MOBILITY & VEHICLE
MECHANICS

https://doi.org/10.24874/mvm.2024.50.04.05
UDC: 629.33:62-592.11

THE INFLUENCE OF THERMAL STRESS OF DISC BRAKES ON VEHICLE DECELERATION

Bojana Bošković[1], *Nadica Stojanović*[2], *Ivan Grujić*[3], *Saša Babić*[4], *Branimir Milosavljević*[5]

Received in August 2024 *Accepted in October 2024*

RESEARCH ARTICLE

ABSTRACT: Braking system is one part of the equation that leads to the desired deceleration of the vehicle. Vehicle dynamics are equally important and should be optimized to achieve maximum deceleration of the vehicle. Whether the driver brakes and stops the vehicle in an emergency, it must be able to stop safely. This means that he does not harm himself or other traffic participants. Velocity makes braking more difficult because higher velocities require higher braking forces. When they are moving at high velocities, more braking force is needed to slow them down. High braking forces lead to high deceleration values. When high braking force is applied, the vehicle will decelerate very quickly, however, high decelerations affect the brakes. In order to slow down the vehicle, a very large braking force is applied, and the work performed will lead to a large amount of thermal energy in the brakes, which can cause them to overheat and thus endanger traffic safety. The paper will define the influence of disc brake thermal stress on vehicle deceleration for different initial velocities

KEY WORDS: *deceleration, braking, thermal stress, traffic safety*

[1] *Bojana Bošković, Academy of professional studies Šumadija, Department in Trstenik, Radoja Krstića 19, 37240 Trstenik, Serbia, bboskovic@asss.edu.rs, https://orcid.org/0000-0001-8622-9874, (*Corresponding author)*
2 Nadica Stojanović, Faculty of Engineering, University of Kragujevac, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, nadica.stojanovic@kg.ac.rs, https://orcid.org/0000-0002-4199-0587
3 Ivan Grujić, Faculty of Engineering, University of Kragujevac, 6 Sestre Janjić Str., 34000 Kragujevac, Serbia, ivan.grujic@kg.ac.rs, https://orcid.org/0000-0003-0572-1205
4 Saša Babić, Academy of professional studies Šumadija, Department in Trstenik, Radoja Krstića 19, 37240 Trstenik, Serbia, sbabic@asss.edu.rs, -
5 Branimir Milosavljević, Academy of professional studies Šumadija, Department in Trstenik, Radoja Krstića 19, 37240 Trstenik, Serbia, bmilosavljevic@asss.edu.rs, -

UTICAJ TERMIČKOG NAPREZANJA DISK KOČNICA NA USPORAVANJE VOZILA

REZIME: Kočioni sistem je deo jednačine koji dovodi do željenog usporavanja vozila. Dinamika vozila je podjednako važna i treba je optimizovati da bi se postiglo maksimalno usporavanje vozila. Bez obzira da li vozač koči i zaustavlja vozilo u slučaju nužde, ono mora biti u stanju da se bezbedno zaustavi. To znači da ne šteti sebi niti drugim učesnicima u saobraćaju. Brzina otežava kočenje jer veće brzine zahtevaju veće sile kočenja. Kada se kreću velikim brzinama, potrebna je veća sila kočenja da bi se usporile. Velike sile kočenja dovode do visokih vrednosti usporavanja. Kada se primeni velika sila kočenja, vozilo će usporiti veoma brzo, međutim, velika usporavanja utiču na kočnice. Da bi se vozilo usporilo, primenjuje se veoma velika sila kočenja, a izvršeni rad će dovesti do velike količine toplotne energije u kočnicama, što može izazvati njihovo pregrevanje i time ugroziti bezbednost saobraćaja. U radu će biti definisan uticaj termičkog naprezanja disk kočnice na usporavanje vozila za različite početne brzine

KLJUČNE REČI: *usporavanje, kočenje, termički stres, bezbednost saobraćaja*

THE MODERN APPROACH TO PROBLEM-SOLVING IN MECHANICAL ENGINEERING - APPLICATION OF ARTIFICIAL INTELLIGENCE

Bojana Bošković, Nadica Stojanović, Ivan Grujić, Saša Babić, Branimir Milosavljević

INTRODUCTION

The first cars were equipped with simple braking mechanisms that were far from efficient and posed significant safety risks. The first disc brakes were patented by Frederick William Lanchester in 1902. The first modern disc brake system was introduced in the production Studebaker Avanti in 1962, which had Bendix disc brakes on all four wheels. The reason this system was so successful was that it used a vacuum booster to reduce the force the driver has to apply to the pedal/shoe during the braking process.

