Vibration Analysis and Optimization of Spur Gear used in EOT Crane Machine

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Abstract

A gear is a rotating machine part having cut tooth, which mesh with another toothed part in order to transmit torque. To design the spur gear to study the weight reduction and stress distribution for cast steel and composite materials. Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. The main objective of this research work is to introduce a new gear material for gear. EN32A, EN24 is selected for suitability analysis. Gears are the important part of any machine application like electric overhead travel, machine tool, automobile for power transmission. The main part of this research work is to identify the natural frequency and natural vibration modes of EN32A, EN24 gear and also the effect of change in mass of gear. This project is based on the topology optimization of the existing gear with the reduction of material from the gear and to reduce the total weight of the gear. F.E. Modelling shall be pursued for deriving analytical solution to the problem while physical experimentation would be done to offer inputs to the work and validate the model at the initial phase of work. Hyper Works is being considered as a CAE tool for Pre-processing, Solving and Post processing. The experiment would be performed on the physical setup for the existing/ benchmark case.
Keywords- Mass, Vibration, Material, EN202, EN32A, EN24, etc.

I. INTRODUCTION

Transmission systems are subjected to noise and vibration under excitation forces, meshing forces, load and speed variation and gear defect are the major source of excitation. Gear is a rotating cylindrical wheel having teeth cut on it and which meshes with another toothed part to transmit the torque or power. Spur gear is a simplest type of gear having its teeth cut parallel to the axis of shaft on which the gear is mounted. Spur gears are used to transmit the power between parallel shafts. They are usually employed to achieve constant drive ratio. Due to globalization, industries are facing an increasing competition. Therefore, it more and more necessary to consider alternative technology of manufacturing materials used for gears. The high volume production industries are continuous searching for the best solution available to optimize the gear to compete the market conditions. Mechanical properties of the

Material influences vibration signature pattern. Each machine has specific vibration signature related to construction and state of machine. If the state of machine changes vibration signature will also changes. The simulation results will shows that the natural frequencies and mode shapes shows different characteristic as we change the material. The influence of the mechanical properties of the material on the vibration signature can be utilized to optimize the gear mass and material.

II. LITERATURE REVIEW

Ashwani Kumar et al. [11-12] studied the effect of mechanical properties of materials on natural frequency and mode shapes of heavy vehicle gearbox transmission casing. Material mechanical properties play an important role for evaluation of frequency, deformation, and stress and strain. Four materials have different density and the origin of material is also different. Grey cast iron has damping property, structural steel has high density and rigidity, Al and Mg alloys have low density. Jiri Tuma [8] has investigated the noise and vibration problems in TARA trucks. The Fourier transform was used for analytical study and the experimental results find the heavy vibration frequency zone (500-2500) Hz. The simulation results of present study are verified with Jiri Tuma experimental results. Chowdhary M.A. et al. [13] have studied the effect of vibration on the coefficient of friction. The vibration has significant effect on properties of stainless steel 304. The authors have studied the fatigue life analysis of different components using finite element analysis method. It shows the reliability of FEA results for evaluation of structure performance. So FEA can be used for the analysis of heavy vehicle truck transmission casing. The dynamic response was studied for planetary gear trains.

G. Dalipaz et al. [7] studied gear condition monitoring based on vibration analysis techniques. The detection and diagnostic capability of some of the most effective techniques are discussed and compared on the basis of experimental results, concerning a gear pair affected by a fatigue crack. In particular, the results of new approaches based on time-frequency and cyclostationarity analysis are compared against those obtained by means of the well accepted cepstrum analysis and amplitude and phase demodulation of meshing harmonics. Moreover, the sensitivity to fault severity is assessed by considering two different depths of the crack. The effect of choosing different transducer locations and different processing options are also shown.

III. PROBLEM STATEMENT AND OBJECTIVES

To determining the best configuration of the Gear Box and its housing for a reliable and safe operation while minimizing the adverse effects of vibrations during power transmission. While accomplishing the objective, a suitable methodology to be introduced as an alternative to the conventional method of experimentation for each iteration or change. At the moment, the Client using its historical data over the vibrations induced or the performance of the gearbox. Any variation in the levels for the design parameters affects the performance. There is no means of predicting the response parameter with the available data. A convenient and reliable methodology for addressing the problem is sought through this dissertation work.
Following are the objectives to be pursued while attempting this work:

- Identifying the natural frequency for the subject gear (singular gear) assigned for the task.
- Using Finite Element Methodology for arriving at suitable levels for the parameters while evaluating performance for each variation introduced.
- Benchmarking the existing configuration for physical experimentation to validate the model. Conducting experiment for the benchmarked (existing) gear using FFT analyzer or suitable technique.
- Validate the Design while comparing with the Test Report.
- Recommending suitable configuration of the gear (material or geometry or mating conditions) through analogy for the validated model for Benchmark.

