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ON THE PARAMETERS INFLUENCING THE BRAKE PEDAL "FEEL" IN PASSENGER CARS

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Abstract– Nowadays there exist two driving forces that impose the development of already existing braking systems and development of new components and technologies: legislation and consumers. Alluding to automotive components and brake components in particular, it is noteworthy mentioning that their design has to include the considerations of not only safety, but also comfort for users. “Brake pedal “feel” is of equal significance for both safety and comfort.Consumers expect a good “feel” of braking for easier driving and to fulfill the driver’s intention of deceleration so that to ensure confidence in the sense of personal safety and comfort.

Key words– Brake pedal, brake pedal feel, pedal characteristics, brake comfort, brake safety

I Introduction

Braking effectiveness is generally determined by vehicle’s ability to decelerate in a timely manner or stopping distance, pedal travel and pedal force [1]. Driver’s intention is to possess full control over vehicle during deceleration by sensing how much force he applies to actuate the braking system and also how much the pedal travels because of the actuated force. Effectiveness of the braking system has a connection with the brake pedal “feel”. Moreover, this effectiveness is important to drivers because there exists a relationship between the stopping distance and the perception quality of the braking process that the driver possesses. Figure 1 presents the definition of brake pedal “feel”. According to this figure, the brake pedal “feel” can be defined in 6 categories [2]. The figure claims that in principle both the conventional braking system and brake-by-wire system may affect the perception of a driver during braking. As a result, the outputs of a good pedal “feel” form customer satisfaction (evaluated from driver’s subjective point of view), comfort and safety. After taking all the above mentioned categories together, one can try to represent parameters which will be able to describe objectively the conditions for a good brake pedal "feel" [2].

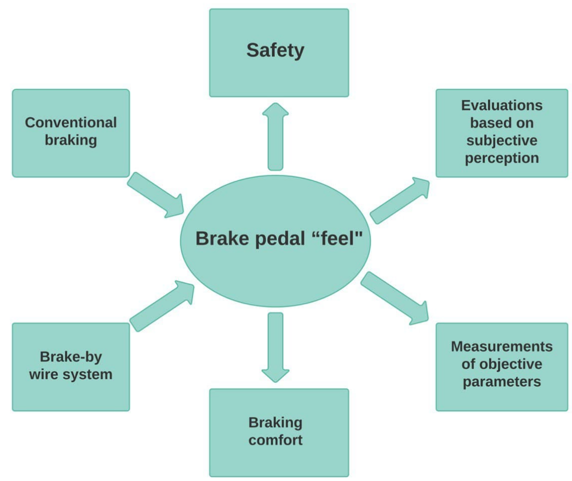

Fig. 1: Definition of brake pedal feel

II Method

Besides, when working with braking system, we have to consider factors which will influence the brake pedal “feel”. Below is presented a short summary of the parameters and factors influencing the feeling that the driver perceives during deceleration:

1. **Brake pedal.** During the design phase of braking systems and brake simulators it is crucial to keep in mind a direct connection between the force the driver applies on the brake pedal and the vehicle deceleration . Hence, a proper selection of the lever ratio of the pedal is necessary since too high force can lead to a vehicle instability whereas an insufficient amount of force may not fully stop the car. A typical brake pedal in passenger cars has a lever ratio from 2.5:1 to 5:1. Moreover, the brake pedal has a high importance to “feel” because it serves as a medium transmitting a force feedback to the driver from the braking system.

2. **Influence of the Tandem Master cylinder on the pedal "feel".** A master cylinder is a "must have" device in conventional braking systems.The main function of the Master cylinder is to transform and amplify the force applied by the driver into a hydraulic force [3]. As a requirement of legislation, the master cylinder has to guarantee a safe and reliable vehicle deceleration even in case the Vacuum Booster fails to work. Moreover, recent advancements in the development of braking systems make master cylinders work in cooperation with such systems as ABS (anti-lock braking system), EBD (electronic brake force distribution)[4]. The geometrical dimensions of the master cylinder play a vital role in the whole braking process. So that to make a good braking at high pressure, it is required to reduce the bore size of the cylinder. On the other hand, the reduction of the bore size leads to the increase of the piston stroke, which, in turn, will increase the pedal stroke.In this regard the geometry of the Master cylinder has to be managed as well in order to comply with dimensions of the whole system. The most common brake system layout for modern passenger cars comprises 2 separate circuits for passenger cars is the diagonal 'split', where each circuit controls one wheel at the front and another at the diagonally opposite rear wheel, e.g. left front and right rear wheels.

