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FEA simulation and RSM based parametric optimisation of vibrating transmission gearbox housing☆

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Summary The main objective of this research work is optimisation of connecting bolts number using Detuning principle. Connecting bolts are used for constraining transmission system on vehicle frame. The model of transmission system designed for FEA and RSM analysis consists of 5—37 connecting bolts for tightly mounting on vehicle frame. At zero displacement condition when all 37 connecting bolts were constraint, natural frequency reaches in a higher order range of 1650.5—3565.1 Hz. This higher order range of frequency makes the model a conservative design when critical frequency for medium duty vehicle varies from 0 to 100 Hz. Using detuning principle and RSM optimisation technique an optimised number of connecting bolts can be identified. Response surface methodology (RSM) has been used for parametric optimisation and finite element analysis (FEA) was used for calculation of modal frequency and mode shapes. FEA analysis was done using ANSYS 14.5 and solid edge, and Pro-E has been used for geometric modelling.

Introduction

RSM and FEA technique has wide application. Since past two decades it has been used for various purposes to solve the problems. For design parameter optimisation in vehicle design RSM was frequently used for long time back. Few examples of RSM and FEA/FEM application in design field were studied as part of literature study to prepare the background of present research work. Patil et al. (2012a) have used the RSM technique in electromechanical Coriolis mass flow sensor (CMFS). Kodiyalam and Sobieski (2001) have used the optimisation method in vehicle design. They have compared the earlier used optimisation methods and advance methods that can be used in vehicle design. Kumar and Patil (2016) have analysed the heavy vehicle

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transmission gearbox housing. Patil et al. (2012b) have studied the sensor performance. Adaptive neuro-fuzzy inference system (ANFIS) was introduced to evaluate the performance of CMFS. The experimental results are in agreement to use ANFIS for CMFS. Kumar et al. (2014a) have used the FEM for analysis of transmission gearbox casing and identified different harmful vibration mode in transmission gearbox housing.

Authors have used RSM for advanced problem optimisation. Heavy vehicle modelling and FEA analysis have been done (Kumar et al., 2014b). Authors have studied vehicle concept modelling and used FEA approach to improve the noise and vibration, stiffness, looseness performance, etc. Researchers also studied vibro-acoustic design optimisation using RSM. The sound problem inside passenger cabin has been studied using FEM—BEM combination. Structural analysis was performed using FEM. RSM was also used for damping structure optimisation analysis. The main advantage of RSM application is it reduces cost of expensive analysis method. The design parameters of model can be varied to create variety of solutions and then the best suited solution will be adopted for production purpose.

Modelling of medium duty transmission gearbox system

Transmission gearbox system has more than 600 parts. The transmission gearbox assembly has transmission housing, input shaft, output shaft, intermediate shaft, gears, synchroniser, bearing, ribs, connecting bolts hole, bosses, fillets, etc. To prevent direct damage of gears it is fitted inside gearbox housing. Gearbox housing is mounted on vehicle frame using bolts. Connecting bolt constraints the motion of housing and makes it tightly fixed with frame. In this research study 5—37 connecting bolts were used for transmission gearbox housing mounting on vehicle frame. FEA simulation using ANSYS 14.5 (ANSYS, 2013) has mesh generation of 2, 14,644 nodes and 1, 24,531 elements using tetrahedron linear elements (Tet 4).

Response surface method results

RSM is a widely used methodology for problems in which output is influenced by many input variable parameters and the goal is to optimise the result. It is first time as per literature, and it is used for selection of material and optimisation of transmission gearbox housing connecting bolts number. Central composite design (CCD) with quadratic function was used for finding the optimal values of design parameters. The process parameters are Young's modulus representing material mechanical property and number of connecting bolts used for mounting of transmission on truck frame. Young's modulus is selected to obtain best suited material for gearbox housing. Young's modulus varied from 110 to 120 and 121 to 128 GPa in two stages. FEA simulation finds the fundamental frequency for both conditions. Using optimisation tool corresponding optimal frequency connecting bolts number was selected.

Based on preliminary investigation the range of design parameters was selected. The Young's modulus range was 121—128 GPa and connecting bolts range were 12—36 in numbers. The output response variable investigated was frequency (Hz). The performance test shows 28 runs. The design layout of transmission gearbox housing was produced using software Design Expert version 9.0 (Design Expert, 2016). ANOVA (Analysis of Variance) result shows the significance of model coefficient, model and lack of fit. The ANOVA results show that the quadratic model is valid. The *F*-value 632.97 of model shows that it is valid. Significant model terms are A, B, AB, A^2, and B^2 (A represents number of connecting bolts and B represents Young's modulus). Quadratic model provided best fit and it has insignificant lack of fit. The regression equation for the frequency variation as a function of two design parameters (A: connecting bolts, B: material properties Young's modulus) is given below:

$$\text{Frequency variation} = +1514.45 + 274.68 * A + 29.73 * B - 13.52 * AB - 51.38 * A^2 + 10.02 * B^2$$

