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RESEARCHING THE INFLUENCE OF THE BRAKE SYSTEM CONFIGURATION ON VEHICLE'S BRAKING PARAMETERS

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INTRODUCTION

The following statements are suggested as the advantages for the application of the disk brakes [5, 11]:

- the friction surface is exposed to the air, which ensures good heat dissipation and minimizes brake fade,
- this exposure also enables reduction of the friction coefficient change as water/moisture and dirt are thrown off more efficiently,
- smaller gabarits,
- driver gets more realistic picture of the vehicle's braking characteristics due to the fact that the dependence of the achieved braking force upon the pressure within the braking system is almost linear,
- easy and quick replacement of the braking pads- thus the easier maintenance.

As the disadvantages one can mention the lack of self-energizing action present in the drum brakes, which affects the disk brakes in the following way: in order to obtain adequate braking force the working cylinder of the greater diameter is needed, as well as the more complex construction of the parking brake mechanism. Also there is the issue concerning the price of the disk brakes .

The need for increased cooling of disc brakes led to the development of vented rotor discs, anyhow the advantages of vented discs over solid discs is the subject of some conjecture. The primary advantage of vented rotors is increased heat dissipation from internal pumping of air, however, under slow speeds the pumping action of the vanes is minimal and only becomes pronounced as the rotor speed increases [12]. At higher speeds the airflow flowing around the disc as a result of the forward movement of the vehicle, tends to prevent effective pumping of air through the vanes [12].

Friction coefficient between the braking pads and the disc was calculated according to the results of the experimental research and is described by the expression [14,15,16] that shows the immense influence of the temperature:

$$\mu_p = 0.512 pp^{-0.047} v^{0.012} \theta^{-0.046}$$

where:

- *pp* – pressure given in bars measured in the front braking line [bar]
- *v* – speed of the vehicle [km/h]
- θ - temperature [°C].

Adequate heat dissipation from brakes is very important in order to achieve vehicle's good braking characteristics. The heat dissipation depends on the airflow in the zone that necessitates cooling. The airflow within the zone of braking actuators is very hard to mould under lab conditions because it depends on the shape of the vehicle. Thus the decision was made to conduct experimental research on the special runway for the purpose of comparing the temperatures on brake actuators used in solid disk brakes and brake actuators used in vented disk brakes respectively.

One can find in the specialized literature a great number of papers that deal with the issue of ABS braking system efficiency as well as with braking characteristics of some vehicles that are equipped with a particular type of ABS [7, 8, 9]. However there are only few papers whose subject is a comparison between braking performances of the vehicles that are equipped with different types of brake system configurations, respectively. The aim of this paper is to try to make a comprehensive overview of the above mentioned issue and to perform and present the experimentally obtained results.

The analysis of the experimentally obtained results concerning braking process is a very complex one due to the dynamic nature of the process itself. This problem – the problem of the complexity regarding the analysis of the influence of the particular values on the output value, which is in this case vehicle's velocity, is further complicated in the case where the various configurations of the brake systems should be taken into consideration.

Due to, Demparcoh software was used for the purpose of data processing . This software is intended for identification of mutual relations in dynamic systems when there are multiple inputs and outputs and the mutual dependence of the input values is probable. The software is interactive and contains the necessary explanations, thus it will not be further discussed in this paper. The mutual dependence of the input values is excluded.

EXPERIMENTAL RESEARCH

In the previously published papers [1,2,10] the vehicle used in the experiment is thoroughly described, as well as the experiment itself.
The vehicle has very good braking characteristics even without ABS and achieves deceleration in compliance with the regulations of 5.8 m/s^2 and with the brake pedal force of 174 N continuously, when the vehicle is ready for driving and with 1 driver i.e. total weight is 1020 kg. For the fully loaded vehicle i.e. 1350 kg total weight, the brake pedal force should be 232 N [13]. However since the time till full halt in an ABS equipped vehicle depends on the initial reaction of the driver (more detailed information in [2]) and that during the experiment the magnitude of the initial speed was not strictly taken as the signal for the beginning of braking, thus for the sake of comparison of the vehicle's achieved speeds, the values shown in the diagrams are slightly smaller than the values of initial speeds.
In order to make an adequate comparison of the vehicle's braking parameters, the disc brakes characterized by the following features were used: the working cylinder diameter of the brake, outer brake disc diameter and active radius of the braking effect were identical. Identical braking pads were also applied. The clamp had to be additionally modified when

