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VIBRATION ANALYSIS OF SPUR GEAR BY MASS REDUCTION AND CHANGING MATERIAL

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Abstract:

Present paper covers the design, vibration (Modal) analysis and results of experimental tests of spur gear. Effort is to increase the fundamental frequencies of existing gear and to improve performance of existing gear without compromising on the performance result of FEM analysis is compared with the experimental result and analytical results.

Keywords **— Vibration analysis**

INTRODUCTION

Gears are used in machines and vehicles for the transmission of power. The design of gears is highly complicated involving many constraints such as strength, pitting resistance, bending stress, scoring wear, and interference in involutes gears etc. The concentration is focused on spur gear sets which are used to transmit motion between parallel shafts. The toothed gear transmission stands unique due to its high efficiency, reliable operation.
The spur gear is the first choice option for gears except when high speeds, loads and ratios direct towards other by using the vibration analysis and parameters such as natural frequency and vibration mode can be calculated. .
Gear noise and vibration is a major problem in many power transmission application .this problem becomes more significant in applications with higher operating speeds the where vibratory excitation which is related to the gear transmission error.[6]
Now a days most of the mechanical systems are subjected to dynamic loading which causes & shortens of the usable time, crack, noise and fatigue, in general the total effect of work for the mechanical system is lowered. Reasons for such behavior are type of loading, construction and conditions of work where the mechanical systems operate.

OBJECTIVES

1. Design and modal analysis of existing gear material(EN9) and gears made of with change in EN19 and EN353 to assess their suitability and to offer alternative for existing materials with performance at par or better.
2. Modal analysis of gears made of EN9,EN19 and EN353 after weight reduction.
3. To check possibility of reducing `Net Weight’ of the component (gear) and subsequently cost savings.
4. To reduce the inventory for raw materials through standardization considering economy of scale.
5. To reduce opportunity cost of shortage.
6. Performing cost analysis to evaluate impact on the original cost.

PROMBLEM DEFINITION

Modal oscillation of gearbox housing walls and other elastic structures is very important for the noise emitted by systems into the surroundings. Modal activity of housing walls is in direct relation with the structure and intensity of noise emitted by the gearbox into the surrounding. Therefore, research of modal activities is of general importance for modelling the process of generation of noise in mechanical systems. The noise emitted into the surroundings by the gearbox is mostly the consequence of natural oscillation of the housing. [5]

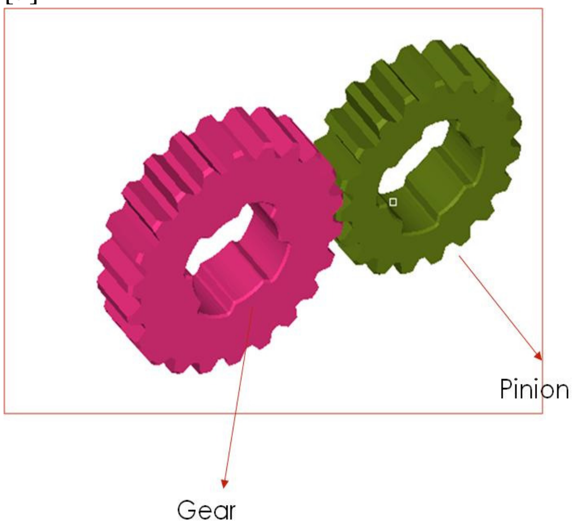


Fig1.3D model of spur gear.

