Development of Improving Model for the Surface Finish of Ball Bearing (Deep Groove) by Optimizing Cutting Parameter

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Abstract Deep groove ball bearing is extensively used to support rotational shafts in engines, in order to improve the surface finish, use of design of experiment (DOE) to investigate the most significant responsive factor, which is contributing in improving surface finish. Based on the results, design of experiment is conducted and tries to optimize the most significant responsive factor. For performing design of experiment, first selecting six variable factors in grinding and four variable factors in honing process were obtained through brainstorming. To improve surface finish of inner and outer track of deep groove ball bearing, hereby, the various experiments were to be conducted independently to know the effect of various process parameters on surface finish of deep groove ball bearing.

Keywords Deep groove ball bearing · Design of experiments (DOE) · Grinding · Honing

1 Introduction

The main persistence of this study is to describe the model preparation for the improvement of the surface finish of deep groove ball bearing by using the methodology of design of experiment, ANOVA (tool), and MINITAB (software). Ball bearings are used as multifaceted part, self-retaining bearing with solid outer rings, inner rings, balls, and cage assemblies.

They are of a simple design, robust in nature, easy to maintain. Due to raceway geometry and the use of balls, deep groove ball bearing can support the axial forces in both direction and radial force. Use of design of experiment (DOE) is to investigate

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most significant responsive factor which is contributing in improving surface texture by using fishbone diagram [1, 2].

Nowadays, poor surface texture has become a sizable problem especially for automobile industry; so to eliminate this problem and to identify the major optimum solution, DOE tool and MINITAB software are used.

2 Research Methodology

The purpose of product or process development is to improve the performance characteristics of the product or process relative to the customer needs and expectations. The purpose of experimentation should be understood how to reduce and control variation of a product and optimizes the cutting parameters to improve the surface finish of ball bearing subsequently [2].

The approach of design of experiment is based on the orthogonal arrays to conduct small, fractional experiments up to larger, full factorial experiments. Note down all the initial conditions in which machine is running and collecting the necessary quality results execute the experiments as per run order [3]. For every experiment, record quality parameters are surface finish, surface roughness, and roundness Talyrond and profile (Fig. 1).

After taking sample pieces, the machine will restore on initial conditions until the next experiment is executed. Final judgment will be taken after doing honing and then check grinding burns [4]. Various experiments were to be conducted independently to know the effect of various process parameters on surface finish as per Table 1.

This is based on the results of the above experiments, if required, process parameters were affecting surface texture to be optimized. The following tables show the experiment done on 64 random bearings for comparison between the various parameters and its response.

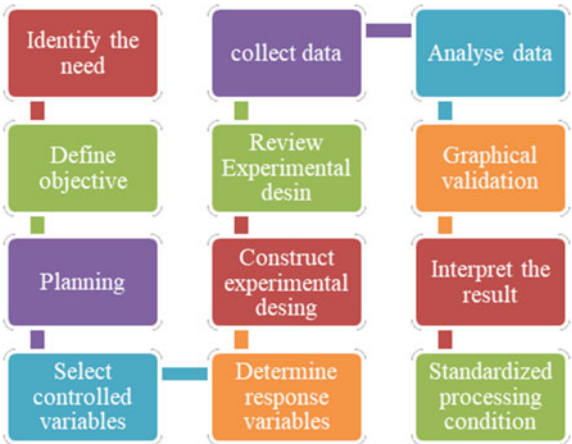

Fig. 1 Design of experiment process and stages

Table 1 Process parameters for surface finish

Area	Experiments planned for followings process parameters
Grinding	Work RPM (process RPM setting)
	Grinding feed rate (fine)
	Dress compensation (draft compensation)
	Dress feed rate
	Grinding feed rate (rough2)
	Spark out time
Honing	Work head RPM (fast)
	Work head RPM (slow)
	Osc. frequency (fast-low)
	Honing time (fast–slow)

3 Design of Experiments for 6205 for Grinding Process

Design of experiment has to be done for 6205 ball bearing for inner race grinding process on random bearings with six different variables on two response factors, i.e., Ra and Talyrond (Table 2).

