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Acoustical Radiation Analysis of the Gearbox

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Abstract: *This paper presents a comprehensive procedure to find the vibrations and noise radiations generated from a gearbox. For this, a dynamic model of a gearbox is built by considering some parameters such as meshing of gear-pair, bearing, gear errors, casing. Now if there are any excitations then vibrations and noise radiations are generated. By considering excitations in bearing load, vibrations and noise radiations are calculated with the help of finite element analysis and boundary element method, and by this vibration response, noise spectrum and resonance frequency range along with various modes of deformations are obtained. At the last with the help of frequency response gearbox improving plans are researched.*

Keywords: Enclosure, Gearbox, Gear-pair, Noise Radiation, Response, Stiffness, Vibration, etc.

I. INTRODUCTION

The gearbox is the device that can regulate the speed and torque of an automobile according to the condition of the road. When at low speed and high torque when an automobile is climbing a steep or it is in starting condition or when it is running at high speed and does not need any torque then the use of gearbox starts. But with many advantages, tight structure, that is high efficiency, stable speed ratio, gearbox used in many industrial fields. When the vibrations are generated in the gearbox, noise is produced and due to the effect of the gear pair dynamic mesh force which affects the stability of the transmission system. Excessive noise produced by a reducer causes strained communication, fatigue, and possible hearing damage. To ensure a safe, smooth, and quiet operation of gear transmission, it is necessary to understand the mechanism of noise radiation and the dynamic response of the gear reducer, their reduction is highly desired.

In this era demand for quieter gears is increasing quickly, an oversized quantity of labour was reported within the reasonably literature on analyzing the vibration and noise of the gearbox. M. Barthod et al. deals with the rattle noise, caused by the fluctuation of the engine torque underneath special conditions, that might cause multiple impacts within the gearbox [1], Choy et al. conferred a way to predict each the noise generated and vibrations by a gear transmission underneath traditional operational conditions [2], Abbes et al. designed the gearbox by implementing a three-dimensional finite-element approach, and also the acoustic response of the system was calculated [3], Kato et al. simulated the noise radiation and vibration of a single-stage gearbox by combining finite-element vibration analysis with boundary part noise analysis [4], Velex and Maatar computed the dynamic responses to mesh stiffness variations for numerical gears [5], Yanyan and Zhen confirmed that the gear-pair assembly is that the main reason for the excitation of the gearbox and reduced the noise through matching the stiffness of the gears [6].

In all the previous research papers excessive simplifications have been made because of the complexity of the gearbox. Tuma gives techniques and procedures to produce less noise gearbox [7], Jianxing Zhou et al. designed a low noise gearbox with the help of acoustic panel method [8], Ognjanović et al. researched about the noise emission inside gearbox depends upon both the disturbances i.e., excitations inside the gearbox and on the insulations of model housing [9], Yogesh V. Patil et al. determines the natural vibrations modes and free frequencies of gearbox casing [10]. Vijaykumar et al. deals with the vibration analysis of the gearbox casing and determines the frequency range which is suitable for the gearbox to prevent resonance in the casing of the gearbox [11], Neeraj et al. proposed a methodology for the designing of a gearbox and its analysis by defining loads which can act as realistic driving conditions [12].

In this study, a procedure is proposed to predict the vibrations and noise radiation coming out of the gearbox. For this, a 4-degree of freedom model is built and by applying bearing force vibrations and noise radiation of the gearbox are going to be predicted. In this various deformation, modes are also calculated, by that resonant frequency can be calculated. And at the last effective method for reducing vibrations can be suggested.

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II. PROCEDURE FOR DESIGN AND ANALYSIS

During gear meshing gear excitation are caused due to fluctuations and gear errors in mesh stiffness, this excitation generates from the gear shaft to the bearings and excites the gearbox and produces noise that radiated from the surface of the gearbox.

The procedure consists of three steps: gearbox modelling and meshing, gearbox vibration analysis with the help of the finite element method, and determination of sound field with the help of boundary element analysis. All those methods are illustrated in figure 1. Both noise radiation and vibrations are calculated with the help of commercial software i.e., Ansys and Actran. Input parameters for analysis are gearbox shape, material, bearing load and so on. The output data are deformations, frequency response, vibrations and noise analysis results. The gearbox is designed according to the contribution of gear dynamics characteristics.

