OPTIMIZATION OF OPERATING PARAMETERS OF JOURNAL BEARING BY TAGUCHI METHOD

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ABSTRCT

This paper deals with the optimization of operating parameters of journal bearing using SAE 20 lubricating oil. During the experiment, process parameters such as speed, and load under three levels are used to explore their effect on the coefficient of friction of the bearing. These experiments are carried out as per Taguchi's principle and the numerical attempts were conducted with an orthogonal array L9. Further, the analysis of variance (ANOVA) is used to identify the significant effects of process parameters, and the optimal journal bearing parameters are obtained using main effect plots. It is observed, that the minimum coefficient of friction of the recommended parametric combination is the speed of 1000 RPM and the load of 2.75 KG.

Index Terms: Journal bearing, speed, load, coefficient of friction and Taguchi method.

I. INTRODUCTION

Journal bearings are rapidly becoming a major application in smaller motors, pumps and blowers. Paper mill rolls often use large specialized Spherical roller bearings. Clearly, anti-friction bearings are best for these applications. Here we still find rolling element bearings used successfully but as speeds increase and temperatures rise, rotor dynamics often become a concern and critical speeds are encountered. This is when damping is required and fluid film bearings become increasingly necessary. Turbo machinery designers and users should consider using fluid film bearings, if running above 3,000 RPM or the machine varies from 500 HP to 1000 HP, There are exceptions of course, and the decision for selection of bearing is ultimately done for every machine individually based on good engineering practice and experience. At different applications a different type of bearings should be employed .At high speed working conditions, journal bearings should be employed. High speed machines running on journal bearings must be without any power losses. These bearings must run efficiently with less co-efficient of friction, control parameters such as load and speed effects the co-efficient of friction. By running the journal bearing at optimized conditions, coefficient of friction gets decreased, so that the friction and power losses in journal bearing are low. The thesis also includes the detail parametric study on the speed, load and coefficient of friction based on the developed Taguchi model.

II. LITERATURE REVIEW

When the journal bearing is under operating condition, a small amount of transmitted power is loosed in the form of heat; this power loss is mainly due to the development of friction between the journal and the bearing. This friction is a function of load and speed of the transmitting shaft. The subsequent sections present, the condition of the journal bearings performance with the parameters of load and speed. In the year 1987 M M Khonsari [1], [3] Present a survey of important papers pertaining to thermal effects of in journal bearings it includes discussion on theoretical, computation and experimental works pertaining to heat effects in journal bearings and also in 2006 ZC Peng [4], studied the thermodynamic models for predicting the 3D temperature field in an air lubricated complaint foil journal bearing. In 1974 garden and J.G Ulschmid [2] studied the operating characteristics of two differences types and they guided the design changes. In 1988 N.Logothetics & A.Haigh [17] characterized and optimized multi-response processes by using Taguchi method in the specialization of Quality and Reliability Engineering. M.Naibant[16] & J A Ghani[15] applied Taguchi method in optimization of cutting parameters for surface roughness in turning & also optimization of end milling parameters. Ng Chin Fei in 2013 aimed to review the research of the practical use of Taguchi method in the optimization of processing parameters for injection molding. Taguchi method has been employed with great success in experimental designs for problems with multiple parameters due to its practicality and robustness

III. OBJECTIVES AND METHODOLOGIES

Objectives: The ever increasing demand of lower initial and running costs for bearings, to withstand competition, has prompted engineers to apply optimization methods in bearing design. The focus of the work is to develop a mathematical modeling Taguchi method, for optimizing the control parameters and also includes the detailed parametric study on the speed, load and coefficient of friction based on the developed Taguchi model.

Methodologies have been adopted:

- Setting of journal bearing test apparatus to take down the values.
- Procurement of SAE 20 lubricating oil.
- Experimentation on Journal bearing based on design of experiments.
- Determination of coefficient of friction μ for the each entire load and speed combination.
- Development of Taguchi model for coefficient of friction.
- Comparison of results that are from Minitab software and manual calculation Taguchi method.
- Parameter studying on development Taguchi model.

