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Topology Optimization of Spiral Bevel Gear for Differential

Mit Patel, Vinay Khatod, Amit Patel, Bharat Prajapati, Pavan Patel

Abstract: ***The Spiral Bevel gear used in differential should be enough stiff to resist the vibrations and stresses encountered during its operation. The gear must also have sufficient strength to bear the bending stresses occurring in the differential assembly in its course of operation. This research is typically focused in designing a differential gear with least weight and minimal stresses. The model of the gear is designed in the Solidworks version 2015 while its analysis is carried in ANSYS 14.5. The number of parameters and levels involved in designing are more; the number of probable models is too many. To choose the optimal parameter among the list of choices, TAGUCHI method along with Finite Element Analysis (FEA) is used. By application of TAGUCHI method, not only the time required to design all the probable models is reduced, but also the time required to analyze all the models is cut down. Orthogonal Array has been incorporated to change the parameters necessary for reducing the weight of the gear. To get the best possible model of gear, FEA is then performed on the designed models. This process not only saves production time, but also prevents material wastage and production cost.***

Keywords: FEA-DOE Hybrid Modeling, FEA Analysis, Gear Optimization, Parametric optimization, Weight reduction.

I. INTRODUCTION

Gears have always been an essential part of the shaft drive. Shaft drive includes components including bevel gears, shafts and bearing put together in a closed housing dipped in lubricating oil. Such an assembly is used in the transmission systems of automobiles. Depending upon the applications, shaft drives can be found in wide ranges in terms of speed ratios, sizes and capacities. Spiral bevel gears have curved teeth formed along spiral angle of 35^0 to the cone axis and pressure angle of 20^0. The teeth engagement in case of bevel gears is more gradual commencing from one end of tooth and across the entire length of the tooth resulting in smaller diameter of gear required for transmitting same load compared to straight teeth gear and quieter operation of the gears. In addition, simulation techniques as employed in the development of automobiles; it assists in identifying the meshing conditions of bevel gears.

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***** Correspondence Author
Mit Patel, Mechanical Department, Silver Oak University, Ahmedabad, India, mitpatel.me@yahoo.com
Vinay Khatod*, Automobile Department, Ganpat University, Mehsana, India, vkhatod92@gmail.com
Amit Patel, Automobile Department, Ganpat University, Mehsana, India, amp05@ganpatuniversity.ac.in
Bharat Prajapati, Mechatronics Department, Ganpat University, Mehsana, India, bdp01@ganpatuniversity.ac.in
Pavan Patel, Mechatronics Department, Ganpat University, Mehsana, India, psp01@ganpatuniversity.ac.in

II. FEATURES AND PROBLEMS OF BEVEL GEAR

Here, presenting the work for spiral gear of differential to reduce stress and material. This spiral gear is used for following specification.

Power:	6.5 kW
RPM:	930
Max Torque:	67 N.m
Gear Ratio:	14:1

Table 1 Material Specification of Cast Steel (Grade-40)

Properties	Grey cast iron
Density, ρ	7100 Kg m^3
Yield tensile strength	400 MPa
Ultimate strength	600 Mpa
Young modulus, E	120 GPa
Passion's ratio, υ	0.25

Force Calculation of given Gear

Data from drawing of bevel gear:

Face Angle δ = 54.35 °

Pressure Angle α = 20 °

Spiral Angle β = 30 °

Tangential force (F_t):

$$F_t = \frac{2T}{d_m} = \frac{2 * 67000}{189} = 709N$$

Axial force (F_x) by considering Concave surface:

$$F_x = \left(\frac{F_t}{\cos\beta}\right)\{(\tan\alpha * \sin\delta) + (\sin\beta * \cos\delta)\}$$

$$F_x = \left(\frac{709}{\cos 30}\right)\{(\tan 20 * \sin 54.35) + (\sin 30 * \cos 54.35)\}$$

F_x = 480.70 N

Radial Force,

$$F_r = \left(\frac{F_t}{\cos\beta}\right)\{(\tan\alpha * \cos\delta) - (\sin\beta * \sin\delta)\}$$

$$F_r = -\left(\frac{709}{\cos 30}\right)\{(\tan 20 * \cos 54.35) + (\sin 20 * \cos 54.35)\}$$

