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TESTING THE CHARACTERISTICS OF FREE AND FORCED OSCILLATIONS ON FAP 2228 OFF-ROAD VEHICLE

*Aleksandar Mićović**
Technical Test Center, Belgrade, Serbia
Dr Vladimir Popović
Faculty of Mechanical Engineering, Belgrade, Serbia
Dragoslava Mićović
Academy of Criminalistic and Police Studies, Belgrade, Serbia
Snežana Jovanović
Technical Test Center, Belgrade, Serbia

The paper presents the testing of free and forced oscillations characteristics on FAP 2228 BS/A-45 off-road vehicle. The testing of free oscillations was conducted according to SORS 9127 (Standard of Defence of the Republic of Serbia) in laboratory conditions. The testing of forced oscillations was conducted in the course of driving on various surface paths - the heath in Deliblatska pescara, gravel at the territory of Fruska gora, on concrete surface at the runway of the Kovin airport, as well as on the asphalt surface of Belgrade-Šid highway. The testing was carried out according to SORS 0318 and ISO 2631 standards, and the results were evaluated according to 2002/44/EC Directive.

Key words: FAP 2228 BS/A-45, Forced oscillations, Free oscillations, Testing, Comfort

INTRODUCTION

The concept of military vehicles refers primarily to engine-driven special purpose off-road vehicles. It covers various military systems driven by internal combustion engines, such as tanks, infantry armoured fighting vehicles, as well as a number of other special superstructures on off-road vehicles. This is exactly the group of vehicles which are not covered by ecological standards in practice.

Figure 1: FAP 2228 BS/A-45

As these vehicles are not used only during war, but also in peace time, it is necessary to establish the standards which must be applied in order to protect the health of their users. A special problem related to military vehicles results from the fact that they are very durable and last long, and therefore they do not fulfil the standards which the automobile industry started applying in the last ten years [05, 07]. Also, due to the special requirements set before the manufacturers regarding dynamic passability, the autonomous movement, the reliability of fitted components, as well as the accommodation of special equipment and weaponry, the price of manufacturing such vehicles is very high. It is a frequent case in practice that during the designing of superstructures to be installed on a basic type of a vehicle the constructors are faced with huge problems how to reduce the level of vibrations and noise inside the cabin to an acceptable level required for uninterrupted operation of the carrier [06, 08]. The main and transversal supports are connected by screws and rivets. The platform is equipped with JOST locks for container connecting. Overall dimensions of the vehicle are (length x width x height) 9,615 x 2,500 x 3,180 mm.

* Technical Test Center, Vojvode Stepe 445, 11000 Belgrade, Serbia; amicovic1@gmail.com

FATIGUE AND VIBRATIONS

Military vehicles are primarily used in off-road, or all terrain conditions. When they are tested, the test drivers from Technical Testing Centre usually cover several thousands of kilometres on various surfaces and in various weather conditions, putting them to test by intensive driving.

Most of these vehicles are in prototype stage of development where various functional failures are possible. This is why the concentration of a test driver is of great importance for the safety of testing. However, the necessary consequence of intensive driving testing is the fatigue which occurs in operators [01]. According to a definition, fatigue is a phenomenon occurring as a consequence of the activities of a human body as a whole or an organic system in overcoming various types of burden defined by work requirements. Fatigue warns a body to cease the activity due to overburden and possible consequences. The important characteristic of fatigue is reversibility.

When they are in drive, all types of vehicles can be a sources of vibrations which are transfered to the whole body of a driver. The risk of health damage increases in people who are exposed to high level of vibrations on a regular basis and over the long term. In order to determine a daily exposure to vibrations (A(8)) or VDV (Vibration Dose Value), it is necessary to know the duration of total daily exposure to vibrations produced by vehicles used during the work process. Only the data referring to the concrete work process should be taken into account at that, i.e. only the time period during which a driver or a crew member was exposed to vibrations.

