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MODAL ANALYSIS OF HEAVY VEHICLE TRUCK TRANSMISSION GEARBOX HOUSING MADE FROM DIFFERENT MATERIALS

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Abstract

Heavy vehicle truck transmission gearbox housing is subjected to load fluctuations, harmonic excitation, gear meshing excitation, gear defects, varying speed and torque conditions. Transmission errors and internal excitations are the root cause of vibration and noise. The main objective of this research work is weight calculation and modal analysis of gearbox housing. For weight calculation four different materials have been selected, apart from weight calculation the material mechanical properties influence on natural frequency and mode shape of transmission gearbox housing was also simulated using modal analysis. Grey cast iron FG260, Grey cast iron HT200, structural steel and Al alloys are the four materials used for the weight calculation process. Zero displacement constraint based boundary condition was applied for simulation. FEA based numerical simulation method was used to find the natural frequency, mode shapes and weight calculation of housing. The FEA simulation results show that the natural frequency of all materials varies (1669-4655) Hz. In weight calculation the weight of Al alloys housing is minimum (21.102 kg).The housing weight of Grey cast iron HT200 and FG260 is same, 54.85 kg. The density of structural steel is high, which increases the weight of housing as 59.80 kg. The modal analysis results show the lateral vibration, axial bending vibration, torsional vibration, and axial bending with torsional vibration. The vibration signature patterns for first twenty modes were studied for four different materials. Solid Edge and Pro-E software have good feature suited for complex geometric modeling. FEA based software Ansys 14.5 is used for modal analysis. The result of this research work has been verified with experimental result available in literature.

Keywords: Gearbox housing, Heavy vehicle truck transmission, Modal analysis, Weight calculation, Torsional vibration mode, Material mechanical properties.

1. Introduction

Noise and vibration harness for heavy truck gearboxes is an advanced field of research in automotive engineering. Researchers have done significant work in this area since past two decades. Heavy vehicle truck transmission gearboxes produce large vibration and noise. Transmission errors, meshing excitation, gear defects and load fluctuations are major sources of vibration. Selection of material for gearbox housing is an important task to reduce the vibration. This research work signifies the material mechanical properties impact on natural frequencies and mode shapes. It is observed from the previous studies that internal excitation is the reason for transmission housing failure.

Dogan [1] has done significant work to reduce the transmission gearbox noise and vibration. The torsional vibration of transmission components causes rattling and clattering noises, this noise is undesirable. For experimental analysis the transmission parameters were varied to reduce the effect of rattle and clatter noise. Wang and yang [2] have investigated the non-linearity on the tooth face in gear dynamics. For numerical simulation backlash, meshing stiffness and frictional forces were used. In this study the critical parameters were identified and chaos, bifurcation with sliding friction was studied. Abouel-Seoud and Abdallah [3] have used vibration response analysis method for the analytical analysis of car gearbox system. They have performed analytical and experimental analysis of a car transmission system. By using physical properties, they have calculated the radiation efficiency. Vandi and Ravaglioli [4] this paper presents the implementation of a simplified engine-driveline model to complete an existing vehicle dynamic model. The engage and disengaged phenomena of clutch were investigated. Nacib and Sakhara [5] have studied the heavy gearbox of helicopters. To prevent break down and accident in helicopters gear fault detection is important. Spectrum analysis and Cepstrum analysis method is used to identify damage gear. Fourier analysis is used for analytical results. Gordon and Bareket [6] have studied the source of vibration. A Sports Utility Vehicle with sensor and data acquisition system is used to find the vibration source. This study was focused on vehicle vibration response from road surface features.

Kar and Mohanty [7] have used motor current signature analysis (MCSA) and discrete wavelet transform (DWT) for studying the gear vibration. Two sources of vibration, transmission errors and gear defects were identified. Czech [8] has described the vibro-acoustic diagnostics of high-power toothed gears. The presented analysis was a experimental work done in a steel plant. The methods of time-frequency, scale-frequency and frequency-frequency analysis were used for vibroacoustic diagnostics. Singh [9] has done two case studies for the vibro-acoustic analysis of automotive structures. Analytical and experimental results were presented for brief description. In first case passive and adaptive hydraulic engine mounts and in second case welded joints and adhesives in vehicle bodies were considered. Tuma [10] has performed the experimental analysis on TARA trucks and found the range of frequency for transmission housing vibration. Jiri Tuma has solved the gear noise problem by introducing an encloser to reduce radiated noise. Fourier transform method is used for the analytical analysis. Analytical result is verified using experimental investigation. The natural frequency of vibration is varying in between 500 Hz to 3500 Hz at varying rpm. The severe vibration occurs at the frequency range of (500-2500) Hz.

Yu and Xia [12] have used the FEM for the structure optimization of the gearbox housing. Grey cast iron HT200 was used as housing material. The simulation results of study were verified with experimental results. Structural optimization method was used to reduce the noise and vibration of gearbox. Pro/E was used as modeling tool. Kuo [13] the objective of this research work was to establish a system model for an AT powertrain using Matlab/Simulink. This paper further analyses the effect of varying hydraulic pressure and the associated impact on shift quality during both engagement and disengagement of the joint elements. Yulong and Weipeng [14] the article focused on a dual-clutch automatic transmission of its hydraulic system. They have calculated the structure size of each body through theory and practical algorithm. The dynamic simulation analysis of hydraulic system for dual clutch automatic transmission was established. Sayer and Busmann et al. [15] this paper highlights the influence of material mechanical properties. The present work investigates about change of material properties by influence of loads and environmental conditions. The DEBRA-25 wind turbine blades from 1984 have been selected as research object. The results of a detailed visual inspection of the blades are described. The experimental work has been performed for the relaxation behaviour of the coupling joints, a full scale static blade test and the natural frequencies of the blade were found.

