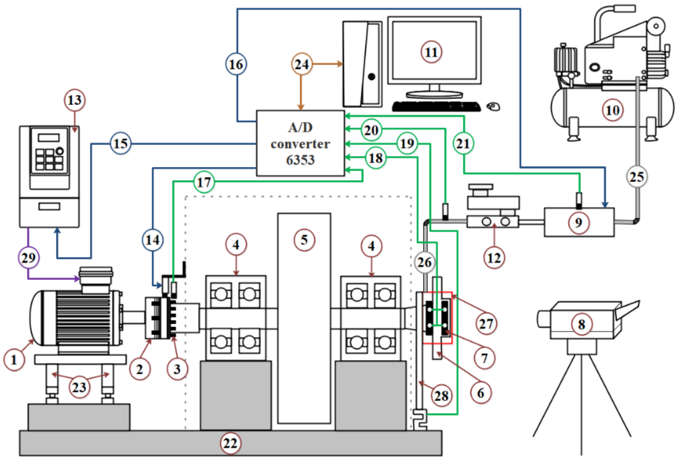

Figure 3. The scheme of the test rig BRAKE DYNO 2020.

3. The plan of the experiment

With aim to determine how the vehicle speed influences on the value of the temperature of the disc brake, it was defined the measurement procedure, figure 4. The first step, includes the defining of the investigation conditions, such are the quarter of the vehicle mass (the test rig simulates the quarter of the vehicle mass ($m_{1/4} = 300$ kg)), brake pressure and the desired speed of the simulated vehicle. The

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next step is to define parameters which should be followed during the investigation process – the output parameters. The output parameters are temperature of brake pads and of the brake disc, the angular speed, the friction coefficient, the brake moment and change of the pressure during the braking process. Besides the defined investigation conditions, on the heat up of the brake disc and brake pads, influence have and the material characteristics, table 1.

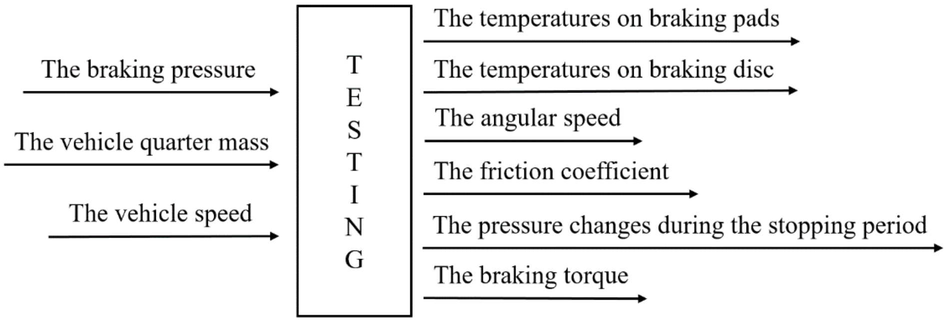

Figure 4. The measurement procedure.

Table 1. The material characteristics of the brake disc and brake pads.

	Disc	**Pad**
Density, kg/m^3	7100	2300
Elastic modulus, GPa	118	20
Poisson ratio, -	0.32	0.3
Thermal conductivity, W/m·°C	53.3	3
Specific heat, J/kg·°C	490	1200
Thermal expansions, °C^{-1}	10.85×10^{-6}	10×10^{-6}

The next step the is the experimental investigation in the laboratory, that is, start of the test rig, and after the achievement of the desired speed for the defined vehicle, the brake activates, simulated vehicle stops, and during the braking process, the input data and output data are collecting and saving on the computer memory. After that, all collected data are processing, analysing and show by diagrams, and on the basis of them, come the conclusions. While the results captured by the thermal camera, are showing in the shape of thermal images.

4. Results and discussion

The change of the temperature on the brake pads, has the shape of the stairs, that is, has constant increment, figures 5 and 6. The greatest increment of the temperature happens after first braking cycle, while with each next braking cycle, the temperature increases more slowly, and to the same conclusion has come and Grzes [13]. By observation of the figure 5, in the case when the speed of the simulated vehicle was 60 km/h, during the first acceleration process, the temperature on brake pads is constant. During the braking it comes to the increment of the temperature, while the greatest increment appears when doesn’t exist rotational movement, that is, when the brake disc is in the steady state. This happens, because, it is necessary time for the heat generated in the contact between the brake disc and brake pads, to conduct inside the brake pads, where are positioned temperature sensors. After that, it follows the next cycle of acceleration, and during this cycle, the temperature on the brake pads has a slight increment. The greatest increment appears, as in the first case, when doesn’t exist rotational movement of the brake disc. Which means, that is necessary to pass some time, in order for the heat generated in the contact of brake disc and brake pads, to conduct by depth of brake pads, all to the temperature sensors, how previously was said. Of course, the temperature of brake pads increases and by depth which

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is behind the temperature sensors. This phenomenon, repeats until the last testing cycle, with that, that the measured temperatures are higher and higher after each braking cycle.