Testing of the human exposure to vibrations which are transferred to the whole body is carried out according to the method defined in ISSO 2631-1:1997, while the detailed instructions on the application of the vibration measuring method are given in the European Standard EN 14253:2003. The level of vibrations expressed as r. m. s. value (root-mean-square) is expressed as acceleration weighted considering frequency measured at the seat of a person sitting in the course of performing their work tasks, i.e. the feet of the person who is standing during the performance of their work tasks, and it is given as m/s^2. The level of vibrations expressed as r. m. s. value is equal to average acceleration measured in the interval of measurement conducted. This is the highest of the three values measured in three orthogonal axes (1.4 awx, 1.4 awy or awz) [09].

The alternative measure of the level of exposure to vibrations is Vibration Dose Value (VDV). VDV has been developed as a measure which represents a better risk indicator or exposure to vibrations with shocks. VDV is expressed in meter per second on 1.75th (m/s1.75) and as opposed to the level of vibrations expressed as r. m. s. value it represents a cumulative measuring result, i.e. it increases as the measuring time is prolonged. This is why it is important to know during all VDV measurements in which time period the value was measured. It should be the highest value measured in one of the three orthogonal axes (1,4 VDVwx, 1,4 VDVwy or VDVwz) [04].

Risk assessment must enable to recognize the method which can control the exposure to vibrations. When evaluating the exposure to vibrations, the work processes that cause them must also be taken into account. Understanding of the manner in which the workers are exposed to vibrations will help recognize the method for the reduction or complete elimination of this exposure [02, 03].

VIBRATION (FREE AND FORCED) MEASURING

Portable MAESTRO human vibration meter, manufactured by 01dB-Metravib, was used to measure the vibrations on the seats of both the driver and passengers in the vehicle cabin and the superstructure. This meter is intended primarily for human vibration measuring, i.e. measuring and calculating the influence on the human body (measurement of vibrations at the workplace which are transferred to the whole body or to the hands).

Alternatively, it is used to measure the level of noise (as four-channel system, the first three channels are intended for three-axis accelerometers, and the fourth channel can be connected to the one-axis accelerometer or to a preamplifier with a microphone; it is adapted for measuring the efficiency of the seat and as a basic vibration meter).

Figure 2: Maestro

Figure 3: NetdB12

Its integration time ranges between 1 and 200 seconds and it has the possibility of start/stop mode, the memory capacity is 2 MB, as well as analogue output: 4-pin LEMO connector for signal recording or monitoring of all four channels within the range from 0.4 to 1000 Hz. The autonomous operation (when not plugged in mode) depends on the battery life and on an average it is from 8 to 13 hours. Free oscillations were measured by NetdB12 (01dB Metravib) vibroacoustic measuring system manufactured by Areva, as well as NF piezoelectric accelerometers (type STS AS135/1A).

FREE OSCILLATIONS MEASURING

Testing of free oscillations was carried out in laboratory conditions on a flat concrete surface according to SORS 9127. The vehicle is equipped with dependent elastic suspension system on the front bridge with leaf springs, additional rubber cushions and telescopic hydraulic shock absorbers (left and right).

Measurements were carried out on two points:

- M_1 – vehicle frame above the middle of the axle, and
- M_2 – vehicle frame above the centre of the tandem of vehicle back axles.

Exciting a vehicle to natural oscillation is performed by stretching, i.e. free fall of the vehicle ends: front end for measuring point M_1 and rear end for M_2. Out of the recorded signal as evaluating parameters for free oscillations fo natural frequency and relative coefficient of damping Ψ are taken. As SORS 9127 refers to comfort characteristics – the evaluation of fo and Ψ parameters is given according to the criteria for human organism. From the recorded oscillation signals the values of fo and Ψ parameters were calculated in the form of damped sine wave and the results are shown in Table 1. On the front axle (M_1) the parameter of natural frequency suggests comfortable drive, while the coefficient of damping lies on the dividing line between comfortable and uncomfortable driving.

