TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Vol. 56, Issue III, September, 2013

LATERAL FORCE VARIATION TIRE TESTING

Adrian Ilie Virgil LEU, Mariana ARGHIR

Abstract: *The paper is a part of study regarding the tire dynamic. In this paper the authors realize a set of lateral force tire testing. In order to evaluate the relationship between lateral force variation and tire wear, we have designed several testing programs by using virtually the same type of vehicles, running on in tandem on the same selected driving course for the same distance and relative speeds.*
Keywords: *tire testing, lateral force, time variation.*

1. DSN SYSTEM

One measurable way to evaluate relative performance of different tire construction is by using a DSN device [1]. DSN or driving severity number device is an accelerometer / speed plotting data installed in each vehicle.

The device is measuring the acceleration amplitude on the 3 axles (lateral, longitudinal and vertical) at given time / distance intervals (Fig. 1).

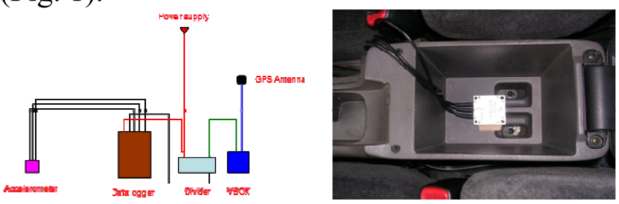


Fig. 1 DSN System

The underlying concept is that if the tires are running in virtually identical conditions, acceleration impact on the vehicle body will have slightly different values depending on the tire construction (and vehicle suspension / mechanical configuration) [10].

By comparing the measurement results from different vehicles we can draw conclusion about tire construction, where the vehicles are identical or about the vehicle suspension / mechanical configuration, where the vehicles are not identical [7].

Here below we're using data from 3 different testing programs. In all 3 programs the vehicles are run in the same area: regional road with lots of hills and curves, going around in a closed course for approximately 10,000Km. [2], [4], [5].

2. HIGHEST CONCENTRATION OF MEASURING POINTS

DSN systems used are identical for all vehicles in the test and they are calibrated before each program. Typical representation of lateral and longitudinal acceleration is represented graphically by value density around a certain level. For instance, in Fig 2 we have Lateral vs. Longitudinal acceleration values for one of the vehicles on a logarithmic scale.

We see that the highest concentration of measuring points (frequency) is around 0G (in stopping / starting). We also see that the longitudinal acceleration has larger variation than the lateral one [6].

In the figures 2 and 3 there are a natural consequence of the fact that the driving course was on local road with city-type of driving (several traffic lights, stop signs, etc.) with relatively low speeds. It is understandable that for a racing vehicle going on around shape track, for instance, this chart would be looking considerably different than the one in our case.

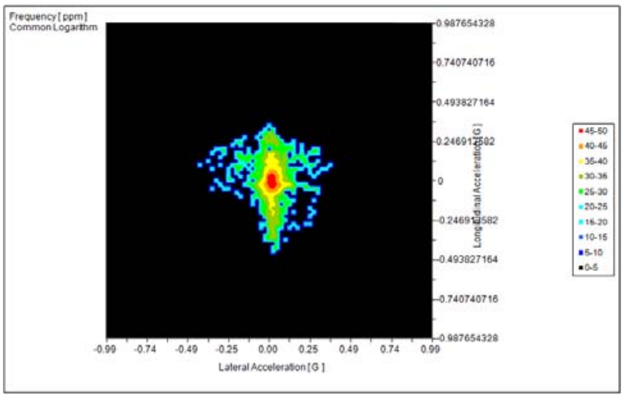


Fig. 2 Lateral vs. Longitudinal Acceleration

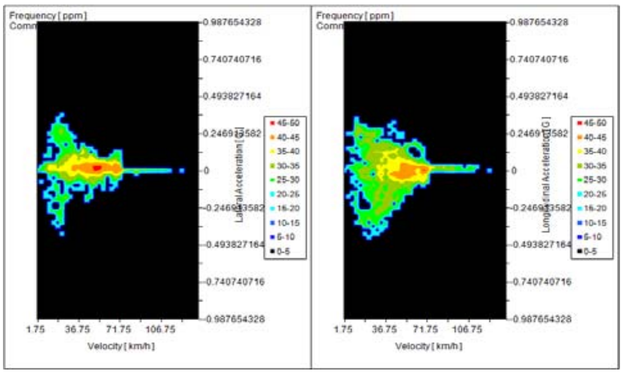


Fig. 3. Lateral and Longitudinal Acceleration vs. Velocity

In figure 3 we have Lateral and Longitudinal Acceleration vs. velocity, we see that the highest density of measurement points is around 50 km/h on lateral acceleration and around 65 – 70 km/h on longitudinal acceleration [11], [12].

This result from the fact that parts of the course contained off-city driving with higher speeds (max speed around 110 km/h) but including lots of heels and curves – local roads only / not highways. We see as well that the highest acceleration variation levels are at low speeds. Again, this is normal, considering this particular selected driving area [8], [9].

Those graphs are also showing that the acceleration pattern induces a high level of stress on the tires. So driving in areas like the selected one here could generally induce tire wear at a faster ratio than normal for NA urban driving.

We are also measuring tire effective wear on a regular basis using a pre-determined procedure. Each tire wear is measured on a regular basis (2 – 2.5kKm) in 5 – 6 different points – depending on tire configuration (see figure 4).

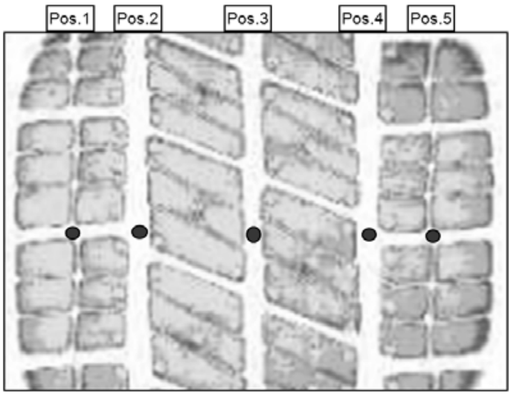


Fig. 4. Measuring Points

2.1. Test # 1

There are 3 tire brands, same size (P185/65R15) on 3 virtually identical vehicles (same manufacturer, same type, same fabrication year, same approximate mileage).

The alignment angles on the vehicles have been altered from initial specifications in order to induce irregular tire wear.

Alignment has been altered mostly for more negative Toe and negative Camber on the front and more positive Toe and less negative Camber on the rear. The wearing pattern of altered alignment angles is taken into consideration for the final evaluation of overall wear.

Test 1

Test Vehicle	Compact Sedan; 3x vehicles		
Total Mileage	10,000km x 3units		
Measurement Interval	approximately every 2,500km		
Tire Rotation	Fixed (NO Tire Rotation)		
Change Vehicle	Fixed (NO Vehicle - Vehicle Rotation)		
Tire Information			
	Vehicle#1	Vehicle#2	Vehicle#3
Front	P185/60R15 84T	175/65R15 84S	P175/65R14 84S
Rear	P185/60R15 84T	175/65R15 84S	P175/65R14 84S
Tire Pressure Condition			
	Vehicle#1	Vehicle#2	Vehicle#3
Front	220kPa	230kPa	220kPa
Rear	220kPa	230kPa	220kPa
Load Condition			
	Vehicle#1	Vehicle#2	Vehicle#3
Front	7.34kN	7.50kN	7.34kN
Rear	6.60kN	6.34kN	6.60kN
Number of Passenger	0		
Alignment Condition	see below		

Fig. 5. Test 1 program card

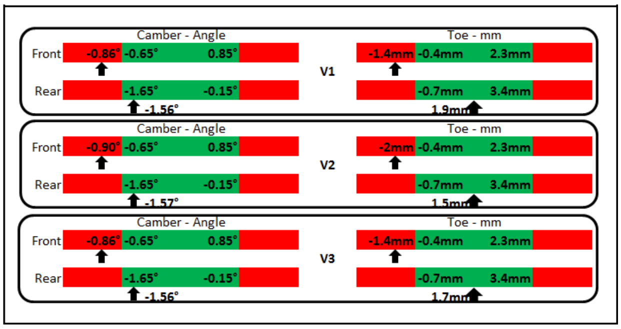


Fig. 6. Test 1 Alignment Data

In figure 7 we see tread wear on each tire for each measuring mileage. Initially all the tires have started with very comparable tread depth pattern. We can see the influence of alignment angles alteration on wear difference at different points on each tire.

