

Design and analysis of spur gear to decrease vibrations using damping particles

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Abstract - *The vibration and noise from spur gear transmission have gigantic pulverization on the mechanical hardware and administrators. Through inelastic impacts and contact between particles, the vitality is frequently dispersed in gear transmission. A powerful model of molecule dampers outfitted transmission is proposed during study. The vibration from gear commitment is that the primary wellspring of the motion and vibration under overwhelming load and rapid speed. In order to scatter the vitality of vibrations, and to reduce as much as possible the vibrations generated, we bring the molecule damping technique into gear transmission. During this paper, the model of the molecule dampers is build inside the characteristic lighting gaps of the apparatus. At that point we utilize the discrete component strategy to explore the kinematics and elements of the damping particles and decide the association between vitality dispersal and grinding coefficient (surface unpleasantness) of the particles at various particle size, constant rotational speed and load. In preset research damping particle of different sizes are selected to study the effect on experimental setup. We found at the end from results that as the particle size goes on increasing the damping effect also increases. Also at low rotational speed, smoother particles have better damping impact, while at fast, more unpleasant particles are better. From modal analysis and experimentation results comparison a correlation is build and found the results are well within the range. There's no apparent connection between the heap and in this way the coefficient of static rubbing. At long last, the recreation results are confirmed by exploratory outcomes.*

Keyword – *Spur gear, Particle damping, and Modal analysis*

I. INTRODUCTION

Particle damping innovation is a type of an auxiliary-mass type vibration damper, where many metal, tungsten carbide, artistic or different sorts of little particles are set inside the cavities of the vibrating structure, or the walled in areas appended to the vibrating structure so as to relieve the reaction of the essential structure. The essential structure vibrates; motor vitality is altogether consumed through the joined impacts of particle-to-particle and particle-to-wall inelastic crashes and frictional misfortunes, creating extensive damping to the essential structure. Particle damping works in combination of impact and friction damping [1]. Particle damping innovation has been broadly utilized because of its effortlessness, moderate cost, great strength, and temperature harshness. Particle dampers are additionally appropriate for work in long-term brutal situations, for example, high temperature, extreme cold, and oil defilement, where different kinds of damping gadgets are not, at this point reasonable or effective, consequently utilizing Particle dampers a low-maintenance damping procedure. Vibration damping can be achieved by suitable lubrication like cutting tool, where the lubrication film, film specific thickness, and degradation of

lubricant are periodic manner [2]. The main measure to decrease the gear vibration is active and passive vibration control. Active method controls the parameters while particle damping is one of the passive vibration controls [4]. The vibration constriction innovation has been broadly utilized in the aviation and apparatus fields, creating numerous sorts of modern applications, for example, the vibration concealment of cutting devices, motor turbine framework in the space transport, and radio wire structures. Vibration concealment for gear transmission can be isolated into dynamic vibration concealment and latent vibration concealment. Dynamic technique smothers vibration is utilized for improving the apparatus produce accuracy by tuning boundaries, or altering tooth. Nonetheless, excitation and time-changing solidness can't be wiped out even by streamlining the structure and Gears' boundaries. Additionally, dynamic vibration concealment has the downside that even smother little vibration utilizing dynamic technique will prompt incredible assembling cost and bulky count and plan. Then again, aloof vibration concealment strategy scatters the vitality from gear transmission by vitality expending hardware. Such vitality is mostly scattered by other hardware, bringing about the decrease of vibration and commotion. The examination on the uninvolved vibration concealment of rigging transmission is generally uncommon, principally concentrating on the investigation of viscoelastic damper and erosion damper. The Particle damping innovation is a sort of aloof vibration concealment innovation. In view of damping instrument, the innovation utilizes particles as the damping media. By grating and inelastic crash of damping particles being placed into the holes of the apparatus, the vibration and noise can be diminished. The particle impact damping is a form of passive vibration control technique wherein the energy of a vibrating system is dissipated through impact and friction in the form of heat, elastic wave, sound etc. [5]. In a particle impact damping technique, a single spherical mass (impactor) is constrained to move between two stoppers or in an enclosure.

Gears are typically classified as highly stressed and functional parts with the task of transferring forces during operation. Adding particle damping to gears opens the possibility of addressing the field of Noise-Vibration-and-Harshness (NVH)-behavior in gear boxes if gears with damping elements are used. Especially vibration causes problems in transmissions, can reduce lifetime, and increases the probability of breakdown. Particle damping offers the potential for the design of a better passive damping technique with minimal impact on the strength, stiffness and weight of a vibrating structure. With a proper choice of particle material, this technique appears to be independent of temperature and is very durable.

The main objectives of the research are as below

1. Understanding the effect of damping particles on the spur gear with different particle size at constant rotational speed and load.

2. To find out natural frequency of spur gearbox without damping particles.
3. To perform model analysis of spur gearbox with damping particles.
4. To create a prototype of spur gearbox and perform FFT analysis.
5. To compare the modal analysis result with FFT analysis result.

The methodology used during this research work is described in short below.

- Initially research papers relevant to the topic are gathered and after going through research papers, conventional design of gearbox is examined.
- A 3-D CAD model will be prepared by studying the conventional design of gearbox.
- Prepared 3-D model will be transferred to ANSYS software and proper meshing will be created on the model for further analysis.
- For determining the natural frequency, modal analysis is performed in ANSYS.
- Modal analysis with different ball size is carried out to get the natural frequencies.
- A prototype of the model is manufactured with provision to add the different balls and sealing them with the side plates.
- FFT analysis will be performed on the prototype without particles and with different size of damping particles.
- Natural frequencies are calculated by using FFT analyzer and collected the results.
- Comparison of ANSYS and FFT results is carried out.
- Conclusion of the research based on the comparison of results.

