ACHIEVING MASS REDUCTION IN THE SPUR GEAR USING TOPOLOGY OPTIMIZATION FOR DESIGN EVALUATION AND ANALYSIS

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ABSTRACT

All manufacturing enterprises strive to develop the optimized product commonly by reducing the weight while ensuring they produce cost effective products that meet their design functionality and reliability. Structural optimization tools like topology optimization along with manufacturing simulation are becoming attractive tools in product design process. These tools also help to reduce product development time. As gears are important elements in a variety of industrial or commercial applications such as machine tool, vehicles, turbines, etc. Objective of this investigation is 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 would focus 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. Experimentation shall be conducted for ascertaining Stiffness of the Gear in the light of feasibility of the Testing setup.

KEYWORDS: *Spur Gear, Topology Optimization, Weight Reduction, Mass reduction*

I. INTRODUCTION

Gears are used in most types of machinery and vehicles for the transmission of power. The design of gears is highly complicated involving the satisfaction of many constraints such as strength, pitting resistance, bending stress, scoring wear, and interference in involutes gears etc. The concentration is focused on spur gear sets which are used to transmit motion between parallel shafts because of the reason that out of the various methods of power transmission, the toothed gear transmission stands unique due to its high efficiency, reliable service, transmit large power, compact layout and simple operation. Gear design is an art as well as an engineering science. Designer based on his design principles and the knowledge about the gear, lays out a gear for a particular application. The community of engineers now knows that applying engineering principles alone cannot suggest a good design. It is, in many cases that the designer's expertise suggests good design. The problem with the conventional design procedure is that it gives out a single solution and the manufacturing is carried out on that basis. The most common situation is for a gear to mesh with another gear; however, a gear can also mesh with a non-rotating toothed part, called a rack, thereby producing translation instead of rotation. Also it is used in transmission system so it is known as speed reducer, which consist of a set of gears, shafts and bearing that the factory mounted in a lubricated housing. Spur gears have teeth that run perpendicular to the face of the gear.

The spur gear is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts. The spur gear is the first choice option for gears except when high speeds, loads and ratios direct towards other by using the topology optimization.

Figure 1: Typical Spur Gear upon mass reduction

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 behaviour. 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.

Benefits CAE using software:

- Design decisions can be made based on their impact on performance.
- Designs can be evaluated and refined using computer simulations rather than physical prototype testing, saving money and time.
- CAE can provide performance insights earlier in the development process, when design changes are less expensive to make.
- CAE helps engineering teams manage risk and understand the performance implications of their designs. Integrated CAE data and process management extends the ability to effectively leverage performance insights and improve designs to a broader community.
- Warranty exposure is reduced by identifying and eliminating potential problems.

When properly integrated into product and manufacturing development, CAE can enable earlier problem resolution, which can dramatically reduce the costs associated with the product lifecycle.

Topology optimization begins with an initial design, which is assumed to be the maximum physical extent of the component, and determines a new material distribution by changing the density and the stiffness of the elements in the initial design while continuing to satisfy the optimization constraints.

II. LITERATURE REVIEW

P.S. Mahar, R.P. Singh [1] reported that the total cost of a pumped water supply system includes the capital costs, the replacement costs, and the energy costs concomitant to the system's operation and pumping units. The optimization model assists to minimize the total annual cost of the pumping main and pump, satisfying the pump characteristic curve equations. This model determines the optimal diameter of pumping main with pump efficiency for a required discharge for an available diameter. Kanakoudis and Tolikas11developed a methodology that analyzes the possible preventive maintenance actions in a water supply system. These studies used techno economic analysis that takes into account all kinds of costs for repair and replacement of trouble causing parts of a network.

The requisite of a nonlinear optimization model is to obtain the diameter of the pumping main and optimal operating conditions of the pump to result in the minimum value of the total cost of the system in terms of head, efficiency, and discharge of the pump and system head requirement are nonlinear in nature. The developed model assist to select the optimal diameter for a particular pump of corresponding efficiency range and it can also be used to evaluate existing pumping systems to predict optimum time to repair or replace the pump. Apart from this, the model also assists for selecting a pump to result in the optimal operating conditions for the requisite values of pipe diameter, discharge, and pressure.