Kostic and Ognjanovic [16] have investigated the natural vibrations of the gearbox housing walls and concluded that vibration and noise can be reduced by varying designing parameters. Miyasato and Junior [17] this work deals with the testing of clutch and the torsional model response. The results were obtained using numerical integration. Minfeng and Yingchun [18] have considered the case of fatigue life estimation for automobile components using FEM. To predict the service life of automobile parts this study plays a significant role. De-gang and Fengzhou [19] have studied that automobile gearbox were subjected to harmonic excitation and meshing excitation which causes vibration and noise problem. FEM has been used as tool to study the fatigue life of components. Saada and Velex [20] have studied the planetary gear trains. The dynamic response was measured using an extended model of gear train system. Velex and Flamand [21] have experimented on planetary trains to study the excitation causes. They have investigated the root cause of harmonic and mesh excitations and concluded that these excitation forces were transmitted to the housing from shaft and bearing causing vibration problem. Li and Guagnqiang [22] have designed a virtual test rig of rear suspension system and studied the fatigue behaviour. The dynamic loading and changing loading conditions cause fatigue failure of suspension. Yu li have developed a virtual real time model to study the design parameters. Kumar and Patil [26] have studied the transmission casing using different materials for fixed-fixed based boundary condition. The natural frequency and mode shape were studied. This analysis can be performed for zero displacement based boundary condition.

The author's research of dynamic characteristics of transmission gearbox housing has significant impact on reduction of vibration and noise. Grey cast iron has good damping properties to reduce the magnitude of vibration waves. The wrong shifting of gears causes clashing. Clashing is a loud noise produced during collision of gear tooth and this collision leads the transmission failure. The transmission gearbox housing provides the fluid tight housing and supports the mountings with moving parts. Transmission fluid reduces the temperature of gear box assembly by releasing the heat through convection. The transmission housing is subjected to axial bending vibration, torsional vibration and axial bending with torsional vibration. The transmission housing motion was constrained using zero displacement constraint based boundary condition. The main objective of this research work is to study the influence of mechanical properties of different materials on natural frequencies and mode shapes of vehicle transmission housing using modal analysis and weight calculation. In this study oil pressure was not considered and sensitivity analysis was not necessary.

2. CAD Model of Transmission Gearbox Housing

The modeling of heavy vehicle truck transmission gearbox housing consists of more than 600 parts. The assembly of gearbox consists of shafts, gears and mountings etc. In present model various reinforcing ribs, drain hole, corners, bosses and fillets and all kinds of bolt holes were considered. Solid Edge and Pro-E [24-25] were used as modeling tools suited for complex geometry. Numerical simulation based Finite Element Analysis (FEA) have powerful analysis features and its results are reliable for product performance measurements. Free vibration analysis was performed and first twenty inherent natural frequencies and mode shapes were evaluated. In order to get the results enough close to the actual situation, only few parts of gearbox was reduced to simplify the design procedure and these parts have no effect on natural frequency. The 3D CAD model of transmission gearbox housing is shown in Fig.1. For free vibration analysis finite element based software, Ansys 14.5 [23] has been used. Figure 2 shows the discretized FEA model of transmission gearbox housing. The meshed model of grey cast iron HT200 consists of 196137 nodes and 113566 elements. Meshing is coarse and fine depends upon geometry. Tetrahedron and hexahedral elements were used for meshing.

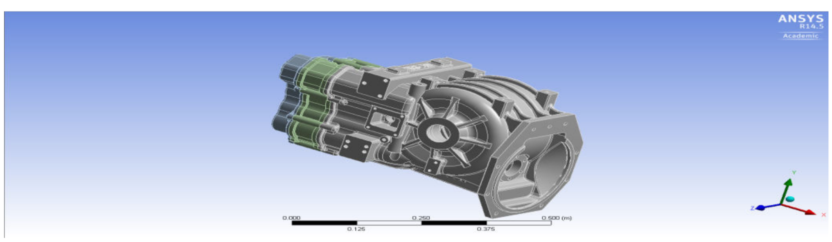


Fig. 1. Model of vehicle transmission gearbox housing.

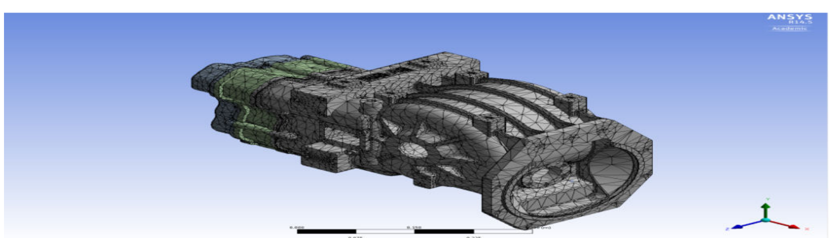


Fig. 2. Meshed model of transmission gearbox housing.

3. Mechanical Properties and Boundary Condition

Grey cast iron has been used as gearbox housing material. It has good damping and manufacturing properties suited for heavy vehicle gearbox housing. Transmission housing is manufactured by casting process in two parts. The materials mechanical properties density, Young's modulus, poisson's ratio, bulk modulus and shear modulus were required for numerical simulation of free vibration. Material properties of grey cast iron HT200 [12], grey cast iron FG260 [11], structural steel and Al alloys properties were taken from materials library of Ansys 14.5 (Table 1). Material based nonlinearity has been considered in this research article. These four materials are used for manufacturing of housing in industry so these are considered for analysis.

Table 1. Materials mechanical property.

