Comparative Study of Maintenance Vehicles Using Vibration Analysis

Ovidiu Ioan Vulcu and Mariana Arghir

Abstract This article justifies the importance of vehicles maintenance throughout their entire running. According to this purpose, we have done a comparative study of vibrational behavior of two vehicles of the same type but different manufacturing years. For both cars, there were made experimental measurements of vibrations on the stand for three significant measurement points: the screw at the cover cleats, the bodywork, and the seat. The results are justified by the history of repairs and maintenance operations.

Keywords Vehicles maintenance · Vehicles vibration · Vehicle wear

1 Introduction

Transportation is one field of economic and social activity through which the movement in space is made of people and goods in order to meet the material and spiritual needs of the society.

The inspection operations, troubleshooting, repair, improvement, etc., which allows ensuring continuity of use, safely, an optimal overall cost of a vehicle, constitute maintenance vehicles [1].

Maintenance of vehicles is a necessity, because the technical condition significantly affects comfort, road safety, and vehicle endurance as a whole.

The main maintenance operations for means of transport are: replacement of worn parts, refilling working fluids, regulating components, and removal of wear factors (vibration, water, dust, acids, etc.).

The efficiency of conveyance maintenance is mainly determined by minimizing the costs of maintenance and repair, by the achievement of the higher running times

O.I. Vulcu (✉) · M. Arghir
Technical University of Cluj-Napoca, Cluj-Napoca, Romania
e-mail: vulcu_ovidiu@yahoo.com

M. Arghir
e-mail: Marghir@mep.utcluj.ro

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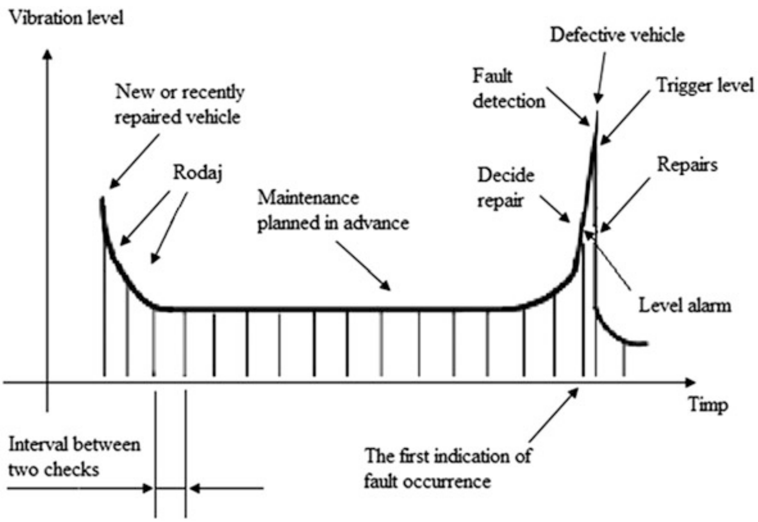


Fig. 1 Operating regime curve of a vehicles [2]

between failures and the maintenance of high ecological parameters. This requires close and continuos observation of the technical condition of cars and periodic testing and diagnosis of these processes in order to detect faults, even the minor ones and determining the most effective intervention solutions.

Inadequate operation and maintenance of the vehicle (using improper maintenance and repair materials, not following the periodicity of technical maintenance and current repairs, inappropriate adjustments, thermal regimes and overly high mechanical stress etc.) determines an accelerated wear of parts and subassemblies vehicle, but with similar features to the normal wear processes.

The maintenance of the transport means, especially motor vehicles, is represented by means of the operating regime curve (Fig. 1).

According to the curve shown in Fig. 1, maintenance actions are carried out at certain times and at certain values of vibration levels. It is observed that when the vehicle is new, it is normal to have high levels of vibration. During the period of running, this level decreases to a value that will remain approximately constant during the exploitation period. Significant increase in vibration parameters indicate a fault and there will be needed a remedial intervention. There is a vibration level value that indicates the vehicle is out of order and the repair is mandatory [2].