F_r = 5.38 N

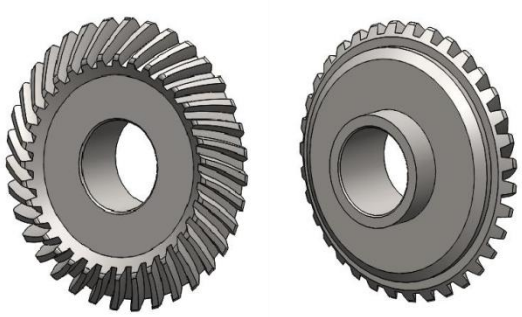

Fig. 1 3D Modeling of Spiral Bevel Gear

III. METHODOLOGY

TAGUCHI method an important subject in the experiments of statistical designing is an aggregation of various mathematical and statistical techniques employed for parametric optimization and analysis of problems where parameters of component are influenced by several variables and the aim is to optimize the parameters. TAGUCHI method is used to analyze the relation between quantitative experimental factors and response.

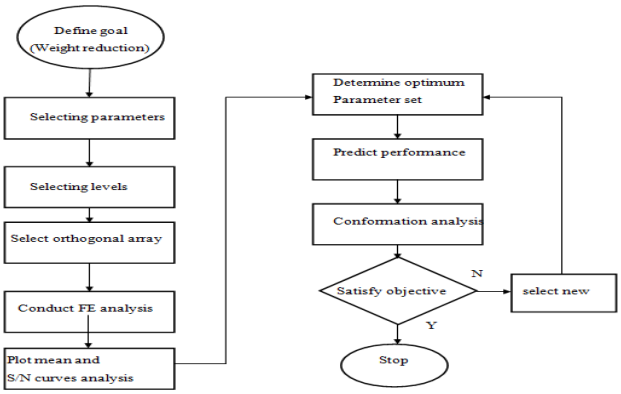

Fig. 2 Flowchart of Experiment

Experiments are planned according to Taguchi's L16 orthogonal array for diameter of circle, number of circle, pitch radius. It has 16 rows corresponding to the number of testes with 4 columns at four levels and 5 parameters. This orthogonal array is chosen due to its capability to check the interactions among factors.

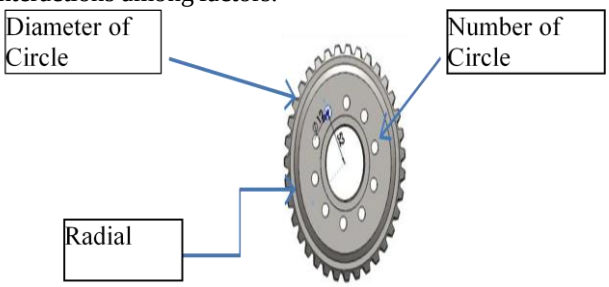

Fig. 3 Structure

The results obtained after the experiments are transferred in to a Signal to Noise (S/N) ratio. The three important categories of S/N ratio for quality characteristics are: (1) The Lower the Better, (2) The Higher the Better and (3) The Nominal the Better. For computing the S/N ratio of quality characteristics for Stress and Deflection; The Lower the Better category has been applied as per the equation:

$$SN = -10 \log_{10}[\frac{i=n}{i=1}(Y_i)^2]$$

Where,

S N= Signal to Noise ratio

n = Number of repetitions of experiment

Y_i = Measured value of quality characteristic

Table 2 Factors and their Levels

SR. NO.	FACTOR	Level-1	Level-2	Level-3
1	Diameter of Circle	10	12	14
2	Number of Circle	10	12	14
3	Radial Pitch	49	52	55

IV. METHODOLOGY

For each set of parameter, shear stress and deflection are measured using FEA in Ansys and the results of analysis are further analyzed using Minitab 17. The types of designed experiments as offered by Minitab are: Factorial, Response Surface, Mixture and TAGUCHI (robust). For all design types, the steps in Minitab to Create, Analyze and Graph an Experimental Design are similar. Minitab provides various analytical and graphical tools to understand the results as obtained by Finite Element Analysis (FEA) for analysis. The Lower the Better category of quality characteristic is used for calculating the S/N ratio for minimum Stress and deflection using Logarithmic Transformation of the Loss function.