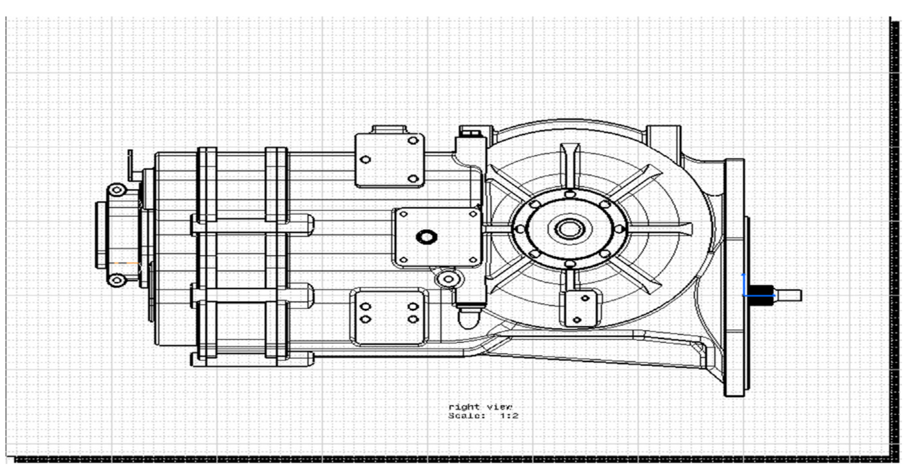


Figure 1 Model of medium duty transmission gearbox system.

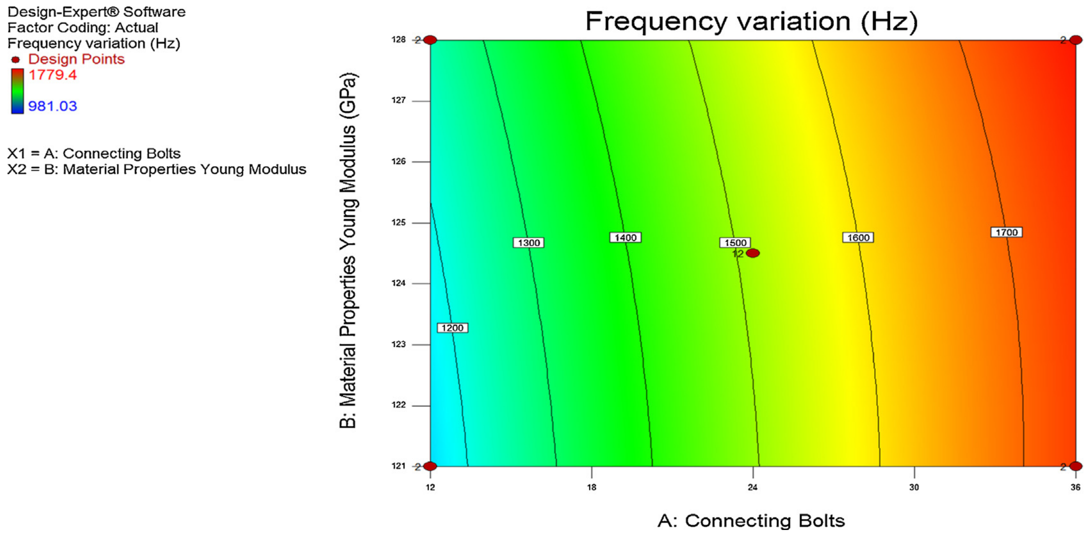
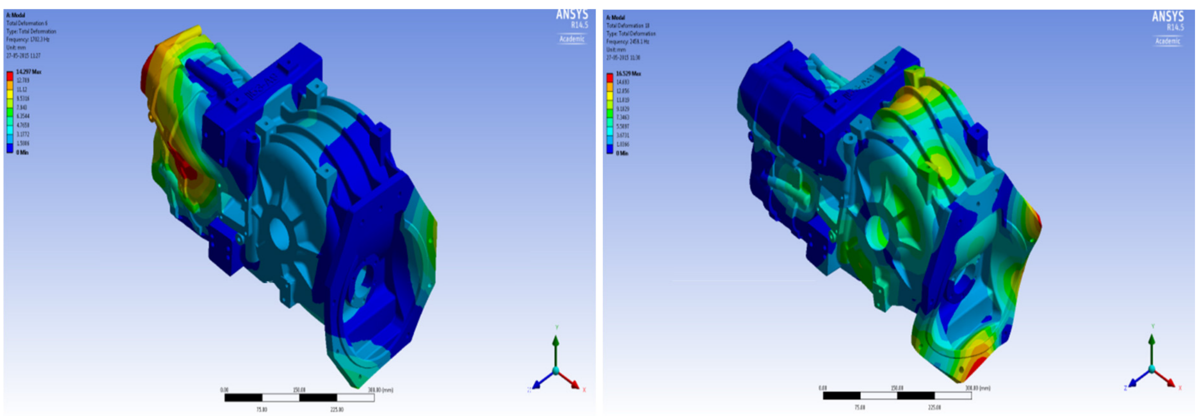


Figure 2 Contour graph for frequency variation with design parameters.