The history of brake technology shows how far it has come, in terms of safety and performance. From a simple rope-operated brake to an advanced electronic braking system, brakes have come a long way over the past hundred years. All this is aimed at improving the state of traffic safety.

The brake system from the aspect of the technical correctness of the vehicle is a system that directly affects the safety of vehicle participation in traffic. The role of the braking system is to slow down and/or stop the vehicle, that is, to adapt to traffic conditions, all in order to prevent a traffic accident. In addition, the role of the brake system is to prevent the vehicle from moving when the vehicle is parked, i.e. to keep it stationary.

The aim of this paper is to define the influence of disc brake thermal stress on vehicle deceleration for different initial velocities, in order to improve traffic safety.

1 VEHICLE DECELERATION

At the beginning of the 16th century, the Italian scientist Galileo Galilei was the first to deal with the concept of acceleration. By studying moving objects, he came to the conclusion that acceleration is exactly a change in velocity over a certain period of time. However, the physicist Isaac Newton just expanded Galileo's discoveries and wrote about it in his book *Philosophiæ Naturalis Principia Mathematica* or just *Principia* [8]. All Newton's laws are defined in this book, which also includes Newton's Second Law, which refers to acceleration and reads: The acceleration of an object depends on the mass of the object and the amount of force applied, Equation 1. Newton's laws played a key role in defining and disseminating acceleration.

$$F = m \cdot a, \tag{1}$$

where:

m – body mass, and

a – acceleration.

The value of deceleration during intensive braking is one of the important input data for traffic accident analysis [5]. In physics, deceleration (negative acceleration) represents a decrease in velocity per time. Deceleration is a vector quantity that can be obtained by taking the first derivative of velocity (also a vector quantity) with respect to time, Equation 2.

$$\overrightarrow{j(t)} = \frac{\overrightarrow{dV}}{dt}\,, \tag{2}$$

where:

$\overrightarrow{j(t)}$ – deceleration (negative acceleration), $d\vec{V}$ – reduction of velocity, and dt – time interval.

The velocity of vehicle participating in a traffic accident, during expertise, is often determined in accordance with the length of traces of braking from tires. In this case, the values of vehicle's velocity are used for calculations, which are selected from the relevant references. Experimental research in such situations where it is necessary to determine the braking parameters of vehicle that participated in the traffic accident are not implemented enough. Therefore, it is of great importance to calculate the velocity of the vehicle in accordance with the defined deceleration values on the basis of which the vehicles limit velocities.

The braking system is one of the most complex systems on the vehicle. Its basic function is to reduce the velocity of the vehicle, as well as to stop the vehicle in a timely manner. The vehicle must ensure that the slowdown is such not to disturb the stability of the vehicle, i.e. the comfort of passengers. Maintenance of the balance between these requirements is challenging. In the last thirty years, numerous researches were conducted to give answers to the question: "What affects the braking process the most?".

In the braking process, it is necessary to achieve the force of braking corresponding to the kinetic energy of the vehicle. There are two types of braking: free and intense/forced braking. The difference between intense and free braking is that in intense braking is achieved almost immediately, so it can be considered constant, while in free braking it takes place through three characteristic phases. The first phase represents a rise of deceleration to maximum value, in the second phase there is a stabilization of deceleration that can now be considered as full deceleration, while in the third phase, deceleration decreases to zero.

The braking process is achieved by friction between brake disc and brake pads. During the friction process, the surface is heated in contact which significantly reduces braking efficiency. The reduction of braking efficiency further leads to reducing the value of deceleration, which causes longer braking distance. This is a huge problem for traffic safety.

2 THE INFLUENCE OF VARIOUS PARAMETERS ON THE DECELERATION

For intersection design, deceleration lane design, traffic simulation modelling, vehicular emission and fuel consumption modelling, etc. deceleration characteristics of vehicles are important. Maximum deceleration rate generally increases with increase in maximum velocity of all vehicle types. Authors [7] conducted that car employ highest deceleration rates while truck use the lowest among the vehicle types.