Table 3 Experimental Results

Sr. No.	Diameter of Circle	Number of Circle	Radial Pitch	Weight	Stress	Displacement
1	10	10	49	6.29	64.26	0.0064
2	10	12	52	6.20	63.68	0.0065
3	10	14	55	6.09	65.65	0.0066
4	12	10	52	6.25	66.49	0.0067
5	12	12	55	6.14	61.87	0.0068
6	12	14	49	6.00	64.86	0.0073
7	14	10	55	6.21	66.22	0.0070
8	14	12	49	6.07	62.79	0.0076
9	14	14	52	5.92	69.82	0.0078

Table 4 Response Table for Mean Weight

Level	Diameter of circle	Number of circle	Radial Pitch
1	6.193	6.250	6.120
2	6.130	6.137	6.123
3	6.067	6.003	6.147
Delta	0.127	0.247	0.027
Rank	2	1	3

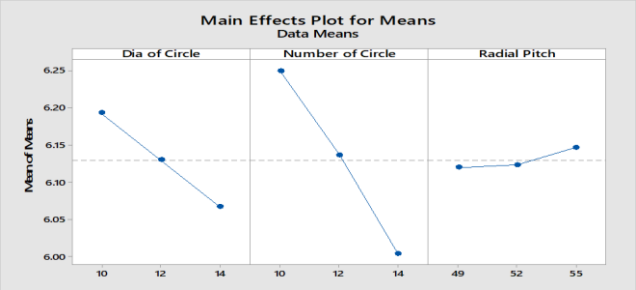

Fig. 4 Main Effect Plot for Mean Weight

Table 5 Response Table of S/N Ratio for Weight

Level	Diameter of circle	Number of circle	Radial Pitch
1	-15.84	-15.92	-15.73
2	-15.75	-15.76	-15.74
3	-15.66	-15.57	-15.77
Delta	0.18	0.35	0.04
Rank	2	1	3

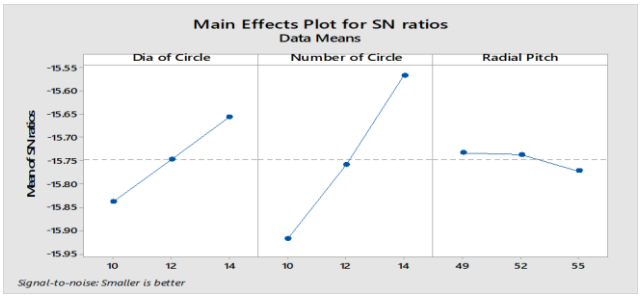

Fig. 5 Main Effect Plot of S/N Ratio for Weight

Table 6 Optimized Set of Parameter for Weight

Level	Diameter of Circle	Number of Circle	Radial Pitch
1	14	14	49

Table 7 Reference Table for Mean Shear Stress

Level	Diameter of circle	Number of circle	Radial Pitch
1	64.24	65.66	63.97
2	64.41	62.49	66.37
3	66.28	66.78	64.58
Delta	2.04	4.29	2.4
Rank	3	1	2

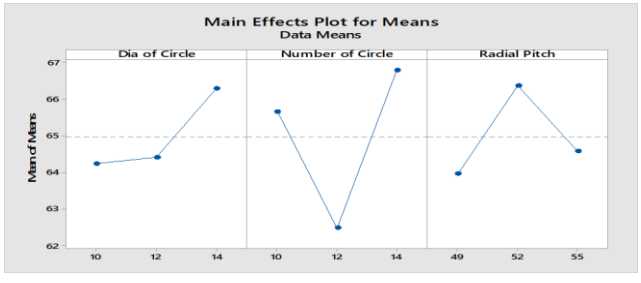

Fig. 6 Main Effect Plot for Shear Stress

Table 8 Response Table of S/N Ratio for Stress

Level	Diameter of circle	Number of circle	Radial Pitch
1	-36.15	-36.34	-36.12
2	-36.17	-35.92	-36.43
3	-36.42	-36.49	-36.2
Delta	0.26	0.57	0.31
Rank	3	1	2

