An Optimization Approach to Product Design in Modeling Gearbox Set

Pranab K Dan and Sourabh Mandol

***Abstract*— The paper presents a novel approach for estimating the load withstanding capacity of a Simpson gearbox utilizing Response Surface Methodology. Careful design planning and decision making increases the chances for successful implementation of the power transmission requirements and this paper aims to simplify the analysis process so that the target performance is achieved without testing multiple prototypes which is time consuming and complicated process.**

***Index Terms*— Planetary gearbox set, Computer Aided Design, Design optimization, Response Surface Methodology**

I. Introduction

The Simpson gearbox consists of two planetary gearset compounded together by a sun gear at the centre [1]. The gear set has three distinct gear drives in which the 3rd gear is the direct drive developed by American Engineer Howard Simpson [2]. Response Surface Methodology is a powerful statistical tool which can be implemented in empirical model building. Response Surface Methodology is an approach for process and design optimization which relay on a complete experimental design to be determined prior to the actual experimentation process occurs [3]. Moreover, by careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. Since its introduction by Box and Wilson [4], The RSM has been used as one of the most effective tools for process and product development which consists of statistical and numerical/mathematical optimization techniques for examining the relationship between one or more response variables and a set of quantitative experimental variables or factors.

Amongst the classical methods of implementing Response Surface Methodology in product and process design, the Box-Behnken design method is the most popular and it is widely used by researchers working in the field of product design and development. Box–Behnken design is one of the significant statistical methods used in the design of experiments. The designs are economically alternative to the central composite design of Response Surface Methods of design optimization. Box–Behnken designs are generally used to analyze the factor at three levels. [5] indicated that the Box– Behnken design does not contain fractional factorial design and the results can be interpreted easily. In a system, the relationship established between the system variables and the corresponding responses are :

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$$f_{th} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i + \cdots + \varepsilon \quad \ldots\text{(i)}$$

where f_{th} represents thrust force, b_0, b_1, b_2,...,b_i are the coefficients that need to be calculated from the regression model., x_1, x_2,..., x_i represent the predictor variables used in the experiments, and ''ε'' shows the error related to the model in calculating the coefficients. The application of Box-Behnken design in different mechanical property analyze can be seen in the study conducted by [6] where the influence of thrust force on drilling glass fiber reinforced polypropylene (GFR/PP) has been examined.

II. METHODOLOGY OF EXPERIMENTATION

The design and assembly was modeled in Solidworks software package utilizing the design toolbox. The assembly was analyzed in ANSYS for obtaining the response and the recorded data was exported to Minitab software package for carrying out the Response Surface Methodology for obtaining results. For experimentation purpose, the specified data was taken into consideration as given in *table 1*.

Table 1: Details of gear members in gearbox

Gear Member	No. of Teeth	Module	Material	Standard
Sun gear	24	1	Structural Steel	ISO
Planet gears	12	1	Structural Steel	ISO
Ring gears	48	1	Structural Steel	ISO

The gear set was analyzed utilizing the design table from the Box-Behnken design considering the input factors: moment, temperature and Face width of sun gear. The Safety factor value based on the yield strength of the material was considered as response. Table 2 emphasizes the overall design table with response data, taken into consideration for the experimentation. The data in table 2 was considered for analysis in the minitab software package utilizing the Response Surface method and Box-Behnken

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design was selected for the same.

Table 2: Design Table for Experimentation

SERIAL NUMBER	MOMENT (Nm)	TEMPERATURE (°C)	FACE WIDTH (mm)	SAFETY FACTOR
01	15.0	30	45	4.22680
02	22.5	45	45	1.47020
03	30.0	30	45	4.22680
04	15.0	45	30	1.74880
05	15.0	60	45	0.88986
06	22.5	30	60	4.40700
07	22.5	60	60	0.93751
08	15.0	45	60	1.54850
09	22.5	30	30	4.97390
10	30.0	60	45	0.88986
11	30.0	45	60	1.54390
12	22.5	45	45	1.47020
13	22.5	45	45	1.47020
14	30.0	45	30	1.74330
15	22.5	60	30	1.50880

The 3D CAD model of Simpson three speed gearbox (shown in *figure 1*) has been designed in SOLIDWORKS 2014 software package.

