Material-Based Vibration Characteristic Analysis of Heavy Vehicle Transmission Gearbox Casing Using Finite Element Analysis

Ashwani Kumar, Arpit Dwivedi, Himanshu Jaiswal and Pravin P. Patil

Abstract Transmission system is the most important part of the vehicle assembly. Truck transmission casing was subjected to vibration induced by the vehicle running, varying speed, and torque conditions. It is required to find the natural frequency and mode shape for accurate prediction of transmission casing life and prevent it from damage. The main objective of this research work is to find the influence of transmission casing material on natural frequency and mode shape of free vibration. Casing is made of material like cast iron, Al alloys, Mg alloys, structural steel, and composites. In this paper, the free vibration analysis of transmission casing has been performed by finite element simulation using ANSYS 14.5 software. The vibration patterns for first twenty modes were studied for all types of materials. The mode shapes show that the natural frequency of all materials varies in the range of 1,000–3,800 Hz. The analysis results were compared with experimental result available in the literature.

Keywords Transmission casing · Cast iron · FEA · Free vibration · Material influence · Modal frequency

1 Introduction

In automobile truck, the main function of engine is to generate power and transmission is used to transmit powers from engine to automobile wheels. This power transmission process is not as simple as it feels. The transmission components or

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L.C. Jain et al. (eds.), *Intelligent Computing, Communication and Devices*,
Advances in Intelligent Systems and Computing 308,
DOI 10.1007/978-81-322-2012-1_56

parts are subjected to varying loading conditions. These varying loading and boundary conditions produce noise and vibration. Various types of damping material like cast iron are used to eliminate and absorb the vibration waves [1, 2]. Noise and vibration are the two technical indexes for the transmission failure, so vibration is selected as a study parameter. Researchers have done various studies on dynamic response of transmission system since past two decades, but it is a very complex procedure in terms of design, measurement, or mathematical modeling.

Automobile transmission system is a combination of gears to meet the torque variation for the varying speed conditions. Transmission system can be classified into three types—automatic, manual, and continuously variable transmission. The simplest type of transmission is manual. Manual transmission is of two types: sliding mesh and constant mesh. The main reason of noise and vibration is wrong shifting of gears, uneven road surfaces, loose fixturing of transmission gears, components, and housing. Clashing is the general phenomena that occur during shifting of gears. Clashing is a loud noise produced during collision of gear tooth, and this collision leads the transmission failure. In other two types of transmission, automatic and continuously variable transmissions, there is less driver interaction [3, 4]. Slack in drive train mechanism produces high vibration known as transmission shock. Transmission shock is the high grade of vibration that may cause the failure of housing [5, 6].

Tuma [7] has studied the noise and vibration of transmission system. Author has solved the gear noise problem by introducing an enclosure to reduce radiated noise. TARA trucks have been selected as a research object. The Fourier transform is used for the analytical analysis. Analytical result is verified using experimental investigation. The extensive noise is produced during the tooth meshing or at structural resonance frequency. The natural frequency of vibration is varying in between 500 and 3,500 Hz at varying rpm. The severe vibration occurs at the frequency range of 500–2,500 Hz. Our results show that the natural frequency of vibration varies from 1,002.5 to 2,954.8 Hz, which is verified by Jiri Tuma results. Åkerblom [8] has performed a literature review and concluded that transmission error is an important excitation mechanism for gear noise and vibration. In addition to transmission error, friction and bending moment are another reason responsible for failure.

Nacib et al. [9] have studied the heavy gearbox of helicopters. To prevent breakdown 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 et al. [10] 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 [11] have used motor current signature analysis (MCSA) and discrete wavelet transform (DWT) for studying the gear vibration. Load fluctuations on the gearbox and gear defects are two major sources of vibration.

2 Three-Dimensional Model of Gearbox Casing

Solid Edge [12] software has good geometric modeling capability. It has various features suited for complex geometry like transmission casing modeling. The geometrical dimensions were obtained from drawing in Dehradun with the permission of manufacturer of truck. We have constructed the geometry by drawing and taking measurements in workshop. Few parts have not been considered for designing to simplify the geometry, and it has no impact on vibration frequency. The CAD model is shown in Fig. 1. For free vibration analysis, finite element analysis (FEA) software ANSYS 14.5 [13] has been used as an analysis tool. Figure 2 shows the meshed model of gray cast iron transmission housing. ANSYS 14.5 has high-quality meshing facility. The meshed model consists of 377,697 nodes and 228,341 elements; linear tetrahedral elements were used for meshing (Fig. 3).

