OPTIMIZATION OF INPUT PROCESS PARAMETERS FOR VIBRATORY BALL BURNISHING PROCESS USING RSM

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ABSTRACT

Burnishing is a chipless finishing method, which employs a rolling tool, pressed against the work piece, in order to achieve plastic deformation of the surface layer. Ball burnishing processes are largely considered in industrial cases in order to restructure surface characteristics. As per previous research the effect of burnishing speed, feed, ball diameter, burnishing force and no. of tool passes playing important role on the quality of the work surface produced and its wearing characteristics. The deforming action of the ball which governs the surface roughness and micro hardness is strongly governed by the trajectory movement of tool. The trajectory movement of tool can be adjusted in proper range by selecting proper combinations of speed, feed, vibration frequency and amplitude. Addition in vibratory technique, the investigation of electromagnetic vibrator using in ordinary ball burnishing process perform reliable and effective surface enhancement. The plastic deformation on the part surface can easily achieved by applying considerably lower pressure as compared to other conventional techniques.

The experimental results are analyzed by utilizing response surface method and developed mathematical and statistical model which helps to optimize vibratory burnishing input parameter.

Keywords: *Vibratory Ball Burnishing, Surface Roughness, Force, Frequency, Feed And Speed, RSM.*

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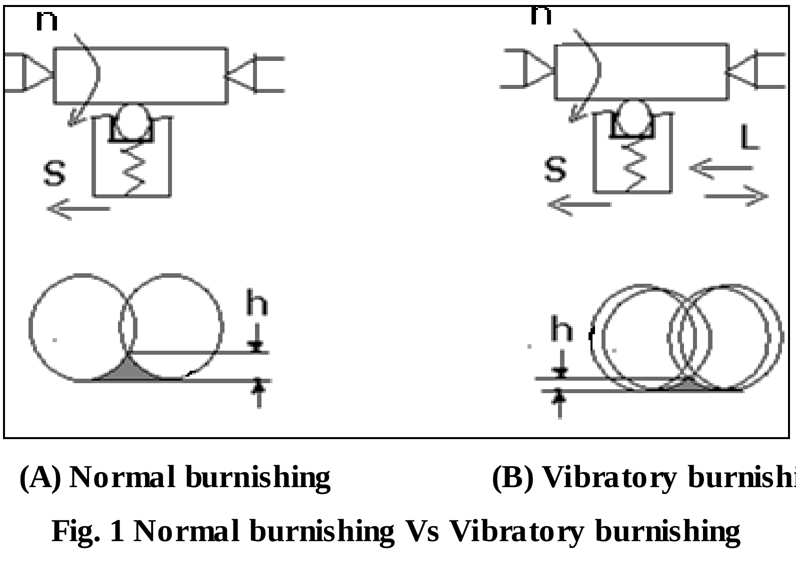
I. INTRODUCTION

Surface characteristic of material plays vital role in performance of a component such as load bearing capacity, fatigue strength, resistance to corrosion, friction, wear, etc. Some of parameters which influence the above performance characteristics are geometric features of the surface, its hardness, and degree of cold work and nature of residual stress induced [1][2].

For improves the performance as well as reliability of component, industries pay attention on surface finish of component. The various metal finishing processes can be mainly divided in two groups, group based on plastic deformation of surface layers, e.g. burnishing, bailazing, shot peening, shot blasting, etc. and group based on cutting action of abrasives, e.g. grinding, polishing, lapping, honing, super finishing, etc.

Burnishing is a chip less metal finishing process in which a rotating roller or ball is pressed against metal piece. It is a cold working process and involves plastic deformation under cold working conditions by pressing hard ball or roller. The burnishing process helps to improve surface finish and hardness. burnishing is a process in which the peaks of metallic surfaces are displaced to fill the valleys by plastic deformation. This can simply achieved by pressing a hard and highly polished ball or roller against the surface of metallic work pieces.

