Topology Optimization of Automotive Gears Using Fea – A Review

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Abstract- *Gears are the major component used to transmit power or motion from on shaft to another and . It's one of the major application is in the automobile gear box. Generally gears fails when the working stress exceeds than the maximum permissible value. In this review approach various articles of concern with topology and weight optimization are studied which mainly focuses on weight reduction with keeping stress values with permissible limit.*

Keywords- Topology Optimization, Weight Reduction, FEA, Spur Gear.

I. INTRODUCTION

Gears are the most common means of transmitting power in the modern mechanical engineering world. They vary from a tiny size used in watches to the large gears used in watches to the large gears used in lifting mechanisms and speed reducers. They form vital elements of main and ancillary mechanisms in many machines such as automobiles, tractors, metal cutting machine tools etc.

Toothed gears are used to change the speed and power ratio as well as direction between input and output.

II. LITREATURE REVIEW

Yuvraj P. Mali et al. identified the magnitude of the stresses for a given configuration of a gear 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. The process constraints for manufacturing the gear also need to be considered while recommending alternative/s. Ease of incorporating the new feature for weight reduction over the existing process of manufacturing and the magnitude of volume of mass (or weight) reduced could be considered as the key parameters for assessment for this work. This study will focus on the weight optimization of the gear, keeping the torque transmitting capacity intact, thus reducing cost of the gear. In this work, the gear will be modeled in modelling software CATIA and analyzed in ANSYS. The results obtained from FEA will be validated by modifying the standard gear and then practically testing torque transmitted and stresses in the gear.

Table 1. Torque Transmitted through Individual Gear

Gear	Torque Transmitted (N-m)
Actual 1st	10.36
Actual 2nd	10.35
Actual 3rd	10.39
Actual 4th	10.36
Optimized 2nd	10.36
Optimized 3rd	10.37
Optimized 4th	10.35

Table 2. Weight Comparison

Gear	Actual Weight (Kg)	Optimized Weight (Kg)	% Reduction
1st	0.263	0.263	-
2nd	0.2	0.175	12.5
3rd	0.133	0.106	20.3
4th	0.104	0.090	13.46
Total	**0.7**	**0.634**	**9.428**

Satyavan S Mokashi et al. investigated possibilities to reduce weight of gear. Reduction of weight has been one the critical aspects of any design. It has substantial impact on vehicle performance, fuel efficiency and in turn reduces the emissions. This work focuses on the design space offered by the component functionality while determining the nature and extent of the mass reduction over the locations identified during Topology Optimization.

The proposed method utilizes software in the FEA domain for analyzing the effects of the variation in the values of the design parameters influencing the modal behavior. Also the computational approach will give the results more close to practical values through simulation. The FEM method is used to analyze the stress state of an elastic body with complicated geometry, such as gear. Also the contact and bending stresses should be calculated by using ANSYS/NASTRAN. In this thesis the analysis of characteristics of in volume spur gears in gearbox is intended for the study by using the FEM.

UTM test setup is used for determining the stiffness of the gear. Gradual load will be applied and corresponding deformation is recorded. The load from the load cells present on the UTM machine will be applied gradually. Display attached to the machine will give a corresponding plot for load Vs displacement i.e. stiffness of the component. In this project the stiffness of the component was validated to compare results obtained from experimentation with results of FEA analysis.

Mario Sosa et al. work focuses on gear design using PM by utilizing finite element method (FEM) to reduce weight and inertia taking into account root bending strength and tooth deflection. First a topological optimization is used to determine feasible candidates for different web designs which have as objective to reduce volume, similar topologies were shown during different loading conditions; and hence, this topology was chosen as a suitable candidate. A shape optimization of the topological candidate was performed having as state variables root bending strength, independent for compressive and tensile side of the tooth loading; and tooth deflection, which in concept can be correlated to static transmission error (TE).

Another aspect in this thesis analyzed is the possibility to incorporate non-trochoid root geometry, a trochoid root is always present when machining with a hob, into the gear root and hence reduce the stress concentration here. Due to the use of PM, a non-symmetric optimized root can be achieved and hence be optimizing compression and tension.

Results showed significantly lower inertia, for example certain results showed 40% reduced when compared to solid gear, with adverse effects as increase in tooth deformation and increase in maximum principal stress. Peak to peak transmission error results of proposed web showed 17% lower result when compared to solid steel. Finally, root optimization showed marginally reduced maximum principal stress, but demonstrations potential with other geometries.