Table 9 Optimized Set of Parameters for Stress

Level	Diameter of Circle	Number of Circle	Radial Pitch
1	10	12	49

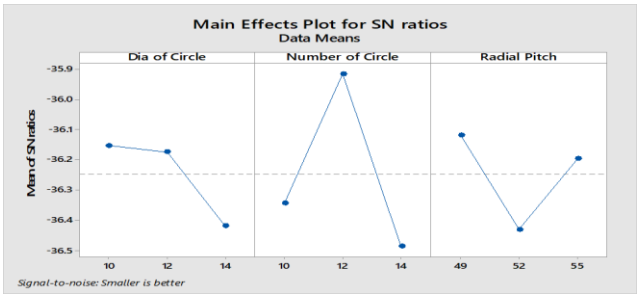

Fig. 7 Main Effect plot of S/N Ratio for Stress

Table 10 Response Table for Mean Deflection

Level	Diameter of circle	Number of circle	Radial Pitch
1	0.006267	0.006467	0.00686
2	0.006933	0.006967	0.00700
3	0.007467	0.007233	0.00680
Delta	0.001200	0.000767	0.00020
Rank	1	2	3

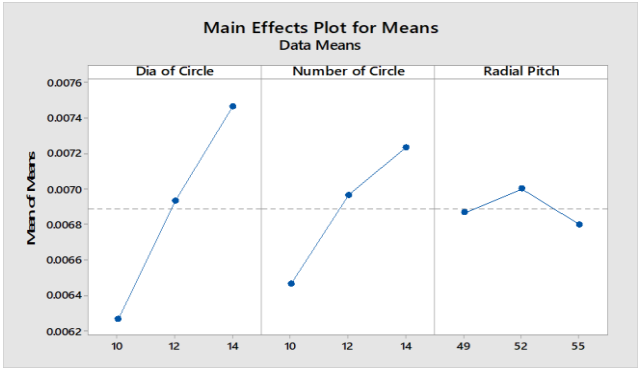

Fig. 8 Main Effect Plot for Mean Deflection

Table 11 Response Table of S/N Ratio for Deflection

Level	Diameter of circle	Number of circle	Radial Pitch
1	44.08	43.82	43.33
2	43.19	43.16	43.13
3	42.55	42.83	43.35

Delta	1.53	0.99	0.23
Rank	1	2	3

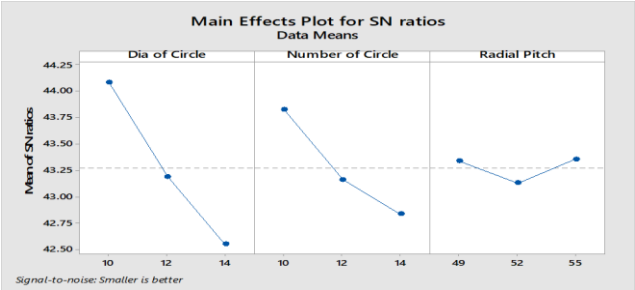

Fig. 9 Main Effect Plor of S/N Ratio for Deflection

Table 12 Optimized Ste of Parameters for Deflection

Level	Diameter of Circle	Number of Circle	Radial Pitch
1	10	10	55

Delta is difference of maximum value and minimum value. Delta value is maximum for diameter of circle and minimum for radial pitch. So the effect of diameter of circle is maximum and radial pitch is minimum on weight.