2 Vibration Sources of the Vehicles

The most important vibration sources that occur while driving a vehicle are: propulsion engine, transmission organs, air resistance to the advance of the vehicle, and road surface quality [3]. During running, the most disturbing are the vibrations coming from the engine compartment or from the car decks. There are some possible causes of producing vibrations [4]:

1. Irregular functioning of the engine caused by insufficient air or fuel or faulty ignition received due to spark plugs, which may lead to mechanical vibration transmission throughout the car.
2. The precarious state suspension increases the level of vibration. Also, vibrations may occur due to the wear of rubber backing.
3. All vehicles have rotating components that are manufactured in tolerance class in sliding regime to function properly. If one of the axles is even slightly distorted, then it may cause vibration along the car. In this case, vibration increases while intensifying the running speed.
4. The vibrations are intensified when brake discs are slotted.
5. The vibrations caused by the deformation of wheels appear quite often.
6. Another reason for the occurrence of vibration is due to the tires. In general, if there are low-quality tires, they deform in time or suffer irregular wear and produce vibrations when running with certain speeds.

3 Experimental Method

In the transport means maintenance and diagnosis on the items using experimental determination of vibration involves the establishment of the measuring device, depending on the parameter to be measured, the measurement points (items) where to put the accelerometer and method of the results analysis. We used as a measuring instrument SVAN 958 vibrometer, and the data obtained will be processed and analyzed using PC software SVAN++ [5].

3.1 Description of the of Passenger Cars Whose Vibration Was Measured

To highlight the vibrator response of a transport means, it was determined that vibration sources are elements of two cars Volkswagen Caravelle with identical characteristics, in the normal state, but with different years of manufacture. The first vehicle, the Volkswagen brand, shown in Fig. 2, for which measurements were made, has the following technical characteristics (as per registration certificate):

– manufacturing year: 2002;
– registration number: AB 07 WNT;
– number of seats: 8 + 1;
– power source: Diesel;
– maximum mass: 2800 kg;

Fig. 2 Vehicle with AB 07 WNT registration number

Fig. 3 Vehicle with CJ 47 ZEK registration number

- power: 75 kW;
- engine capacity: 2461 cm^3;
- total running: 428,988 km.

The second vehicle, the Volkswagen brand, for which measurements were made, is shown in Fig. 3.

Technical characteristics (according to the registration certificate) of the vehicle from Fig. 3 are:

- manufacturing year: 1999;
- registration number: CJ 47 ZEK;
- number of seats: 8 + 1;
- power source: Diesel;
- maximum mass: 2800 kg;
- power: 75 kW;

– engine capacity: 2461 cm^3;
– total running: 575,366 km.

3.2 The Measurement of the Vibration

The measurement was carried out according to the following conditions:

– measurements were performed on ITP stand (Periodic Technical Inspection);
– vehicles had a normal operating condition;
– measurement points for both vehicles were:
  (1) P1—screw the cover cleats (rocker arms);
  (2) P2—the bodywork under the windshield;
  (3) P3—front driver's seat.
– mounting accelerometers in the three measuring points was performed using special magnetic elements;
– measurement axes were complied according to ISO 8002: 1994 standard. This standard presents analytical parameters and the presenting results method of vibration measurements for land vehicles.

4 Vibration Measurement Results Obtained for the Two Vehicles

4.1 Results Obtained for the First Vehicle

Vibration measurement mode, in the P1 first measurement point is illustrated in Fig. 4.

According to Fig. 4, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

– Oz axis measurement for channel 1 is Ch1;
– Oy axis measurement for channel 2 is Ch2;
– Ox axis measurement for channel 3 is Ch3.

Table 1 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P1 measuring point, determined experimentally on the 3 coordinate axes.

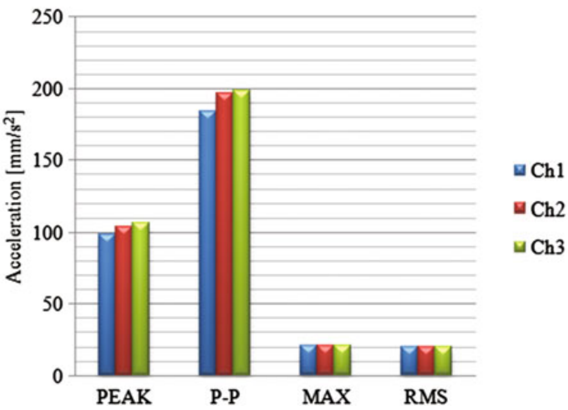
The numerical values in Table 1 are presented by graphical form in Fig. 5. From Table 1 and Fig. 5, it is observed that the highest values of vibration acceleration are along the Ox horizontal direction.

