Deulgaonkar. 2016. *Int. J. Vehicle Structures & Systems*, 8(1), 23-27
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.8.1.05

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Vibration Measurement and Spectral Analysis of Chassis Frame Mounted Structure for Off-Road Wheeled Heavy Vehicles

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ABSTRACT:
Chassis mounted structure is a base component for shelters or containers mounted on heavy transport vehicles. When the vehicle is driven in rough terrains or during off-road transportation this structure has a significant role in protecting the sophisticated cargo and intelligent tracking systems placed inside the shelters. During off-road transportation or warhead conditions the vehicle is subjected to large unevenness in load due to road or soil irregularities in rough terrains, which causes vibrations to be induced in the vehicle. As the nature of vibrations induced in vehicle during travel on off-road or cross-country terrains is random and unpredictable, there is a concern to analyse the vibration response of chassis and chassis mounted structures is needed. Present work deals with vibration measurement and spectral analysis of a chassis mounted structure designed for off-road and commercial transport vehicles. The road profile on which the vibration measurement has been carried out includes paved road and cross-country terrain segments. The vibration measurement has been carried at three different vehicle speeds. Signal analysis procedure for the acquired test data is discussed. The chassis mounted structure under concern is intended to hold two shelters or containers. From the vibration measurement at critical locations, g-(RMS) and g-(peak) values for paved and cross-country roads have been found out. Power spectral density values have also been found on chassis and structure for the same transport situations. Major inferences include the evaluation of minimum and maximum g-values (peak & RMS) on chassis and chassis mounted structure. Power spectral density graphs are constructed from which the dominant frequency for both road profiles is found out.

KEYWORDS:
Vibration measurement; Off-road vehicle; Spectral analysis; Levelled base, Power spectral density

CITATION:
V.R. Deulgaonkar. 2016. Vibration Measurement and Spectral Analysis of Chassis Frame Mounted Structure for Off-Road Wheeled Heavy Vehicles, *Int. J. Vehicle Structures & Systems*, 8(1), 23-27. doi:10.4273/ijvss.8.1.05

1. Introduction

Off-road transport and off-road vehicles possess extensive position in commercial and defence applications for economic progress and safety of a nation. Off-road vehicles are categorized as wheeled vehicles intended for off-road transport and amphibians' intended for sea or water mode of transport. Off-road wheeled vehicles are utilized in applications such as agriculture, patrol, military rescue & fire-fighting operations, mining, construction and war-head situations [1]. Stability of wheeled off-road transport vehicle is of concern when it carries telecommunication devices, intelligent computer tracking systems that needs to be separated from surrounding environment due to requirement of specific temperature/pressure conditions for proper functioning of the circuitry involved. Closed containers or shelters mounted on a levelled base are used in circumstances where the cargo needs to be isolated from surrounding environment or when the vehicle is subjected to wide range of vibration levels.

Levelled base or chassis mounted structure is an integrated component with chassis frame of the vehicle [2]. The integration of platform with vehicle chassis is carried with the use of suitable number of U-bolts which are located at required locations over chassis length. Owing to varying magnitude of vibration levels in off-road travel situations, these threaded fasteners get loosened. Nassar et al [3] developed a mathematical model for vibration induced loosening of threaded fasteners subjected to harmonic excitation & devised integral equations for cyclic shear forces and bearing thread friction torques. They also established relationship between dynamic shear force and bending moment through a mathematical model based on relative slippage between the friction surfaces. In order to reduce the potential loosening of bolts at elevated amplitudes of vibration, these bolts must have to be tightened with higher pre-loads. They also should possess higher bearing and thread friction coefficients.

The need of levelled bases for off-road vehicles was identified by Senthilkumar et al [4]. They designed and developed a chassis frame mounted platform for Tatra 8x8 vehicles. Using finite element analysis, they simulated the behaviour of the platform under the action of load and experimentally verified the same using strain measurement technique. Vibration analysis has also been carried out to stipulate the dynamic behaviour of the platform for different tracks. Further this work on levelled bases for was extended by Deulgaonkar et al [5, 8-11] for applications including defence and commercial off-road transportation. They carried out hand calculations, finite element analysis and experimentation of chassis mounted platform for intense loads. They presented a method to calculate gross section modulus of combined sections used in heavy off-road vehicles when their platform is integrated with chassis. They prepared full scale computer aided models of platform and carried out finite element analysis of the same. They further experimentally verified the same platform by manufacturing a prototype. Close correlation has been observed between the experimental and finite element analysis results. They also stipulated the behaviour of chassis mounted structure for variant loads.