Materials	Density (kgm^{-3})	Young's Modulus (Pa)	Poisson's Ratio	Bulk Modulus (Pa)	Shear Modulus (Pa)
Grey Cast Iron HT200	7200	1.1e+011	0.28	8.33e+010	4.296e+010
Grey Cast Iron Grade FG 260	7200	1.28e+011	0.26	8.89e+010	5.07e+010
Structural Steel	7850	2.0e+011	0.30	1.67e+011	7.692e+010
Al Alloys	2770	7.1e+010	0.33	6.96e+010	2.669e+010

Free-free boundary condition applied no constraint on the movement of transmission housing. Housing is free to move in all direction having 6 dof. Due to free movement in all direction, the amplitude of vibration is high. So this boundary condition is not much suited for control of vibration. The zero displacement constraint based boundary condition were applied by constraining the 37 connecting bolts hole positions against motion. In actual term this boundary condition signifies that the vehicle housing is tightly mounted on chassis frame using 37 connecting bolts and constrained to move in all direction by fixing 6 degree of freedom of housing. Figure 3 shows the five directional constraint positions of transmission gearbox housing. Housing is tightly fixed on vehicle chassis frame using 37 constraint bolts to prevent the looseness condition. Ansys 14.5 based workbench module has good simulation features. For simulation to obtain the natural frequencies and mode shapes, suitable boundary condition representing practical application was applied. In software environment to simulate this zero displacement constraint based boundary condition connecting bolts hole positions were fixed (Fig. 3). So all dof is constraint and housing is rigidly fixed on chassis. Loose transmission may cause excess vibration and harm to transmission system [1]. So the transmission system may be fully tight mounted on chassis using bolts.

4. FEA Simulation Results and Discussion

The FEA based free vibration analysis of truck transmission gearbox housing evaluates result for first twenty inherent natural frequencies and mode shape. Table 2 shows the variation of natural frequencies for all four materials. Zero displacement constraint based boundary condition was used for the simulation.

The FEA simulation shows that the natural frequencies of grey cast iron HT200 varies (1669-3576) Hz, grey cast iron FG260 varies (1801.4-3852.6) Hz, structural steel (2155-4625) Hz and Al alloys (2163-4655) Hz. The higher order frequency variation shows the excellent structural rigidity by eliminating lower order frequency (Table 2). The critical frequency range for heavy vehicle truck transmission housing varies (0-74) Hz. So in order to eliminate the resonance the frequencies should not fall in this range. The present simulation results show higher order frequency (1669-4655) Hz, much higher than critical frequency. For trucks Lower order frequency causes resonance of gearbox housing. Resonance occurs due to matching of harmonic excitation frequency with natural frequency of gearbox causing excessive vibration and leads to failure of vehicle transmission system. Higher order frequencies of a material housing ensure prevention from resonance. Free vibration analysis results conclude, all materials are suitable for transmission housing manufacturing. Figure 4 shows the ten selected mode shapes and corresponding natural frequency of grey cast Iron HT200 transmission gearbox housing.

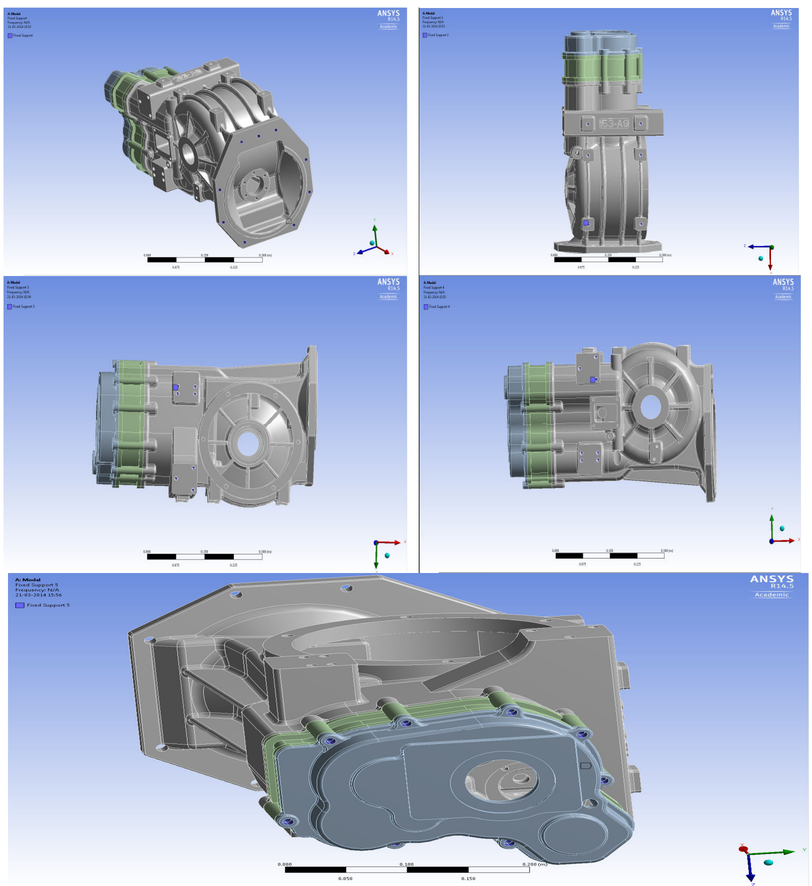
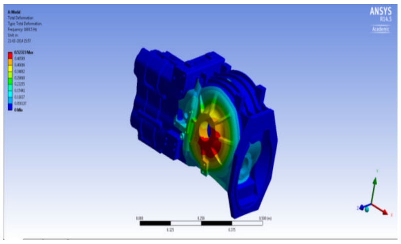
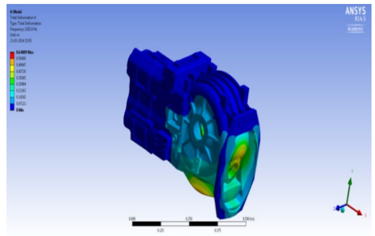


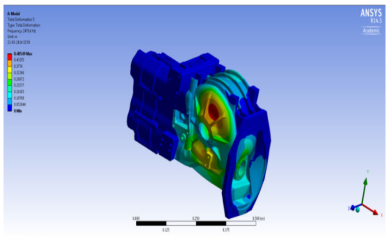
Fig. 3. Connecting bolts constraint positions of transmission gearbox housing.



