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Investigation on the shape optimization effect on structural analysis of a spur gear

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Abstract:
Power transmission systems uses gears is a common phenomenon in automotive industry. The torque transmitted and speed are the most important parameters in the power transmission gear box. Material selection is one of the important criteria for the gear analysis. In this paper, cast carbon steel and 2014 grade aluminum alloy steel are chosen for the static analysis of a spur gear. A weight reduction of 12.93 % is observed and 15.47 % of von-mises stresses is decreased from the shape optimizationin cast carbon steel due to high density of the material.In 2014 grade aluminum steel, a weight reduction of 12.92 % and 2.2 % of von-mises stresses is increased due to low density of the material. Results are compared for both materials to estimate the sustainability of the material yield strength.
Keywords: *Shape optimization, torque, deformation, Von-mises stresses.*

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I. Introduction

Spur gears are simple, cost effective and durable to achieve constant speed drive. Spur gear design accommodates rolling rather than sliding and good heat resistance and high mechanical efficiency based on the effective cooling. Light weight and high strength materials are to be chosen for the good design of spur gear[1].Weight optimization has an important role in maximizing the service life of a gear and to enhance the bearing capability. In shape optimization, choosing the module, number of teeth and providing the cut holes in the gear body is essential for reducing the induced stresses[2]. The properties are chosen for Cast carbon steel and 2014 Aluminum Alloy materials listed in Table: 1.

Table: 1 Material Properties

S.No.	Material	Yield Strength (N/mm^2)	Density, (kg/m^3)	Poission's Ratio	Young's Modulus (N/mm^2)
1	Cast carbon steel	248	7800	0.32	200000
2	2014 Aluminum Alloy	90	2800	0.33	73000

II. Methods/Experimental

Gear weight is an important property for evaluating the induced stress against applied load. In this context, the spur gear is optimized by creating rectangular oblong holes in the structure is one of thecreative ideas to achieve the weight optimization. The spur gear is modelled using the commercial software "Solidworks" and structural analysis is conducted to evaluate the deformation, Von-mises stress and Strain in the body of the gear. To achieve the results, the meshed model of the gear is applied with the required boundary conditions and loading parameters.

III. Literature Survey

Shape optimization varies by changing the structure of the gear. This can be achieved by providing oblong holes in the body of the gear resulting the weight reduction. Less weight gears reduce the weight of the gear box and increase the efficiency of the engine. Results obtained reflect the trade-off effects of multiple objectives by increase in optimal weight value[2]. Anand Kumar Gaurav et. Al., chosen material removal in the helical gear structure to minimize the stress and deformation along with factor of safety within the permissible limit.In this paper a set of helical gear pair is chosen with AGMA standards with design variables such as module, face width, number of teeth on pinion and helix angle. Design constraints considered are bending stress, compressive stress, module, gear ratio and center distance. These results were used for data validation and improved design for lighter weight gear and checked for the percentage of weight optimization[3].Zhi-Gen Wang et.al., narrated a multi-objective optimization to reduce the vibration levels by minimizing misalignment and linear tip relief parameters using commercial software. Finally dynamic experiments were performed at various speeds to compare dynamic simulations and experimental results[4].Naveen Kumar et.al., performed design optimization for the given values of forces, torque and factor of safety in accordance to custom vehicle. e gear weight is optimized at specific regions and simulation is carried out using solidworks and Ansys software to show the difference in weight and factor of safety between optimized and un-optimized gear models [5].

However,the shape optimization is to be performed to different materials for % of stress induced and weight reduction to protect the gear box and increase the life of the engine. Oblong holes are used in the place of elliptical holes to sustain the effect of the weight reduction and fatigue and cyclic stresses are not considered in this part of research.A typical static analysis is to be performed to evaluate the weight of the gear, deformation, von-mises stress and equivalent strain to estimate the material sustainability.

Problem description

A typical spur gear drive is taken and the power transmitted is 2 kW at 100 rpm. To improve the shape optimization, six elliptical holes are created to reduce the weight of the gear and to improve the efficiency of the gear box.

