Effect of Various Parameters on Material Removal Rate in Flashing Operation of Precision Steel Ball Manufacturing Process

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Abstract

Precision balls are used in critical aeronautical bearings, guidance system balls for space and military applications, precision valves, automotive bearings and other applications where higher precision is necessary. However, since the surface finishing process necessary for the balls to achieve the required surface quality and geometric accuracy is time consuming and expensive, it increases the manufacturing cost significantly and therefore confines their widespread application. Hence, the development of a more economical finishing method becomes a critical problem in the application of advanced Steel ball manufacturing. The major concern of the current study is to investigate the performance of the Flashing machine in the initial stage. In flashing of steel balls, the influence of the groove depth of plates on the Material Removal rate of balls is analyzed experimentally. Five flashing plates with different groove depth are used. A shallow round groove is equivalent to a V groove with a large angle. A deep round groove corresponds to a V groove with a small angle. From the experimental readings, regardless of the groove depth of the Gap plate, the one where the groove of the rotary plate is deep it is found that MRR is large. Best MRR is found at the combination of 0.1 D – 0.3 D.

The experiment for Flashing was designed using a full factorial design with two levels for each input variable (2^k factorial design). Since there are three factors, each at two levels, the design is 2^3 factorial design which requires 8 runs to complete all the possible combinations. Factors taken for the experiments are Pressure between two plates, No. of Grooves in plates & RPM of Ring Plate. From the main effect plots, to achieve higher Material removal rate pressure should be at its higher level, RPM should be also at higher level, No. of grooves should be at its lower level. Also from the experiments the percentage contribution of various parameters on Material removal rate are Pressure having 58.16% , RPM having 16.86%, No. Of grooves having 23.90%. Analyzing the various process parameters, their influence in the operation & experiments are conducted at NHB Bearings Company.

Keywords—Flashing, Material Removal Rate, Regression model, Design of Experiments

1. INTRODUCTION TO BALL MANUFACTURING PROCESS

The finishing process of steel balls can be divided into two steps, firstly rough lapping (grinding), and secondly fine lapping (polishing). In the first step − lapping, maximum material removal rate is the goal while achieving fairly good ball roundness and maintaining no consequent ball surface and subsurface damage. The first step is lapping in which most of the stock from the ball is removed at a higher material removal rate. The second step in the finishing process is polishing, in which the ball surface roughness, roundness, dimensional and geometric accuracy are achieved.

The major concern of the current study is to investigate the performance of the Flashing machine in the initial stage. Flashing is an initial operation to generate spherical surface of Ball which requires higher pressure as compare to lapping. Lapping is a gentle, final operation commonly used with low speed and low pressure to generate ultra- fine finishes, extreme flatness or roundness, and critically close tolerances. However, the usual definition of lapping is the random rubbing of a part against a lap (usually of cast iron composition or another material that is softer than the part) using an abrasive mixture in order to improve fit and finish.

As a first step toward improving process modeling, “Material Removal Mechanisms in Lapping & Polishing” by C.J. Evans, E.paul, D.Dornfeld reviews the fundamental mechanisms of material removal in lapping and polishing processes and identifies key areas where further work is required. The four Process components: The work piece, Fluid, Granule, Lap. [1] Two types of HIPed Si3N4 bearing ball blanks with different surface hardness and fracture toughness were lapped under various loads, speeds, and lubricants using a novel eccentric lapping machine in “Examination of the material removal mechanisms during the lapping process of advanced ceramic rolling elements” by J. Kang, M. Hadfield . In which the lapped surfaces were examined by optical microscope and SEM. Different lapping fluids affected the material removal rate at lower lapping loads, but they had much less influence on the material removal rate at higher lapping loads. The preliminary conclusion is that the material removal mechanism during the lapping process of silicon nitride balls using this eccentric lapping machine is mainly mechanical abrasive wear. [2] The design of a novel eccentric lapping machine for finishing advanced ceramic balls by J. kang & M. Hadfield. Two kinds of HIPed (Hot Isostatically Pressed) silicon nitride ball blanks (13.25 mm ~ 13.50 mm in diameter) were lapped and polished to 12.700 mm using this machine. A maximum material removal rate of 68 µm per hour was achieved at the lapping step, which is much higher than by the traditional concentric lapping method. The polished ball surface roughness Ra value is 0.003 µm, and the ball roundness is 0.08~0.09µm which is above grade 5, and close to grade 3 of the precision bearing ball specification.[3] The cost of finishing operation is very much higher so J. Kang and M. Hadfield done the "Parameter optimization by Taguchi Methods for finishing advanced ceramic balls using a novel eccentric lapping machine". [4] The low-order-waviness is improved when both the fixed lap and rotating lap have deep grooves. The medium-order-waviness is improved when the fixed lap has deep grooves, while the rotating lap has shallow grooves. The high-order-waviness is also improved effectively when the grooves on the fixed lap are deep, and the grooves on the rotating lap are shallow.[5][6] J. Kang and M. Hadfield, suggests that in order to obtain better surface quality, the diamond particle size should be reduced gradually in previous lapping process, to avoid leaving any deep scratches on the ball surface.[7]

