

RESEARCH ARTICLE

Development of Magnetic Float Polishing Machine for Steel Balls

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Abstract

Traditional magnetic float polishing machine is limited to use for polishing of ceramic balls only and this traditional setup is not used for polishing of steel balls, due to the limitation of magnetic property of the ball material. The objective of this study was to finish the magnetic material in magnetic float polishing machine and thus, a new apparatus was intended for polishing steel balls. The polishing chamber was aimed to repel the magnets present at base and float to lift the balls to have point contact with rotor. ANOVA was applied to observe the effect of polishing machining parameters on percentage improvement in surface finishing. The parameters selected were time (30, 60, 90, 120 and 150 min), speed of rotor (450, 710, 1120, 1800 and 2800 rpm), abrasive powder (SiC) concentration (10, 15, 20, 25 and 30%) and mesh size (220, 320, 400, 600 and 1000 μm) optimized by response surface methodology (RSM). The findings showed that for the combination of numerous constraints for which the Percentage Improvement in Surface Finishing (PISF) was found maximum.

Keywords: Magnetic float polishing, steel balls, machining, polishing chamber, surface finishing, abrasive powder.

Introduction

Traditional bearings made from AISI52100 or M50 steel have very limited performances when used at very high speed, temperature and corrosive environment (Umehara *et al.*, 2006). Also the quality of the surface finishing produced by polishing process also affects the reliability and performance of the bearing (Komanduri *et al.*, 1999). The cost-factor for ball bearing material selection is also crucial as it directly impact the product cost. The ceramic balls are superior from steel balls but cannot be used in all working conditions due to high cost; they are suitable only for very high temperature, very high speed where steel balls failed to perform. So, we use steel ball bearings where the temperature and speed are not too high. Finishing of the steel balls is done with the method of Lapping process. This method takes a very long processing time because of low polishing speed (~ 50 rpm) and cause damage to surface because of high load (~10 N per ball) and use of diamond abrasive (Komanduri *et al.*, 1999). Magnetic Float Polishing (MFP) is a technique which is more likely to replace the conventional polishing process. MFP is highly efficient and produces high quality balls for bearing applications. This process involves metal removal using harder abrasives with respect to the work material. High PISF with minimal subsurface damage is obtained with harder abrasive. Komanduri *et al.* (1999) presented an overview of the work carried out in the finishing of Si_3N_4 balls for bearing applications. For this, they used a process known as the magnetic float polishing (MFP).

They stated a "gentle" process in which very low levels of controlled force (0.5-2 N) is applied. They divided the whole process in three stages. In the first stage, they remove the material as rapid as possible. In this stage, the damage to the surface was minimal. The second stage was the semi-finishing stage in which the objective was to carefully monitor size and sphericity and in the last stage sphericity, size and finish are closely controlled to meet the final requirements. The first process involves mechanical removal of material with harder and coarser abrasives, such as coarse B_4C ; the second process involves the use of "less" harder and finer abrasives, e.g., medium to fine B_4C or SiC; and the third process was the use of "much" softer abrasives, e.g., CeO_2 , ZrO_2 , and Cr_2O_3 that can chemo-mechanically react with the work material (Si_3N_4) and/or the environment (air or water) to generate a smooth surface. The end results was that the chemo-mechanical polishing of Si_3N_4 balls with CeO_2 abrasive yields an extremely smooth and damage-free surface with a surface finish Ra of 4 nm and an Rt of 40 nm and a sphericity of 0.15-0.25 m. Kang (2005) used two types of HIPed Si_3N_4 bearing ball blanks with different surface hardness and fracture toughness under various loads, speeds and lubricants. A novel eccentric lapping machine was used in this process. The lapped surfaces were examined by optical microscope and SEM. The results of the experiment showed that the material removal rate for type 1 ball blanks were 3-4 fold of type 2 in most cases.

Changing lapping fluids may also affect the material removal rate at lower lapping loads, but they had much less impact on the material removal rate at higher lapping loads. The SEM micrographs tell that the grain pull out prevailed on the lapped surface of type 1 ball blanks and the surface of type 2 featured bulk material removals by micro-cracking. Under extreme high lapping load, damages and surface cracks were found and SEM with EDX exposed steel from the lapping plate had transferred to the ceramic ball surface. The preliminary conclusion was that the material removal mechanism during the lapping process of silicon nitride balls using this eccentric lapping machine was mainly mechanical abrasive wear. Wilshaw's and Lawn indentation model on brittle materials was used to explain the difference in material removal rate for the two types of ball blanks.