IV. ESTABLISHMENT OF 3D MODEL

Catia V5 is used for the designing the solid geometry of gear models the solid geometry of gear model. Figure 1 shows the 3D model of gear geometry.

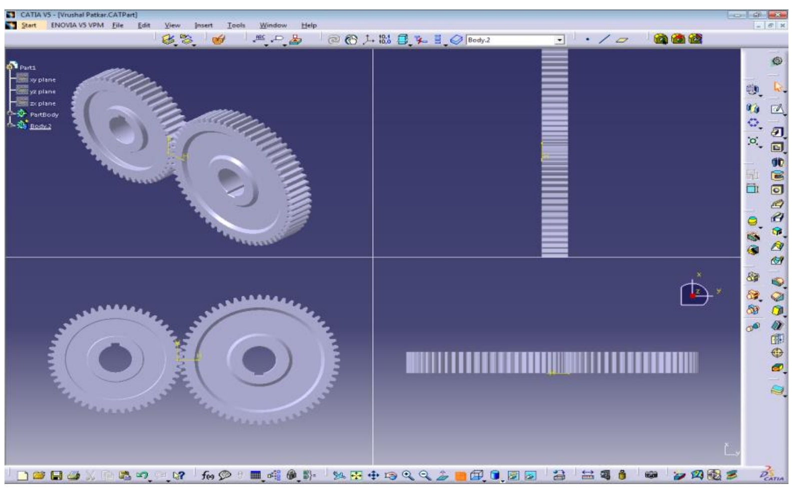


Fig. 1: 3D solid model of gear geometry

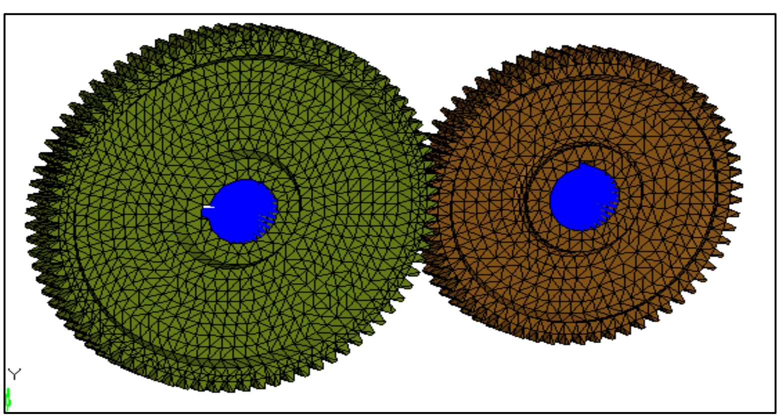


Fig. 2: FEA based meshed model of gear geometry.

