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Topology Optimization Based Design of Lightweight and Low Vibration Gear Bodies

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Abstract- This article presents a new approach aiming to reduce gear vibration and weight by modifying its body structure. The primary objective was to reduce vibration and noise emission of spur gears. For this purpose, a solid gear body was replaced by a lattice structure, which was expected to raise the torsional compliance of the body. The lattice structure was configured and optimized by a FE-based topology optimization software. For experimental purposes, the optimized gear was produced from Titanium alloy Ti-6Al-4V ELI using Selective Laser Melting technique. In the tests, the sound pressure of various running gear pairs was measured in order to estimate and compare the properties of a solid gear, of a lattice gear, and of a lattice gear, filled with polymer to increase the structural damping. It was experimentally confirmed that the cellular lattice structure of a gear body and addition of a polymer matrix may significantly reduce the vibration.

Keywords: Propeller Shafts, ANSYS, SolidWorks, Analysis, Composite Material, Conventional Steel, Mechanical Properties

1. Introduction- Gears have a wide variety of applications. Gears generally fail when the working stress exceeds the maximum permissible stress. These stresses are proportional to the amount of power transmitted by the gears. This project intends to identify the magnitude of the stresses for a given configuration of a 2 wheeler gears transmitting power while trying to find ways for reducing weight of the gear. The philosophy for driving this work is the lightness of the gear for a given purpose while keeping intact its functionality. Ease of incorporating the new feature for weight reduction over the existing process of manufacturing and the magnitude of volume of weight reduced could be considered as the key parameters for assessment for this work. This study will focus on the weight optimization of the 2 wheeler gear set, keeping the torque transmitting capacity intact, thus reducing the material cost of the gear. In this work, baseline design is modeled in Catia software and analyzed in FEA software. Weight reduction areas are identified and stresses are compared between baseline and optimized design.

1.2 TYPES OF GEARS

1. Spur Gear
2. Helical Gear
3. Double Helical gear
4. Bevel Gear
5. Spiral Bevel Gear
6. Hypoid Gear
7. Crown Gear
8. Worm Gear
9. Non-Circular Gear
10. Rack & Pinion
11. Epicyclic Gear Train
12. Sun & Planet Gear
13. Harmonic Gear
14. Cage Gear
15. Cycloidal Gear
16. Magnetic Gear
17. Miter Gear
18. Sprockets
19. Face Gear
20. Straight Sides Splines

2. Topology Optimization

2.1 Background:

Topology optimization is a form of generative design software that utilizes a mathematical model (algorithm) to design solutions that optimize the material, density, shape, and space.

2.2 Advantages Topology Optimization:

Topology optimization can create a significant shift in the business landscape in a short time. Let’s have a look at the top ones.

- Cost Reduction
- Short Product Development Cycle
- Weight Reduction
- Scalable and Complex Designs
- Sustainability

2.3 Disadvantages Topology Optimization:

Topology optimization is still at the early stages of its development. Although a powerful technology, the tool has limitations. Following are the roadblocks that you can face

- Complex Designs
- Initial Costs

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- Expensive Manufacturing
- Manual Constraints
- Proper Training
- Limited Use of Raw Materials

3. **Related Work:**

1. **Mr. Bhatt Parth Jitendrabhai "A Review on Design, Analysis and Material Optimization of High Speed Helical Gear by Changing Different Design Parameters Using FEA Approach", International Journal of Engineering Sciences & Research Technology.**
In this paper author have been presented a brief review of design and modeling and analysis of high speed helical gear for contact and bending stress using hertz, lewis and AGMA equations and ANSYS with various face width and helix angle and found their effect due to bending and contact stress and its value compared. And also deferent material is tried for weight reduction and cost optimization.
2. **Sarfraz Ali N. Quadri, Dhanajay R. Dolas "Mass Reduction of Involute Spur Gear under Static Loading "American Journal of Mechanical Engineering and Automation.**
This paper showcases a general view of mass optimization of spur gear under static loading. It states Finite element analysis method for the spur gear tooth using ANSYS 14.5. It further studies the mass of spur gear with inclusion of different geometries. The results show the effect of different geometries on stresses produced and it gives the best geometry which gives safer results with optimized mass of the spur gear.
3. **Mr. Sarfraz Ali, N. Quadri and Mr. Dhanajay R. Dolas, "Gear Pair Design Optimization by Genetic Algorithm and FEA", Department Of Mechanical and Production Engineering, Sathyabama University, Chennai, India.**
By studying above cases we concluded that, while optimizing the complex problems of mechanical system a Genetic Algorithm is important tool. So optimization of gear pair consisting of various parameters, objectives and constraints can be done easily using Non-conventional optimization technique i.e. Genetic Algorithm as compared to conventional techniques.
4. Mr. Sa'id Golabi, Mr. Javad Jafari Fesharaki, Mrs. Maryam Yazdipoor "Gear Train Optimization Based On Minimum Volume/Weight Design by Using the Matlab Program" Mechanism And Machine Theory 73 (2014) 197–217.
In this study the general form of objective function and design constraints for the volume of a gear train has been written and by using the Matlab program, the overall volume of one, two and three-stage gear trains is minimized. Next by considering some values for transmission power, hardness of material and gearbox ratio as input data for gearbox parameters, the results from the optimization program have been presented in the form of practical curves. The practical curves can be used to..