Fig. 4 Location vibration measuring system for P1 measurement point

Table 1 Effective vibration accelerations obtained on the three channels, in P1 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	98.288	184.289	20.701	19.838
Ch2	103.872	196.562	20.630	19.792
Ch3	106.537	198.609	20.989	20.091

Fig. 5 Chart of effective vibration acceleration measured on the three channels, from the P1 measuring point



For example, the maximum RMS acceleration along the Ox horizontal direction is 20.09 mm/s^2. This is confirmed by the oscillogram given in Fig. 6.

Vibration measurement mode, in the P2 measurement point is illustrated in Fig. 7. According to Fig. 7, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

– Oz axis measurement for channel 1 is Ch1;
– Oy axis measurement for channel 2 is Ch2;
– Ox axis measurement for channel 3 is Ch3.

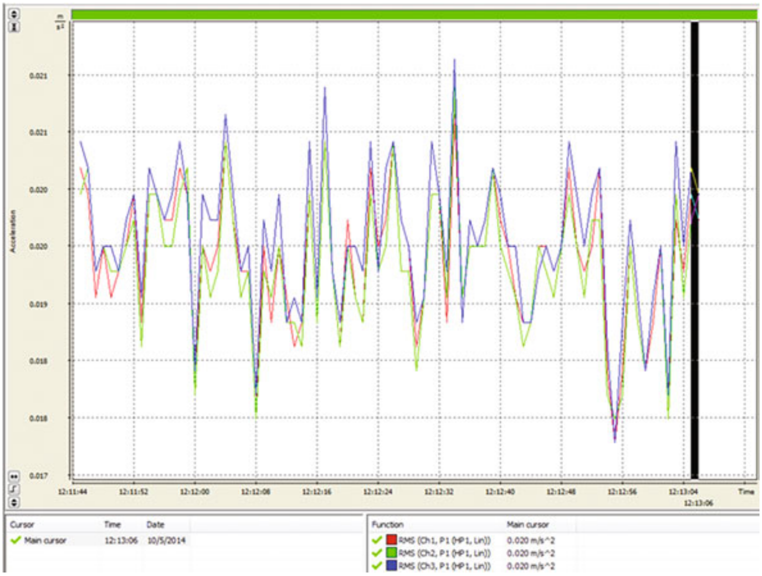


Fig. 6 Oscillogram of RMS acceleration from the P1 measuring point

Fig. 7 Location vibration measuring system for the P2 measurement point

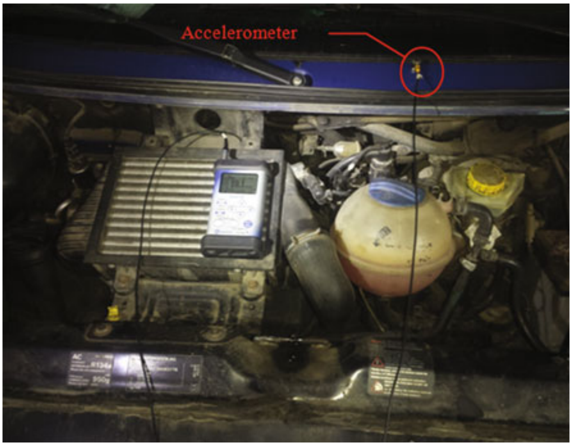


Table 1 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P2 measuring point, determined experimentally on the three coordinate axes.

The numerical values in Table 2 are presented in a graphical form in Fig. 8.

From Table 2 and Fig. 7, it is observed that the highest values of vibration acceleration are along the Ox horizontal direction. For example, the maximum RMS acceleration along the Ox horizontal direction is 19.88 mm/s^2. This is confirmed by the oscillogram given in Fig. 9.

Table 2 Effective vibration accelerations obtained on the three channels in the P2 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	88.614	177.215	20.370	19.521
Ch2	89.743	178.443	20.441	19.656
Ch3	112.720	201.372	20.725	19.884

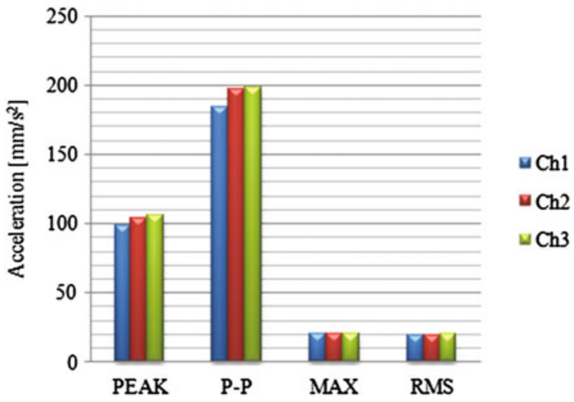


Fig. 8 Chart of effective vibration acceleration measured on the three channels from the P2 measuring point