Vehicles with higher maximum velocity have higher deceleration time, deceleration distance, and lower deceleration rates. At deceleration manoeuver, vehicles with high velocity needs more time to stop compared to one with low velocity [9]. The critical velocity (at which driver attains maximum deceleration) changes with vehicle type and increases with approach velocity. This indicates that at higher approach velocity, the drivers achieve their maximum deceleration rate quickly to stop at the earliest [4].

While braking, most of the kinetic energy are converted into thermal energy and increase the disc temperature [3]. This is very dangerous because overheating may result in brake system breakdown. Through the brake disc the temperature stability is achieved [2]. The highest thermal loads happen during rescue braking near the start of the deceleration phase [1].

Kudarauskas [6] conducted an experiment and concluded that the settled deceleration of vehicles with ABS varied from 8.00 m/s^2 (when the velocity was 40 km/h), then 8.41 m/s^2 (upon 60 km/h) up to 8.76 m/s^2 (upon 80 km/h), and the maximum values often were over 9 m/s^2. In vehicles without ABS, deceleration varied from 7.00 m/s^2 (upon 40 km/h), 6.89 m/s^2 (upon 60 km/h) up to 6.66 m/s^2 (upon 80 km/h), and the maximum values often were up to 8.3 m/s^2. On increase of initial velocity, the difference of deceleration in vehicles with and without ABS increased as well and was equal (for different velocities) to 11.5%, 18.1% and 24%, respectively.

Stojanovic et al. [10] conducted two experimental tests for the same vehicle type for different velocities (60 km/h and 80 km/h) were the other parameters: initial temperature, the mass of the simulated vehicle, number of repetitions) were the same for both tests. The authors came to the conclusion that an increase in initial velocity causes a longer braking distance as well as a higher disc temperature.

3 EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF TEMPERATURE ON DECELERATION FOR DIFFERENT INITIAL VELOCITIES

The test rig for the experimental investigation of disk brakes thermal stresses is BRAKE DYNO 2020 and its scheme is shown in Figure 1.

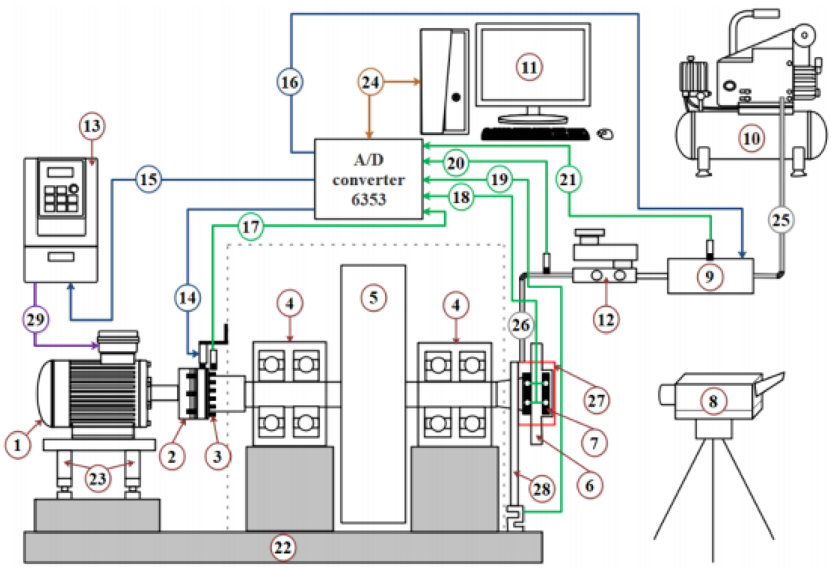

Figure 1 The scheme of the test rig

An experimental investigation was carried out with the aim of determining how the vehicle velocity affects the value of the temperature of the disc brake, how it is further reflected in the value of the deceleration and braking distance. Before starting the measurement, the test conditions were defined, Figure 2. The test rig simulates a quarter of the vehicle's mass, which for each initial velocity value was 300 kg. The pressure in the brake installation was the same for all measurements – 5 MPa. The initial velocities were varied and were 60 km/h, 70 km/h, 80 km/h, 90 km/h and 100 km/h, respectively.

Based on the obtained data on the drop in speed over time, the actual value of the deceleration was obtained. The braking distance is calculated as the integral of the speed in a certain time interval:

$$S = \int_{t_0}^{t_1} V(t)dt \tag{3}$$

Where:

t_0 – time at the beginning of the braking process (it is usually taken to be $t_0 = 0$), and

t_1 – time required to stop the vehicle.