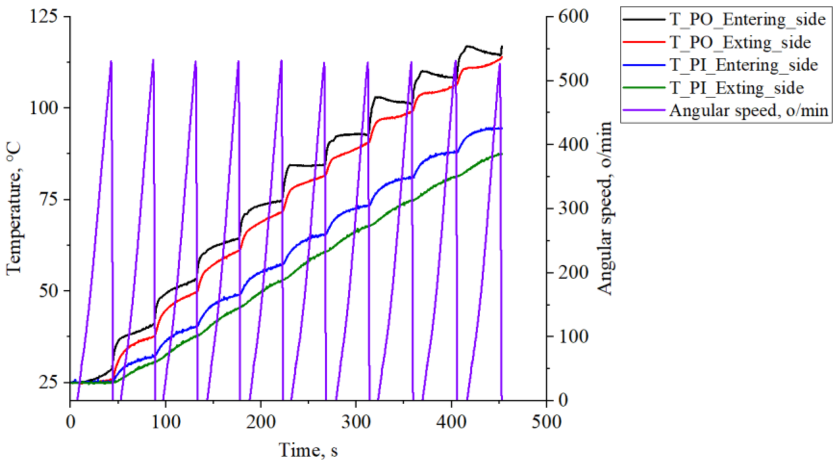

Figure 5. The temperature change on brake pads for the vehicle speed 60 km/h.

The same behaviour of the temperature change of brake pads, was recorded and for the case when the vehicle speed was 80 km/h, figure 6. However, for the case, when the vehicle speed was 80 km/h, temperatures were higher for about 50 °C, compare to the case when the vehicle speed was 60 km/h. Which is logic, because the same vehicle was simulated, that is, the vehicle with the same characteristics, only the speed was different.

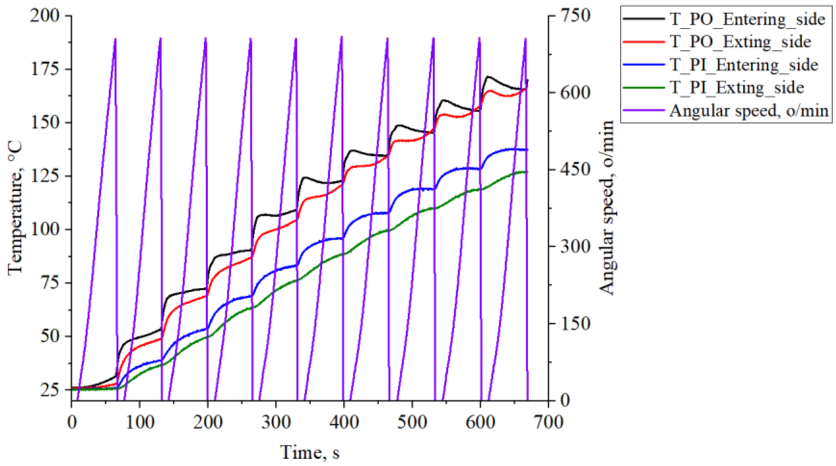

Figure 6. The temperature change on brake pads for the vehicle speed 80 km/h.

The highest temperatures appear on the external brake pad, and that on the entering side of the brake pad. By figures 7 and 8, is shown the dependence of the temperature of external brake pad, braking pressure, braking moment, angular speed and friction coefficient in the function of time, during the 10^{th} braking cycle, for the cases when the vehicle speed was 60 km/h and 80 km/h.