4. **Theoretical design:**

4.1 **Details**

Terms used in Gears: The following terms, which will be mostly used in this chapter,

1. Pitch circle. 2. Pitch circle diameter 3. Pitch point. 4. Pitch surface. 5. Pressure angle or angle of obliquity. 6. Addendum. 7. Dedendum. 8. Addendum circle. 9. Dedendum circle.
Root circle diameter = Pitch circle diameter × cos φ, where φ is the pressure angle.
10. Circular pitch 11. Diametral pitch. It denoted by pd.

Mathematically, Diametral pitch,

$$pd = \frac{T}{D} = \frac{\pi}{pc}$$

Where, T = Number of teeth, and

D = Pitch circle diameter

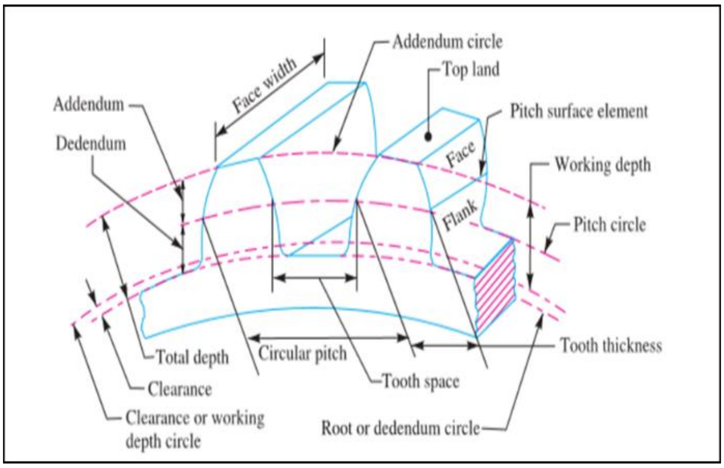

Fig: Terms used in gears

12. Module. It is usually denoted by m. Mathematically, Module,

m = D / T

13. Clearance.14. Total depth. 15. Working depth. 16. Tooth thickness. 17. Tooth space. 18. Backlash. 19. Face of the tooth. 20. Top land. 21. Flank of the tooth. 22. Face width. 23. Profile 24. Fillet radius. 25. Path of contact. 26. Length of the path of contact. 27. Arc of contact. The arc of contact consists of two parts, i.e.

a. Arc of approach.
b. Arc of recess.

4.2 Systems of Gear Teeth

The following four systems of gear teeth are commonly used in practice.

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1. 14.5° Composite system,
2. 14.5° Full depth involute system,
3. 20° Full depth involute system, and
4. 20° Stub involute system.

The 14.5° composite system is used for general purpose gears. It is stronger but has no interchangeability. The tooth profile of this system has cycloidal curves at the top and bottom and involute curve at the middle portion. The teeth are produced by formed milling cutters or hobs. The tooth profile of the 1 2 14 /° full depth involute system was developed for use with gear hobs for spur and helical gears.

The tooth profile of the 20° full depth involute system may be cut by hobs. The increase of the pressure angle from 14.5° to 20° results in a stronger tooth, because the tooth acting as a beam is wider at the base. The 20° stub involute system has a strong tooth to take heavy loads.

Table. Standard proportions of gear systems.

S. No.	Particulars	$14\frac{1}{2}°$ composite or full depth involute system	20° full depth involute system	20° stub involute system
1.	Addendum	1m	1m	0.8 m
2.	Dedendum	1.25 m	1.25 m	1 m
3.	Working depth	2 m	2 m	1.60 m
4.	Minimum total depth	2.25 m	2.25 m	1.80 m
5.	Tooth thickness	1.5708 m	1.5708 m	1.5708 m
6.	Minimum clearance	0.25 m	0.25 m	0.2 m
7.	Fillet radius at root	0.4 m	0.4 m	0.4 m

Design Considerations for a Gear Drive:

In the design of a gear drive, the following data is usually given:

1. The power to be transmitted.
2. The speed of the driving gear,
3. The speed of the driven gear or the velocity ratio, and
4. The centre distance.

