Aspects of wear braking process on brake discs and brake pads in the construction of commercial vehicles

M F Popa[1], D M S Capătă[1] and N Burnete[1]

[1]Technical University of Cluj-Napoca, Department of Automotive Engineering and Transports, 103-105 B-dul Muncii Street, Cluj Napoca 400641, Romania

madalin.popa@live.com

Abstract. Economy and low pollution are essential requirements imposed on modern cars. The continuous increase in travel speeds, coupled with the massive increase in the number of vehicles worldwide, has led to the need for the development and use of braking systems to a very high standard. The exploitation of commercial vehicles has as a central factor the profit, which in turn is built on the highest availability of the vehicle and the lowest possible maintenance costs. Both aspects of profit are found in the process of wear of the elements in the braking system. For the owner of a truck, wear is measured in costs (parts and time for repairs). This study shows the result of analyzing multiple sets of data collected from trucks brake control unit in various stages of maintenance and highlights key factors influencing the braking process, also seeking solutions for increased braking performance, reduced wear, reduced maintenance costs for the braking system and increasing the availability of a truck. The processing of braking data and analysis of the braking process, based on the measured data, allowed the identification of some predominant influence factors in the wear of the disc brakes of the analyzed commercial vehicles.

1. Introduction

Since the invention of cars, they radically changed the world and people's way of life. A personal vehicle means independence from specific factors. Commercial vehicles are the ones that support an essential part of the economy, primarily through freight and passenger transport services, and secondly through the jobs in the many adjacent areas. Modern vehicles have evolved with technological advancement and have become complex structures capable of moving at higher speeds to the highest standards. At the same time, the steep increase in the number of vehicles has made it necessary to increase traffic safety in several ways, starting with the development of the central safety systems and continuing with the creation and development of driver assistance systems.

The braking system is one of the most critical safety systems on a vehicle, and it contributes significantly to avoiding accidents and increasing traffic safety. The complexity of current braking systems tends towards a technological peak, represented by their use in the construction of autonomous vehicles. Already on a series of vehicles, there are encountered braking assistance systems, the operation of which is based on analyzes, tests, and results from the actual operation of the vehicles [1].

2. Basics of the study. Elements of analysis

Elgharbawy, M. et al. in [1] points out that data collection and analysis can be used to improve performance in operation or to create programming algorithms for rolling and braking assistance systems.

Jingliang, D. et al. in [2], they are talking about introducing into the systems of the assist systems of predefined data sets, taken from the exploitation or experimental analysis, which underlie their operation. Thus, if the braking system has delays due to mechanical defects, it will not be possible to calculate and perform the brakes in the most efficient way, so in this case, in order to eliminate the errors and in order to be braked at the maximum parameters, it is necessary knowing the exact functioning of the mechanical systems and avoiding unforeseen failure.

Classical braking systems convert kinetic or potential energy into heat by friction [3] and as such, the braking process must be analyzed by the tribological aspect of friction, and the main problems being studied are related to the variation of some parameters during braking (distribution and variation temperature friction coefficient, heat flux variation, wear, noise and vibration, particle emissions, durability).

The interdependence between the friction coefficient and the temperature has a decisive role in influencing the braking performance. Alexey, V., et al. [3], analyze the heat flow distribution for plate and disc braking and find that on the model used the maximum temperature is recorded on the disc (490°C) and then the temperature drops to the hub area (100°C). Thus, almost 93% of the energy is taken up by the disk in the form of heat and only 6% in the brake pads. The temperature problem also has a significant influence on wear, emphasizing the process according to the working conditions, and in the case of thermal overloads, the lack of braking capacity can be achieved. An excellent heat transfer can mean faster heat dissipation and hence reduced wear.

