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Study the internal surface and geometrical characteristics of cylindrical workpiece in ECH

Jatinder kapoor[1], Sandeep Salaria[2]

***Abstract*—Electrochemical honing (ECH) is an electrolytic precision micro-finishing technology based on the hybridization of the electrochemical machining and conventional honing process. The ECH technology provides the controlled functional surface generation and fast material removal capabilities of work piece in a single action. This paper presents the distinctive findings of wide-ranging experimental research designed to explore the effect of key ECH process parameters on the workpiece surface micro-geometrical and material removal aspects. In the present work, an experimental setup was designed to study the effect of key parameters on the performance of internal surface and geometric characteristics. The electrolyte concentration, rotary speed, sticks out pressure and flow rate are process parameters selected for the experimental work. Design of experiment is employed for conducting the experiment and analyzing the data. Quadratic equations have been developed to analyze the effect of parameters and their interaction on response parameters. The improvement in surface roughness (SR) is observed at maximum value of electrolyte concentration and stick out pressure, medium value of flow rate and rotary speed. The improvement in out of roundness (OOR) is observed at maximum value of rotary speed, medium value of electrolyte concentration and flow rate and minimum value of stick out pressure.**

Keywords— Electrochemical Honing, Surface roughness, Out of Roundness, Electrolyte concentration, Stick out pressure

I. INTRODUCTION

Surface quality and shape deviations play vital roles in the functional performance of engineering components. Electro-chemical-based hybrid manufacturing processes are gaining considerable attention owing to their distinct capabilities. To meet the challenging from the manufacturing community regarding surface quality, tolerances, and productivity requirements for critical and tribologically significant components made of ultra-hard difficult- to-machine advanced materials, hybrid manufacturing processes play very important role [1]. Electrochemical honing (ECH) is a hybrid electrolytic precision micro-finishing technology distinguished by a distinct coupling of the electrochemical machining and conventional honing actions to generate controlled functional surfaces and fast material removal capabilities in a single operation. ECH is capable of offering a unique range of benefits not obtainable by either of the processes to the processed surfaces, when applied independently [2]. ECH has flexi-features with regard to the control of work surface distinctiveness. A surface having a distinct cross- hatch lay pattern coupled with compressive residual stresses can be generated to provide an improved oil retention capability (and, consequently reduced friction and wear) and excellent fatigue endurance coupled together for better tribological performance of the component. A completely stress free surface required for some critical application can also be produced. More than 90 per cent of material removal occurs through electrolytic action. ECH is much faster than conventional honing and even internal grinding [3 –5]. Surface finishes of the order of 0.04 µm and tolerances within±0.002 mm can be achieved [6]. The ability of ECH to apply these benefits productively has led to its wide spread use in many industries including the aerospace, auto, petrochemical reactor, mould, dies, roller, and gear Industries [7, 8]. The application of ECH for gear teeth finishing was reported by Chen et al. [9]. The process has been found swiftly to improve the geometrical error in the work gear tooth profile. Guoqiang et al.[10] presented field-controlled electrochemical honing of gear teeth. The method was reported to produce any type of tip or root relief easily. It was pointed out that accuracy of the tooth profile can also be improved, provided the error in the tooth profile of all the teeth is nearly the same. ECH is still in its infancy in many respects. The para-metric relationships, material removal mechanism, surface quality issues, and part-macro geometrical aspects have not been evaluated effectively. Budzynski [11] attempted optimization for ECH of cylindrical holes that were considerably deformed by heat treatment. A study on high-speed electrochemical honing was done by Dubey [12]. The electric voltage across the inter electrode gap, tool rotary, and reciprocating speeds are found to influence significantly the work surface roughness improvement in the electro-chemical honing process. Better results dictate the use of a greater gap voltage, higher rotary speed, and lower reciprocating speed. In another investigation,

Dubey [13] highlighted the results of a comprehensive study on time-dependent behavior of the ECH process. Processing time-dependent improvement pat-terns of surface micro- and part-macro geometrical performance characteristics and material removal rate in ECH have been explored. Major improvements in R_a, R_{max}, out-of-roundness, and cylindricity were found to be realized during the first few ECH cycles, followed by a diminishing pattern of improvement. Literature survey further reveals that the most of the research work has been directed towards the honing with honing tool having four grit stones, which is used for large cylindrical components. Very less work is reported for the honing of small sizes holes, which can only be machined with tool having single honing stick. So it is proposed to design the setup to the finishing of small sizes holes with single grit stone.

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[1] Jatinder kapoor is working as Associate Professor in Mechanical Engineering in Guru Nanak Dev Engineering College, Ludhiana, Punjab , India.

[2] Sandeep Salaria is working as Assistant Professor in Arni University, HP, India.

