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Dynamic Vibration Characteristics Analysis of Truck Transmission Gearbox Casing with Fixed Constraint of Vehicle Frame Based on FEA

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Abstract

Truck transmission gearbox casing is subjected to vibration induced by the harmonic excitation, meshing excitation, load fluctuations, gear defects, varying speed and torque conditions. Noise and vibrations are the reasons for the transmission failure. The transmission gearbox casing vibrations are the resultant of internal excitation caused by the gear meshing process and transmission error. This internal excitation produces a dynamic mesh force, which is transmitted to the casing through the shafts and bearings. The objective of this research work is to simulate the relation between dynamic vibrations of transmission and fixed constraint of vehicle frame. Transmission casing is tightly fixed on vehicle frame using connecting bolts. 37 connecting bolts were used to fix the casing on vehicle frame. If connecting bolts were loosened, it causes heavy vibration and deformation. For transmissions type multi degree freedom system the natural frequency and vibration mode are important modal parameters. First 10 inherent natural frequencies and corresponding mode shapes were evaluated. Grey cast iron HT200 was used as casing material. FEA based numerical simulation method was used to find the dynamic response of the casing. The numerical simulation method used reciprocity principle to apply the mesh forces transmitted to the casing and to determine the main responsible forces for the vibration of the casing. The FEA simulation results show that the natural frequency of one bolt unconstraint condition varies from (1637.2 – 2674) Hz. The analysis results were verified with experimental result available in literature.

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Keywords: FEA; Mounting Bolts; Natural Frequency; Excitation; Unconstraint ;Transmission Casing.

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1. Introduction

Noise and vibration reduction problem in heavy vehicle industry is a continuous development goal. Vehicle transmission system determines the overall level of noise together with the engine, bodywork and chassis. The rattling and clattering noise caused by vehicle transmissions under torsional vibration condition and produced by loosen part vibration of transmission components moving backwards and forwards within their clearances when not under load. Reciprocity Principle has been used to determine the failure frequencies and vibration mode for transmission casing. Using reciprocity principle gear and shafts are suppressed and all the forces transmitted through the bearings were applied on the empty casing. The main reason of heavy vibration is the resonance caused by the lower order frequency of transmission gearbox body.

Ji Wang et al. [1] have investigated the non-linearity of gear dynamics. The numerical simulation parameters of tooth face, meshing stiffness and backlash was optimized. Vandi et al. [2] have studied the engine driveline model to study the vehicle dynamics. Particular case was studied of engaged and disengaged clutch. Lei Yulong et al. [3] the author have studied the hydraulic system of dual clutch automatic transmission. They have calculated the structure size of each body through theory and practical algorithm. The dynamic simulation model of hydraulic system of dual clutch automatic transmission was established.

S¨ureyya Nejat Dogan [4] has studied the transmission components. The vibration of transmission components causes rattling and clattering noises. The cause of rattling and clattering noise is torsional vibration of transmission components, this noise is undesirable in character. The transmission parameters were varied by experimental analyses, showing the effect on propensity to rattle and clatter. Shawki S et al. [5] have studied the car gearbox using vibration response analysis method .They have performed analytical and experimental analysis of a car transmission system. The radiation efficiency was calculated By using physical properties. Shaban Ghavami Jolandan et al. [6] have used a new method fault classification to study the gearbox. A MF 285 series gearbox was used. Piezoelectric transducers transfer the frequency signal for H, W and B conditions. H, W and B represents the healthy gear with tooth face worn, broken at three working speed (700, 1500 and 1800 rpm). The features of signal were extracted using descriptive statistic parameters. Kei-Lin Kuo [7] the objective of this research work was to establish a system model for an automatic transmission 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.