Table 1: Natural frequency f_o and relative coefficient of damping Ψ

Vehicle	***Measuring points***	***Parameters***	***Measured values***	***Comfort evaluation***
FAP 2228 with container	M_1	f_o	2,3 Hz	Comfortable
		ψ	0,35	Conditionally comfortable
	M_2	f_o	3 Hz	Conditionally comfortable
		ψ	0,9	Uncomfortable

On the measuring point at the centre of tandem axle (M_2) the parameter of natural frequency is within the range of conditionally comfortable driving, and the coefficient of damping suggests extremely uncomfortable driving. Table 2 shows the results of measuring the total weight of the vehicle with the container, as well as the weight distribution on the sides and axles.

In addition to the surface on which the vehicle is being driven, one of the most important parameters that have significant influence on measuring results is also the speed of the vehicle. This parameter has been chosen based on more than 20-year-long experience of the researchers of testing vehicles on testing paths in both Deliblatska pescara and Fruska gora. Realistic average speed on this type of surface is 30 km/h, but in order to obtain a more comprehensive insight into the measuring results and their comparison, the testing was also carried out at the speed of 40 km/h. Figures 4 through 6 show the examples of measuring results, while Table 3 shows the general results for all types of surfaces and all vehicle speeds.

Table 2: Weight distribution on axles and sides

				Vehicle without the container [kg]	Vehicle with the container [kg]
Total weight, G_{tw}				**10900**	**16100**
WEIGHT DISTRIBUTION	**Front axle**		Left wheel, G_{fl}	2400	2380
			Right wheel, G_{fr}	2670	2620
			Total, G_f	5070	5000
	Tandem axle	**Middle axle**	Left wheel, G_{ml}	1550	2940
			Right wheel, G_{mr}	1540	2920
			Total, G_m	3090	5860
		Rear axle	Left wheel, G_{rl}	1360	2630
			Right wheel, G_{rr}	1380	2610
			Total, G_r	2740	5240
		Total tandem weight, G_T		5830	11100
	Left side of the vehicle, G_l			5310	7950
	Right side of the vehicle, G_r			5590	8150

Table 3: General review of forced oscillations measuring results

Path	Measuring point	Speed (km/h)	Equivalent three-axle acceleration related to comfort a_v (m/s^2)	Comfort evaluation	Equivalent three-axle acceleration related to health a_v (m/s^2)	Recommended maximum exposure
Asphalt	Driver	50	0.78	somewhat	0.85	22h22m13s
		60	0.74	somewhat	0.81	23h54m28s
		70	0.73	somewhat	0.80	24h34m1s
	Codriver	50	1.06	uncomfortable	1.13	11h7m22s
		60	1.04	uncomfortable	1.11	11h29m44s
		70	0.98	uncomfortable	1.04	12h55m2s
	Crew	40	0.64	somewhat	0.67	28h14m37s
		50	0.80	uncomfortable	0.84	18h17m1s
		60	1.33	very uncomfortable	1.40	6h43m18s
Concrete	Driver	60	0.88	uncomfortable	0.97	17h36m50s
		80	0.99	uncomfortable	1.08	13h28m10s
	Codriver	50	1.11	uncomfortable	1.19	10h10m39s
		70	1.05	uncomfortable	1.16	12h42m1s
Heath	Driver	30	1.18	uncomfortable	1.36	11h38m31s
		40	1.64	very uncomfortable	1.87	5h38m41s
	Codriver	30	1.36	very uncomfortable	1.50	7h26m32s
		40	1.57	very uncomfortable	1.73	5h30m06s
Gravel	Driver	20	1.06	uncomfortable	1.12	10h22m39s
		30	1.46	very uncomfortable	1.63	6h42m55s
		40	1.17	uncomfortable	1.32	10h55m4s
	Codriver	20	1.40	very uncomfortable	1.50	6h25m16s
		30	1.37	very uncomfortable	1.48	6h50m31s
		40	1.64	very uncomfortable	1.77	4h43m41s
	Crew	30	0.99	uncomfortable	1.07	12h43m28s
		40	1.43	very uncomfortable	1.51	5h46m11s