Amirhossein H. et al. in [4], notes that the frictional force is transferred at disk trough brake pads. As a result of the friction, because the brake pads are made of a softer material, they will wear out more strongly, opening the way and studying the influence of the materials in the braking process. Also, in the same study [4], it is stressed that although friction is a great source of energy loss in mechanical systems, in automobiles, this is an essential factor in vehicle control. Among the factors of influence of wear, identified in the same study can be mentioned: brake pad geometry and the presence of channels in the middle of the plate for the disposal of waste material or impurities; the distance traveled between slip points, etc.

Most studies find that simulation of real conditions comes with several challenges and compromises [5], and the mathematical models that are created become very complex if too much data is introduced. To validate the results, both methods are used in parallel: finite element computerized simulation and experimental experimentation on the stand [6].

To find an optimal solution for improving braking performances, it is necessary to analyze several factors such as operating conditions and external factors of influence; properties of materials; wear process; variation of heat flux; noises and vibrations; system or component durability, availability and maintenance.

3. Experimental procedure

Commercial vehicles are often used in substantial, long-term and high-load conditions. This emphasizes the wear of the elements in the braking system and makes it necessary to continuously monitor the wear degree in order not to cause severe damage to the discs. In light commercial vehicles with a maximum authorized mass of fewer than 3.5 tons, the braking system is hydraulically operated and does not differ significantly from that of cars. Brake pads wear monitoring is carried out through a car dashboard that will alert the driver when one of the plates has exceeded the maximum wear limit. This is done by an electric circuit whose signal can have only two values.

For heavy trucks, due to the need for much higher braking forces, the brakes are pneumatic. The proper braking is done by actuating the brake piston mechanism (using levers) from the brake caliper, which in turn presses the plate from the inside towards the disc. At the same time, the brake caliper slides on its guide pins and allows the outer brake pad to contact with the disk.

This mechanism also contains a sensor that records the position of the pistons in the caliper, which it sends to a control unit in the form of an electrical signal. The signal sent by the position sensor is processed by the brake control unit (or the maintenance unit), and the information can be used to display on board the degree of wear of the brake pads or to calculate the remaining time until full wear. There are cases in which braking will be differentiated on each wheel, depending on the degree of wear, as far as possible and without significantly affecting the braking properties or trajectory. This means that the brake control unit will try to brake more, the wheels at which the wear is lower and will brake with a smaller force, the wheels at which the wear is higher.

For this paper, most of the mileage data on which the service interventions took place were taken from the truck control units through the diagnostic socket (OBD) using diagnostic software. The data are in the form of tables and have been categorized into a database created explicitly for this purpose. Another part of the data was taken from the service booklet.

The study also contains some practical measurements to link the wear, expressed as a percentage, of the actual value of the used parts. Both used parts and new spare parts were also compared and analyzed. The paper also exemplifies some cases of specific wear on the brake pads, which were captured in pictures and represented cases with a reduced but essential frequency.

One of the objectives of the paper starts from the analysis of the values provided by the position sensor in the caliper, regarding the wear of the brake pads and makes a report of the wear on the number of kilometers traveled for different types of use. Another aspect studied in the paper relates to the monitoring and analysis of the operating conditions until the first intervention in service on the braking system. In this idea we have analyzed the number of kilometers traveled until the first replacement of the brake pads (front or rear axle); the dimensions of the brake pads and discs were measured and compared with the initial values.

Based on the analysis of these aspects and based on the stored data it was found that it is necessary to divide by exploitation categories because the values of the wear and the maintenance intervals vary significantly for the trucks running in Romania compared to the trucks frequently running on Europe routes. In this respect, three main factors have been identified which favor the increased use of brakes: the average road inclination in Romania, which favors the intense use of the braking system [8]; dust, mud, salts and non-slip material during the winter season - these cause deposits that most often block the stirrup mobility or favor abrasive wear; the human factor through the driving style becomes essential in the wear process of the braking system. On vehicles running on motorways, braking is slower and much lower in number; in this situatio, it is useful to use an auxiliary braking system, but this comes with its advantages and disadvantages.