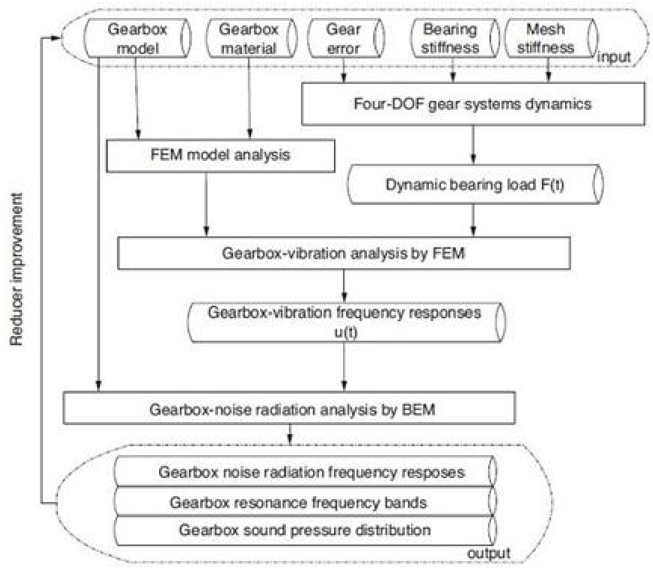

Figure 1: Analysis Procedure of Gear Reducer Noise Radiation [8]

III. DESIGN OF A GEARBOX

A. Lower Casing

Figure 2 shown is a lower casing. The base of this casing has some bolt holes by which the gearbox is fixed.

Figure 2: Lower Casing Model

The meshing of the lower casing consists of 28047 nodes and 15901 elements as shown in figure 3.

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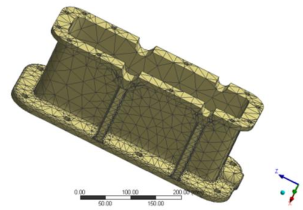

Figure 3: Meshed Lower Casing

B. Upper Casing

The upper casing is the most crucial part of the gearbox because if there is any vibration or noise it can directly affect the upper casing. Figure 4 shown is upper casing having the same properties as the lower casing and its meshed casing is shown in figure 5 which consists of 17671 nodes and 9851 elements.

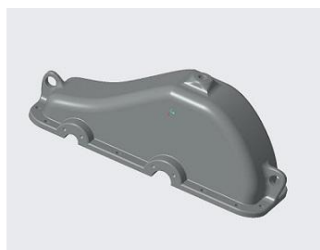

Figure 4: Upper Casing Model

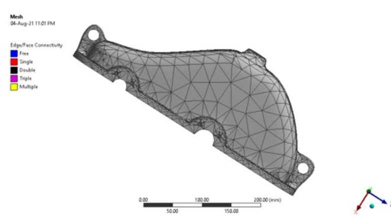

Figure 5: Meshed Upper Casing

C. Gear and Pinion Caps

Both gear and pinion cover are mounted on the casing and in between the upper and the lower casing. The shaft of both gear and pinion passes through these covers. Figure 6 shows the gear cover.

Figure 6: Gear and Pinion Cap

Meshed part of it is shown in figure 7 which consists of 11042 nodes and 5787 elements. Pinion cover is also same as gear cover.

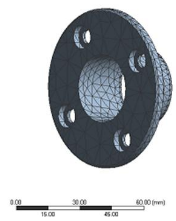

Figure 7: Meshed Gear and Pinion Cap

D. Gearbox Full Assembly

The gearbox of size 480 mm long, 187 mm wide and 355 mm height is shown in figure 8.

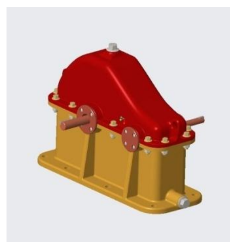

Figure 8: Gearbox Assembly Model

Meshed gearbox design consists of 245968 nodes and 122598 elements are shown in figure 9.

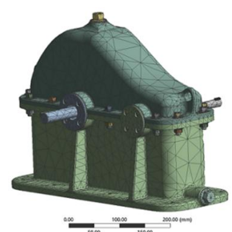

Figure 9: Meshed Gearbox

Each part of the gearbox is designed and assembled on Parametric CREO 5.0, material selections and boundary conditions to be applied in ANSYS 18.0. Material selection for each part of gear is shown in table 1.

TABLE 1: PARTS AND ITS MATERIALS

Sr. No.	Parts	Materials
1	Upper casing	Cast steel
2	Lower casing	Cast steel
3	Gear and pinion caps	Cast steel
4	Gear pair	Grey cast iron
5	Roller bearing	Bearing steel
6	Nut and bolts	Stainless steel

Material and its properties are shown in table 2.

