Optimization of Stiffeners of Differential Gearbox Casing by Vibration and Stress Analysis

Aditya K. Nimbalkar[1], Y. B. Chaudhary[2]

***Abstract*— The differential gearbox casing is an vital part in the vehicle. The casing consists of different sets of helical gears, spur gears and three bearings to support the shafts. The bottom portion is filled with oil. In a power transmission gear system, the vibration generated at the gear mesh is transmitted to the gearbox housing through the shafts and bearings. To do the analysis of entire gearbox casing it is necessary to do the analysis of casing, set of gears and effect of oil. Optimization and structural modification is necessary to reduce component complexity, weight and subsequently cost. This project work does the analysis of casing which is die cast ALSi132 material equipped with sets of stiffeners on either side. The use of the stiffener is to reduce vibration, stress and noise. The objective of the project is to analyze differential gearbox casing of Bajaj Three Wheeler Vehicle for modal and stress analysis. The theoretical modal analysis should be validated with experiment result from Fourier frequency transformer analysis.**

***Index Terms*— Differential gearbox casing, Fourier Frequency transform, Modal and Stress analysis, , Optimization, Stiffeners, Vibration.**

I. Introduction

The differential gearbox casing is very important part of any automobile vehicles. It consists of various sets of spur and helical gears. It also consists of three bearing to support the shafts carrying gears. For lubrication purpose bottom part of gearbox is filled with oil. The gear meshing generates vibration which is transmitted to gearbox casing through bearings. Hence analysis of gearbox casing is of great importance. To reduce the vibrations generated due to gear meshing stiffeners are incorporated in casing. Optimization and structural modifications is necessary to reduce component complexity, weight and product cost. This project aims at Static stress analysis of Three Wheeler Differential Gearbox casing and optimization of stiffeners using gear mesh frequency. The objective of this project is to do Optimization of 4 sets of stiffeners and its layout of Differential Gear Box Casing. So we conduct Stress and Modal analysis of differential casing with original set of stiffeners and optimized set of stiffeners which was finalized after comparison of natural frequency results with Gear Meshing Frequency. Also we have conducted linear static stress analysis of the casing by applying the forces which are calculated from the given data, then compared the stress values for casing original stiffeners and optimized set stiffeners with the safe value. The casing in this project is made by casting using material AlSi132 with stiffeners on both sides. Still yet the work done in this area includes torsional as well as bending vibration analysis using empirical formulae and iterative methods with simplified assumption that throw of casing has only one degree of freedom. This assumption is not sufficient to get exact idea about nature of vibration and stress in casing material. Multiple degree of freedom are considered in this project to get advanced analysis. One of the major obstacle in analysis is the complex geometry of casing. This problem is tackled by use of FEM package. The FEM techniques helps in carrying vibration analysis and stress distribution under applied load. The results of FEM analysis are compared with Fast Fourier Transform results for validation.

This work was supported in part by the Extencore Solutions Pvt. Ltd., Pune.

Corresponding Authors
Aditya K Nimbalkar.[1] Tel.: +91 8888637638
P.G Student (Mechanical Design Engineering)
[1]Department of Mechanical Engineering
[1]NDMVP'S KBT COE, Nasik, Maharashtra, India.
Savitribai Phule Pune University, Pune, Maharashtra, India.
E-mail address: aditya.nimbalkar001@gmail.com

Y. B. Chaudhary.[2] Tel.: +91 9975558893
Associate Professor
[2]Department of Mechanical Engineering
[2]NDMVP'S KBT COE, Nasik, Maharashtra, India.
Savitribai Phule Pune University, Pune, Maharashtra, India.
E-mail address:. uraj20@rediffmail.com

II. Literature Review

Tushar Khobragade[1] worked on Static analysis of Gearbox Casing. Author has worked on differential casing of Light duty Diesel Engine. Casing is statically analysed using two softwares namely Hypermesh and ANSYS. The results obtained from softwares are compared with each other. Mirunalini Thirugnanasambandam[2] worked on design and analysis two stage speed reduction gearbox housing. This work aimed at design and finite element modelling using

