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Optimizing weight of a Gear using Topology Optimization

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***Abstract*— The objective of this paper is to reduce the weight of a gear present in a compound gear train and to reduce the overall rotational inertia of the gearbox. Topology optimization method is used for ideal material distribution of gear structure such that the objective function is maximized. Topology optimization on the gear was performed using Altair INSPIRE V9.5 and the CAD model of the gears was created using SOLIDWORKS 2016 and the optimized gear was analyzed in ANSYS 16.0. Using various results from inspire a gear was produced which was 67.816% lighter than the original gear and had 58.831% less rotational inertia with a final factor of safety of 1.3.**

***Index Terms*— Topology Optimization, Weight Reduction, INSPIRE, Gear Optimization, Rotational Inertia reduction**

1) INTRODUCTION

Gears are the most commonly used positive drive transmission systems. But sometimes they can become overdesigned leading to heavy gears.[1] This over designing may be cause due to dimensional or space constraints.
The gain in weight leads increase in rotational inertia which reduces the efficiency at the start of a gear drive.
The goal here is optimize a simple spur gear present in a simple 2-stage compound gear train using INSPIRE V9.5.
The software used topology optimization which is basically an iterative process where the nodes are removed from the body one by one until the targeted factor of safety is not reached. [1] If due to removal of the node the factor of safety falls below the specified factor of safety the node id returned to the structure. This is how INSPIRE can optimize a gear by repetitive finite element analysis to optimize the structure of a component.

2) LITERATURE SURVEY

Optimization via this method is a mathematical approach that optimizes the material -layout within a given design space. The redistribution works under a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of requirements. Using topology optimization, engineers can find the best concept design that meets the design requirements.[2]
Topology optimization has been implemented using finite element methods for the analysis, and optimization techniques based on the methods of moving asymptotes, genetic algorithms, optimality criteria method, level sets and topological derivatives. [2]
Topology optimization is used at the concept level of the design process to arrive at a conceptual design proposal that is then fine-tuned for performance and manufacturability. This replaces time consuming and costly design iterations and hence reduces design development time and overall cost while improving design performance. [2]
In some cases, proposals from a topology optimization, although optimal, may be expensive or infeasible to manufacture. These challenges can be overcome using manufacturing constraints in the topology optimization problem formulation. Using manufacturing constraints, the optimization yields engineering designs that would satisfy practical manufacturing requirements. [2]

3) WORKING OF TOPOLOGY OPTIMIZATION IN A GEAR

As topology optimization is an iterative process, the following steps are performed in the sequential manner to determine the most optimized structure for a given set of constraints.

3.1 Defining Objective

To minimize mass of a gear and achieve a final factor of safety around 1.2.[5]

3.2 Applying material

The first step is to apply the material to all the present bodies. The material chosen for the gear is SAE 8620.

Table 1: SAE 8620 Properties

Sr.No.	Properties	Value(MPa)
1	Maximum ultimate tensile strength	1270
2	Maximum yield strength	1150

3.3 Design and a Non-Design space

The second step during topology optimization of a gear is to divide the body into design and non-design space. Design space is the part of the body where topology optimization takes place and the remaining Non-Design space remains untouched. [5]

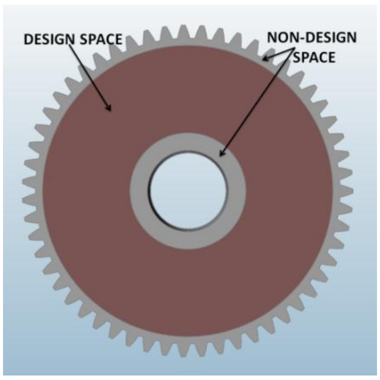


Figure 1: Design and Non-Design space of a gear

3.4 Calculation of Forces

The force present on the gear in the compound gear train is calculated as follows.