File	Vozac 40km MM1.cmg					
Location						
Start	05-03-13 11:11:47					
End	05-03-13 11:13:25					
Whole body						
Quality	Health					
Body position	Seated					
Measurement location	Seat					
Type	aw					
Axis	X	Y	Z	Overall	Overall	Exposure
Weighting	Wd	Wd	Wk	av	A(8)	
Coefficient	1.4	1.4	1			
Level (m/s2)	0.65	0.63	1.37			
Corrected (m/s2)	0.91	0.89	1.37	1.87	1.37	8h
Warning level (m/s2)					0.50	1h 4m 1s
Maximum level (m/s2)					1.15	5h38m41s
eVDV dose (m/s 1.75)	16.57	16.21	24.97			8h
Exposure level A(8) is above maximum level						

Type	Peak factor			
Axis	X	Y	Z	Max.
Peak factor	3.48	3.15	3.68	3.68
Peak factor is smaller than 9				
According to Standard 2631-1, A(8) assessment is recommended				

Type	VDV				
Axis	X	Y	Z	Max.	Exposure
Weighting	Wd	Wd	Wk	VDVeq	
Coefficient	1.4	1.4	1		
VDV dose (m/s 1.75)	2.81	2.67	6.40		
Corrected (m/s 1.75)	3.94	3.74	6.40	6.40	1m38s
Warning level (m/s 1.75)				9.10	
Maximum level (m/s 1.75)				21.00	
VDV level is below warning level					

File	Vozac 40km MM1.cmg			
Location				
Start	05-03-13 11:11:47			
End	05-03-13 11:13:25			
Whole body				
Quality	Comfort			
Body position	Seated			
Measurement location	Seat			
Type	aw			
Axis	X	Y	Z	Overall
Weighting	Wd	Wd	Wk	av
Level (m/s2)	0.65	0.63	1.37	1.64
1.25 m/s2 <= Aeq <= 2.50 m/s2 : very uncomfortable				

Figure 4: Driver's seat, speed 40 km/h, heath

CONCLUSION

In order to obtain more comprehensive results on asphalt and concrete surfaces respectively, the measurements were carried out at constant speeds ranging from 40 to 80 km/h. Tests were made on the Kovin airport runway and on the part of highway near Sremska Mitrovica. Regardless of a relatively wide speed interval, the results obtained of the equivalent levels of vibrations at the driver's seat range from 0.9 to 1 m/s2 for the concrete surface and about 0.75 m/s2 for asphalt surface; it can, therefore, be concluded that various speeds on either concrete or asphalt surface do not have any significant influence on the level of vibrations on either driver's or co-driver's seat. It can be noticed that at the same speed the vibrations at the co-driver's seat are about 10% higher on a concrete surface, but also about 30% on the asphalt surface.

File	Vozac 80 Asfalt pista Kovin.cmg					
Location						
Start	14-11-12 16:30:43					
End	14-11-12 16:32:05					
Whole body						
Quality	Heath					
Body position	Seated					
Measurement location	Seat					
Type	aw					
Axis	X	Y	Z	Overall	Overall	Exposure
Weighting	Wd	Wd	Wk	av	A(8)	
Coefficient	1.4	1.4	1			
Level (m/s2)	0.34	0.28	0.89			
Corrected (m/s2)	0.48	0.39	0.89	1.08	0.89	8h
Warning level (m/s2)					0.50	2h32m46s
Maximum level (m/s2)					1.15	13h28m10s
Exposure level A(8) is above warning level						