Model generation and strategy

A typical spur gear is developed using commercial software and a torque of 190.98 N-m from the calculations is applied on the gear tooth face to evaluate the results. Gear hub is taken as fixed hinge which is connected to the shaft to deliver the rated torque. A structural analysis is performed to the gear materials mentioned in table:1 for both unoptimized and shape - optimized gear to compare the results and the topology of the gear is represented in Fig: 1(a) and Fig: 1(b).

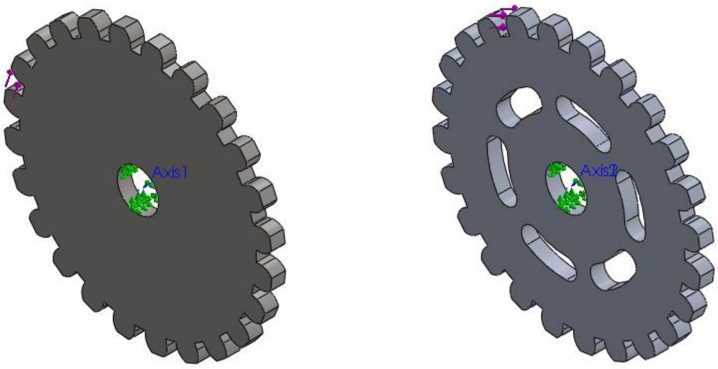

Fig: 1(a) Unoptimized gear modelFig: 1(b) Shape optimized gear model

IV. Results and Discussion

A typical solid mesh is chosen for both models and a total maximum number of elements of 6193 are chosen for the analysis represented in Fig: 2. A maximum number of nodes were 11348 observed, having aspect ratio of 6.19 and having aspect ratio less than 3% is reached 96.3% to convergence the results.