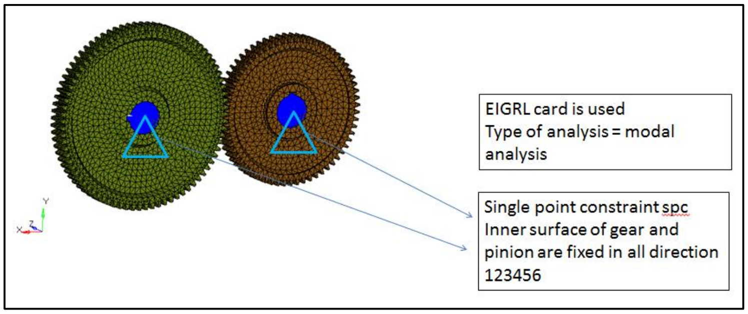


Fig. 3: SPC constraint boundary condition

V. MATERIAL PROPERTIES AND BOUNDARY CONDITIONS

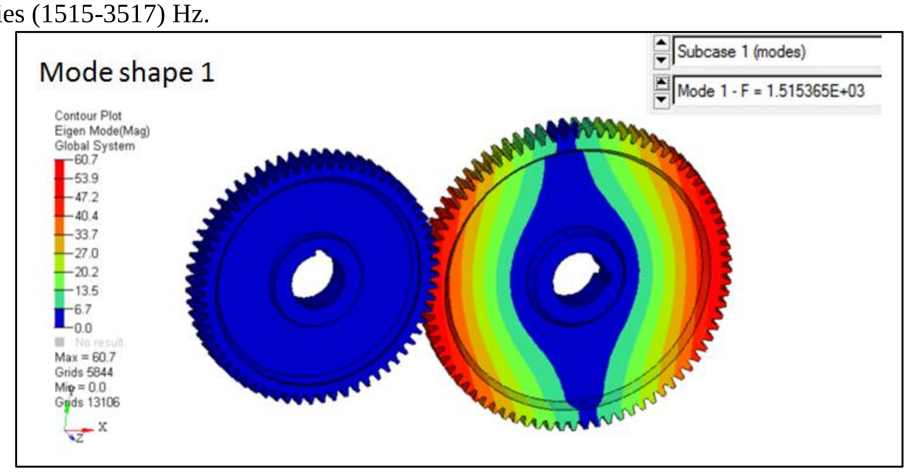
Figure 3 shows the single point constraint based boundary condition. The blue colour shows the constraint condition. This paper is concern with the mechanical properties influence on natural frequencies without considering manufacturing prospects. Mechanical properties of materials used for the modal analysis are elastic modulus, poisons ratio and material density. The material properties are-

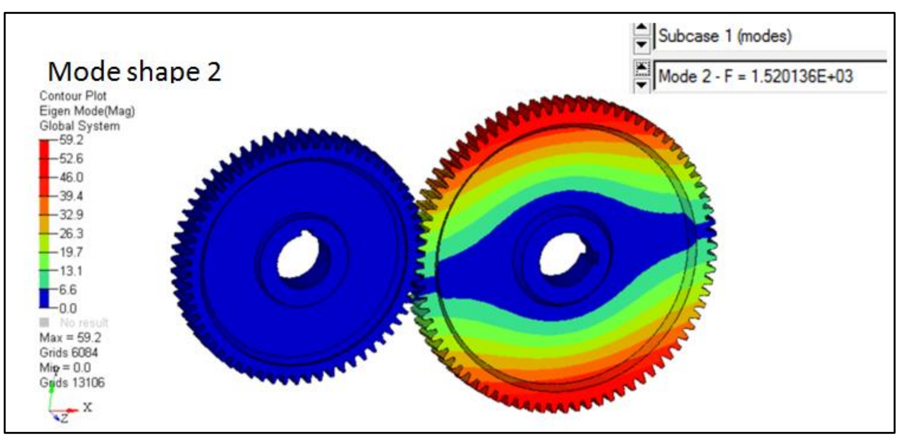
Table 1: Properties of Material

Material Variant	*Young's modulus*	*Poisson ratio*	*Density*	*Tensile Strength(MPa)*	*Yield Strength(MPa)*
EN202	*2.0 e + 05*	*0.280*	*7.9 e - 09*	*550*	*240*
EN32A	*2.1 e + 05*	*0.3*	*7.9 e - 09*	*430*	*310*
EN24	*1.9 e + 05*	*0.270*	*7.9 e - 09*	*850*	*680*

VI. FREE VIBRATION ANALYSIS RESULTS (EN202)

The numerical simulation presents the first ten mode shapes and corresponding natural frequency. For EN202 material the natural frequency varies (1515-3517) Hz.