Umehara *et al.* (2006) designed and built a new apparatus for the finishing of large size/large batch silicon nitride (Si_3N_4) balls by magnetic float polishing technology for hybrid bearing applications. The polishing chamber was so designed that during polishing it can self-align with the upper part of the polishing chamber connected to the spindle. For higher accuracy and alignment of the system, machining is done on the upper part of the chamber. The finishing methodology consisted of mechanical polishing followed by chemo-mechanical polishing. Boron carbide (B_4C), silicon carbide (SiC) and cerium oxide (CeO_2) are the three abrasives used in this investigation. There are three stages in polishing, roughing stage for maximum material removal without any damage to the surface, intermediate stage for size and sphericity and final finishing stage to achieve best surface finish and sphericity. Best material removal rate is achieved by applying Taguchi method to optimize the polishing conditions. Level average response analysis had indicated that at load of 1.5 N/ball, with abrasive concentration of 20% and a speed of 400 rpm would give a high material removal rate using B_4C (500 grit) abrasive. A groove was formed on the bevel of the upper part of the chamber. In the roughing stage, it was preferable, though it is not necessary to machine the groove after each run to maintain high material removal rates. In the intermediate or semi-finishing stage, groove helps in the improvement of sphericity. In the final stage, machining of the groove is necessary for rapid improvement in the surface finish. A batch of 46, 3/4 in Si_3N_4 balls was finished to a final dia of 0.7500 with an average sphericity of $w0.25$ mm (best value of 0.15 mm) and an average surface finish, R_a of $w8$ nm (best value of 6.7 nm) with an actual polishing time of 30 h. This technology was easy to implement in industry and does not requires high capital investment. Sadiq and Shunmugam (2009) presented a scheme for the finishing of external curved surfaces, by give rotation while the abrasive-mixed magneto-rheological fluid (or abrasive-mixed MR fluid) was pushed up and down.

Since, the relative motions resemble those present in conventional honing, the proposed method was named as 'Magneto-rheological Abrasive Honing' (MRAH). The study outlines the design and development of magneto-rheological abrasive honing setup. A cylindrical pole faces DC electromagnet was used and measurement for magnetic flux density is done. Experiments were conducted with aluminium and austenitic stainless steel work pieces to understand the effect of magnetic field. Effect of initial roughness, rotation of work-piece and process duration on finishing was investigated with ground austenitic stainless steel work-pieces. It was observed that the improvement in finish was better for rougher surface and higher rotation speed of work piece and a reduction in roughness was consistent with process duration. Klocke and Zunke (2009) investigated polishing processes of silicon based advanced ceramics. It was shown that depending on the slurry, the material removal mechanisms differ. Observed effects were explained by dominating mechanical or chemo-mechanical removal. This is based on the phenomenological analysis of experimental results using advanced metrology, such as SEM, AFM and TEM.

Singh *et al.* (2010) used a relatively new micromachining technology based on magnetic assistance in the recent past to produce quality surface finish on these materials. The magnetic abrasives play crucial role of cutting tools in these processes. However, the magnetic abrasives were not easily available as these were produced by special techniques. Keeping the above facts in view, this study highlights major existing technologies that were used to manufacture magnetic abrasives and also the main performance characteristics of magnetic abrasives has also been studied as regards to micromachining of various surfaces.

Materials and methods

Experimental apparatus: The improved apparatus for magnetic float polishing machine was constructed at the institute. The 3D sectioned model of MMFP is shown in Fig. 1.

Fig. 1. 3D sectioned model of MMFP apparatus.