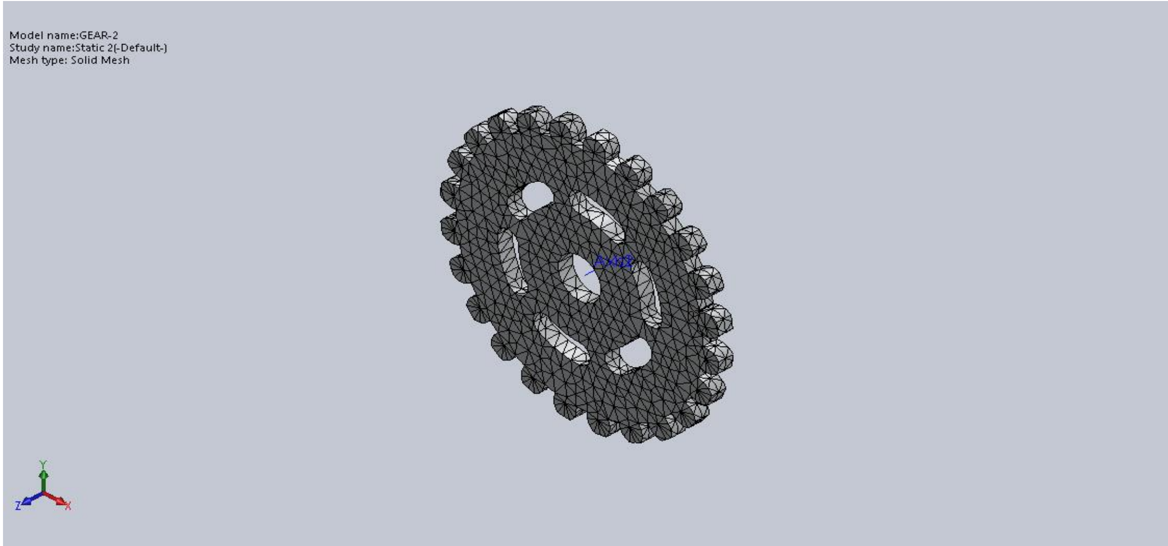

Fig: 2 Meshed model

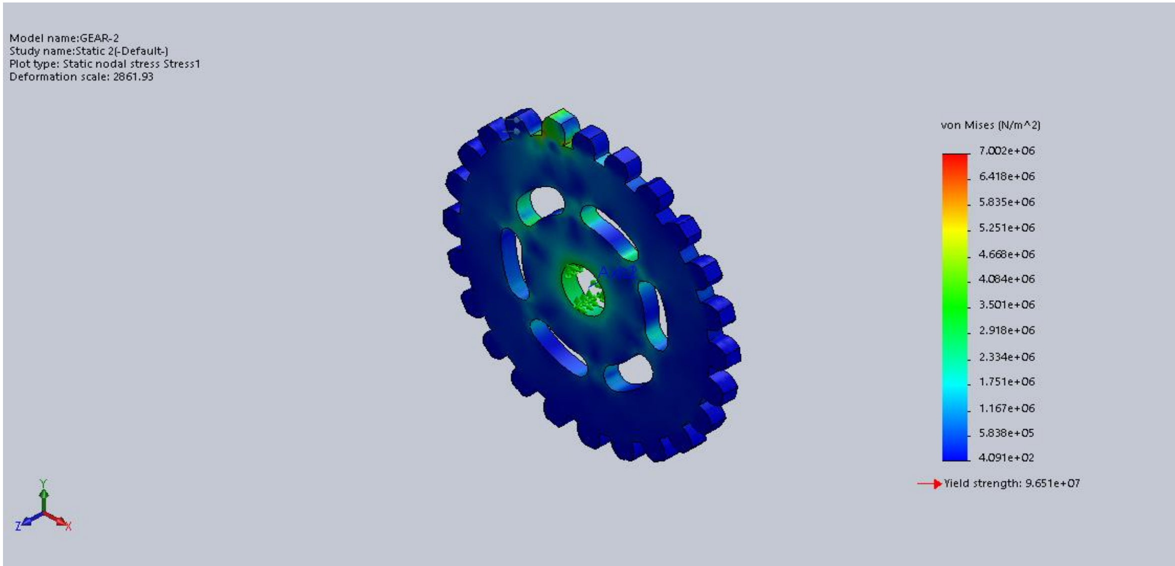

Fig: 3 Von- mises stress contour

The deformation, Von-mises stress as represented in Fig: 3 and strain parameters from the simulations for an unoptimized gear and optimized gear are tabulated from Table:2. The percentage of weight reduction is one of the important goals of the study is analyzed and tabulated from Table:3.Table: 2 Static analysis resultsof gears

S.No.	Material	Deformation (mm)		Von-mises stress (MPa)		Strain $x10^{-5}$	
		Unoptimized gear	Optimized gear	Unoptimized gear	Optimized gear	Unoptimized gear	Optimized gear
1	Cast carbon steel	0.0042	0.0055	7.678	6.490	2.781	2.380
2	2014 Aluminum Alloy	0.0116	0.00151	6.850	7.002	7.290	6.972

Table: 3 Percentage of weight reduction of gears

S.No.	Material	Weight of the gear (kg)		% of weight reduction
		Unoptimized gear	Optimized gear	
1	Cast carbon steel	16.4923	14.3604	12.930
2	2014 Aluminum Alloy	5.9203	5.1550	12.926

The results related to the deflection, von-mises stress and strain are compared and furnished from Fig: 4, Fig: 5 and Fig: 6, for unoptimized gear and optimized gear with the numerical values. In the same method, the percentage of weight reduction in the gear is shown in Fig: 7 for unoptimized gear and optimized gear.