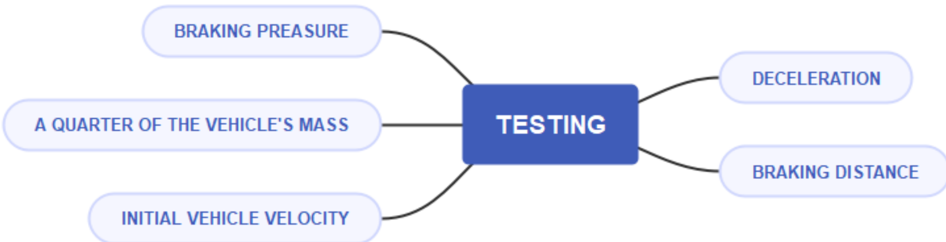

Figure 2 Experimental procedure

The input parameters are set on the test rig. After that, the desired initial velocity is achieved. After reaching the desired initial velocity, the brake is activated for the desired vehicle. During the braking process from the desired initial velocity to complete stopping, simulating intense braking, and the velocity drop is monitored. All obtained data for each measurement is stored on the computer memory. The last step is the processing and analysis of the obtained data, and certain conclusions are drawn based on the obtained analysis.

4 RESULTS AND DISCUSSION

Five measurements were taken and all measurements were with the same initial conditions (a quarter of the vehicle's mass was 300 kg, and the pressure in the brake installation was 5 MPa).

During the braking process, at an initial velocity of 60 km/h, the temperature of the brake pad was 32.1 °C. The maximum deceleration value was 8.44 m/s^2, while the braking distance was 21.7 m, Figure 3.

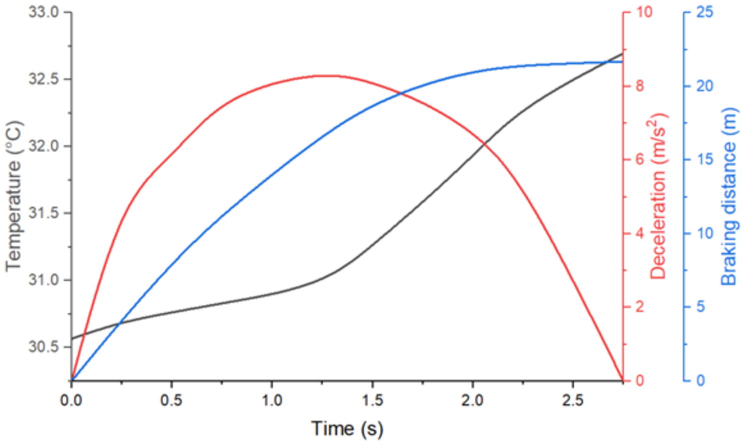

Figure 3 Dependence of deceleration and braking distance on temperature for initial velocity 60 km/h

In a repeated experiment, the value of the initial velocity was changed. When the initial velocity was 70 km/h, the maximum temperature measured on the brake pad was 36.2 °C. The maximum deceleration value measured is 10.9 m/s^2. The braking distance for initial velocity of 70 km/h was 28.2 m, as shown in Figure 4.

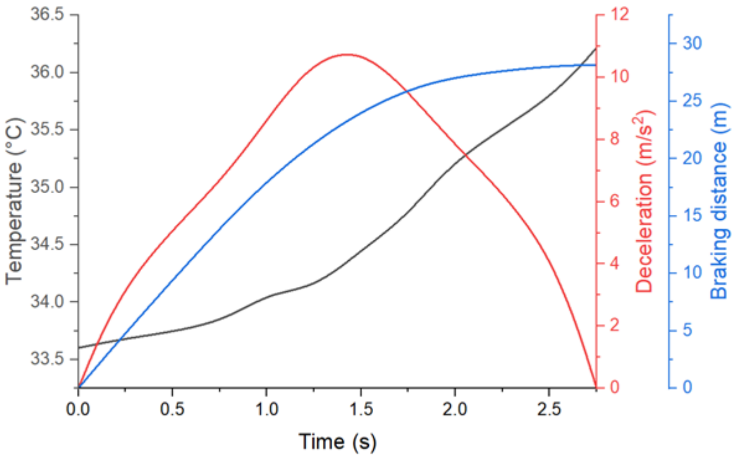

Figure 4 Dependence of deceleration and braking distance on temperature for velocity 70 km/h

The third measurement, Figure 5, that was carried out and had the same initial conditions as the previous two measurements, with the fact that in the third measurement the initial velocity was 80 km/h. Maximum measured temperature was 39 °C, the maximum recorded deceleration value was 9.8 m/s^2, while the braking distance was 39.2 m.