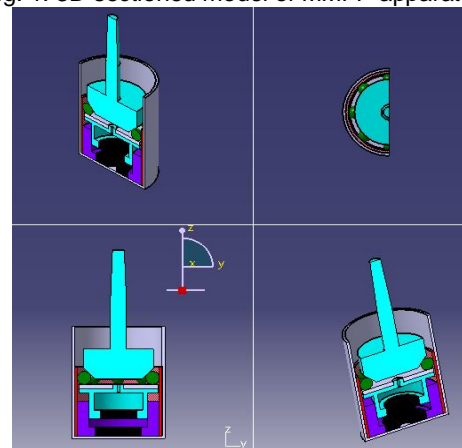
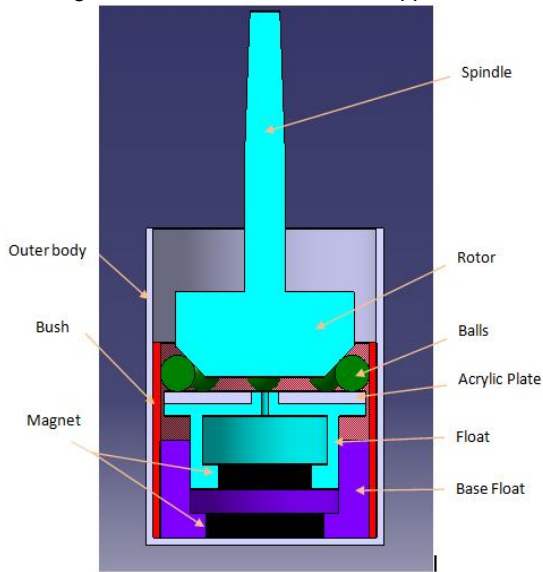


Fig. 2. Nomenclature of MMFP apparatus.



MMFP apparatus contains two magnets called base float magnet and acrylic float magnet placed in such a way they repel each other providing to and fro motion to float. This helps to complete the balls to make 3 point contact with rotor, bush and acrylic plate. The nomenclature of modified magnetic float polishing is shown in Fig. 2. Mild steel was used as ball material for bearing application. Selected input parameters and their range are shown in Table 1.

Table 1. Input parameters for observations.

Parameter	Unit	Range
Time (A)	min	30-150
Speed (B)	rpm	450-2800
Mesh size (C)	µm	220-1000
Abrasive quantity (D)	%	10-30

In the present study, percentage Improvement in Surface Finishing (PISF) was measured after conducting total 30 numbers of experiments using Response surface methodology (RSM). After the completion of all the 30 experiments, the result was obtained for PISF. The relationship for PISF is given as:

$$PISF = \frac{\text{Initial roughness} - \text{final roughness}}{\text{initial roughness}} \times 100$$

Results and discussion

Experimental data of time, speed, mesh size and quantity of abrasive with response PISF is shown in Table 2. For different combinations of independent parameters (time, speed, mesh size and abrasive quantity) the PISF is calculated. Table 3 shows The Model F-value of 5.18 implies that the model is significant. There is only a 0.16% chances that a "Model F-Value" is large which could occur due to noise.

Table 2. Experimental data of Time, Speed, Mesh size and Abrasive quantity with Response PISF.

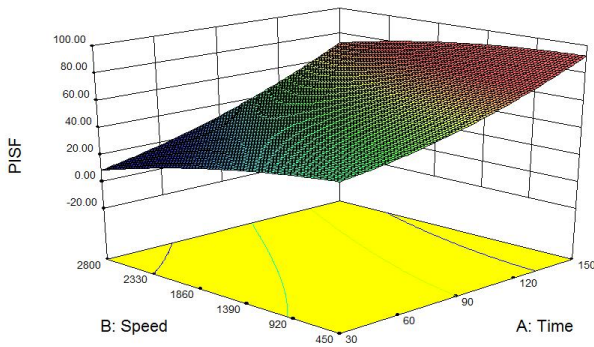
Std.	Run	A	B	C	D	PISF (%)
17	1	60	1800	600	25	22.54
10	2	90	1120	400	30	60.24
25	3	90	1120	400	20	44.90
29	4	90	450	400	20	47.54
15	5	60	710	320	25	30.25
11	6	90	1120	400	20	58.54
30	7	60	1800	600	15	49.54
13	8	60	1800	320	15	41.26
27	9	120	710	600	25	70.24
22	10	90	1120	400	20	43.24
3	11	30	1120	400	20	35.24
1	12	120	1800	600	25	68.65
19	13	60	710	600	25	44.12
4	14	120	710	320	15	38.24
6	15	60	710	600	15	63.25
7	16	150	1120	400	20	76.83
14	17	90	1120	400	10	46.84
8	18	90	1120	220	20	30.45
16	19	120	710	320	25	69.54
18	20	120	1800	320	25	51.25
23	21	90	1120	1000	20	43.25
28	22	60	1800	320	25	45.21
12	23	120	710	600	15	72.15
21	24	90	1120	400	20	64.14
24	25	60	710	320	15	42.18
2	26	120	1800	600	15	71.24
26	27	120	1800	320	15	54.23
20	28	90	1120	400	20	42.35
9	29	90	1120	400	20	45.23
5	30	90	2800	400	20	40.26

Table 3. Analysis of variance for PISF of individual parameter and combined effect of linear, interactive and quadratic level of PISF.