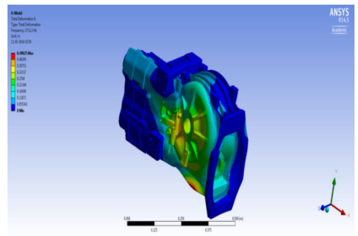
Mode 1 f1= 1669.3 Hz



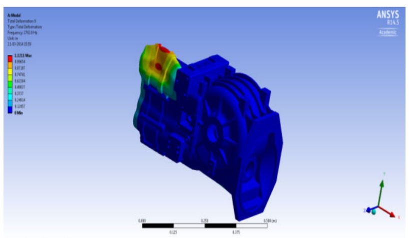
Mode 4 f4= 2282.8 Hz



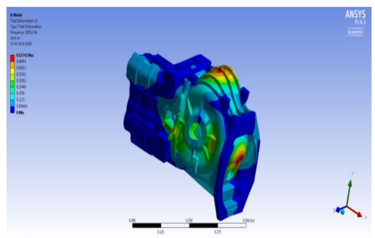
Mode 5 f5= 2479.6 Hz



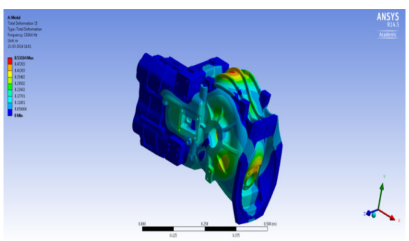
Mode 8 f8= 2711.3 Hz



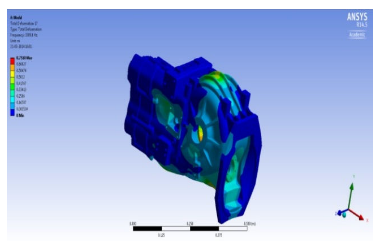
Mode 9 f9= 2762.9 Hz



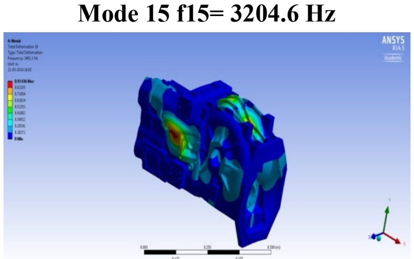
Mode 11 f11= 2925.6 Hz



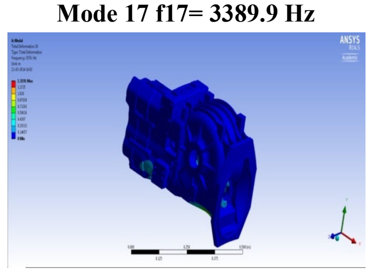
Mode 15 f15= 3204.6 Hz



Mode 17 f17= 3389.9 Hz



Mode 19 f19= 3491.1 Hz



Mode 20 f20= 3576 Hz

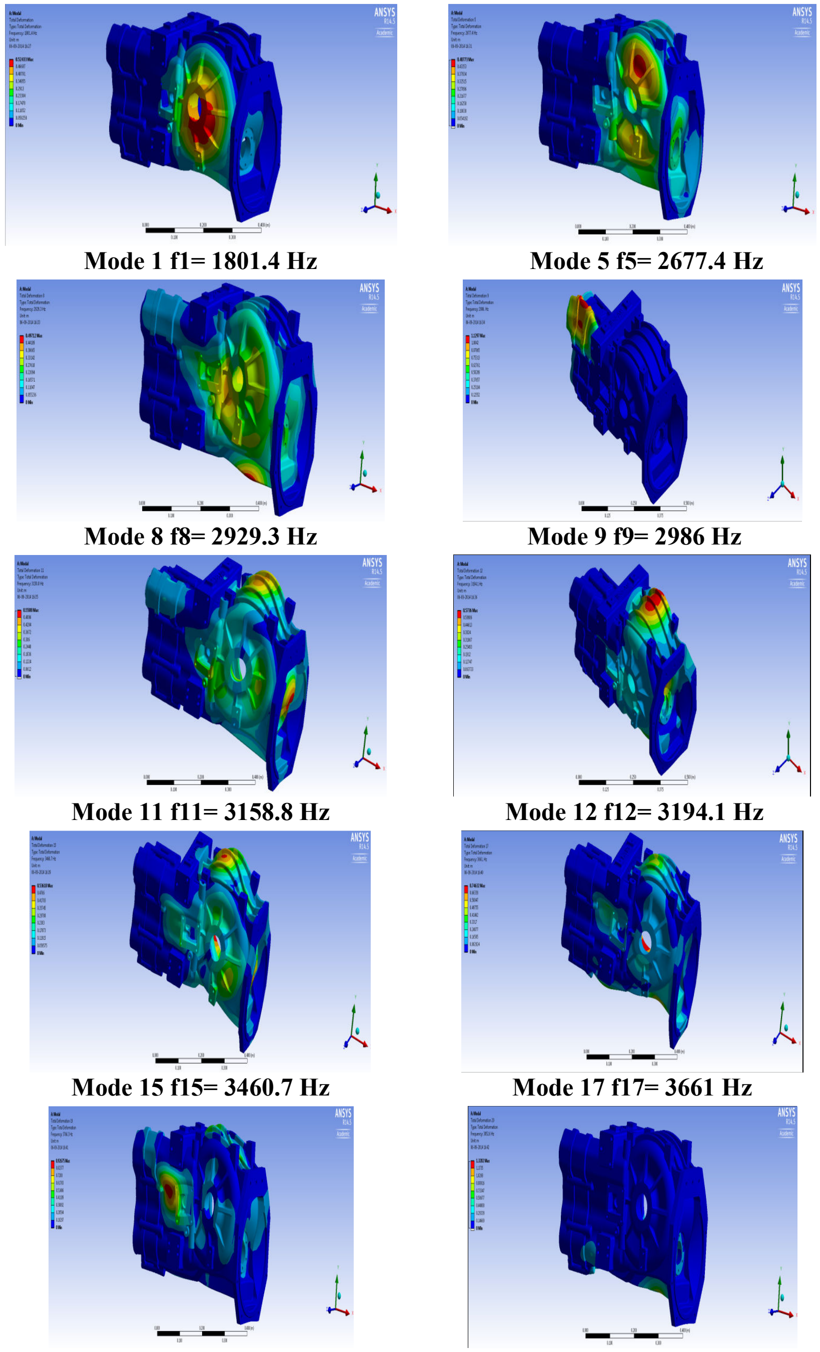
Fig. 4. Ten different mode shapes (1, 4, 5, 8, 9, 11, 15, 17, 19 & 20) of grey cast Iron HT200 transmission gearbox housing.