IV. EXPERIMENTATION

Experimental design is a body of knowledge and techniques that assist the experimenter to conduct experiment economically, analyze the data, and make connections between the conclusions from the analysis and the original objectives of the investigation [7]. Although the major emphasis in this book is on engineering products/processes, the methods can be applied to all other disciplines also. The traditional approach in the industrial and the scientific investigation is to employ trial and error methods to verify and validate the theories that may be advanced to explain some observed phenomenon. This may lead to prolonged experimentation and without good results. Some of the approaches also include one factor at time experimentation, several factors one at a time and several factors all at the same time. These approaches are explained in the following sections. Conventional Test Strategies One-factor experiments: The most common test plan is to evaluate the effect of one parameter on product performance. In this approach, a test is run at two different conditions of that parameter. Suppose we have several factors including factor A. In this strategy we keep all other factors constant, and determine the effect of one factor. The first trial is conducted with factor A at first level and the second trial is with level two. If there is any change in the result (difference in the average between Y1 and Y2), we attribute that to the factor A. If the first factor chosen fails to produce the expected result, some other factors would be tested. Please insert table from the taguchi book hear page no 34 table 2.1 several factors one at a time: Suppose we have four factors (A, B, C, D). In this strategy, the first trial is conducted with all factors at their first level. This is considered to be base level experiment. In the second trial, the level of one factor is changed to its second level (Factor A). Its result (Y2) is compared with the base level experiment (Y1). If there is any change in the result (between Y1 and Y2), it is attributed to factor A. In the third trial, the level of factor B is changed and the test average Y3 is compared with Y1 to determine the effect of B. Thus, each factor level is changed one at a time, keeping all the other factors constant.

This is the traditional scientific approach to experimentation. In this strategy, the combined effect due to any two/more factors cannot be determined [8]. Several factors one at a time: Suppose we have four factors (A, B, C, D). In this strategy, the first trial is conducted with all factors at their first level. This is considered to be base level experiment. In the second trial, the level of one factor is changed to its second level (Factor A). Its result (Y2) is compared with the base level experiment (Y1). If there is any change in the result (between Y1 and Y2), it is attributed to factor A. In the third trial, the level of factor B is changed and the test average Y3 is compared with Y1 to determine the effect of B. Thus, each factor level is changed one at a time, keeping all the other factors constant. This is the traditional scientific approach to experimentation. In this strategy, the combined effect due to any two/more factors cannot be determined.

Several factors all at the same time:

The third and most urgent situation finds the experimenter changing several things all at the same time with a hope that at least one of these changes will improve the situation sufficiently. In this strategy, the first trial is conducted with all factors at first level. The second trial is conducted with all factors at their second level. If there is any change in the test average between Y1 and Y2, it is not possible to attribute this change in result to any of the factor/s. It is not at all a useful test strategy. These are poor experimental strategies and there is no scientific basis. The effect of interaction between factors cannot be studied. The results cannot be validated. Hence, there is a need for scientifically designed experiments.

Fig.1. Experimental setup of journal bearing

Fig.2. Manometer out lets from the Journal bearing

Design of Experiments Using Orthogonal Arrays

Orthogonal Arrays (OAs) were mathematical invention recorded in early 1897 by Jacques Hadamard, a French mathematician. The Hadamard matrices are identical mathematically to the Taguchi matrices; the columns and rows are rearranged.

Nomenclature of Arrays

$L_a(b^c)$

L=Latin square
a=number of rows
b=number of levels
c=number of columns (factors)

Standard Orthogonal Array:

Two level series	Three level series	Four level series	Mixed level series
$L_4(2^3)$	$L_9(3^4)$	$L_{15}(4^5)$	$L_{18}(2^1,3^7)$
$L_8(2^7)$	$L_{27}(3^{13})$	$L_{64}(4^{21})$	$L(2^{11},3^{12})$
$L_{16}(2^{15})$	$L_{81}(3^{40})$		
$L_{32}(2^{31})$			
$L_{12}(2^{11})$			

V. MODELING:

The journal bearing is a very complex phenomenon which is very much stochastic in nature and which depends upon a number of variables. A small change in one variable can abruptly change the output. So it is very difficult to establish models without mathematical and soft computing analysis. In this chapter the Taguchi process is modeled.