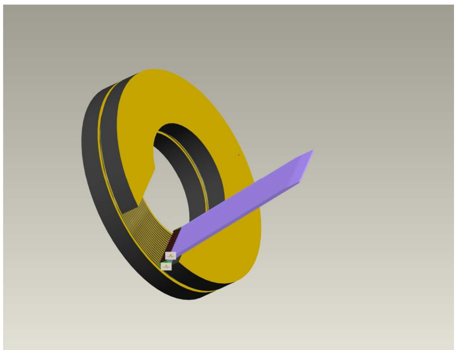
2. THEORETICAL ANALYSIS:

2.1 FLASHING OPERATION:

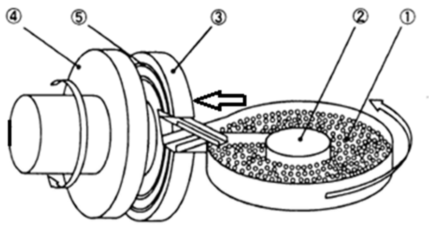
Headed blanks are ground between two metal plates. Flashing is an initial operation in the ball manufacturing Process, this operation is followed by Heading Operation. After the Heading Process the Geometry of the ball is not perfectly round but it having different diameter at poll & equator. To make this geometry perfectly round flashing operation is carried out. So in flashing spherical surface will be generated. For different ball sizes there are different flashing machines. In flashing machine the hydraulic unit which is used for creating pressure is installed behind the Gap plate (Fix plate). The Ring plate is mounted on shaft which is connected with motor with the help of Belt & pulley drive. Conveyor is also mounted on one shaft which is connected with another motor.

2.2 INFLUENCE OF GROOVE DEPTH:

In flashing of steel balls, the influence of the groove depth of plates on the Material Removal rate of balls is analyzed experimentally. Five flashing plates with different groove depth are used. A shallow round groove is equivalent to a V groove with a large angle. A deep round groove corresponds to a V groove with a small angle. In Flashing there isn't any control on groove depth while running of batch. In Grinding operation Diamond dresser is used to dress the grind wheel so there is a control on groove depth while running of batch. Flashing machine uses cast iron plate which cannot be dressed while running. So here for the experimentation purpose, there will be use of separate combinations of plates. For each experiment there is a requirement of separate set of plates.



(Fig 2.1.1)



1. balls 2.conveyor 3. Gap plate(Fix) 4. Ring Plate(Rotating) 5.groove
The Principle Of Ball Flashing

(Fig 2.1.2)

(Fig 2.1.3)

If groove depth reaches to 50% of sphere diameter, the surface of both plates contacting, then processing becomes impossible. Therefore, usually depth of the 40~45% of sphere diameter is designated as the application limit. But because, industrially it is necessary to consider cost, it is not possible to begin early groove depth from the limited depth vicinity. On the other hand, with plane surface the touch area of sphere becomes small, material removal rate is quite small. Therefore at the time of experimenting, realistic, it choose the range of the 10~30% of sphere diameter industrially as an early groove depth. Here 10%, 20% & 30% sphere diameter is called as 0.1D, 0.2D and 0.3D (as for D sphere diameter). The below table show the combinations of Groove Depth.