4. Results and discussions

Heavy trucks are equipped with various types of auxiliary braking systems. The majority of trucks have an auxiliary braking system with engine gas discharge or compression release (known as "Jake Brake"). This type of compression-releasing auxiliary brake is very used and can generate a braking force of up to 400 KN (about 85% of the engine power [7]), but it has the main disadvantage of the braking noise. For higher braking forces, retarders are used (hydrodynamic deceleration). They can achieve braking forces of up to 4000 KN [7] but come with disadvantages such as mass and extra costs. The current study also took into account the retarder auxiliary braking system and in particular its influence on the wear of the main brake components. The results indicate a significant increase in the use of brake pads in retarder trucks, as shown in figure 1, where: *pf* and *pr* represent the replacement of the brake pads on the front or rear respectively; *with Ret* and *without Ret* - with or without auxiliary braking system (retarder); *Ro* and *EU* refer to the exploitation conditions (*Ro*- run in Romania and *Eu* - run on motorways in Europe).

It is noted that there are no significant differences in wear between a retarder truck running in Romania and one without a retarder running on highways in Europe. This aspect, together with the analysis of interventions on the braking system on trucks running in Romania, highlights the need to identify wear reduction solutions caused by external factors such as driving style, infrastructure and road conditions. On the other hand, the importance of the "Jake Brake" auxiliary braking system, which offers a reduced braking torque, covers a significant percentage of the braking demand. It should be noted that all non-retarder trucks in the study are equipped with an auxiliary braking system such as Jake Brake.

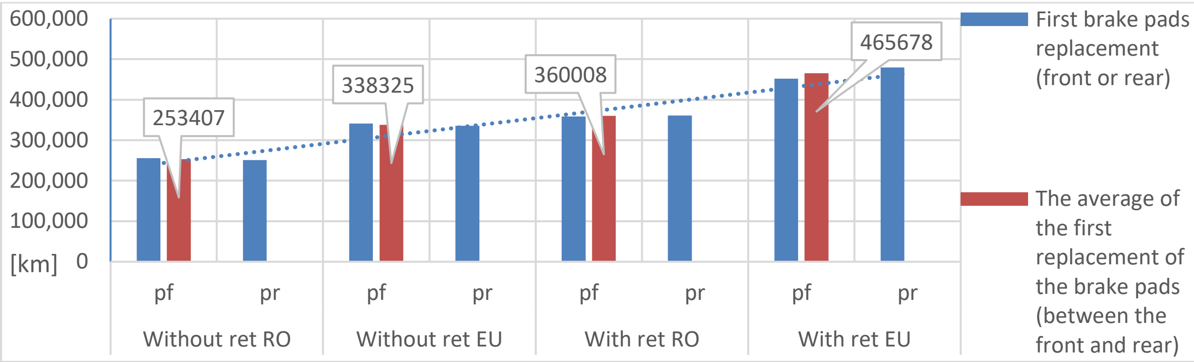

Figure 1. Average mileage at which the first brake pad replacement was performed

Retrieving data from the Brake Control Unit provides details of the replacement of the brake pads and the wear values at the time of reading. Based on these data, the frequency of replacement of the front and rear axle brake pads from the tractors were analyzed and the main trends were identified. Thus, for vehicles traveling in central and Western Europe, in about 40% of cases, the front axle pads are worn for the first time, and in 20% of cases, the first intervention is done at the rear axle. This can be explained by the analysis of the transported cargo and its distribution in the semi-trailer. In the rest of the cases, the brake pads were replaced by the same intervention on both the front and the rear. Some carriers prefer an advance replacement to just 80% of the brake pad thickness to reduce the number of service entries and to avoid excessive wear on the plates (which can also damage brake discs and increasing repair costs). In this respect, if the front side pads are worn 100% and 80% worn on the rear, it is possible to choose the option of total replacement (preventive), which will guarantee a longer service life without any intervention to the braking system.