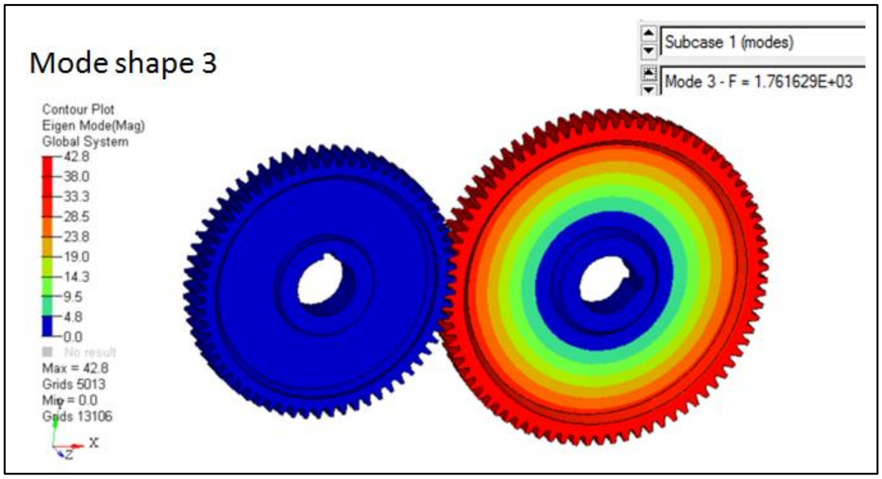


Fig. 4: Mode shape and natural frequency of EN202

Figure 4 shows the vibrations mode shapes and corresponding natural frequency. Single point constraint based boundary condition was used for simulation. In free vibration analysis the load is selected by program automatically.

Table 2: Natural Frequency by FFT

Natural Frequency (Hz)	*Reading Determined by FEA Method*	*Reading recorded during Physical Experimentation*	*% Variation in Result [Analysis Vs Experiment]*
1st Mode	*1515.3*	*1562*	*2.90%*
2nd Mode	*1520.1*	*1578*	*3.50%*
3rd Mode	*1761.6*	*1789*	*1.50%*

VII. Mass and Material Optimization and Results

To improve resonated or natural frequency of the gear to shift the mode shape, here we are going to analyze the existing gear with 3 different materials.

A. Purpose

1) To improve the natural frequency of the gear.
2) To reduce the cost of gear by using the material that fulfills the requirement of the machine tool.
3) To improve the weight of product/gear

VIII. Establishment of 3D Model

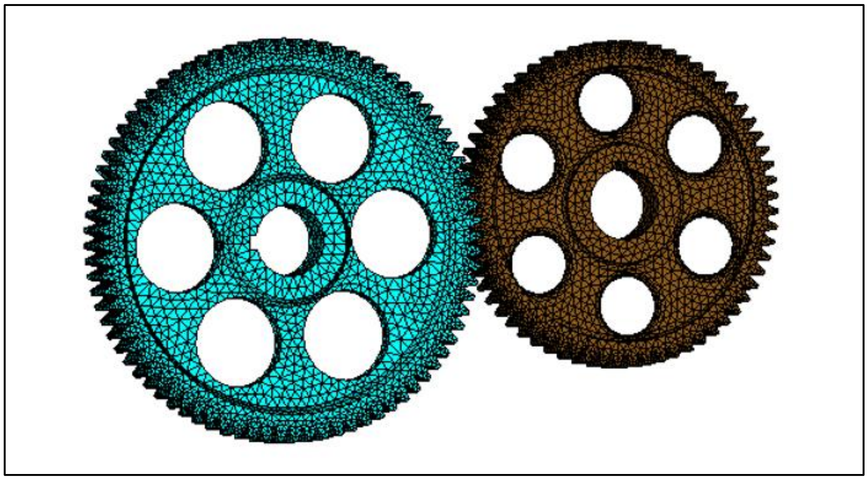


Fig. 5: FEA based meshed model of gear geometry.