Table 2: Force calculations

Sr. No.	LOADS	VALUE(Nm)
1	Torque From Engine	19.66
2	Torque after CVT	76.674
3	Torque after primary gear reduction	225.7623

$$\text{Force on the gear} = \frac{2 * \mathbf{M_t}}{D}$$

$$= \frac{2 * 225.7623}{137.5 * 10^{-3}} = \mathbf{3283.815\ N}$$

3.5 Load Case

This force is applied on a single tooth along a line at the pitch circle diameter distance from the center. The shaft hole of the gear is given a hole center support(cylindrical support) and is locked in both translational and rotational degrees of freedom. The force applied is 3283.815N

Material of gear: SAE 8620[5]

Maximum ultimate tensile strength: 1560 MPa

Maximum yield strength: 1525 MPa

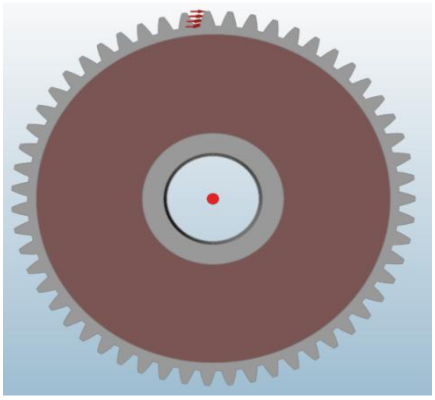


Figure 2: Load case in case of gear

3.6 Symmetry constraints

As the force is applied on only one tooth the optimization will occur only around that region. To observe optimization around the entire gear symmetric constraints are applied. This will ensure symmetric material removal. Three cases are taken containing 3sectors respectively to see which symmetry optimization gives better results.

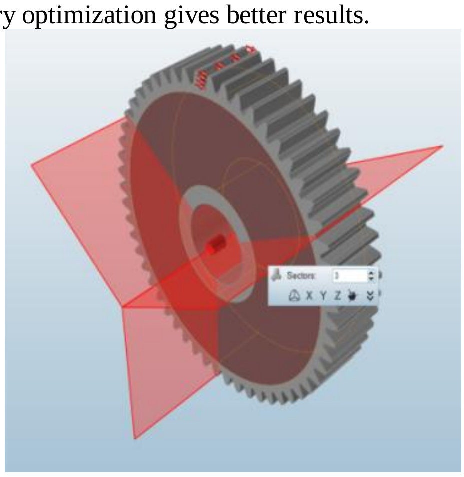


Figure 3: Symmetric constraints for gears (3 sectors)

3.7 Optimization results

The entire program was run according to the above mentioned steps for min mass criterion and a final factor of safety of 1.2 , on the same gear with different no. of symmetry constraints and the following results were obtained in INSPIRE V9.5.

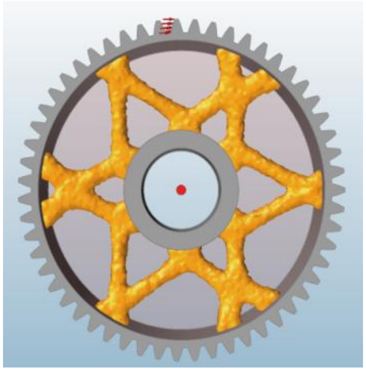


Figure 4: Results of optimization (for 3sectors)

4) REDESIGNING OF GEARS

The CAD model of original gear on which topology optimization is carried out is given below

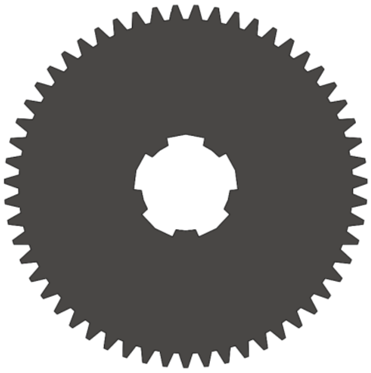


Figure 5: Original CAD model of gear created in solidworks-2016

After the results were obtained the CAD models of the optimized gears were created by removing the same profiles from the original gears as specified in the results. The CAD modeling was done on SOLIDWORKS 2016. The optimized gears are given in the fig below:-

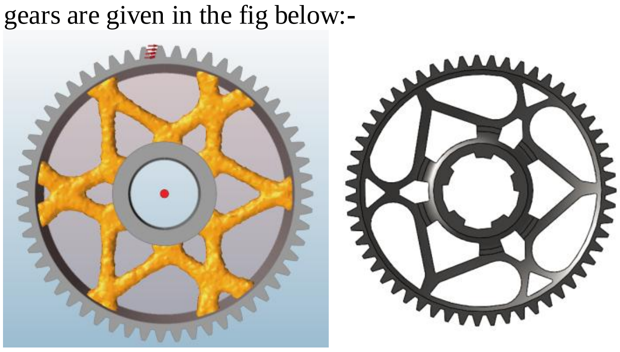


Figure 6: Final - Optimized gears for (3 sectors) created in solidworks-2016

5) VALIDATION

To validate the current prepared models, a finite element analysis was performed to ensure that the design is within safety limits. The analysis was carried on ANSYS 16.0. The loads and constraints were same as used for optimization. The gear material is considered as homogenous and isotropic. The problem domain is considered as axis- symmetric. Inertia & body force effects are negligible during the analysis.