After conducting all 64 experiments, collecting the results of all the experiments analyzes the data by ANOVA table and interprets the results which then standardize the processing condition if required. It is the procedure of splitting the variance of the observation into the variance caused by the variable and the variance caused by noise [5]. It helps to check if the linear relation between *y* and *x* is significant [4, 6]. Table 3 shows the Ra response for inner race of ball bearing response on the following.

The analysis of ANOVA outcomes is as follows:

1. All the above critical values (*P*) are more than 0.05.
2. Critical value (*P*) should be less than 0.05 for significant factor selection.
3. On the basis of above results, we can come to conclusion that none of the sources affects the surface roughness (Ra) value at this level.

Hence, machining conditions are already at optimum level for surface texture and no scope of further improvement.

Table 4 shows the Talyrond for inner race of ball bearing response on the following.

The analysis of ANOVA outcomes is as follows:

1. Two out of six critical values (*P*) are less than 0.05.
2. Critical value (*P*) should be less than 0.05 for significant factor selection.
3. After analyzing, the above-given results, we can come to conclusion that two factors work RPM and grinding feed rate (fine) which affects the roundness (Talyrond) value.

However, not all these sources affect the surface finish of the product.

Table 2 Design matrix and data collection—inner race

Std order	Run order	Variable parameter						Response	
		Work RPM	Grinding feed rate (fine)	Dress compensation	Dress feed rate	Grinding feed rate (R-2)	Spark out time	Ra Avg	Talyrond Avg
60	1	914	0.01	0.02	0.01	0.043	1.5	0.4642	1
34	2	914	0.008	0.02	0.008	0.04	1.5	0.4504	0.82
52	3	914	0.01	0.02	0.008	0.043	1.5	0.4637	0.83
42	4	914	0.008	0.02	0.01	0.04	1.5	0.4889	0.73
16	5	914	0.01	0.03	0.01	0.04	1	0.4214	0.87
8	6	914	0.01	0.03	0.008	0.04	1	0.4361	0.77
1	7	710	0.008	0.02	0.008	0.04	1	0.4332	0.67
2	8	914	0.008	0.02	0.008	0.04	1	0.3567	0.6
15	9	710	0.01	0.03	0.01	0.04	1	0.3549	0.83
9	10	710	0.008	0.02	0.01	0.04	1	0.3795	0.97
27	11	710	0.01	0.02	0.01	0.043	1	0.3812	0.82
61	12	710	0.008	0.03	0.01	0.043	1.5	0.3921	0.68
57	13	710	0.008	0.02	0.01	0.043	1.5	0.3843	0.4

Table 3 ANOVA table for Ra response

Analysis of variance for Ra Avg., using adjusted SS for tests							
S. no	Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
1	Work RPM	1	0	0	0	0	1
2	Grinding feed rate (fine)	1	0.0067	0.007	0.0067	1.6	0.22
3	Dress compensation	1	0.0057	0.006	0.0057	1.3	0.25
4	Dress feed rate	1	0.0016	0.002	0.0016	0.4	0.54
5	Grinding feed rate (rough-2)	1	0.0001	1E-04	0.0001	0	0.86
6	Spark out time	1	0.0002	2E-04	0.0002	0.1	0.8
7	Error	57	0.245	0.245	0.0043		
8	Total	63	0.259				

Table 4 ANOVA table for roundness (Talyrond) response

Analysis of variance for Talyrond Avg., using adjusted SS for tests							
S. no	Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
1	Work RPM	1	0.3828	0.383	0.3828	8.2	0.01
2	Grinding feed rate (fine)	1	0.318	0.318	0.318	6.8	0.01
3	Dress compensation	1	0.0073	0.007	0.0073	0.2	0.7
4	Dress feed rate	1	0.0005	5E-04	0.0005	0	0.92
5	Grinding feed rate (rough-2)	1	0.0005	5E-04	0.0005	0	0.92
6	Spark out time	1	0.0343	0.034	0.0343	0.7	0.4
7	Error	57	2.67	2.67	0.0468		
8	Total	63	3.414				

Design of experiment has to be done for 6205 ball bearing for inner race grinding process on random bearings with six different variables on two response factors, i.e., Ra and Talyrond.

