ON PREDICTION OF MOTOR VEHICLE BRAKE PAD WEAROUT

Maris Gailis, Dainis Berjoza
Latvia University of Agriculture
maris@electromobile.lv

Abstract. During vehicle maintenance some components, such as motor oil and filters are replaced when a certain period of time has passed or mileage reached. The braking system components which are subject to friction and wearout have to be replaced when certain minimal thickness is reached. Manufacturers of vehicles provide information about the initial and minimal size of braking components. It is a rare situation if the brake pads or discs are found at minimal thickness during inspection at scheduled maintenance. In the real aftersales workshop conditions mechanics have to evaluate the condition of the brake pads and discs and determinate whenever to propose replacement of either component. Dynamics of wear of brake components on vehicles differ from the front or rear axle and inner or outer pad. Correct prediction of the service life can reduce the maintenance costs and probability of unexpected vehicle breakdown. The service life of the brake components depends on many conditions, such as the vehicle model, type of road, style of driving etc. The road conditions in Latvia differ from other European countries with high ratio of unpaved roads. Some of the vehicles sold in Latvia have maximum maintenance periodicity up to 40 000 km but brake pads are wearing out at 30 000 km. Therefore, a correct model of prediction of brake component wear for the local conditions can only be based on the data collected from the local data sources. The paper presents a model of the service life of brake components for 3 different types of vehicles manufactured by the French automobile producer Renault. The model is based on regression analysis of the data collected at workshops of the manufacturer's official dealerships. The samples were selected from the vehicles belonging to randomly chosen owners to include most of population.

Keywords: automobile, periodicity, maintenance, brake systems.

Introduction

Maintenance of automobiles is a set of diagnostic and replacement operations that are performed with certain periodicity. Maintenance operations should be designed in a way that ensures a sufficient level of reliability, safety and comfort. Keeping the exploitation parameters on a certain level is connected with the expenses which are paid in full by the user or owner of the automobile.

The automobile market in Europe certainly belongs to the type where the customer is the king. Citizens of some African or Asian countries probably do not have much to choose from the available automobile brands or workshops, but in Europe the situation is quite different. To remain in business, the product itself, image, aftersales experience and all the costs should be comparable and similar to the competitor costs within the same class. That is the reason why benchmarking is so developed in automobile industry.

The trend to prolong maintenance periodicity started in Europe at the very end of the 20^{th} century. At the moment of writing this article, typical maximal periodicity for visiting workshops to perform maintenance operations for a light passenger automobile of M category from European producers, sold and serviced within the EU, is up to 30 000 km. For commercial vans of the category N1 the manufacturers recommend periodicity of maintenance up to 40 000 km.

To reach such periodicity, the vehicle must be designed in a certain way and must be equipped with air and fuel filters of large capacity. Usually the manufacturer recommends adjusting the periodicity of maintenance according to the conditions of the vehicle use. Normally, adjusting means shortening of the mileage between inspections and replacement of certain elements, such as engine oil and engine air filter.

It is hard to evaluate the exact condition of filters, engine oil or coolant without use of special testing equipment or chemical analysis in laboratory. Consequences of exceeded mileage of the use of a typical maintenance element do not always reveal immediately.

The automobile braking system has a specific maintenance program. There is periodicity, recommended by the manufacturer, for replacement of braking liquid, checking and adjusting of handbrake and cleaning and adjusting of rear drum brakes. The parts of the automobile braking system, that are subject to rubbing and therefore wear out, have to be checked during scheduled maintenance and replaced if necessary. With extended maintenance periodicity it is becoming hard for the mechanics, performing servicing, to determine should the brake pads must be replaced or they will last till the next scheduled visit. Overestimated remaining resource may lead to sudden failure of the brake pads, and as a consequence, breakdown of the vehicle and possible damage of other parts of the braking system, such as the brake disc and caliper piston. Underestimating of the remained brake component service life will increase the exploitation costs and negative impact on environment. Both described outcomes are highly undesired and must be avoided by using a prediction technique, which is both precise and simple enough to be used in automobile workshop conditions.

Modeling of brake pad wearout for rail vehicles, using the analysis of regression is described in [1]. Rail vehicles are used in more predictable and stable conditions, for instance, the rail track is normally never unpaved or covered with mud. An insight into the modern brake system technology, challenges and tribology is well described in [2]. The maintenance of the frictional mechanism and importance of wear balance is discussed in [3].