II. LITERATURE REVIEW

Louis Gagnon et al. [1] Particle dampers are gadgets that work by a blend of effect and grinding damping. They scatter the vitality of a framework by moving it to a bed of particles. This bed is geometrically compelled to stay inside a holder fixed to the vibrating framework. In that capacity, the movement caused collaboration happening inside the compartment damps the ingested vitality. The fundamental dissipative systems included are: impacts between the compartment dividers and the particles and between the particles themselves; sliding rubbing between the equivalent; and, moving grinding between the equivalents. For impacts between the particles and the depression dividers to happen, both ought to be out-of-stage with one another. Plan models, explanatory definitions, numerical models, and trial arrangements for such dampers are assembled. Demonstrating approaches are introduced both for Particle connection and for frameworks furnished with Particle dampers.

M. Amarnath et al. [2] Gears are one of the most widely recognized instruments for transmitting force and movement and their utilization can be found in various applications. Studies on gear teeth contacts have been considered as one of the most convoluted applications in tribology. The progressions in working conditions, for example, increment in temperature, load, decrease in consistency result decline in ointment film thickness and corruption of greasing up oil subsequently setting off a few kinds of failures on tooth surfaces viz. pitting, scraping, small scale pitting, scoring, and spalling, these flaws impact changes in vibration signals. Creator presents the consequences of exploratory examinations did to evaluate wear in spike Gears of single stage prod gear box under weariness test conditions. The

investigations considered the grease film thickness examination, wear instrument concentrates on gear tooth surfaces, oil corruption investigation utilizing Fourier change infrared radiation (FTIR) strategy alongside vibration signal examination.

Sarfraz Ali N. Quadri et al. [3] In this exploration work the modal examination of involute prod gear pair is completed utilizing limited component investigation apparatus ANSYS programming. Apparatus commotion and vibration is a significant issue in many force transmission applications this issue turns out to be increasingly noteworthy in applications with higher working paces, where there is vibratory excitation which is identified with the rigging transmission mistake. The modal investigation of spike gear was perform to decide the normal mode shapes and frequencies of the current prod gear pair and to nearly break down with frequencies of the geometrically adjusted involutes prod gear pair during free vibration just as in pre-stress condition. The modal examination is done on both the current spike gear just as geometrically adjusted involutes prod gear in two conditions for example Common recurrence and Forced recurrence in pre-stress stacking.

Yuxiang Huang et al. [4] As an inactive method for vibration decrease, molecule damping is fundamentally applied to the even or vertical consistent field. Be that as it may, it is only here and there applied to radiating fields. Under fast and substantial stacking, the vibration of tooth surfaces of rigging transmissions turns out to be increasingly extreme shortening gear administration life and enlarging noise. Under divergent stacking, the molecule framework displays various attributes, for instance, particles are expelled toward the end farthest from the middle. We examined gears with bored by means of openings loaded up with damping particles. Utilizing the discrete-component technique, we built up a vitality dispersal model for the molecule framework representing contact and inelastic crashes. Vitality dispersal and damping qualities of this framework were broke down. Analyses were likewise led with the apparatus framework having distinctive molecule filling rates. The outcomes show that this filling rate is a significant boundary related with molecule damping in a radiating field. An unsatisfactory filling rate would essentially lessen damping adequacy. With changes in revolution speed and burden, the rigging transmission framework has diverse ideal filling rates.

Nazeer Ahmad et al. [5] Honeycomb sandwich overlays which are the essential auxiliary component of rocket have intrinsically low damping. In this paper, we propose to improve the damping qualities of such structures by including damping particles in the cells of the honeycomb. This paper presents displaying of a cantilever shaft developed with honeycomb structure with the hexagonal honeycomb cells, loaded up with particles. The shaft is exposed to outer powerful loads and the collaborations of damping particles with the dividers of the cells and its general impact on the recurrence reaction work (FRF) and the damping of the bar are acquired.

BASIC BLOCK DIAGRAM

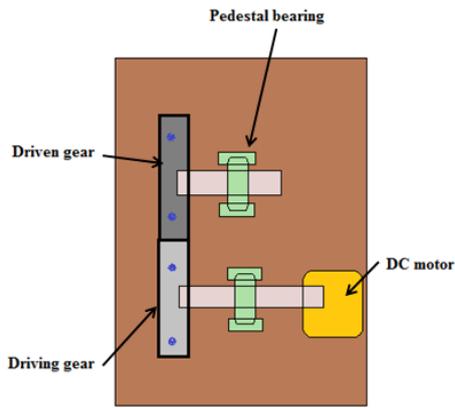


Fig 1 Basic block diagram of particle damping

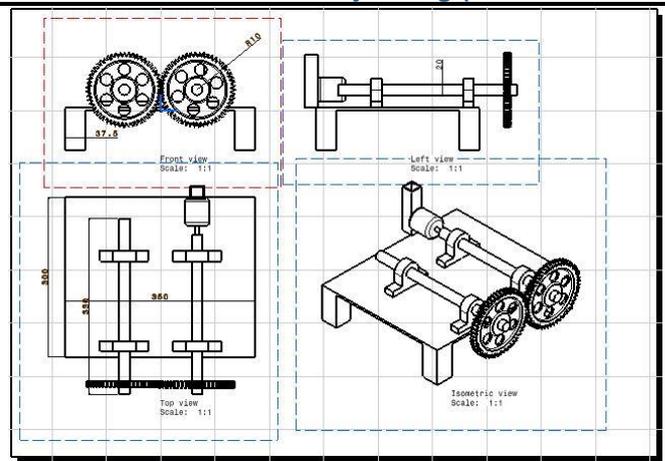


Fig 3 drafting of spur gear box

III. VIBRATION ANALYSIS OF SPUR GEAR

CATIA MODEL-

The experimental set up is built in Catia V5 by using the part design module. The best part of building the setup in Catia V5 is that the gear geometry built can be imported in the ANSYS model very easily.

