International Journal of Advance Research in Science and Engineering
Volume No.06, Special Issue No.(02), December 2017
www.ijarse.com
IJARSE
ISSN: 2319-8354

Taguchi Method - A Tool for Total Product Design in Concurrent Engineering

Pankaj Kumar Chauhan[1], Prabhat Ranjan[1]

[1]*Assistant Professor, Department of Mechanical Engineering, G.L.B.I.T.M Greater Noida, India.*

ABSTRACT

Productivity is of major economic significance in the current competitive global market. Due to growing costs and globalization of the marketplace, improvements in productivity require the creation of a reliable design in the shortest possible time through use of concurrent engineering principles. This is particularly important for designing complex engineering systems that require a large investment of resources, have long life cycles, and in which multidisciplinary working groups are involved. The present work aims to understand the robust design techniques that can be used in concurrent product design to enhance design productivity during research and development. The robust design techniques are used to evaluate quickly the design alternatives and to develop comprehensive, robust, flexible, and modifiable top-level specifications. A product that is robustly designed will provide customer satisfaction even when subjected to extreme conditions on the manufacturing floor or in the service environment. Taguchi method is an important tool which is used in present work to demonstrate the robust design technique for example of hydrodynamic journal bearing performance optimization.

***Keywords:* Concurrent engineering (CE), Product Design, Robust Design Technique, Taguchi Method, Hydrodynamic journal bearing.**

I INTRODUCTION

Concurrent engineering is defined as a systematic approach to the integrated simultaneous design of products and processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost schedule, and user requirements. With the increased level of integration of design and manufacturing, problems have arisen that are beyond traditional solution methodologies.

Productivity is of major economic significance in the current competitive global market. Due to growing costs and globalization of the marketplace, improvements in productivity require the creation of a reliable design in the shortest possible time through use of concurrent engineering principles. The present work aims to understand the robust design techniques that can be used in concurrent product design to enhance design productivity during research and development.

The objective of this work is the creation of a reliable and robust design through concurrent systems analysis in the shortest possible time. Improvements in industrial productivity are strongly related to improvements in design productivity. To improve the design productivity, we are interested in examining the means for developing initial design specifications that could accommodate the changes that a design is subject to during the entire design process or a product's normal life.

Specially, we address for enhancing design productivity in designing complex systems concurrently by increasing design knowledge in the early stages of design. Increasing design knowledge facilitates making early decisions more *comprehensive* based on better information. It is widely accepted that the *quality* of a design can be improved if downstream information is used when making up-stream decisions. This calls for more effort to be invested earlier in a system realization time-line.

The benefits of introducing the concurrent engineering analyses using robust design technique in the early stages of design are schematically illustrated in Figure 1.1

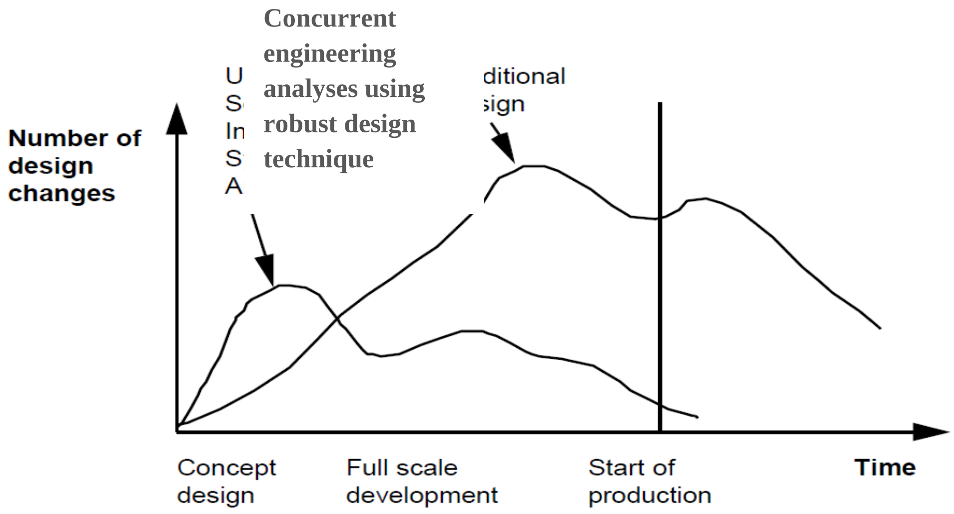


Figure 1.1 - Concurrent engineering analyses using robust design technique forreducing the no. of design change

In a traditional design process, sophisticated analysis tools are used by specialists in individual disciplines and in the later design stages. CE provides an initiative of the product development community that has the goal of reducing the length of the product design and manufacturing cycle time by allowing teams of engineers to develop design modules concurrently from their perspectives. This work aims to understand one of the methodological approaches

(*Techniques* agent of 7Ts) that could support the use of high fidelity analyses in the early stages of designing complex systems.