TABLE 2: MATERIAL PROPERTIES

Sr. No.	Material	Properties

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		ρ	μ	E
1	Cast steel	7800	0.30	207
2	Grey cast iron	7200	0.28	110
3	Bearing steel	7850	0.30	208
4	Stainless steel	7750	0.31	193

Where, **ρ** is density and its unit is kg/m^3
μ is the piosson's ratio and it is unit less
and **E** is modulus of elasticity and its unit is GPa.

IV. ANALYSIS

The finite element analysis of gearbox is based on some assumptions that are, the gear-pair is assumed to be a static rigid body, shaft mass does not affect gearbox analysis assumed as negligible mass, shaft and gear-pair deflections are neglected.

A. Gearbox Vibration Analysis

With the help of modal analysis Lanczos method natural frequency in different modes of the gearbox is calculated with the help of Ansys 18.0. In this analysis, various deformational modes are found with a different natural frequency. After importing material properties bottom part of the gearbox are fixed. After this solver solving under a program-controlled mechanism without any damping condition within 0 Hz to 20000 Hz total of 8 modes are found as shown in figure 10.

B. Gearbox Dynamic Response Analysis

In this analysis for the dynamic response, a bearing load is applied and this analysis is known as harmonic response analysis, with the help of this total deformation of gearbox and the frequency response for the amplitude that is deformation can be calculated. For this within a frequency range of 0 Hz to 5000 Hz total 200 modes are calculated. Frequency response with deformation is shown in figure 11.

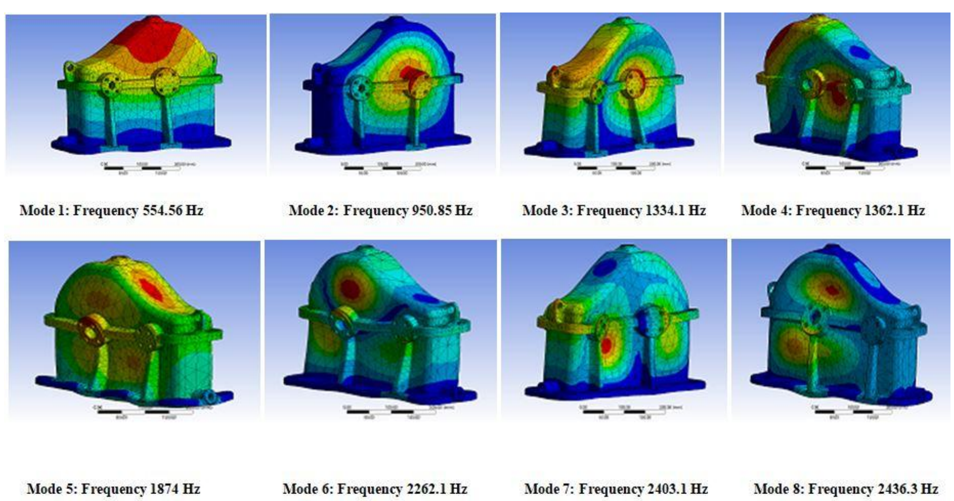

Figure 10: Modes of Gearbox with Different Frequencies

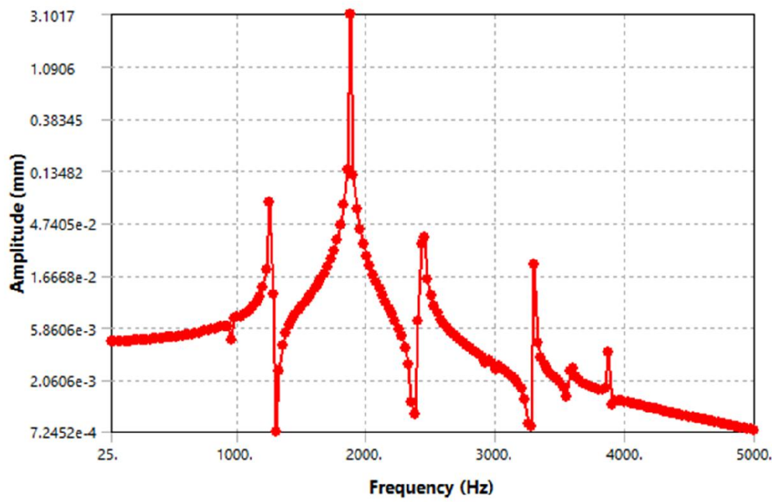

Figure 11: Frequency Response for Deformation of the Gearbox

From the above figure at around 1850 Hz deformation is maximum i.e., around 3.1017 mm, so if gearbox frequency matches this frequency, then the condition of resonance may arise. At 1850 Hz directional deformation of gearbox along the x-axis is shown in figure 12.