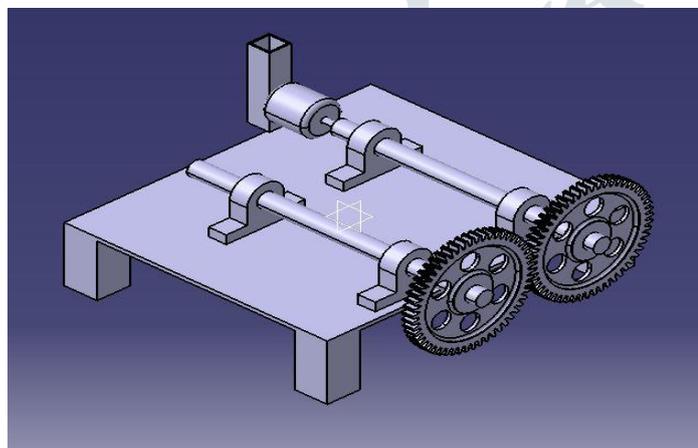


Fig 2 Catia model of spur gear

MATERIAL PROPERTIES OF SPUR GEAR BOX

Material selection is the one of the most important parameter for the gear train and power train where we need to transfer the rotational motion to the translator motion or vice versa. Also while selection the material it is important to check its frictional properties and wear properties. The material used for the gear should possess less wear and heat dissipation properties as they are subjected to high heat build at very heavy load transmission. ANSYS give use the flexibility to choose variety of materials. Table 1 shows the material properties of the material.

Properties of Outline Row 3: Structural Steel			
	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m ⁻³
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C ⁻¹
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Table 1: Material properties of spur gear box

DRAFTING OF SPUR GEAR BOX –

To get the overall dimensions of the setup a drawing is prepared in Caita V5. The image below showed a basic layout of the setup. For better over view we can use the drawing module in depth to get the all dimensions of the gear.

Spur gear geometry

The important gear pair geometry which is used and analyzed is as shown in the figure 5 below. The gear is in no fault situations and is ready for further simulations steps. This geometry is also imported in the ANSYS for the further boundary condition applications. The small core outs shown are used for addition of the damping particles.

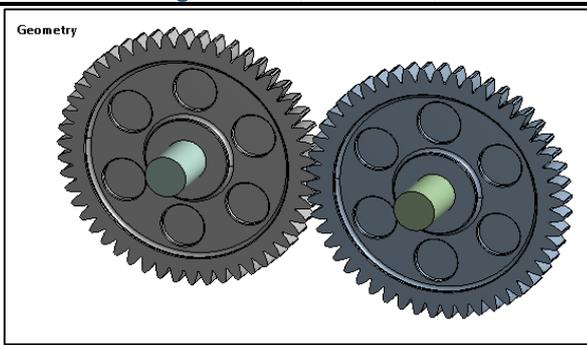


Fig.No.5 Geometry of Spur Gear

Mesh

ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Metaphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you have to wait for mesh generation.

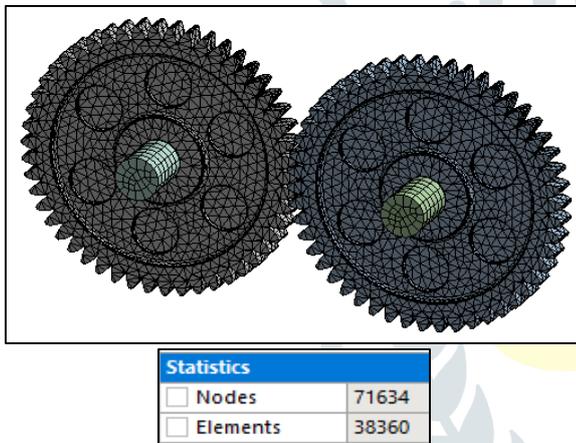


Fig.No.6 meshing of spur gear box

Boundary Condition

A boundary condition for the model is the setting of a known value for a displacement or an associated load. For a particular node you can set either the load or the displacement but not both.

The main types of loading available in FEA include force, pressure and temperature. These can be applied to points, surfaces, edges, nodes and elements or remotely offset from a feature.

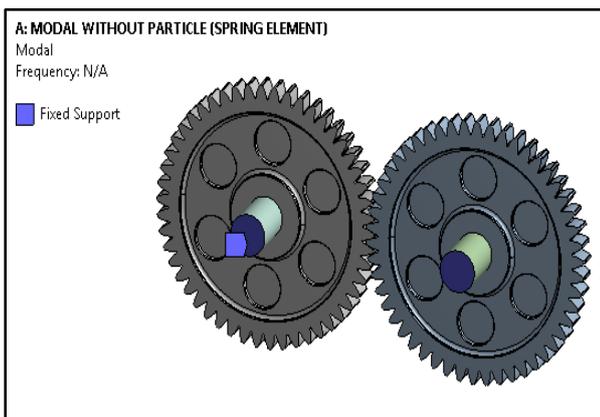


Fig.No.7 boundary condition of spur gear box

Modal analysis

Mode shape 1- Figure 8 shows the mode shape 1 in which we see the maximum deformation in red color. In this mode application of axial forces towards each other are applied. The central hub of the gear pair is stable and has minimum deflection represented in blue color.