ANSYS. The ANSYS solutions were evaluated with different theoretical solutions such as Raleigh's energy method and were found consistent. A. A. Hobert[3] describes the analysis of axle carrier assembly. The aims of analysis were to model the separation of crown and pinion under drive and coast load and to produce reasonably accurate stress information for axle carrier shell. William R. Kelley[4] has described Dynamic Correlation study of Transfer case housing. Dynamic correlation, Comparison of Mode shapes and natural frequencies was used to evaluate the accuracy of Finite Element model. Mitesh Patel[5] worked on finite element analysis of triple reduction gearbox that constitutes driving mechanism. The load calculation of helical gear were performed using CAD package. Static analysis was performed using combination of shell and solid element to determine the deflection and stress analysis.

III. System Model

Existing component consists of excessive numbers of stiffeners. It is required to reduce number of stiffeners without affecting mechanical functionality, strength and durability of component. It is simultaneously checked whether vibration and noise emitted from component are reduced by relocation and renumber of stiffeners.

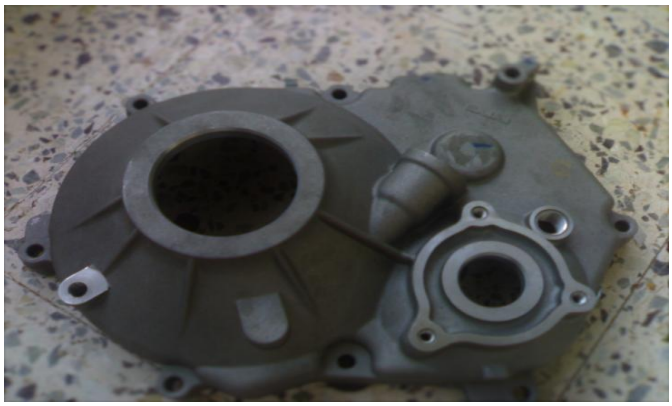

Fig. 1. Existing Component (Front Portion)

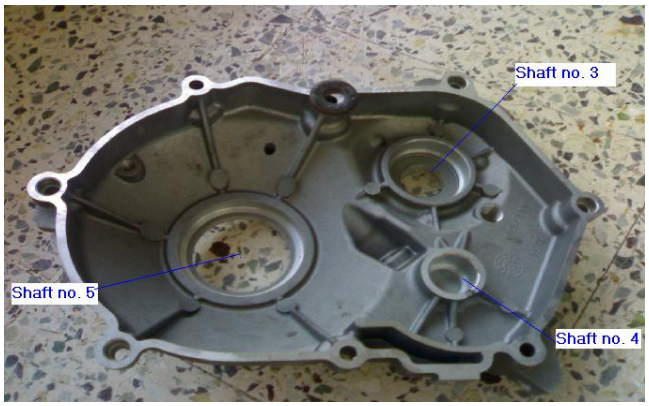

Fig. 2. Existing Component (Rear Portion)

IV. Methodology

Methodology for project is as follows;

1. Formation of Model using CREO 3.0
2. Finite Element Meshing using Hypermesh 13.0 of 3-D Model
3. Force and Reaction Calculations using given data
4. Static and Dynamic Analysis (Finite Element Analysis) using ANSYS 14.5.
5. Experimental Validation using fast Fourier Transform
6. Optimization using results and rechecking of safe conditions.

V. Methods Of Analysis

The two methods used for analysis of casing are

1. Stress Analysis &
2. Modal Analysis

Stress Analysis: Static Stress Analysis is done using ANSYS 14.5 by applying calculated forces and boundary conditions. Stress levels of existing and optimized model are compared. Von mises Stress is used as criteria for comparison.