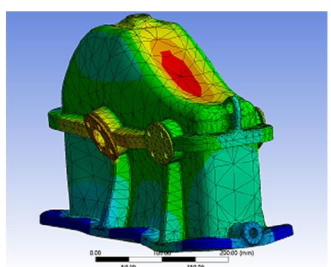

Figure 12: Directional Deformation Along x-axis

C. Noise Radiation Analysis

To calculate the noise radiation coming out of that gearbox frequency response of velocity generated from the harmonic response analysis is worked as the input in harmonic acoustic analysis. For this a spherical enclosure is prepared which surrounds the gearbox as shown in the figure 13.

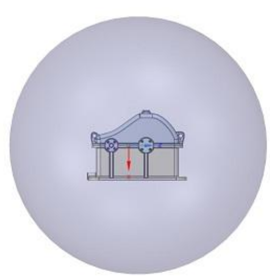

Figure 13: Spherical Enclosure Surrounds Gearbox

This spherical enclosure consists of the properties of air such as its density is 1.2 kg/m^3 and speed of sound inside this cavity is 334 m/s. The frequency response with the sound pressure level of radiated power between 0 Hz to 2500 Hz is shown in figure 14.

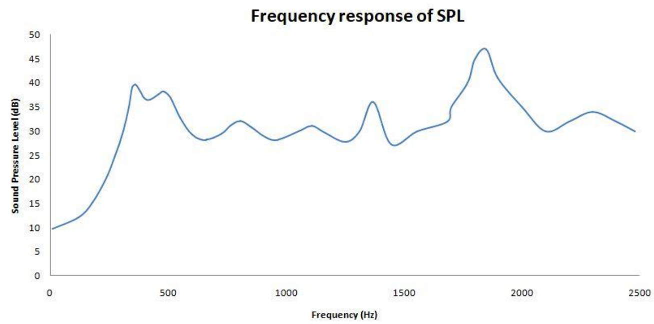

Figure 14: Frequency Response for SPL of Radiated Power of the Gearbox

V. REASONS FOR THE EXCITATIONS IN A GEARBOX

While transmitting power, the gear pair assembly is one of the main reasons for the vibrations and noise radiations from the gearbox. The main reasons for the gearbox vibrations are only due to rotating elements inside the gearbox such as gear-pairs, bearings, shafts. The part which affected the most by vibrations is its upper case. Various reasons for the excitations are as follows:

1. Gear-pair mesh stiffness: Stiffness of gear-pair varies with time when gear rotates with respect to pinion which results in vibration in the gearbox.
2. Deviations in the profile of tooth: If there are any deviations of tooth from its position then vibration may arise.
3. Effects of load: Some gears are made to bear a limit load but if there is any load which is more than the limit then vibrations are generated.
4. Manufacturing errors: If there is any manufacturing error then it directly affects the stiffness of the gears and then vibrations are generated.
5. Wear: With the time due to continuous loading condition gears becomes weak due to continuous wear and because of those vibrations start arising in the gearbox.
6. Misalignment of shafts: If there is any misalignment in the shaft due to looseness of mechanical components then shafts start deflecting on its mean position and vibrations are generated in the gearbox.

A finite element of gear-pair having gear ratio 17/51 is shown in figure 15 in which for the calculation of stiffness of meshed gear pair some parameters are needed to be assumed such as driven gear is fixed and torque T applied on the driving gear that is the pinion gear, and there is a constraint applied between the teeth of both the gears that are contact constraint.

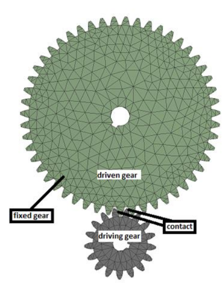

Figure 15: Finite Element Model of the Gear-Pair

VI. IMPROVEMENT IN THE GEARBOX

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Since from the research done it is clear that the most affected part of the gearbox is the upper casing and in the upper casing mostly top panel of that casing, other from that the second most affected part is the side panels of the gearbox where bearings are placed, so the gearbox is needed to be improved. By inserting ribs of 4 mm thickness in the gearbox as shown in figure 16 a support between the casings becomes stronger and because of some material addition they also bear vibrations and the overall effect becomes less. Also, the deformation of the gearbox was reduced to 3-4 times i.e., 0.67924 mm at 1850 Hz after inserting the ribs and the response of frequency with deformation is shown in figure 17.