In case of vibratory ball burnishing process, the burnishing tool is given an additional vibratory motion in the direction parallel to the axis of work piece with normal motion given in ordinary burnishing process. Vibratory motion of tool offers certain specific advantages on ordinary process like surface finishing as shown in figure 1.



(A) Normal burnishing **(B) Vibratory burnishing**

Fig. 1 Normal burnishing Vs Vibratory burnishing

Vibratory burnishing process improve the surface properties of material because it provide more complex trajectory movement of the deforming element related to the irregularities of the initial surface which are being deform. This is equivalent to super finishing process in which increase in the cutting ability of an abrasive grain is obtain by making the trajectory of its motion more complex relative to the surface being treated.

The literature reveals that considerable attention is paid towards studying the influences of various process parameters on the surface characteristics produced by normal burnishing process. Not much attempts have been made towards studying the influence of process parameters like speed, feed, burnishing force, frequency, amplitude of vibration on the surface characteristics like surface finish.

The present paper aim at systematically studying the effect of process parameters like speed, feed, burnishing force, frequency, amplitude of vibration and their interaction with surface roughness of the component using vibratory ball burnishing process.

Experiments will be plan according to statistical design of experiment to improve the reliability of results. Mathematical model fitted to the experimental data will help in selection of optimum process parameters for vibratory burnishing process.

II. EXPERIMENTAL DETAIL

The experimental set up is designed as shown in figure 2 and 3. The experimental set up consists of two elements: Single ball burnishing tool and Tool vibrating system

The flexible single ball burnishing tool is selected because it offers the following distinctive advantages like very easy to adjust and measure burnishing force directly by measuring the deflection of pre calibrated spring. In case of sudden increase in burnishing force, any damage to the burnishing tool or fixture arrangement can be avoided.

Oscillation required in the vibratory process are mostly obtained either by mechanically (ultrasonic transducer or eccentrically load) or by electromagnet. The essential need in nature of oscillation used in vibratory burnishing process is that vibration can easily controllable as per requirement and oscillation gives sinusoidal grooves form on the surface layer of the work piece. These both basic requirements in the vibrations can satisfactorily fulfill by using electro magnet.

The burnishing tool was vibrated along the axis of the lathe by using an electrodynamic vibrator specially develops for this purpose. The vibrator was designed to produce the peak to peak force of 42 kgf during vibration.

Fig.2 Experimental set up

Fig.3 Vibratory unit mounted on tool post of centre lathe

III. PLANNING OF EXPERIMENTS

To improve the reliability of results, experiments were planned on the basis of Response Surface Methodology (RSM) technique for statistical design of experiments. The input process parameters were selected on the basis of literature reveals recommendation for normal burnishing process. [3, 4, 5, 6] the vibration frequency and amplitude were selected by analyzing the motion of ball on the job surface. The range of process parameters selected for experimentation is listed in table 1.

Table 1. Experimental Condition

1.	Work material	: M.S.(C-20), H.B. 170
2.	Size of work piece	: Ø 25 mm
3.	Burnishing speed	: 60-304 rpm (4.71 – 23.88 m/min)
4.	Burnishing feed	: 0.07 – 0.24 mm/rev
5.	Burnishing force	: 5 -25 kgf (50 -250 N)
6.	Ball material	: Hardened alloy steel (Minimum HRC = 60)
7.	Size of ball	: 10.5 mm
8.	Frequency	: 10 – 50 Hz
9.	Amplitude	: 0.15 – 2.1 mm

Central composite rotatable design for 4 variables was chosen [7]. These ranges of parameters are coded for RSM design as follow:

1. Speed, X_1 = (log speed in m/min – log 10.603) ÷ log 1.5
2. Feed, X_2 = (feed in mm/rev – 0.16) ÷ 0.04
3. Burnishing force, X_3 = (force in kgf – 15) ÷ 5

4. Frequency, X_4 = (frequency in Hz – 30) ÷ 10

The final coded variables for RSM design are given in table 4.2.