(Table 2.2.1)

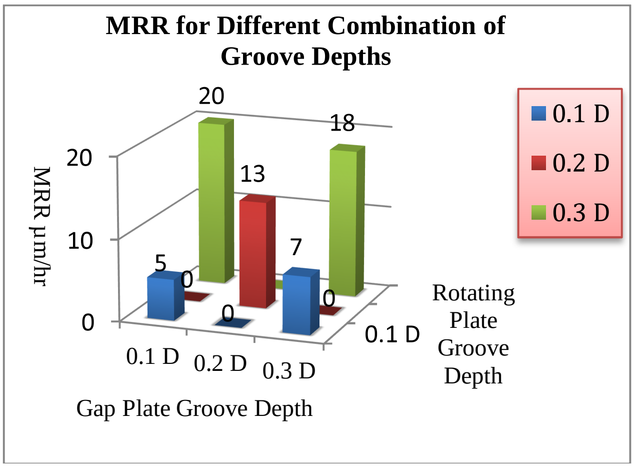
Fixed Plate (Gap Plate)	Rotating Plate		
	0.1 D	*0.2 D*	*0.3 D*
0.1 D	o	-	o
0.2 D	-	o	-
0.3 D	o	-	o

By performing the experiments with different combinations of plates, following observations are made.

Material Removal Rate for Each combination of Plates:

(Table 2.2.2 : MRR µm/hr)

Fixed Plate (Gap Plate)	Rotating Plate		
	0.1 D	*0.2 D*	*0.3 D*
0.1 D	5	-	20
0.2 D	-	13	-
0.3 D	7	-	18



(Fig 2.2.1)

In Above chart on X axis groove depth of the Gap Plate, in Y axis MRR is shown, Rotating Plate Groove Depth which is displayed in the Z axis concerning when it processed with combination of the respective groove depth. From the chart, regardless of the groove depth of the Gap plate, the one where the groove of the rotary plate is deep it is found that MRR is large. In addition, groove depth of the rotary plate in same case, groove depth of the Gap plate changing, difference did not occur in MRR. From this, MRR that groove depth of the plate of rotary side influence is received more strongly than fixed (Gap) part. Best MRR is found at the combination of 0.1 D – 0.3 D.

2.3 DOE in Flashing

The process of Flashing has been long considered an art due to the tremendous amount of variability and subjectivity involved. The quality of flashing differs from operator to operator and the results are highly inconsistent. The material removal rate, surface finish, and spread depend on the proper control of flashing parameters such as flashing pressure, flashing speed of rotation, Number of groove, flash ring material, weight and size, abrasive size and type, work piece material, coolant type and hardness. To attain the desired outcomes, it is imperative to select proper values for the flashing control parameters. Moving the art of flashing into a science and quantifying the results can solve many of the above problems.

Controllable Parameters	Plate RPM, No. Of Grooves, Groove Depth, Flashing Pressure, Coolant Type & Temperature, Abrasive Grit size, Size of Plates etc
Response Parameters	Material Removal Rate, Spread, Flashing Cycle time, Surface Roughness

(Table 2.3.1 Controllable & Response Parameters)

Factorial designs have been found to be most efficient for experiments that involve the study of the effects of two or more factors, which is the case here. Thus, in this research, the experiments were designed using factorial design concepts.

2.3.1 Objectives of the Experiment

The following are three main objectives of conducting a set of experiments for manual lapping:

- Explore the fundamental relationships among key parameters of flashing in a scientific approach.
- Gather data on the most critical parameters for a given set of product constraints.
- Use analysis of the results as a source of supporting information for understanding Flashing parameters and their relationships.

2.3.2 Parameters Under Consideration:

The following sub-sections explain the parameters under consideration in conducting Flashing experiments by classifying them into uncontrollable, controllable, and response parameters.

2.3.2.1 Uncontrollable Parameters

The following parameters are uncontrollable and may be considered random variations in conducting the experiments. These parameters may somewhat affect the quality of Flashing Ball surfaces.