Type	Peak factor			
Axis	X	Y	Z	Max.
Peak factor	3.18	3.18	3.83	3.83
Peak factor is smaller than 9				
According to Standard 2631-1, A(8) assessment is recommended				

Type	VDV				
Axis	X	Y	Z	Max.	Exposure
Weighting	Wd	Wd	Wk	VDVeq	
Coefficient	1.4	1.4	1		
VDV dose (m/s 1.75)	1.38	1.13	4.32		
Corrected (m/s 1.75)	1.94	1.58	4.32	4.32	1m22s
Warning level (m/s 1.75)				9.10	
Maximum level (m/s 1.75)				21.00	
VDV level is below warning level					

File	Vozac 80 Asfalt pista Kovin.cmg			
Location				
Start	14-11-12 16:30:43			
End	14-11-12 16:32:05			
Whole body				
Quality	Comfort			
Body position	Seated			
Measurement location	Seat			
Type	aw			
Axis	X	Y	Z	Overall
Weighting	Wd	Wd	Wk	av
Level (m/s2)	0.34	0.28	0.89	0.99
0.80 m/s2 <= Aeq <= 1.60 m/s2 : uncomfortable				

Figure 5: Driver's seat, speed 80 km/h, asphalt

File	Suvozac 50 Asfalt pista Kovin.cmg					
Location						
Start	14-11-12 16:34:06					
End	14-11-12 16:35:47					
Whole body						
Quality	Health					
Body position	Seated					
Measurement location	Seat					
Type	aw					
Axis	X	Y	Z	Overall av	Overall A(8)	Exposure
Weighting	Wd	Wd	Wk			
Coefficient	1.4	1.4	1			
Level (m/s2)	0.32	0.29	1.02			
Corrected (m/s2)	0.45	0.41	1.02	1.19	1.02	8h
Warning level (m/s2)					0.50	1h55m26s
Maximum level (m/s2)					1.15	10h10m39s
Exposure level A(8) is above warning level						
Type	Peak factor					
Axis	X	Y	Z	Max.		
Peak factor	3.16	3.18	3.08	3.18		
Peak factor is smaller than 9						
According to Standard 2631-1, A(8) assessment is recommended						
Type	VDV					
Axis	X	Y	Z	Max. VDVeq	Exposure	
Weighting	Wd	Wd	Wk			
Coefficient	1.4	1.4	1			
VDV dose (m/s 1.75)	1.35	1.24	4.19			
Corrected (m/s 1.75)	1.89	1.73	4.19	4.19	1m41s	
Warning level (m/s 1.75)				9.10		
Maximum level (m/s 1.75)				21.00		
VDV level is below warning level						

File	Suvozac 50 Asfalt pista Kovin.cmg			
Location				
Start	14-11-12 16:34:06			
End	14-11-12 16:35:47			
Whole body				
Quality	Comfort			
Body position	Seated			
Measurement location	Seat			
Type	aw			
Axis	X	Y	Z	Overall av
Weighting	Wd	Wd	Wk	
Level (m/s2)	0.32	0.29	1.02	1.11
0.80 m/s2 <= Aeq <= 1.60 m/s2 : uncomfortable				

Figure 6. Co-driver's seat, speed 50 km/h, asphalt

Considering that both seats (the driver's and co-driver's) are equipped with the same type of seats, it can be concluded that the distribution of burder, as well as the choice of vehicle suspension system have influence on this irregularity. The oscillations measured during driving on the asphalt surface at the driver's and co-driver's seat suggest uncomfortable drive, particularly at the speed of 50 km/h.

Measuring of forced oscillations in the field following the comfort ability criteria suggests that driving at both the driver's and co-driver's seats can be classified as very uncomfortable on the macadam. This conclusion is also valid for the drive at the speed of 40 km/h on the heath. In general, the results for the co-driver's seat are more unfavorable. In regard to the criteria of harm to health, the driving in this off-road vehicle on both the heath and macadam surfaces should be limited in time until the stated warning levels of vibrations.

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