MODEL OF EXITING GEAR

Tabel 1 : Gears parameters

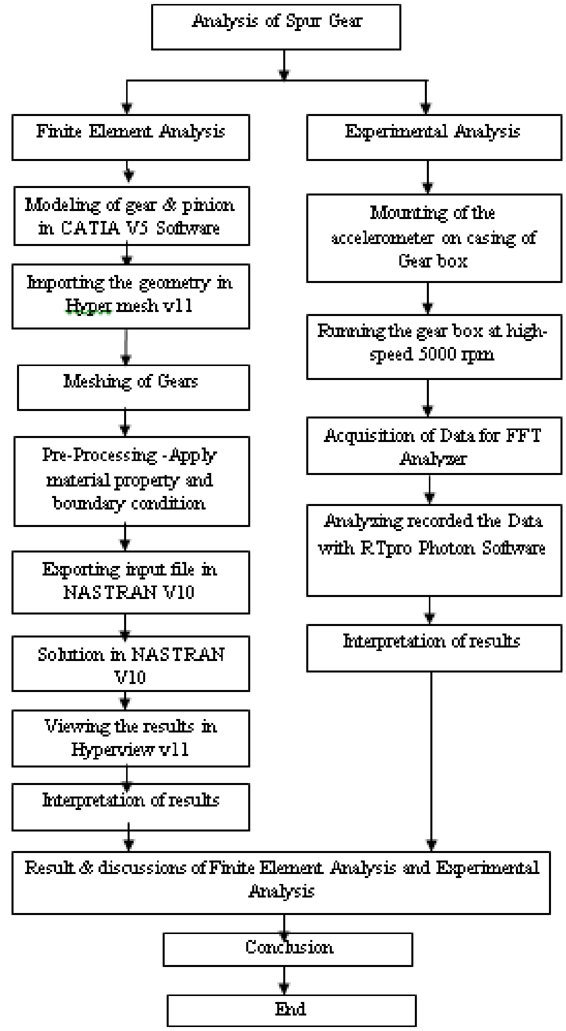
Parameter	Pinion	Gear
Thickness	2.884 mm	2.8 mm
Width	9.842 mm	9.842 mm
Root radius	16.271 mm	19.558 mm
Addendum radius	19.05 mm	22.225 mm
Pitch Circle radius	17.646 mm	20.350 mm
Pitch	5.8 mm	5.956 mm
Module	1.85	1.52
No. of teeth	19	22

1. Material Used: EN9
2. Type Spur Gear
3.Application for case Study: Automotive.

Modeling of spur gear is in CATIA

Catia stand for computer aided three dimensional interactive application. The most widely used software in modelling now a days is a catia.

METHODOLOGY



ANALYTICAL METHOD

The result of studying free oscillations of the system are own frequencies or own vectors.the simplest case as the system without damping and action of external forces so it is described by a differtional equation.

$m \ddot{X} + k \dot{x} = 0$

fundamental frequency is

$$w = \sqrt{\frac{k}{m}}$$

k= stiffness

natural frequency is

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

apply torsional theory , rotational stiffness is

for pinion ,

$$K_1 = \frac{J_P G}{R_P} \quad \text{.........(1)}$$

where ,

$$J_P = \frac{\pi}{32}\left(D_p^4 - d^4\right)$$

$$G = E/2(1+\vartheta)$$

"G" is the rigidity modulus of the material

"J" is the second moment of area about the rotation axis

For Gear,

$$K_2 = \frac{J_g G}{R_g} \qquad \text{............(2)}$$

$$K_{eq} = \frac{K_1 . K_2}{K_1 + K_2}$$

for pinion,

$$f_P = \frac{1}{2\pi}\sqrt{\frac{K_{eq}}{I_P}} \text{ ....(a)}$$

for gear,

$$f_G = \frac{1}{2\pi}\sqrt{\frac{K_{eq}}{I_G}} \text{...................(b)}$$

with the use of torsional theory we calculate natural frequency[9]

MODAL ANALYSIS OF EXITING GEARS

Modal analysis, which means the study of the structure mode shape under excitation to its natural frequency, is important in the design stage.

The finite element program Nastran was used to calculate the natural frequencies & mode shape of spur gear.

Modal analysis can predict the resonance of structure excited by the dynamic input.

Vibration (modal analysis)is a very effective technique for gear box health monitoring & fault detection .Health monitoring for gearbox is an improvement aspect to avoid failure of the machine .Using the free vibration analysis one calculates critical parameters such as natural frequencies & vibration modes that are essential for almost all dynamic investigations.