In numerical simulation for grey cast iron HT200 various vibration modes have been identified like torsional vibration, axial bending vibration. Torsional vibration and axial bending causes more damage to the vehicle transmission system. Torsional vibration produces undesirable rattling and clattering noises. Mode shapes 1, 4, 8 and 19 are torsional vibration. Mode 1 shows heavy vibration and deformation at centre of housing. This torsional vibration is performing at centre side on transmission housing. Mode 19 shows heavy vibration at centre and left corner with deformations. Axial bending vibrations were found in modes 9, 11 and 15. In axial bending vibration gearbox housing tries to bend from the centreline. The 15 and 19 modes are axial bending vibration with torsional vibration, both axial bending and torsional vibration happens in upper and lower side. Mode 20 has highest natural frequency of 3576 Hz with lowest deformation. The overall weight of grey cast iron HT200 transmission gearbox housing is 54.85 kg (Table 3). The simulation results show that the material is well suited for heavy vehicle truck transmission gearbox housing.

Figure 5 shows the results of numerical simulation for grey cast iron FG260. Mode 1, 5 and 8 is torsional vibration. Mode 1, 5 shows vibration and deformation at centre side. Mode 8 shows deformation in bottom portion. Axial bending vibrations were found in modes 9, 11 and 12. The 15, 17 and 19 modes are axial bending vibration with torsional vibration, both axial bending and torsional vibration happens in upper and lower side. Mode 5, 15 and 19 causes heavy vibration. Mode 20 has highest natural frequency of 3852 Hz with almost zero deformation. The overall weight of grey cast iron HT200 transmission gearbox housing is 54.85 kg (Table 3). Table 2 shows the variation in natural frequency for grey cast iron HT200 and FG260. For mode one (f1) the difference of frequency is 132 Hz and for twenty mode (f20) the difference of frequency is 276 Hz. For different mechanical properties of materials the natural frequency and corresponding mode shapes of the transmission gearbox housing change its value.

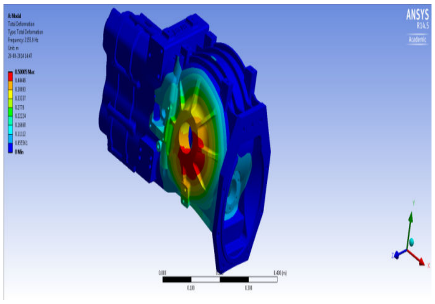
Figure 6 shows the results of numerical simulation for structural steel transmission gearbox housing. Mode 1, 5 and 13 is torsional vibration. Mode 1, 5 shows deformation at centre side. Mode 13 shows acceptable deformation in centre portion. Axial bending vibrations were found in modes 8 and 16. The 10, 11, 15 and 19 modes are axial bending vibration with torsional vibration, both axial bending and torsional vibration happens in upper and centre portion. Mode 11 and 19 causes heavy vibration. The material density of structural steel is 7750 kg/m3 so overall weight of structural steel transmission gearbox housing is 59.802 kg (Table 3) which is higher in comparison to other materials. Generally in industrial application the structural steel housing used for static heavy machinery. It has less damping characteristics but rigidity of housing structure is high and can bare harmonic excitation transferred to the transmission in running condition.

Figure 7 shows the 10 mode shape and corresponding natural frequency of Al alloys transmission gearbox housing. The density of Al alloys is 2770 kg/m3. It is lightest material in series of four materials and overall weight of Al alloys transmission gearbox housing is 21.102 kg (Table 3) which is very less in comparison to other materials. The reduction in weight is achieved by (58-60) %. Mode 1, 4, 5 and 8 is torsional vibration. Mode 1, 5 and 8 shows deformation at centre side. Mode 4 shows the deformation in downside of housing. Mode 10 shows acceptable deformation in front portion but end portion shows vibration, large deformation. Axial bending vibrations were found in modes 12, 16 and 19. The 14 and 18 modes are axial bending vibration with torsional vibration.

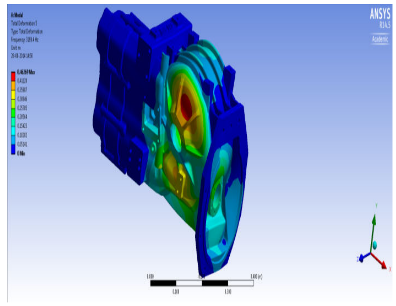


Mode 1 f1= 1801.4 Hz
Mode 5 f5= 2677.4 Hz
Mode 8 f8= 2929.3 Hz
Mode 9 f9= 2986 Hz
Mode 11 f11= 3158.8 Hz
Mode 12 f12= 3194.1 Hz
Mode 15 f15= 3460.7 Hz
Mode 17 f17= 3661 Hz
Mode 19 f19= 3766.3 Hz
Mode 20 f20= 3852.6 Hz

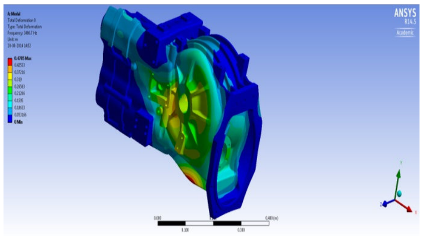
Fig. 5. Ten different mode shapes (1, 5,8,9,11,12,15,17,19 & 20) of grey cast Iron FG260 transmission gearbox housing.