- *Operator's variability* or *subjectivity*

Uncertainties of human performance are unavoidable. This is the main reason why the outcome of Flashing is generally inconsistent. Examples of operator's variability include lack of knowledge, Improper measurement and skill level.

- *Environmental factors*

A Flashing operation is preferably to be performed in a clean and steady environment. However, this is not always possible. Examples of environment factors include temperature, vibration, and dirt.

2.3.2.2 Controllable Parameters (Input Parameters)

The controllable parameters used in the experiments are basically process control parameters. These parameters can be categorized into "constants" and "variables". Since the 2^k factorial design is used, there are only two levels for each variable.

(A) CONSTANT:

- Flash ring Plate material

  Cast iron is the most widely used material for Flash ring. Balls used in experiment are of stainless steel.
- Flash ring plate diameter

  Since there is only one size of Flash ring plate available for the experiments, the Flash ring plate size is a constant here.
- Coolant Type

  For the all experiments the coolant used is Polycool 86.
- Coolant Temperature

  Coolant temperature is kept constant throughout the process which is kept 25° c for whole operation.

(B) VARIABLE:

- Pressure

  In this experiment pressure will be varying & this is 2^k factorial design so there is two values of pressure will be chosen.
- No. Of Grooves

  Here no. of groove will also be varied.
- Plate RPM

  Two different values of RPM are used in performing this experiment. Plate RPM is believed to be among critical process parameters.

2.3.2.3 Responses (OUTPUT PARAMETERS)

- Material Removal Rate: MRR is measured as µm/hr.

2.3.3 Explanation for Experimental Design

The experiment for Flashing was designed using a full factorial design with two levels for each input variable (2^k factorial design). Since there are three factors, each at two levels, the design is 2^3 factorial design which requires 8 runs to complete all the possible combinations. Here the experiment will be having replicates of 2. So for each combination the no of readings are 2.

Below table shows the factors and their levels of interests.

(Table 2.3.3 Factors & Levels of interests)

Factors	Levels
Pressure	25 Kg/cm^2 & 30 Kg/cm^2
No. of Grooves	15 & 18
RPM of Ring Plate	90 rpm & 110 rpm

3. EXPERIMENTAL RESULTS:

3.1 MATERIAL REMOVAL RATE (µm/hr)

(Table 3.1.1 Experimental Results for MRR)

RPM (A)	NO. OF GROOVES (B)			
	15		*18*	
	PRESSURE (C)		PRESSURE (C)	
	25 kg/cm^2	*30 kg/cm^2*	*25 kg/cm^2*	*30 kg/cm^2*
90	10	13	7	11
	8	14	5	10
110	12	18	9	12
	10	16	8	14

Calculation For MRR:

(Table 3.1.2 - 2^3 Effect table for MRR)

Treatment Combination	Coded Factors			Material Removal Rate		Total
	A	B	C	Replicate 1	Replicate 2	
1	-	-	-	10	8	**18**
a	+	-	-	12	10	**22**
b	-	+	-	7	5	**12**
ab	+	+	-	9	8	**17**
c	-	-	+	13	14	**27**
ac	+	-	+	18	16	**34**
bc	-	+	+	11	10	**21**
abc	+	+	+	12	14	**26**

Effect of A = $\frac{1}{4n}$(a + ab + ac + abc – 1 – b – c – bc)
= 2.625

Effect of B = $\frac{1}{4n}$(b + bc+ ab +abc – 1 – a – c -ac)
= - 3.125

Effect of C = $\frac{1}{4n}$(c + ac + bc + abc – 1 – a – b – ab)
= 4.875

Effect of AB = $\frac{1}{4n}$(ab + abc + c + 1 – ac – bc – a – b)
= - 0.125

Effect of BC= $\frac{1}{4n}$(bc + abc + a + 1 – ab – ac – b – c)
= - 0.375

Effect of AC = $\frac{1}{4n}$(ac + abc + b + 1 – ab – bc – a – c)
= 0.375

Effect of ABC = $\frac{1}{4n}$(abc + a + b + c – ab – bc – ac – 1)
= - 0.375

Sum of Squares:

$SS_A = \frac{(Contarst\ A)^2}{8n} = \frac{(Effect\ Of\ A \times 4n)^2}{8n} = 27.56$

$SS_B = \frac{(Contarst\ B)^2}{8n} = \frac{(Effect\ Of\ B \times 4n)^2}{8n} = 39.0625$

$SS_C = \frac{(Contarst\ C)^2}{8n} = \frac{(Effect\ Of\ C \times 4n)^2}{8n} = 95.06$

$SS_{AB} = \frac{(Contarst\ AB)^2}{8n} = \frac{(Effect\ Of\ AB \times 4n)^2}{8n} = 0.0625$

$SS_{AC} = \frac{(Contarst\ AC)^2}{8n} = \frac{(Effect\ Of\ AC \times 4n)^2}{8n} = 0.5625$

$SS_{BC} = \frac{(Contarst\ BC)^2}{8n} = \frac{(Effect\ Of\ BC \times 4n)^2}{8n} = 0.5625$

$SS_{ABC} = \frac{(Contarst\ ABC)^2}{8n} = \frac{(Effect\ Of\ ABC \times 4n)^2}{8n} = 0.5625$

$SS_{total} = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}^2 - \frac{y_{...}^2}{8n}$
= 174.9375

$SS_{Error} = SS_{total} - SS_A - SS_B - SS_C - SS_{AB} - SS_{BC} - SS_{AC} - SS_{ABC}$
= 11.505

ANOVA:

(Table 3.1.3 ANOVA For MRR)

Source Of Variation	Sum of Square	DOF	Mean Square	F_0	F_{table} $F_{0.05,1,8}$	Significant / Insignificant
A	27.56	1	27.56	19.16		*Significant*
B	39.06	1	39.0625	27.16		*Significant*
C	95.06	1	95.06	66.10		*Significant*
AB	0.0625	1	0.0625	0.0434	5.32	*Insignificant*
BC	0.5625	1	0.5625	0.3911		*Insignificant*
AC	0.5625	1	0.5625	0.3911		*Insignificant*
ABC	0.5625	1	0.5625	0.3911		*Insignificant*
Error	11.505	8	1.4381			
Total	174.93	15				

$SS_{Model} = SS_A + SS_B + SS_C + SS_{AB} + SS_{BC} + SS_{AC} + SS_{ABC}$
= 27.56 + 39.0625 + 95.06 + 0.0625 + 0.5625 + 0.5625 + 0.5625
= 163.43

3.2 Percentage Contribution:

% Contribution of Factor A
(RPM) = $\frac{27.56}{163.43} \times 100 = 16.86$ %

% Contribution of Factor B
(No Of Grooves) = $\frac{39.0625}{163.43} \times 100 = 23.90$ %

% Contribution of Factor C
(Pressure) = $\frac{95.06}{163.43} \times 100 = 58.16$ %

3.3 2^3 Design Model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x_3$$

Where y = Function of Model (MRR),
x_1, x_2, x_3 = RPM, No. of grooves & Pressure respectively.
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_{12}, \beta_{13}, \beta_{23}, \beta_{123}$ = Coefficient

$\beta_0 = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}}{abcn}$ = 177/16 = 11.0625

$\beta_1 = \frac{effect\ of\ A}{2}$ = 2.625/2 = 1.3125

$\beta_2 = \frac{effect\ of\ B}{2}$ = -3.125/2 = -1.5625

$\beta_3 = \frac{effect\ of\ C}{2}$ = -4.875/2 = -2.4375

$y = 11.0625 + 1.3125x_1 - 1.5625x_2 - 2.4375x_3$

Now from the below graphs the value of pressure will be selected at higher level, rpm is also at higher level & no. of grooves will be at lower level