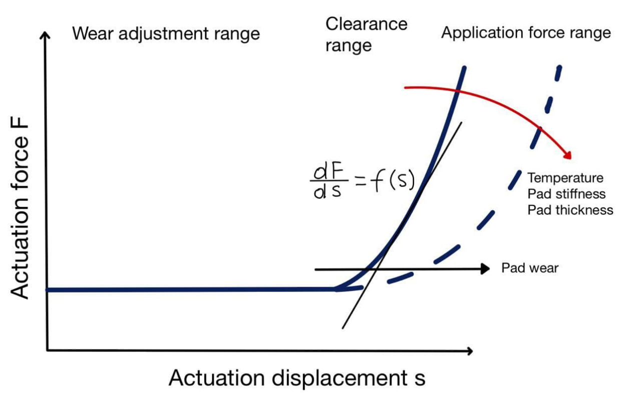

Fig. 2: Force-displacement relationship during the braking process

3. **Effect of Vacuum Booster on brake pedal "feel".** The idea of fitting a vacuum booster to passenger cars and light commercial vehicles originated from the global market demand for the reduction of the brake force that drivers have to apply and a high level of efficiency. The brake vacuum booster increases the input force from the brake pedal and transmits it through the master cylinder to the brake calipers through the hydraulic circuit and reduces the pedal effort during braking operation. Earle [5] stated the best trade-off between brake pedal effort and braking effort transmitted to the calipers from cost effectiveness point view can be achieved given that the vacuum booster is designed properly. It can be mentioned that in order to provide a good brake pedal "feel" for the driver, the pedal lever ratio and hydraulic ratio should have a correspondence to the characteristics of the brake vacuum booster. The brake booster must be able to enhance the performance of braking, and the force amplified by the booster can provide positive feedback of brake pedal 'feel' by diminishing the pedal effort and pedal stroke. In other words, the braking performance of a vehicle is highly dependent on the capabilities of brake booster [6].

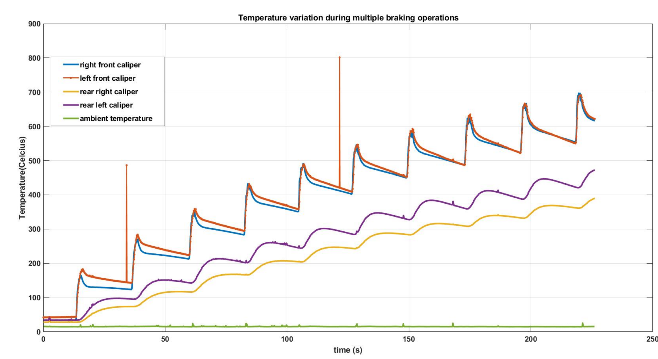

Fig. 3: Temperature of brake calipers during multiple sequential braking operations

4. **The influence of brake calipers on the brake pedal "feel".** In addition the pedal lever ratio and the hydraulic ratio, the proper selection of materials for the braking system is of significant importance since they will affect the feelings the driver perceives during braking. Especially this is concerned with the friction material used. According to Day and Shilton [7], the functional requirements of a brake friction material are as follows:

- To provide consistent and reliable friction force.
- To be durable, the effective life must be equivalent to the manufacturer's service target.
- To be mechanically and thermally strong to withstand the load applied.
- To minimize the noise and vibration issues.
- To be environmentally friendly.
- To be cost effective in design, manufacturing,maintenance and use.