Modal Analysis: It is study of dynamic properties of structures under vibration excitation. The goal of Modal analysis is to determine natural mode shapes and frequencies of casing under free-free condition using ANSYS 14.5.

VI. Simulation Results

1. Solid Model and Meshing:

Model is created using CREO 3.0. and finite element model is created using Hypermesh 13.0. Element type used for creating model is Solid 45. Eight nodes having 3 DOFs each are used to define element. MPC184 (Beam) elements having all six degree of freedom are used to model rigid parts of structure such as shaft housing.

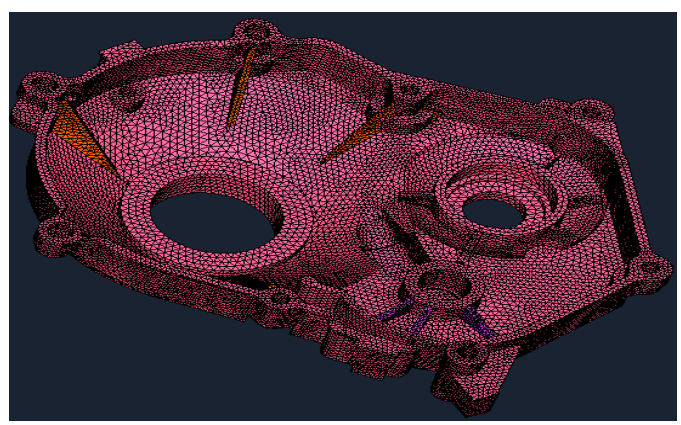

Fig. 3. Meshed 3D Model

2. Modal Analysis:

Modal analysis is performed under free-free conditions. First 10 natural frequencies are found out using Modal analysis. Basic equations are solved by Block Lanczos methods.

TABLE I
NATURAL FREQUENCY UNDER FREE-FREE CONDITION

Mode	Frequency (Hertz)
1.	0.0000
2.	0.0000
3.	6.77204E-04
4.	1.24520E-03
5.	1.39359E-03
6.	1.58150E-03
7.	914.60
8.	1212.2
9.	1576.5
10.	1857.4

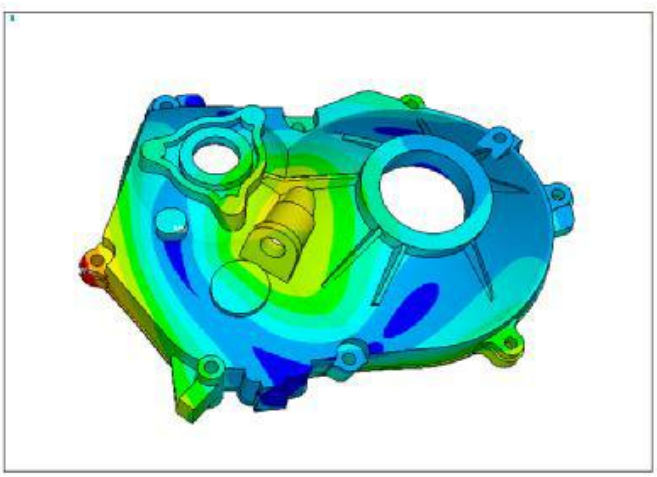

Fig. 4. Mode Shape With all Stiffeners

VII. Experimental Results

Experimental results are obtained by using fast Fourier transform. It consists of Exciter and Transducers. Casing is excited with hammer and its frequencies are measured with transducer. Accelerometer is used as transducer for this setup. The results are displayed on screen in graphical form. Fig .5. shows the General Test Configuration of set up.

The heart of the test system is the controller, or computer, which is the operator's communication link to the analyzer. The analyzer provides the data acquisition and signal processing operations. For making measurements on simple structures, the exciter mechanism can be as basic as an instrumented hammer. Transducers, along with a power supply for signal conditioning, are used to measure the desired force and responses.

