# Design and Optimization of Rear axle Gears for Commercial Vehicles

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## Abstract

***This research addresses responses of single stage hypoid rear axle gears to geometrical analysis and optimization. The entire analysis is done for single stage hypoid rear axle gears .The method used is Finite element modeling by using ANSYS 12.1 and analysis for which the inputs are obtained from gear standard ANSI/AGMA 2005-D03.The responses to geometrical analysis of hypoid gear caused by stress levels are determined .Components which are much affected by the running and loading conditions are identified. Taguchi optimization method is used for hypoid gear to increase efficiency and life of it. Finally conclusions based on results and recommendations which can be extensions of this research are also presented.***

**Keywords:** Hypoid gear, Geometrical analysis, optimization, ANSYS, AGMA, Taguchi

## 1. INTRODUCTION

Since the beginning of automobile history, rear axles have been used in rear wheel driven vehicles, both in passenger cars as well as in commercial vehicles. In general, tractor-trailer combinations or truck-trailers are used for this type of transport of goods.

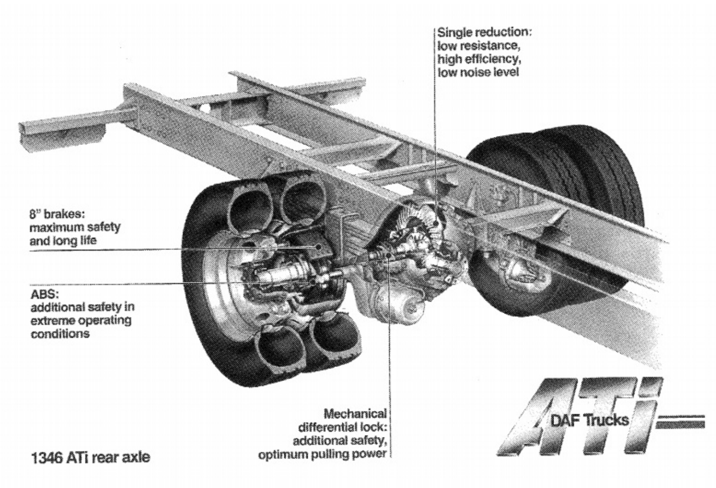


**Figure 1** Single Reduction Hypoid Rear Axle

Almost all commercial vehicle over 6 tonne are equipped with rear wheel drive, where the power is transmitted from the engine though a gearbox and drive shaft system to the rear axle of the vehicle. Generally, two types of rear axles are applied in rear wheel driven vehicles: the single reduction and the hub reduction rear axle. The single reduction rear axle consists of a spiral bevel or a hypoid gear. It is mostly used for typical long distance transport applications and it is most widely spread. The hub reduction axle is a two stage reduction axle, mostly consisting of a first stage spiral bevel gear reduction coupled with a planetary stage in each wheel hub.

## 2. DESIGN OF REAR AXLE GEARS

### 2.1 Calculation Method

Input Power (P) = 3 Kw [1]
Input rpm (N1) = 1200 [1]
Required Output rpm = 300[1]

Velocity Ratio = Input rpm / output rpm
= 1200 /300
= 4
Accuracy requirement = AGMA class Q11 [2]
Based on AGMA standard we have prepared the design and final outcome of the design values are:

**Table 1**: Hypoid Dimension sheet

| Sr No | Parameter | Value of parameter |
|---|---|---|
| 1 | Number of teeth | N = 32, n = 08 |
| 2 | Diametral pitch | Pd = 4.178 |
| 3 | Face width | FP = 1.840 in, FG = 1.600 in |
| 4 | Pinion offset | E = 1.500 in |
| 5 | Pressure angle Pinion concave | □1 = 15°30’ |
| 6 | Pressure angle Pinion convex | □2 = 24°30’ |
| 7 | Shaft angle | Σ = 90 |
| 8 | Cutter radius | rc = 4.500 in |
| 9 | Outer cone distance | AoG = 5.6518 in |
| 10 | Mean cone distance | AmP = 5.038 in, AmG = 4.846 in |
| 11 | Pitch diameter | d = 3.454 in, D = 10.771 in |
| 12 | Outer addendum | aoG = 0.103 in |
| 13 | Outer dedendum | boG = 0.375 in |
| 14 | Working depth | hk = 0.434 in |
| 15 | Whole depth | htP = 0.487 in, htG = 0.478 in |
| 16 | Outside diameter | do = 4.101 in, Do = 10.834 in |