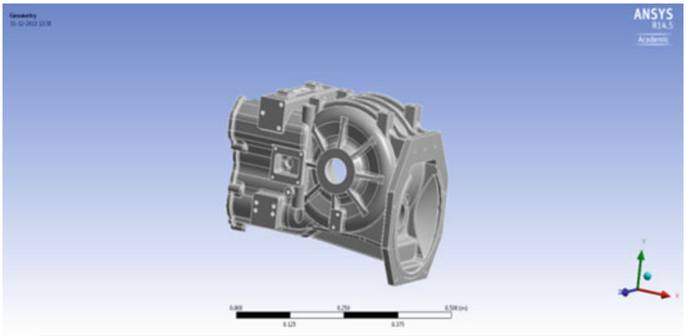

Fig. 1 CAD model

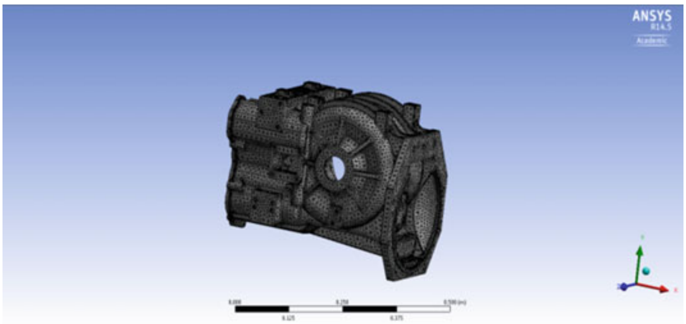

Fig. 2 Mesh model

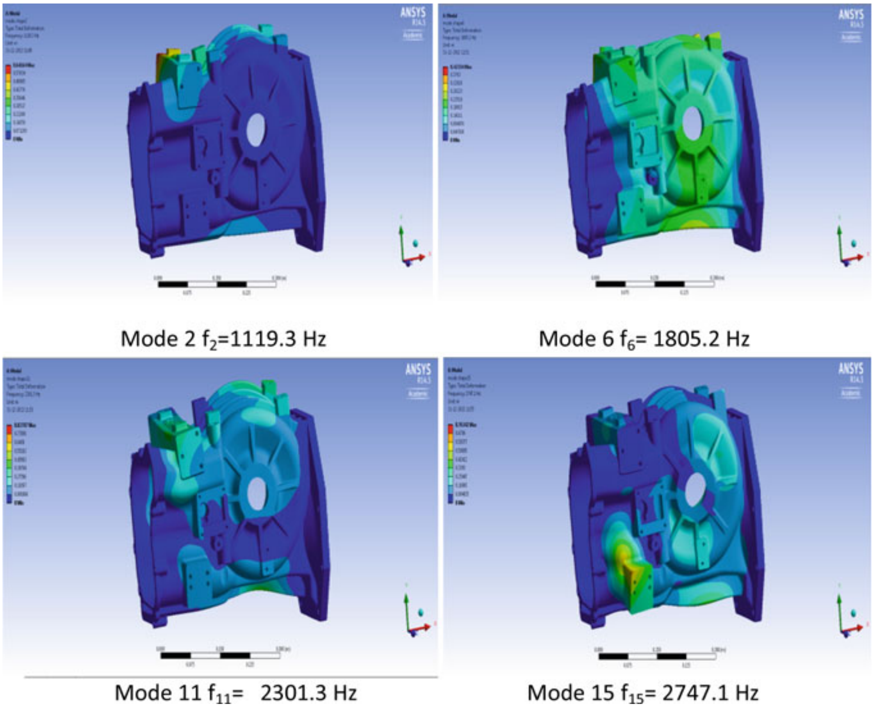

Fig. 3 Four different mode shapes (2, 6, 11, and 15) of gray cast iron transmission casing

3 Material Properties and Boundary Conditions

Transmission casing is manufactured by different process depending on size and various others factors. Casing is mounted on truck frame using fixtures. Loosing of fixtures may cause serious vibration and noise problem. Since past many years, cast iron is used for the truck transmission casing because of its damping properties. We have selected a series of four transmission casing materials gray cast iron grade FG 260, structural steel, Al alloy, and Mg alloy for the analysis of material influence on mode shape and natural frequency. In selection of materials, the main consideration is frequency analysis without considering manufacturing prospects. Elastic modulus, Poisson ratio, and material density are required for free vibration analysis.

Table 1 shows the material properties of different materials. The mechanical properties of gray cast iron grade FG 260 have been taken from the Metals Databook [14]. Structural steel, Al alloy, and Mg alloy are available as engineering material in the material library of ANSYS 14.5 [13]. Boundary conditions play important role in vibration analysis. There are two predefined boundary conditions in ANSYS for free vibration analysis. These are free–free and fixed–fixed boundary conditions.