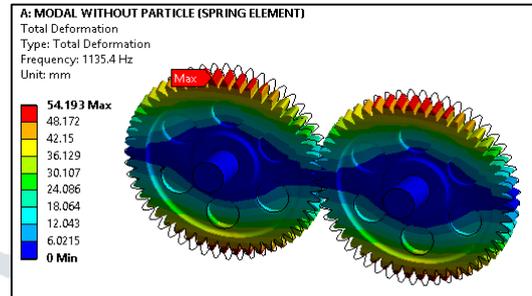


Fig.8 Mode shape 1

Mode shape 2- In the second mode shape shown in figure 9 we can see the maximum deformation is going on increasing. Due to which the gear in engagement area are with minimum deformation and this deformation goes on increasing as we go out radially away from axis. The natural frequency of the mode shape is 1250 Hz.

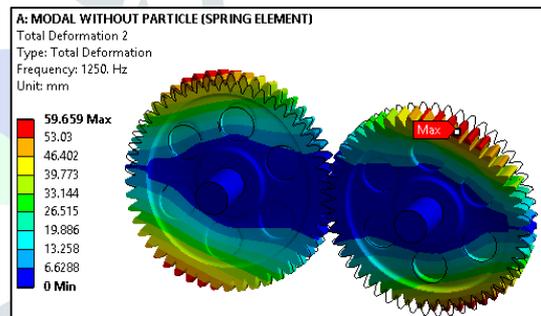


Fig.9 Mode shape 2

Mode shape 3 – Is shown in figure no. 10 shows again more deformation compared to earlier two mode shape. In this mode shape we can see the deformation is more at the extreme ends of the gear. As we can see the natural frequency is increasing.

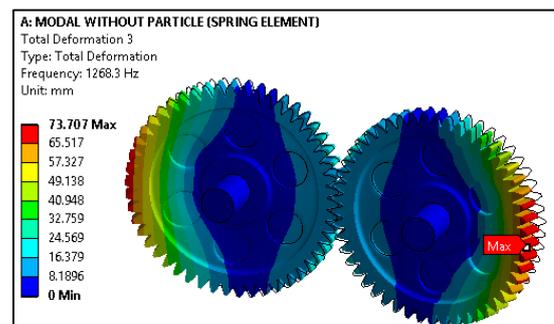


Fig.10 Mode shape 3

Mode shape 4 - Natural frequency of the mode shape 4 shown in figure 11 is 1309.9 Hz. And this is going on increasing. It means the probability of this gear pair failure is decreasing in this mode shape. The max deformation with which the system can withstand is also more.

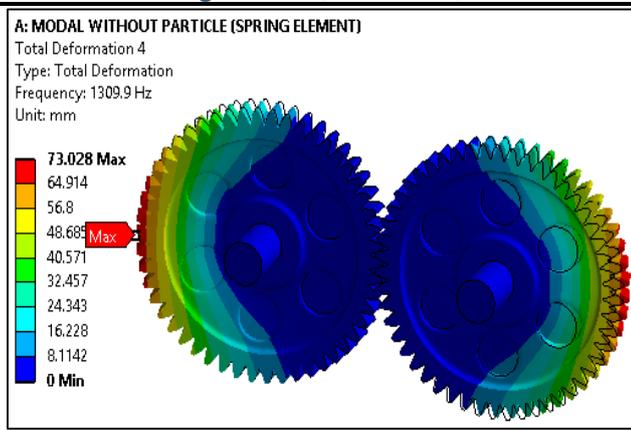


Fig.11 Mode shape 4

Mode shape 5 - The best result among all the mode shape can be seen in the 5th mode shape shown in the figure no. 12. The natural frequency is more compared to all and deformation is less. It means failure chances are less with less deformation.

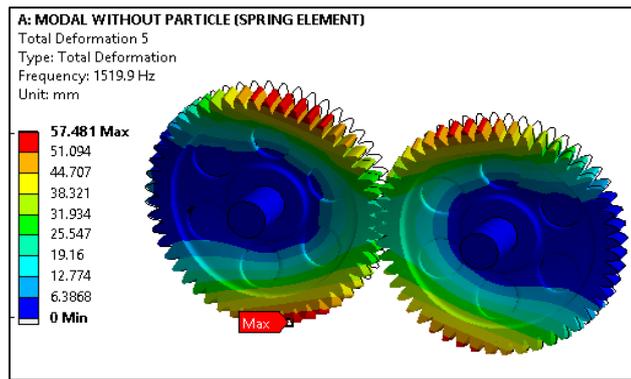


Fig.12 Mode shape 5

The particle damping technology is a kind of passive vibration suppression technology. Based on damping mechanism, the technology uses particles as the damping media. By friction and inelastic collision of damping particles being put into the cavities of the machinery, the vibration and noise can be reduced. This technology has the advantage of owning a remarkable damping effect, resisting high temperature, having little modification of the original structure, and adding less mass to the machinery. At present, the technology has become one of the frontiers of the vibration suppression field, and has been widely used in many fields. However, the particle damping technology in the field of gear transmission has not been studied thoroughly. Thus, applying the particle damping technology into gear transmission will fill this gap.

Gear with damping particles-

To analysis the spur gear with different ball size or particle size we need to make a provision. In the first step we drill out the material from gear. Then to add the ball in the cored area we need to build two side plates which can be screwed on the gear as in the figure 13. And in between these two plates the balls can be held together.

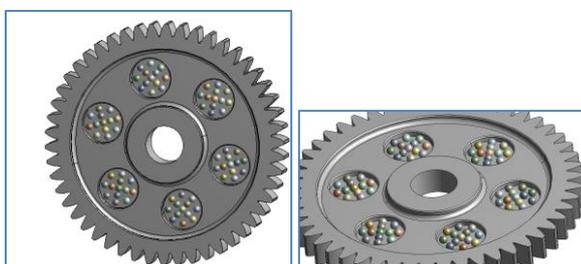


Fig.13 cad with damping particles

The gear geometry is imported in the ANSYS as in figure 14 for further analysis.