## 3. CAD MODELING OF REAR AXLE GEARS

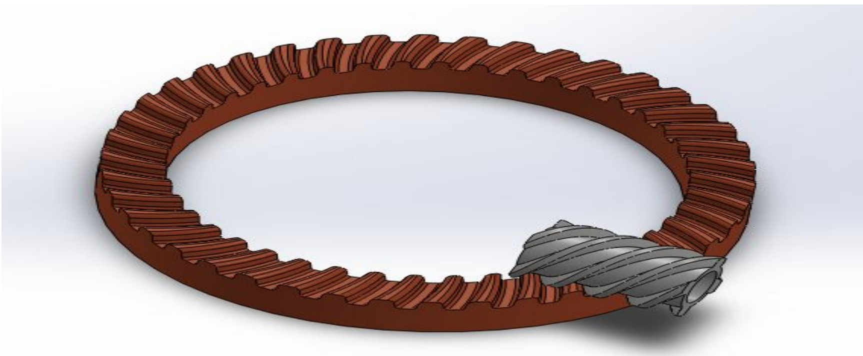

**Figure 2** Hypoid Gear and ring model

Established three-dimensional solid model of hypoid gear in Solid Work 2013 which is the modal of a car provided by the manufacturer [1]. The number of driving gear teeth is Eight; the number of driven gear teeth is thirty two. According to cutting machining principle of gear, establish the three-dimensional model of the driving and driven gear. After completion of the modelling, the virtual assembly of driving and driven gears completed.

## 4. FE ANALYSIS OF HYPOID GEAR IN ANSYS WORK BENCH

### 4.1 Result and Analysis

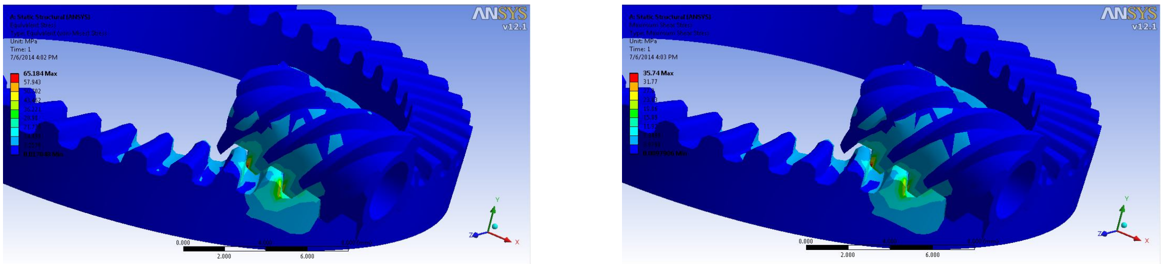

**Figure 3** Geometry of Hypoid pinion and gear using static analysis

Based on Static and Dynamic analysis result of Hypoid pinion and gears generated which is within limit and mention in below table

**Table 2**: Static and Dynamic analysis Hypoid pinion and Gears

| **Static** | **Max.** | **Min.** |
|---|---|---|
| Equivalent stress in Mpa | 65.184 | 0.01704 |
| Shear stress in Mpa | 35.74 | 0.0098 |
| **Dynamic** | **Max.** | **Min.** |
| Equivalent stress in Mpa | 64.186 | 0.0168 |
| Shear stress in Mpa | 35.193 | 0.0096 |

## 5. VALIDATION OF OPTIMIZATION RESULT

After experiment testing compare FE analysis and Experiment data:

**Table 3**: FE and Experimental result comparison

| **Sr No.** | **FE Analysis Results (MPa)** | **Experimental Results (MPa)** | **% Difference** |
|---|---|---|---|
| 1 | 64.186 | 63 | 3.35 |

Above Results shows that FE Analysis Results Closely matches with experimental Results. So we can say that FE Analysis is a good tool to replace costly and time consuming experimental work.

## 6. OPTIMIZATION OF HYPOID GEARS

Optimization is a mature field due to the extensive research that has been conducted over the last about 60 years. Many types of problems have been addressed and many different types of algorithms have been investigated. The methodology has been used in different practical applications and the range of applications is continuously growing[5].