Snežana Ćirić Kostić et al. [8] have investigated the natural vibrations of the housing walls and concluded that it can be prevented by designing parameters. Ashwani Kumar et al. [9] have studied the free vibration analysis of truck transmission housing. Grey cast iron grade FG260 was used as casing material. The authors have concluded that the natural frequency varies from (1002-2954) Hz for only transmission housing side connecting bolts constraint based boundary conditions. Milosav Ognjanović et al. [10] the authors have studied the machine system disturbances like collisions, rolling and sliding. Gear tooth profile is subjected to deformation and free vibration due to elastic properties under impact meshing process. Jiri Tuma [11] has performed the analytical and experimental research work on Tara trucks to investigate the noise and vibration problem of vehicle transmission. In order to reduce the noise and vibration he introduced an encloser. Fourier transform results state that the natural frequency varies (500-3500) Hz. The heavy vibration was observed in range (500-2500) Hz. Fujin Yu et al. [12] have studied the dynamic vibration of the transmission gearbox using FEM numerical simulation method. The structure of gearbox was optimized to reduce the noise and vibration. The analytical result was verified with experimental results. Ashwani Kumar et al. [16] the authors have investigated the problem of loose transmission housing for 2 and 3 connecting bolts unconstraint based condition. The paper presents the dynamic vibration monitoring of truck transmission gearbox casing for grey cast iron HT200 using FEA numerical simulation method. The natural frequency for 2, 3 bolts unconstraint condition varies from (1340-2338) Hz and (1311-2058) Hz. The fall in natural frequency from zero displacement constraint based condition to 2 and 3 bolts loose transmission condition was (21-28) %. The loose condition of casing leads to failure condition.

2. Three Dimensional Model of Truck Transmission Gearbox Casing

The finite element based numerical analysis provides a powerful analysis tool for evaluation of various results, its reliable results can be used for evaluation of product performance. FEA based free vibration analysis of truck transmission gearbox casing plays an important role for noise reduction and vibration absorption of gearbox. The present research work concentrate on dynamic vibration response of casing with fixed constraint of vehicle frame. The study continues in two phases, in first phase the natural frequency of truck transmission casing were identified with zero displacement constraint based boundary condition. These natural frequency and vibration mode shows the fully fixed condition of casing on vehicle frame. All 37 bolts were firmly fixed on frame, this condition is known as fixed constraint of vehicle frame. In second phase the aim was to find a relation between transmission vibration and fixed constraint of vehicle frame. One bolt was loosened from all positions and FEA based numerical simulation find the results for this condition. The results of this study offer dynamics optimization design of the grey cast iron HT200 truck gearbox casing.

The design model of automobile truck transmission system consists of more than 600 components and it is a complex and very critical to design a full practical model of automobile truck gearbox. It consist of various oil drain hole, corners, reinforcing ribs, bosses and fillets and connecting bolts holes .The result of free vibration analysis to be close to the actual situation, only few components of gearbox will be reduced. The precise reliable results can be used for transmission performance evaluation. Solid Edge and Pro-E [14-15] software was used for design. The solid CAD model is shown in figure 1. ANSYS 14.5 [13] is FEA based analysis tool for structures. ANSYS 14.5 work on nodes and elements concept. Elements are connected at a point known as node. This process is known as meshing. The fine meshing ensures more accurate results but increases calculation time. Figure 2 shows the discretized finite element model of transmission gearbox casing. The meshed model have 1,96,137 nodes and 1,13,566 elements. Transmission casing is firmly mounted on vehicle frame using connecting bolts. Loosening of connecting bolts cause heavy vibration and noise problem. First 10 natural frequencies and corresponding vibration modes were evaluated for two phase study (Table 1). In first phase of study when all 37 connecting bolts were constraint, natural frequencies vary from 1669.5 Hz to 2865.5 Hz.

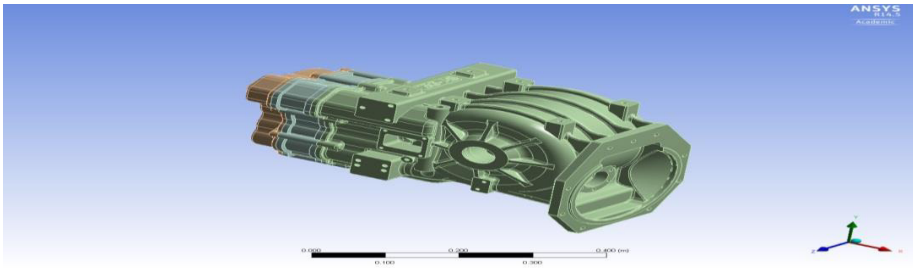


Figure 1. 3 D model of heavy vehicle transmission gearbox casing.