II. EXPERIMENTAL SETUP

The design and development of the ECH setup (Fig. 1) is based on the problem objectives, various appropriate design contemplations applicable to different system elements, operational efficiency, and flexibility, as well as manufacturing and cost considerations. The set up comprises five major subsystems: power supply, electrolyte supply and cleaning system, ECH tool and drives, work holding and positioning system, and frame and housing. A low d.c. potential in the range of 2–28 V (adjustable) with current adjustable up to 210 A is applied across an electrolyte flooded inter electrode gap (IEG) between the stainless steel cathode tool body and anode workpiece. The power supply can be operated either as a constant current or as a const ant voltage power source. The negative terminal of the power supply is connected to the ECH tool through a copper carbon brush slip ring assembly, while the positive terminal is directly connected to the workpiece using copper lugs. The ECH tool designed with sever unique features, is stroked through the work-bore in a controlled generating motion of simultaneous rotation and reciprocation, employing precisions speed controlled drives. The honing stick maintain a uniform tool work gap and preferentially scrub the passivating electrolytic metal oxide microfilm from higher work surface profile are as to correct the surface geometrical inaccuracies .

Figure 1 Electrochemical Honing Setup

III.EXPERIMENTATION

An ASTM 35 cast iron cylindrical block of bore 50 mm and length 70 mm was selected as the workpiece specimen in the present study, as the internal cylindrical honing is the most common commercial application of the ECH process and the work material is commonly used in automobile cylinders. The selection of process parameters was done on the basis of preliminary experimentation. The present investigation focuses on the percentage improvement in surface roughness (Δ R_a) and Out of Roundness (Δ OOR) to assess the process micro geometrical performances.

IV DESIGN OF EXPERIMENT (DOE)

Design of Experiment is a structured, organized method that is used to determine the relationship between the different factors affecting a process and the output of that process. A Taguchi matrix experimental robust design is proved to be an efficient tool to produce high-quality products at low cost. The objective of the Taguchi robust design is to determine the optimal parametric settings, while ensuring process performance insensitive to various sources of random variation. Matrix experiments using special matrices, called orthogonal arrays (OA), allow the effects of several parameters to be determined efficiently.

V RESULTS AND DISCUSSION

The experimental trial results were analyzed using the analysis of means (ANOM) and the analysis of variances (ANOVA). The effect of a factor level is the deviation it causes from the overall mean response and the process of estimating the main effects of each process input parameter. Taguchi L27 method has been used during experimentation[14]. According to this method a total of 27 experiments were performed. The design according to which experimentation was performed is shown in Table 1.

Table 1 Input Parameters and their range

Input Parameters	Designation	Level		
		L1	L2	L3
Electrolyte Concentration (g/l)	A	100	150	200
Stick out Pressure (kpa)	B	7	14	21
Flow Rate (l/m)	C	10	20	30
Rotary Speed(rpm)	D	90	140	190

The experimental observations have been recorded in Table 2.

Table 2 Experimental Observations

Trial Run	R_a(I) µm	R_a(f) µm	Δ R	OOR(I) µm	OOR(f) µm	Δ OOR
1	3.75	1.67	55.46	20.53	5.57	71.78
2	3.64	1.61	55.78	22.82	6.48	71.58
3	3.85	1.7	55.72	20.46	5.77	71.76
4	3.84	1.69	55.49	20.31	6.07	71.48
5	3.57	1.58	55.69	21.91	6.28	71.30
6	3.34	1.48	55.58	20.82	5.95	71.76
7	3.92	1.74	55.46	21.39	6.08	71.57
8	3.64	1.61	55.80	20.82	5.91	71.57
9	3.68	1.64	55.52	21.28	6.10	71.30
10	3.55	1.57	55.52	20.51	5.78	71.80
11	3.45	1.53	55.49	19.63	5.65	71.20
12	3.67	1.63	55.57	19.37	5.55	71.30
13	3.88	1.72	55.47	19.57	5.52	71.76
14	3.82	1.69	55.52	21.14	6.00	71.58
15	3.96	1.75	55.8	21.56	6.09	71.71
16	3.33	1.48	55.47	21.00	5.98	71.48
17	3.44	1.53	55.57	21.12	6.06	71.30
18	3.36	1.48	51.78	20.22	5.76	71.80
19	3.48	1.53	52.78	20.75	5.95	71.80
20	3.57	1.57	53.8	20.87	5.88	71.58
21	3.82	1.70	55.46	21.92	6.18	71.57
22	3.38	1.49	55.69	22.26	6.35	71.48
23	3.43	1.51	55.72	18.92	5.37	71.57
24	3.51	1.55	55.8	21.37	6.13	71.30
25	3.86	1.71	55.49	20.95	6.03	71.20
26	3.52	1.56	56.57	21.08	6.07	71.20
27	3.49	1.55	55.47	21.24	6.00	71.70

The effects of process parameters on response characteristics like Surface roughness(SR) and Out of Roundness (OOR) has been described in this section.