Development of Taguchi Model Using Minitab Software

Data collected from Taguchi/Orthogonal Array (OA) experiments can be analyzed using response graph method or Analysis of Variance (ANOVA). The response graph method is very easy to understand and apply. This method requires expiring statistical knowledge [7]. For practical /industrial applications, this method may be sufficient. Analysis of variance (ANOVA) has already been discussed in the earlier chapters. This method accounts the variation from all sources including error term. If error sum of squares is large compared to the control factors in the experiment, ANOVA together with percent contribution indicate that the selection of optimum condition may not be useful. Also for statistically validating the results, ANOVA is required. In this chapter how various types of data are analyzed is discussed. The main criteria for the design of journal bearing are the power loss due to heat generated which in turn depends on bearing friction. It is found that, the coefficient of friction for journal bearing is a function of bearing characteristic number.

Taguchi Approach for Optimization:

The experimentation studies were performed on an journal bearing apparatus during experimentation the effect of various input parameters such as RPM, LOAD on the output parameters such as coefficient of friction of Journal Bearing have been studied .experiments were performed on Journal Bearing apparatus of having journal of 50mm diameter and 70mm length with lubricating oil of SAE 20.the numerical values of control parameters at different levels are shown in table 1.in this present case two parameters each at three levels with no interaction effect has been considered. The total degree of freedom has been calculated below.

Actors and Their Levels:

S.NO	Factor	Symbols	Parameters	Units	Level 1	Level 2	Level 3
1	A	N	Speed	rpm	1000	1300	1500
2	B	L	Load	Kg	1.4	2.3	2.75

Degree of Freedom:

A degree of freedom in a statistical sense is associated with each piece of information that is estimated from the data. For instance, mean is estimated from all data and requires one degree of freedom (do) for that purpose. Another way to think the concept of degree of freedom is to allow 1df for each fair (independent) comparison that can be made in the data. Similar to the total. Sum of squares, summation can be made for degrees of freedom.

Total do = do associated with factors + error do Degree of freedom required for the problem are

Main factors = 2 (Each factor as 2 degree of freedom) =4

Error Degree of Freedom =4

Total =8

To accommodate 2 do, we have to use *L*9 (32) OA.

The required linear graph for Illustration

The required linear graph is closer to part of the standard linear graph.

The Standard L_9 Orthogonal Array:

Trail NO	A	B
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Experimental Results:

TRAIL NO	SPEED (rpm)	LOAD (kg)	COEFFICIENT OF FRICTION
1	1000	1.4	0.01866
2	1000	2.3	0.01208
3	1000	2.75	0.01046`
4	1300	1.4	0.02361
5	1300	2.3	0.0153
6	1300	2.75	0.01300
7	1500	1.4	0.02693
8	1500	2.3	0.01739
9	1500	2.75	0.01469

VI. RESULTS AND DISCUSSIONS

Effects of Input Factors on Coefficient Of Friction:

The selected parameters have different effects on the journal bearing performance [9]. Analysis of variance **(ANOVA)** is used to identify the significant effects of process parameters and the optimal journal bearing parameters are obtained using the main effects plot. The characteristics that lower values correspond to better Journal Bearing performance such as coefficient of friction is called "lower is better " (LB) in quality engineering . The signal to noise (S/N) ratio could be an effective graphical representation to find the significant parameter by evaluating the minimum variance. The equation which is used for calculating the S/N ratio is "lower is better" (LB).

$$\text{S/N ratio}=10\log\left(\frac{1}{r}({y_1}^2+{y_2}^2+{y_3}^2+\cdots {y_n}^2)\right)$$

The value of S/N ratio of the journal bearing performance for each experiment run of l_9 OA can be calculated for coefficient of friction using equation and it is represented in table to obtain the effects for Journal Bearing parameters for each level, the S/N ratio values of each fixed parameter and level in each machining performance is summed up.