ANOVA for response surface quadratic model						
Analysis of variance table [Partial sum of squares – Type III]						
Source	SS	df	MS	F Value	p-value Prob>F	
Model	4768.13	14	340.58	5.18	0.0016	significant
A-Time	1224.25	1	1224.25	18.60	0.0006	significant
B-Speed	272.88	1	272.88	4.15	0.0598	
C-Mesh Size	23.95	1	23.95	0.36	0.5553	
D-Quantity	346.37	1	346.37	5.26	0.0366	significant
AB	12.23	1	12.23	0.19	0.6726	
AC	128.13	1	128.13	1.95	0.1832	
AD	379.57	1	379.57	5.77	0.0297	significant
BC	169.88	1	169.88	2.58	0.1290	
BD	59.35	1	59.35	0.90	0.3573	
CD	394.33	1	394.33	5.99	0.0272	significant
A2	81.20	1	81.20	1.23	0.2841	
B2	40.39	1	40.39	0.61	0.4456	
C2	629.70	1	629.70	9.57	0.0074	significant
Residual	987.13	15	65.81			
Lack of Fit	561.70	10	56.17	0.66	0.7309	Not significant
Pure Error	425.43	5	85.09			
Cor Total	5755.26	29				
Std. Dev.	8.11		R-Squared		0.8285	
Mean	50.43		Adj R-Squared		0.6684	
C.V. %	16.09		Pred R-Squared		0.3610	
PRESS	3677.35		Adeq Precision		8.658	

Values of "Prob > F" is less than 0.0500 indicate model terms are significant. In this case A, D, AD, CD and C2 are significant model terms. Values greater than 0.1000 indicate that the model terms are not significant. The "Lack of Fit F-value" of 0.66 implies the Lack of Fit is not significant relative to the pure error. There is a 73.09% chance that a "Lack of Fit F-value" is large which could occur due to noise. After polishing steel balls on MMFP, the effect of various input parameter's on PISF can be observed in 3D graphical representation. These show the effect of simultaneous variation of two factors on PISF keeping the other two factors constant. Figure 3 represents the relationship between Time (A) and Speed (B) and their effect on PISF by keeping Abrasive size (C) and Abrasive quantity (D) constant. PISF increases with increase in time, but with increase in speed it first increases up to 950 rpm after that, with increase in speed PISF decreases.

Fig. 3. Combined effect of Time and Speed on PISF.



The effect of Time (A) and Mesh size (C) on PISF by keeping Speed (B) and Quantity (D) constant is shown in Fig. 4. PISF increases with increase in time, but with increase in Mesh size it first increases, after that, with increase in Mesh size, PISF decreases apparently.

Fig. 4. Relationship between Time and Mesh size for PISF.

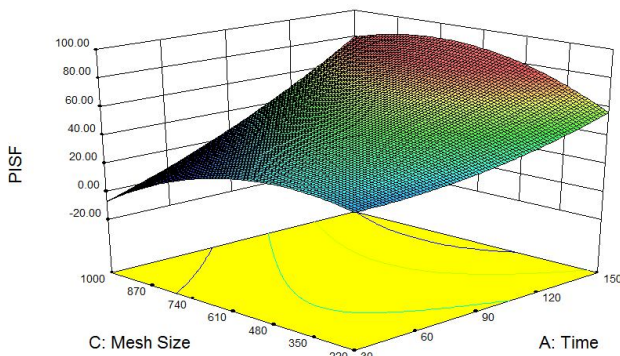
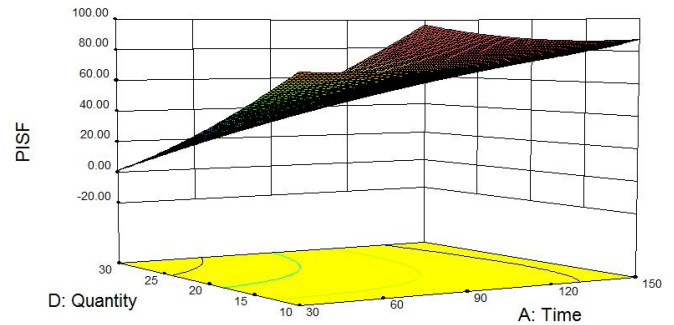