Table 13 Optimum Set of Parameters

Sr. No	Diameter of Circle	Number of Circle	Radial Pitch	Weight	Stress	Displacement
1	14	14	49	5.92	66.139	0.0080
2	10	12	49	6.25	65.142	0.0066
3	10	10	55	6.29	62.810	0.0064

V. RESULT AND DISCUSSION

The model of modified structure as per the dimension given in Table is created in solid works 2012.The model is then saved in IGES format which can be directly imported into ANSYS workbench. Optimized gear dimension are Diameter of circle is 14, number of circles are 14 and redial pitch is 49mm. total 9.09% weight reduce.

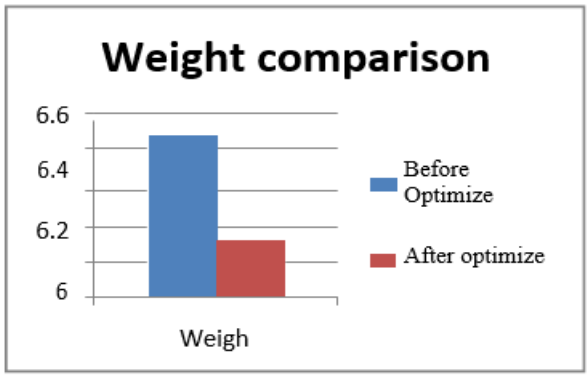

Fig. 10 Result Comparison

The TAGUCHI method based on Finite Element Analysis has effectively reduced the time and effort needed for assessing the design variables of implants. Using the analysis of S/N ratio, the desirable parameter combination for lowest possible weight of gear with permissible stress is found. After the analysis, 14 mm circle diameter, 14 numbers of circles and 49 mm radial pitch are the optimal parameters of gear for designing. Results obtained from FEA are confirmed using optimum Combination and is found that weight of gear has been cut off by 9.09%.

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AUTHORS PROFILE

Mit Patel, Assistant professor Silver Oak College of Engineering is currently pursuing his Ph. D. in Solar Distillation System. He has achieved the degree of Master of Engineering and Bachelor of Engineering in Mechanical Engineering. During his tenure as an Assistant Professor, he has guided many research projects at Graduation and Post-Graduation level. He has published his research papers in various National and International journals. Not only this, he has presented his research theories in number of Conferences.

Vinay Khatod, Assistant Professor at Ganpat University achieved Bronze Medal in Master of Engineering program from Gujarat Technological University in Mechanical Engineering (I. C. Auto.). He pursued his Bachelor of Engineering in Automobile Engineering from Indus University, Ahmedabad. During his Academics he has designed and fabricated an Engine running on Alternative Fuel to Preserve Environment from Harmful Pollutants. Also, he re-modeled F-Head Engine to increase its efficiency. He has guided number of Projects at Diploma and Bachelor's Level. He has published couple of scholarly articles in National and International Journals and Conferences. He has attended number of Seminars, Conferences and Workshops for continual Development and understanding future engineering inventions.

Amit Patel, Assistant Professor at B. S. Patel Polytechnic, Ganpat University completed his Graduation from Gujarat Technological University. During his teaching period he guide lots of diploma Automobile students for their projects, and also arrange number of automation workshop at college like ROBOTICS, ARDUNO ROBOTICS, IOT AND VEHICLE OVERHAULING. And also present three international paper in general and conference also.

Bharat Prajapati, Assistant Professor at Ganpat University achieved Master of Engineering from Gujarat Technological University in Mechanical Engineering (CAD/CAM). He pursued his Bachelor of Engineering in Mechcatronis Engineering from Hemchandracharya North Gujarat University, Patan. During his academic he conducted laser cutting experiment and find out the better cutting parameters. He has guided number of Projects at Diploma and Bachelor's Level. He has published couple of scholarly articles in National and International Journals and Conferences. He has attended number of Seminars, Conferences and Workshops.

Pawan Patel, Assistant Professor in Mechatronics Engineering Department Ganpat University, Mehsana. He pursued his Bachelor of engineering in Automobile engineering from Gujarat University, Ahmedabad. During his Academics he has guided number of Projects at Diploma Level.

He has attended number of Seminars, Conferences and Workshops for continual Development and understanding future engineering inventions, and also arrange workshop and expert sessions on various topics like Vehicle Overhauling, Vehicle Evaluation Techniques.