It is noticeable that the tires on the front have a more accelerated and more pronounced uneven wear; especially on V2 and V3. We can also see that the tread depth pattern radially on tire is very different at the last measuring mileage. This is caused both, by alignment alteration and tire construction. Since there was the same driver on the same vehicle for the whole duration of the program, it is highly possible that the driving manner had a certain impact on the overall wear (Fig. 8).

In spite of the fact that there are three different tire brands, overall average tire wear is very comparable from car to car (see Table). Tire wear however, is very different from tire to tire (see figure 8).

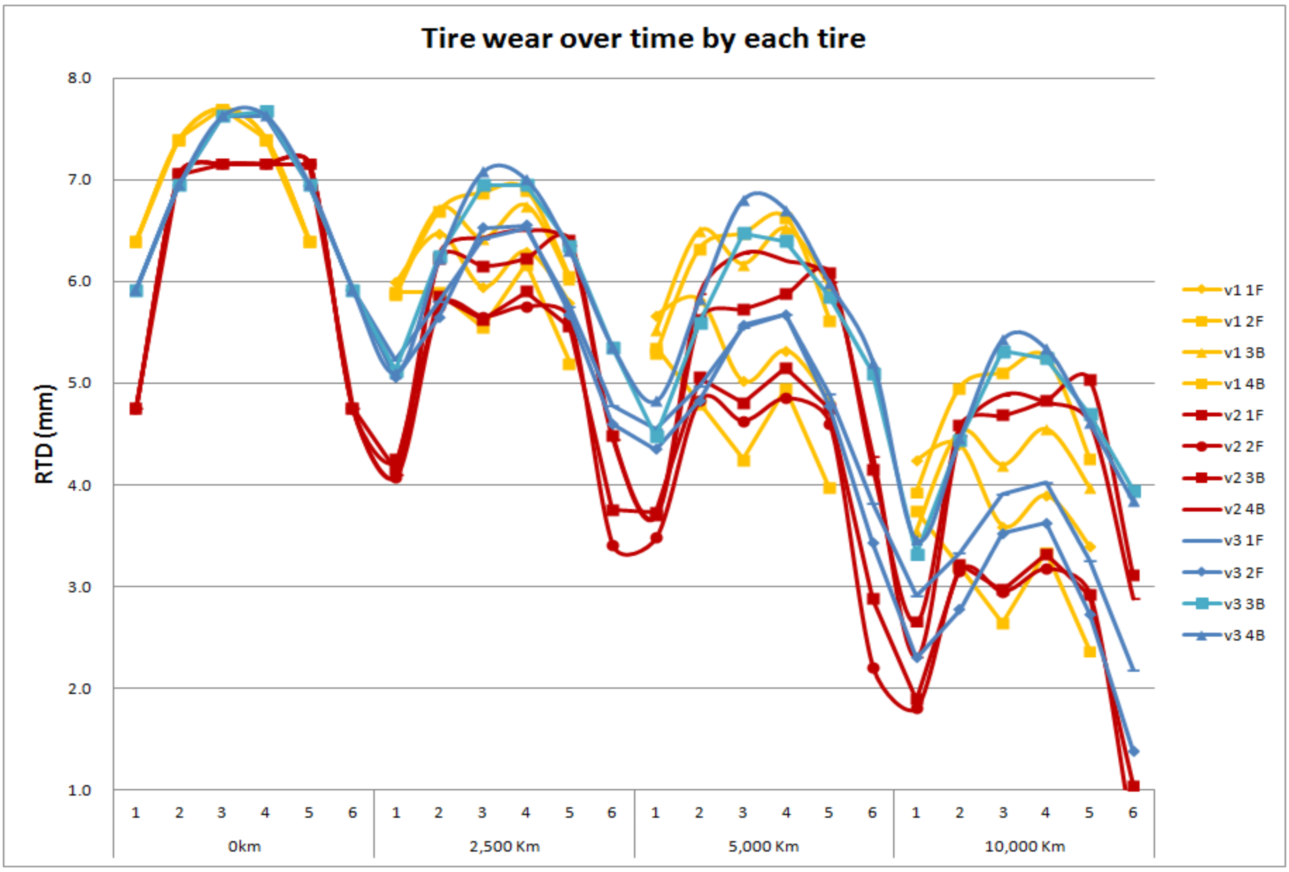


Fig. 7 Test #1 Tire wear on the 3 vehicles

Table 1. Average Tread Remaining Depth on each vehicle

RTD	V1				V2				V3			
(mm)	1F	2F	3B	4B	1F	2F	3B	4B	1F	2F	3B	4B
0 Km	7.06	7.06	7.06	7.06	6.33	6.33	6.33	6.33	6.83	6.84	6.84	6.83
2,500 Km	6.11	5.75	6.37	6.48	5.14	5.04	5.62	5.68	5.75	5.68	6.16	6.18
5,000 Km	5.34	4.67	6.14	6.07	4.39	4.10	5.19	5.39	4.91	4.77	5.65	5.89
10,000 Km	3.91	3.06	4.16	4.70	2.56	2.42	4.15	4.00	3.27	2.72	4.49	4.52