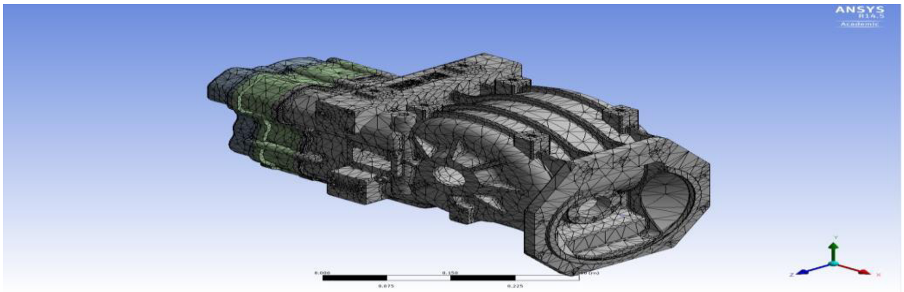


Figure 2 Meshed model of transmission gearbox casing

3. Material Properties and Boundary Conditions

Grey Cast Iron HT200 a damping material has been selected as transmission casing material. It was good on both criteria of vibration and manufacturing prospectus. The Mechanical properties Elastic modulus, Poisson ratio and density were required for free vibration analysis. The grey cast iron HT200 material properties are- elastic modulus – 1.10e11 Pa, Poisson ratio- 0.28, density-7200 kg/m3 [12]. Ansys 14.5 workbench module is used for free vibration simulation. Ansys simulation required to define and apply the boundary conditions. Zero displacement constraint boundary condition is applied on transmission casing. It is applied by constraining the 37 connecting bolts position. Figure 3 shows the front and side view of transmission casing with connecting bolts hole. These bolts hole were used to constraint the motion of transmission casing. All 37 connecting bolts hole were constraint against motion. In actual running condition if the fixturing bolts were loosen it may cause heavy vibration and failure of transmission system. The results show that there is a variation of (2-6) % fall in natural frequency due to looseness of one connecting bolt from all five positions. Fall in natural frequency signify the condition of resonance.

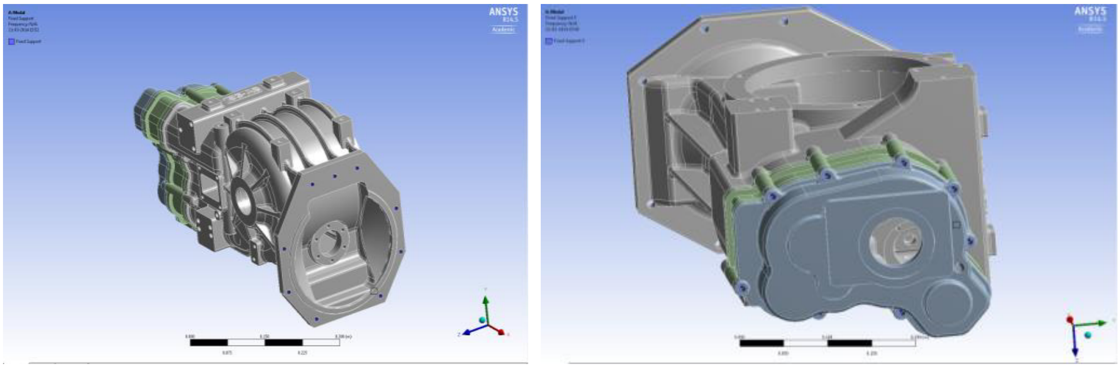
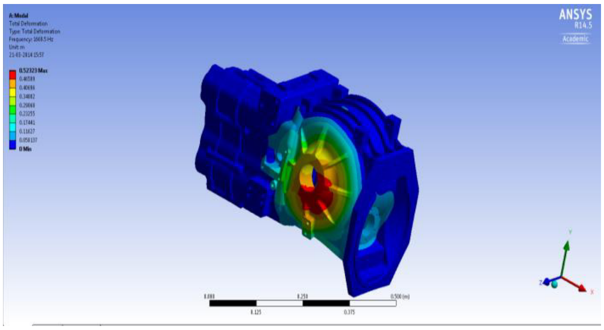


Figure 3 Connecting bolt positions of transmission gearbox casing.

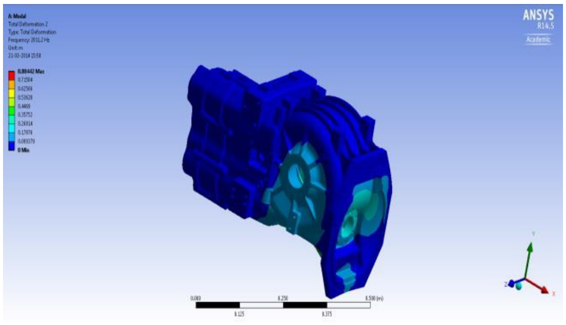
4. Computation of Results and Discussion

In modal analysis the load is applied by program automatically, by applying the suitable boundary conditions. The simulation was done for two conditions and each condition material property and boundary condition was same. Table 1 represents the first ten natural frequencies for zero displacement constraint condition and one bolt loosened condition. To simulate the same environment for casing zero displacement based constraint has provided. In general, the main reason of causing transmission vibration is internal harmonic excitation.