Table 1 Material properties

S.No.	Material	Elastic modulus (Pa)	Poisson ratio	Material density (kg/m^3)
1	Gray cast iron grade FG 260	1.28e11	0.26	7,200
2	Structural steel	2.0e11	0.30	7,850
3	Al alloys	0.71e11	0.33	2,770
4	Mg alloys	0.45e11	0.35	1,800

Table 2 Variation of modal frequency of four different materials

Mode	Gray cast iron (modal frequency Hz)	Structural steel (modal frequency Hz)	Al alloy (modal frequency Hz)	Mg alloy (modal frequency Hz)
1	1,002.5	1,291.7	1,291.6	1,273.2
2	1,119.3	1,444.5	1,448	1,430
3	1,332.7	1,718.8	1,721.4	1,698.8
4	1,665.5	2,152.2	2,161.7	2,137.5
5	1,692.4	2,186.7	2,196	2,171.1
6	1,805.2	2,328.5	2,332.4	2,302.1
7	1,916.1	2,472.6	2,478.4	2,447.3
8	2,117.3	2,730.5	2,733.9	2,697.2
9	2,151.7	2,777.3	2,784.7	2,750.1
10	2,282	2,946.1	2,954.4	2,917.8
11	2,301.3	2,968.1	2,973.1	2,934.7
12	2,473.5	3,188.5	3,190.7	3,147.1
13	2,488.6	3,211.8	3,219.5	3,179
14	2,675.8	3,456.8	3,470.5	3,430.4
15	2,747.1	3,550.8	3,567.8	3,528.1
16	2,766.1	3,569.4	3,577.5	3,532.6
17	2,826.1	3,650.6	3,664.4	3,621.5
18	2,878.6	3,714.3	3,721.9	3,674
19	2,885.5	3,723.4	3,731.9	3,684.8
20	2,954.8	3,816	3,829.6	3,784.8

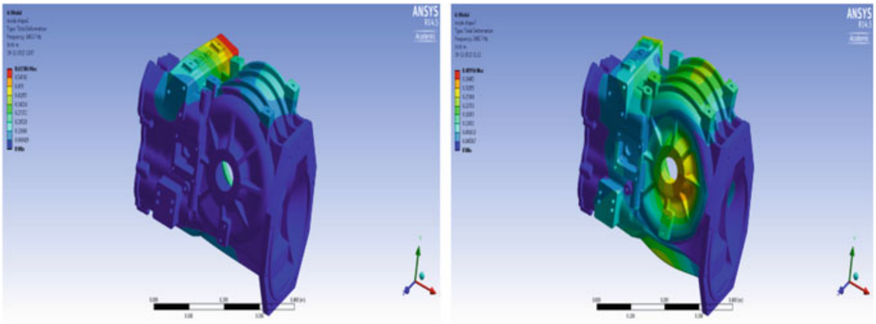

Fig. 4 Two different mode shapes (2 and 7) of structural steel transmission casing

4 Modal Analysis Results and Discussion

The mode shapes and natural frequency of transmission housing have been evaluated using ANSYS 14.5 solver. Mathematical simulation is performed for fixed–fixed boundary condition. In free vibration analysis, load is selected automatically by solver. The first 20 mode shapes and corresponding natural or modal frequencies for four different materials are shown in Table 2. Different vibration mode shapes (bending, torsional, axial bending vibration, and combination of two vibrations) were obtained. Figure 4 shows the six different mode shapes and corresponding natural frequency of gray cast iron grade FG 260 transmission casing. The frequency range varies from 1,002.5 to 2,954.8 Hz. Modes 2, 4, and 6 are torsional vibration modes. This torsional vibration is performed at single left side on transmission housing. Modes 11, 15, and 19 are axial bending vibration. In axial bending vibration, the transmission body bends from the center line.

For structural steel, the frequency range varies from 1,291.7 to 3,816 Hz. Modes 2 and 6 are torsional vibration modes. Modes 7 and 13 are axial bending vibration, where transmission body is twisted about center line. Modes 15 and 19 are bending modes. The frequency range for all materials is 1,002.5–3,784 Hz (Table 2). This range of frequency variation is same 500–3,500 Hz as the experimental result obtained by Tuma [7]. The frequency range of gray cast iron 1,002.5–2,954.8 Hz is min (Table 2).

5 Conclusion

Analysis results show that transmission housing is subjected to torsional vibration, axial bending vibration, and axial bending with torsional vibration. The first 20 vibration mode shapes and corresponding natural frequencies have been calculated using ANSYS 14.5 FEA-based simulation software. The transmission housing motion is constrained by considering the fixed–fixed boundary conditions. The 3D solid model is generated using SOLIDEDGE software and is transferred to ANSYS 14.5. In this research work, we have considered the problem of influence of transmission casing material on mode shapes and natural frequency. The FEA result shows that on design and vibration index, all four materials can be used as a truck transmission casing without considering the manufacturing prospects. FEA offers satisfactory results. The simulation result is verified with the experimental result available in the literature.

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