the vented disc was used (disc width 19 mm, the width of the paddle slot 6 mm) because of the difference in width between the vented and the solid disc brakes.
The following measurements were taken: time measured from the beginning of the braking action, the speed of the vehicle, brake pedal force, the pressure of the working fluid within the brake lines directed to the left front wheel, the pressure of the working fluid within the brake lines directed to the rear wheels in front of the braking corrector, the angular speed of each wheel and finally temperature on the front left wheel disk. Throughout the measuring, we made pauses for brakes cooling. The FADE test was also conducted according to the rules and regulations of the technical documentation of Zastava automobili, i.e. Research and Development Center [13], which is morestringent than ECE 13 rulebook.

From the aspect of examining the correlations between the different brake system configurations it is very important to perform measuring, concerning the already mentioned vehicle, when the vehicle's ABS is turned on as well as when it is turned off in the following cases:

- front axle- disk brake; rear axle – drum brakes;
- both front and rear axles - disk brakes;
- front axle - vented disk; rear axle – drum brakes;
- front axle - vented disk; rear axle - disk brakes.

For all brake system configurations the following measurements were taken in the following cases:

1. initial speed 80 km/h till halt for a vehicle carrying 2 passengers and 20 kg luggage
2. 2. initial speed 80 km/h till halt for a vehicle carrying 5 passengers and 50 kg luggage
3. initial speed 140 km/h till halt for a vehicle carrying 2 passengers and 20 kg luggage
4. initial speed 140 km/h till halt for a vehicle carrying 5 passengers and 50 kg luggage.

For the purpose of the illustration only, and due to the lack of space, experimental results for one case of initial speed and one loading state of the vehicle braking with its ABS turned on will be presented in this paper. So, on the pictures 1,2,3,4 are shown measured values for the vehicle carrying 2 passengers and 20kg of luggage from 80 km/h till full halt-driver M.