IX. FREE VIBRATION ANALYSIS RESULTS

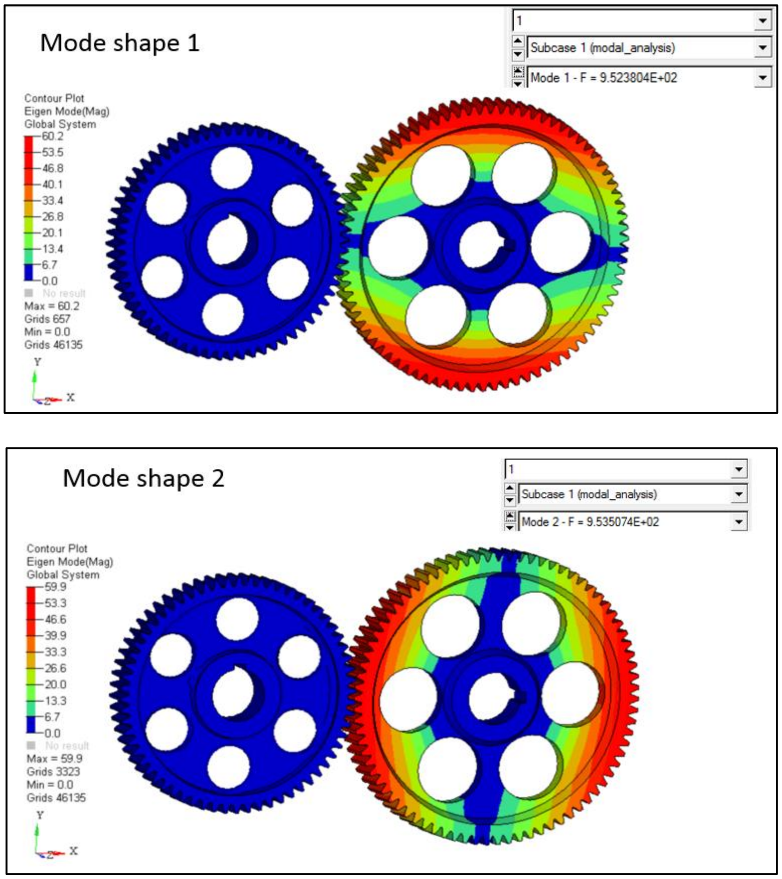


Fig. 6: Mode shape and natural frequency of EN32A

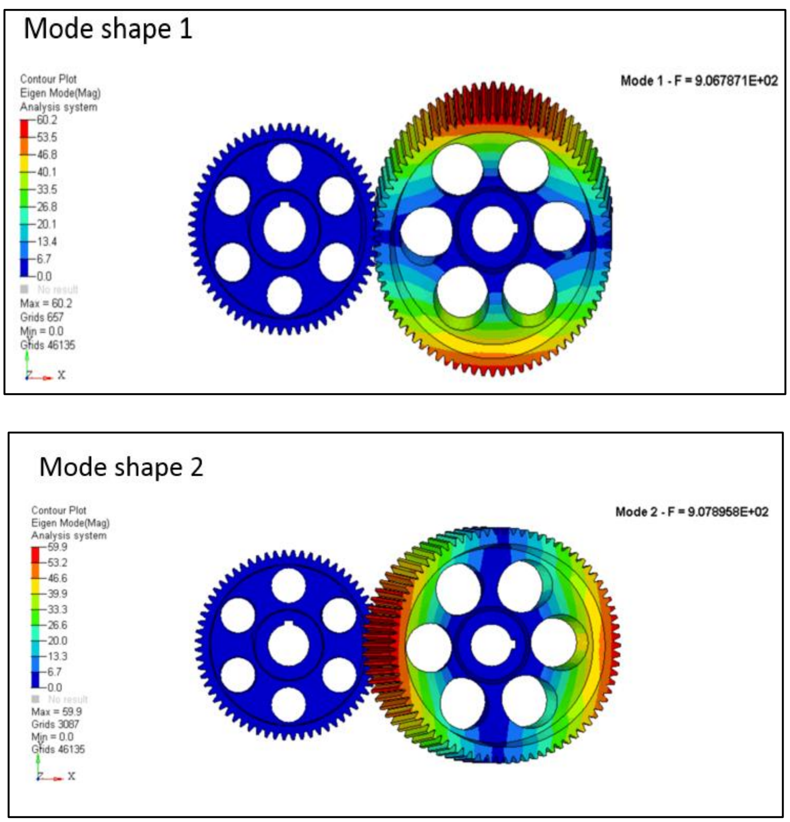


Fig. 7: Mode shape and natural frequency of EN24

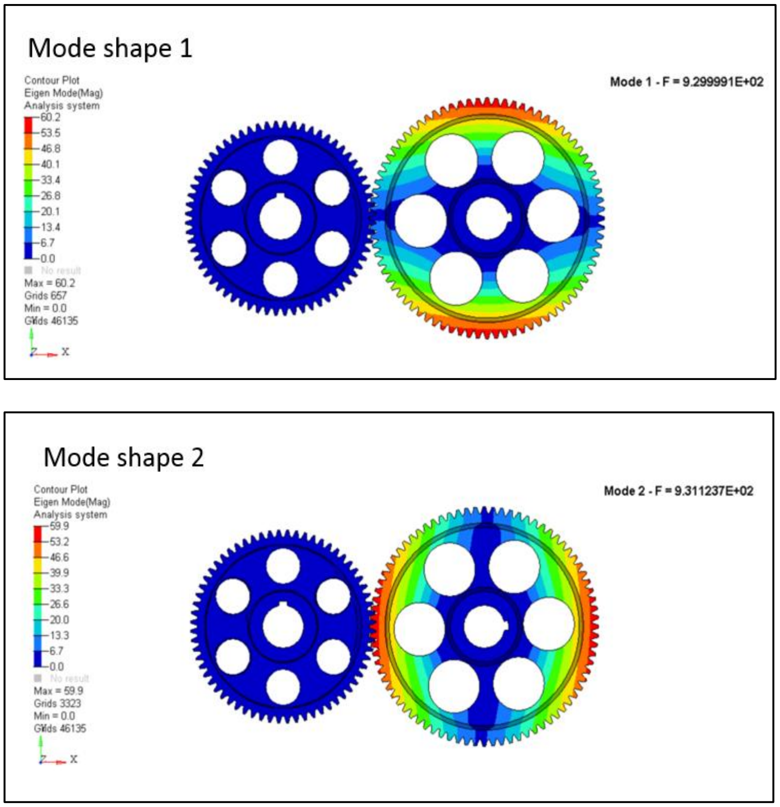


Fig. 8: Mode shape and natural frequency of EN202

Figure 6 shows the mode shapes and natural frequency of EN32A material. The natural frequency varies (952-2866) Hz. The frequency (f10=2866 Hz) shows the highest frequency for EN32A material.

Figure 7 shows the mode shapes and natural frequency of EN24 material. The natural frequency varies (906-2737) Hz. The frequency (f10=2737 Hz) shows the highest frequency for EN24 material.