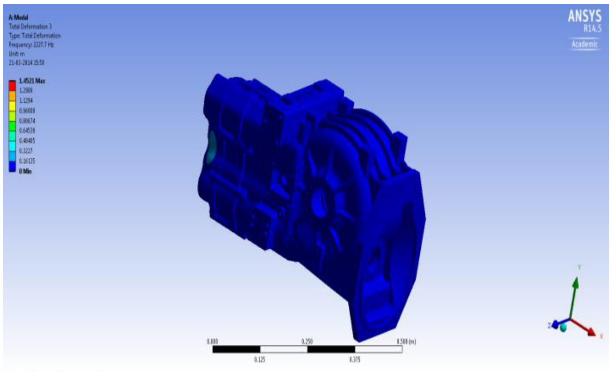
Fully fixed constraint of vehicle frame fixed all 37-bolt holes and provides rigid mounting of casing on chassis frame. The paper deals with the problems of loosen bolts condition. In first phase all bolt constraint based natural frequency, mode shapes (figure 4) were calculated and in next phase loosen bolt (figure 6) based natural frequency, modes shape were calculated. Figure 3 shows the constraint bolt holes position. When bolts were, loosened from its fixed position there is fall in natural frequencies. Table 1 shows the modal frequency variation in constraint and unconstraint condition. The results shows that loosen bolts may cause resonance condition due to inclusion of low frequencies. For zero displacement constraint condition the natural frequencies varies from (1669.5-2865.5) Hz. From figure 4, mode 1 & 2 is torsional vibration. This torsional vibration is performed at front and backside on transmission casing. Axial bending vibration has been find in 8 , 9 mode. The 10 mode is torsional vibration. Figure 4 shows the different mode shapes and corresponding natural frequency. The range (1669.5-3576) Hz of natural frequency for grey cast iron HT200 analysis were in the same range (500-3500) Hz as the experimental result obtained by the Jiri Tuma [11]. The FEA simulation results are in agreement with the experimental literature results [11]. In Jiri Tuma results the heavy vibration take place in range of (1000-2500) Hz. Mode 5,7 and 9 are in this range and causes heavy vibration can be analysed from mode shapes.