Materials and methods

To evaluate the dynamics of automobile brake pad wear and look for a possibility to predict periodicity of inspection, field data were collected. Three different models and modifications of vehicles produced by the French carmaker Renault S.A.S. were chosen:

- Trafic II
- Master III, front wheel drive;
- Master III rear wheel drive, twin wheels.

The vehicles have a decent market share in Latvia. All selected samples that are sold and used in Latvia were serviced at official dealers. Only genuine brake system spare parts were used.

Brake pad wear was measured at each replacement. To gather information on the dynamics of wear, measurements of brake components, subjected to wear, were conducted during regular servicing or repairs of suspension. Measurements of pad thickness were made using a vernier caliper at four points and included backplate. As used pads are oxidized, with rough surface, precision of the measurement was not very high. For each measurement session, the mileage since previous pad replacement was noted. The data were prepared using spreadsheet software Microsoft Excel and regression analysis performed, using software package IBM SPSS.

Results and discussion

Genuine brake pads for the automobile Renault Trafic II currently are being manufactured by the company Federal Mogul, brand Ferodo. The pads are not equipped with the brake pad wear indicator. The thickness of the new brake pad, including the backplate is 18 mm for front pads, 17 mm for rear, minimal thickness is 9 mm. The thickness of the backplate is 7 mm [4]. Graphical representation of the brake pad wear data and regression plots is shown in Figure 1.

To evaluate correlation between the mileage and pad wear, the analysis of liner regression can be used. Linear regression plots show that there is difference of the wear rate for inner and outer pads. The wear rate of inner pads is higher on both front and rear axles. So, the brake pad wear is not balanced and not optimized for the abrasive polluted road conditions in Latvia.

The automobile Renault Master III is fitted with brake pads, manufactured by the Continental AG. The vehicle can be built with front or rear wheel drive. Rear wheel drive may have twin or single wheels. Though the vehicle is equipped with advanced electronically controlled brake pad wear warning system, it does not perform well in the local Latvian conditions. Sensor wiring is often damaged and cut by chips and stones from unpaved roads. Only inner pads are fitted with sensors, but the wear rate is greater on outer pads for the rear wheel drive version with twin wheels. The thickness of the new brake pad, including the backplate is 18 mm for all pads, minimal thickness is 10 mm. The thickness of the backplate is 7 mm [5].

Graphical representation of the brake pad wear data and linear regression plots for Renault Master III are shown in Figures 2 and 3.