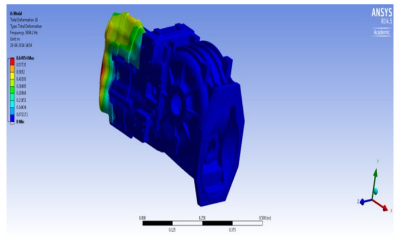
Mode 1 f1=2155.9 Hz



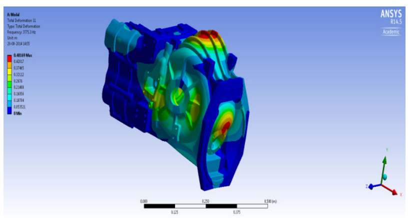
Mode 5 f5=3199.4 Hz



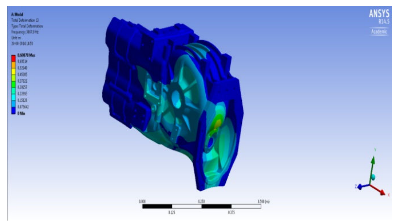
Mode 8 f8=3496.7 Hz



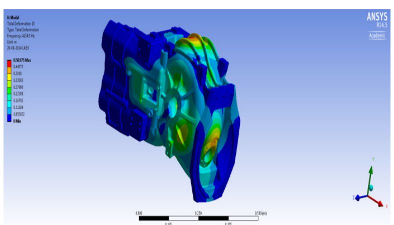
Mode 10 f10=3694.1 Hz



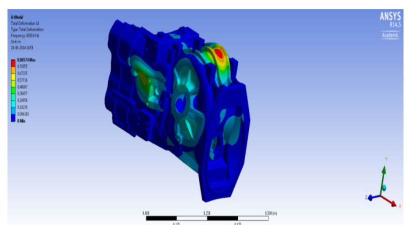
Mode11 f11=3775.3 Hz



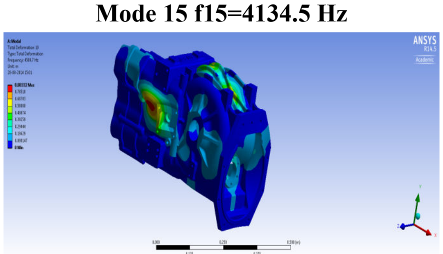
Mode 13 f13=3867.9 Hz



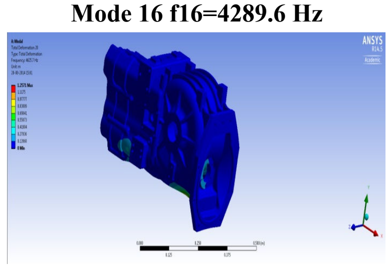
Mode 15 f15=4134.5 Hz



Mode 16 f16=4289.6 Hz

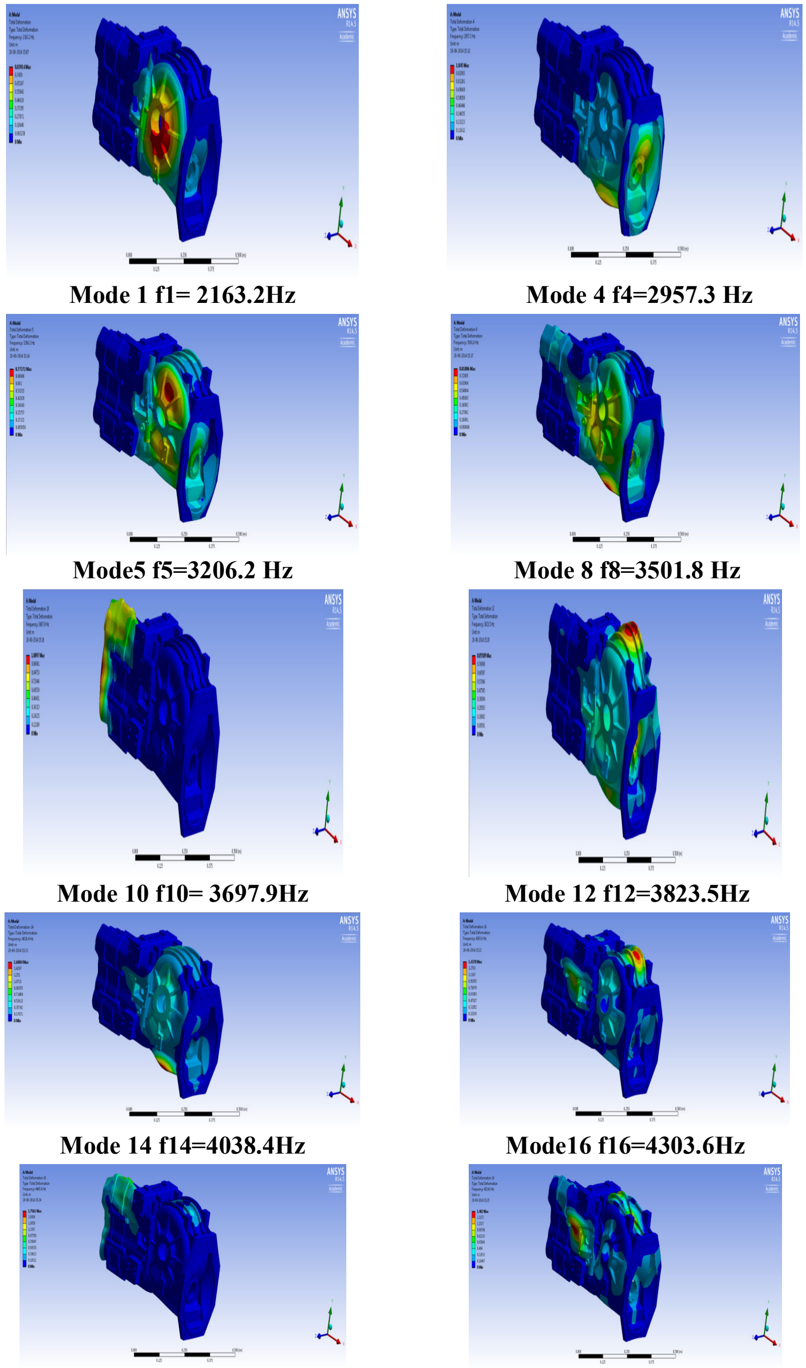


Mode 19 f19=4508.6 Hz



Mode 20 f20=4625.7 Hz

Fig. 6. Ten different mode shape (1,5,8,10,11,13,15,16,19 & 20) of structural steel transmission gearbox housing.



Mode 1 f1= 2163.2Hz

Mode 4 f4=2957.3 Hz

Mode5 f5=3206.2 Hz

Mode 8 f8=3501.8 Hz

Mode 10 f10= 3697.9Hz

Mode 12 f12=3823.5Hz

Mode 14 f14=4038.4Hz

Mode16 f16=4303.6Hz

Mode 18 f18=4465.4Hz

Mode 19 f19=4524.9Hz

Fig. 7. Ten different mode shape (1,4,5,8,10,12,14,16,18 & 19) of Al Alloys transmission gearbox housing.

Table 2. Natural frequency variation for heavy vehicle transmission housing.

Grey Cast Iron HT200 (Hz)	Grey Cast Iron FG260 (Hz)	Structural Steel (Hz)	AL Alloys (Hz)
1669.5	1801.4	2155.9	2163.2
2011.2	2171.9	2595	2600.9
2227.7	2397.4	2884.5	2906.7
2282.8	2463.5	2947.5	2957.3
2479.6	2677.4	3199.4	3206.2
2599.9	2808.1	3354	3360.7
2674.3	2886.1	3452.9	3463.9
2711.3	2929.3	3496.7	3501.8
2762.9	2986	3562.2	3566.5
2865.5	3097.3	3694.1	3697.9
2925.6	3158.8	3775.3	3784
2957.6	3194.1	3815.7	3823.5
2998.7	3239.4	3867.9	3874.6
3124.7	3375.4	4030.6	4038.4
3204.6	3460.7	4134.5	4143.
3322.3	3585.3	4289.6	4303.6
3389.9	3661	4373.4	4382
3454.7	3729.9	4457.4	4465.4
3491.1	3766.3	4508.7	4524.9
3576	3852.6	4625.7	4655.4

Table 3. Weight calculation of heavy vehicle truck transmission gearbox housing using different materials.

	Grey Cast Iron HT200	Grey Cast Iron FG260	Structural Steel	AL Alloys
Total Mass	54.85 kg	54.85 kg	59.802 kg	21.102 kg