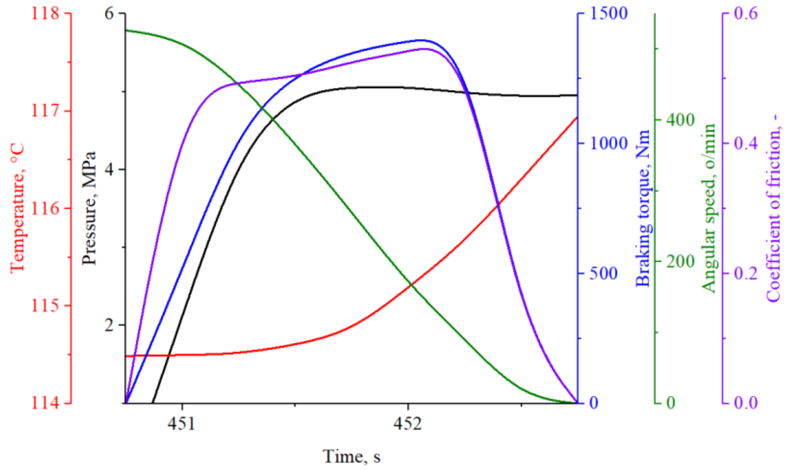

Figure 7. The dependence of temperature, braking pressure, braking moment, angular speed and friction coefficient during the 10th braking cycle, when the speed of the simulated vehicle was 60 km/h.

The value of the temperature does not change until the value of the pressure in the system don't achieves maximum value, figure 7. The shapes of the curves which describe the braking moment and friction coefficient almost the same, because one depends from another [14, 15]. The behaviour of the temperature on the entering side of the external brake pad, braking pressure, braking moment, angular speed and friction coefficient is the same for both cases, that is for case when the speed of the simulated vehicle was 60 km/h and 80 km/h.

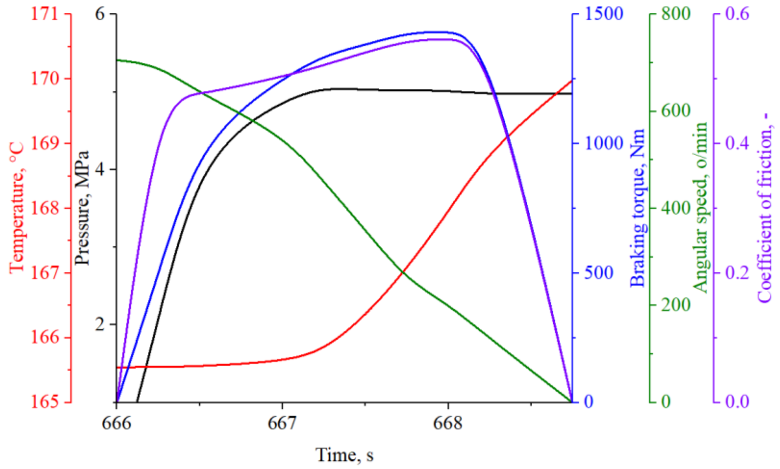

Figure 8. The dependence of temperature, braking pressure, braking moment, angular speed and friction coefficient during the 10th braking cycle, when the speed of the simulated vehicle was 80 km/h.

The temperature field of the brake disc for the 1st and 10th braking cycle is shown on the figure 9, for the case, when the speed of the simulated vehicle was 60 km/h. While by figure 10 is shown for the case when the speed of the simulated vehicle was 80 km/h. The final temperature on the entering side of the external brake pad for the case of 60 km/h was 116.95 °C, while for the case of 80 km/h was 169.98 °C. The speed increment of 20 km/h, cased the temperature increment of 45.34 %.