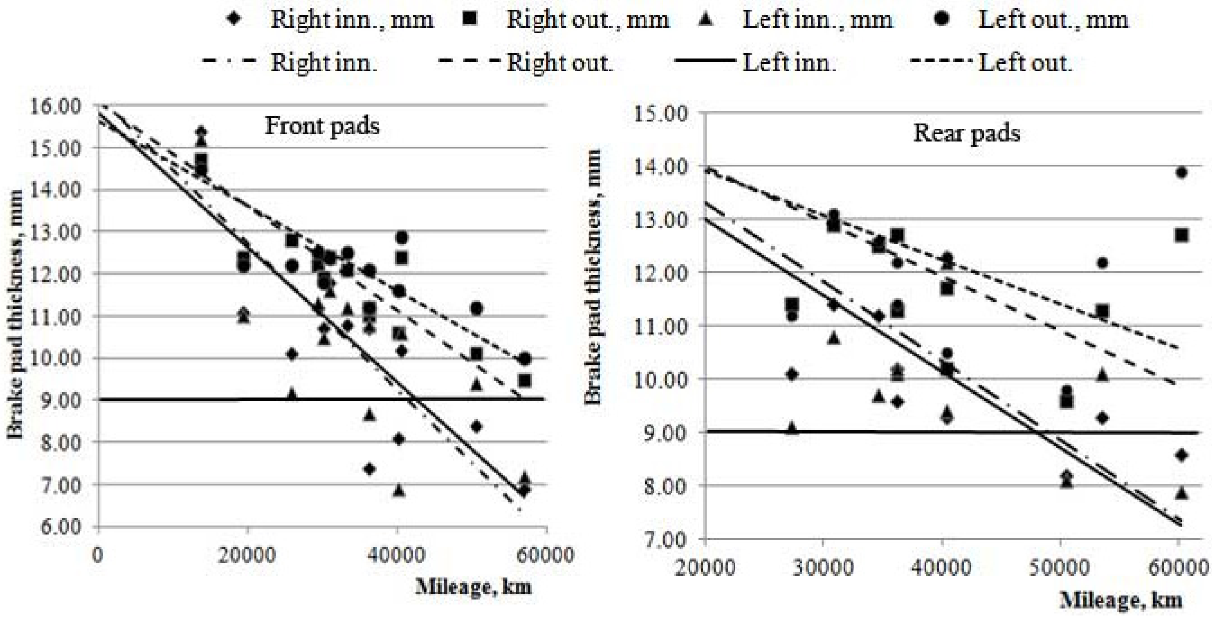

Fig. 1. **Brake pad wear data, Renault Trafic II**

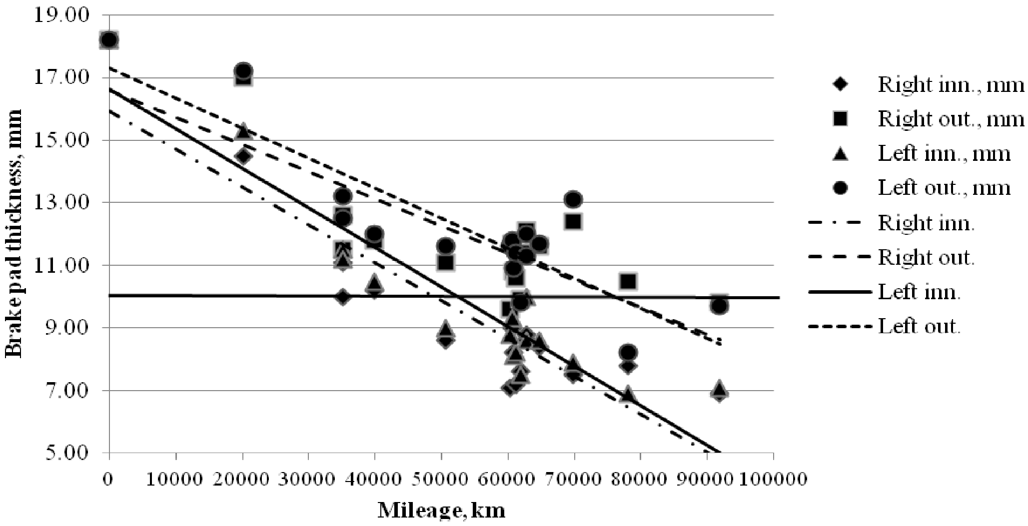

Fig. 2. **Brake pad wear data, Renault Master III, front pads**

As the regression plots show, brake pad wear is not balanced for the tested vehicle types. Inner our outer pads are wearing faster, depending on the vehicle type. As fail of one pad means fail of all braking system, prediction must be based on the data from the pad set of higher wear rate. As stated by other authors, brake pad wear is a stochastic process [1 – 3]. The wear rate depends on the road conditions, driving style, design, market specification and technical condition of the automobile. The main cause of wear normally is frictional braking. It is hard to measure the exact amount of braking, so wear rate can be attributed to mileage.

Using tools for statistical data analysis, such as Microsoft Excel or IBM SPSS, equations of regression can be generated [6]. These empirical equations may be used for obtaining mean service life of brake pads and to predict the remaining service life of brake pads on a specific vehicle during scheduled maintenance or brake pad inspection.

$$y = b_1 x + b_0 ; \tag{1}$$

where x – mileage, km;
y – thickness of brake pads, mm;
b_0 – coefficient of intercept;
b_1 – coefficient of slope.

To judge the adequacy of the regression model, the simplest way is to calculate the coefficient of determination R^2. If the value of the coefficient of determination is close to 1, there is significant correlation between two parameters of linear regression. The coefficient of determination can also be used to evaluate the ability of the method of linear regression to describe variations of dependable parameters. For instance, 80 % of traffic rear right inner brake pad wear rate data can be explained by mileage. Analysis of residuals, F-test and t-test also can be used to validate the model, based on the regression analysis [7].