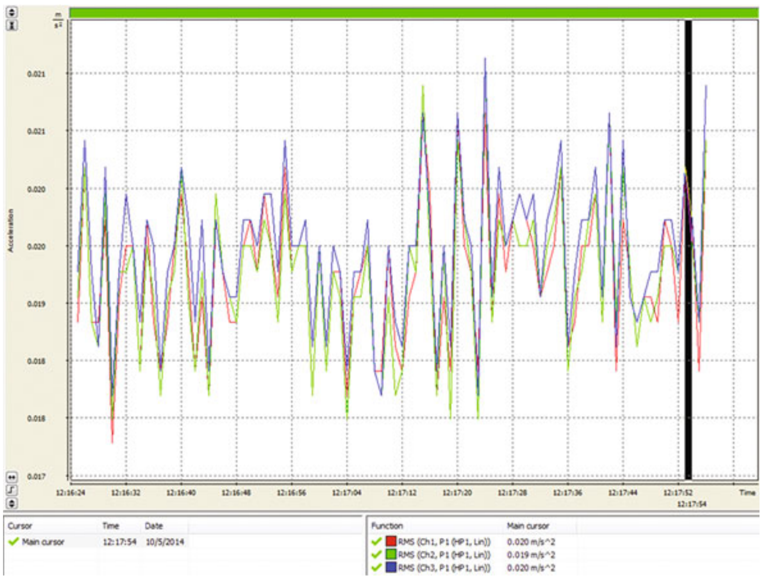


Fig. 9 Oscillogram of RMS acceleration from the P2 measuring point

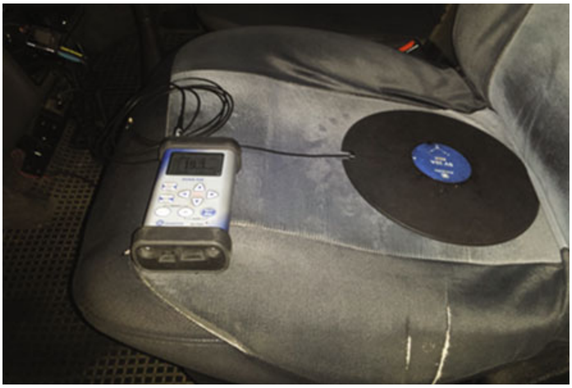


Fig. 10 Location vibration measuring system for the P3 measurement point

Vibration measurement mode, in the P3 measurement point, is illustrated in Fig. 10.

According to Fig. 10, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

- Ox axis measurement for channel 1 is Ch1;
- Oy axis measurement for channel 2 is Ch2;
- Oz axis measurement for channel 3 is Ch3.

Table 3 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P3 measuring point, determined experimentally on the three coordinate axes. The numerical values in Table 3 are presented in graphical form in Fig. 11.

From Table 3 and Fig. 11, it is observed that the highest values of vibration acceleration are along the Oz vertical direction.

For example, the maximum RMS acceleration along the Oz vertical direction is 641.95 mm/s^2. This is confirmed by the oscillogram given in Fig. 12.

Analyzing the results of vibration obtained in the three measuring points of the first vehicle, it follows that the acceleration is greatest at the P3 point, i.e., the front seat, along the vertical direction. Also acceleration values obtained for the first two measurement points are very close.

Table 3 Effective vibration accelerations obtained on the three channels in the P3 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	977.237	1634.933	447.198	437.019
Ch2	869.961	1663.413	377.138	366.438
Ch3	1144.195	2282.969	652.379	641.948

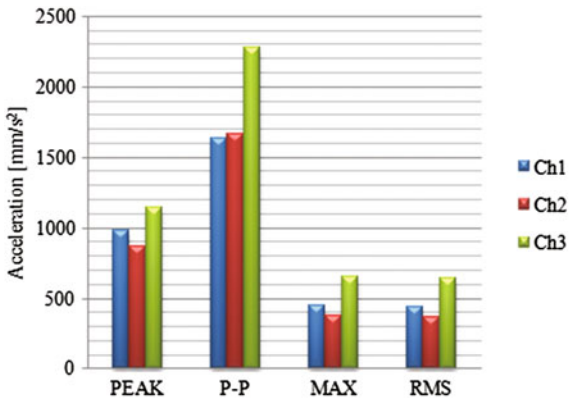


Fig. 11 Chart of effective vibration acceleration measured on the three channels from the P3 measuring point

Fig. 12 Oscillogram of RMS acceleration from the P3 measuring point

4.2 Results Obtained for the Second Vehicle

Vibration measurement mode, in the first measurement point P1, is illustrated in Fig. 13.