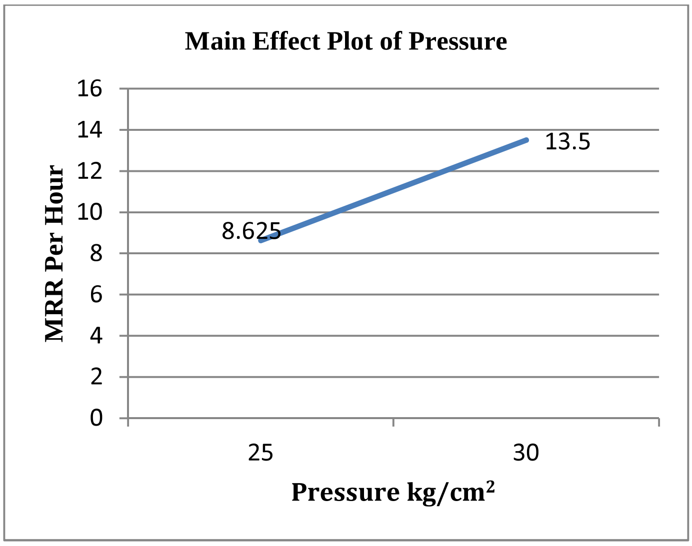
So, $x_1 = 1, x_2 = -1, x_3 = 1$
y = 11.0625 + 1.3125(1) - 1.5625(-1) - 2.4375(1)
= 11.5

y_{mean} = 11
so, residual e = 11 – 11.5 = - 0.5

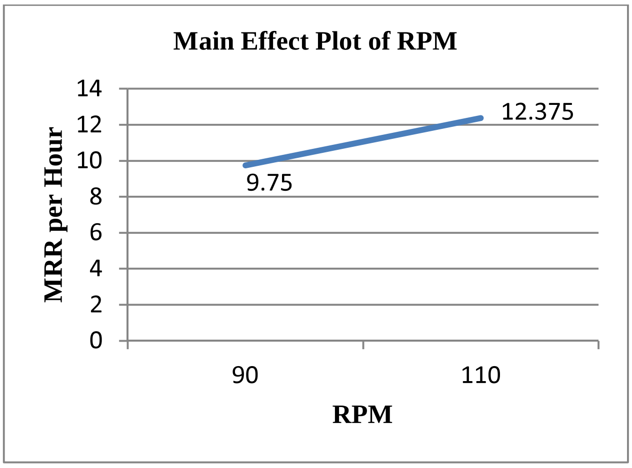
The residual is the difference between the observed & fitted value of y.

Now final parameters to achieve maximum MRR are, RPM = 110, Pressure = 30kg/cm^2, No. of grooves = 15

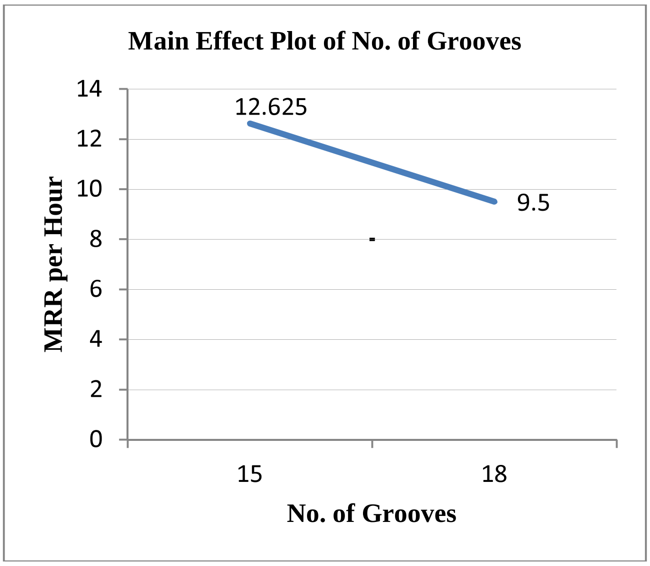
At above level of these parameters the residual is also -0.5 So, fitted regression model is true for these levels.



3.2.1 Main Effect plot of MRR Vs Pressure



3.2.2 Main Effect plot of MRR Vs RPM



3.2.3 Main Effect plot of MRR Vs No. of Grooves

From the main effect plots figure 3.2.1, to achieve higher Material Removal rate pressure should be at its higher level so the value of pressure should be 30 kg/cm^2. Same way from figure 3.2.2 RPM should be also at higher level so the value will be 110 rpm & from the figure 3.2.3 No. of grooves should be at its lower level to achieve maximum MRR so the number of grooves should be 15. Also at these level of the parameters the residual (error) found from the regression model is -0.5 which is very less so the value of these parameters satisfying the required function.