Fig 1: Screenshot of the 3D CAD model developed in solidworks

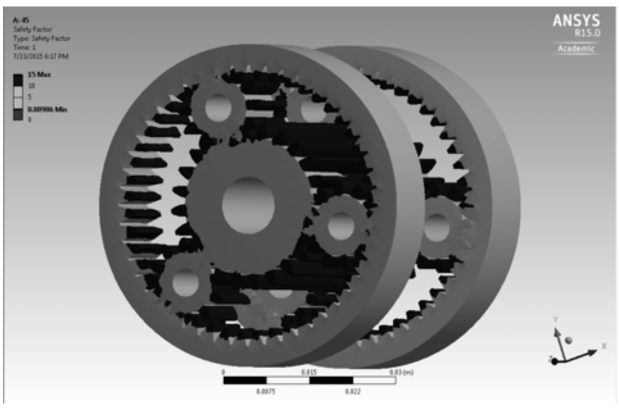

Fig 2: ANSYS simulation screenshot for obtaining safety factor

III. RESULTS AND DISCUSSION

Utilizing the data in table 1, the RSM method was applied for analysis. Box-Behnken design yielded the following results (exported from Minitab Software interface):

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.123839	99.74%	99.26%	95.79%

Table: 3 Coded Coefficients

TERM	EFFECT	COEF	SE COEF	T-VALUE	P-VALUE	VIF
Constant		1.4702	0.0715	20.56	0.000	
Moment	-0.0025	-0.0013	0.0438	-0.03	0.978	1.00
Temperature	-3.4021	-1.7011	0.0438	-38.85	0.000	1.00
Face Width	-0.3845	-0.1922	0.0438	-4.39	0.007	1.00
Moment*Moment	-0.2225	-0.1113	0.0644	-1.73	0.145	1.01
Temperature*Temperature	2.3988	1.994	0.0644	18.61	0.000	1.01
Face Width*Face Width	0.5744	0.2872	0.0644	4.46	0.007	1.01
Moment*Temperature	0.0000	0.0000	0.0619	0.00	1.000	1.00
Moment*Face Width	0.0004	0.0002	0.0619	0.00	0.997	1.00
Moment*Temperature	-0.0022	-0.0011	0.0619	-0.02	0.987	1.00

Regression Equation in Un-coded Units

Let, Moment = M, Temperature = T, Face Width = F;
Then, the obtained regression equation can be stated as:

$$Safety\ Factor = 19.52 + 0.0888\,M - 0.5929\,T - 0.1275\,F - 0.00198\,M^2 + 0.005331\,T^2 + 0.001276\,F^2 \quad \ldots \text{(ii)}$$

Fits and Diagnostics for Unusual Observations:

Obs	Safety Factor	Fit	Resid	Std Resid	
7	0.9375	1.0624	-0.1249	-2.02	R
9	4.9739	4.8490	0.1249	2.02	R

R Large residual

Thus, from the above we see that a regression equation has been generated in which the predictive Residual square (R^2) value and the adjusted R^2 value are close. The value is close to 100 interpreting a very high predictive ability. For all the factors as well as interaction, the Variance Inflation Factor (VIF) are all close to one, interpreting that all the factors are not correlated with one another.

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The best design is predicted as follows:

Table 4: Best Design Prediction

Response	Goal	Lower	Target	Upper Weight	Importance
SAFETY FACTOR	Maximum	0.88986	4.9739	1	1

Thus, interpreting the results, we see that a safety factor of 4.849 is obtained by setting the input parameters of moment = 22.4242 Nm, Temperature = 30^{o}C and Face width = 30mm. This is the highest safety factor value and thus indicates an optimized design point. Verifying the results in ANSYS by inputting the same values we get a safety factor value of 4.9742 which is the highest value obtained so far, thus confirming the validity of the test *(figure 3)*.

Fig 3: Optimized design

IV. CONCLUSION

The results emphasizes that an optimal design can be reached from this outcome and thus, the mathematical model will be useful in studying the effects of the input factors on the response. This will help designers build successful products complying with the required specification without utilizing classical mechanical failure theories for analyzing the same system which is time consuming and complicated.

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