4 Design of Experiments for 6205 for Honing Process

Design of experiment has to be done for 6205 ball bearing for inner race honing process on random bearings with four different variables on two response factors, i.e., Ra and Talyrond. Same is done as grinding process (Tables 5 and 6).

Table 7 shows the results of four different variables in the two respective response and their response after analysis for honing process.

Table 8 shows the results of ANOVA table for surface finish of the tested bearings, where the p value is more than 0.05 for all parameters.

The analysis of ANOVA outcomes is as follows:

Table 5 Table variable factors, fixed factors, and other factors of honing process

Variables factors

Factor	Name	Low level	High level	Units
A	Work head RPM (fast)	2000	3000	RPM
B	Work head RPM (slow)	1500	2500	RPM
C	Osc. frequency (fast-low)	450–150	600–200	CPM
D	Honing time (fast–slow)	10–2	13–2	Sec

Fixed factors

Factor	Name	Value	Unit
1	Honing stone (rough)	WA3000RH28–30-SANWA	–
2	Honing stone (finish)	19R6000RH(-)22-IZUHO	–
3	Rough stone pressure	0.20–0.24	MPa
4	Finish stone pressure	0.24–0.28	MPa
5	Clamp pressure	0.25–0.35	MPa
6	M/c idle time	2.5	s
7	Main line air pressure	0.4	MPa
8	Oscillation angle	30–40	deg

Other fixed factor (environmental)

S. no	Environmental factor	Value
1	Tooling condition	Constant
2	Coolant condition	
3	Environment temperature	
4	Operator skill	
5	Gauge’s	
6	Machine	
7	Input material	
8	Inspection method/machine	

Table 6 Response test result

Response	Name	Std
1	Surface roughness (Ra)	0.04 max
2	Roundness (Talyrond)	2.0

1. All the above critical values (*P*) are more than 0.05.
2. Critical value (*P*) should be less than 0.05 for significant factor selection.
3. On the basis of the above results, we can come to conclusion that none of the sources affects the surface roughness (Ra) value at this level.

Hence, machining conditions are already at optimum level/optimized for surface texture and no scope of further improvement [7, 8].

Table 7 Results (response) of experiments

Std order	Run order	Variable parameter				Response	
		Work head RPM-fast	Work head RPM-slow	Osc. frequency fast-low	Honing time sec. fast–slow	Surface finish (Ra) µm (Avg.)	Roundness (Talyrond) µm (Avg.)
4	1	3000	2500	450 ~ 150	10 ~ 2	0.0201	0.5
1	2	2000	1500	450 ~ 150	10 ~ 2	0.0203	0.87
16	3	3000	2500	600 ~ 200	13 ~ 2	0.019	0.82
3	4	2000	2500	450 ~ 150	10 ~ 2	0.0303	0.78
12	5	3000	2500	450 ~ 150	13 ~ 2	0.0201	0.52
13	6	2000	1500	600 ~ 200	13 ~ 2	0.0217	0.88
14	7	3000	1500	600 ~ 200	13 ~ 2	0.0181	0.65
7	8	2000	2500	600 ~ 200	10 ~ 2	0.0239	0.78
8	9	3000	2500	600 ~ 200	10 ~ 2	0.0243	0.58
10	10	3000	1500	450 ~ 150	13 ~ 2	0.0265	0.58
5	11	2000	1500	600 ~ 200	10 ~ 2	0.0263	0.72
2	12	3000	1500	450 ~ 150	10 ~ 2	0.0159	0.78
15	13	2000	2500	600 ~ 200	13 ~ 2	0.0177	0.78
11	14	2000	2500	450 ~ 150	13 ~ 2	0.0184	0.75
6	15	3000	1500	600 ~ 200	10 ~ 2	0.02	0.82
9	16	2000	1500	450 ~ 150	13 ~ 2	0.0251	0.8

Table 8 ANOVA table for surface finish (Ra) response

Analysis of variance for surface finish, using adjusted SS for tests							
S. no	Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
1	Work head RPM (fast)	1	0.0000237	0.0000237	0.000023	1.4	0.27
2	Work head RPM (slow)	1	0	0	0	0	0.99
3	Osc. frequency (fast-low)	1	0.0000019	0.0000019	0.0000019	0.1	0.75
4	Honing time (fast-slow)	1	0.0000131	0.0000131	0.0000131	0.8	0.41
5	Error	11	0.0001391	0.0001391	0.0000176		
6	Total	15	0.0002318				

Table 9 shows the results of ANOVA table for roundness of the tested bearings, where the *p* value of work RPM (fast) is less than 0.05.