Table 2. Coding of parameters

Level	X_1 Speed		X_2 Feed, mm/rev	X_3 Burnishing force , kgf	X_4 Frequency, Hz
	rpm	m/min			
-2	60	log 4.712	0.070	5	10
-1	90	log 7.068	0.127	10	20
0	135	log 10.603	0.160	15	30
+1	202	log 15.865	0.200	20	40
+2	304	log 23.876	0.240	25	50

The required burnishing force was adjusted by measuring the compression of the pre calibrated spring. Frequency of vibration adjusted by AC Rapid drive. The Ra value of surface roughness was measured by Surface Roughness Tester TR-110. Average of 3 observations was taken as the final observation.

IV. MATHEMATICAL MODEL

The model which correlates the process parameters to the response is required to be obtain in the following form,

$$Y = b_0X_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{12}X_1X_2 + b_{23}X_2X_3 + b_{34}X_3X_4 + b_{14}X_1X_4 + b_{13}X_1X_3 + b_{24}X_2X_4 \quad \text{.......(1)}$$

Where Y is the response parameter and b_0, b_1, b_2… are unknown coefficient to be determined. Total of 31 experiments have been conducted each having the combination of various values of process variables X_1, X_2, X_3 and X_4. The response parameters of surface roughness of the work piece are to be measured before and after vibratory burnishing process. Each combination of various parameters given in table 3. and corresponding value of response parameters for those particular combinations given rise to one equation in the form of equation (1). From the results of 31 tests, 31 such equations can be obtained. For calculating the coefficients, these simulations equations are required to be solved. They can be represented as,

$$[Y]_{31X1} = [X]_{31X15}\,[B]_{15X1}$$

This system of equations is solved to get the coefficients in the matrix [B] with the response [Y].

Table 3. Experimental observation

Sr. No.	Speed X_1	Feed X_2	Force X_3	Frequency X_4	Surface roughness (Ra) in µm
1	-1	-1	-1	-1	3.28
2	+1	-1	-1	-1	2.56
3	-1	+1	-1	-1	3.57
4	+1	+1	-1	-1	5.02
5	+1	-1	+1	-1	3.44
6	-1	+1	+1	-1	3.54
7	+1	+1	+1	-1	3.41
8	-1	-1	+1	-1	3.37
9	+1	-1	+1	+1	2.06
10	-1	+1	+1	+1	1.51
11	-1	-1	+1	+1	1.05
12	-1	+1	+1	+1	2.88
13	-1	-1	-1	+1	2.69
14	-1	+1	-1	+1	4.16
15	+1	-1	-1	+1	2.65
16	+1	+1	-1	+1	4.40
17	-2	0	0	0	3.05
18	+2	0	0	0	3.33
19	0	-2	0	0	1.83
20	0	+2	0	0	4.43
21	0	0	-2	0	3.50
22	0	0	+2	0	3.74
23	0	0	0	-2	3.57
24	0	0	0	+2	1.57
25	0	0	0	0	3.67
26	0	0	0	0	3.11
27	0	0	0	0	3.34
28	0	0	0	0	3.38

29	0	0	0	0	3.05
30	0	0	0	0	2.62
31	0	0	0	0	3.07

For the adequate model the coefficients in matrix [B] which are less significant are eliminated from further analysis by using Student's *t* – test [7]. The variance of observations at the central point was calculated with confidence interval for 10% significance level. Coefficients having an absolute value less than the confidence interval were eliminated from the fitted model.

To check the adequacy of model, the analysis of variance was carried out. The result of analysis of variance for surface roughness is shown in table 4. The ratio of mean sum due to lack of fit to mean sum of experimental error (The F – Ratio) was calculated for the surface roughness. This value is less than 4.06 – the F-ratio for 95% confidence level. Thus the adequacy of the model is established.