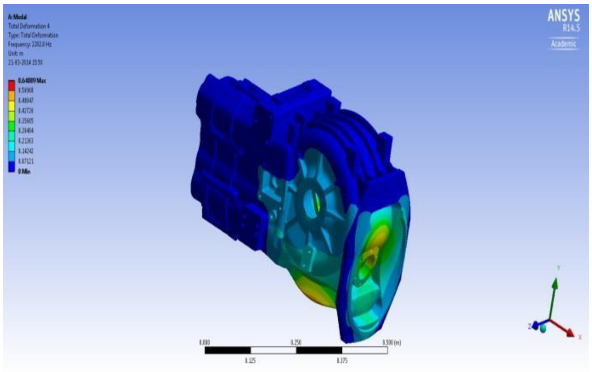
Mode 1 f1= 1669.3 Hz



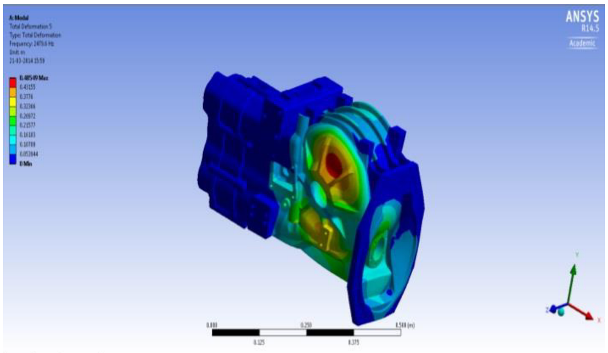
Mode 2 f2=2011.2 Hz



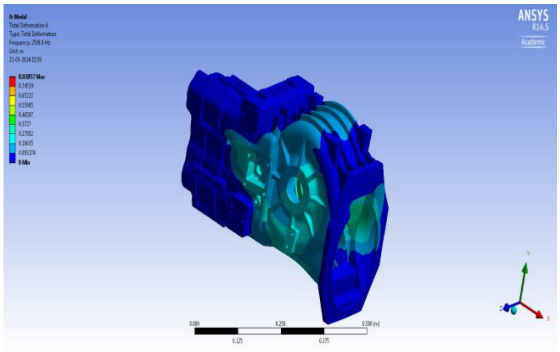
Mode 3 f3=2227.7 Hz



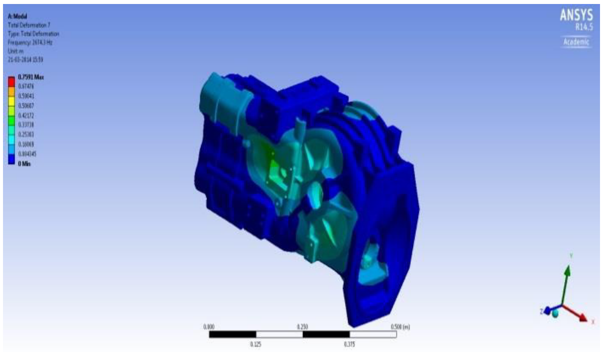
Mode 4 f4= 2282.8 Hz



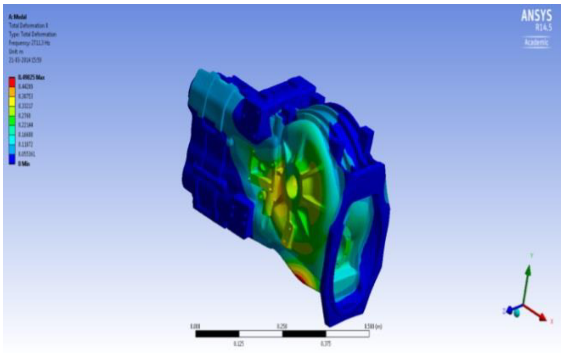
Mode 5 f5= 2479.6 Hz



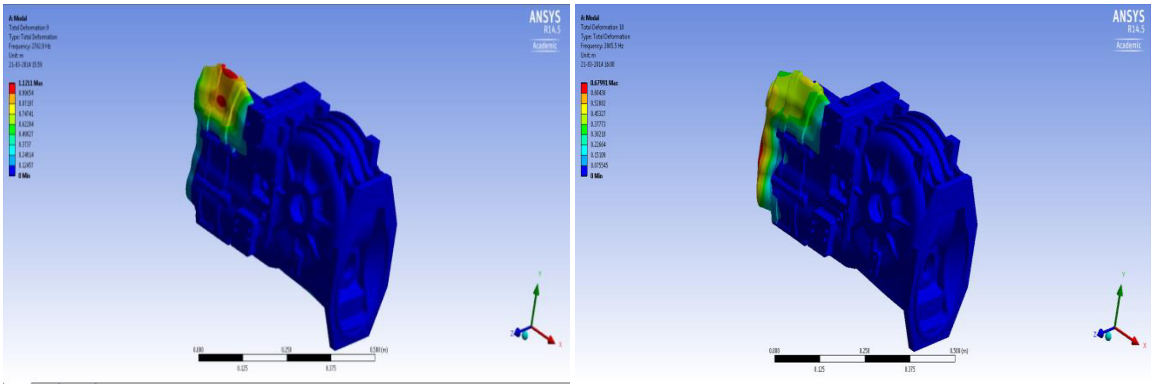
Mode 6 f6= 2599.9 Hz



Mode 7 f7=2674.3 Hz



Mode 8 f8= 2711.3 Hz



Mode 9 f9= 2762.9 Hz Mode 10 f10 =2865.5 Hz

Figure 4 Vibration mode shapes and natural frequency of all bolts constraint based analysis.

In second part of study one bolt was loosen from chassis frame. Figure 5 shows the position of unconstraint bolt holes. Unconstraint condition signifies that bolt holes were loosened and free to move.