According to Fig. 13, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

Fig. 13 Location vibration measuring system for the P1 measurement point

- Oz axis measurement for channel 1 is Ch1;
- Oy axis measurement for channel 2 is Ch2;
- Ox axis measurement for channel 3 is Ch3.

Table 4 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P1 measuring point, determined experimentally on the three coordinate axes.

The numerical values in Table 4 are presented in graphical form in Fig. 14.

From Table 4 and Fig. 15, it is observed that the highest values of Peak-to-Peak and Max vibration accelerations are along the Oy transversal direction, 209.4 and 19.8 mm/s^2, respectively. RMS acceleration is higher along the Ox horizontal direction, valued at 18.5 mm/s^2. This is confirmed by the oscillogram given in Fig. 15.

Vibration measurement mode, in the second measurement point is illustrated in Fig. 16. According to Fig. 16, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

- Ox axis measurement for channel 1 is Ch1;
- Oy axis measurement for channel 2 is Ch2;
- Oz axis measurement for channel 3 is Ch3.

Table 4 Effective vibration accelerations obtained on the three channels in the P1 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	104.954	192.309	19.770	18.450
Ch2	104.954	209.411	19.792	18.450
Ch3	103.633	190.766	20.022	18.535

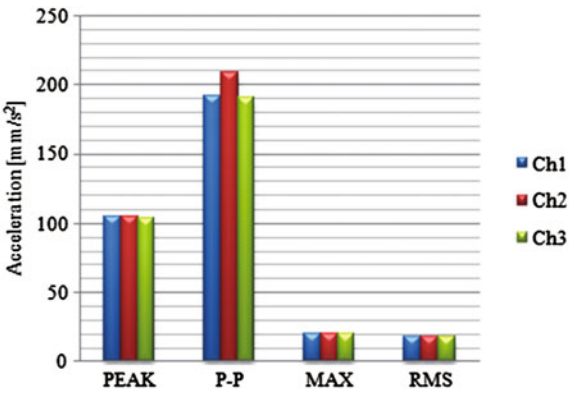


Fig. 14 Chart of effective vibration acceleration from the P1 measuring point

Fig. 15 Oscillogram of RMS acceleration from the P1 measuring point

Table 5 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P2 measuring point, determined experimentally on the three coordinate axes.

The numerical values in Table 5 are presented in a graphical form in Fig. 17.

From Table 5 and Fig. 17, it is observed that the highest values of vibration acceleration are along the Oz vertical direction. For example, the maximum RMS

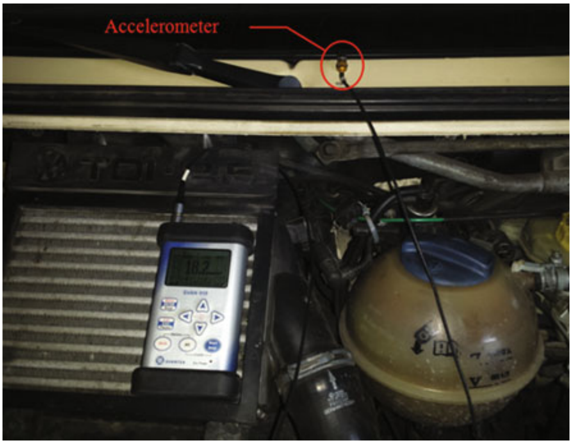


Fig. 16 Location vibration measuring system for the P2 measurement point

Table 5 Effective vibration accelerations obtained on the three channels in the P2 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	99.655	181.134	18.030	16.943
Ch2	96.939	179.887	18.009	16.866
Ch3	96.383	184.289	18.281	17.080

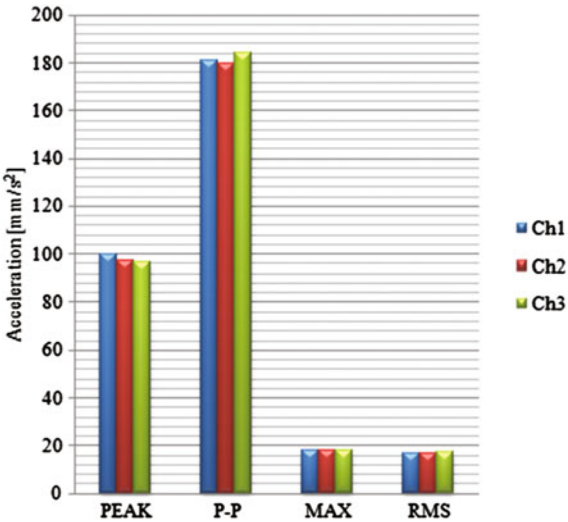


Fig. 17 Chart of effective vibration acceleration measured in the P2 measuring point

acceleration along the Oz vertical direction is 17 mm/s^2. This is confirmed by the oscillogram given in Fig. 18.