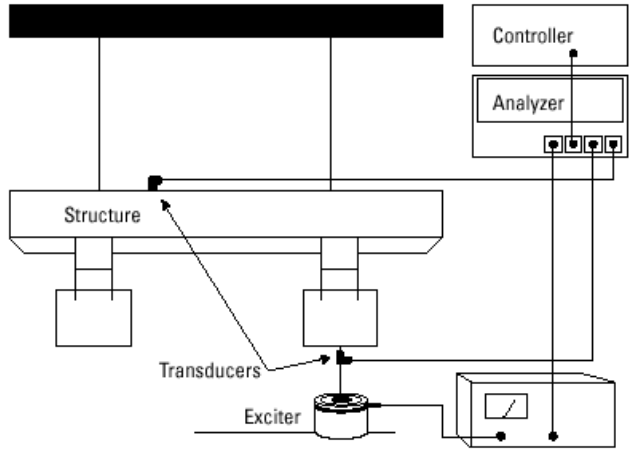

fig. 5. General Test Configuration

TABLE II
COMPARISION OF FREQUENCIES

Mode	ANSYS Frequency	Experimental Frequency
1.	914.60	868.70
2.	1212.2	1272
3.	1576.5	1533.70
4.	1857.4	1772

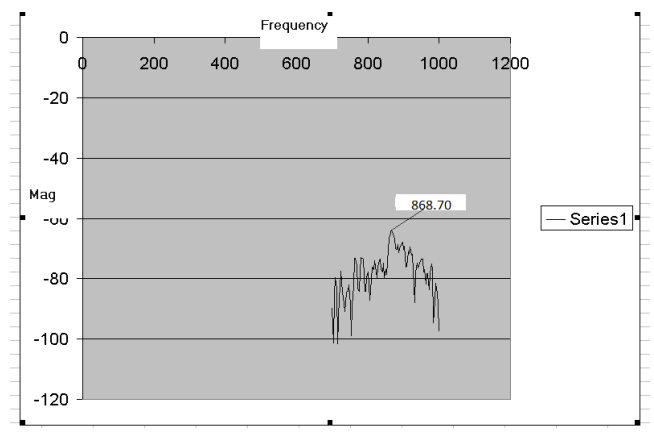

Fig. 5. Graphical results

VIII. Optimization Of Stiffeners

Stiffeners are incorporated in system to reduce the Noise, Vibration and Stress. Excessive number of stiffeners will add unnecessary weight to the system. Therefore number of stiffeners are chosen wisely without affecting mechanical functionality, strength, & durability of component. The set of stiffeners for which excited frequency coincides with natural frequency i.e. condition of resonance, are excluded from calculation. Excited frequencies are calculated by multiplying Gear Mesh Frequencies by series of natural frequencies, 2,3,4,5 & 6.

$$\text{Gear Mesh Frequency} = T \times \frac{N}{60}\ Hz$$

Where,
T= no. of teeth,
N= speed of rotating shaft.

TABLE III
GEAR MESH FREQUENCY

Fundamental Frequencies	II 2xf	III 3xf	IV 4xf	V 5xf	VI 6xf
457	914	1371	1828	2285	2742
838	1676	2514	3352	4190	5028
1182	2364	3546	4728	5910	7092
1486	2972	4458	5944	7430	8916

Twelve set of stiffeners has been considered for optimization. These set are nothing but different no. of stiffeners. For each set frequencies are calculated and compared with excited frequencies to check out the condition of resonance.