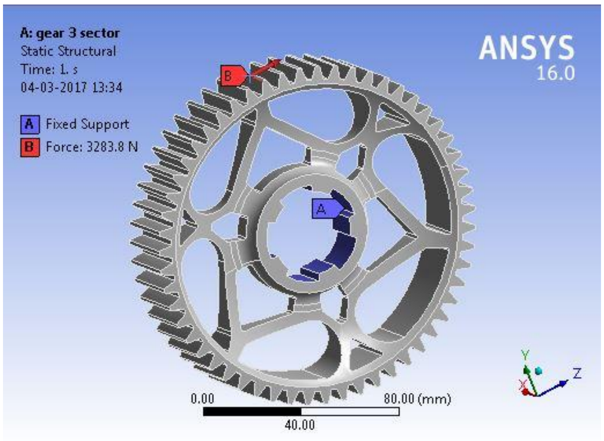


Figure 7: Loads and constraints applied on 3 sector optimized gear

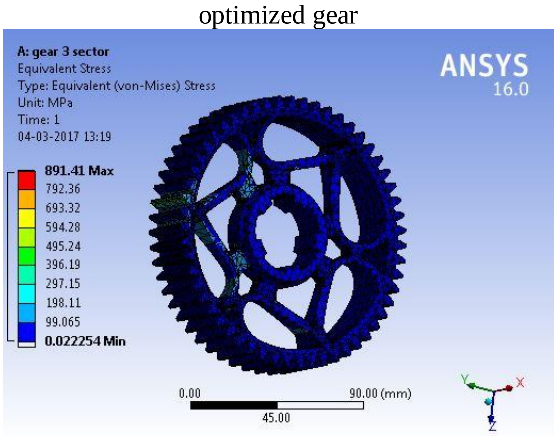


Figure 8: Equivalent stress of 3 sector optimized gear

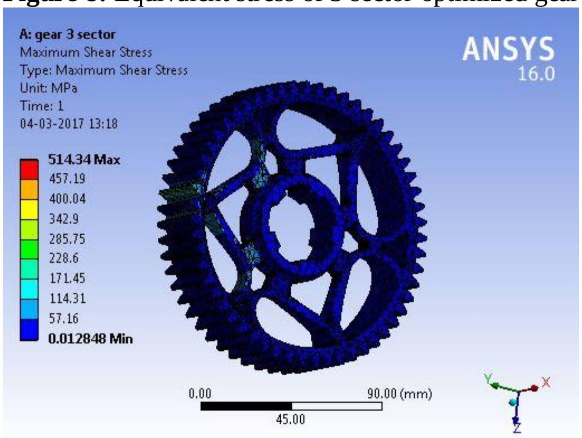


Figure 9: Max shear stress of 3 sector optimized gear

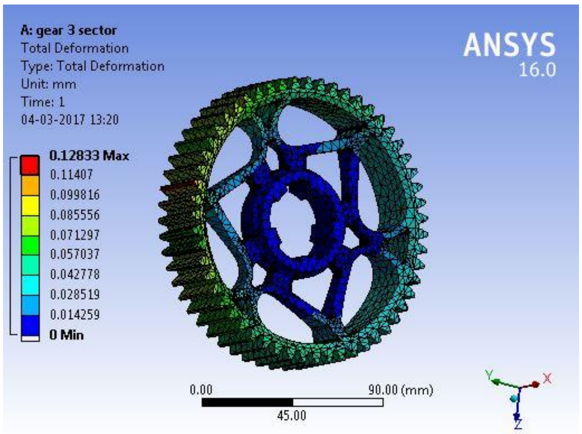


Figure 10: Total Deformation of 3 sector optimized gear

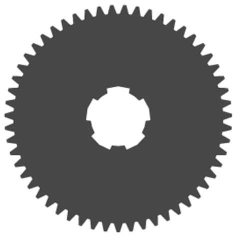
Using maximum shear stress theory [6] the yield strength in Shear is half of the yield stress in tension.