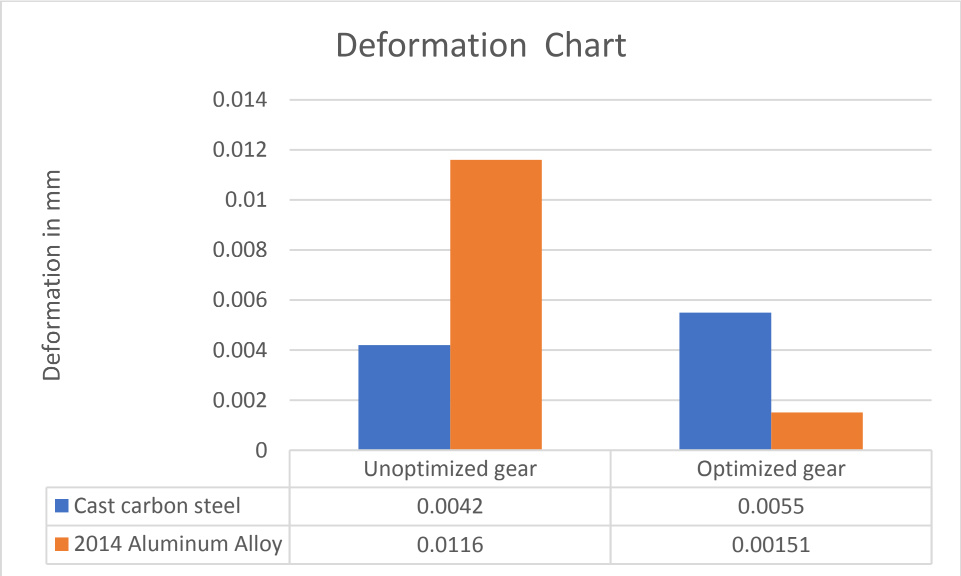

Fig: 4 Deformation chart

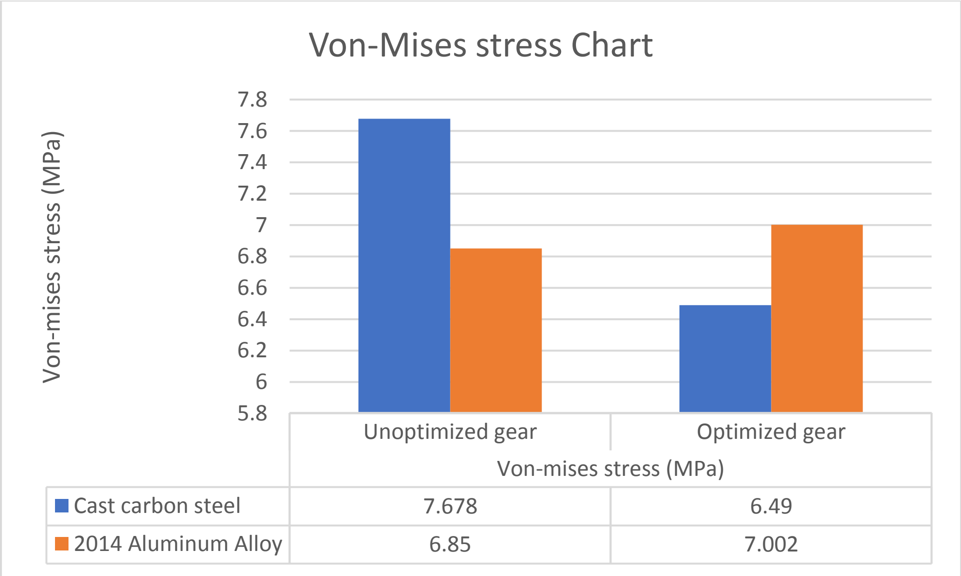

Fig: 5 Von-Mises Stress chart

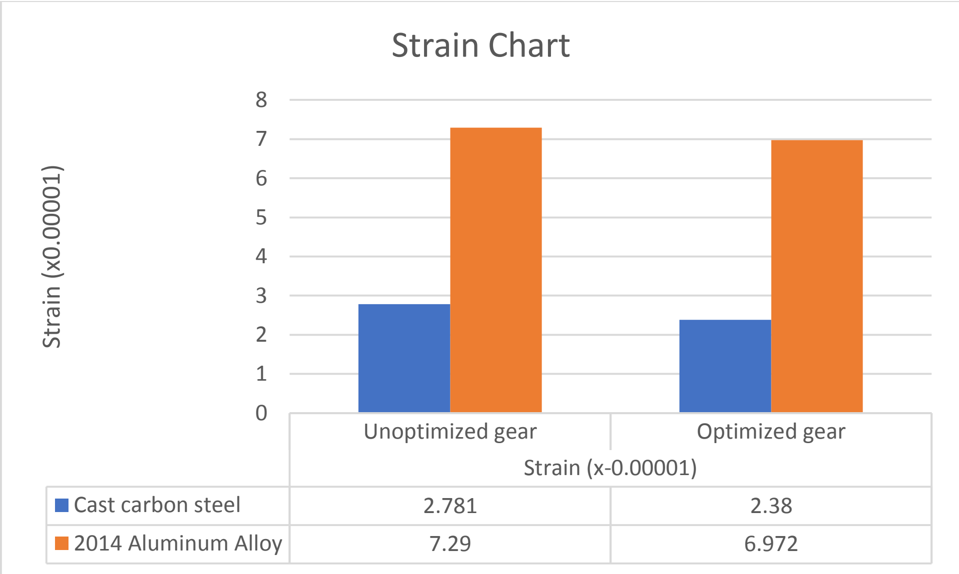

Fig: 6 Strain chart

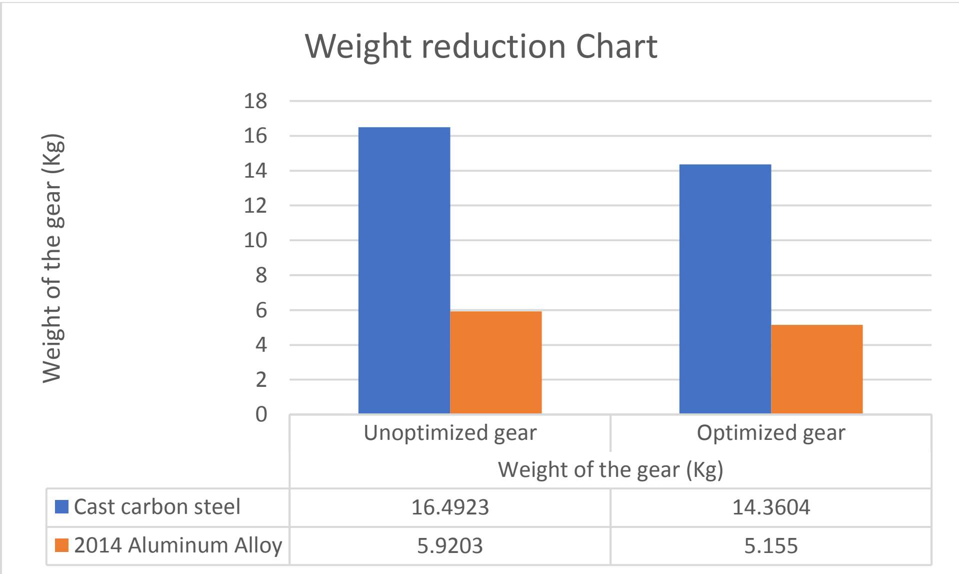

Fig: 6 Weight reduction chart

V. Conclusions

Gear is typically modelled and optimized for the weight reduction to save the life of the gear box. A considerable maximum weight reduction of 12.93% is observed in Cast Carbon Steel and 12.926% is in 2014 Aluminum Alloy Steel.A remarkable von-mises stress reduction of 15.47% recorded in Cast Carbon Steel and 2.2% is increased in 2014 Aluminum Alloy Steel.

List of abbreviations
Not Applicable

Declarations
Authors' contributions
I declare that this research paper is composed solely by myself and that it has not been replicated in other work. The materials information provided is from the standard materials properties and all the results are taken from the simulations carried by me. I hereby confirm that all the parameters like deformation, Von-mises stress and Strain that are stated in the manuscript are true to the best of my knowledge. I declare that the results tabulated in the manuscript is compared from the results of simulations and validated according to the simulated results from the "Solidworks" software.

Author's Profile

Author is masters in Mechanical Engineering from Bharath Institute of Higher Education and Research and Doctorate from JNTU-Hyderabad, India. Published many articles in conferences and International Journals. Interested in simulation and analysis of typical profiles in mechanical and aerospace industries related requirements.

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