4. CONCLUSIONS:

From the Fig 2.2.1, regardless of the groove depth of the Gap plate, the one where the groove of the rotary plate is deep it is found that MRR is large. In addition, groove depth of the rotary plate in same case, groove depth of the Gap plate changing, difference did not occur in MRR. From this, MRR that groove depth of the plate of rotary side influence is received more strongly than fixed (Gap) part. Best MRR is found at the combination of 0.1 D – 0.3 D. So the Groove depth of the gap plate will be 0.1D & the Groove depth of the ring plate will be 0.3D to achieve the maximum MRR.

So the life of the gap plate will increase.

DOE was performed for three parameters at two different levels. In that DOE MRR was found for different operating parameters. The parameters were Operating Pressure, Plate RPM & Number of Grooves. From ANOVA table 3.1.3 it is seen that the main parameter effects are significant, interaction effects of these parameters are insignificant.

Also the percentage Contribution of these parameters are :

- Pressure having 58.16% , RPM having 16.86%, No. Of grooves having 23.90% effect on MRR.
- From the main effect plots to achieve higher Material Removal rate pressure should be at its higher level so the value of pressure should be 30 kg/cm^2, should be also at higher level so the value will be 110 rpm & No. of grooves should be at its lower level to achieve maximum MRR so the number of grooves should be 15.
- Also at these level of the parameters the residual (error) found from the regression model is -0.5 which is very less so the value of these parameters satisfying the required function.

ACKNOWLEDGEMENT:

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REFERENCES

[1] C.J. Evans, E.paul, D.Dornfeld " Material Removal Mechanisms in Lapping & Polishing" J. JSPE 68(7) (2002), pp 640-653.

[2] J. Kang, M. Hadfield "Examination of the material removal mechanisms during the lapping process of advanced ceramic rolling elements" Wear 258 (2005), pp 2–12

[3] J. Kang, M. Hadfield "A novel eccentric lapping machine for finishing advance ceramic balls" Proc. Inst. Mech. Eng., part B 215(2001), pp 781-795.

[4] J. Kang and M. Hadfield "Parameter optimization by Taguchi Methods for finishing advanced ceramic balls using a novel eccentric lapping machine" Journal of Engineering Manufacture, Part B Vol.215, PP 69-78, 2001

[5] B. Zhang, T. Uematsu, A. Nakajima, High efficiency and precision grinding of Si3N4 ceramic balls aided by magnetic fluid support using diamond wheels, JSME. Int. J. Ser. C 41 (3) (1998) , pp 499–505.

[6] T. Kurobe, H. Kakuta , M. Onoda, "Spin angle Control Lapping of balls" J. JSPE 63(5) (1997) pp 726-730.

[7] J. Kang and M. Hadfield " The polishing process of advanced ceramic balls using a novel eccentric lapping machine". Proc. Inst. Mech. Eng., part A 220,(2003) pp 230-241

[8] Pratik Patel & Saurin sheth "Kinematics of V-Groove in Flashing For Manufacturing Of Precision Steel Balls" NCAET – 2012 , KIT & RC , Kalol

[9] Childs THC, Mahmood S, Yoon HJ, "The material removal mechanism in magnetic fluid grinding of ceramic ball bearings". Proc Inst Mech Eng Part B 1994;208(1) , pp47-59.

[10] The manufacture of Steel ball (Developments of machines & Methods) by Robert H. Grant Published by Machinery, New York
[11] The Evaluation of steel ball industry by Hoover Steel Ball
[12] Hand Book of Lapping & Polishing By Ioan D. Marinescu, Eckart Uhlmann, Toshiro K. Doi CRC press
[13] Design & Analysis of Experiments 5th Edition By. Douglas C. Montgomery, Wiley India Edition
[14] Introduction to Statistical Quality Control, 5th Edition by Douglas C. Montgomery, (c) 2005 John Wiley & Sons, Inc.
[15] Wu CFJ, Hamada M. Experiments: Planning, Analysis, and Parameter Design Optimization. Wiley: , 2000