Table 4. Analysis of variance for surface roughness

Sr. No.	Source	Sum of squares	Degree of freedom	Mean squares	F – value
1	First order terms	13.85	04	3.4625	
2	Second order terms	5.41	10	0.5410	
3	Lack of fit	3.0538	10	0.3053	2.88
4	Experimental error	0.6532	06	0.1089	
5	Total	22.967	30	0.7655	

Hence, the final form of model is as follow,

$$Y = 3.18\ X_0 + 0.16\ X_1 + 0.54\ X_2 – 0.26\ X_3 – 0.44\ X_4 – 0.15\ X_4^2 + 0.18\ X_1X_2 – 0.26\ X_2X_3 – 0.34\ X_3X_4 \quad \ldots\ldots (2)$$

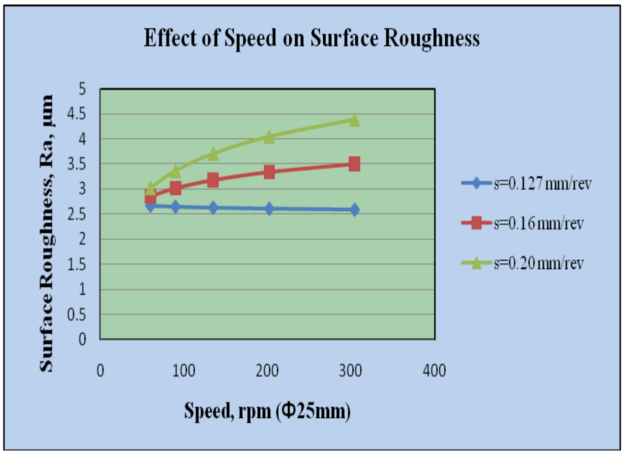
V. RESULTS AND DISCUSSION

The results are discussed under various process parameters are as under:

1) Influences of Speed

We can clearly see from the figure 4, that surface finish improve straight way with decrease in speed. However, A. M. Hassan [3], found from their experimental investigation in ordinary burnishing process that surface finish improve at certain level even speed is increased and there after increased in speed decrease surface finish.

In other words, at lower burnishing speed, the surface layer is plastically deformed to a greater depth because of comparatively more friction between ball element and work piece.



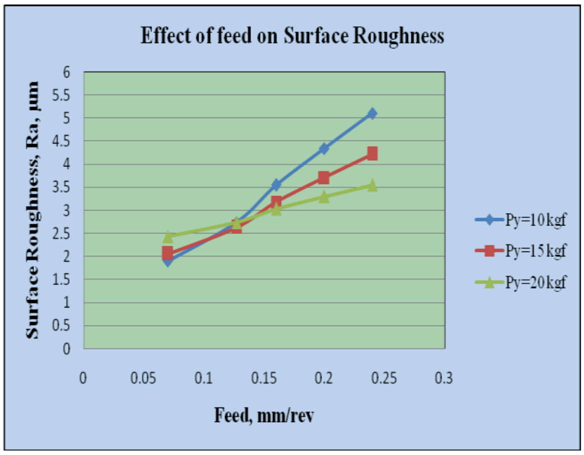


Fig. 4 Effect of Speed on surface roughness ***Fig. 5 Effect of feed on surface roughness***

2) Influences of feed

It is cleared from the figure 5 that surface roughness increase with increase in feed. This means that effectiveness of ball burnishing decreasing with increasing feed rate. There is an interaction between the ball force and the feed. With the combination of larger force and lower feed surface roughness increase due to over hardening and consequent flaking of the surface layers, similarly with the combination of lower force and larger feed surface finish reduced due to insufficient amount of burnishing force could not deform plastically surface layer of work piece. For better surface finish, it is preferable to use force 10 to 15 kgf with the feed of 0.1 mm/rev.

3) Influence of burnishing force

From the result of graph it is clearly indicate an interaction in ball force, feed and speed. figure 6 shows that for a constant feed rate with the increase with force initially surface finish improves and then deteriorates by further increase in force. The surface finish improve with increase in burnishing force at certain level, i.e. up to 15 kgf force and then reduce with increasing in force. This type of behavior of material is due to following reasons.