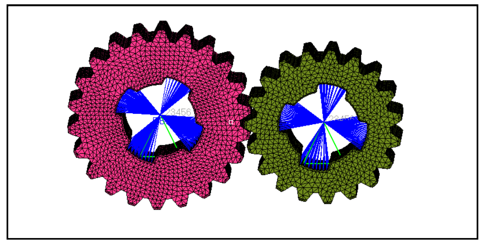
MESH SETTING OF THE GEAR IN NASTRAN

Table 2 Material property

Material (steel)	Young's moduluse5 mpa	Poisons ratio	Density Kg/mm3e-4
EN9	2.06	0.3	7.8
EN19B	2.10	0.29	7.8
EN353	2.2207	0.264	7.8

The gear designs are imported .In modal analysis using FEM ,gear model is meshed with tetrahedral elements .The model consist of 101501 nodes & elements 62081.FEM is a technique of predicting the performance of a real structure under precise load and displacement condition.

BOUNDRY CONDITION OF EXITING GEAR



SPC
(SINGLE POINT CONSTRAINT 123456)

FIG.2 MESH MODEL WITH BOUNDARY CONDITION

The mode shape of the gear in FEM are calculated independently of the excitation, means that the structure is only mass and stiffness distribution dependent.

MODE SHAPES AND FREQUENCIES OF EXITING GEARS WITH TWO DIFFERENT MATERIAL (EN19B AND EN 353)

Table 3 Two modes of frequencies for EN9 material

Operating Mode	Frequency (Analytical)	Frequency (nastran)	Percentage Difference
Mode (pinion)	30908	32227	4
Mode (gear)	44795	41561	7

The percentage difference is calculated by normalizing the nastran data with the analytical values. As seen in TableI the values of the frequencies computed by the analytical formulas agree well with the values obtained in nastran. For the nastran analysis, spur gear was meshed with RBE2 elements with the guided boundary conditions applied at the centre at SPC .

EN9 is existing material. it,s frequencies is32227 HZ and effort is to increase the fundamental frequencies by changing material and to improve performance of existing gear without compromising on performance.

The present used material of a spur gears is EN9 in this project gear is designed using two different material EN 19B and EN 353 . Analytical calculation and analysis is done for spur gear using EN9,EN19B and EN353.3D Modeling is done in CATIA V5 and analysis is done in NASTRAN