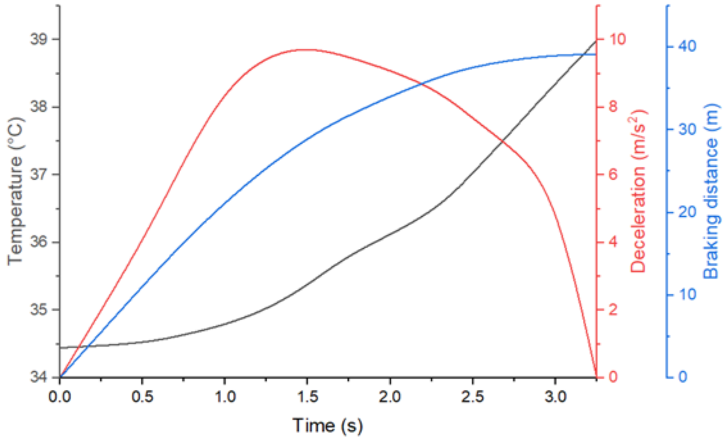

Figure 5 Dependence of deceleration and braking distance on temperature for initial velocity 80 km/h

In the fourth measurement, the initial velocity was 90 km/h, Figure 6. All other conditions were as in previous measurements. The temperature measured on the brake pad was 44.9 °C, the maximum deceleration measured was 11 m/s^2, and the braking distance was 44.6 m.

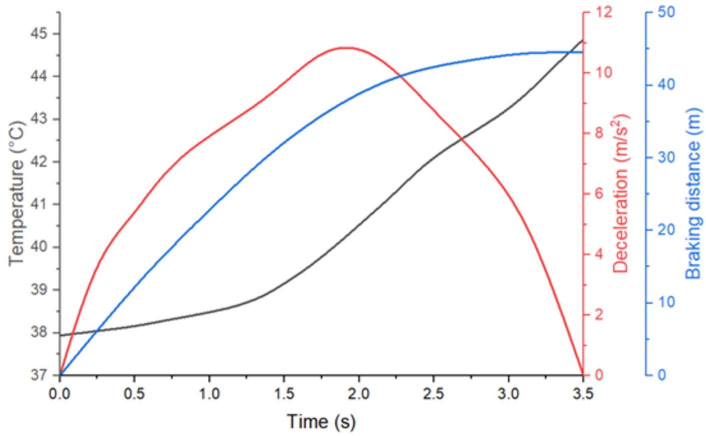

Figure 6 Dependence of deceleration and braking distance on temperature for initial velocity 90 km/h

In the last measurement, at an initial velocity of 100 km/h, the maximum measured temperature was 44.9 °C, as well as in the previous measurement at a velocity of 90 km/h. The maximum deceleration value was 10.9 m/s^2, and the braking distance was 61.2 m, as shown in Figure 7.

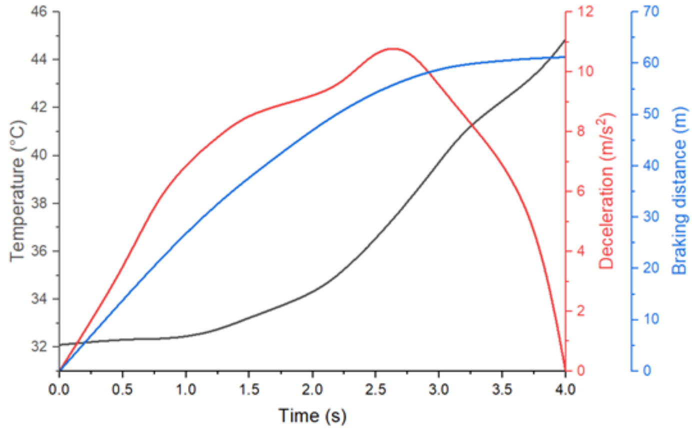

Figure 7 Dependence of deceleration and braking distance on temperature for initial velocity 100 km/h

It can be concluded that with the increment of initial velocity, there was an increase in temperature, as well as an increase in the braking distance, which tripled. However, the trend of change in deceleration is different. The highest value of deceleration was recorded at velocities 70 km/h, 90 km/h and 100 km/h, and the lowest at a velocity of 60 km/h, shown in Figure 8.