From some common technique of CE, the present work aims to understand the robust design techniques that can be used in concurrent product design to enhance design productivity during research and development. The robust design techniques are used to evaluate quickly the design alternatives and to develop comprehensive, robust, flexible, and modifiable top-level specifications. *Taguchi method* is an important tool which is used in present work to demonstrate the robust design technique for example of hydrodynamic journal bearing performance optimization.

The objective of the research contained in this work is to investigate the application of Taguchi's method to the design of hydrodynamic journal bearing performance optimization. The goal is to be able to predict the optimum values for the system parameters - that is, the values that will satisfy the prescribed engineering requirements so that the system is robust (insensitive to the causes of variation of the desired response). Analytical models and design guides are used to simulate the necessary "experiments".

II. LITERATURE REVIEW

The concept of concurrent engineering was first proposed as a means to minimize the product development time, since than many interpretation of concurrent engineering have emerged in literature. Today concurrent engineering is much more encompassing. Concurrent engineering is a systematic approach to the integrated concurrent design of the product and their related process including manufacturing and support. This approach is intended to cause the developer from outset to consider all the elements of product life cycle from conception to disposal including quality, cost, schedule and user requirements. (Winner Et Al, 1992)

Fewer design changes and shorter lead time both equate to quicker response to customer needs. However, there are even better reasons for using concurrent engineering that is lower rejection and scrap rate on the shop floor instantaneously improve profit. (25) In response to the increasing pressures from global competitiveness there is a growing investment of effort to enhance design productivity by implementing principles embodied in concurrent engineering (1-3)**.** Various developments in improving design productivity are more or less associated with the enablers for seven influencing agents (7Ts) of CE (talents, tools, task, teamwork, technology, techniques, and time) as defined by Prasad (3). From some common technique of CE, the present work aims to understand the robust design techniques that can be used in concurrent product design to enhance design productivity during research and development.

Hydrodynamic journal bearings are typical critical power transmission components that carry high loads in different machines (Bouyer and Fillon, 2011). Therefore, it is essential to know the expected operating conditions of the bearings to gain high performance and avoid failure at the initial stage. The available predictive techniques for bearing analysis can be categorized into rigorous and rapid techniques (Campbell et al., 1968; Martin, 1983;

Majumdar, 1994). The use of numerical methods involves very detailed analysis of bearing geometry but tend to be expensive in skill and time and lack of accuracy in the determination of the overall performance of sliding bearings (Reddyhoff et al., 2005; Mahieux, 2005; Podevin et al., 2005; Arghir et al., 2003; Sahlin et al., 2005; De Kraker et al., 2007; Rezaei et al., 2009). Traditionally, the classic one-factor-at-a-time experimental approach had been applied to evaluate journal bearing behaviour by changing one variable while the other factors are constant. This technique is laborious and time consuming and seldom guarantees the determination of optimal conditions (Kasolang and Dwyer-Joyce, 2008; Survase et al., 2006; Deligant et al., 2011; Dimitrios et al., 2011).

The existing literature shows that most authors concerned with the study of the pressure of thin film by using the one-factor-at-a-time technique (PawelKrasowski, 2011; Nuruzzaman et al., 2010; Sharma and Pandey, 2009; Stolarski, 2010). (PawelKrasowski, 2011) has simulated the oil-film pressure distribution for laminar and steady oil flow in journal bearing. (Nuruzzaman et al., 2010) have calculated the pressure distribution and load capacity of journal bearing using finite element method. Their results were compared with analytical results. In another studies (Sharma and Pandey, 2009; Tsuneo Someya, 2003; Valkonen, 2010), experimental investigations were performed based on one-factor -at-a-time procedure to discuss the development of pressure profiles in the oil-film of slide journal bearing. These studies revealed that without considering the effects of other factors led to incorrect conclusions, due to the presence of interactions between the factors. In another work, (Stolarski, 2010), the inconsistency of the pressure profiles from experimental study with the theory results and has shown insufficient agreement.