Horvath et al [6] determined the influence of payload on the dynamic stresses in vehicle structures. In their research, the transported load is accounted as passive mass. In commercial vehicles such as buses and trucks the transported load contributes to the vehicle vibrations not only as a mass but also due to result of its damping action and spring stiffness. They used realistic simulation of payloads which greatly alters the vehicle stresses as compared with passive modeling. They have also shown that in realistic vehicle models of elastic structure, active loads/passengers reduce the vehicle vibrations by 10 to 30%. Mills et al [7] created a finite element idealization of truck chassis and predicted deflections under various types of load. They determined torsion constants for beams with warping restraints by a subsidiary program using elements to represent beams. They evaluated the response of truck chassis for load conditions as out-of-plane bending, torsion, brake torsion and lateral loading. Thorough consideration of vibration inputs to the platform is much essential in carrying out design for dynamic loading conditions. The sources, which excite the vibrations of the vehicle structure fall into road roughness and on-board sources. The on-board sources arise from rotating components and include the tyre/wheel assemblies, the driveline, and the engine. The vibratory motion generated at the tyre-road interface gets transferred to the sprung mass of the vehicle through unsprung mass after attenuated by the suspension provided. The platform, which is mounted on the chassis, forms the part of sprung mass.

The spectral characteristics of vibration response of the sprung mass are normally seen to have been determined by natural frequencies of sprung and unsprung masses. By classical design of the motor vehicles, the sprung mass is chosen to have its natural frequency at or just above 1Hz. In this paper, vibration measurement and spectral analysis of a chassis mounted off-road and commercial transport vehicle structure are carried out for the paved road and cross-country terrains. From the vibration measurement at critical locations, g-(RMS), g-(peak) and Power Spectral Density (PSD) values have been processed to find out the dominant frequency for the paved road and cross-country terrains.

2. Vibration measurement

The measurement of vibration in terms of acceleration at critical locations on chassis mounted platform and selected locations on the chassis has been carried out. Measurements on the platform have been carried out mainly to find the acceleration levels and the frequency characteristics of vibration. This information on the level and the frequency characteristics is important in view of protection of sophisticated equipment mounted inside the shelter against the severity of vibration. Measurements on the chassis have been carried out to obtain the characteristics of vibration inputs transferred from chassis to platform for further use in finite element analysis of platform. Accelerometer locations for vibration measurement are selected on front, mid and rear portions of the platform. Vibration measurement is carried on paved and cross-country roads for five and four track segments respectively. The vehicle speeds for paved road were 15kmph and 25kmph and for cross-country road was 20kmph. Location of accelerometers for vibration measurement is shown in Fig. 1.

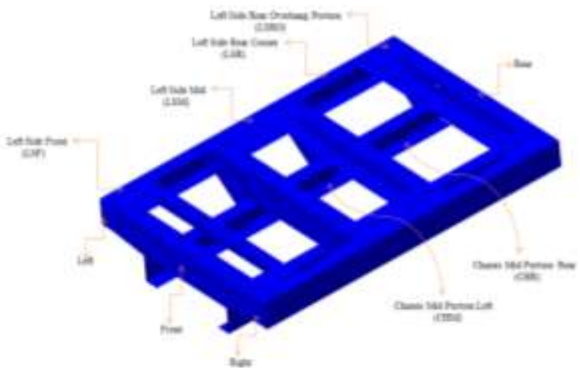

Fig. 1: Accelerometer locations on chassis mounted structure for vibration measurement

The test conditions are selected prevailing to the situations to which the vehicle is subjected during rough road travel. Instrumentation for the vibration measurement includes accelerometers, data acquisition system and analysis software. Vibration measurement was conducted on the paved and cross-country roads at constant speed. The sections of roads were selected such that they exhibit approximately uniform characteristics throughout their length. Constant speed and uniform characteristics of sections are prerequisites for obtaining stationary signals. The tyre inflation pressure maintained during the measurement was 300 MPa. The specifications of the accelerometer used for vibration measurement are given in Table 1. The accelerometer signals were transferred to the data acquisition system through Teflon jacketed cables. The data acquisition system used for measurement comprises of Wave Book 14 (WBK 14) and WBK 512. The data was acquired in two sets. The duration of signal acquisition for a single set on paved and cross-country track was 30 seconds. The specifications of the data acquisition system are given in Table 2. The vibration signals were acquired using Dasy-Lab software. The signals acquired were processed and the frequency analysis of these processed signals is carried out using HVLab (Human Vibration Laboratory) software. The acquired acceleration signals in time domain were first imported into HVLab software for analysis using IMPORT command. The signals have been processed to obtain Root Mean Square (RMS) values and PSD with 0.5 Hz resolution. The high frequency noise is filtered using Lobutter command.