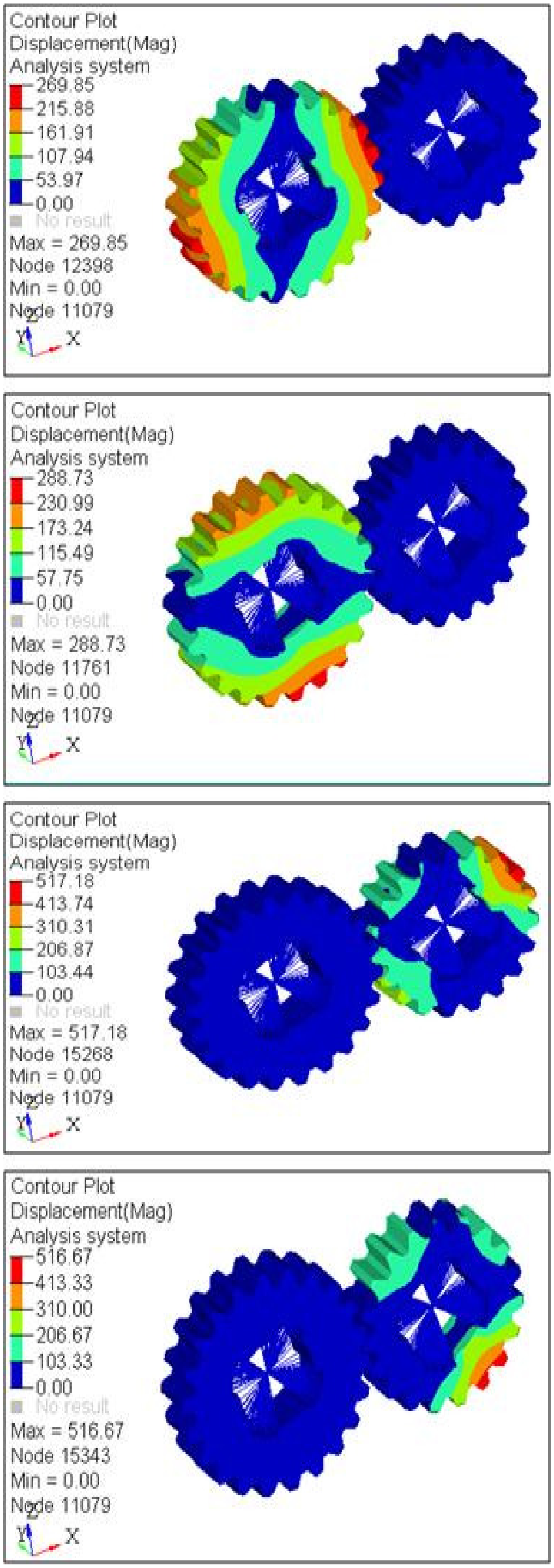


Fig 3. Mode shapes for EN9 Material

Table 4 Two Modes Of Frequencies for EN19b material

Operating mode	Frequency (Analytical)	Frequency (nastran)	Percentage Difference
Mode (pinion)	30850	32220	4
Mode (gear)	44350	41800	7

Modal analysis of different two materials EN9 and EN19B having same frequencies so we use another material(EN353).

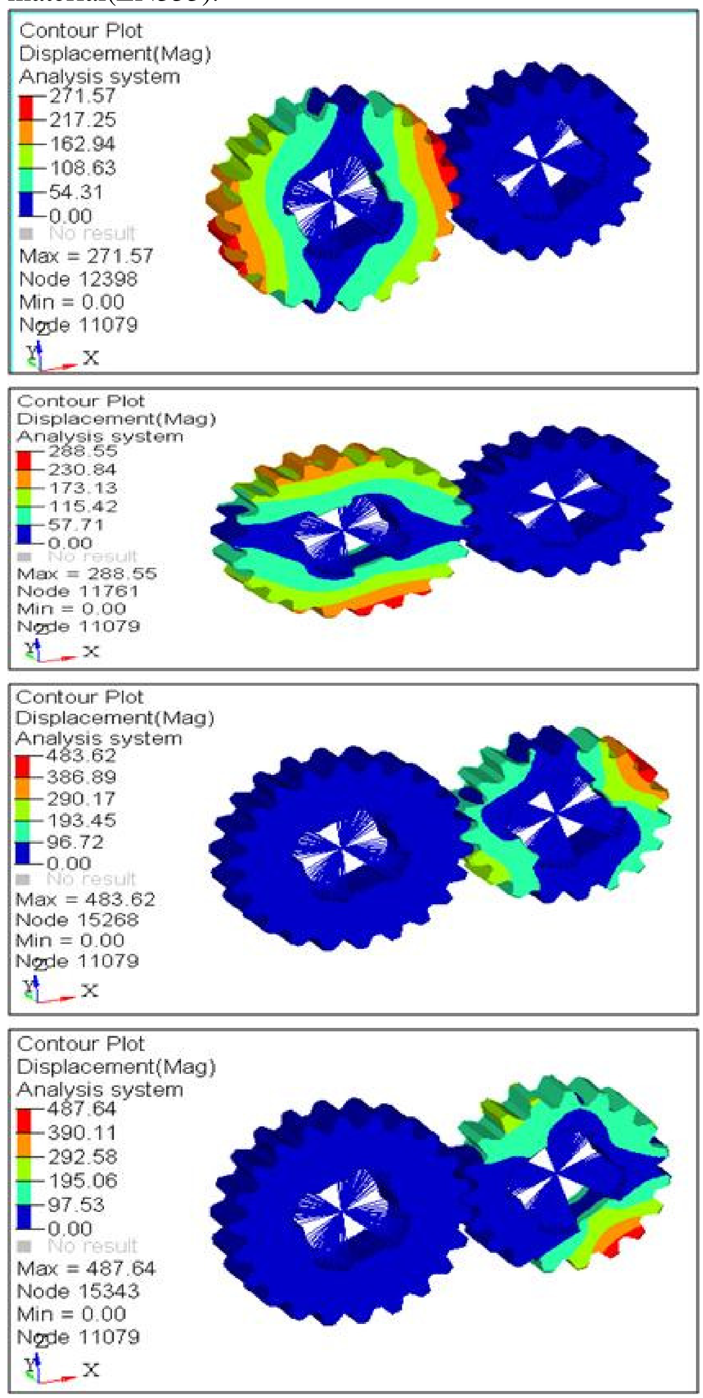


Fig 4 .mode shapes for EN19B material.