Ssy = 0.5Syt
Factor of safety = Ssy/shear stress in disc

6) RESULT

All the results of all the optimized gears are compiled below:-

Table 3 : Result compilation for original and 3 sector optimized gear.

	Original Gear	***3 Sector Optimized gear***
		
Weight(gm)	*2995.729*	*964.123*
Inertia (gm mm^4)	4019329.799	1654715.969
Material	SAE 8620	SAE 8620
Max. Stress(MPa)	811.52	891.41
Max. Disp.(mm)	0.1132	0.12833
Max. Shear Stress(MPa)	430	514.34
Factor of Safety	1.53	1.39

7) CONCLUSION

Topology optimization was performed on a gear by determining the correct load case and constraints. The results were obtained which showed reduction in weight from 2995.729gm gear to lightest gear of weight 964.123gm which is approximately reduction in weight by 67.816% and rotational inertia by 58.831% . All of this was achieved by keeping the factor of safety of the gear at greater than the desirable value of 1.2.

References

[1]DongkaiXu ,JunChen ,YuchengTang ,JianCao, Topology optimization of die weight reduction for high-strength sheet metal stamping *International Journal of Mechanical Sciences ,Volume 59, Issue 1, (2012), (P 73-82)*

[2] Cavazzuti, M., Baldini, A., Bertocchi, E., Costi, D., Torricelli, E., & Moruzzi, P. (2011a). High performance automotive chassis design: a topology optimization based approach. *Structural and Multidisciplinary Optimization, Vol.44 (1), pp45-56.B.*

[3] Xiang Bian , Zongde Fang ,Kun Qin, Lifei Lian , Baoyu Zhang Multi-objective Topology Optimization for Bevel Gear and Geometrical *Reconstruction Trans-Tech Publication,Switzerland* , 2013

[4] Mohd Nizam Sudin, Musthafah Mohd Tahir, Faiz Redza Ramli, Shamsul Anuar Shamsuddin ,Topology Optimization in Automotive Brake Pedal Redesign *International Journal of Engineering and Technology (IJET)*

[5] Swapnil Thigale, Chinmay Shah, Weight Reduction in Brake Disc using Topology Optimization, *IJRET: International Journal of Research in Engineering and Technology,2016*

[6] V B Bhandari (1994), Design of Machine Elements, *Third Edition , Pg 108.*

[7] LIN Dan-yi,LI Fang Topological optimization of continuum structure based on ANSYS(China)

[8] Kaya, N., Karen, İ., & Öztürk, F. (2010). Re-design of a failed clutch fork using topology and shape optimization by the response surface method. Materials & Design, 31(6), 3008-3014.

Bendsøe, M.P. and Sigmund, O. (2003) Topology Optimization - Theory, Methods and Applications. Springer Verlag, Berlin Heidelberg.

[9] Tushar M. Patel, Dr. M. G. Bhatt, Harshad K. Patel. (2013). Parametric Optimization of Eicher 11.10 Chassis Frame for Weight Reduction Using FEADOE Hybrid Modeling.*IOSR Journal of Mechanical and Civil Engineering,6(2), 92*-100

[10] Auer, B. J. (2005). Size and Shape Optimization of Frame and Truss Structures Through Evolutionary Methods (Doctoral dissertation, University of Idaho).

[11] Liangchi Zhang, Chunliang Zhang and Tielin Shi Weight Reduction Design of Gear Drive Based on Parameter and Structural Optimization *Advanced Materials Research (Volumes 139-141)*

[12] R. S. Kajabe1, R.R.Navthar2. "Optimization of Disc Brake Rotor with Modified Shape (2015).

[13] Vaibhav A. Ajmire and Sangeeta N. Bansode. "Structure Optimization of Disc Brake." (2015)

[14] Vasim Bhashir Maner, M. M. Mirza, ShrikantPawar. "Design Analysis and Optimization For Foot Casing Of Gearbox." 3rd Irf International Conference, (2014).

[15] VirajRajendraKulkarni, AmeyGangaramTambe. "Optimization and Finite Element Analysis of Steering Knuckle." (2013).

[16] LotharHarzheim, Gerhard Graf. "A review of optimization of cast parts using topology optimization." (2005).

[17] Nitin S Gokhale. "Practical Finite Element Analysis." (2008).

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