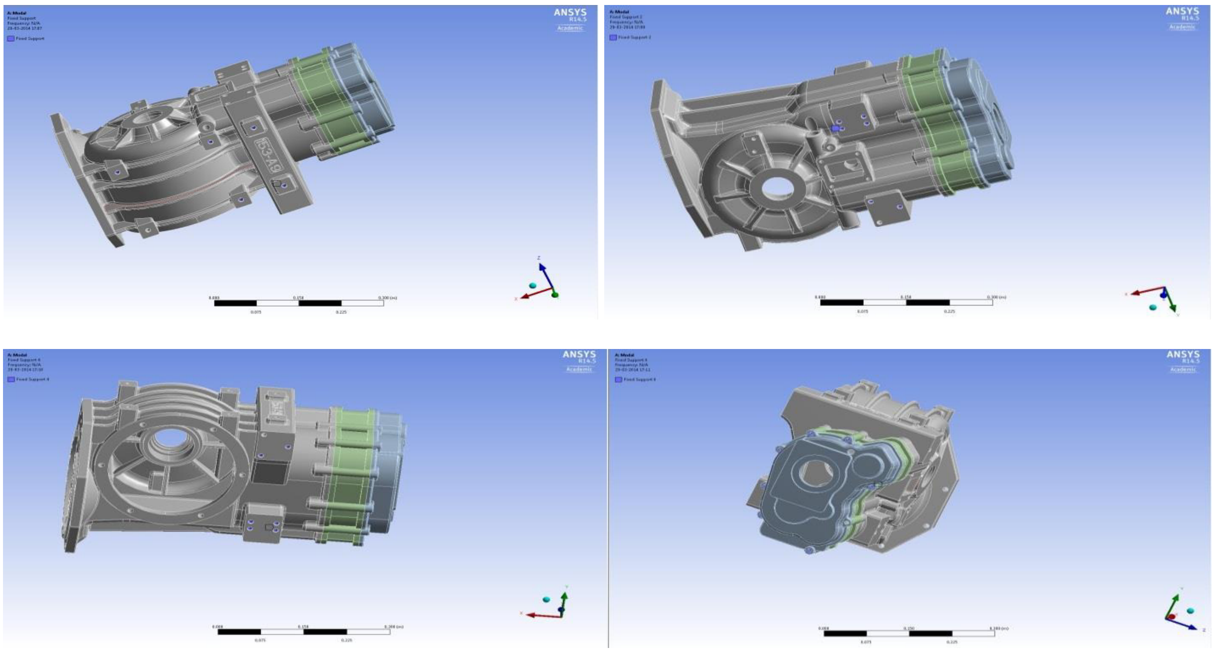
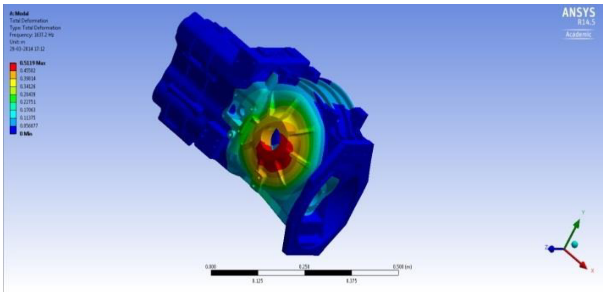
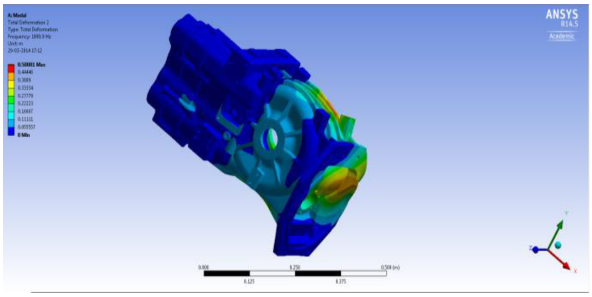


Figure 5 One bolt unconstraint based analysis.

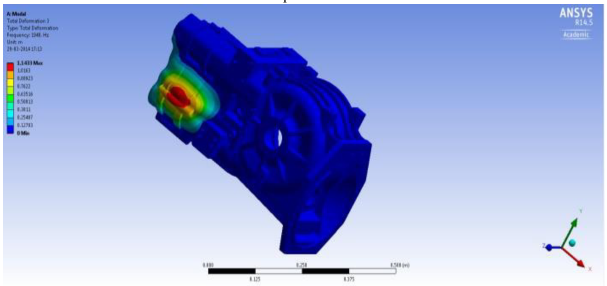
When one connecting bolt was unconstraint from all five positions the natural frequency varies (1637-2674) Hz (Table 1). For the first mode the natural frequency decreases by 32 Hz (2%) and for the tenth mode the difference is widen up and increases to 191 Hz (6%). It shows that the one bolt unconstraint or loosened condition reduce the natural frequency by (2-6) % and these lower order natural frequency caused internal excitation which leads resonance. Mode 3, 4 & 5 is torsional vibration. This torsional vibration is performed at back right side on transmission casing. Axial bending vibration was find in mode 7. The 10 mode is axial and torsional vibration causes heavy vibration and excess deformation at centre line. Figure 6 shows the different mode shapes and corresponding natural frequency for two bolts loosen condition.