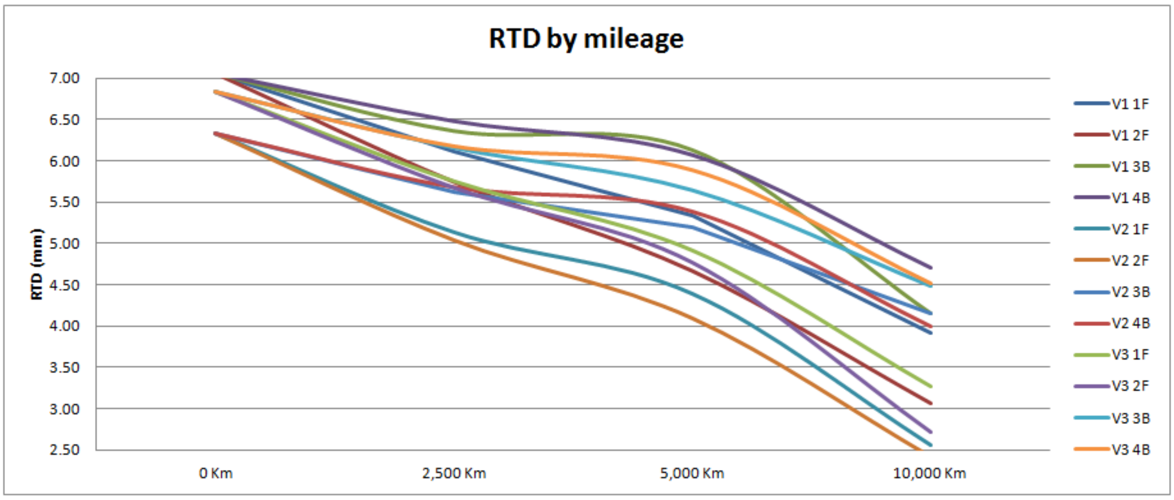


Fig. 8. Test #1 – Average Tire Wear

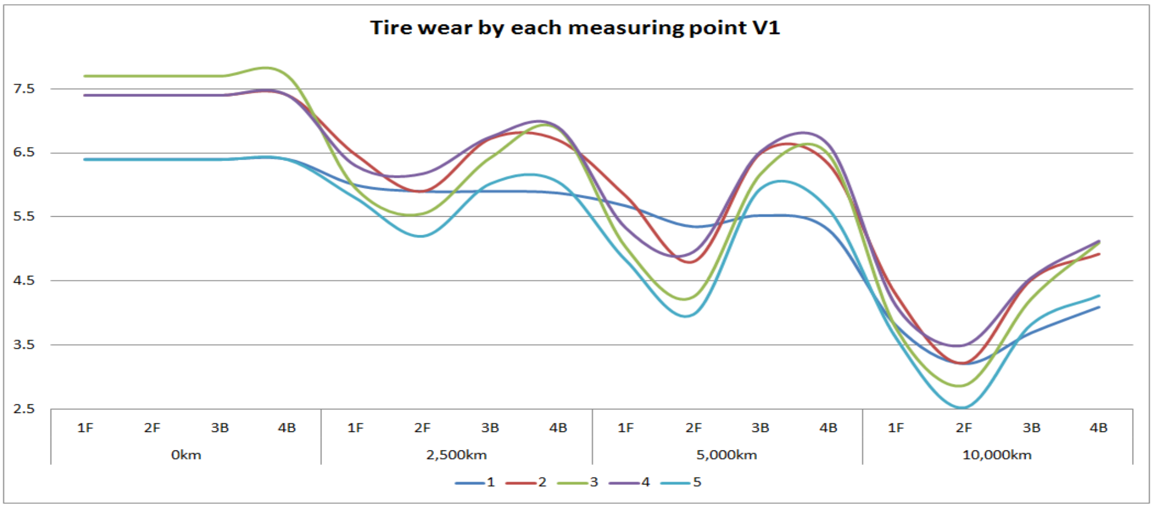


Fig. 9. Tire wear by each measuring point V1

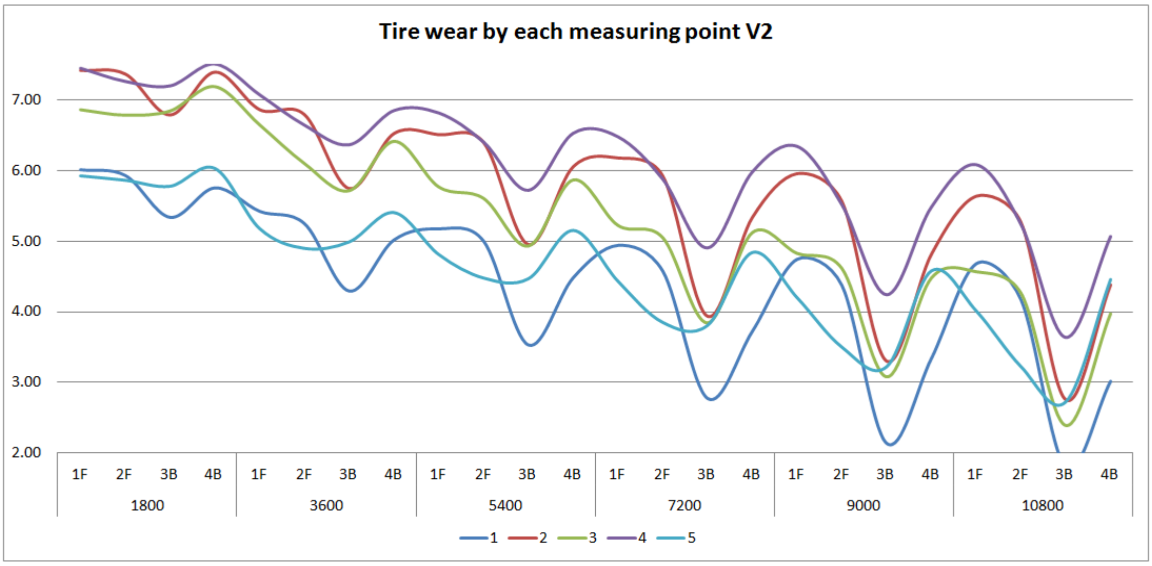


Fig. 10. Tire wear by each measuring point V2

It's interesting to note that average tire wear on the same tire seems to have steeper trend at the beginning of the tire life.

When we analyze wear by each measuring point, we see that #1 and #5 (shoulders) have started at a lower lever but #1 has a much more consistent level during the program. Here too we see that tires on the front are wearing up faster than the tires on the rear.

On vehicle V2 shoulder points are #1 and #6. Again we see that #1 has a more consistent value. The wear on tires 2F and 4B are more severe than on the other tire on the same axle. V2 has the most consistent wear trend of center area compared to V1 and V3. Tire 3B has considerably more wear than the other ones.

On V3 the wear is more consistent comparable to V1 and V2. Here too, tire 3B has considerably more wear than the other ones.

DSN measurements show Vertical DSN much higher than the lateral and longitudinal ones (see Table), as a confirmation of the fact that the testing area was in a hilly region.