### 6.1Outline of Optimization Process

The shape optimization of components in dynamic mechanical systems requires several quantities. These quantities are to be derived in all iteration of the optimization process. They result from various types of analyses and the optimization process is obtained by a combination of these analyses. Fig 1 outlines the stages with respect to the order in which they are carried out during the batch process. In the following section some basic aspects of each step of the process shown above are described in more detail in order to provide the reader with the necessary background for all analysis domains involved [3].

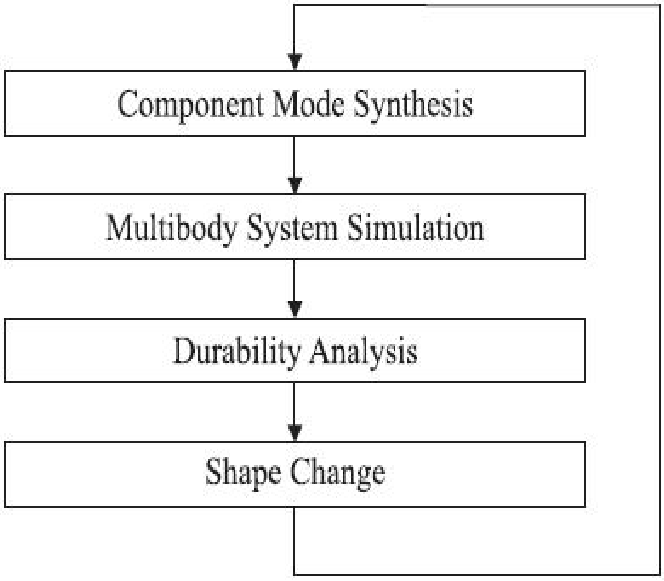


**Figure 3** Stages of Optimization Process

**Table 4** Optimization Table

| Sr No. | Offset Distance | Face Width | Shaft Angle |
|---|---|---|---|
| 1 | 25 | 21 | 75 |
| 2 | 25 | 20 | 74 |
| 3 | 25 | 19 | 73 |
| 4 | 26 | 21 | 74 |
| 5 | 26 | 20 | 73 |
| 6 | 26 | 19 | 75 |
| 7 | 27 | 21 | 73 |
| 8 | 27 | 20 | 75 |
| 9 | 27 | 19 | 74 |

**Table 5** Result Table of Optimization

| Sr No. | Offset Distance | Face Width | Shaft Angle | Stresses(Mpa) |
|---|---|---|---|---|
| 1 | 25 | 21 | 75 | 68.18 |
| 2 | 25 | 20 | 74 | 67.18 |
| 3 | 25 | 19 | 73 | 66.18 |
| 4 | 26 | 21 | 74 | 60.155 |
| 5 | 26 | 20 | 73 | 65.184 |
| 6 | 26 | 19 | 75 | 66.585 |
| 7 | 27 | 21 | 73 | 64.18 |
| 8 | 27 | 20 | 75 | 63.25 |
| 9 | 27 | 19 | 74 | 67.89 |