Vibration measurement mode, in P3 measurement point is illustrated in Fig. 19.

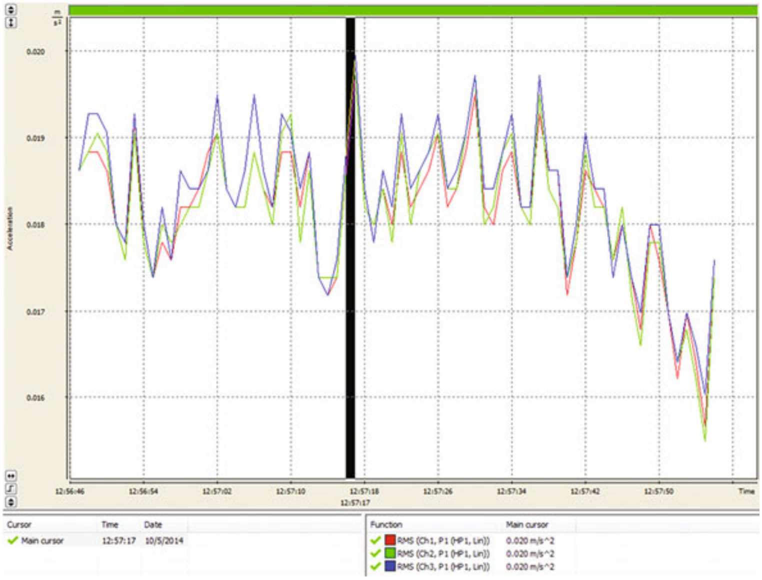


Fig. 18 Oscillogram of RMS acceleration from the P2 measuring point

Fig. 19 Location vibration measuring system for the P3 measurement point

According to Fig. 19, the measurement axes of vibrations have the following correspondence with accelerometer measuring channels:

– Ox axis measurement for channel 1 is Ch1;
– Oy axis measurement for channel 2 is Ch2;
– Oz axis measurement for channel 3 is Ch3.

Table 6 contains the effective values of vibration acceleration, type Peak, Peak-to-Peak (P-P), Maximum and RMS (Root Mean Square), obtained in P3 measuring point, determined experimentally on the 3 coordinate axes.

Table 6 Effective vibration accelerations obtained on the three channels in the P3 measurement point

Measurement canal	Acceleration (mm/s^2)			
	PEAK	P-P	MAX	RMS
Ch1	710.395	1345.860	257.040	244.343
Ch2	732.825	1380.384	318.787	291.407
Ch3	573.456	1026.833	197.015	188.582

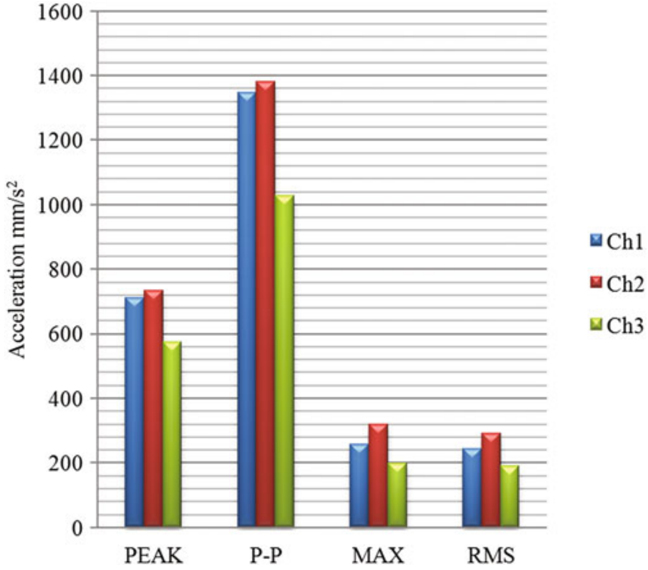


Fig. 20 Chart of effective vibration acceleration measured in the P3 measuring point

The numerical values in Table 6 are presented in graphical form in Fig. 20.