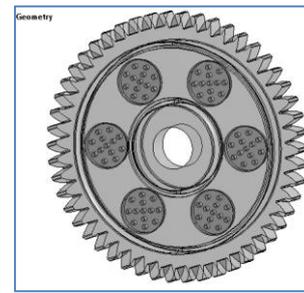
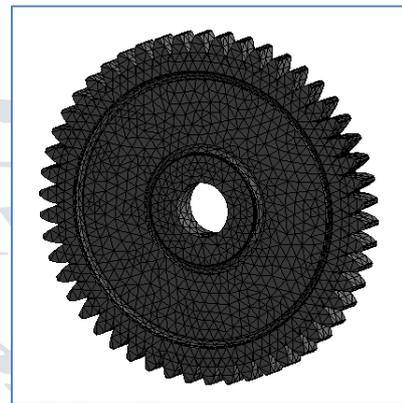


Fig.14 Geometry imported in ANSYS

The meshed gear component after importing it from the design looks like as in the figure 15. The number of nodes is 65438 and number of elements are 37413.



Statistics	
Nodes	65438
Elements	37413

Fig.15 Details of meshing

DAMPING PARTICLES OF 4 MM SIZE

The figure 16 shows the gear with fixed boundary condition at the center. The meshing of the geometry is kept and the particle size is adjusted.

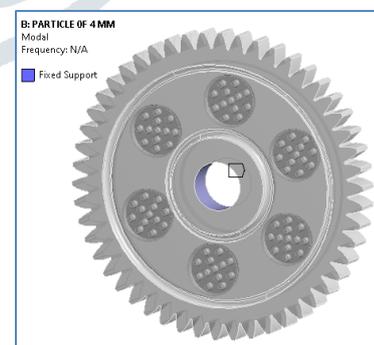


Fig.16 Details of boundary condition

Initially gear is fixed at Centre to determine mode shape with respective natural frequency and mode shape.

In the figure 17 we can see the first mode shape for particle size 4 mm. The natural frequency which we can see is 1602 Hz which is greater than the natural frequency of the first mode shape of the 3 mm particle size.

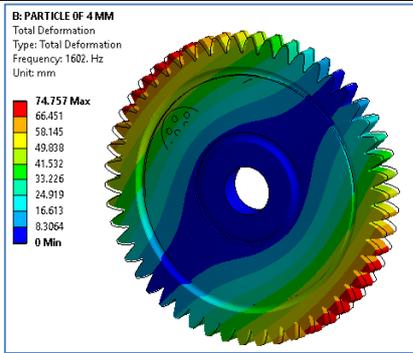


Fig.17 Mode shape 1

In the figure no. 18 we can see the second mode shape. The natural frequency which we can see is 1602 Hz. which is again greater than the natural frequency of the second mode shape of the 3 mm particle size. Deformation is along the periphery but shifted to diagonally opposite quadrant

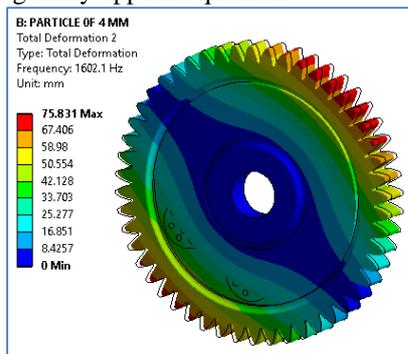


Fig.18 Mode shape 2

In the figure no. 19 we can see the third mode shape. The natural frequency which we can see is 1832.2 Hz which is again greater than the natural frequency of the third mode shape of the 3 mm particle size. Deformation is along the periphery of the gear geometry

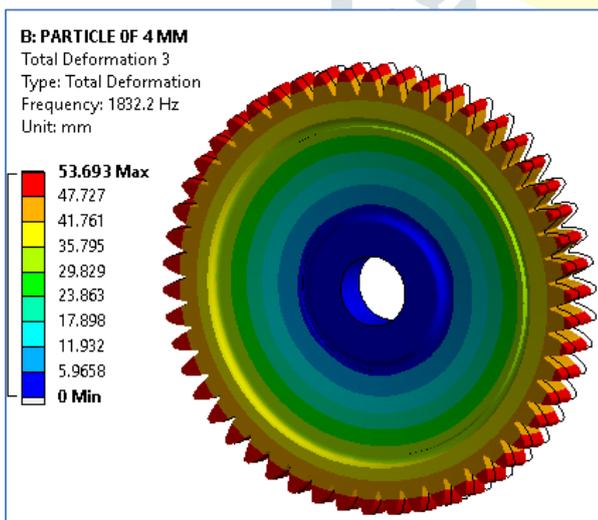


Fig.19 Mode shape 3

In the figure 20 we can see the forth mode shape. The natural frequency which we can see is 2257.4 Hz which is again greater than the natural frequency of the forth mode shape of the 3 mm particle size. Deformation is along the quadrant of the gear profile.

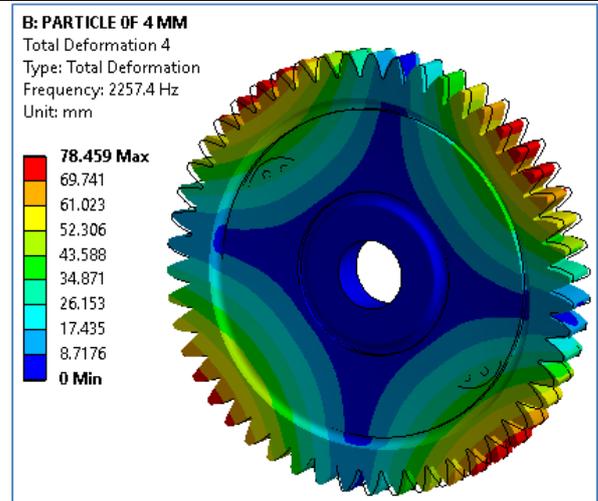


Fig.20 Mode shape 4

In the figure 21 we can see the fifth mode shape. The natural frequency which we can see is 2258.1 Hz which is again greater than the natural frequency of the fifth mode shape of the 3 mm particle size. Deformation is along the quadrant of the gear.