12 Bolt, Mode 6 f6= 1702.3 Hz

12 Bolt, Mode 18 f18= 2459.1 Hz

Figure 3 FEA simulation results at 12 connecting bolts constraint condition.

The regression equation in terms of coded factors (*A*, *B*) is useful for making predictions.

Fig. 2 (contour graph) shows the effect of design parameters (connecting bolts, Young's modulus) on frequency (output response). The linear profile fitting of surface graph is according to quadratic model. The first natural frequency or fundamental frequency for 12—36 connecting bolts and Young's modulus 121—128 GPa varies from 981.03 to 1779.4 Hz. As number of connecting bolts increases, frequency increases linearly in higher order range. Higher order frequency is desired to eliminate the resonance condition. From Fig. 2 it can be concluded that frequency and connecting bolts have proportional relation. As connecting bolts increases frequency increases. At 12 connecting bolts the frequency increases rapidly and the maximum value of frequency (1779.4 Hz) was obtained at 36 connecting bolts. It shows that to constraint the transmission gearbox housing on truck frame use 12 or more connecting bolts (Fig. 3).

ANSYS 14.5 was selected for FEA analysis. For modal analysis subspace method was selected and load is applied by programme automatically. For constructing FEA model of transmission gearbox housing (Fig. 1) tetrahedron element (uniform mesh form, Tet 4) and intelligent grid pattern were selected. For accurate and precise results element size was kept less and grid number higher. For too small element size, meshing will be dense which increases computing time.

FEA numerical simulation was used for simulating the RSM output response. First 20 natural frequency and mode shapes were obtained at 12, 20, 30 and 37 connecting bolt conditions. These FEA results were used for determining whether in actual condition the fundamental frequency varies from 981.03 to 1779.4 Hz or not. Fig. 4 shows frequency variation and connecting bolts variation. As the number of connecting bolts increases the natural frequency shifted in higher order range. The lowest frequency 1183.3 Hz was found at 12 connecting bolts and highest natural frequency 3565.1 was found at 37 connecting bolt conditions. FEA results show that the fundamental frequencies vary 1183.3—1650.5 Hz which is in the same range as evaluated by the RSM. The RSM fundamental frequency is 981.03—1779.4 Hz.

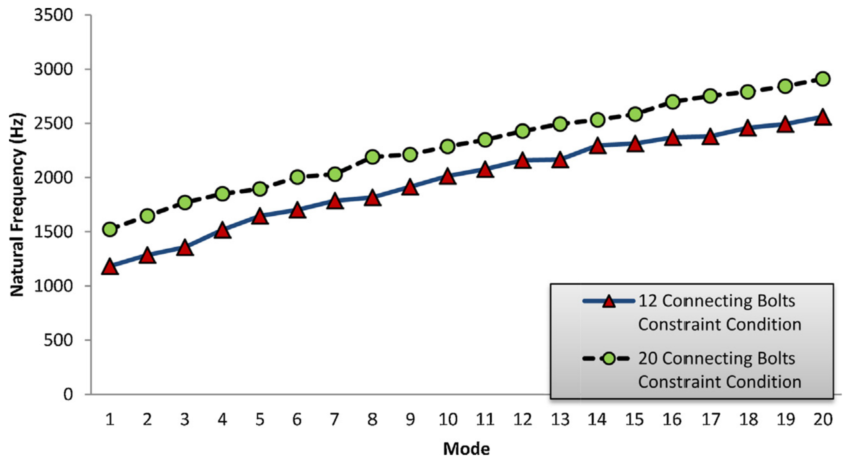


Figure 4 Graphical representation of frequency variation for connecting bolts variation.

Conclusions

RSM and FEA based numerical optimisation and vibration analysis show the effect of design parameters on frequency response. Numbers of connecting bolts directly affect the frequency. A proportional relation was found between these two parameters. The contour plot shows a linear relation between constraint connecting bolt and frequency response. The FEA numerical results show that the natural frequencies vary 1183.3—3565.1 Hz as changing the number of connecting bolts 12—37 and fundamental frequencies vary 1183.3—1650.5 Hz. Mode shape shows bending vibration, torsional vibration and bending with torsional vibration. The natural frequency depends on stiffness and mass of housing material. This research study has theoretical and practical significance in design stage of medium duty heavy vehicle truck transmission gearbox system. RSM and FEA results are in agreement.

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