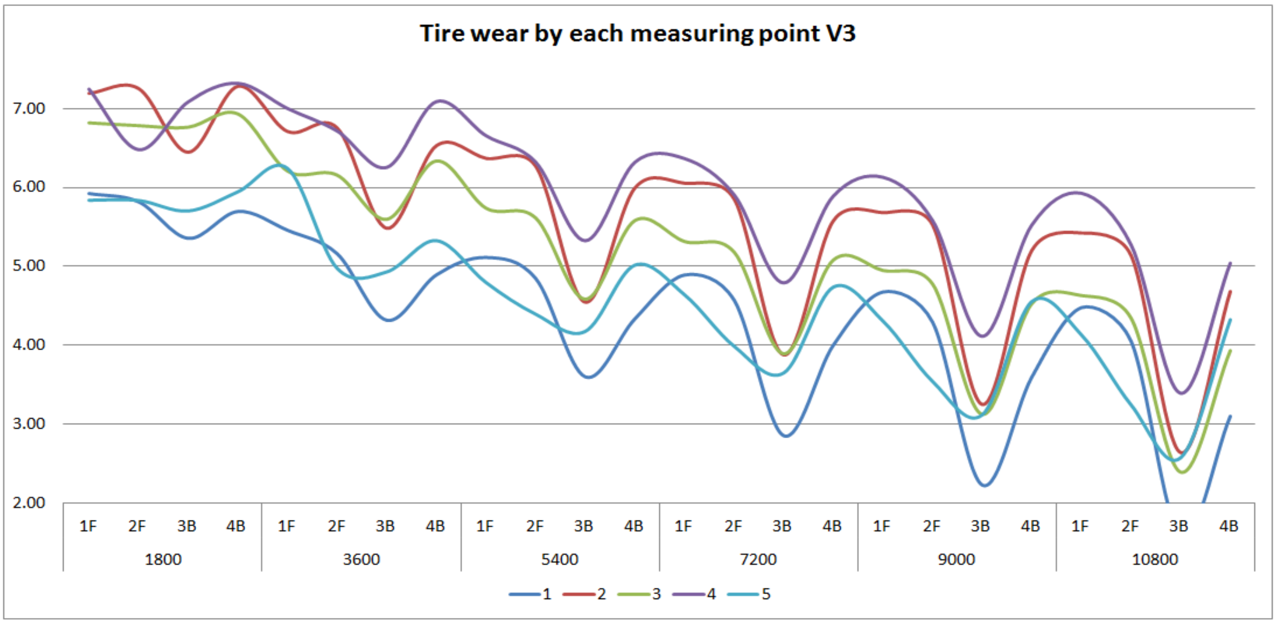


Fig. 11. Tire wear by each measuring point V3

Table 2. Test #1 – DSN vs. Tire Wear

	DSN				Average	Wear (mm/1000Km)			
	Total	Lateral	Long	Vertical	Speed	2,500Km	5,000Km	10,000km	Average
V1	1.09	0.59	0.50	1.83	100Km/h	0.31	0.22	0.39	0.31
V2	0.64	0.42	0.22	0.96	88Km/h	0.34	0.21	0.37	0.29
V3	0.89	0.49	0.40	1.26	97Km/h	0.31	0.22	0.39	0.30

V1 DSN is the highest, while the average speed was also the highest one. Since we didn't rotate drivers, the speed and DSN reflect driving manner for each driver. We see a direct proportional relationship between vehicle speed, DSN number, and tire wear.

2.2. Test # 2

There are three large sedans, virtually identical vehicles, there different tire brands, same size of tires (P215/55R17). Alignment angles have been altered to higher negative camber (front and back) and higher negative Toe on the front. The drivers have changed vehicles every 2,700km (Fig. 12).

In figure 13 we see tread wear on each tire for each measuring mileage. Initially all the tires have started with very comparable tread depth pattern. We can see the influence of alignment angles alteration on wear difference at different points on each tire especially on the rear axle of the 3 vehicles. Also wear pattern on transversal view is not very consistent along the time.

Test 2

Test Vehicle		Large Sedan x 3 vechicles	
Total Mileage		10,000km each	
Measurement Interval		1,800km	
Tire Rotation		Fixed	
Change Vehicle		2,700km	
Tire Information			
	Vehicle 1	Vehicle 1	Vehicle 1
Front	P215/55R17 93V	P215/55R17 93H	P215/55R17 93H
Rear	P215/55R17 93V	P215/55R17 93H	P215/55R17 93H
Tire Pressure Condition			
Front		230kPa	
Rear		230kPa	
Load Condition			
Front		9.8kN	
Rear		7.4kN	
Number of Passenger		0	
Alignment Condition		see below	

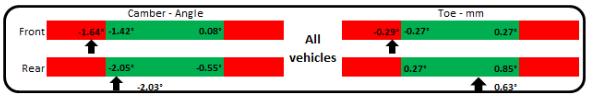


Fig.12. Test 2 Program Card

It is noticeable that the tires on the rear have a more accelerated and more pronounced uneven wear; especially on V1 and V3.

We can also see that the tread depth pattern transversally on tire is very different at the last measuring mileage. This is caused both, by alignment alteration and tire construction. Since there was a driver change on regular basis, the driving manner should have no impact on the overall wear. Tire wear is very different from tire to tire (see figure 14), especially the tires 3B (on the back).

When we analyze wear by each measuring point, we see that #1 and #6 (shoulders) have started at a lower lever but #1 has a much more consistent level during the program. Here too we see that tires on the rear are wearing up faster than the tires on the front (Fig. 15).

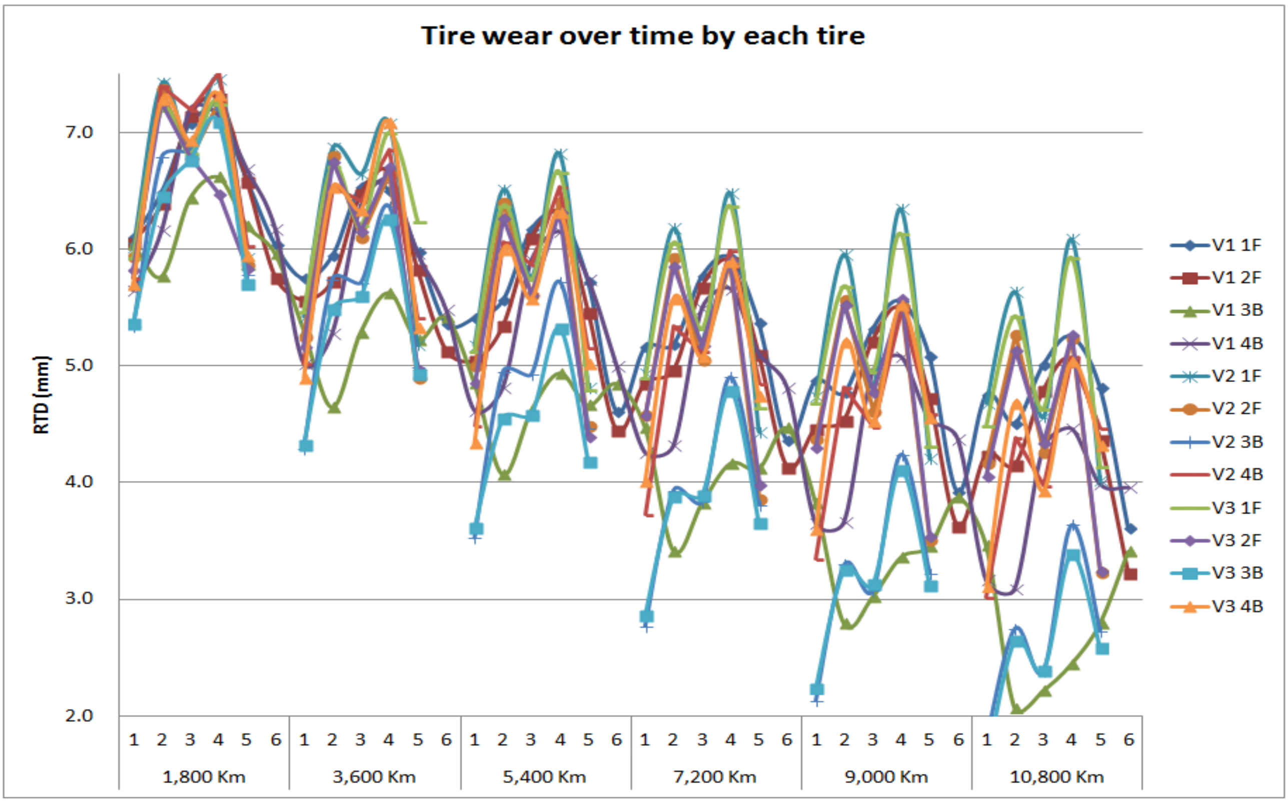


Fig. 13. Test #2 Tire Wear on the 3 Vehicles

On vehicle V2 shoulder points are #1 and #5 (Fig. 16). Again we see that #1 has a more consistent value but has a rather high level of fluctuation, however. #2 and #4 have the minimum amount of wear. The wear on tire 3B is much more severe than on the other tires. We also see a somehow accelerated center wear; #3 has a rather steeper trend line. Tire 1F seems to have the least amount of wear followed by 2F.

Large sedan vehicles tend to have a higher body mass and steering and suspension systems are designed for a more comfortable drive. Therefore, it is very possible that the stress level on the rear tires is higher than on the front tires (Fig. 14).