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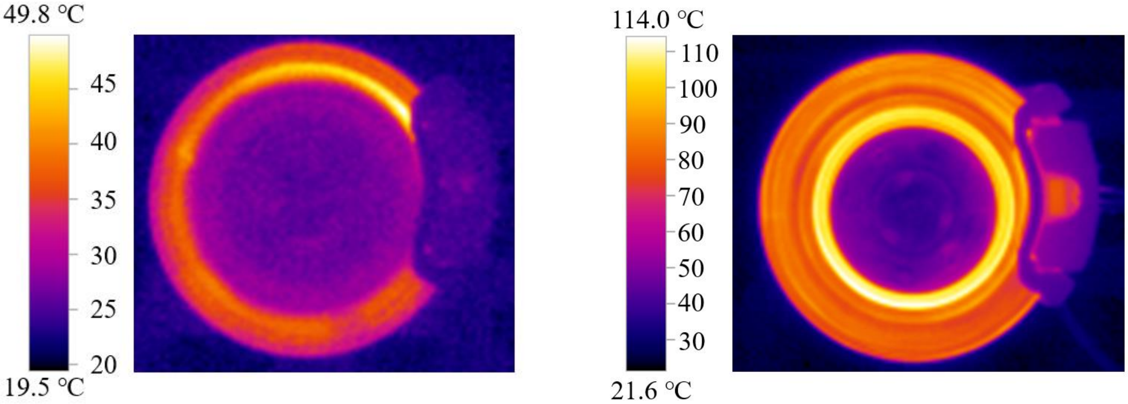
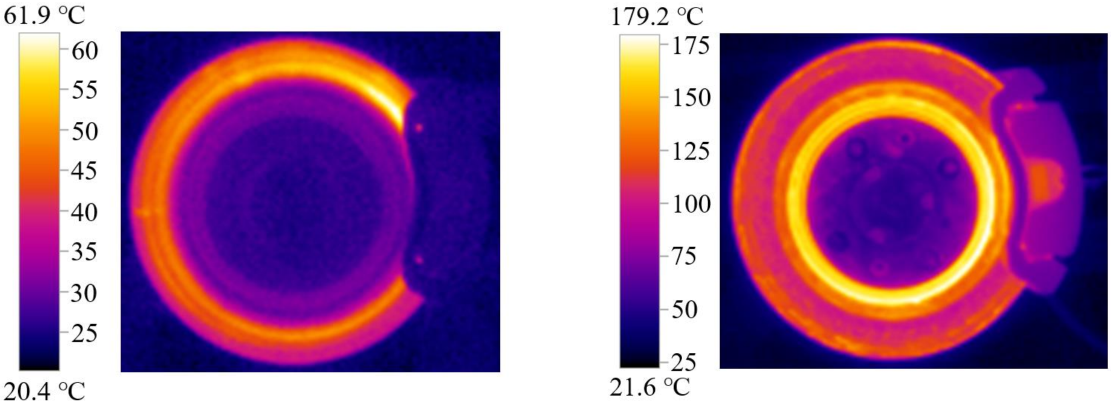


a) b)

Figure 9. The temperature field on the contact surface of the brake disc during the first and tenth braking cycle, for the case when the speed of the simulated vehicle was 60 km/h.



a) b)

Figure 10. The temperature field on the contact surface of the brake disc during the first and tenth braking cycle, for the case when the speed of the simulated vehicle was 80 km/h.

During the 1st braking cycle, by exit of the brake disc from the contact with the brake pad, are noticeable hot bands, on the contact surface of the brake disc, and that, one hot band for the case when the speed of the simulated vehicle was 60 km/h (figure 9.a), and two hot bands for the case when the speed of the simulated vehicle was 80 km/h (figure 10.a). The consequence of hot bands is the reduced contact between the brake disc and brake pads, which can result with the appearance of one or more hot bands, as in the research of Panier et al. [10]. The temperature of the brake disc, after ten consecutive braking cycles, in the case of the vehicle speed 60 km/h, was 114 °C, while for the case of the vehicle speed 80 km/h, was 179.2 °C. The increment of the vehicle speed for 20 km/h, after ten consecutive cycles of acceleration and stop, caused temperature increment of 57.19%. Also, at the end should emphasize, if the obtained temperatures overcome critical temperatures. The moment, when the temperature overcome the critical value, is the moment when the temperature of the brake disc overcome the value of 650 °C [8], which wasn't happened in this research. However, the optimal temperature, that is, the temperature when a best braking performance can be achieved (the greatest value of the friction coefficient), is when the temperature on the contact surface of the brake disc is around 150 °C [14, 16].

5. Conclusion

The exploitation conditions such is the vehicle speed and besides that, also and the vehicle parameters such is the vehicle mass, influence on the thermal stresses of the brake disc and brake pads. Of course, and the type of braking, in great amount influence on the thermal stresses. In this paper, were conducted two experimental tests, for ten consecutive accelerations and stops, for the same vehicle. The only difference was the speed of the vehicle at the beginning of braking process. The highest values of the temperature appeared in the case of greater vehicle speed. Besides that, on the basis of the type of the temperature field, which appears on the contact surface of the brake disc, comes the conclusion that in these regimes of the vehicle drive, appear the highest thermal stresses, which further influence on the mechanical stresses. Future researches should direct to the investigation of brake discs with different shape of ribs, as well as to brake discs and brake pads manufactured from alternative materials, under normal and extreme exploitation conditions.

Acknowledgment

This paper was realized within the framework of the project “The research of vehicle safety as part of a cybernetic system: Driver-Vehicle-Environment”, ref. no. TR35041, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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