Table 1: Specifications of the Senso-tech accelerometer

Parameter	Description
Sensitivity	15 mV/G (nom)
Mounted natural	27 kHz
Transverse sensitivity	5 % (max)
Frequency response	+/- 5% 2 Hz to 5 kHz
Output impedance	<100 Ω
Transducer resistance	1G Ω (min)
Strain sensitivity	1 G equivalent (max)
Shock	3000 G (peak half sine)
Vibration	2000 G (peak)
Operating temperature	-40^o to 200^o F
Electrical termination	10-32 UNF coaxial connector
Cable	5 Feet, Teflon Jacketed
Grounding	Single Return
Current	2 to 10 mA

Table 2: Specifications of data acquisition system

Parameter	Description
Environment	Operating: 0° - 50° C
Power consumption	512mA - 1.4A max @ 15VDC
Input power range	10 VDC to 30VDC
Input power fuse	F201, 4A Mini ATO
Vibration	MIL STD 810E
PC Communication	Enhanced parallel port
Channel capacity	8 built-in voltage channels

3. Results and discussion

For paved and cross-country tracks, the measured vibration g (RMS) and g (peak) values at six sections are summarized in Table 3 and 4 respectively. The vibration levels recorded on the platform vary with the type of test track and the driving speed(s). The maximum g- (RMS) value measured at platform rear is found to be more compared to the front and mid portions of the platform. The lower g-(RMS) values at front and mid portions are attributed to efficient load transfer from rear portion to the mid and front portions of the chassis mounted structure. Due to increased magnitude of load in mid and front portions on the platform, overall damping offered by the chassis mounted structure is raised at these locations resulting in low magnitudes of vibration. For each of the six vibration measurement locations on the chassis mounted structure on paved and cross-country tracks, the PSD curves are shown in Fig. 2 to 5. The peak values of PSD for both tracks are given in Table 5. The first peak is observed in the frequency interval of 0 to 5 Hz. This peak occurs at 1.4Hz (dominant frequency) in almost of all the spectral responses on the various locations on the platform and chassis.

Table 3: Vibration acceleration, g (RMS) levels

Track sections	Paved road, accelerometer locations						Cross-country track, accelerometer locations					
	LSF	LSM	LSR	LSRO	CHM	CHR	LSF	LSM	LSR	LSRO	CHM	CHR
1	0.168	0.158	0.213	0.201	0.140	0.2188	0.100	0.098	0.114	0.117	0.127	0.466
2	0.179	0.162	0.235	0.224	0.149	0.2560	0.122	0.122	0.143	0.148	0.127	0.278
3	0.202	0.165	0.210	0.208	0.139	0.2325	0.106	0.093	0.096	0.108	0.120	0.239
4	0.180	0.192	0.205	0.210	0.146	0.2568	0.121	0.107	0.114	0.134	0.121	0.153
5	0.179	0.169	0.201	0.189	0.123	0.2118	0.114	0.100	0.154	0.158	0.130	0.245
6	0.163	0.152	0.309	0.307	0.228	0.3788	0.102	0.088	0.122	0.142	0.118	0.222

Table 4: Peak acceleration, g (peak) levels

Track sections	Paved road, accelerometer locations						Cross-country track, accelerometer locations					
	LSF	LSM	LSR	LSRO	CHM	CHR	LSF	LSM	LSR	LSRO	CHM	CHR
1	0.715	1.921	1.473	1.352	0.705	0.910	0.537	0.658	0.607	1.240	0.410	1.41
2	0.767	1.250	1.881	2.323	1.530	3.090	1.156	1.744	3.142	3.410	1.010	1.61
3	0.927	1.060	1.541	0.890	0.595	0.903	0.924	0.700	0.548	0.568	0.683	1.06
4	0.823	2.703	1.016	1.120	0.773	1.161	0.789	0.832	2.272	2.764	2.900	1.85
5	0.935	1.024	1.183	1.064	0.700	1.395	0.896	0.474	0.831	1.087	0.635	1.12
6	0.731	1.340	2.366	2.33	2.286	2.064	0.560	0.420	0.666	0.791	0.542	1.05