Figure 8 shows the mode shapes and natural frequency of EN202 material. The natural frequency varies (929-2804) Hz. The frequency (f10=2804 Hz) shows the highest frequency for EN202 material.

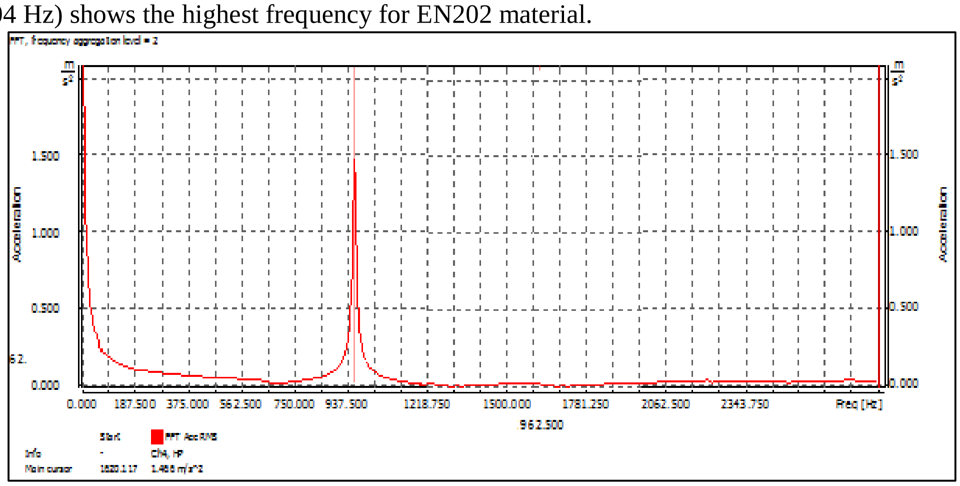


Fig. 9: Plot of Natural frequency of EN32A

Table 4: Mode shape and natural frequency

Variant No.2 Mass-1.855 Kg			
MATERIAL	*EN32A*	*EN24*	*EN202*
Mode Shape	*Freq(Hz)*	*Freq(Hz)*	*Freq(Hz)*
1	*952.38*	*906.78*	*929.99*
2	*953.50*	*907.89*	*931.12*
3	*1247.33*	*1187.28*	*1217.80*
4	*1737.74*	*1659.91*	*1700.60*
5	*1737.84*	*1659.99*	*1700.69*