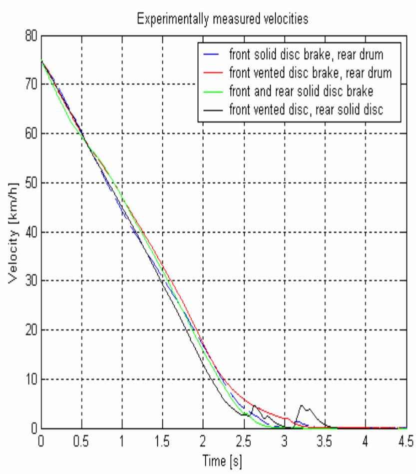

Figure 1:*Experimentally measured velocities*

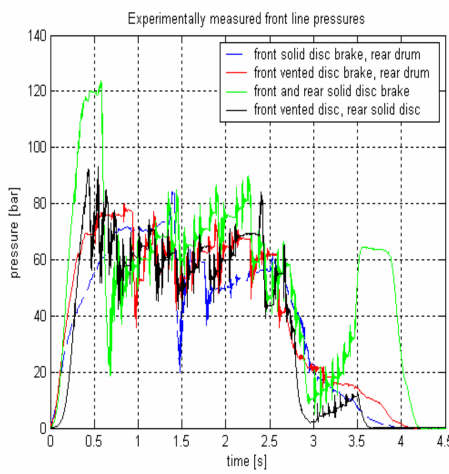

Figure 2: *Experimentally measured front line pressures*

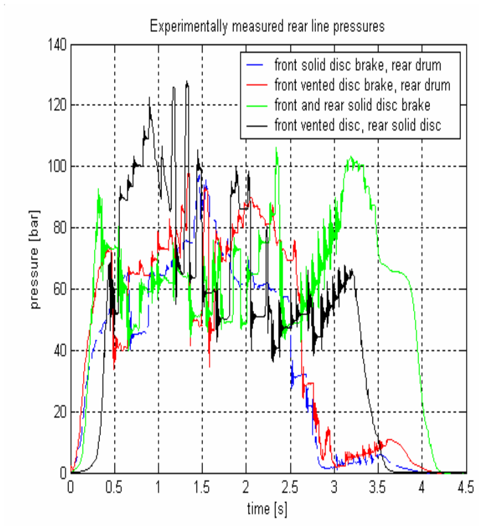

Figure 3: *Experimentally measured rear line pressures*

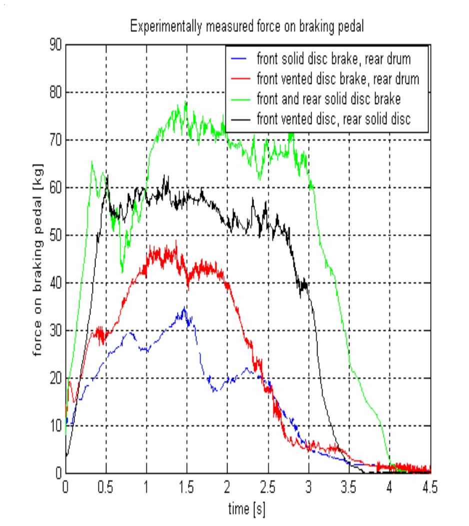

Figure 4: *Experimentally measured force on braking pedal*

Figures 5 and 6 show contiguous diagrams for the achieved temperatures during the braking process implemented within the FADE test framework, for the vehicles equipped with vented or solid disk on their front axle, while drum brakes are mounted on the vehicles' rear axle in both cases.

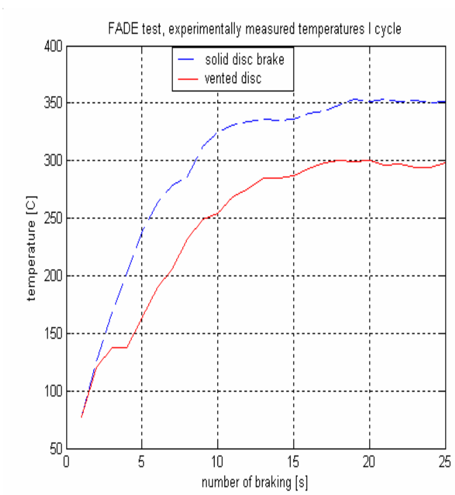

Figure 5: *FADE test – I cycle*

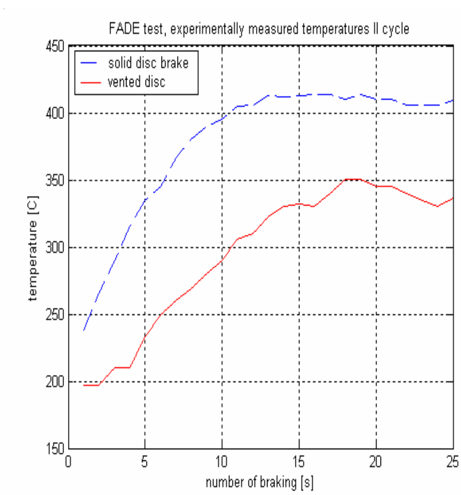

Figure 6: *FADE test – II cycle*

It is evident from the Figures, that the temperature of the brake actuator is significantly higher for the solid disk. In order to determine the degree of decline the vehicle's braking performances, which occurred due to the increase in temperature in brake actuators, additional measurements were taken.