S/N Ratio for Coefficient of Friction:

Experimental Result:

S.no	Coefficient of friction (μ)	S/N ratio -10 * log (sum(Y^2)]
1	0.01866	34.58
2	0.01208	38.358
3	0.01046	39.6092
4	0.02361	32.538
5	0.0153	36.306
6	0.01300	37.72
7	0.02693	31.394
8	0.01739	35.194
9	0.01469	36.658

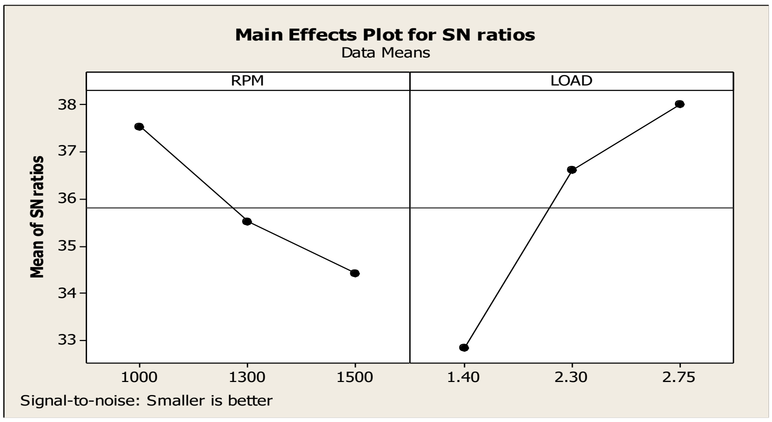
Response Table for S/N Ratios:

Level	A	B
1	37.52	32.84
2	35.52	36.62
3	34.42	38
Delta	3.1	5.16
Rank	2	1

From the calculation of main effects for each level of the factors the main effects are shown in table. The main effects values are plotted in figure for RPM, LOAD the influence of each one of the factors of each level on the machining performance was shown in main effects plot. The levels having the major contribution are selected from the plot are the optimized levels for the particular factor

Main Effects Plots for S/N Ratios:

The analysis of variations was used to find out the relative importance of journal bearing parameter with respect to coefficient of friction .table gives the ANOVA result for coefficient of friction. From the analysis of table, it was found that the RPM (10.526%) and LOAD (36.42%) have statistical significance on coefficient of friction



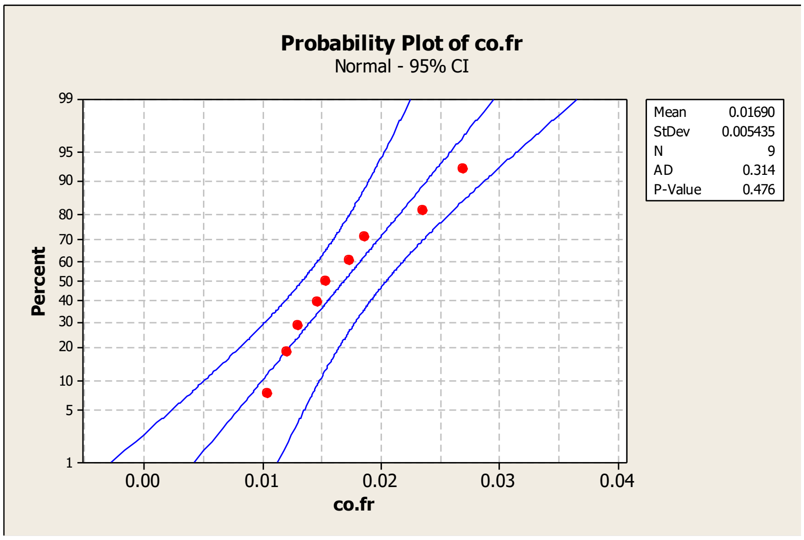
Source of variation	Sum of squares	Degrees of freedom	Mean Square	*F*0	*C*(%)	Rank
SPEED	0.00005	2	0.000025	6.9	10.526	2
LOAD	0.000173	2	0.0000865	37.28	36.42	1
Error	0.0000145	4	0.000003625	65.51	53.05	
Total	0.0002375	8			100	