Tanweer S. Desmukh, V.K Gahlot [2] articulates that the flow in sumps is always complicated due to interference of individual intakes, especially when all the pumps are not working. Computational fluid dynamics (CFD) analysis is a tool that can be used to provide insight into flow phenomena and hydraulic designs of an intake structure. The undesirable flow conditions in the sump and its approach area is due to vibration, cavitation, rough running. Most of the studies have explored the following problems in pump as:

[i] Large scale turbulence generated in the approach to sump.

[ii] Vortices generated by flow past pier noses, screen gates and other structural members.

[iii] Vortices generated at fluid shear zones formed at discontinuous flow boundaries in the vicinity of the pump.

[iv] Vortices generated in the boundary layer at the sump walls and floor vorticity generated by the flow past the pump column.

The computational study was done for the pumping system of a cooling tower having three pumps.

The prototype model comprises of leading channel, approach channel, forebay, pump sump and intake. The result proved that by reducing the angle of expansion in the horizontal plane improves the flow conditions considerably.

Jong-Woong Choi [3] investigated the sump model to examine the flow structure around pump intake. In this study, flow uniformity according to the flow distribution in the pump intake channel is examined to find out the cause of vortex occurrence in detail. A multi-intake pump sump model with 7 pump intakes and a single-intake pump sump model are adopted for the investigation. Furthermore, effectiveness of anti-submerged vortex device (AVD) for the suppression of the vortex occurrence in a single pump intake, as well as in a multi-intake pump sump model has been examined by the methods of experiment and numerical analysis. The results show that most high value of flow uniformity is found at the inlet of pump intakes 3 and 5 in the multi-intake pump sump with 7 pump intakes. Strong submerged vortex can be successfully suppressed by AVD installation on the bottom of pump intake channel just below the bell mouth.

A. Rossetti, et al. [4] grail was to explore the possibilities of an innovative two-stage micro pump. They discern two main categories of pump, which are: displacement pumps, which exert pressure on a finite volume of fluid by one or more moving boundaries and dynamic pump, which continuously add energy to the fluid, increasing either its momentum or its pressure or both. Among the mechanical pumps, the Rotary Shaft Pumps (RSP) provides the integration of the impeller on the driving mechanical shaft, reducing the manufacturing costs and allows avoiding the problems related to the blade tip clearance leakage. Disk pumps (DPs), are centrifugal bladeless viscous pumps. The purpose of this research was the integration of a RSP and a DP in a two-stage micro pump and the resulting micro pump was expected to retain the features of both RSP and DP: high efficiency and head typical of RSP and the high stability of DP pumps. The resulting model was compact, durable in design and consisted of three components, namely; the shaft, the bearing and the casing. Afterwards CFD analysis and experimental tests were carried out for different rotational speeds. The result proved that the model was the best among the others when compared with others.

III. PROBLEM DEFINITION

In the automotive domain, companies strive to design light weight vehicles. Besides the saving in the material cost, the lighter design helps to reduce fuel consumption (consequently higher fuel efficiency) and better performance. The scope for this dissertation work shall be limited to reduction in mass by using ‘Topology optimization'. The target for mass reduction is aimed at 3% to 5% for the Spur Gear. Also the functional aspect of the gear needs to be taken care of during the assessment of mass. Manufacturing practices followed for the existing design cannot be overlooked while arriving at the feasible alternatives.