After the 25 braking cycles were completed during the second test, the vehicle was sped up to the velocity of approximately 140 km/h (initial braking speed deviation is within permitted limits). As it has been previously mentioned in this paper, the implemented research procedure is much stricter than the one prescribed by the ECE regulations. Again, the braking action was done as if it were panic braking. The results of these measurements are given in Figures 7-10. According to the speeds measured during the braking action, the declarations were computed for this 26th braking that belongs to the second FADE cycle and are given in the Figure 11.

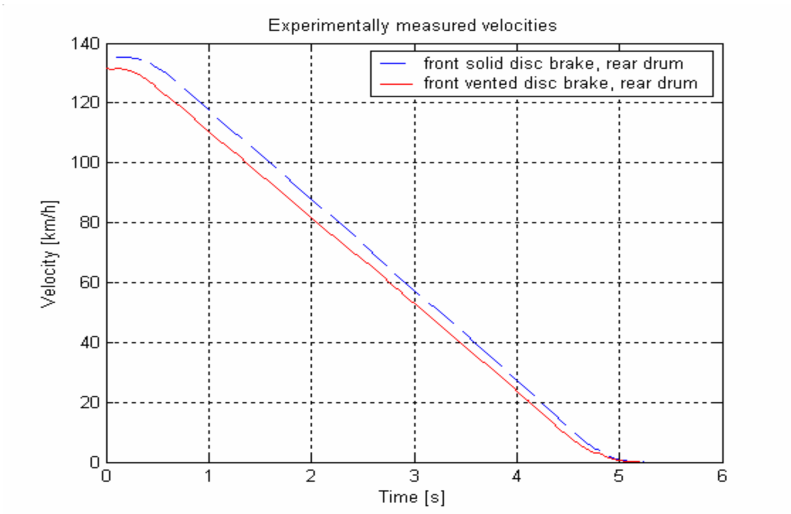

Figure 7: Measured velocities at the initial speed 140 km/h with 5 passengers and 50 kg lugg. driver Z

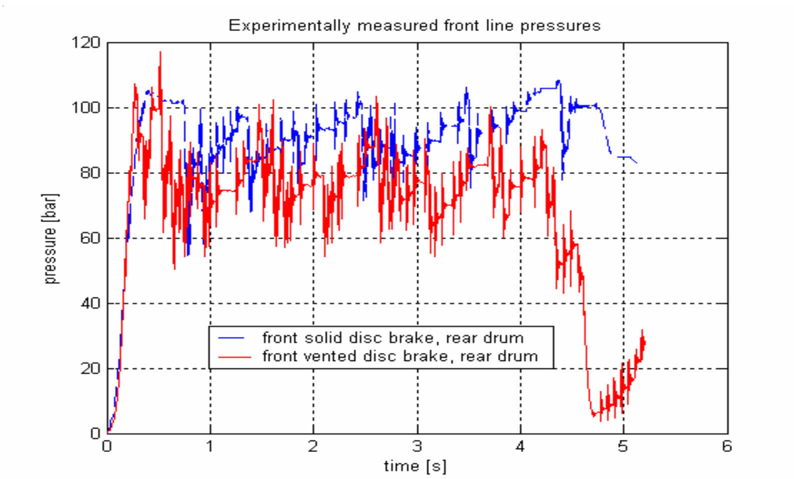

***Figure 8:** Front link pressures at the initial speed 140 km/h with 5 passengers and 50 kg lugg. driver Z*

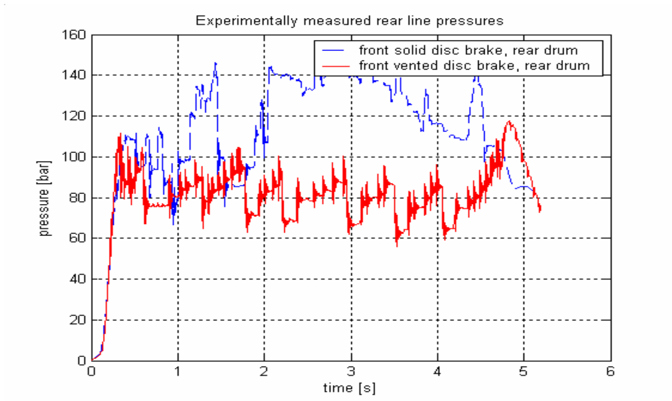

Figure 9: *Rear link press. at the initial speed 140 km/h with 5 passengers and 50 kg luggage driver Z*