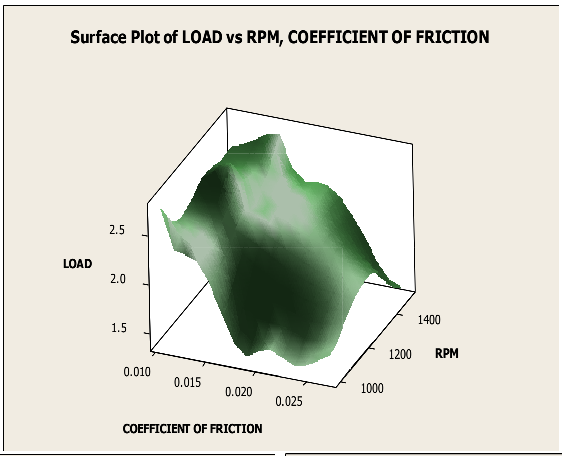
Thus by utilizing experimental results and computed values of S/N ratio, averages effect of response value and average S/N ratio are calculated for coefficient of friction and presented in table. Higher the S/N ratio corresponding to the better the performance characteristics regardless of their category, so optimal level of the Journal Bearing parameters is the level with greatest S/N ratio value. Based on results of analysis of S/N ratio, the optimal journal bearing performance for the coefficient of friction is obtained at SPEED of 1000 RPM and LOAD of 2.75 kg.

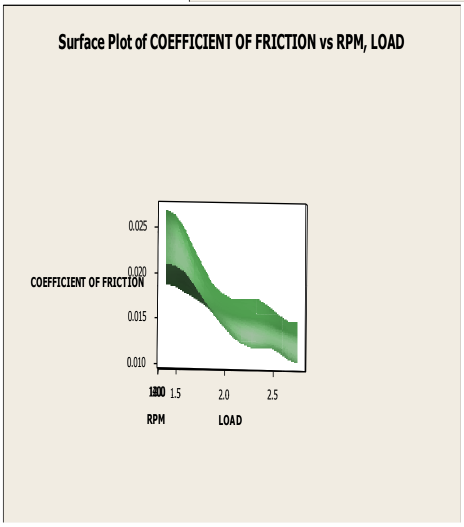
Nominal Probability Plot Former:

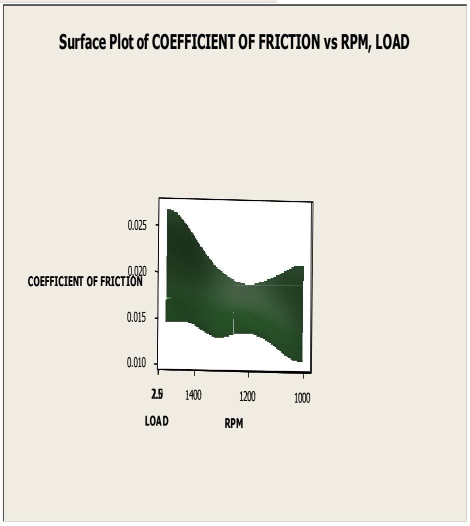
The normal probability plot showed the set of values of responses are very close to median of set values and not deviated from mid value. Normal probability plot for coefficient of friction is shown in figure.

Probability plot of coefficient of friction:









Developing the Taguchi Modal Manually and Analyzing the Input Data.