A topological optimization was devised in which to acquire ideas of how to design a gear web which complied with the following conditions:

a) Minimum weight and inertia as possible
b) Same or similar stiffness for each tooth

Conclusion from this work is Inertia was significantly lowered, 40% when compared to solid gear in the final run and optimization resulted in marginally lower stress.

Vaibhav Pimpalte. work focuses gears from two wheeler gear set are analyzed for static loading under the application of tangential load resulting from maximum torque in the given application. After studying the stress distribution on baseline gears, weight reduction areas are identified on given gears and geometrical features are added on the gear to reduce the weight. Static analysis is conducted on the optimized gears under the application of same loading and comparative results are presented about stress distribution between baseline and optimized gears and weight reduction is outlined for each gear of gear set.

For this study, actual gear set consisting of four gears is considered and CAD model is created by measuring the basic dimensions of each gear in CATIA software.

Table 3. Stress Comparison

Gear	*Baseline Design- Stress values (MPa)*	*Optimized Design- Stress Values (MPa)*	*% Increase in stresses*
Gear-1	55.92	-	-
Gear-2	105	122.07	16.25
Gear-3	76.74	80.34	4.69
Gear-4	116..5	129	10.72

Table 4. Weight comparison between baseline and optimized gears

Gear	*Baseline Design- Weight (Kg)*	*Optimized Design- Weight (Kg)*	*% Decrease in weight*
Gear-1	0.263	-	-
Gear-2	0.2	0.168	16
Gear-3	0.133	0.111	16.54
Gear-4	0.104	0.0875	15.86

Ulrich Heiselbetz (Daimler AG.) et al. *mainly focuses on* for lightweight design of a gear wheel for a truck transmission in several steps. It also provides short information about a very easy way to specify shape basis vectors in the shape optimization as an example for advanced modelling capabilities. In addition, information about costs and the realised benefits are presented.

At first the current design of the gear wheel is analysed. Subsequently, a FEA-based topology optimization is performed for the loaded gear wheel. Due to revolving load the geometry has to be cyclic symmetric. Undercuts are not allowed by the manufacturing process. The result of this step is a new design draft. The transformation of the draft into a CAD model is done by a design engineer. With the same loads and boundary conditions as in the topology optimization a shape optimization is performed for the new gear wheel. There, cyclic symmetry must be retained. This step is to decrease stress maxima and to smooth strains.

The first step of a topology optimization is the definition of a design space. It denotes the region where geometrical modification.

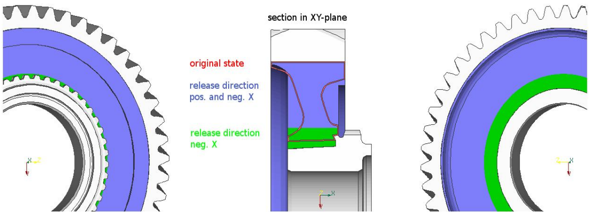

Fig. 1 Model Description

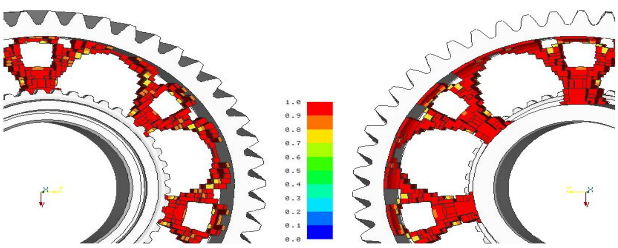

Fig. 2 Topology Optimization

The design constraints for the topology optimization are:

- maximum von Mises stress at the surface between design space and gear rim
- cyclic symmetry with seven sectors and planar symmetry within each sector
- maximum weight

The highest possible stiffness is used as design objective. So, a new draft with maximum stiffness for all load cases under a given weight is sought.

III. CONCLUSION

- In this design of gears, there is still room for research, especially when the performance is the primary objective.
- Gear design can also be optimized by selecting appropriate material.
- Composites provide much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure.
- Friction and speed plays important role in the gear stress cycle and useful fatigue life.
- Finite element analysis is viable approach to perform design optimization quickly as compared to solving complex partial differential equations.
- With the research data collected so far, it is evident that there is a room to optimize gear geometry without affecting its strength.
- Finite element approach can be utilized to identify stress and deformation in the gear geometry.
- Optimizing the gear geometry by removing material from low stress regions can give improved design that can be beneficial for overall performance of the transmission system as well as better life of bearings and shafts.

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