### 6.2 Minitab Results for Taguchi Analysis

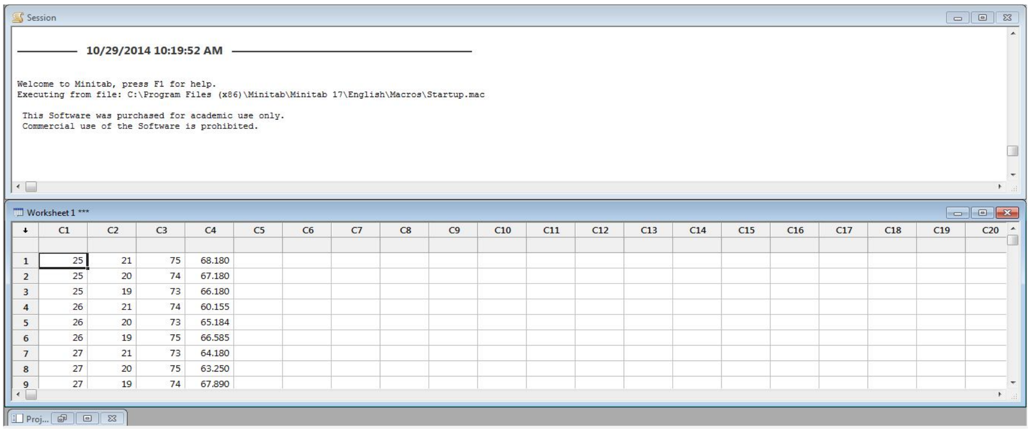

**Fig 4** Data added in Work sheet

### 6.3 Effect of Each Variable

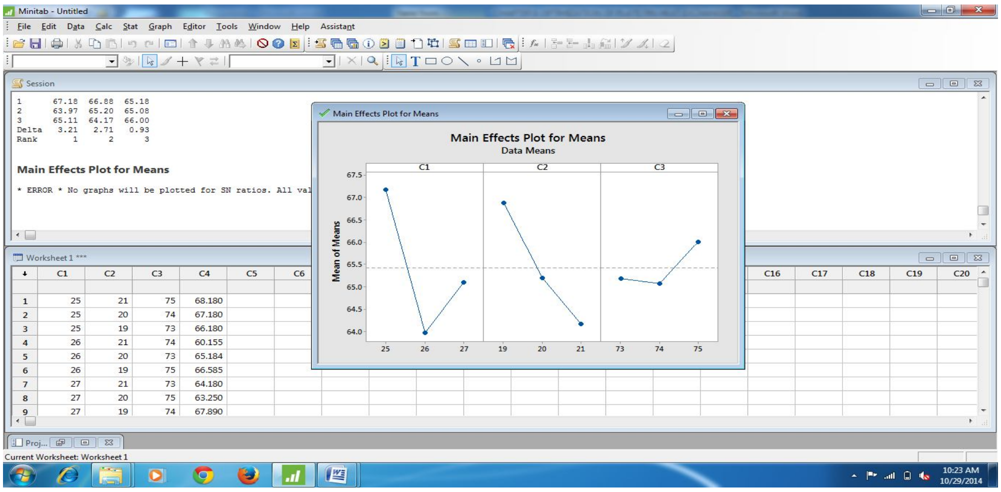


**Fig 5** Main effect plot for means

**Table 6** Best combination from Taguchi Analysis Table

| Sr No. | Offset Distance | Face Width | Shaft Angle | Stresses(Mpa) |
|---|---|---|---|---|
| 1 | 27 | 21 | 74 | 57.19 |

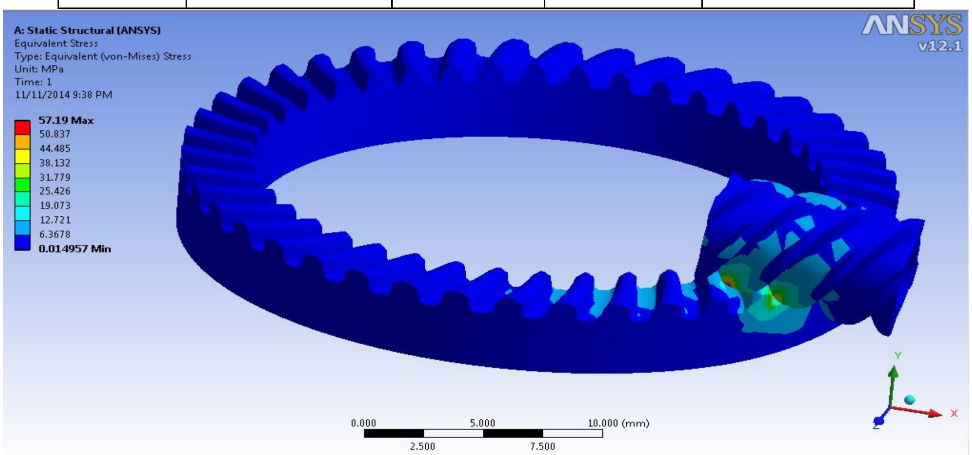


**Fig 6** Main effect plot for means Generated Von mises stress = 57.19 Mpa

**Table 7** Comparison of Minitab and Ansys result

| | Minitab Results(Mpa) | Ansys 12.1 Result |
|---|---|---|
| **Von mises** | **57.5** | **57.19** |

Above FE analysis result shows that Minitab optimization fairly matches with Ansys Results [4].

## 6. CONCLUSION

In this study, the responses of rear axle are determined under actual loading condition and find maximum effecting parameter on the stress level of hypoid gear like offset distance, face width and shaft angle.

From the results obtained in the analysis, the following can be concluded:

1. Dynamic FE analysis Results fairly match with Experimental testing results.
2. To study basic application and specification of Hypoid Gear.
3. Static FE analysis Result over or under estimate the actual condition
4. Optimization is performed based on Taguchi design. Taguchi design gives 57.5 MPA optimized value for von Misses stress which match with FE analysis Results.

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