TABLE IV
SET OF STIFFENERS CONSIDERED

Mode	A	B	C	D
1.	8	5	5	5
2.	6	5	5	5
3.	4	5	5	5
4.	8	4	5	5
5.	6	4	5	5
6.	4	4	5	5
7.	8	5	4	5
8.	6	5	4	5
9.	4	5	4	5
10.	8	4	4	5
11.	6	4	4	5
12.	4	4	4	5

TABLE V
FUNDAMENTAL FREQUENCIES AS PER DIFFERENT SETS

Mode	1	2	3	4	5	6	7	8	9	10
8555	2114	2770	4491	4787	5394	5756	5913	6165	6808	6852
6555	2111	2769	4490	4786	5398	5759	5919	6167	6815	6851
4555	2111	2732	4479	4786	5390	5750	5918	6161	6730	6488
8455	2112	2770	4491	4785	5391	5750	5907	6161	6808	6851
6455	2110	2722	4471	4784	5344	5746	5905	6157	6728	6843
4455	2110	2722	4471	4784	5344	5746	5905	6137	6728	6843
8545	2112	2769	4485	4786	5393	5758	5912	6167	6796	6851
6545	2111	2732	4470	4786	5390	5746	5916	6161	6722	6845
4545	2110	2721	4469	4784	5345	5745	5904	6157	6728	6843
8445	2110	2761	4470	4786	5395	5758	5896	6166	6805	6850
6445	2110	2760	4461	4787	5405	5761	5904	6165	6805	6848
4445	2108	2723	4457	4787	5388	5750	5904	6160	6728	6844

These frequencies are compared with gear mesh frequencies. It is found that mode no. 6555, 8455, 8545 are subjected to resonance and these set is excluded from consideration.

TABLE VI
FUNDAMENTAL FREQUENCIES WITHOUT ALL STIFFENERS

Mode	Frequency (Hz)
1.	0.0000
2.	0.0000
3.	0.0000
4.	0.0000
5.	0.8670E-03
6.	0.1040E-02
7.	843.1201
8.	1151.3586
9.	1429.1102
10.	1696.5160

Variation in natural frequencies of existing model and model without stiffeners is less and there is no possibility of resonance. Further safe conditions are checked by Static stress analysis.

IX. Result

Following table shows comparison of Existing and Proposed model;

TABLE VII
COMPARISION OF FREQUENCIES

Mode	Existing Frequency	Proposed Frequency
1.	914.60	843.12
2.	1212.2	1151.35
3.	1576.5	1429.11
4.	1857.4	1696.51

X. Conclusion

1. ANSYS frequencies are compared with Gear mesh frequencies and no resonance condition found.
2. Natural frequencies of model with and without stiffeners are compared and also with operating frequencies. Proposed model is safe from all point of view.

3. Model without stiffeners has been proposed for further analysis and judgment.

ACKNOWLEDGEMENT

I take this opportunity to thank the people who helped me through this project. I am grateful Prof. A. B. Kakade, HOD of Mech. Dept., Prof. N. K. Kharate, PG Coordinator. I am very thankful to my project guide Prof. Y. B. Chaudhary for his continuous help and guidance.