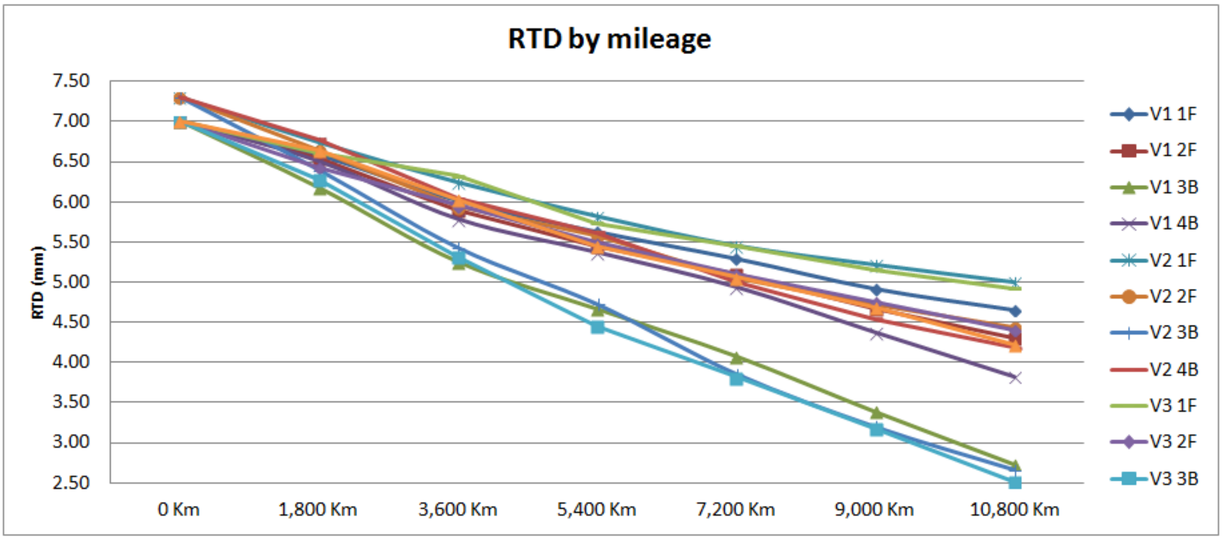


Fig. 14. Test #2 Average RTD

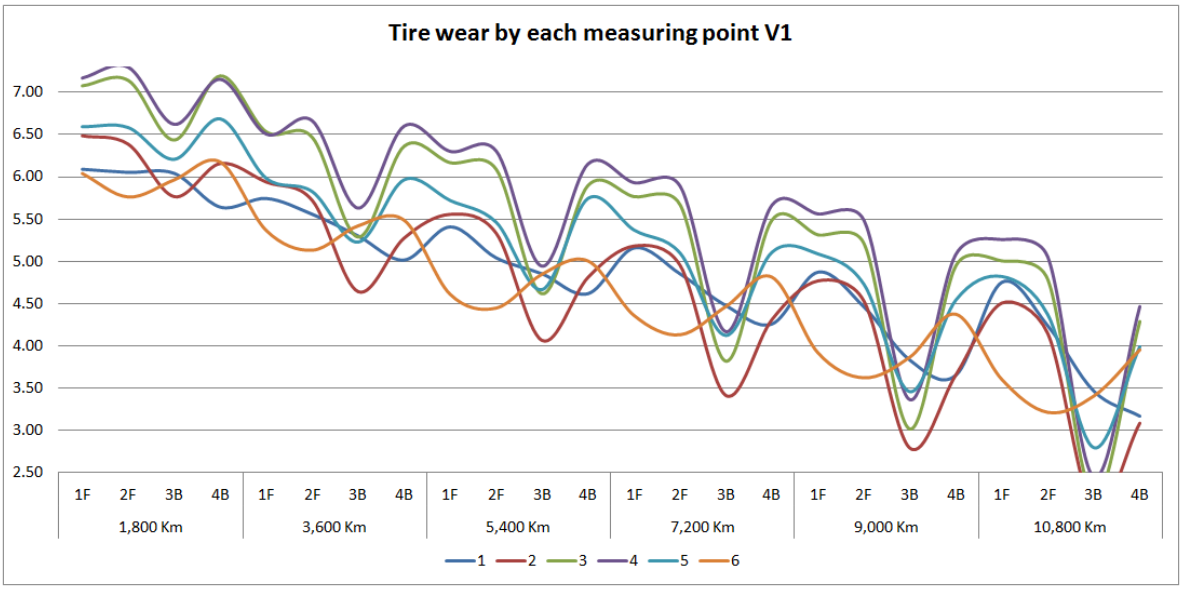


Fig.15. Tire wear by each measuring point V1

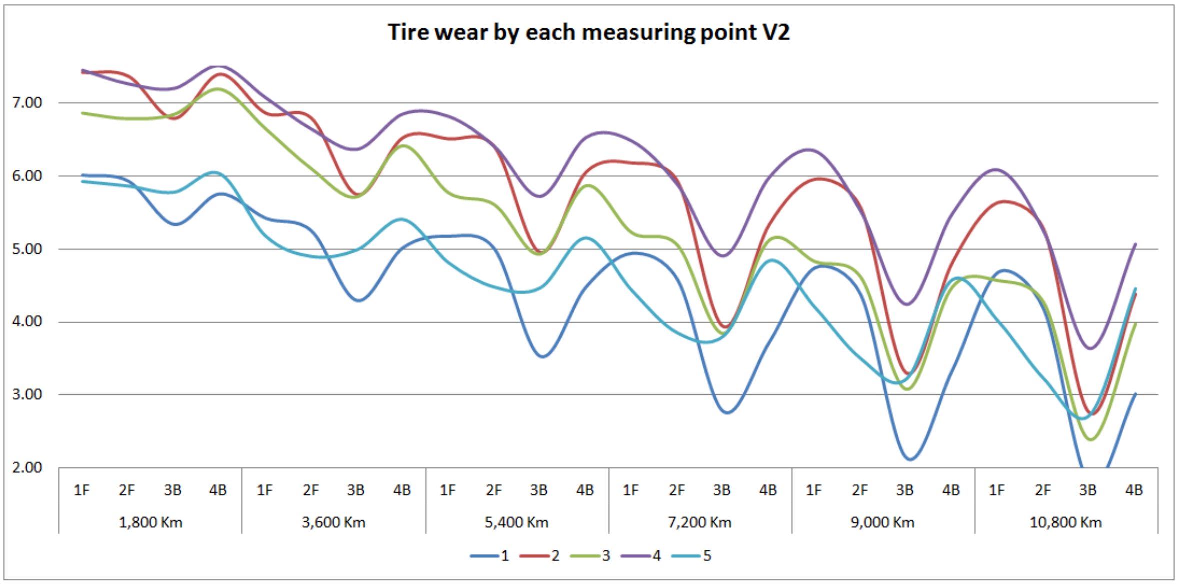


Fig. 16. Tire wear by each measuring point V2

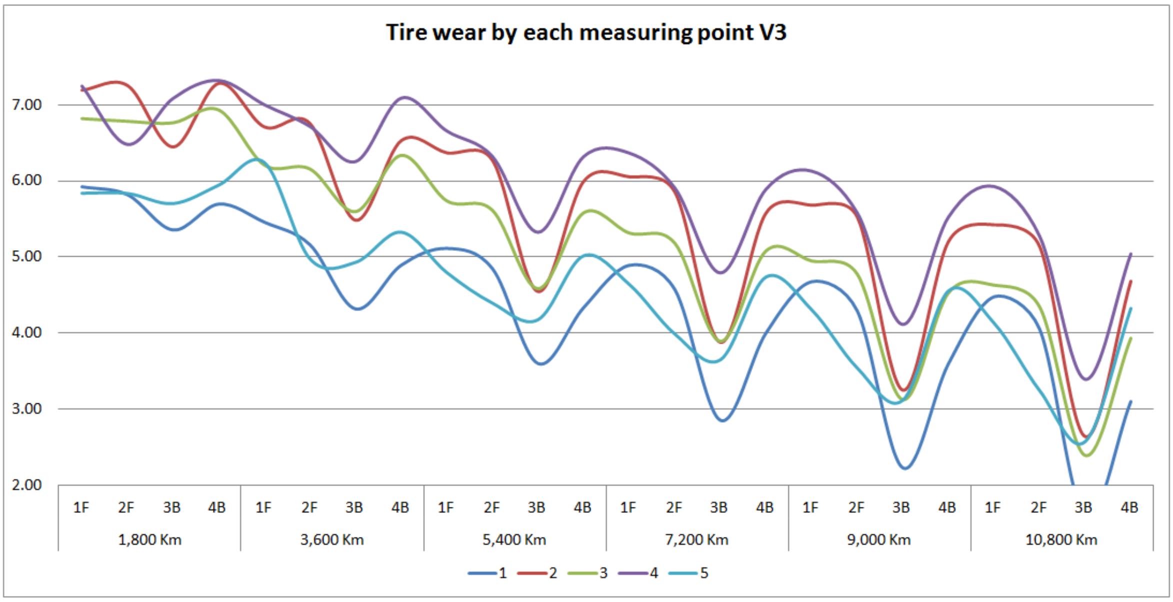


Fig. 17. Tire wear by each measuring point V3

Table 3. Test #2 - Average Remaining Tread Depth

RTD	V1				V2				V3			
(mm)	1F	2F	3B	4B	1F	2F	3B	4B	1F	2F	3B	4B
0 Km	7.00	7.00	7.00	7.00	7.30	7.30	7.30	7.30	7.00	7.00	7.00	7.00
1,800 Km	6.58	6.54	6.17	6.50	6.74	6.65	6.39	6.78	6.60	6.43	6.27	6.64
3,600 Km	6.01	5.89	5.25	5.78	6.24	5.94	5.42	6.05	6.32	5.95	5.32	6.04
5,400 Km	5.63	5.45	4.66	5.37	5.82	5.58	4.72	5.62	5.74	5.49	4.45	5.45
7,200 Km	5.29	5.10	4.08	4.94	5.45	5.06	3.85	5.00	5.45	5.10	3.82	5.06
9,000 Km	4.92	4.67	3.39	4.38	5.22	4.72	3.20	4.54	5.15	4.75	3.17	4.68
10,800 Km	4.66	4.30	2.73	3.82	5.00	4.43	2.66	4.18	4.92	4.41	2.52	4.22

Table 4. Test #2 - DSN vs. Tire Wear

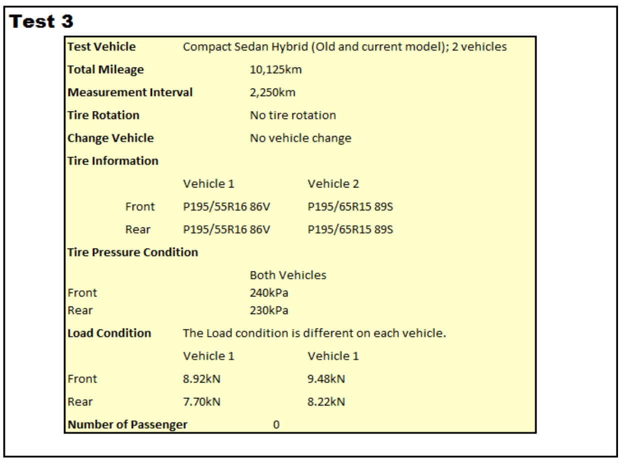
	DSN				Average	Wear (mm/1000Km)						
	Total	Lateral	Long	Vertical	Speed	1,800 Km	3,600 Km	5,400 Km	7,200 Km	9,000 Km	10,800 Km	Average
V1	1.32	0.98	1.18	1.76	86.0Km/h	0.31	0.40	0.25	0.24	0.29	0.26	0.29
V2	1.62	0.72	1.90	1.90	85.7Km/h	0.37	0.40	0.27	0.33	0.24	0.19	0.30
V3	1.17	1.00	1.17	1.34	86.0Km/h	0.29	0.32	0.35	0.24	0.23	0.23	0.28

On V3 the wear is very comparable to V1 and V2. Here too, tire 3B has considerably more wear than the other ones. Since we changed the drivers on the vehicles, the average speed for the three vehicles is very comparable (see Table). However, we can see small differences between DSN values and Tire Wear (see Table 4. Test #2 - DSN vs. Tire Wear).