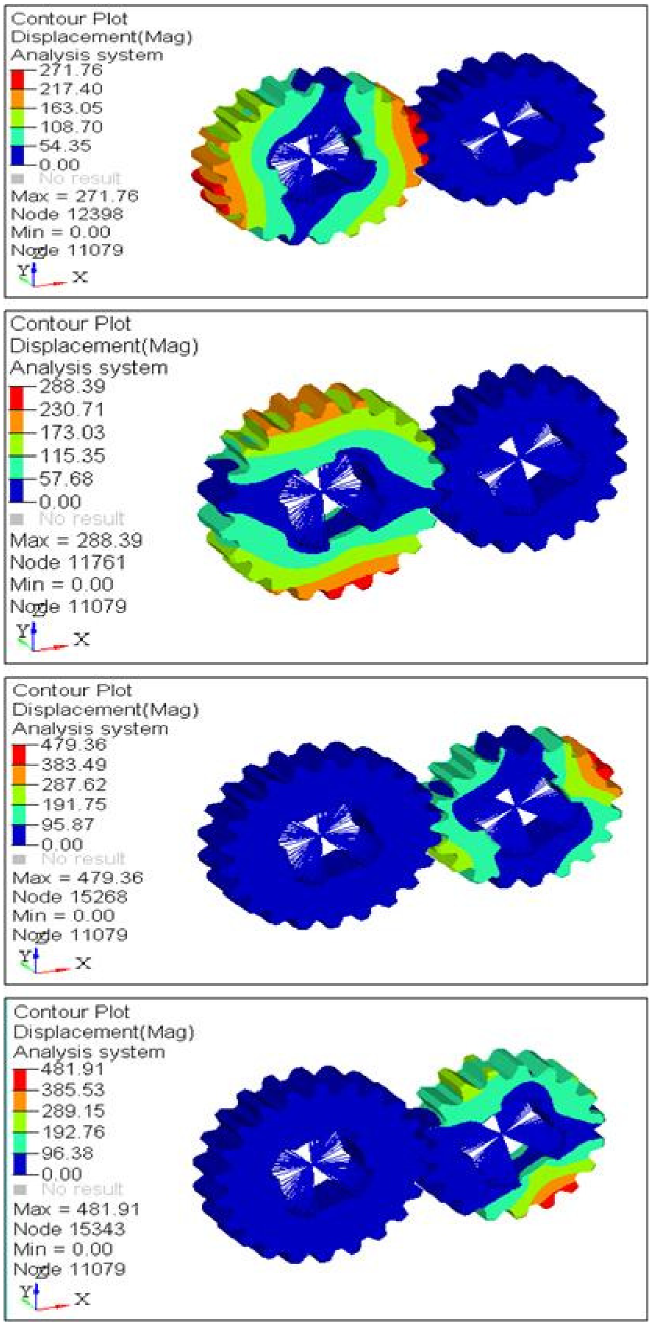


Fig 5.mode shapes for EN353 material.

After modal analysis of EN353 material have different mode shapes and frequencies.EN353 material frequencies is increased. It is more than EN9 material.

Table 5 Two Mode Frequencies for EN353 material

Operating Mode	Frequency (Analytical)	Frequency (nastran)	Percentage Difference
Mode (for pinion)	31367	33350	5.90
Mode (for gear)	44424	51780	14

MODEL OF MODIFIED GEAR

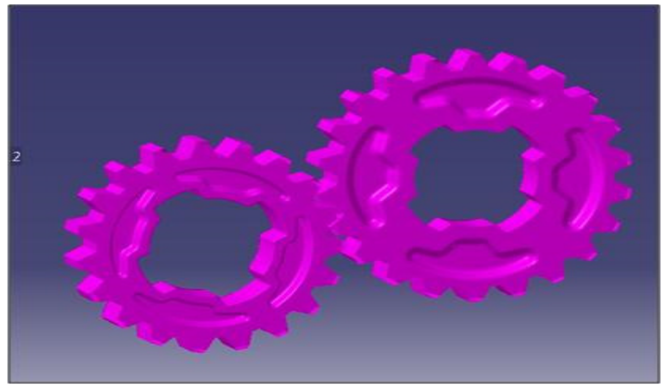


Figure6:3D model modified of spur gear.

we can save material and cost by improving the stiffness of the gear with the help of stiffness.so we redesign the geometry.parameters are same only mass is removed from the central region and stiffness is increased by changing the geometry In exiting gear resonance condition is not found hence considered for weight optimization.Weight optimisation is carried out by reducing material from exiting gear.