At lower burnishing force, the deforming action of the ball may insufficient to cause the requisite metal flow from the asperity peaks to valley. On the other hand, higher force may over stressing and over hardening of surface layer leading to particle break down, i.e. flaking of surface layers. Similar result trends also been observed by A. M. Hassan [3].

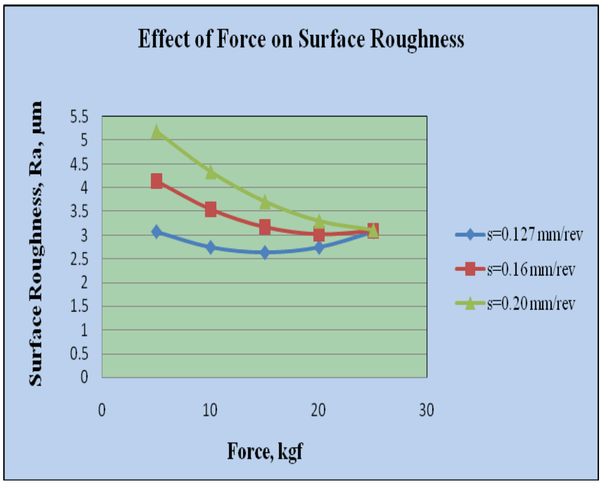


Fig. 6 Effect of force on surface roughness

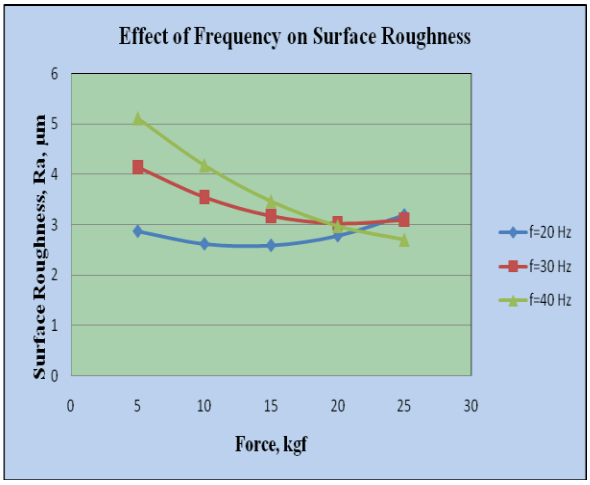


Fig. 7 Effect of frequency & force on surface roughness

4) Influence of frequency

Figure 7 shows an effect of vibration frequency on the surface finish of work piece. It indicates that with the increasing the frequency surface finish improves. A combination of lower frequency and lower burnishing force surface finish is good but with increasing force combination with higher frequency gives the better result. It is clearly observed that in vibratory ball burnishing process, with higher frequency good surface finish is obtain due to ball passes over same spot again and again leading to the deforming action on work piece.

VI. CONCLUSION

- Surface roughness is increased with increase in speed, best result is obtained with lower speed 90 rpm (4.712 m/min)
- The effectiveness of ball burnishing decreasing with increasing feed rate. There is interaction between the ball force and the feed. With the combination of larger force and lower feed surface roughness increase due to over hardening and consequent flaking of the surface layers, similarly with the combination of lower force and larger feed surface finish reduced due to insufficient amount of burnishing force could not deform plastically surface layer of work piece. For better surface finish, it is preferable to use force 15 to 20 kgf with the feed of 0.127 mm/rev.
- Surface finish of work piece is good with a combination of lower frequency and lower burnishing force but with further increased force with higher frequency gives the better result.
- The surface roughness (Ra) of turned work piece was 10.22 µm, which was reduced to 4.08 µm by normal burnishing. The lowest experimental surface roughness (Ra) of

work piece is obtained 1.05 µm by vibratory ball burnishing tool with combination of 90 rpm speed, 0.127 mm/rev feed, 20 kgf burnishing force and 40 Hz frequency.

The surface finish of turned work piece is improved 60% with the help of normal burnishing tool and further improved 30% with the use of vibratory technique on centre lathe.

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