6	*2015.81*	*1920.46*	*1969.29*
7	*2140.52*	*2033.67*	*2087.20*
8	*2144.21*	*2037.33*	*2090.90*
9	*2553.07*	*2424.40*	*2488.66*
10	*2866.01*	*2737.81*	*2804.82*

Table 5: Natural Frequency by Experimentation

Natural Frequency (Hz)	*Reading Determined by FEA Method*	*Reading recorded during Physical Experimentation*	*% Variation in Result [Analysis Vs Experiment]*
1st Mode	*952.38*	*962.5*	*1.010%*

X. EXPERIMENTAL ANALYSIS

In the experimentation setup FFT analyzer divided into following instruments: -
1) Standard shaker or hammer
2) Vibration Sensor
3) Analyzer (Svantek FFT)
4) PC (Personal Computer)
5) Connection Cables

XI. CONCLUSION

For base model we have used three materials that are EN32A, EN24& EN202. EN32A is the best material solution for the gear because of
1) Natural frequency in case of EN32A is greater than EN24 & EN202.
2) Cost of EN32A is low than both EN24 & EN202.

Hence, EN32A is recommended as suitable alternative material

XII. MASS OPTIMIZATION OF EN32A AND RESULTS

In this section we have proposed 3 variant of the gear for material EN32A, which we have found the best suited material for the gear in terms of natural frequency and cost of material. Further by optimizing the gear geometry we are going to reduce the mass of the gear. The optimized gear geometry is as below.

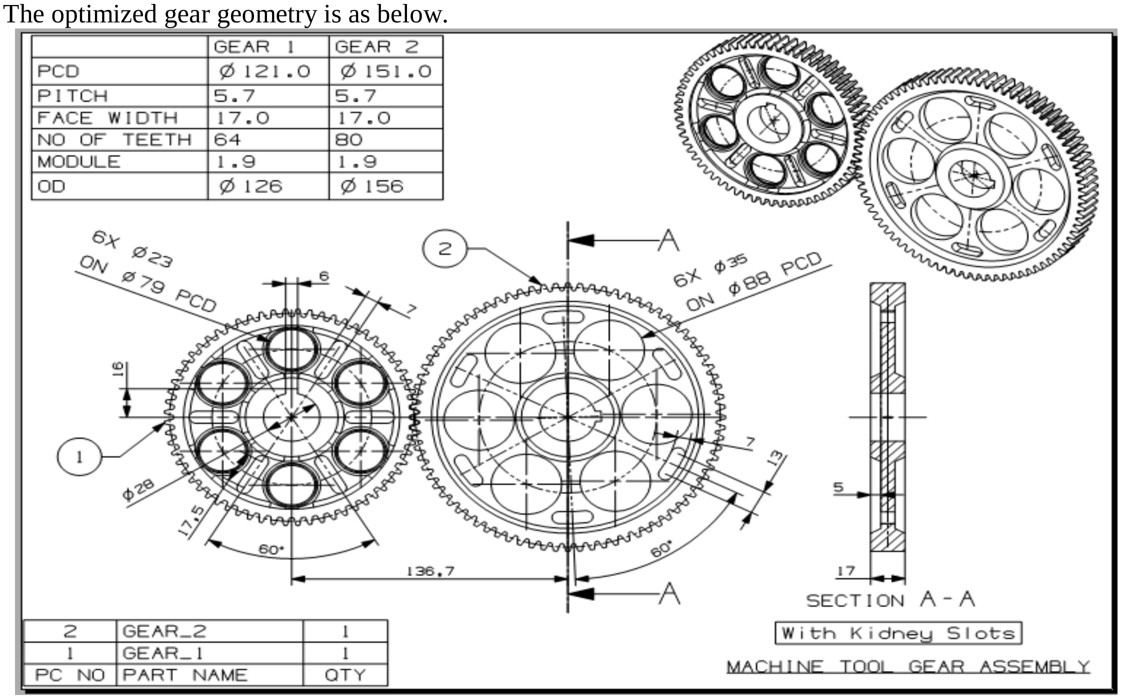
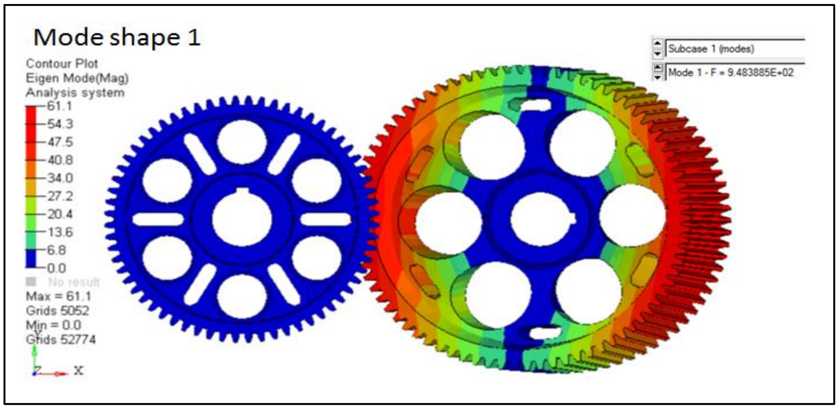