The frequency range for all materials is (1669.5-4655) Hz (Table 2) for all material. The minimum frequency for four materials is 1669 Hz (grey cast iron HT200) and maximum frequency is 4655 Hz (Al alloys). This range of frequency variation is same (500-5000) Hz as the experimental result obtained by the Tuma [10]. The simulation result shows that all four materials can be used for truck transmission housing. The minimum frequency range can be find with grey cast iron HT200 (1669-3576) Hz and maximum with Al alloys (2163-4655) Hz.

Figure 8 shows the frequency variation for all four materials. From graph it is concluded that the frequencies for grey cast iron FG260, structural steel and Al alloys are in same range.

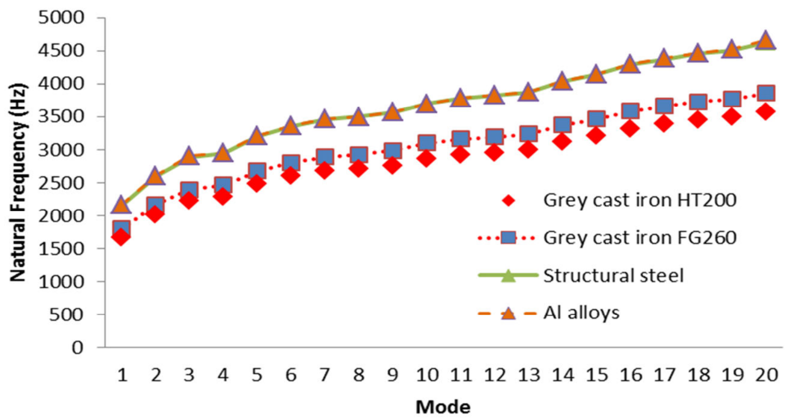


Fig. 8. Natural frequency variations for transmission housing.

5. Conclusions

This research work has theoretical importance in study of heavy vehicle transmission gearbox housing. The numerical simulation results can be used for evaluation of product performance. To get the accurate result the natural frequency range was increased. The concluding observations from the present research work are given below.

- The weight of housing was calculated for four different materials. Al alloys has minimum weight. Grey cast iron HT200, grey cast iron FG260, structural steel and Al alloys provides excellent structural rigidity by eliminating lower order frequency and reduces the chances of resonance against harmonic excitation.
- Materials mechanical properties have dominating effect on natural frequencies, mode shapes and weight. The first 20 natural frequency and mode shapes were find out. Zero displacement constraint boundary condition fixed the 37 connecting bolts hole tightly to simulate the results.
- The frequency range for all four materials vary (1669-4655) Hz, which is verified by the literature experimental results of Tuma [10]. Vibration mode shapes like torsional vibration, axial bending vibration, combination of axial and torsional vibration were identified for all materials.
- The FEA result proposed that on design and vibration index grey cast iron HT200, FG260, structural steel and Al alloys can be used as truck transmission housing material.