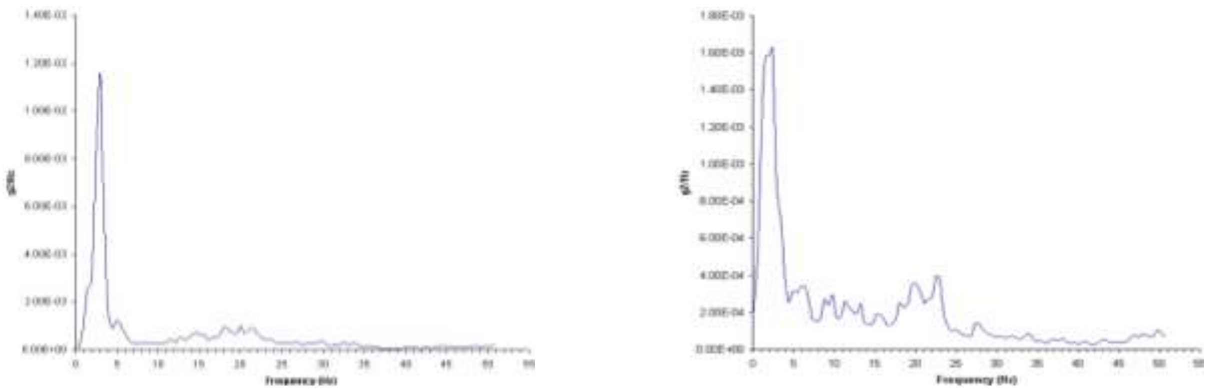

Fig. 2: PSD Curve for left side rear corner (LSR) on the platform, Paved road (Left) and Cross-country track (Right)

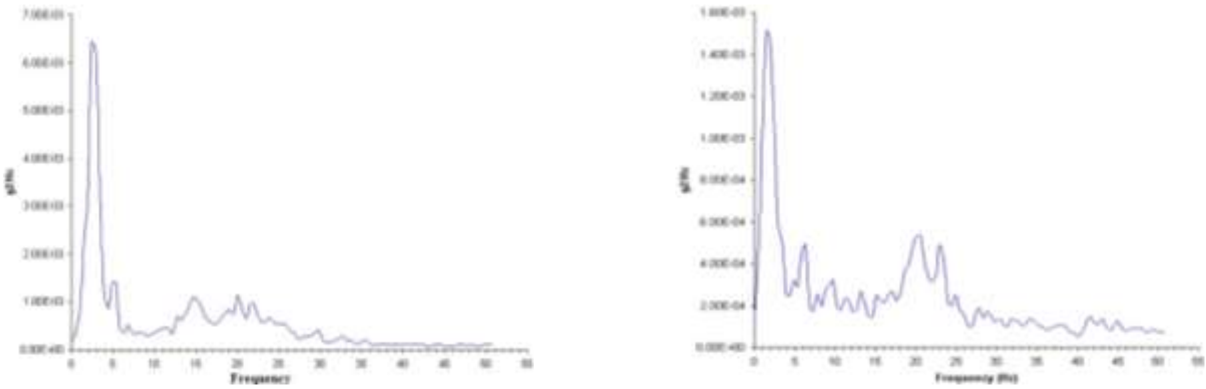

Fig. 3: PSD Curve for left side rear overhang portion (LSRO) on the platform, Paved road (Left) and Cross-country track (Right)

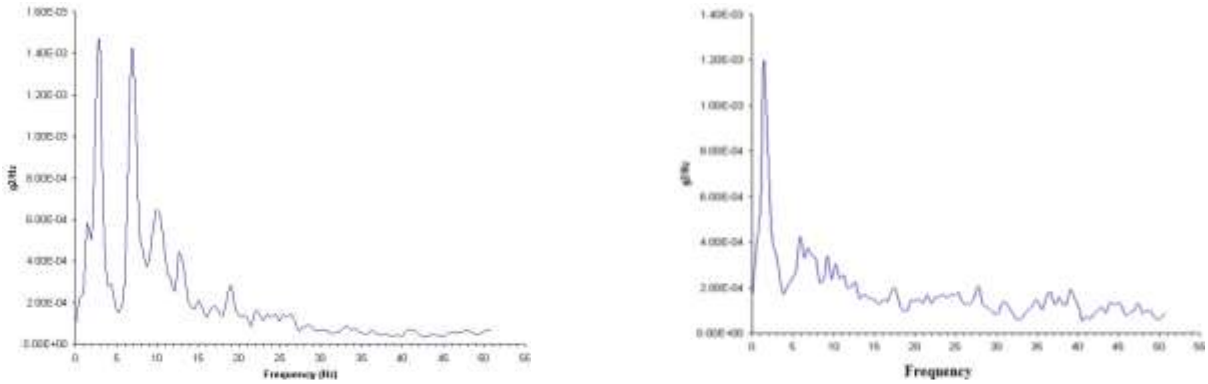

Fig. 4: PSD Curve for chassis mid portion left (CHM) on the platform, Paved road (Left) and Cross-country track (Right)