From Table 6 and Fig. 20, it is observed that the highest values of vibration acceleration are along the Oy transversal direct. For example, the maximum RMS acceleration along the Oy transversal direction is 291.4 mm/s^2. This is confirmed by the oscillogram given in Fig. 21.

Analyzing the results of vibration obtained from the three measuring points of the second vehicle, it follows that the acceleration is highest at the P3 point, i.e., the front seat, along the Oy transversal direction. Also acceleration values obtained for the first two measurement points are very close.

Fig. 21 Oscillogram of RMS acceleration from the P3 measuring point

5 Maintenance Operations History of the Two Vehicles

Knowing the maintenance operations history, it is necessary to make a correct analysis of the results as vibration measurements in order to make a diagnosis by comparing the values obtained.

To prevent technical failures and restoring regular working capacity of vehicles is performed a number of periodical works with preventive or corrective character, by various complexity. Routine maintenance is characterized by typology, periodicity, and planning.

Preventative car maintenance and routine inspections can go a long way when it comes to keeping the car in peak condition. Following the manufacturer's car maintenance schedule will save time and money. When it adheres to vehicle maintenance guidelines, it is necessary to take action against unwelcomed damage and future costly repairs.

Periodicity of maintenance work is expressed in traveled units, namely equivalent kilometers and it is established by normative function of vehicle and maintenance type.

Repairs have different degrees of complexity. These are the following:

(a) current repair: technical corrective interventions and troubleshooting applied during operation;
(b) average repairs: technical corrective interventions consisting of partial disassembly, repair, or replacement of aggregates and other review;

(c) major repairs: complex technical interventions that involve complete disassembly of motor vehicles and reconditioning of all components so as to achieve initial operating parameters (parameters set in the factory).

Table 7 contains the history of the first vehicle maintenance operations for the last 7 years.

Table 8 contains the history of the first vehicle maintenance operations for the last 3 years.

From Tables 7 and 8 are observed that in both vehicles were respected periodic maintenance periods and current repairs and media interventions were performed.

Table 7 The first vehicle maintenance operations

Type of intervention	Date	Indicated km
Replace distribution system	25.07.2007	158,000
Change engine oil and filter	29.08.2007	160,000
Change clutch kit: disc, pressure bearing, pressure plate	01.02.2008	166,820
Change rotule (upper and lower)	01.02.2008	166,820
Change alternator belt	01.02.2008	166,820
Change gas oil filter	06.04.2008	175,000
Change return hose (injectors)	06.04.2008	175,000
Change engine oil and filter	11.04.2008	175,000
Change gearbox oil	11.04.2008	175,000
Change right steering power link and bellows	17.05.2008	178,300
Change engine oil and filter	09.09.2008	196,399
Change pollen filter	09.09.2008	196,399
Change brake pads, front	12.09.2008	197,000
Change distribution system: rollers, water pump, belts, valves, cleats	04.02.2009	205,000
Change engine oil and filter	06.07.2009	212,331
Change alternator bearings	06.07.2009	212,331
Change brake pads, rear left	07.07.2009	225,000
Change air filter	20.07.2009	225,250
Change engine oil and filter	29.07.2009	226,770
Change two tires, front	29.07.2009	226,770
Change 4 rotule (2 inferior, 2 superior), head straight bar 4 bushings steering box, torsion bar bushings.	12.08.2009	229,900
Change power steering oil	12.08.2009	229,900
Setting direction	12.08.2009	229,900
Change clutch kit: disc, pressure bearing, pressure plate, flywheel	10.09.2009	236,400
Change engine oil and filter	28.09.2009	240,629
Change front brake pads	06.11.2009	244,000
Change engine oil and filter	22.12.2009	253,240

(continued)

Table 7 (continued)