For two control parameters each at three levels with no interaction effect has a total degree of freedom 8. Hence a standard L_9 orthogonal array is selected for experimental design matrix

The Standard L_9 Orthogonal Array:

Trail NO	A	B
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

Experimental Results:

TRAIL NO	SPEED (rpm)	LOAD (kg)	COEFFICIENT OF FRICTION
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6	1500	2.75	0.01300

7	1000	1.4	0.02693
8	1300	2.3	0.01739
9	1500	2.75	0.01469

The correction factor (CF):

$CF = \frac{T^2}{N}$

Where,

T = grand total and

N = total number of observations

$$CF = \frac{0.1522^2}{9} = 0.00257$$

SS_{Total} is computed using the individual observations (response) data as already discussed.

$$SS_{Total} = \sum_{i=1}^{N} Y^2 - CF$$

Where N=total no of observations

Y=grand total

$$SS_{Total} = \sum_{i=1}^{9} 0.0169^2 - 0.00257 = 0.0002375$$

The factor (effect) sum of squares is computed using the levels totals .

$$SS_A = \frac{A_1{}^2}{NA_1} + \frac{A_2{}^2}{NA_2} + \frac{A_3{}^2}{NA_3}$$

Where,

A_1 = level 1 total of factor A

NA_1 = number of observations used in A_1

A_2 = level 2 total of factor A

$NA2$ = number of observations used in A_2

$$SS_A = \frac{0.0137^2}{3} + \frac{0.0173^2}{3} + \frac{0.01967^2}{3} = 0.00029$$

$$SS_B = \frac{B_1{}^2}{NB_1} + \frac{B_2{}^2}{NB_2} + \frac{B_3{}^2}{NB_3}$$

Where,

B_1 = level 1 total of factor B

NB_1 = number of observations used in B_1

B_2 = level 2 total of factor B

NB_2 = number of observations used in B_2

$$SS_B = \frac{0.0230^2}{3} + \frac{0.0149^2}{3} + \frac{0.0127^2}{3} = 0.0003$$

The error sum of squares is calculated by subtracting the sum of all factor sums of squares from the total sum of squares.

$SS_e = SS_{TOTAL} - (SS_A + SS_B)$

This error sum of squares is due to replication of the experiment, is called experimental error or pure error.

$SS_e = 0.0002375 - (0.00029 + 0.0003) = 0.000296$

ANOVA Results for Coefficient of friction (μ)

Source of variation	Sum of squares	Degrees of freedom	Mean Square	*F*0	*C*(%)	Rank
A	0.00005	2	0.000025	6.9	10.526	2
B	0.000173	2	0.0000865	37.28	36.42	1
Error	0.0000145	4	0.000003625	65.51	53.05	
Total	0.0002375	8			100	

Calculation of S/N ratios for predicting the optimum values

Smaller the better: Here, the quality characteristic is continuous and non-negative. It can take any value between 0 to -∞. The desired value (the target) is zero. These problems are characterized by the absence of scaling factor (ex: surface roughness, pollution, tire wear, etc).

The S/N Ratio:

S.no	Coefficient of friction (μ)	S/N ratio -10 * log (sum(Y^2)]
1	0.01866	34.58
2	0.01208	38.358
3	0.01046	39.6092
4	0.02361	32.538
5	0.0153	36.306
6	0.01300	37.72
7	0.02693	31.394
8	0.01739	35.194
9	0.01469	36.658

In Taguchi method the optimum parameters are obtained at maximum S/N ratio. Hence the optimum control parameters are SPEED = 1000 RPM,

LOAD = 2.75 kg

The predicted μ value from the above table is

μ_{pred} = Y+ (B-Y)+(A-Y)
= (A+B) -Y
= (0.0137- 0.01271) - (0.0169)
= 0.00951

CONCLUSION:

The experimental results which are based on calculated S/N ratio, and ANOVA, the following conclusion are drawn for journal bearing performance.

(i) The load and the speed are the most significant parameters for obtaining minimum coefficient of friction.

(ii) For minimum coefficient of friction the recommended parametric combination is speed of 1000 RPM and load of 2.75 KG.

(iii) The Taguchi method seems to be an efficient methodology to find out the optimum journal bearing parameters, as experiment was based on minimum number of trails conducted to obtain optimum cutting parameters.

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