BOUNDRY CONDITION OF EXITING GEAR

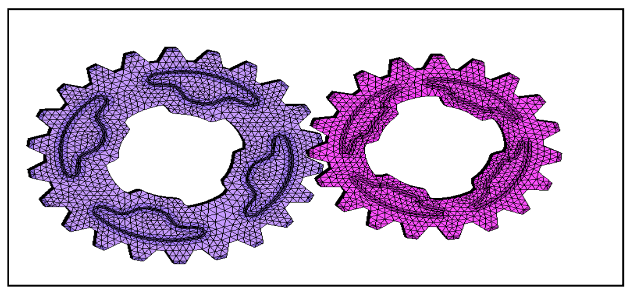


Figure 7: Mesh model with boundary Condition

The mode shape of the gear in FEM are calculated independently of the excitation, means that the structure is only mass and stiffness distribution dependent.

MODE SHAPES AND FREQUENCIES OF EXISTING GEARS WITH TWO DIFFERENT MATERIAL (EN19B AND EN353)

Table 6: Two Modes Of Frequencies for EN9 material

Operating Mode	Frequency (Analytical)	Frequency (nastran)	Percentage Difference
Mode (pinion)	33742	34840	3
Mode (gear)	47334	46680	1

The percentage difference is calculated by normalizing the nastran data with the analytical values. As seen in TableI, the values of the frequencies computed by the analytical formulas agree well with the values obtained in nastaran. For the nastran analysis, spur gear was meshed with RBE2 elements with the guided boundary conditions applied at the centre at SPC .