During the study it was found that the wear values of vehicles with retarder compared to those with only the Jake Brake type system can`t be compared in the same graph without taking into account the route. It is necessary to divide into two categories: with or without a retarder and the type of the route. Under running conditions in Romania only a 50…70% wear may occur after a run of only 20,000...40,000 km although in highway conditions this wear corresponds to a distance of 150,000...200,000 km. This underlines once again the massive influence that this system has on the wear and tear and the fact that the analysis of the influence of infrastructure in developing countries has a particularly important role in determining the maintenance costs of the braking system.

4.1. Experimental determinations

In operation, the main problems that lead to excessive wear are caused by blocking the brake calipers due to dust and mud on the road; suppressing the movement of the brake pads; nonconforming parts; overstretching, uneven and unexpected wear, aggressive driving style. There are, however, situations where it has been found that the brake assembly (brake caliper, sliding mechanism, brake pads) operate in parameters, but the reported wear was powerful. Such a case was found in replacing the brake pads in a truck running in mixed conditions (Romania and Europe). At a distance of 225,538 km, the wear indicated by the control unit (after processing the signal received from the piston position sensor in the brake caliper) was 107% (more detailed, on the rear - left the wear was 100%, on the right 72% and the front left the wear was 64%, respectively 72% on the right). After disassembly and careful analysis of the braking system, it was found that on the rear left of the outer pad, the friction seals were worn out and the braking was done for a while with the metal plate support, as shown in figure 2. A mechanical fault could have caused a wear abnormality like this. It is known that there is a software in the brake computer that attempts to uniform wear on each wheel (by managing the braking force on each wheel).

As a result of the measurements on the worn surface of the inner brake pad holder, the profile of the wear can be contoured (in the radial direction from the hub to the outside). There is thus slower wear on the edges and very pronounced towards the inside, having two maximum zones, figure 4.

a)

b)

Figure 2. Excessive wear of the interior brake pad a)Top view; b)Side view

Figure 3. Wear on the brake disc and brake pads

The central area shows traces of thermal overload. In most cases of advanced wear, both the disc and the plates form a strip on the outer edge where wear is slower. A border is often formed at the edge of this area as shown in figure 3. This means that the edge of the disc remains a very narrow strip but much higher than the surface of the brake disk. This can be explained by the fact that the heat transfer is very active on edge, which also reduces wear. In the central area of the disc the temperatures are high, so the wear is high and decreases in the radial direction towards the hub.

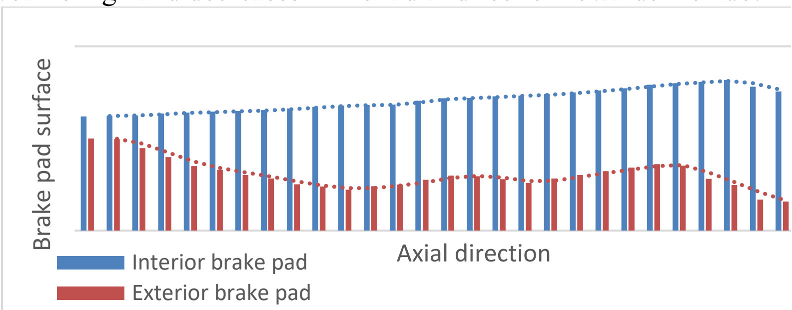

Figure 4. The wear profile of the left rear brake pads after a run of 225,538 km

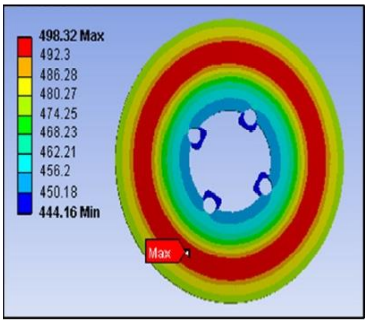

Figure 5. Temperature contours in °K [9]

A similar profile is also obtained in the measurement of the brake discs, estimated by measuring the wear profile in a radial direction from the hub to the outside, figure 6. The measurements were carried out on a truck run exclusively in Romania with 444,476 km. Again, there is more pronounced wear on the inner part, which decreases in intensity towards the extremities. This confirms that the heat flow propagates through thermal conductivity from the plates and disc, to the hub and then to the other parts, and by convection and radiation from the parts to the air. The wear profile also fits with the mathematical model in the study [9], the maximum wear being in the area of the maximum temperature indicated in the study as it shows in figure 5. In [9] maximum temperature zones, they correspond to the maximum pressure zones.