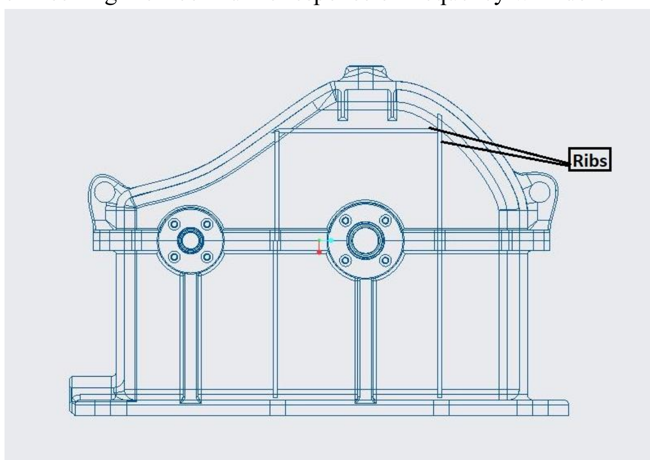

Figure 16: Wireframe Model Showing Ribs

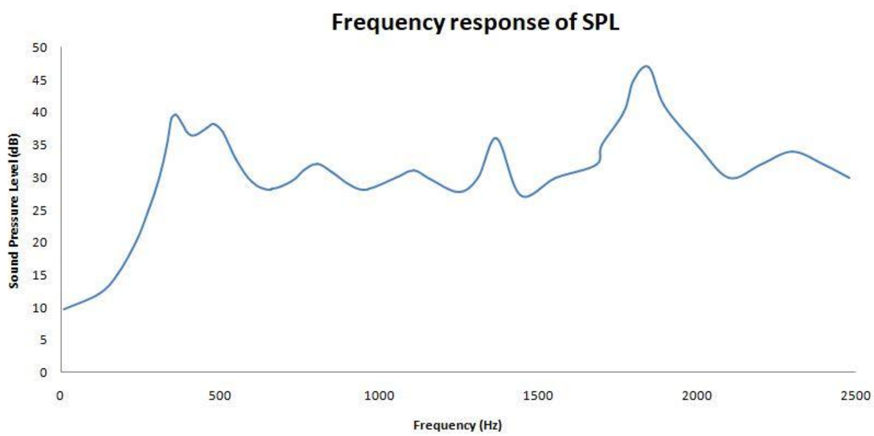

Figure 17: Frequency Response for Deformation of Improved Gearbox

After inserting ribs there is a huge improvement in the noise reduction of the gearbox i.e., between 1700 Hz to 2000 Hz SPL goes to 39 dB i.e., difference of 8 dB at around 340 Hz SPL reduced from 40 dB to 36 dB as compared to the normal gearbox as shown in figure 18.

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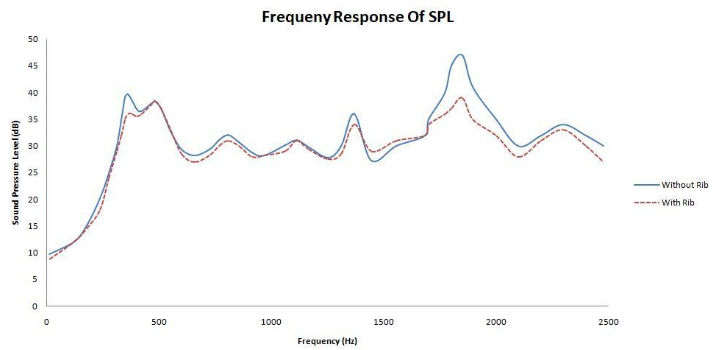

Figure 18: Comparison of Frequency Response for SPL of Radiated Power with and Without ribs in the Gearbox

VII. CONCLUSION

For the prediction of vibrations and noise radiation of the gearbox, a procedure is developed.

1. Natural vibrations modes of the gearbox are being calculated with the help of modal analysis.
2. For the production of excitations in the gearbox, a bearing force is applied to it by which frequency response with deformation of the gearbox is being calculated.
3. With the help of frequency response of velocity of the gearbox acoustic analysis of the upper casing and side panel of the gearbox is done for the calculation of noise radiations and frequency response for sound pressure level of radiated power is calculated.
4. For the reductions of vibrations and noise radiations, some changes are made by inserting ribs which increases the structural stiffness of the gearbox and by this resonance problem occurring at some frequency can be solved.

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