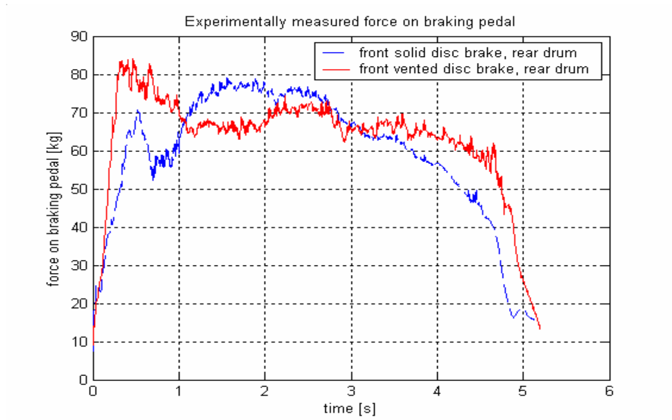

Figure 10 : *Measured forces on pedal at the initial speed 140 km/h with 5 passengers and 50 kg lugg driver Z*

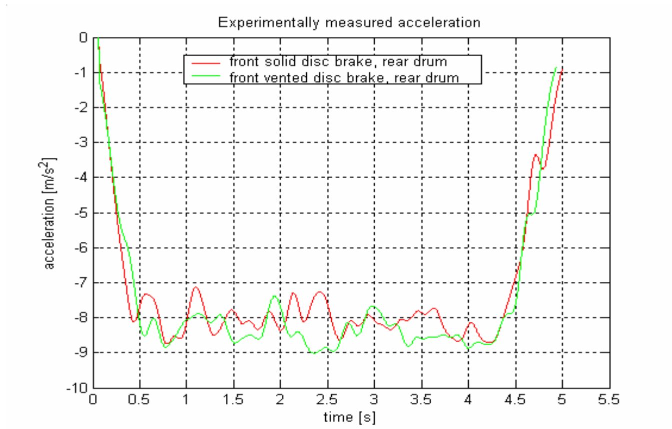

Figure 11

CORELATIVE RELATIONS INSIDE THE BRAKE SYSTEM

Due to the shape of the curves represented on the diagrams it is very hard to draw the conclusion about the influence of the particular values on the system's output value, in this case the velocity of the vehicle. This problem is further complicated by the fact that the force on the brake pedal was not constant for the different conditions during the experiment.

In order to analyze the influence of the measured values on the speed of the vehicle, the partial coherence functions on the braking pedal force and the pressure of the front and rear lines for the output value of the vehicle's speed will be shown. Demparcoh software was used for the purpose of data processing.
For the purpose of the clear overview of the diagram, and due to the lack of space, only the comparative results of the two cases of different initial speed and one loading state of the vehicle braking with its ABS turned on will be presented in this paper.