Hereby, the analysis of ANOVA outcomes is as follows:

1. One out of four critical values (*P*) is less than 0.05.
2. Critical value (*P*) should be less than 0.05 for significant factor selection.
3. After analyzing the above experiments' results, conclusion is that one factor work head RPM (fast) affects the roundness (Talyrond) value.

Table 9 ANOVA table for roundness (Talyrond) response

Analysis of variance for Talyrond Avg., using adjusted SS for tests							
S. no	Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
1	Work head RPM (fast)	1	0.077934	0.077934	0.077934	7.8	0.02
2	Work head RPM (slow)	1	0.021267	0.021267	0.021267	2.1	0.17
3	Osc. frequency (fast-low)	1	0.012656	0.012656	0.012656	1.3	0.28
4	Honing time (fast-slow)	1	0.000156	0.000156	0.000156	0	0.9
5	Error	11	0.109635	0.109635	0.009967		
6	Total	15	0.221649				

However, work head RPM (fast) is not affecting on the surface texture of the product.

5 Mathematical Modeling Done by Regression Analysis

Regression analysis is usually used to evaluate the relationship between any two or more dependent variables on independent variables, which shows the effect of that variables on main factor. Regression analysis has been done with response of ball bearing with different variables for inner race ball bearing [1, 9].

Regression Analysis: Ra Avg. versus work RPM, grinding feed rate, dress compensation, dress feed rate, and grinding feed rate-2. The regression equation is

$$\begin{aligned}\text{“Ra Avg.} &= 0.00895 + 0.000012\,\text{Work RPM} - 0.000004\,\text{Grinding Feed rate(Fine)}\\ &\quad - 0.000000\,\text{Dress compensation} - 0.0064\,\text{Dress feed rate}\\ &\quad - 0.0001\,\text{Grinding Feed rate}(R{-}2)\text{"}\end{aligned} \tag{1}$$

Regression Analysis: Talyrond Avg. versus work RPM, grinding feed rate, dress compensation, dress feed rate, and grinding feed rate-2. The regression equation is

$$\begin{aligned}\text{“Talyrond} &= 0.0409 + 0.000036\,\text{Work RPM} + 0.000006\,\text{Grinding Feed rate(Fine)}\\ &\quad - 0.000000\,\text{Dress compensation} - 0.0080\,\text{Dress feed rate}\\ &\quad - 0.0125\,\text{Grinding Feed rate}(R{-}2)\text{"}\end{aligned} \tag{2}$$

6 First Section Results & Conclusion of Experimental Data for Grinding & Honing Process

In order to improve surface finish, 64 experiments on grinding M/c & 16 experiments on honing M/c for both inner and outer races have to be done (total 80 experiments for each). In each experiments, we have taken three sample pieces for all quality checks and analyzed the results on both machines [3].

After analyzing the data, results show that:

1. The two factors work RPM and grinding feed rate (fine) affect the roundness (Talyrond) value in inner race grinding process.
2. The one factor work head RPM (fast) affects the roundness (Talyrond) value in inner race honing process.
3. The two factors work RPM and dress feed rate affect the Talyrond value in outer race grinding.
4. All the machining conditions are already at optimum level and do not affect the surface texture of the product.

7 Results with Graphical Representation

In order to improve surface finish, 64 experiments have to be done on grinding machine and 16 experiments on honing machine for both inner and outer races (total 80 experiments for each process).

In each experiments, we have taken three sample pieces for all quality checks and analyzed the results on both machines. After analyzing the results, for surface roundness concluded that one factor work head RPM (fast) affects the roundness (Talyrond) value but work head RPM (fast) is not affecting on the surface texture of the product.

Two factors work RPM and dress feed rate affect the Talyrond value.

All the machining conditions are already at optimum level and do not affect the surface texture of the product.

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