REFERENCES

1. Tushar Khobragade, P. Priadarshani, "Static analysis of gearbox casing", Report of technology centre, cotton greaves ltd., HTC'08
2. Mirunalini thirugnanasambandam, Bhubaneswari parida, Design of Transmission Housing, Proc Indian Natn Sci Acad 75 no. 4.pp. 137-143, 2009
3. A. A. Hobert, A. O. Currie, analysis of automotive axle carrier assembly and comparison with test results, test report of Borg warner Australlia
4. William R. Kelley, L.Dean Isley, and Thomas J.Foste Of Borg- "Dynamic Correlation Study Transfer Case Housings", Warner Automotive Power train systems Sterling Heights, MI, USA.
5. Mitesh Patel, A.V.Patil , stress and design analysis of triple reduction gear box casing, IJIRST –International Journal for Innovative Research in Science & Technology| Volume 2 | Issue 02 | July 2015 ISSN (online): 2349-6010
6. Ravi Narayanaswamy and Charles D. Glynn Borg Warner, "Vibro-Acoustic Prediction of Low-Range Planetary Gear Noise of an Automotive Transfer Case", Automation Avenue Auburn Hills, Minnesota, October 2005.
7. Parag Bute, R. J. Patil, vibration analysis using finite element methodology to evaluate the response of gear housing of an automotive to the material and its mass properties, International Journal of Scientific Research and Management Studies (IJSRMS), Volume 1 Issue 9, pg: 289-296
8. Vasudeva Rao S, Soundararajan. S, Optimization of Front Axle Mounts Vibration Characteristics for Driveline Integration with Chassis, General Motors technical report
9. Mr. Recard, failure report of differential for Dynotech Engineering Inc. with American Metallurgical consultants, Inc.
10. Ravi Narayanaswamy and Charles D. Glynn Borg Warner, "Vibro-Acoustic Prediction of Low-Range Planetary Gear Noise of an Automotive Transfer Case", Automation Avenue Auburn Hills, Minnesota, October 2005.
11. Svend Gade, Breuk and Kjaer, Operational model analysis on Wind turbine Gearbox, Sound & Vibration Measurements, Germany and Christian Fenselau, Technology R&D – NVH, Germany.
12. Snežana Ćirić Kostić, Milosav Ognjanović, "The Noise Structure of Gear Transmission Units and the Role of Gearbox Walls" FME Transactions, Faculty of Mechanical Engineering, Belgrade. (2007)
13. M. Sofian, D. Hazry, "A study of Vibration Analysis for Gearbox Casing Using Finite Element Analysis" International Conference on Applications and Design in Mechanical Engineering (ICADME) October 2009.
14. Prof. K. Gopinath, Prof. M. M. Mayuram, " Machine Design II, Module 2, Lecture 17- Design of Gearbox", available online at nptel.com.
15. Dr. P. Selvakumar, " Fatigue Simulation for Differential Casing of Farm Tractor Through FEMFAT -Max", 1st Indian FEMFAT user conference, Pune, 22 Jan 2013.
16. P. D. Patel & D. S. Shah, " Steady-state Thermal Stress Analysis of Gearbox Casing by Finite Element Method", International Journal of Mechanical and Industrial Engineering (IJMIE) ISSN No. 2231 –6477, Vol-2, Iss-4, 2012.
17. Vasim Bashir maner, M. M. Mirza, Shrikant Pawar, Design Analysis and Optimization for Foot Casing of Gearbox, Proceedings of 3rd IRF International Conference, 10th May-2014, Goa, India, ISBN: 978-93-84209-15-5.
18. Andrzej Maciejczyk , Zbigniew Zdziennicki, A technical report on Design Basic of Industrial Gear Boxes, Technical university of lodz.
19. Shengnan Zhuang, A technical report on Gearbox Housing Topology Optimization with respect to Gear Misalignment, Linköping University, May 2012.
20. Nitin Kapoor, Virender Upneja, Ram Bhool and Puneet Katyal, Design and stress strain analysis of composite differential gear box, International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 7, July 2014.
21. Bhavin Gajjar, Finite Element Analysis of Gearbox Housing, IJSRD - International Journal for Scientific Research & Development| Vol. 2, Issue 03, 2014 | ISSN (online): 2321-0613
22. M. Mahesh Babu, Y. Rameswara Reddy, Stress Analysis of Gearbox Casing Using ANSYS Workbench, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064, Volume 4 Issue 7, July 2015.

Aditya K. Nimbalkar has Completed his Bachelor's degree in Mechanical Engineering from Maharashtra Institute of Technology in 2013. He is currently pursuing Master of Engineering from Savitribai Phule Pune University. His research of interest includes Static and Modal analysis of components.
(Email id: aditya.nimbalkar001@gmail.com)

Prof. Y. B. Chaudhary has completed his B.E.(Mech.) in 1996. and his M. TECH. in Mechanical Engineering in 2001. He is working as Professor at NDMVP'S KBTCOE, Nashik. He has a total teaching experience of about 18 years.
(Email id : uraj20@rediffmail.com)