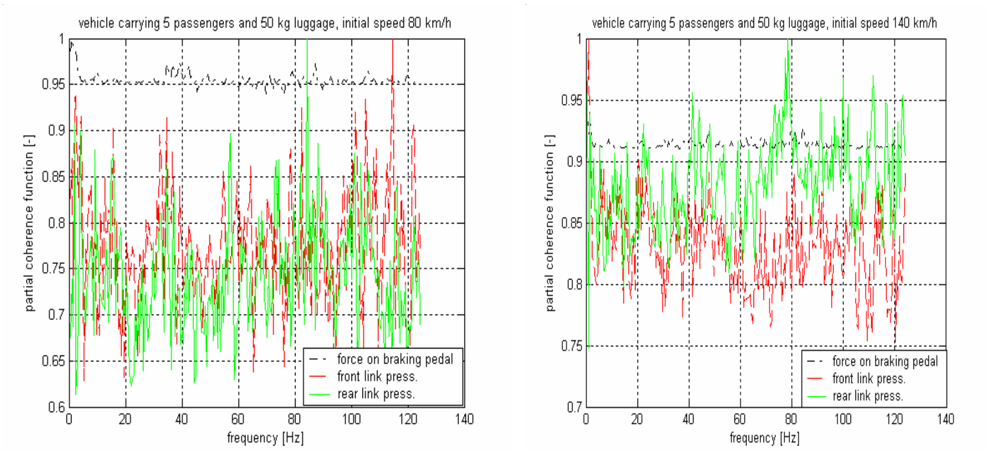

***Figure 11**: Partial coherence functions for vehicle with front solid disk, rear drum brakes*

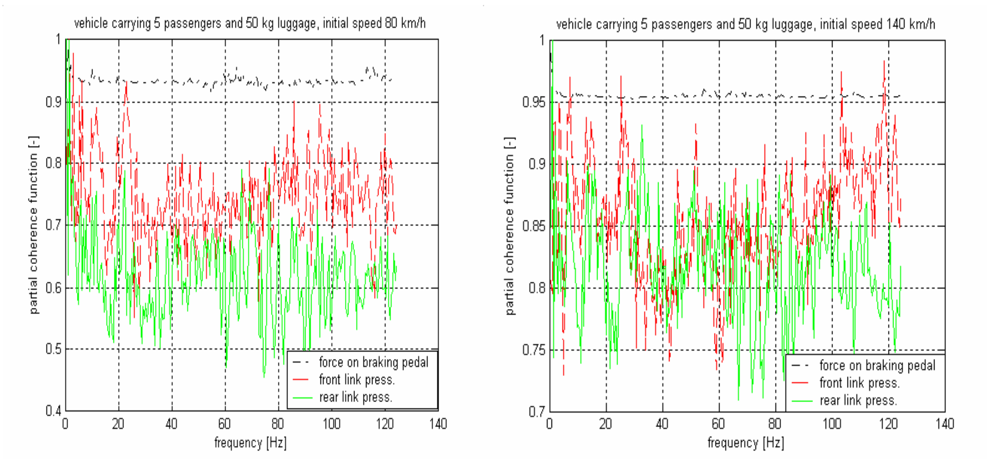

***Figure 12**: Partial coherence functions for vehicle with front and rear solid disk brakes*

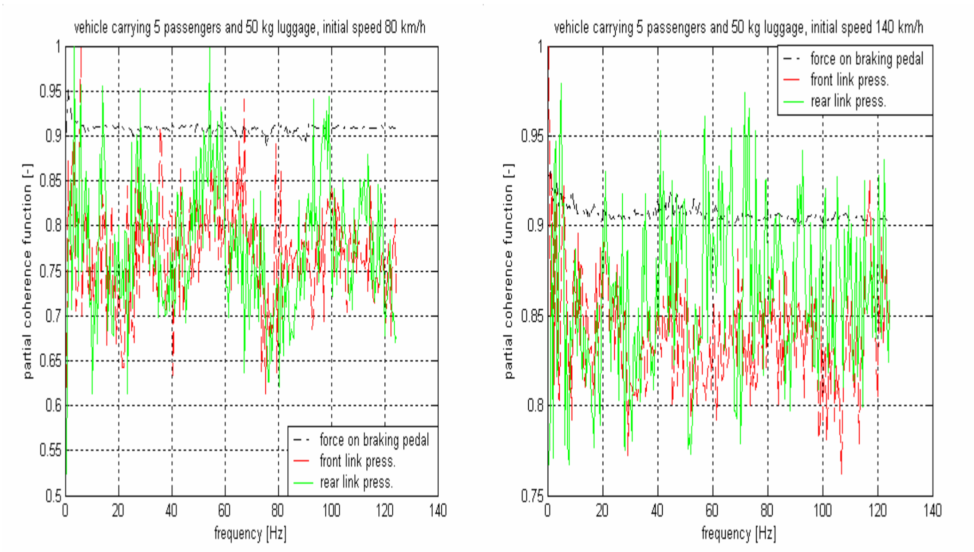

Figure 13: *Partial coherence functions for vehicle with front vented disk, rear drum brakes*