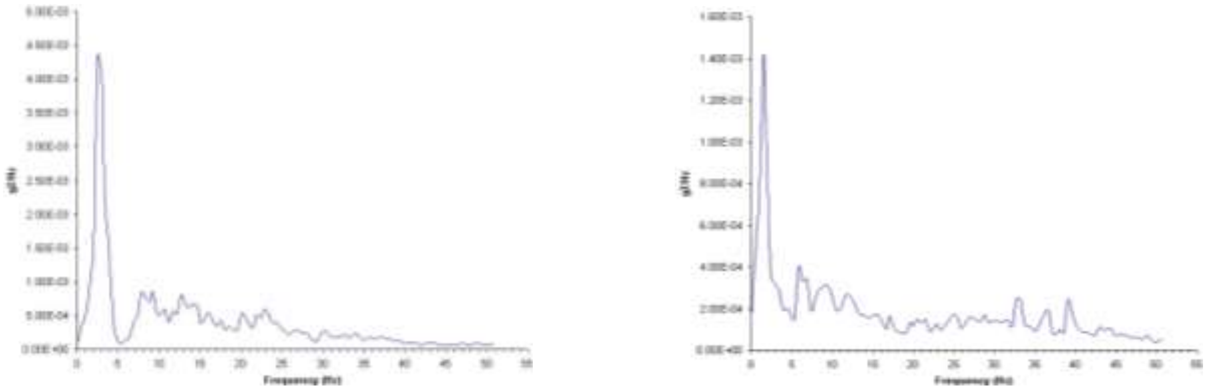

Fig. 5: PSD Curve for left side front (LSF) on the platform, Paved road (Left) and Cross-country track (Right)

Table 5: PSD ($\times 10^{-3}$ g^2/Hz) peak values

Track sections	Paved road, accelerometer locations						Cross-country track, accelerometer locations					
	LSF	LSM	LSR	LSRO	CHM	CHR	LSF	LSM	LSR	LSRO	CHM	CHR
1	3.193	1.636	12.0	6.210	2.220	3.424	63.37	52.15	1.688	1.978	90.07	136.0
2	2.615	1.205	12.0	7.719	1.632	3.791	1.420	1.194	1.623	1.507	63.15	1.516
3	3.684	1.588	5.56	5.707	9.592	1.627	54.61	50.63	49.70	51.91	35.05	1.115
4	4.667	3.282	4.39	4.937	1.351	2.025	1.287	70.26	93.17	93.43	55.85	1.380
5	1.557	2.020	11.0	6.396	1.451	3.651	1.070	83.81	1.531	1.874	77.16	1.351
6	4.334	4.024	7.40	6.509	3.979	2.954	78.88	48.65	3.443	4.580	5.354	2.186

4. Conclusions

The vibration measurement and spectral analysis of a chassis mounted structure designed for off-road and commercial transport vehicles on paved road and cross-country track at different vehicle speeds were undertaken in this paper. The vibration levels in terms of g-RMS and g-peak at six locations on the chassis platform and their PSD values are tabulated. The PSD graphs depicted the vibration characteristics of the chassis and the platform in frequency domain. The dominant frequency of all responses in found to be 1.4 Hz. The vibration levels at the rear of the platform were found to be higher than the other locations. This is due to efficient load transfer from the rear of platform to the mid and front portions of the platform leading to overall damping of chassis mounted platform. This result in lesser damage to the cargo inside the shelter mounted on platform.

ACKNOWLEDGEMENTS:

Author is grateful to Board of College & University Development, University of Pune for funding this research work. Author is grateful to Automotive Research Association of India, Pune for providing and S.P. Kallurkar, Principal, Atharva College of Engineering, Mumbai for his continuous support and guidance during this research. Author would like to thank K. Senthilkumar, Scientist F, Vehicles Research & Development Establishment, Ahmednagar, for always helping during this research. Author is thankful to Marathwada Mitra Mandal's College of Engineering, Karvenagar for providing necessary facilities and technical support during this research.

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