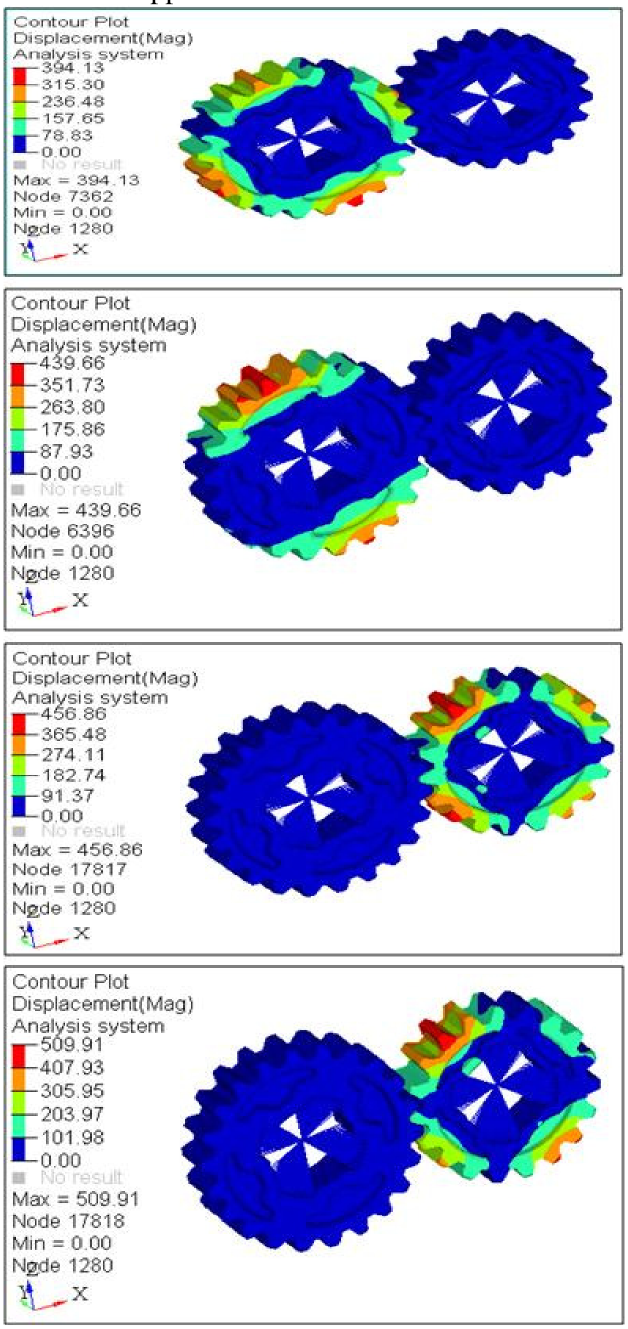


Figure 8:mode shapes for EN9 material.

Table 7:Two Modes Of Frequencies for EN353 material

Operating Mode	Frequency (Analytical)	Frequency (nastran)	Percentage Difference
Mode (pinion)	33464	36230	7.6
Mode (gear)	46942	46094	1

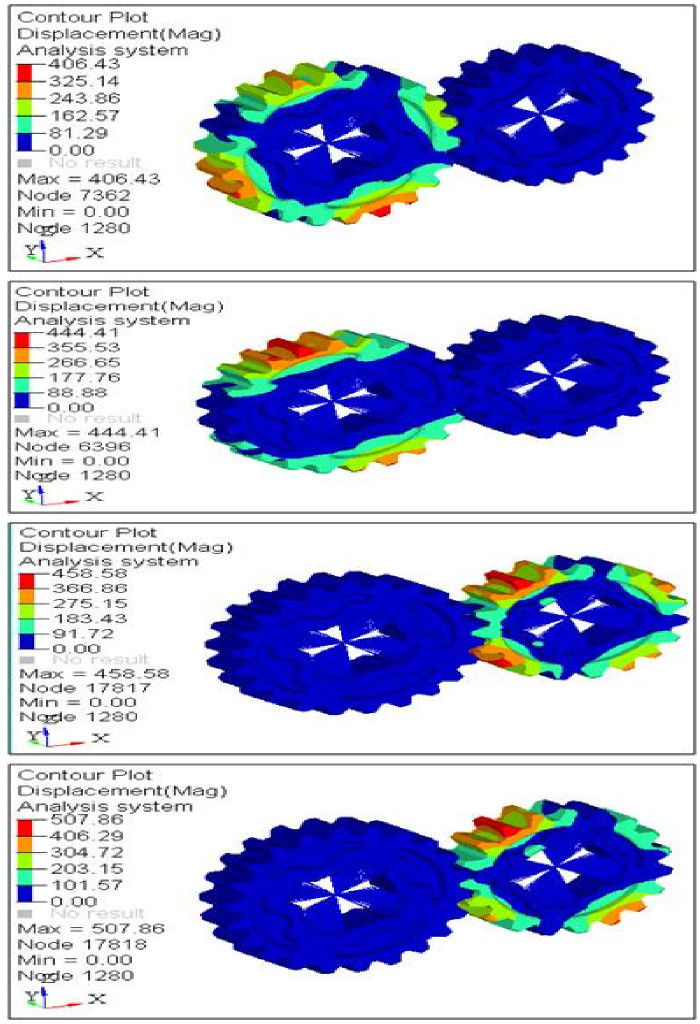


Figure 9: .mode shapes for EN353 material.

Above figure shows that mode 1,2,7and 8
Which having torsional moment and displacement in X direction.

FEA RESULTS AND VALIDATION

Tabel 8 : Change in natural frequency is observed as follows for the exiting model & modified model

Mode	Existing Model frequency Hz		Modified Model frequency Hz	
	EN9	EN 353	EN9	EN 353
1	32227.6	33354.06	34835.30	36277.70
2	32471.1	33597.41	35854.19	37088.20
3	33491.3	34528.55	36196.80	37431.30
4	34409.5	35882.12	37364.87	38516.80
5	37607.6	39195.74	410272.2	42852.50
6	41561.5	43304.49	44342.19	45917.80

7	49844.7	51783.93	44387.01	46094.80
8	49928.0	51890.16	46677.18	48355.90
9	50227.3	52333.02	46791.05	48471.10
10	50837.5	52665.49	49166.31	50818.20