Generic Specifications of gears:

- Typical Material used: EN9/ EN19/ EN24/ 16MnCr5 / SCM415 / AISI 8620
- Type : Spur Gear
- Application for case Study: Automotive / Machine Tool

IV. Scope Of The Work

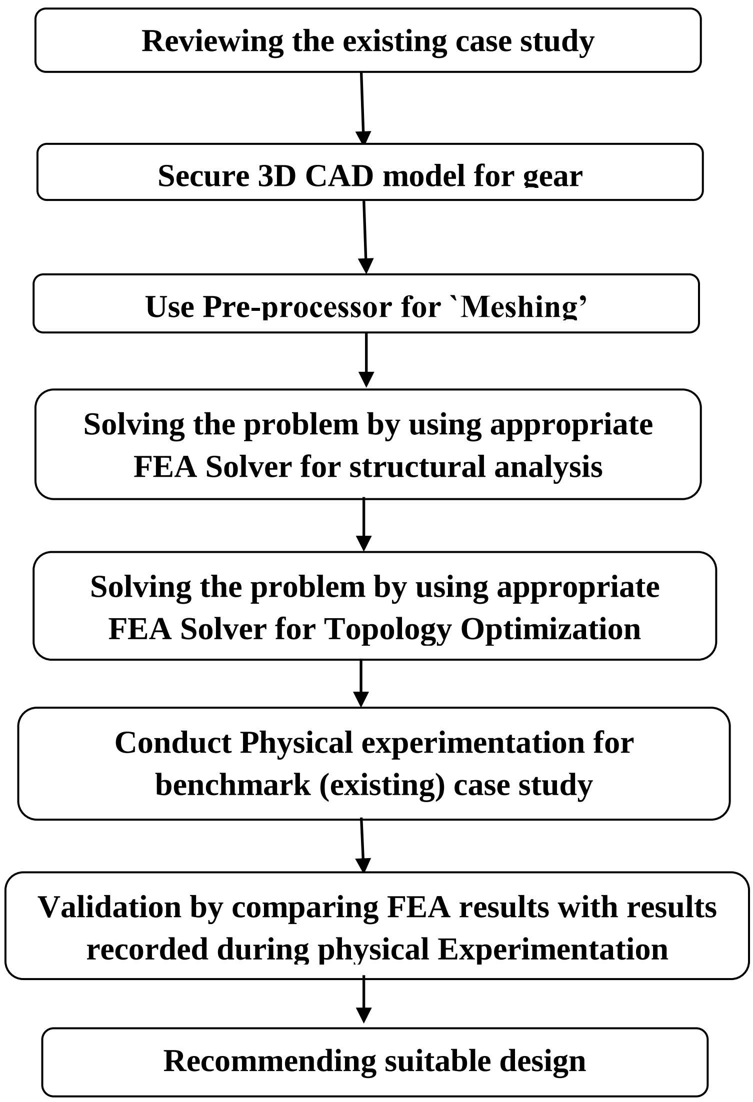
This work would consider engaging `Topology Optimization' as an Analytical tool for determining the scope of mass reduction in the existing design of the Gears. CAE tools like RADIOSS, Optistruct or suitable solvers shall be deployed to realize the results during the analysis phase of the work. The preliminary investigation over the results as secured during structural analysis of the `benchmark' component shall be validated for stiffness.

V. Objectives Of The Study

The following are the objectives of the study:

1. Study the existing component design
2. Benchmarking the stresses or the stress concentration over the existing geometry
3. Depending on these results, identify the area for weight Optimization
4. Revising the geometry for reducing the mass of the component
5. Conducting FEA/ CAE analysis for evaluating the new (revised) design
6. Recommending suitable design considering merits of the changes made
7. Validating the Design through alternative methodology (typically physical experimentation)

Proposed Flow Chart and Methodology



Test Setup for Physical Experimentation

Figure 2. Typical Test setup for Physical Experimentation for determining Stiffness

Figure shows the typical test setup 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.

VI. VALIDATION

In this project work we will be validating the stiffness of the component by comparing results obtained from experimentation with results of FEA analysis. The existing configuration shall be used for experimentation for reasons of availability and feasibility. Once validated with the existing configuration for the given performance parameter, the results shall be applicable for the recommended solution.

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