Those differences can be caused by slight differences in vehicle suspensions but mostly by differences in tire constructions. As in the previous program, we see a direct relationship between DSN and average tire wear.

2,3, Test # 3

We have the old and the new model of the same compact sedan hybrid vehicle. No tire rotation, no driver rotation. Camber was changed toward more positive values. Tire size: 195/65R15 89S.


Test 3

Test Vehicle	Compact Sedan Hybrid (Old and current model); 2 vehicles	
Total Mileage	10,125km	
Measurement Interval	2,250km	
Tire Rotation	No tire rotation	
Change Vehicle	No vehicle change	
Tire Information		
	Vehicle 1	Vehicle 2
Front	P195/55R16 86V	P195/65R15 89S
Rear	P195/55R16 86V	P195/65R15 89S
Tire Pressure Condition		
	Both Vehicles	
Front	240kPa	
Rear	230kPa	
Load Condition	The Load condition is different on each vehicle.	
	Vehicle 1	Vehicle 1
Front	8.92kN	9.48kN
Rear	7.70kN	8.22kN
Number of Passenger	0	

Fig. 18. Test #3 Program Card

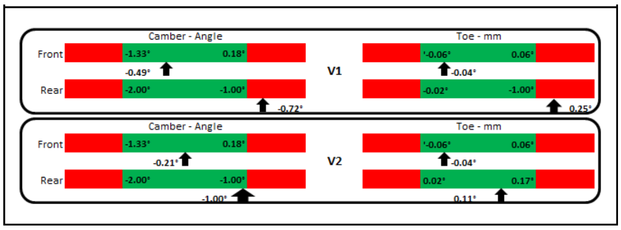


Fig. 19. Test 3 Alignment Data

Average tire wear is slightly different from tire to tire (see figure 19). We see that tire on V1 left front has the most severe wear.

Tire wear pattern is somehow different from tire to tire though (see figure 21). There are two tires with a faster wear. Tires on V1 left front has a very severe wear as well as the tire on V2 right rear. We can also see that the tread depth pattern radially on tire is very different at the last measuring mileage. This is caused both, by alignment alteration and tire construction. Since there was the same driver on the same vehicle for the whole duration of the program, it is highly possible that the driving manner had a certain impact on the overall wear.