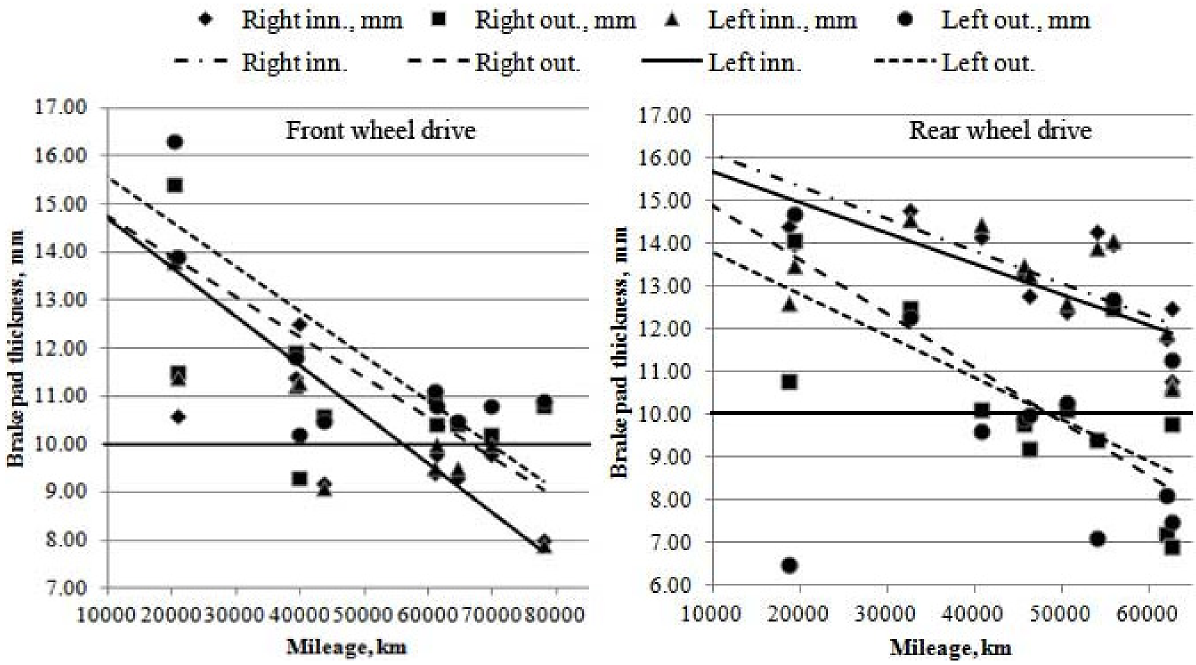

Fig. 3. **Brake pad wear data, Renault Master III, rear pads**

Using equations of regression, the mileage can be calculated, at which brake pads with higher wear rate may reach minimal thickness. At given mileage, the interval of individual confidence of the brake pad thickness can be calculated; using the method described in [6] or tools of software package IBM SPSS. The interval was calculated for probability of 9 5%. That means, 95 % of brake pads of the same type, used in similar conditions as the collected samples, will reach the thickness within the given interval at the predicted mileage. The values of regression coefficients, predicted mileage and confidence intervals of the pad thickness are shown in Table 1. Graphical presentation of the results for the vehicle Renault Master III, front right internal brake pad wear is shown in Figure 4.

Table 1

Results of linear regression analysis

Parameter	**Trafic II front pads**	**Trafic II rear pads**	**Master III front pads**	**Master III FWD rear pads**	**Master III RWD rear pads**
Higher wear rate, pad	Right internal	Right internal	Right internal	Left internal	Right external
Coefficient R^2	0.758	0.798	0.831	0.768	0.690
Coefficient b_0	16.267	16.160	15.932	15.703	16.182
Coefficient b_1	$-148 \cdot 10^{-6}$	$-173 \cdot 10^{-6}$	$-121 \cdot 10^{-6}$	$-102 \cdot 10^{-6}$	$-127 \cdot 10^{-6}$
Predicted mileage, km	49101	41387	49025	55912	48677
Lower *CI* of pad thickness, mm	5.851	6.181	7.358	6.825	6.256
Upper *CI* of pad thickness, mm	12.139	11.850	12.606	13.175	13.779

The confidence intervals of the brake pad thickness at the predicted mileage are wide, with lower limit even below the thickness of the backplate for most types tested. That means, a certain amount of brake systems will fail if periodicity of inspection will be predicted using the presented method. For the future work, prediction of brake pad inspection periodicity based on the theory of reliability should be created and evaluated.