A significant work of modal analysis and weight calculation of heavy vehicle truck transmission gearbox housing has been done based upon the simulation investigation. Finite element analysis offers satisfactory results. The results of this research work will provide reference in design stage of heavy vehicle truck transmission gearbox housing and has theoretical reference value for the dynamics analysis of the gearbox housing.

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References

1. Dogan, S.N. (1999). Loose part vibration in vehicle transmissions Gear rattle. *Transactions Journal of Engineering and Environmental Science*, 23, 439-454.
2. Wang, J.; Zheng, J.; and Yang, A. (2012). An Analytical Study of Bifurcation and Chaos in a Spur Gear Pair with Sliding Friction. *Procedia Engineering,* 31, 563-570.
3. Abouel-Seoud, S.S.; Mohamed, E.S.; Abdel-Hamid, A.A.; and Abdallah, A.S. (2013). Analytical Technique for Predicting Passenger Car Gearbox Structure Noise Using Vibration Response Analysis. *British Journal of Applied Science & Technology*, 3(4), 860-883.
4. Vandi, G.; Cavina, N.; Corti, E.; Mancini, G.; Moro, D.; Ponti, F.; and Ravaglioli, V. (2014). Development of a software in the loop environment for automotive powertrain systems. *Energy Procedia*, 45, 789 – 798.
5. Nacib, L.; Pekpe, K.M.; and Sakhara, S. (2013). Detecting gear tooth cracks using cepstral analysis in gearbox of helicopters. *International Journal of Advances in Engineering & Technology,* 5, 139-145.
6. Gordon, T.J.; and Bareket, Z. (2007). Vibration Transmission from Road Surface Features– Vehicle Measurement and Detection. *Technical Report* for Nissan Technical Center North America, Inc. UMTRI-2007-4.
7. Kar, C.; and Mohanty, A.R. (2006). Monitoring gear vibrations through motor current signature analysis and wavelet transform. *Mechanical Systems and Signal Processing*, 20, 158–187.
8. Czech, P. (2012) Diagnosis of industrial gearboxes Condition by vibration and time frequency, Scale-frequency, frequency-frequency analysis. *Metalurgija*, 51, 521-524.
9. Singh, R. (2000). Dynamic design of automotive systems-Engine mounts and structural joints. *Dynamic design of automotive systems,* 25, 319-330.
10. Tuma, J. (2009). Gearbox Noise and Vibration Prediction and Control. *International Journal of Acoustics and Vibration,* 14, 1-11.
11. The Metals Databook (2008). Tata McGraw- Hill. Fourth Edition. ISBN-13: 978-0-07462300-8.
12. Yu, F.; Li, Y.; Sun, D.; Shen, W.; and Xia, W. (2013) Analysis for the Dynamic Characteristic of the Automobile Transmission Gearbox. *Research Journal of Applied Sciences, Engineering and Technology,* 5, 1449-1453.
13. Kuo, K. (2011) Simulation and Analysis of the Shift Process for an Automatic Transmission. *World Academy of Science, Engineering and Technology,* 52, 341-347.

14. Yulong, L.; Xingzhong, L.; and Weipeng, L.(2011) Hydraulic System Optimization and Dynamic Characteristic Simulation of Double Clutch Transmission. *Procedia Environmental Sciences,* 10, 1065 – 1070.
15. Sayer, F.; Bürkner, F.; Blunk, M.; Wingerde, A.M.; and Busmann, H.G. (2009) Influence of Loads and Environmental Conditions on Material Properties over the Service Life of Rotor Blades, *Dewi Magazin No*. 34, 24-31.
16. Kostic, S.C.; and Ognjanovic, M. (2007). The Noise Structure of Gear Transmission Units and the Role of Gearbox Walls. *FME Transactions,* 35,105-112.
17. Miyasato, H.H.; Simionatto, V.G.S.; and Junior, M.D. (2011). Study of the gear rattle phenomena in automotive powertrain systems. Proceedings of COBEM 2011. 21st International Congress of Mechanical Engineering. 1-10.
18. Minfeng, H.; and Yingchun, J. (2008). Fatigue life analysis of automobile component based on FEM. *Mechanical Research and Application,* 21, 57-60.
19. De-gang, L.; Weixing, H.; and Fengzhou, W. (2004) . Fatigue Life Analysis of a Component Based on the Finite Elements Technology. *Journal of The China Railway Society,* 26, 47-51.
20. Saada, A.; and Velex, P. (1995). An extended model for the analysis of the dynamic behavior of planetary trains. *ASME Journal of Mechanical Design,* 117, 241-247.
21. Velex, P.; and Flamand, L. (1996). Dynamic response of planetary trains to mesh parametric excitations. *Journal of Mechanical Design Transactions of the ASME,* 118, 7-14.
22. Li, Y.; and Guagnqiang, W. (2006). Analysis on Fatigue Life of Rear Suspension Based on Virtual Test rig. *Computer Aided Engineering,* 15, 128-130.
23. Ansys R 14.5. (2013). Academic, Structural analysis Guide.
24. Solidedge (2006). Version 19.0.
25. Pro-E 5.0. (2013). Designing guide manual.
26. Kumar, A.; Dwivedi, A.; Jaiswal, H.; and Patil, P.P. (2015). Material Based Vibration Characteristic Analysis of Heavy Vehicle Transmission Gearbox Casing Using Finite Element Analysis (FEA). *Advances in Intelligent Systems and Computing,* 308, 527-533.