Type of intervention	Date	Indicated km
Change gas oil filter	22.12.2009	253,240
Change airflow	22.12.2009	253,240
Change air filter	20.03.2010	262,580
Replace distribution system	22.03.2010	263,000
Change engine oil and filter	15.04.2010	267,020
Replace belts, accessories	26.04.2010	271,000
Change tensioner belt accessories	30.05.2010	273,000
Change pollen filter	30.05.2010	273,000
Change front tire	21.06.2010	276,214
Change engine oil and filter	25.06.2010	279,300
Change engine oil and filter	20.12.2010	293,000
Change brake pads, front and rear	23.12.2010	296,700
Repair steering box	20.01.2011	300,000
Change engine oil and filter, air filter	22.03.2011	302,500
Change front tire	01.06.2011	311,000
Change engine oil and filter	09.07.2011	317,800
Change pollen and airs filters, distribution system, bellows, belt, drive shaft	25.07.2011	319,450
Change telescopes	21.09.2011	325,500
Change engine oil and filter, air filter, gas oil filter	31.10.2011	333,626
Change front brake pads and pollen filter	10.03.2012	344,825
Change engine oil and filter and air filter	05.04.2012	345,500
Change brake pads and bearing, rear	06.06.2012	35,200
Change vacuum pump, tires, gas oil filter, stabilizer bar bushings, anti-roll connecting rods	12.11.2012	366,295
Change engine oil and filter	20.12.2012	371,000
Change engine oil and filter	22.06.2013	382,359
Change distribution system, water pump, compressor bearing	26.06.2013	382,441
Change rear brake pads	10.10.2013	392,000
Change engine oil and filter and air filter	09.11.2013	393,434
Change pivots, bushings, gearbox support	04.12.2013	395,000
Change engine oil and filter and air filter	03.03.2014	404,146
Change alternator bearings, brushes, coil collectors	28.05.2014	414,339
Change engine oil and oil filter, air filter, gas oil filter, brake sleeves	28.05.2014	414,339
Change engine oil and oil filter, air filter, gas oil filter, brake sleeves	27.08.2014	426,000

Table 8 The second vehicle maintenance operations

Type of intervention	Date	Indicated km
Change engine oil and filter	22.06.2012	402,300
Change clutch kit: disc, pressure bearing, pressure plate	30.07.2012	407,700
Change engine oil and filter	01.09.2012	425,000
Change engine oil and filter	18.09.2012	429,500
Change engine	14.12.2012	445,000
Change engine oil and oil filter, air filter, gas oil filter	14.12.2012	445,000
Change engine oil and filter	18.02.2013	459,000
Change tire	03.03.2013	461,000
Change rear and front brake pads	09.05.2013	476,000
Change engine oil and filter	17.07.2013	489,000
Change pollen filter, air filter	27.08.2013	405,000
Replace distribution system	27.08.2013	405,000
Change engine oil and filter, air filter	12.09.2013	416,900
Change clutch kit: disc, pressure bearing, pressure plate	12.09.2013	416,900
Change engine oil and oil filter, air filter	28.11.2013	430,000
Change rear and front brake pads	28.11.2013	430,000
Change engine oil and filter, air filter	19.12.2013	442,000
Change pollen filter, air distribution system, bellows, drive shaft, belt	20.01.2014	452,300
Change engine oil and filter, air filter, gas oil filter	07.03.2014	476,000
Replace distribution system	20.04.2014	481,200
Change rear and front brake pads	05.05.2014	492,000
Change engine oil and filter, air filter	02.06.2014	508,700
Change pollen filter, air filter, distribution system	16.07.2014	522,000
Change engine oil and filter	01.08.2014	535,000
Change clutch kit: disc, pressure bearing, pressure plate	01.08.2014	535,000
Change engine oil and filter	05.11.2014	549,300
Change rear and front brake pads	23.10.2014	551,100
Change tire	23.10.2014	551,100
Change engine oil and filter, air filter, gas oil filter	12.12.2014	562,800

6 Comparative Analysis of Results

Comparing the results obtained by measuring vibration in three points, for two vehicles of the same brand but different years manufacturing can be observed the following:

- the first car is newer with 3 years to the second;
- the second car has a total running of more than 146,378 km than the first vehicle;

– the vibration values measured for the first vehicle are higher although it is newer than the second. This can be explained by the fact that the engine of the second car was changed in the last period of operation.
– the acceleration values obtained in the front seat, i.e., P3 measuring point, where the first vehicle is double the other case.

Distribution belts and water pump were replaced following the analysis of the data obtained and the specialist recommendation for the first vehicle.

7 Conclusions

After the comparative study of maintenance by using vibration measurements, the following can be concluded:

– the vibration behavior of vehicles differ according to the measuring point;
– the vibratory behavior of the vehicle depends on how their maintenance and repairs carried out especially during the operation;
– the maximum acceleration values are mainly along vertical direction, i.e., along the piston engine movement direction;
– because the engine of the second vehicle was replaced, it explains that the first vibrating higher. At the same time, we can say that the first motor vehicle engine shows superior vibration in the second case.

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