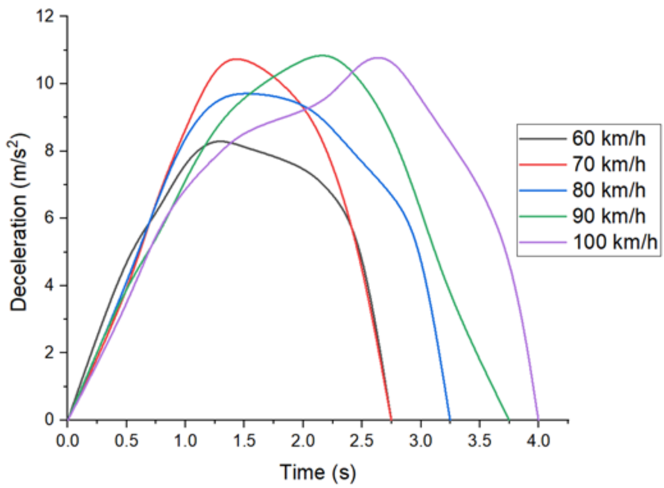

Figure 8 Deceleration for different initial velocities

The deceleration values obtained on the test bench differ from the ideal deceleration values because they do not take into consideration the deceleration of the whole vehicle, but the deceleration of the disc brake. Floating calliper is the reason for the appearance of peaks.

The obtained deceleration values differ from those shown in the paper [7], because the authors considered decelerations for different categories of vehicles, and therefore the masses of those vehicles differ from the mass used in this research.

5 CONCLUSION

The mass of the vehicle, the pressure in the brake installation, as well as the initial velocity have a great influence on the braking process. The research carried out led to the conclusion that the braking temperature increases as the velocity increases in passenger vehicles, as does the braking distance. The deceleration is the smallest for the velocity of 60 km/h, and almost approximately for the initial velocities of 70 km/h, 90 km/h and 100 km/h.

Further research should be directed at investigating how repeated braking, characteristic for stop-and-go driving, affects deceleration and braking distance.

REFERENCES

[1] Adamowicz, A., Grzes, P.: "Analysis of disc brake temperature distribution during single braking under non-axisymmetric load", Applied Thermal Engineering, Vol. 31, 2011, pp. 1003-1012,

[2] Agrawal, K., Patil, L.N., Chavan, K.V., Nimbalkar U.D.: "A computational analysis of heat transfer in solid and vented disc brakes: CFD simulation and thermal performance assessment", Multiscale and Multidisciplinary Modeling, Experiments and Design, 2024,

[3] Akop, M.Z., Kien, R., Mansor, M.R., Mohd Rosli, M.A.: "Thermal stress analysis of heavy truck brake disc rotor", Journal of Mechanical Engineering and Technology, Vol. 1, No. 1, 2009, pp. 43-52,

[4] Bokare, P.S., Maurya, A.K.: "Acceleration-deceleration behaviour of various vehicle types", Transportation Research Procedia, Vol. 25, 2017, pp. 4733-4749,

[5] Kolla, E., Ondruš, J., Gogola, M., Šarić, Ž.: "Braking characteristics of the specified modern electric vehicle during intensive braking", Advances in Science and Technology Research Journal, Vol. 14, No. 3, 2020, pp. 125-34,

[6] Kudarauskas, N.: "Analysis of emergency braking of a vehicle", Transport, Vol. 22, No. 3, 2007, pp.154-159,

[7] Maurya, A.K., Bokare, P.S.: "Study of deceleration behaviour of different vehicle types", International Journal for Traffic and Transport Engineering, Vol. 2, No. 3, 2012, pp. 253-270,

[8] Newton, I.: "Philosophiæ naturalis principia mathematica", Londini: Apud G. & J. Innys, 1726,

[9] Omar, N., Prasetijo, J., Daniel, B.D., Abdullah, M.A.E., Ismail, I.: "Study of car acceleration and deceleration characteristics at dangerous route FT050", 4th International Conference on Civil and Environmental Engineering for Sustainability (IConCEES 2017), 4–5 December 2017, Langkawi, Malaysia, pp. 1-6,

[10] Stojanovic, N., Grujic, I., Abdullah, O.I., Belhocine, A., Glisovic, J.: "The determination of the disc brake thermal stresses for different vehicle speeds", 9th International Congress Motor Vehicles & Motors 2022, Kragujevac, 2022, pp. 1-8.