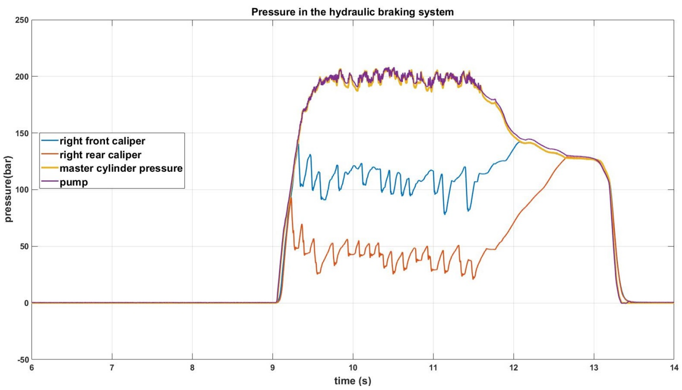

Fig. 4: Pressure dynamics during a hard braking

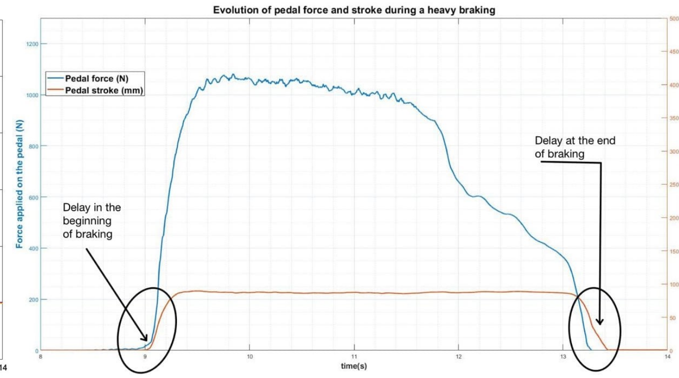

Fig. 5: Applied Force(N) and pedal stroke (mm) during a heavy braking

One of the most crucial parameters influencing the braking process is the temperature of the friction material. At too high temperatures there may arise a phenomenon called brake fading [8]. As a result of the temperature increase, the friction coefficient of the friction material drops dramatically. When speaking about the braking procedure, we realize that the pressure generated in the hydraulic circuit can reach decades of bars and for this reason we have to consider the pad deformation as well. The more the deformation is, the higher is the pedal travel. Also, it is worth mentioning that pad wear and thickness affect the braking operation and, in turn, the brake pedal “feel”. Figure 2 describes the relationship between the actuation force and the pedal displacement with the effects of temperature, pad wear and thickness taken into account.

III PARAMETRIC ANALYSIS OF THE DECELERATION PROCESS.

For an objective analysis of the brake pedal "feel", it is necessary to analyze the dynamical behaviour of different parameters under the deceleration phase. For the scope of this paper, the dynamics of brake caliper temperature, pressure in the hydraulic circuit of the braking system and also the vehicle speed during the braking procedure will be presented. Section II indicated the parameters that may influence brake pedal feel, especially those parameters related to the friction material used in the braking system. As can be seen in Figure3, during multiple sequential braking operations the temperature of the brake calipers can reach a value of 700°C . The temperature should be taken care of in order to avoid brake fading phenomenon (the friction coefficient of the friction material in the brake calipers starts to decrease drastically as a result of a temperature increase after a certain limit). The figure also shows that the front calipers have a higher temperature than the rear ones. This is explained by the fact that the front calipers are supplied with a higher hydraulic pressure. The dynamical behaviour of the pressure in the hydraulic circuit during a heavy braking process is shown in Figure 4. From the figure it may become quite evident that during a heavy braking procedure the pressure in the brake and the hydraulic pipelines can reach a value of 200 bar.This fact implies that the design of the braking system components has to be done with great care. it can also be seen that the front calipers are subjected to a higher pressure than the rear ones and this fact justifies the relation between the temperature and pressure in the calipers. The pressure in rear calipers has to be reduced by a proper valve to avoid rear wheel locking and a potential vehicle instability.

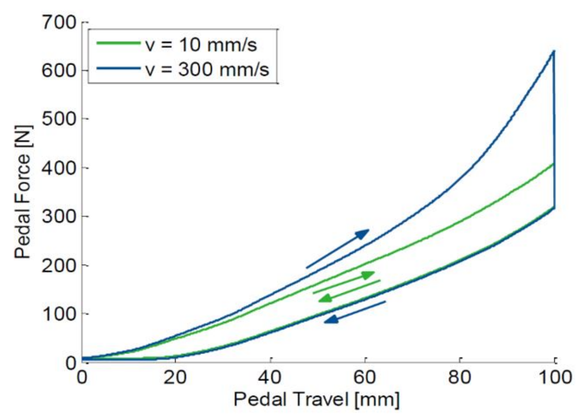

Fig. 6: Pedal Force-stroke characteristic curve [9]

Another important step in understanding the behaviour of the braking system and simultaneously feedback from the pedal, one could investigate the behaviour of the force the driver exerts on the pedal and the pedal stroke (displacement). Figure 5 shows how the pedal force and the pedal stroke change during a heavy braking process. One can see that during a heavy braking process the force exerted by the