Increased wear of the inner part may be due to the fact that the inner brake pad is pressed directly by the piston but, to operate the outer brake pad, it is necessary to move the caliper on the guide bolts, which is not monitored by the sensors and which is often suppressed due to mechanical defects or the influence of external factors. Also, no wear on the disc is monitored by any sensor. This can pave the way for a system to monitor both the brake disk wear and the brake caliper mobility on its bolts. Identifying such solutions would significantly contribute to reducing the cost of premature wear of parts of the system.

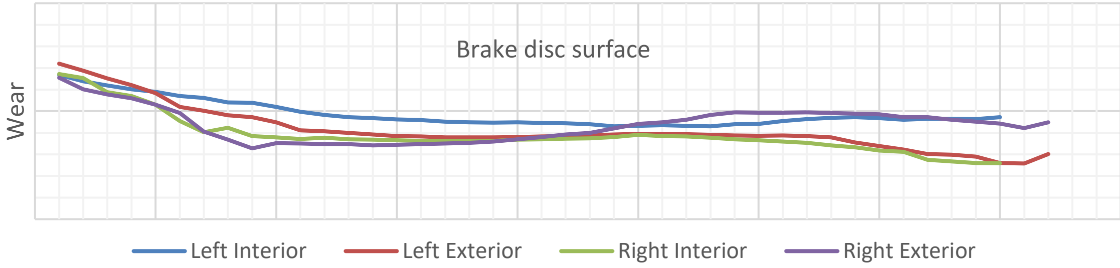

Figure 6. Wear profile on the surface of the brake disk

Another aspect of the data analyzed shows that around 60% of cases, brake pad wear is significantly higher on the right, figure 7. Data from 55 trucks sorted by different criteria was analyzed. This aspect of more pronounced wear on the right side could be explained by the fact that the road has a slight inclination to the right. In the literature of road construction, in alignments, the inclination of the transversal profile (road inclination and sloping) is right to the right direction and is currently 2% - 2.5% [8]. Road inclination must have the normative value because an insufficient incline leads to slow drainage of water from the road, which can lead to loss of adhesion at high speeds. In this case, when decomposition of the weight, on the right wheel comes to a further force of pressure, the effect of which is observed in the wear process.

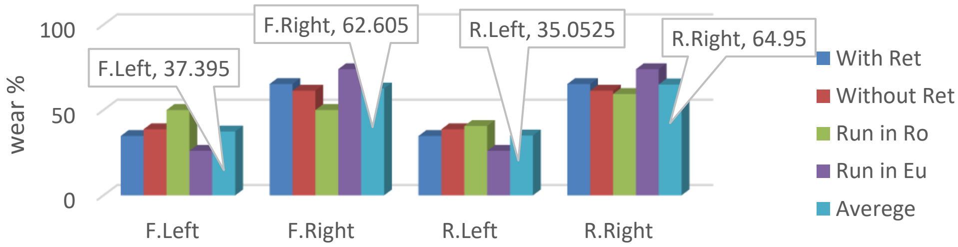

Figure 7. Situations in which the wear is higher on the right side [%]

Removing wear differences on each wheel is a challenge and is a necessary measure to reduce maintenance costs because when wear differences more significant than 10% have been reported, the life of the set on the deck decreases with at least 15%. Also, depending on how late the problem is detected, the brake discs can be affected in various forms (scratches, deformations, or cracks due to thermal overload).