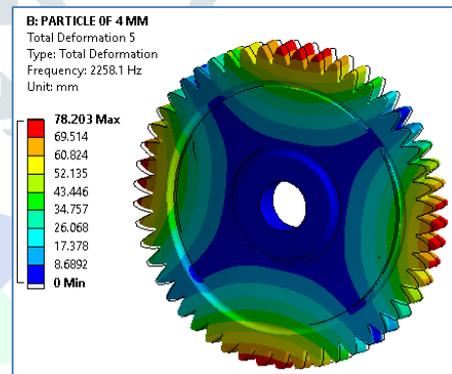


Fig.21 Mode shape 5

In the figure no. 22 we can see the sixth mode shape for 4 mm size. The natural frequency which we can see is 3623.9 Hz which is again greater than the natural frequency of the sixth mode shape of the 3 mm particle size. Deformation is along the periphery of the gear.

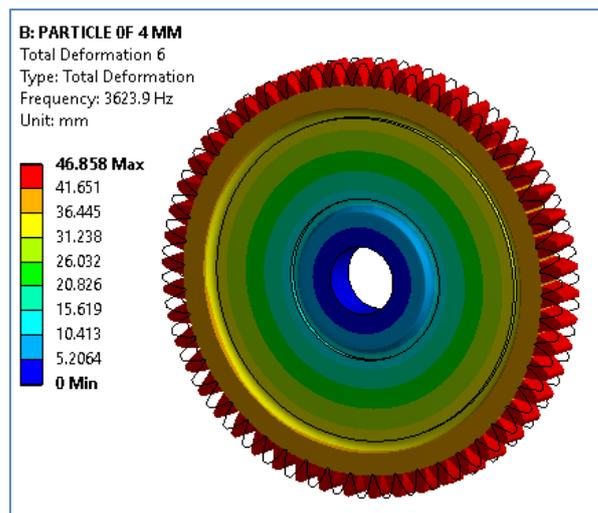


Fig.22 Mode shape 6

Tabular Data		
	Mode	Frequency [Hz]
1	1.	1602.
2	2.	1602.1
3	3.	1832.2
4	4.	2257.4
5	5.	2258.1
6	6.	3623.9

Table 2 Tabular data of mode shape with respective natural frequency

In the similar way ANSYS simulation for the gears is done for particle size of 2.5 mm and 3 mm diameter balls. The tabular format for it is shown in the table for the comparison.

Without particles Frequency (Hz)	2.5 mm particles Frequency (Hz)	3 mm particles Frequency (Hz)	4 mm particles Frequency (Hz)
1205.4	1571.2	1591.9	1602
1206.1	1571.6	1593.1	1602.1
1440.3	1801.6	1823	1832.2
1863.3	2246.5	2254.2	2257.4
1863.5	2246.9	2254.8	2258.1
3524.2	3627.9	3625.8	3623.9

Table 3 Comparison of natural frequencies

Looking at the trend of increasing the natural frequency with the ball size we can come to a conclusion that as ball size goes on increasing the natural frequency also increases.

IV. EXPERIMENTAL SET-UP AND TESTING

FFT analysis using DEWE-43 data acquisition system.

FFT is one main property in any sequence being used in general. To find this property of FFT for any given sequence, many transforms are being used. The major issues to be noticed in finding this property are the time and memory management. Two different algorithms are written for calculating FFT and Autocorrelation of any given sequence. Comparison is done between the two algorithms with respect to the memory and time managements and the better one is pointed. DEWE-43 Universal Data Acquisition Instrument is used for recording the reading from FFT.

Experimental procedure -

- Initially two gears of specified dimensions are selected and mounted along shaft connected to motor of 300 RPM with assembled on a rigid base frame.
- Bearing are used to provide support and also measure acceleration value for accelerometer mounting location.
- Two specified dimension ball bearing are selected as damping particles to study damping behavior by

placing 8 quantities of ball bearing in each slot provided on gear.

- Motor is provided with power supply due to which rotation of gears starts and accelerometer is placed on bearing to measure damping effect which is measured on DWESOFT software on laptop.

Different images in figure 23 we can see the mounting point for the accelerometer probe, addition of the balls, complete setup and test running . The probe is mounted on the driven gear pedestal bearing with some manual provision to mount it.