The following requirements must be met in the design of a gear drive:

a) The gear teeth should have sufficient strength so that they will not fail under static loading or dynamic loading during normal running conditions.
b) The gear teeth should have wear characteristics so that their life is satisfactory.
c) The use of space and material should be economical.
d) The alignment of the gears and deflections of the shafts must be considered because they effect on the performance of the gears.
e) The lubrication of the gears must be satisfactory.

For designing the gear set for Bajaj Pulsar 220 2 Wheeler motorcycle, we have the following input parameters:

Power = 15 kW (20.4ps) @ 8500 rpm

T = 18.55 Nm @ 7000 rpm

Power for maximum torque,

$$P = \frac{2\pi NT}{60} = 13.59\ kW$$

We assume 20˚ stub system for design the gear

Therefore,

Pressure angle = 20˚

Addendum = 0.8m

Dedendum = 1 m

Clearance = 0.2m

Working depth = 1.6m

Whole depth = 1.8

Tooth thickness = 1.5708m

Minimum number of teeth on pinion = 14

We assume, module m = 2

We select material for gear as 50C8 steel

σut = 965 – 1030 Mpa

σc = 862Mpa

E = 190-210 GPa

μ = 0.27-0.3

Lewis Equation:-

$$y = 0.175 - \frac{0.841}{T}\ for\ 20°\ stub\ system$$

$$\sigma_{max} = \frac{My}{I}$$

M = max bending moment @ BC = $W_T \times h$

WT = Tangential load

h = length of tooth

Y = hay thickness of tooth at BC = $\frac{t}{2}$

I = Moment of Inertia at centre line of tooth = $\frac{bt^3}{12}$

b = width

$$\sigma_{max} = \frac{(W_T \times h)\,{}^{t}/_{2}}{bt^3/_{12}}$$

$$y = \frac{t^2}{6hpc}$$

Where, Pc = λm

Permissible working stress

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$$\sigma = \sigma_o \times C_V$$
$$\sigma_o = Allowable\ \sigma$$
$$C_V = Velocity\ factor$$
$$C_v = \frac{3}{3 + \vartheta}, v < 12.5m/s, ordinary\ wt$$
$$O = \frac{4.5}{4.5 + \vartheta}, v < 20\ m/s, carefully\ wt$$
$$= \frac{6}{6 + \vartheta}, v < 12.5\ m/s, accuratly\ wt$$
$$= \frac{0.75}{0.75 + \sqrt{\vartheta}}, v < 20\ m/s, pricision\ gears$$

ϑ = pitch line velocity in m/s

Design Procedure

$$W_t = \frac{P}{\vartheta} \times C_s$$

ϑ = pitch line velocity in m/s

$$\vartheta = \frac{\pi DN}{60}$$

D = Pitch circle in meters

D = mT

T = No. of teeth

$$D = \frac{2 \times 35}{1000} = 0.07m$$
$$\vartheta = \frac{\pi \times 0.07 \times 7000}{60} = 25.65\ m/s$$
$$C_s = Service\ factor$$

Service factor for steady 8 – 10 hrs/day = 1

$$W_t = \frac{13.59 \times 1000}{25.65} \times 1$$
$$W_t = 529.82\ N$$

5. **FEA CHAPTER:**

5.1 Background

The Finite Element Method (FEM) is a numerical technique to find approximate solutions of partial differential equations. It was originated from the need of solving complex elasticity and structural analysis problems in Civil, Mechanical and Aerospace engineering. In a structural simulation, FEM helps in producing stiffness and strength visualizations. It also helps to minimize material weight and its cost of the structures.

STATIC ANALYSIS:

Static analysis deals with the conditions of equilibrium of the bodies acted upon by forces. A static analysis can be either linear or non-linear. All types of non-linearity allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc. This chapter focuses on static analysis.

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those carried by time varying loads. A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects.

A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time.

The kinds of loading that can be applied in static analysis includes, externally applied forces, moments and pressures. Steady state inertial forces such as gravity and spinning imposed non-zero displacements.

A static analysis result of structural displacements, stresses and strains and forces in structures for components caused by loads will give a clear idea about whether the structure or components will withstand for the applied maximum forces. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary.