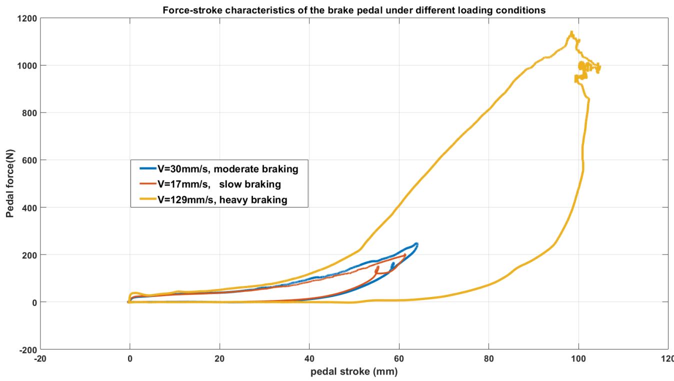

Fig. 7: Characteristic curves of the pedal during different braking regimes

driver can reach a high value of 1000N. It follows that the pedal and other mechanical components have to withstand high loads generated by the driver. When the driver releases the pedal, both the force and stroke fall to zero value. However, it should be mentioned that both in the beginning and the end of the braking operation there is a delay of the profiles which is characterized by the time response of the pedal.In order to improve the perceptions of the driver, the time delay should be reduced as much as possible. The next step could be to plot the curve of relationship between the applied force and the pedal displacement. According to [9],the force-stroke characteristic of a brake pedal represents a hysterical curve which depends not only on the pedal force and stroke, but also on the pedal movement speed during braking (Figure 6). The most optimal solution will be to combine several different braking operations (the pedal speed varies) in one plot. They will represent the general behavior of the pedal force as a function of the pedal stroke. In Figure 7 are represented 3 characteristic curves corresponding to 3 different braking regimes and 3 different average pedal speeds. The dimensions of the hysterical characteristic curves highly depend on how fast the pedal travels during the braking process, especially during heavy braking.

IV Conclusion

The main two reasons for which the development of the braking system has to be done are the passenger safety and comfort. Braking system is one of the most important systems in modern vehicles. The components have to be developed in such a manner to guarantee a safe vehicle deceleration under different road and traffic conditions. Besides, nowadays the overall market requires that the braking system be not only efficient from safety point of view, but also from ergonomic point of view. The braking system has to work efficiently in the sense that lower driver effort could lead to a required output. Moreover, understanding the objective parameters influencing the perception of drivers during the deceleration phase makes it possible to develop brake pedal simulators which can be used for testing in automobile manufacturing companies, gaming industries and driver training schools. Finally, obtained results could be used for the development of brake-by-wire system where there is no direct connection between the brake pedal and the hydraulic circuit. Even without a direct connection the driver has to "feel" how much force he applies by pushing the brake pedal.

References

[1] Duboka C. Arsenic Z. Todorovic, J. Braking system quality for customer satisfaction. *SAE Technical Paper Series*, 1995.

[2] David G. Ebert and R. Kaatz. Objective characterization of vehicle brake feel. 1994.

[3] Ljubo Vlacic, Michel Parent, and Fumio Harashima. *Intelligent Vehicle Technologies*. 01 2001.

[4] Xiaoxiang Gong, Weiguo Ge, Juan Yan, Yiwei Zhang, and Xiangyu Gongye. Review on the development, control method and application prospect of brake-by-wire actuator. *Actuators*, 9(1), 2020.

[5] S. R Earle. Vacuum pumps as an everyday source for brake actuation servo assistance. *Braking Road Vehicles International Conference. London, UK, Institution of Mechanical Engineerss*, 1993.

[6] Lepeshko J. Ivanov, V. and V. Boutylin. The kinetic brake booster. *SAE technical paper*, 2001.

[7] Shilton B. R Day, A. Braking of road vehicles. *Braking of Road Vehicles*, pages 1–472, 01 2014.

[8] Olumide Towoju. Braking pattern impact on brake fade in an automobile brake system. *Journal of engineering sciences*, 6:E11–E16, 04 2019.

[9] Michael Flad, Simon Rothfuss, Gunter Diehm, and Sören Hohmann. Active brake pedal feedback simulator based on electric drive. *SAE International Journal of Passenger Cars - Electronic and Electrical Systems*, 7:189–200, 05 2014.