Fig. 11: 3D solid model of gear geometry



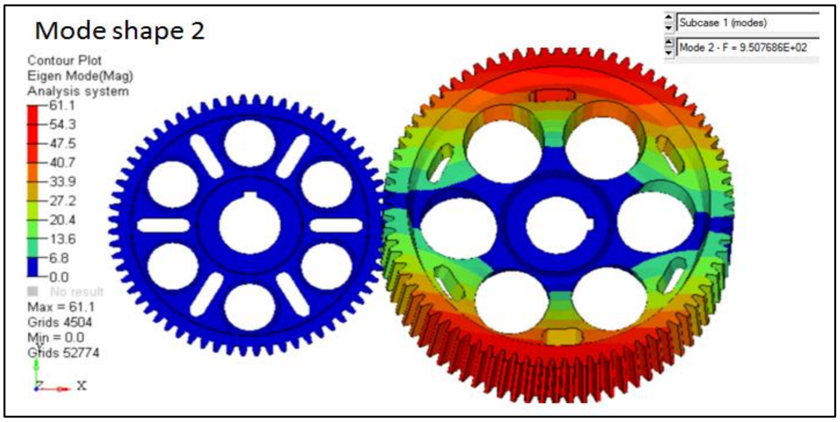


Fig. 12: Mode shape and natural frequency of EN32A.

XIII. CONCLUSION

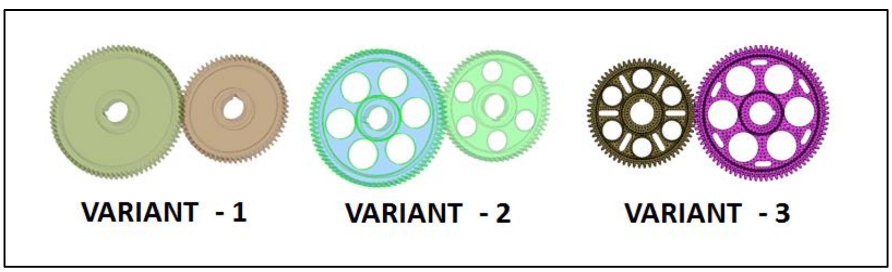


Table 6: Natural Frequency by FFT for EN32A

Mass	*2.312 kg*	*1.855 kg*	*1.736 kg*
Mode Shape	*Benchmark (Material EN202)*	*Variant-2 (Material EN32A)*	*Variant-3 (Material EN32A)*
1	*1515.3*	*952.3*	*697*
2	*1520.1*	*953.3*	*697.7*
3	*1761.6*	*1247.3*	*990*
4	*2115.1*	*1737.78*	*1570.5*
5	*2119.7*	*1737.8*	*1571.3*
6	*2832.4*	*2015.8*	*1826.9*
7	*2850.3*	*2140.5*	*2235.7*
8	*3204.4*	*2144.3*	*2241.7*
9	*3506.1*	*2530*	*2660.4*
10	*3517*	*2866*	*2949.1*

As the stiffness increases natural frequency also increases. Variant no.3 has the least mass while also complying with the generic band for the natural frequency determined for the other variants. This advantage of mass reduction for Variant no.3 makes it the prospective variant for recommendation. Also, the cost for EN32A is lowest among all the alternative materials.

The research work has concluded that the mechanical properties are directly related with natural frequency and vibration mode shapes. First 20 natural frequencies were evaluated for four different materials and a comparison tables was prepared.

FEA based analysis tool HYPERMESH was used for simulation. Single point constraint based boundary condition was used.

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