Tabel 8 : Comparison of Change in mass of Exiting & Modified gears

Types of Model	Material	Mass in Kg	% of reduction
Existing	EN9	0.1510	12.5
	EN353	0.1527	13.09
Modified	EN9	0.1325	12.5
	EN353	0.1327	13.09

We have improved performance of modified gear and increased fundamental natural frequencies at optimum weight.
After modal analysis of modified gears,frequencies and mode shapes for En9 and En353 was found.If mass or geometry is changed then frequencies and mode shapes changes..Reduction in mass increases frequencies increases.we save material and cost by improving the stiffness of the gear with the help of changing geometry.

EXPERIMENTAL SET UP

Fig No .10 Test set up

It is proposed to induce a defect on a particular tooth of a chosen gear in the gear box & generate the vibrations.

To sense the vibration signal generated by the gearbox an accelerometer has been used. In order to process the vibration signal sensed by the accelerometer on FFT Analyzer has been selected. With the use of experimental set up we can identify the natural frequencies for the component using the principle of resonance.
Typically FFT Analyzer is used for determining the same.
The computational approach given results more close to practical values through analyses.[7]

EXPERIMENTAL RESULTS

Type of test: Vibration test
Aim of test: To record natural frequency through physical experimentation while comparing results with finite element modeling
Name of the Port: Automotive gear
Machine Type: FFT Analyzer[8]
Instrument used: Accelerometer, RT Pro Photon software

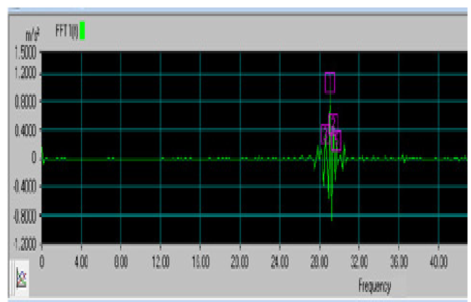


Fig No 11. Test graph

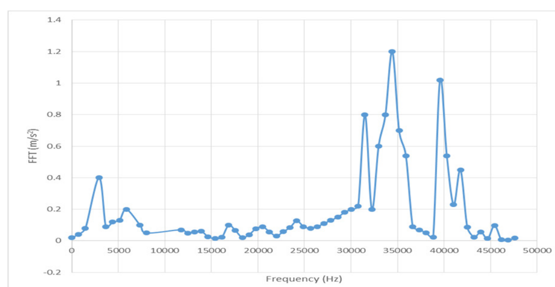


Fig No 12. FFT graph

Tabel 10: Gears parameters

Material (EN9)	Readings determined by FEA Method	Reading recorded during physical experimentation	% Variation results analysis Vs Experiment
1	32227 HZ	34612 HZ	6.80%

The natural frequency of gear obtained through FFT Test concurs fairly with the results obtained by FEA Method. Considering variation in the material properties and specification in the test specimen, the results are acceptable

CONCLUSION

Modal analysis is evolved as standard tool for structural dynamic problem analysis &design optimization. The research area is very dynamic with a focus on performance improvement, test cost reduction and the development of new application areas. Table 3,4 and 5 result concluded that En353 material is better for spur gear.10% validation is allowed in experiment and computational analysis .Hence the results are validated and modification in material has brought 4% error reduction.

The natural frequency of gear (EN9) is obtained from FFT test fairly agrees with the results obtained by Finite Element Analysis(modal analysis). Variation in experimental and computational analysis is 6.8% which is within the permissible limit of 10%.

Performance of gear made of EN19 is at par and made of EN353 is higher than EN9. Technical feasibility is higher for both alternate materials. However, EN19 has higher and EN353 has lower economical feasibility than EN9. Commercially EN19 is preferable. Selection of EN19 will also solve the problem of standardization and subsequently reduce the cost of inventory as EN19 is used by the company on regular basis for other components

After detailed analysis it has been observed that EN19 and EN353 are superior to EN9 in their performance even after weight reduction .However, commercially EN19 is preferable. Selection of EN19 will also solve the problem of standardization and subsequently reduce the cost of inventory.

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