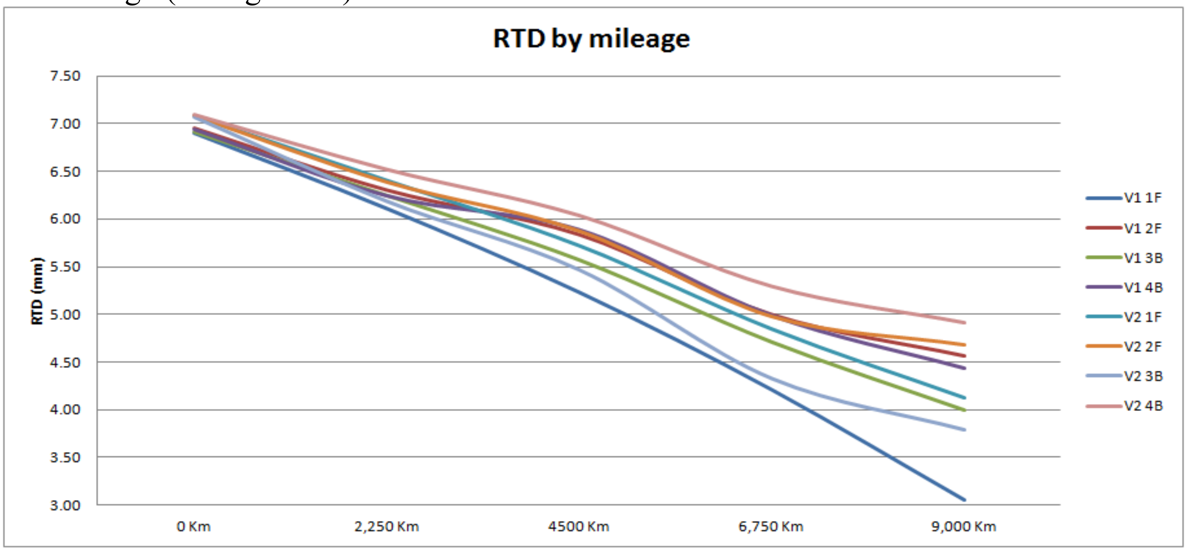


Fig. 20. Test #3 Average RTD

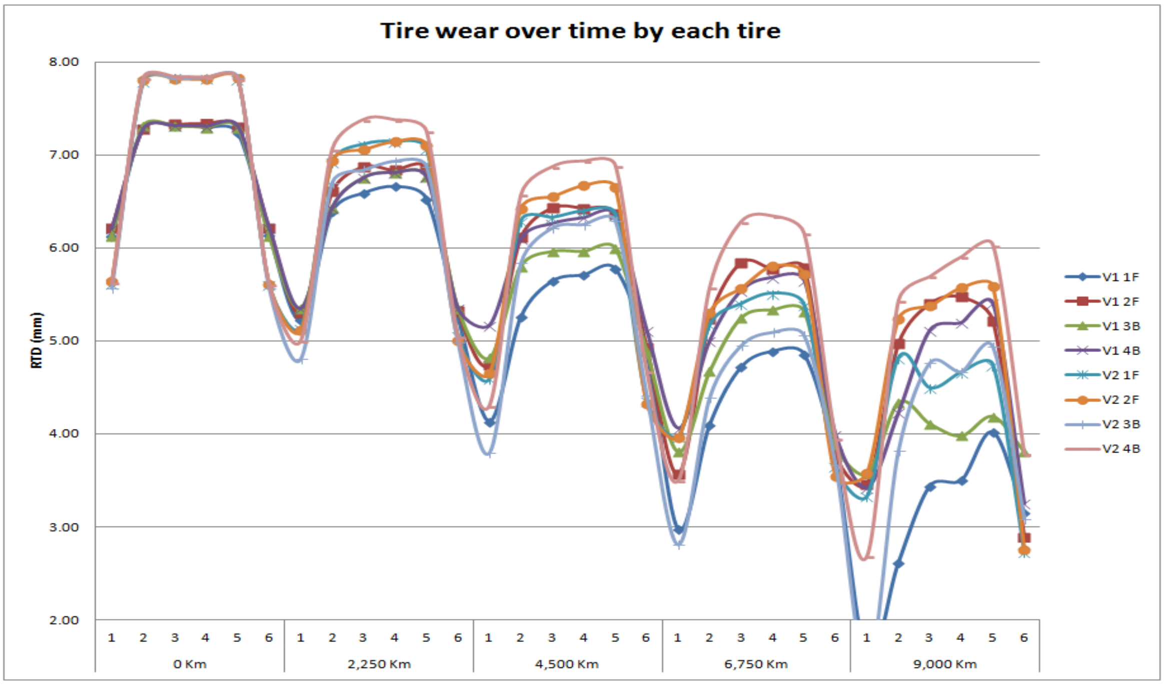


Fig. 21. Test #3 - Tire Wear on the 2 Vehicles

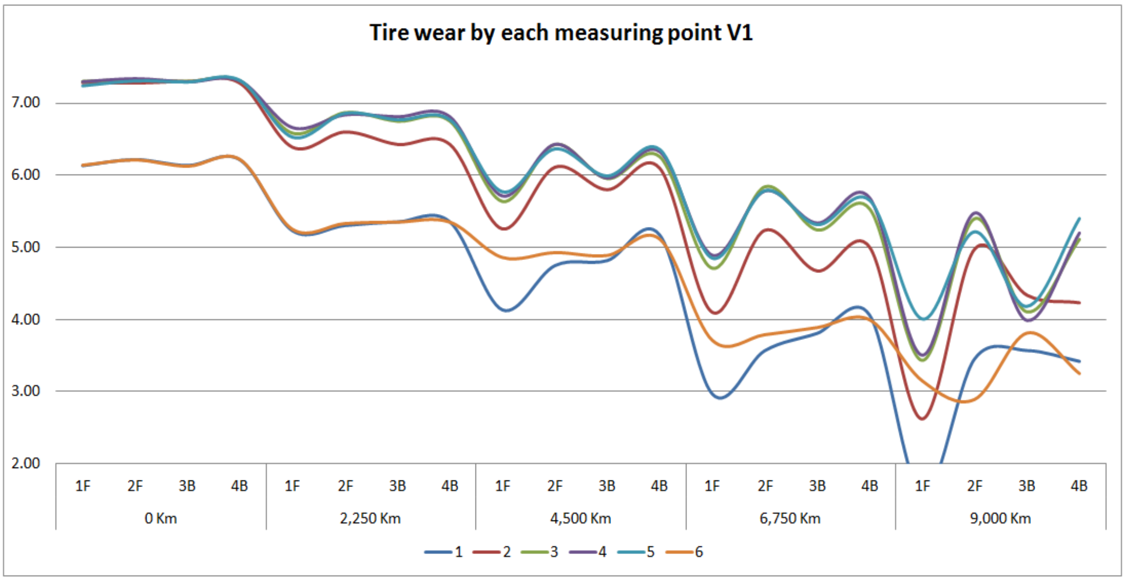


Fig. 22. Tire wear by each measuring point V1

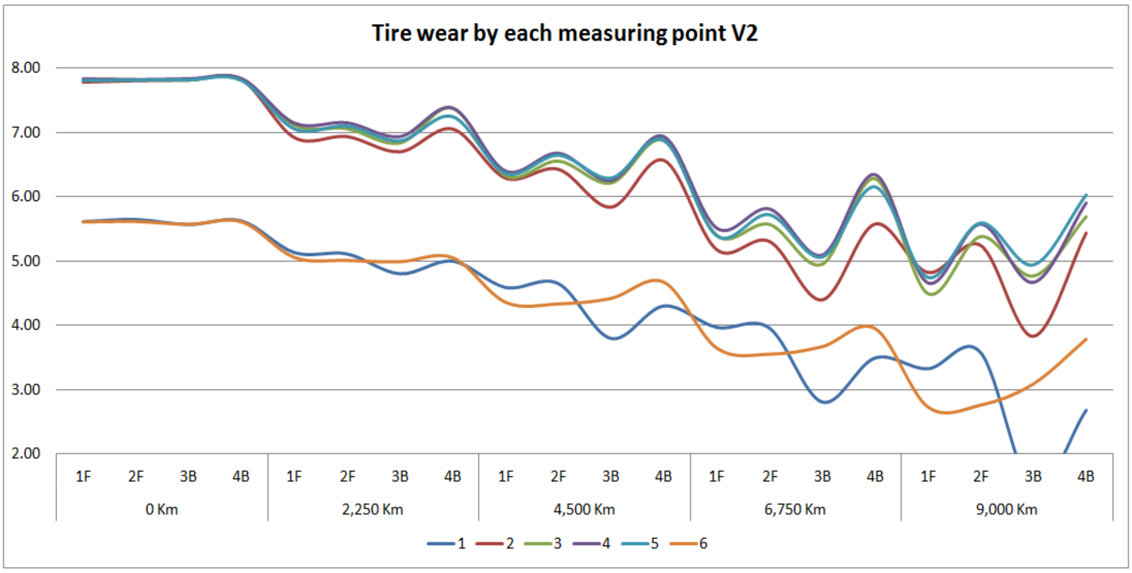


Fig. 23. Tire wear by each measuring point V2

Table 5. Test #3 Average Remaining Tread Depth

RTD	V1				V2			
(mm)	1F	2F	3B	4B	1F	2F	3B	4B
0 Km	6.90	6.95	6.91	6.94	7.08	7.09	7.07	7.09
2,250 Km	6.11	6.30	6.24	6.24	6.40	6.39	6.19	6.52
4500 Km	5.23	5.84	5.57	5.89	5.72	5.88	5.47	6.04
6,750 Km	4.21	5.00	4.71	4.99	4.85	4.98	4.33	5.30
9,000 Km	3.05	4.57	4.00	4.44	4.13	4.69	3.79	4.92

Table 6. Test #3 DSN vs. Tire Wear

	DSN				Average	Wear (mm/1000Km)				
	Total	Lateral	Long	Vertical	Speed	2,250Km	4,500km	6,750km	9,000km	Average
V1	0.54	0.34	0.20	0.25	83.70	0.30	0.25	0.30	0.29	0.29
V2	0.57	0.35	0.19	0.22	83.70	0.30	0.26	0.30	0.20	0.26

When we analyze wear by each measuring point, on V1 we see that #1 and #6 (shoulders) have started at a lower lever but #6 has a much more consistent level during the program. Here too we see that tire on the left front is worn-out much faster than the other ones. Wear pattern is going transversally from most worn-out on the outside to less worn on the inside. This is consistent with a Feather Edge type of wear, very probably caused by Toe misalignment.

On vehicle V2 shoulder points are #1 and #6. Again we see that #6 has a more consistent value. The wear on tires 3B is more severe than on the other tires. V2 has the most consistent wear trend of center area compared to V1.

Remaining tread depth at the end of the program was very comparable (see Table). We had very few tires with a faster wear.

DSN number was very low for the two vehicles while the speed was identical (see

Table 6. Test #3 DSN vs. Tire Wear).

It's very interesting to notice that the vehicle with higher DSN number had actually lower tire wear. This can be explained by better vehicle suspension and better tire construction.

3. GENERAL CONSIDERATIONS ON LATERAL FORCE VARIATION AND TIRE WEAR

Some of the most important factors that influence Tire Wear are the Tire Force Profile, Pavement abrasiveness and Tire Running Temperature. Out of the three, the most important is the Tire Force, specifically Tire Lateral Force. It is possible for us to measure the lateral g-forces acting on the tire while driving and process the values under a single – valued number called Driving Severity Number (DSN).

DSN is expressing the relationship between tire lateral forces variation and tire wear. We have tested different tires on same track, same tire running temperature, very comparable speeds and comparable driving manner. We altered steering direction alignment specifications on the vehicles to induce irregular wear for additional study.

Generally we see a direct relationship between vehicle speed, DSN and tire average wear even when the tires didn't actually wear up in the same pattern.

However, on very similar driving conditions we did notice some differences in DSN and tire wear and we think this can be explained mainly by differences in tire construction. Therefore we can conclude that we can use DSN to identify differences in tire construction as well.