These limitations of one-factor-at-a-time technique can be overcome by using Taguchi Robust design approach. The objective of the research contained in this work is to investigate the application of Taguchi's method to the example for design of hydrodynamic journal bearing performance optimization. The bearing performance evaluation needs so many experimental runs to find the characteristics of the bearing. In order to reduce the number of experimental runs, we have chosen the Taguchi technique [10], which suggested the experimental robust design techniques [7–9] used for achieving the consistency of performance.

III PROPOSED WORK

3.1 example Problem Description

A journal bearing on an1800 rpm steam turbine rotor supports a gravity load of 17 kN. The journal diameter has been established as 150 mm in order to provide sufficient shaft stiffness. A forced feed lubrication system will supply SAE 10 oil, controlled to an average film temperature in range of 65- 75 ^{0}C. Proportion of *L/D* = 1/2 is desired for convenient use of the design charts. Design engineer is interested to optimize the effect of minimizing combinations of oil flow and power loss with maximization of minimum oil film thickness under Trumpler design constraints using Taguchi robust design approach and overall evaluation criteria.

3.2 Problem Solution

3.2.1 Decisions and Assumptions

i. The 1-2 MPa range of representative unit sleeve bearing loads given for steam turbine in design table is selected.

ii. Bearing parameters are selected to operate in optimum range.

iii. The lubricant is supplied to the bearing at atmospheric pressure.

iv. The entire heat generated in the bearing is carried away by the oil.

3.2.2 Design Analysis

Given *L/D* = 1/2

D = 150 mm

Hence L = D/2 = 150/2 =75 mm

N =1800 rpm = 1800/60 = 30 rps

W = 17 kN

By P = W/LD = $\frac{17x1000}{75x150}$ = 1.511 MPa

Based on decision 1, where P = 1-2 MPa

Evaluating for whole range of P at three levels

P = 1 MPa, 1.511 MPa, 2 MPa

So that W at three levels can be evaluated under design constraints

W = 11.25 kN at P = 1 MPa by P = W/LD

W = 17 kN given, and P = 1.511 MPa calculated above

W = 22.50 kN at P = 2 MPa by P = W/LD

Average film temperature = 65 – 70 ^{0}C

Evaluating for whole range of temperature at three levels

T = 65 ^{0}C, 70 ^{0}C, 75 ^{0}C

From design chart dynamic viscosity μ at three levels of temperature

At T = 65 ^{0}C, μ = 11 mPa-s

At T = 70 ^{0}C, μ = 9.25 mPa-s

At T = 75 ^{0}C, μ = 7.76 mPa-s

At *L/D* = 1/2, the optimum operating range is between S = 0.037 and S = 0.35

At these ranges by Sommerfeld number equation,

$$S = \left(\frac{r}{c}\right)^2 \left(\frac{\mu N}{P}\right)$$

And by clearance range equation $0.001r \leq c \leq 0.002r$

Clearance range is 0.05 to 0.12 mm

Assuming factor of safety = 2 as per Trumpler design constraints

Evaluating for whole range of C at three levels

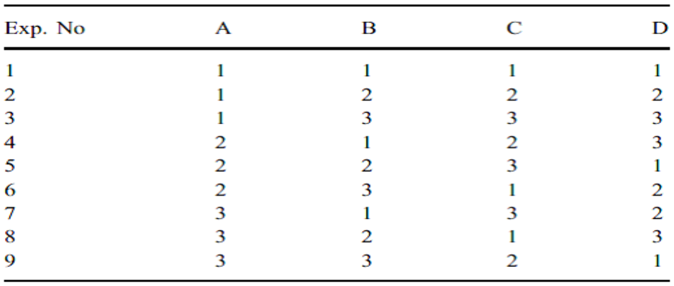
C = 0.074 mm, 0.0895 mm, 0.105 mm

3.3 Optimization Process

3.3.1 Selection of Factor Levels and Orthogonal array

Three factors each at three levels are chosen for optimization. And L_9 orthogonal array is chosen for performing analyses. Which are as under:

Table 3.1 - L_9 orthogonal array



Exp. No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

As there are four factors in the Table 3.1 and we are analysing three factors so fourth column of factor D is eliminated. Three factors and there levels are shown in Table 3.2 as under:

Table 3.2 – Selection of Factor and Levels

Factor	**Assignment**	**Levels**		
		1	**2**	**3**
Dynamic viscosity (μ) mPa-s	A	11	9.25	7.76
Clearance (C) mm	B	0.074	0.0895	0.105
Unit load (P) MPa	C	1	1.511	2

3.3.2 Analyses

Design engineer is interested to optimize the effect of minimizing combinations of oil flow and power loss with maximization of minimum oil film thickness under Trumpler design constraints using Taguchi robust design approach and overall evaluation criteria.

Table 3.3 – Individual response, OEC, and S/N ratio for corresponding trial

Exp. No	A	B	C	Response values			OEC	S/N ratio
				Min oil film thicknessh 0 (mm)	Friction Power loss H (watt)	Oil flow rate Q (mm^3/s)		
1	11	0.074	1	0.0313	1356.1	60022.4	61.1	35.71
2	11	0.09	1.511	0.0242	1343.1	78850.4	31.6	30.00
3	11	0.105	2	0.0203	1368.3	96629.2	8.3	18.42
4	9.25	0.074	1.511	0.0222	1295.3	64188.2	38.1	31.62
5	9.25	0.09	2	0.0187	1284.9	81652.0	19.5	25.79
6	9.25	0.105	1	0.0275	989.7	92943.7	65.6	36.34
7	7.76	0.074	2	0.0175	1233.0	66467.2	28.9	29.20
8	7.76	0.09	1	0.0250	929.9	78513.6	71.6	37.10
9	7.76	0.105	1.511	0.0195	985.7	96946.4	40.6	32.17

After getting the three response values (oil film thickness, friction power loss, and oil flow rate), response are converted into single response by overall evaluation criteria (OEC). After that S/N ratio are calculated. Individual response value, combined OEC, and S/N ratio are showed in Table 3.3.

3.3.3 Analyses of Mean (ANOM)

Mean of each factor at each level is known as analyses of mean. Factor levels with maximum S/N ratio are chosen as optimum levels. After that ANOVA (analyses of variance) is performed. ANOM result is shown in Table 3.4 as below.

Table 3.4 - ANOM result

Factor	Assignment	Levels		
		1	2	3
Dynamic viscosity (µ) mPa-s	A	28.04301	31.24912	32.82697
Clearance (C) mm	B	32.17893	30.96224	28.97793
Unit load (P) MPa	C	36.38695	31.26419	24.46795

By ANOM result optimized Factor Level are A_3 B_1 $C_{1.}$

3.3.4Analyses of Variance (ANOVA)

Analysis of variance is performed and results are shown in Table 3.5 as below. Factor C (unit load) is of 76.93 % in optimized performance of minimizing combinations of oil flow and power loss with maximization of minimum oil film thickness under Trumpler design constraints using Taguchi robust design approach and overall evaluation criteria with 40 % weight age to oil film thickness with maximization objective, 40% weight age to friction power loss with minimization objective and 20% weight age to oil flow with minimization objective.

Table 3.5 - ANOVA Result

Factor	**Sum of Square**	**Degree of freedom**	**Estimate effect**	**Mean sum of square**	**F ratio**
Dynamic viscosity (μ) mPa-s	35.66	2	12.79 %	17.83	2.743
Clearance (C) mm	15.66	2	5.62 %	7.83	1.205
Unit load (P) MPa	214.49	2	76.93%	107.245	16.5
Error	13	2		6.5	
Total	278.81	8			

3.4 RESULT

As per result of the robust design concluding result are as under:

- Factor C (Unit load) contribute highest 76.93% in optimization performance of maximization of oil film thickness with 40% weight age, minimization of friction power loss with 40% weight age and minimization of oil flow with 20% weight age.
- At 95% confidence level value of F (2,2) statistics is 19. This shows that modal is acceptable with 95% confidence level.
- At this level frictional power saving and saving in pumping power due to optimized oil flow by supplying pump under the achievable minimum oil film thickness and other design consideration can be achieved.
- By varying the weight age given to objective function corresponding optimized level with level of confidence can be calculated.