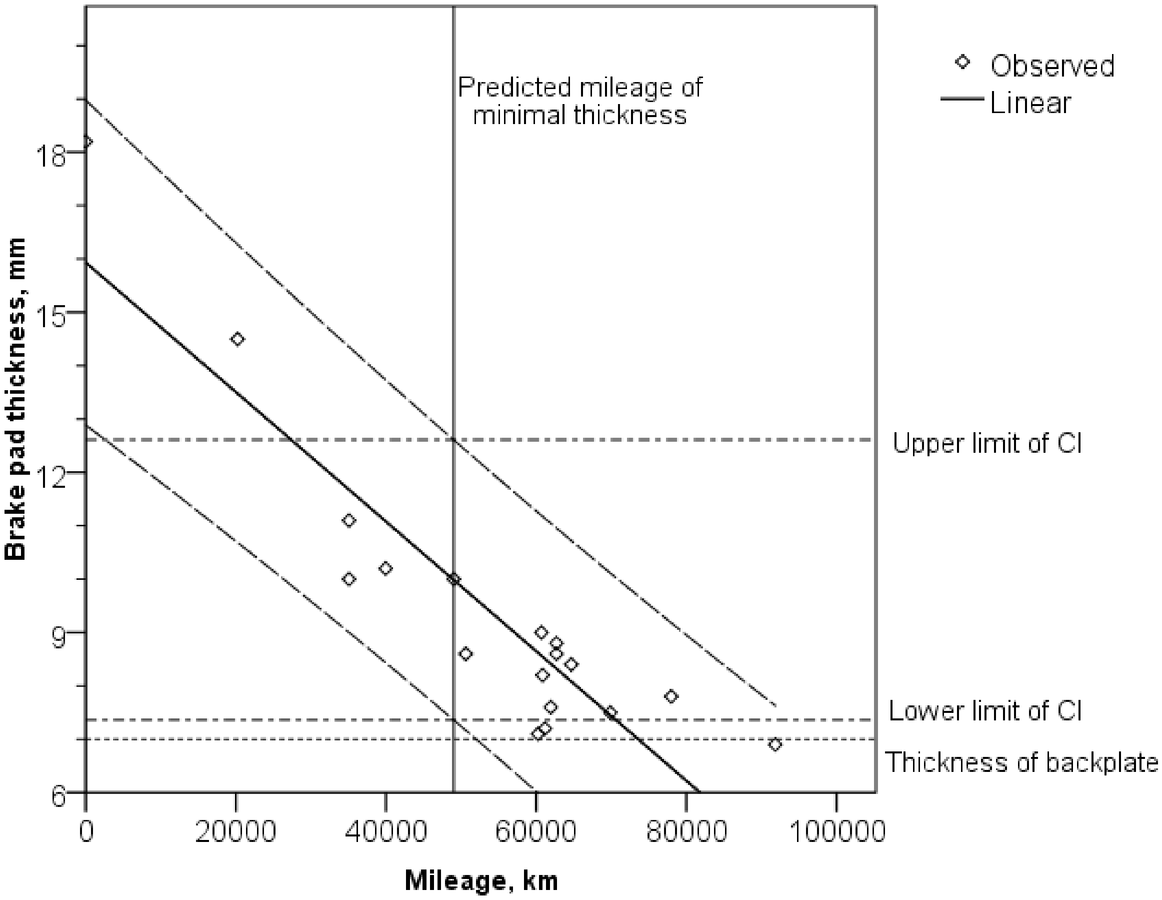

Fig. 4. **Results of prediction, Renault Master III, front inner pad**

Conclusions

1. Wear of frictional elements of the braking system is a process with a stochastic nature, but it can be attributed to mileage.
2. Wear of the brake pad set may become unbalanced depending on the local conditions of use.
3. On the observed vehicle types with single wheels the inner brake pads have higher wear rate.
4. The brake pad wear indicator for Renault Master III with rear twin wheel drive is fitted on the pad with lower wear rate; therefore, the warning system cannot work properly.
5. The analysis of linear regression can be used to describe the wear rate of automobile brake pads.
6. Average mileage of the brake pad service life in Latvia for modern Renault vans is within 40 000 – 50 000 km.
7. The observed variance of the data does not allow acceptable prediction of brake pad wear, using modeling based on linear regression.

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