We can conclude that DSN will not relate wear to individual tire forces due to load transfer or vehicle roll, suspension characteristics or alignment alterations. But if we consider the tires and vehicle as a system and we assume that there are no alterations to the alignment angles and all other characteristics are equal, we can use DSN to predict tire wear as a correlation between the accelerations in the three dimensions.

BIBLIGRAPHY

[1] Bevly D, Gerdes JC, Wilson J, Zhang G. The Use of GPS Based Velocity Measurements for Improved Vehicle State Estimation. Chicago, IL: American Control Conference; 2000.

[2] Cars Direct. UTQG Number. In: Auto Standards. 2009.

[3] Frank F, Hofferberth W. Mechanics of the pneumatic tire. Rubber Chemical Technology; 1983.

[4] Huang SC, Soedel W. Response of rotating rings to harmonicand periodicloading and comparison with the inverted problem. Journal of Sound and Vibration 118 (1987) 253–270; 1987.

[5] Leu A, Arghir M. Correlations between Lateral Forces variation and Tire Wear. Cincinnati, OH: Rubber Division; 2012.

[6] Mark JE, Erman B, Erich FR. The Science and Technology of Rubber. Burlington, MA: Elsevier Academic Press; 2005.

[7] Riepl A, Reinalter W, Fruhmann G. Rough Road Simulation with tire model RMOD-K and FTire. Kanagawa, JP: Taylor & Francis, London UK; 2003.

[8] Rubber Manufacturers Association. Managing Scrap Tires - What Consumers can do to Minimize Scrap Tires. Washington: RMA; 2006.

[9] Sinelnikov ED. Rigiditatea radială a pneurilor de automobile. Automobilnaia Promişlenosti nr. 6; 1959.

[10] Stephant J, Carara A, Meizel D. Virtual sensor, application to vehicle sideslip angle and transversal forces. IEEE Transactions on Industrial Electronics; 2004.

[11] Urban G, Nano M. Analysis of Vehicle Behavior to Find Criteria for Steering Robot Tests. Luleå University of Technology Department of Engineering Sciences and Matematics; 2010.

[12] Van NN, Matsuo T, Koumoto T, Inaba S. Effects of Tire Inflation Pressure on Soil Contact Pressure and Rolling Resistance of Farm Tractors. Laboratory of Agricultural System Information and Technology; 2007.

Variația forței laterale în testarea pneului

Rezumat: *Această lucrare este parte component a studiului dinamicii pneului. In această lucrare autorii realizează un set de experimente "in situ" pentru testarea forței laterale a pneului. In scopul de a evalua relația dintre variația forței laterale şi suprafața acoperitoare a pneului, autorii au priectat şi realizat câteva programe de testare a unor tipuri de vehicule, care rulează în tandem în aceleaşi condiții de conducere, pe aceeaşi diatnță u aceeaşi viteză.*

Adrian Ilie Virgil LEU, PhD. Student, Eng., Technical University of Cluj-Napoca, Department of Mechanical Engineering Systems, no. 103-105 B-dul Muncii, Cluj-Napoca, ROMANIA.

Mariana ARGHIR, Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Mechanical Engineering Systems, no. 103-105 B-dul Muncii, Cluj-Napoca, ROMANIA, e-mail: marianaarghiryahoo.com; Mariana.Arghir@mep.utcluj.ro, Of. Tel: (+) 40 264 401 657.