Figure 8. Abrasive and thermal overload (truck without retarder)

Figure 9. Corrosive wear 132,000 km / 2 years

Figure 10. Cracks caused by thermal overload

During the study, it was found that abrasive wear, corrosion wear and wear due to thermal overload figures 8 to 10 have a significant frequency in influencing the premature removal of brake pads and discs. In some cases, figure 9, worn plates at 80% of the capacity have been replaced due to the high degree of decomposition due to superior corrosion. At this stage, the wear is exponential, and the traffic safety conditions are no longer met.

5. Conclusions

Commercial vehicles are sophisticated vehicles that, in addition to the increased gauge, frequently circulate with heavy loads on the same runways as cars. However, the braking systems fitted to trucks must respond promptly to operating requirements, be as economical and sustainable as possible and comply with, or even contribute to improved traffic safety.

Infrastructure and external factors have a significant impact on braking system usage and implicitly on maintenance costs. On the one hand, the average inclination of national roads, in the absence of highways, is much higher and leads to an increase in the number of brake applications and on the other hand these conditions make the driver a significant factor influencing the durability of the brake pads by the adopted driving style. Another aspect is corrosion and abrasion, favored by moisture, mud, and anti-skidding on the road. These types of wear have the highest frequency at the studied trucks.

The presence of an auxiliary braking system is all the more significant as the maximum braking force is more considerable. The importance of an auxiliary braking system is most noticeable for vehicles frequently traveling on highways, with the use of the same set of brake pads exceeding an average of 450,000 km. Also, the presence of an auxiliary retarder system almost eliminates overloading of the braking system and greatly reduces maintenance costs.

The faster wear of the brake pads on one of the truck's axles is conditioned by operating factors such as load and distribution of the load in the semi-trailer and road conditions. The different wear of the brake pads on the same axle has as its main causes, mechanical defects (primarily the brake caliper) most frequently caused by deposits and corrosion. More substantial wear on the right side of the brake pads (in a significant percentage) may be caused by the right-hand slope of the road (according to the design standard). It is also to be noted that the increased wear of a single brake pad or uneven wear leads to a drastic decrease in the durability of the whole system.

As a way to prevent local overloads caused by blocking the mobility of the brake caliper or pads, a monitoring system for both caliper mobility and disk status would be useful. This could increase traffic safety and reduce maintenance costs.

6. Acknowledgments

The practical part of the paper and the data acquisition took place at RMB Inter-Auto, dealer, and Mercedes-Benz partner.

References

[1] Elgharbawy M., et al., Adaptive functional testing for autonomous trucks*, International Journal of Transportation Science and Technology*, 2018.

[2] Duan J., et al., Driver braking behavior analysis to improve autonomous emergency braking systems in typical Chinese vehicle-bicycle conflicts, *Accident Analysis and Prevention* **108** 2017, 74–82.

[3] Vdovin A., et al., A coupled approach for vehicle brake cooling performance simulations, *International Journal of Thermal Sciences* **132,** 2018, 257–266.

[4] Hatam A., Khalkhali A. Simulation and sensitivity analysis of wear on the automotive brake pad, *Simulation Modelling Practice and Theory* **84**, 2018, 106–123.

[5] Blau P.J., Jolly B.C.: Wear of truck brake lining materials using three different test methods. *Wear* **259**, 2005, 1022–1030.

[6] Adamowicz A., Grzes P.: Influence of convective cooling on a disc brake temperature distribution during repetitive braking. *Therm. Eng*. **31**, 2011, 2177–2185.

[7] ***Daimler Media Website and Xentry portal, www.media.daimler.com, last accessed 09.09.2018.

[8] ***National company for road infrastructure administration, *Road technical bulletin*, no **12**/2011.

[9] Dhir D.K.,: Thermo-mechanical performance of automotive disc brakes. *Materials Today Proc*. **5**, 2018, 1864–1871.