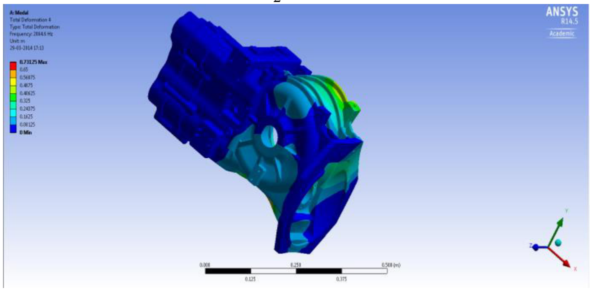
Mode 1 f_1= 1637.2 Hz



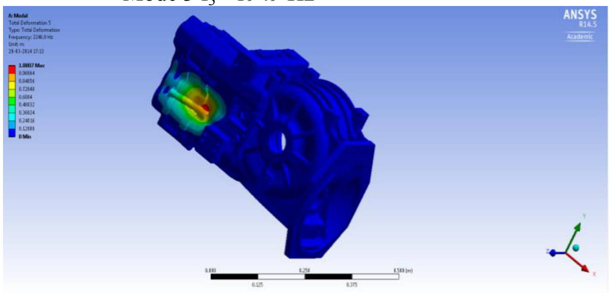
Mode 2 f_2= 1888.9 Hz



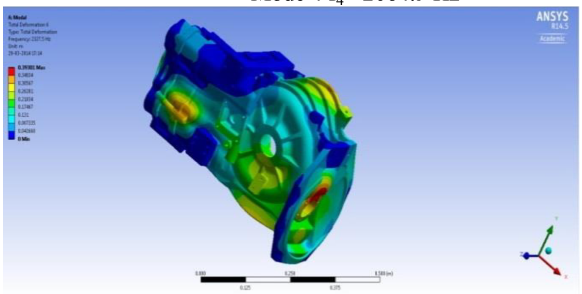
Mode 3 f_3= 1949 Hz



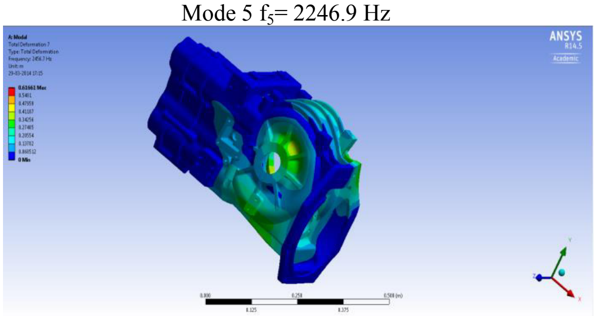
Mode 4 f_4= 2064.9 Hz



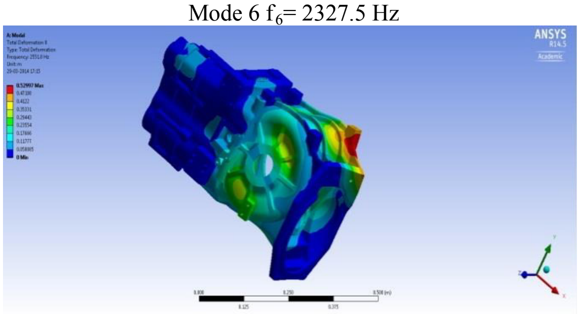
Mode 5 f_5= 2246.9 Hz



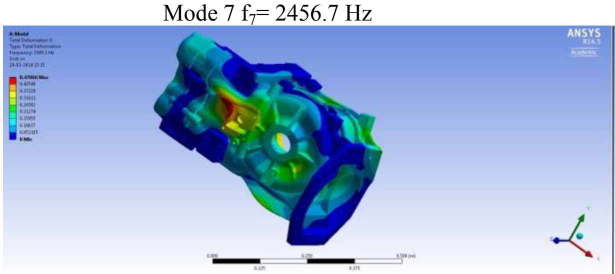
Mode 6 f_6= 2327.5 Hz



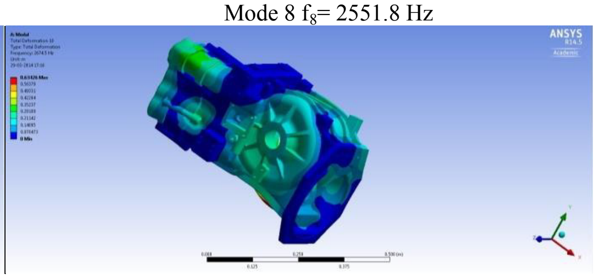
Mode 7 f_7= 2456.7 Hz



Mode 8 f_8= 2551.8 Hz



Mode 9 f_9= 2588.3 Hz



Mode 10 f_{10}= 2674.5 Hz

Figure 6 Natural frequency and vibration mode of one bolt unconstraint based Modal analysis.