A. EFFECT ON SURFACE ROUGHNESS

The effect on surface roughness of various input parameters is explained with the help of Analysis of variance (ANOVA). Table 5.3 is used to summarize the test for significance of regression model, test for significance for individual model coefficient and test for lack of fit. Summary output reveals that quadratic model is statistically significant for response at the three different conditions. Significant model terms were identified at 95% significance level. Goodness of fit was evaluated in order to check the reliability and precision of the model. The Model F-value of 77.72 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Final equation in terms of coded factors for SR :-
SR=+55.62+0.18*A[1]0.049*A[2]+0.047*B[1]-0.043*B[2]+0.056*C[1]-1.219E-003*C[2]-0.033*D[1]-0.026*D[2]

Table 3 Regression Analysis for Surface Roughess

Source	Sum of squares	df	Mean square	F-value	p-value prob>F	
Model	0.45	6	0.075	77.72	<0.0001	Significant
A-Electrolyte concentration	0.31	2	0.15	159.40	<0.0001	
B-Flow rate	8.90E-003	2	4.90E-003	4.67	0.0217	
C- Stick out pressure	0.033	2	0.16	16.95	<0.0001	
Residual	0.019	20	9.615E-004			
Lack of fit	6.164E-033	2	3.082E-033	4.25	0.0309	
Pure error	0.13	18	7.259E-004			
Cor total	0.47	26				

Figure 2 shows the effect of SR with the variation of flow rate and stick out pressure. At high values of flow rate and stick out pressure maximum surface roughness is observed.

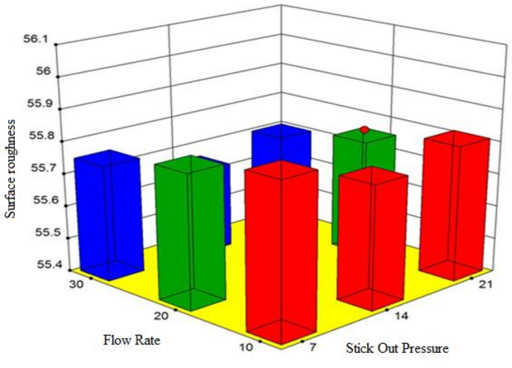

Fig 2:- Effect of Stick out Pressure and Flow rate on SR

B. EFFECT ON OOR

Table 4 is used to summarize the test for significance of regression model, test for significance for individual model coefficient and test for lack of fit. Summary output reveals that quadratic model is statistically significant for response at the three different conditions. Significant model terms were identified at 95% significance level. Goodness of fit was evaluated in order to check the reliability and precision of the model. The Model F-value of 263.59 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, D are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Final Equation in Terms of Coded Factors for OOR:
OOR=+71.51-0.23*A[1]-0.037*A[2]-0.015*B[1]- 3.030E-003*B[2]-0.067*C[1]-1.212E- 003* C[2]-0.061*D[1]+0.015*D[2]

Table 4 Regression Analysis for OOR

Source	Sum of squares	df	Mean square	F-value	p-value prob>F	
Model	1.15	6	0.19	274.04	<0.0001	Significant
A-Electrolyte concentration	0.94	2	0.47	673.52	<0.0001	
C- Stick out pressure	0.028	2	0.014	19.80	<0.0001	
D- Rotary speed	0.011	2	5.40E-003	7.71	0.0033	
Residual	0.014	20	7.009E-004			
Lack of fit	0.014	5	2.804E-003			
Pure error	0.000	15	0.000			
Cor total	1.17	26				

Figure 3 shows the effect of OOR with the variation of flow rate and stick out pressure. At high and low values of Stick out pressure and maximum values of electrolytic concentration, maximum OOR is observed.

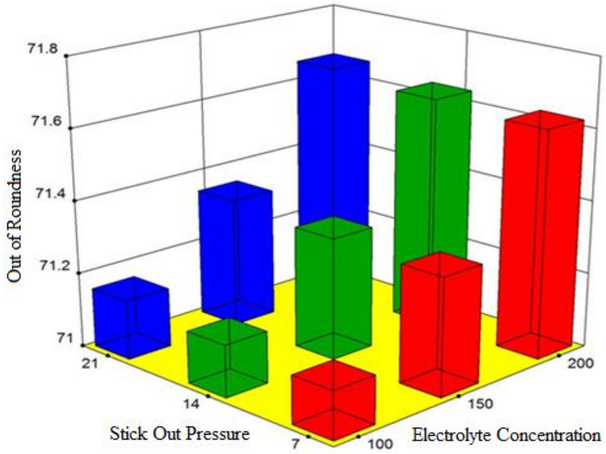

Fig 3:- Effect of Stick out Pressure and Electrolyte Concentration on OOR

VI CONCLUSION

With in the range of test conditions employed in the present experimental work, the following conclusions can be made:

1. Decrease in the value of surface roughness is observed at higher values of electrolyte concentration and flow rate for a fixed stick out pressure.
2. For a fixed value of electrolyte concentration, surface roughness decreases at higher values of stick out pressure and increases at higher values of rotary speed.
3. Decrease in surface roughness is observed at higher values of electrolyte concentration and flow rate.
4. For fixed value of flow rate, surface roughness decreases at higher values of stick out pressure and increase at higher values of rotary speed.
5. Increase in the value of OOR is observed at higher values of electrolyte concentration and flow rate for a fixed stick out pressure.

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