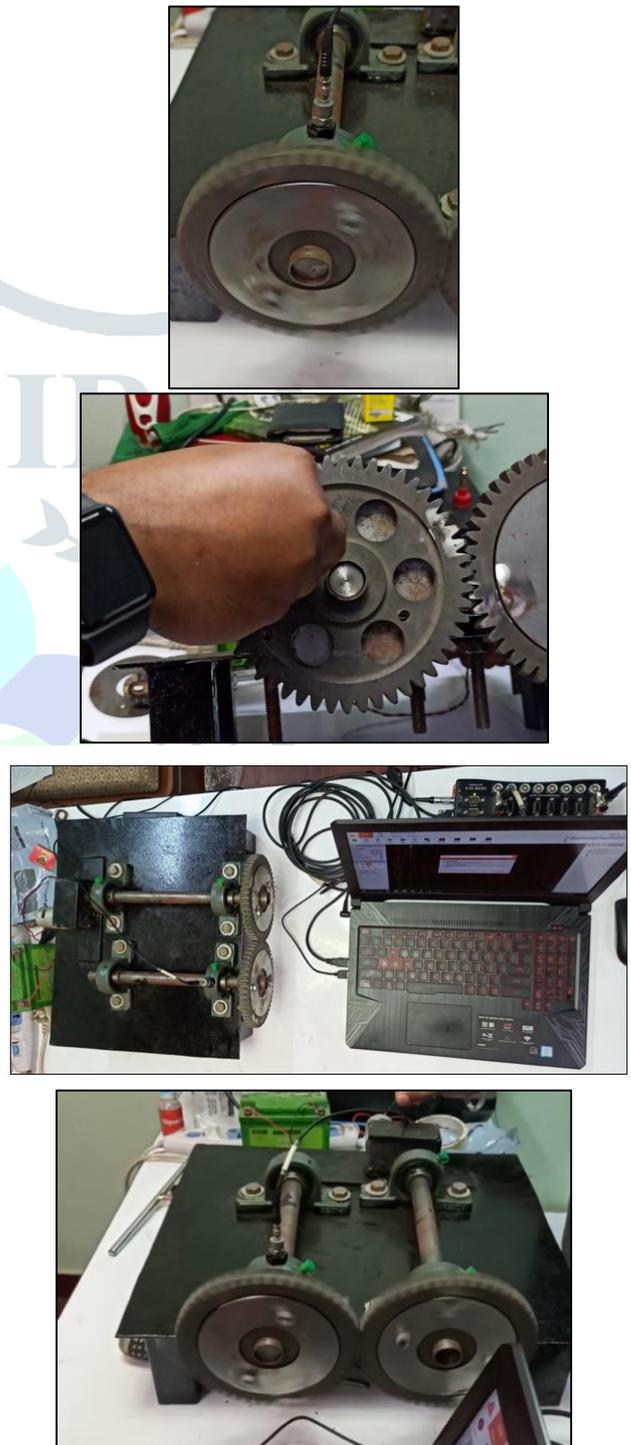


Fig.23 Experimental setup

Natural frequency plot without particles is shown in figure 24.

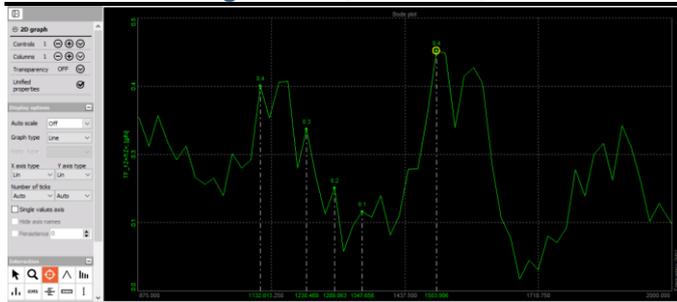


Fig.24 Setup natural frequency

Table 4 shows the comparison of natural frequency with FEA and with experimentation.

MODE SHAPE	Natural Frequency FEA (Hz)	Natural Frequency experimental (Hz)
1	1205	1132
2	1206	1230
3	1440	1437
4	1863	1503
5	1863	1718

Table no. 4 Natural frequencies of analysis and experimentation

Experimental readings and plots for different particle size and without particles.

1) Plot for the gear without particles.



Fig.25 Without particle

- Acceleration is observed around 3.63 g.

2) Plot for the gear with 3mm size particles.

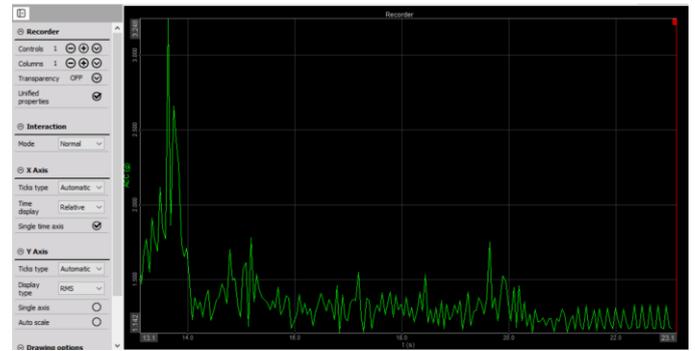


Fig.26 particle of 3 mm diameter

- Acceleration is observed around 3.24 g.

3) Plot for the gear with 5mm size particles.

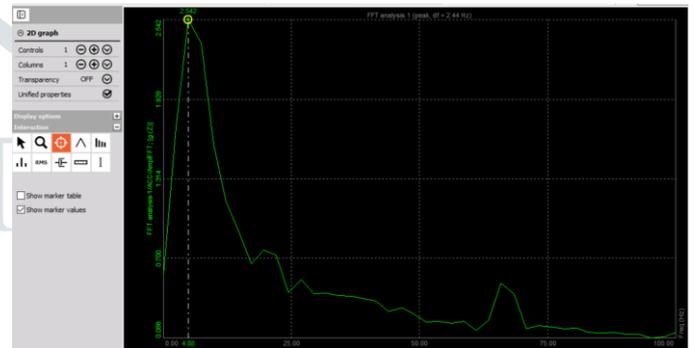


Fig.27 particle of 5 mm diameter

- Acceleration is observed around 2.54 g.

4) Plot for the gear with 8 mm size particles.



Fig.28 Particle of 8 mm diameter

- Acceleration is observed around 2.29 g.

5) Plot for the gear with 10 mm size particles.

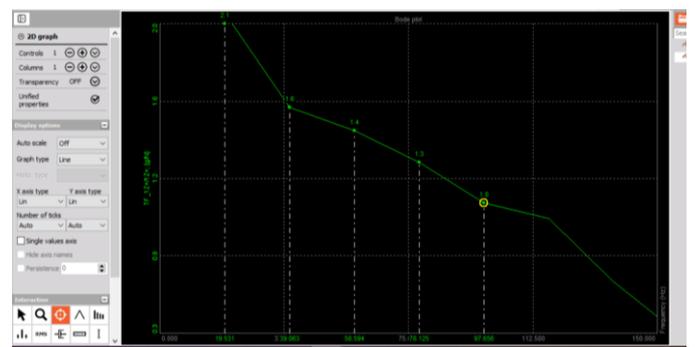


Fig.29 Particle of 8 mm diameter

- Acceleration is observed around 2.1 g.