Table 1 Modal frequency variation

S.N.	All Bolts Constraint Boundary Condition	One Bolts Loose Boundary Condition
1.	1669.5	1637.2
2.	2011.2	1888.9
3.	2227.7	1949
4.	2282.8	2064.9
5.	2479.6	2246.9
6.	2599.9	2327.5
7.	2674.3	2456.7
8.	2711.3	2551.8
9.	2762.9	2588.3
10.	2865.5	2674.5

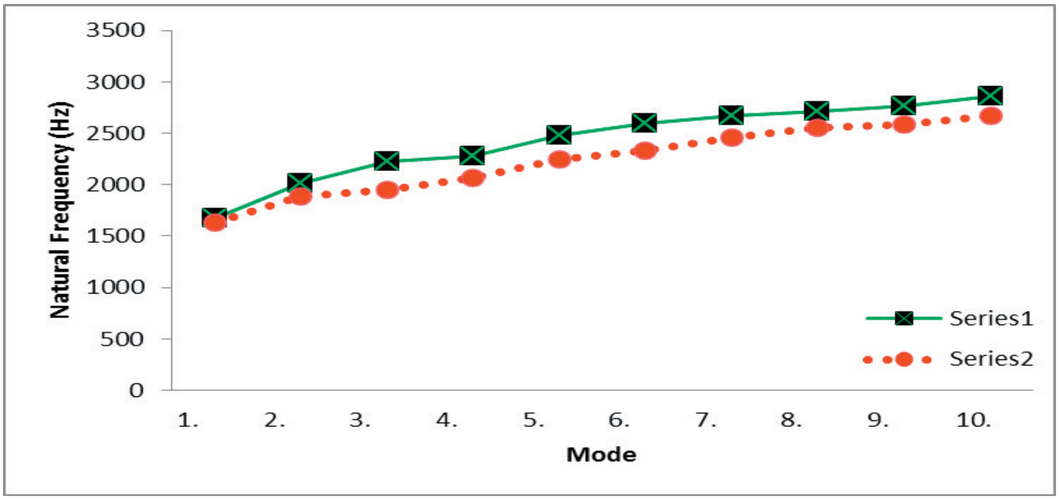


Figure 7 Natural Frequency Variation-Zero Displacement condition (series 1) and one bolt unconstraint condition (series 2).

5. Conclusion

The simulation results of research work have theoretical importance for design optimization of transmission casing. The present simulation results provides the vibration response of the casing, axial excitation forces and bending moments play a important role to induce vibration by transferring internal harmonic excitation caused by the gear meshing process to casing through bearing and shafts. Noise and vibration are the two technical indexes for the transmission failure. Zero displacements constraints were applied for free vibration analysis. Table 1 shows the natural frequency variation (1669.5-3576) Hz for grey cast iron HT200, which are in a safe mode starting from 1669.5 Hz, showing absence of very low order natural frequency. Grey cast iron HT200 is suitable as a transmission casing material. The simulation results were verified with the experimental result available in the literature. When one connecting bolt was loosened the natural frequency varies in range (1637-2674) Hz. For the first mode shape there is a difference of 32 Hz (2%) and for the tenth mode the difference is widen up and increases to 191 Hz (6%) in comparison with fully fixed constraint of vehicle frame (37 connecting bolts constraint, zero displacement constraint condition) (figure 7). Simulation results shows that one bolt unconstraint or one bolt loosened condition reduce the natural frequency by (2-6) %. In conclusion, the numerical simulation has confirmed that bolts unconstraint condition causes vibration and noise failure of the transmission gearbox casing. FEA based simulation results shows, the dynamic vibration response due to loosen bolt of the casing. Using the realistic approach the mechanical properties of transmission casing were also considered for the analysis. Grey cast iron HT 200 was used for the truck transmission casing because of its damping properties. Various vibration modes were identified for casing. The numerical simulation based provides satisfactory results. The present research work can be extended for connecting bolts positional based unconstraint analysis for transmission casing.

Acknowledgement

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