IV CONCLUSION

In a traditional design process, sophisticated analysis tools are used by specialists in individual disciplines and in the later design stages. CE provides an initiative of the product development community that has the goal of reducing the length of the product design and manufacturing cycle time by allowing teams of engineers to develop design modules concurrently from their perspectives. This work aims to understand one of the methodological approaches (*Techniques* agent of 7Ts) that could support the use of high fidelity analyses in the early stages of designing complex systems. From some common technique of CE, the present work aims to understand the robust design techniques that can be used in concurrent product design to enhance design productivity during research and development. The robust design techniques are used to evaluate quickly the design alternatives and to develop comprehensive, robust, flexible, and modifiable top-level specifications. *Taguchi method* is an important tool which is used in present work to demonstrate the robust design technique for example of hydrodynamic journal bearing performance optimization.

As per result of the robust design for the example of hydrodynamic journal bearing used in present work concluding result are as under:

- Factor C (Unit load) contribute highest 76.93% in optimization performance of maximization of oil film thickness with 40% weight age, minimization of friction power loss with 40% weight age and minimization of oil flow with 20% weight age.
- At 95% confidence level value of F (2,2) statistics is 19. This shows that modal is acceptable with 95% confidence level.
- At this level frictional power saving and saving in pumping power due to optimized oil flow by supplying pump under the achievable minimum oil film thickness and other design consideration can be achieved.
- By varying the weight age given to objective function corresponding optimized level with level of confidence can be calculated.

REFERENCES

1. Montgomery DC Design and analysis of experiments, 5thedn. John Wiley & Sons Inc, New York (2001).
2. A. KhaliliMeybodi, A. Assempourand and S. Farahani, A general methodology for bearing design in non-symmetric T-shaped sections in extrusion process, *Journal of Materials Processing Technology 212,2011, 249-261.*
3. Andras Z. Szeri, Composite-film hydrodynamic bearings, International Journal of Engineering Science (2010); 48: 1622-1632.
4. C.W. Wu, G.J. Ma, Abnormal behaviour of a hydrodynamic lubrication journal bearing cause by wall slip, *Tribology International 38,2005, 492-499.*
5. R. I. Winner, J. P. Pennell, H. E. Bertrand and M. M. G. Slusarczuk, The Role of Concurrent Engineering in Weapons System Acquisition,*IDA Report R-338, Institute for Defense Analysis, Alexandria, Virginia, 1988.*
6. K. Hutchison and D. R. Hoffman, Implementing Concurrent Engineering,*High Performance Systems*, 1990, 40-44.
7. B. Prasad, Concurrent Engineering Fundamentals: Integrated Product Development, 2,1986.
8. M. S. Phadke, *Quality Engineering Using Robust Design*, Prentice Hall, Englewood Cliffs, New Jersey, 1989.
9. N. P. Suh, *Principles of Design,* Oxford University Press, Oxford, U.K., 1990.

10. A. Khuri and J. A. Cornell, *Response Surfaces: Designs and Analysis*, Marcel Dekker Inc., New York, 1987.
11. F. Mistree, O. F. Hughes and B. A. Bras, "The Compromise Decision Support Problem and the Adaptive Linear Programming Algorithm", *Structural Optimization: Status and Promise*, edited by M. P. Kamat, AIAA, Washington, D.C., 1993, pp. 247-286.
12. G. E. P. Box and N. R. Draper, *Empirical Model-building and Response Surfaces*, Wiley Series in Probability and Mathematical Statistics, John Wiley & Sons, New York, 1987.
13. W. Chen, J. K. Allen, D.P. Schrage, and F. Mistree, Statistical Experimentation Methods for Achieving Affordable Concurrent Design, AIAA Journal, 35 (5), May 1997, 893-900.
14. G. Taguchi, Off-Line and On-Line Quality Control Systems, *Proceedings of the International Conference on Quality Control, Tokyo, Japan, 1978*.
15. W. Chen, J. K. Allen, K-L. Tsui, and F. Mistree, A Procedure for Robust Design" *Transaction of the ASME Journal, Journal of Mechanical Design, 118, 1996, pp. 478-485.*
16. W. Chen, A Robust Concept Exploration Method for Configuring Complex Systems, *Ph.D. Dissertation, Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia, 1995.*