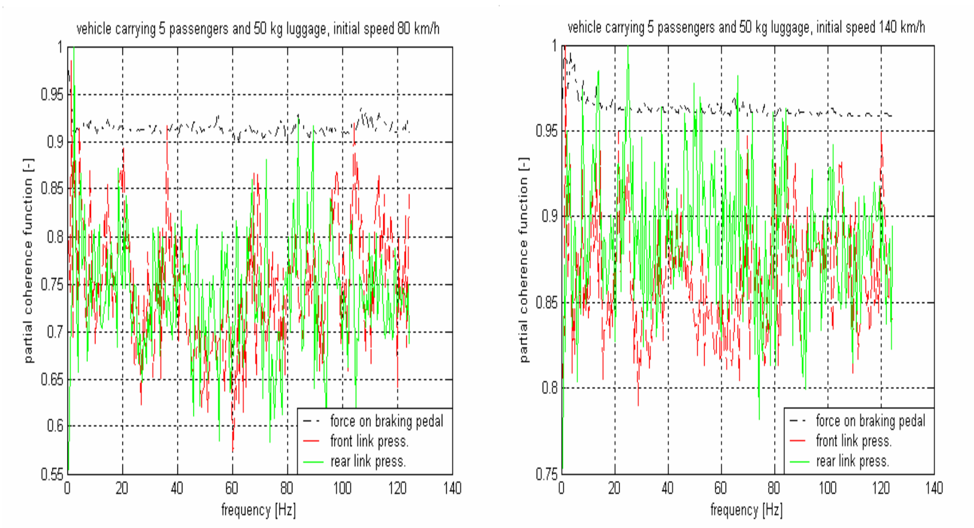

Figure 14: *Partial coherence functions for vehicle with front vented, rear solid disk brakes*

CONCLUSIONS

From the figures 11 – 14 we can conclude that, concerning the value of the partial coherence functions, there is a significantly large dependence between the vehicle's velocity and the force exerted on the brake pedal as well as the pressure in the brake lines.

The influence of the force exerted on the brake pedal is the smallest for the vehicle that has vented disk brakes in front and drum brakes on the rear. This is a logical result since the mean pressure values achieved in the front wheel brake installation, when the vented disk was mounted on the front axle, were smaller than the mean values of the pressure measured in other cases where the front brakes were solid disk brakes [1]. Due to the operating mode and the dependence of the braking force upon the input pressure for both disk and drum brakes, when the drum brakes are mounted on the rear axle the smaller force that acts on the pedal is needed.

The influence of the brake pedal force and the pressure in the front braking system for vehicles with different brake on the rear axle installation does not differ greatly. For the loaded vehicle, the influence of the pressure in the vehicle's rear braking system installation on the speed of the vehicle, is greater when the drum brakes are in the rear.

The advantages of the vented disks are not significantly distinguishable during a single panic braking [3]. The substantial advantages of vented disk brakes are clearly distinguishable during FADE test. The achieved results point to a fact that in the conditions of repeated braking actions, vented disks achieve better results. From the Figures 5 and 6 one can see that the temperature of the vented disk brake pad is much smaller than the temperature of the solid disk pad when both are found under the same experimental conditions. During the experiment a 10 minute pause between the first and the second measurement phase was made. It is interesting that both types of brakes cooled off for approximately 100°C. This is due to the fact that the thermocouple was placed on the braking pads that are made of identical material and possess identical characteristic, also when the vehicle is not in motion these brake pads do not touch brake disks. However, one can see from the Figure 6 that the solid brakes showed more rapid increase in temperature in the first 5 seconds of the test.

According to the assumption expressed at the beginning of this paper, the advantages of ventilated disc brakes were clearly distinguished when the initial speeds at the beginning of braking were greater, figures 13, 14.

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