CONCLUSION

- It is observed from modal analysis result that as damping particle size increases enhancement in existing natural frequency is observed.
- FEA and experimental natural frequency are nearly identical in without particle contribution.
- From experimental results it is observed that increasing the particle size increases the damping effect.
- Particle size of 10 mm observed acceleration around 2.1 g, 8 mm size observed acceleration around 2.29 g, 5 mm size around 2.54 g and 3 mm size around 3.24 g compared to without particles 3.63 g acceleration.
- So we can conclude from the reading trend that as the particle size increase the acceleration goes on reducing.

REFERENCES

- [1] "A review of particle damping modelling and testing" by Louis Gagnon , Marco Morandini. Journal of Sound and Vibration 459 (2019) 114865, Institute of Aerodynamics and Gas Dynamics, University of Stuttgart, 70569, Stuttgart, Germany (2019)
- [2] "Assessment of surface contact fatigue failure in a spur geared system based on the tribological and vibration parameter analysis" by M. Amarnath , Sang-Kwon Lee (2015)
- [3] "Comparative Modal analysis of conventional spur gear with modified involute spur gear" by Sarfraz Ali N. Quadri International Research Journal of Engineering and Technology (IRJET) (2015)
- [4] "Energy dissipation mechanism and experiment of particle dampers for gear transmission under centrifugal loads" by Wangqiang Xiaoa , Yuxiang Huang. LiaaDepartment of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, China (2015)
- [5] "Vibration Analysis of Spur Gear- FEA Approach" by Subodh S. Lande 1P.G. Scholar, Design Engineering (Mechanical), A.D.C.E.T. Ashta (M.S.) India (2015)
- [6] " Modeling and experimental study of a honeycomb beam filled with damping particles" by Nazeer Ahmad , R. Ranganath ISRO Satellite Centre, Indian Space Research Organization, Vimanapura Post, Bangalore 560017, India (2016)
- [7] "Vibration analysis for tooth crack detection in a spur gear system with clearance nonlinearity" by Yi Yang, Wenkai Xia, Jianming Han International Journal of Mechanical Sciences 157–158 (2019) 648–661 (2019)
- [8] " Vibration Analysis Of Coated Spur Gears " by M. Karthick, M.Sundarraaj and T.Raja Volume 9, Issue 2, February 2018, pp. 409–416 Article ID: IJMET_09_02_042 (2018)
- [9] "Vibration Analysis and Optimization of Spur Gear Used in EOT Crane Machine" by Swapnil S.Kulkarni GRD Journals- Global Research and Development Journal for Engineering | Volume 1 | Issue 9 | August 2016
- [10] Amit Aherwar, Md. Saifullah Khalid. "Vibration Analysis Techniques For Gearbox Diagnostic: An International Journal Of Advanced Engineering Technology" E-Issn 0976-3945.
- [11] Ebersbach et al, (2005), "The investigation of the condition and faults of a spur gearbox using vibration and wear debris analysis techniques", international conference on wear of materials, wear 260, pp. 16-24
- [12] Jianming Yang (26 September 2012) "Vibration analysis on multi-mesh gear-trains under combined deterministic and random excitations" Mechanism and Machine Theory 59 (2013) 20–33
- [13] Tugan Eritenel RobertG.Parker (2012) "Three-dimensional nonlinear vibration of gear pairs" Journal of Sound and Vibration 331 (2012) 3628–3648
- [14] Gang Liu, Robert G. Parker "Impact of tooth friction and its bending effect on gear dynamics" By (18 October 2008) Department of Mechanical Engineering, The Ohio State University, 201 W. 19th Avenue, Columbus, OH 43210, USA Journal of Sound and Vibration 320 (2009) 1039–1063
- [15] Wangqiang Xiaoa,, Jiani Lia, Tianlong Pana, Xin Zhangb, Yuxiang Huang "Investigation into the influence of particles' friction coefficient on vibration suppression in gear transmission" China (2016) Mechanism and Machine Theory 108 (2017) 217–230
- [16] Cundall, P.A.,Strack, O.D.L. 1979 A discrete numerical model for granular assemblies Principal Engineer, Advanced Technology Group,
- [17] "Research on the impact of surface properties of particle on damping effect in gear transmission under high speed and heavy load" By Wangqiang Xiao, Zhiwei Chen, (19 May 2017)
- [18] Yi Yang, Wenkai Xia, "Vibration analysis for tooth crack detection in a spur gear system with clearance nonlinearity" International Journal of Mechanical Sciences 157–158 (2019) 648–661 2019
- [19] M. Karthick, M.Sundarraaj and T.Raja "Vibration analysis of coated spur gears" International Journal of Mechanical Engineering and Technology (IJMET) Volume 9, Issue 2, February 2018, pp. 409–416 Article ID: IJMET_09_02_042
- [20] Sarfraz Ali N. Quadri1, Dhananjay R. Dolas "Comparative Modal analysis of conventional spur gear with modified involute spur gear" Sarfraz Ali N. Quadri1, Dhananjay R. Dolas July-2015 (20) 2015
- [21] Investigation of mitigation of vibrations in gear system through particle damping, Shubham Hengade, Anshul Gangele, PG Scholar, Professor, Department of Mechanical Engineering, Sandip University, Nashik, Maharashtra, India. 2020 JETIR June 2020.