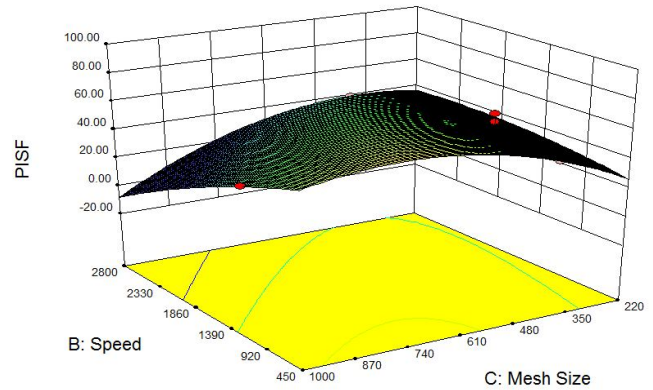
Figure 5 explains the relationship between Time and Abrasive quantity and their effect on PISF by keeping Abrasive size and Speed constant. With higher Abrasive quantity of 30 g and maximum Time of 150 min, value of PISF is found highest.

Fig. 5. Relationship between Time and Abrasive quantity for PISF.



Correlation between Mesh size and Speed and their influence on PISF by keeping Time and Abrasive quantity constant is given in Fig. 6. PISF increases with increase in Mesh size up to 740, but evidently PISF decreases with further increase in Mesh size of abrasive. Also with increase in speed for Abrasive mesh size of 220, PISF increases.

Fig. 6. Effect of Mesh size and Speed on PISF.



Relationship between Abrasive quantity and Speed and their effect on PISF by keeping abrasive size and Time constant is shown in Fig. 7. It has been observed that there is a continuous progression in PISF with lesser Abrasive quantity and very slow rotor speed. It is observed that at 450 rpm speed and 10 g Abrasive quantity, PISF achieved maximum value of 74%.

Fig. 7. Relation between Speed and Abrasive quantity and their effect on PISF.

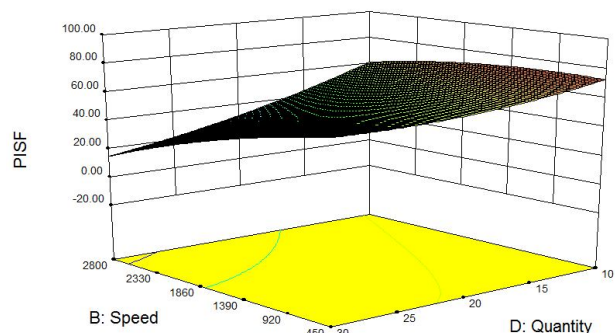
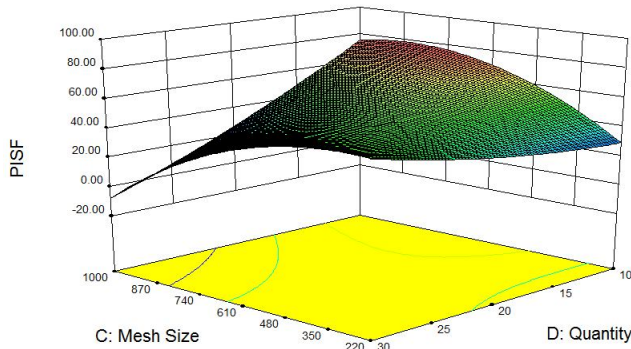


Figure 8 gives the idea about the relationship between Quantity and Mesh size and their effect on PISF by keeping Speed and Time constant. PISF increases with significant decrease in mesh size to 480 and then decreases slightly with further decrease in mesh size. But, with increase in quantity, PISF increases.

Fig. 8. Relation between Mesh size and Abrasive quantity and their effect on PISF.



Conclusion

Modified magnetic float polishing is an efficient and cost effective polishing process for the finishing of ball, suitable for bearing applications. It involves fine mechanical polishing and uses high polishing speed, controlled polishing force and flexible support system result in high quality. At low speed of 450 rpm and time of 150 min, the value of PISF is maximum when mesh size and abrasive quantity are kept constant. With high mesh size of 740 and maximum time of 150 min, value of PISF is observed as maximum. About 95% PISF is achieved with maximum abrasive quantity (30%) at maximum time for machining (150 min).

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