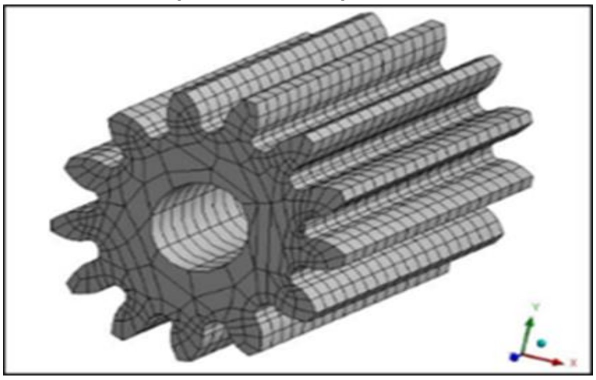

Fig: Meshing

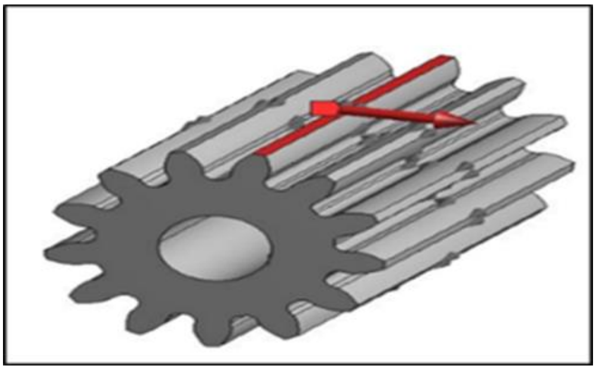

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Fig: Boundary Condition

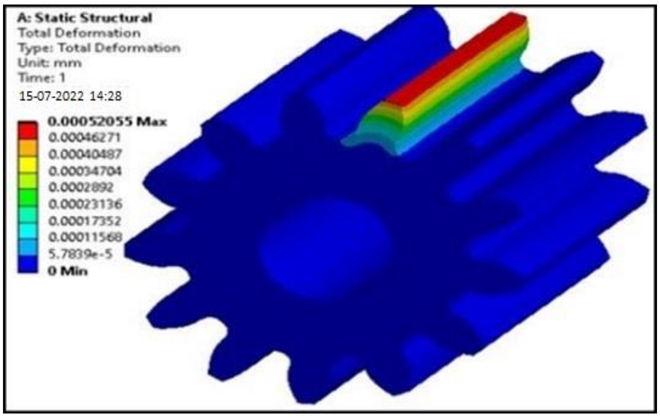

Fig: Total Deformation

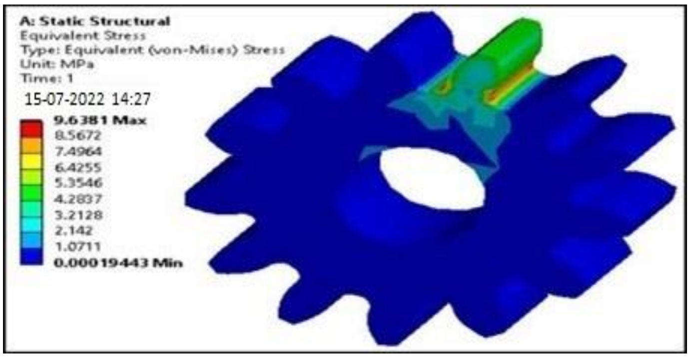

Fig: - Von-Mises Equivalent Stress

CONCLUSION:

This paper showcases a general view of mass optimization of spur gear under static loading. It states Finite element analysis method for the spur gear tooth using ANSYS 19. It further studies the mass of spur gear with inclusion of different geometries. The results show that, it is possible to reduce the weight of these gears without much increase in stresses and keeping the functionality of gears intact.

A pinion gear with an angular velocity ranging from 100 rpm drives the gear with a gear ratio of 2 at 3Kw power. Fusion 360 CAD software is used to create the 3D model. 3D model is imported to ANSYS workbench for FEA Analysis. For precision, the 3D model in the ANSYS workbench environment has been meshed with a specific mesh at the gear tooth surface. Boundary and loading conditions were applied as needed. Total Deformation simulation results were presented with their highest value at the tooth tip or tooth root, this data helps us to prevent failure conditions and design high-performance gear systems.

References- 1. Mr. Bhatt Parth Jitendrabhai "A Review on Design, Analysis and Material Optimization of High Speed Helical Gear by Changing Different Design Parameters Using FEA Approach", International Journal of Engineering Sciences & Research Technology.

2. Sarfraz Ali N. Quadri, Dhanajay R. Dolas "Mass Reduction of Involute Spur Gear under Static Loading "American Journal of Mechanical Engineering and Automation.

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